SMART 2014

The Third International Conference on Smart Systems, Devices and Technologies

ISBN: 978-1-61208-363-6

July 20 - 24, 2014

Paris, France

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Luigi Patrono, University of Salento, Italy
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SMART 2014

Foreword

The Third International Conference on Smart Systems, Devices and Technologies (SMART 2014), held between July 20-24, 2014, in Paris, France, continues a series of events covering tendencies towards future smart cities, specialized technologies and devices, environmental sensing, energy optimization, pollution control and socio-cultural aspects.

Digital societies take rapid developments toward smart environments. More and more social services are digitally available to citizens. The concept of ‘smart cities’ including all devices, services, technologies and applications associated with the concept sees a large adoption. Ubiquity and mobility added new dimensions to smart environments. Adoption of smartphones and digital finder maps, and increasing budgets for technical support of services to citizens settled a new behavioral paradigm of city inhabitants.

We take here the opportunity to warmly thank all the members of the SMART 2014 Technical Program Committee, as well as the numerous reviewers. The creation of such a broad and high quality conference program would not have been possible without their involvement. We also kindly thank all the authors who dedicated much of their time and efforts to contribute to SMART 2014. We truly believe that, thanks to all these efforts, the final conference program consisted of top quality contributions.

Also, this event could not have been a reality without the support of many individuals, organizations, and sponsors. We are grateful to the members of the SMART 2014 organizing committee for their help in handling the logistics and for their work to make this professional meeting a success.

We hope that SMART 2014 was a successful international forum for the exchange of ideas and results between academia and industry and for the promotion of progress in the field of smart systems, devices and technologies.

We are convinced that the participants found the event useful and communications very open. We hope that Paris, France, provided a pleasant environment during the conference and everyone saved some time to enjoy the charm of the city.

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Smart Grid Services Framework for Building Management Systems

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***Abstract*— We present a research position for mapping use cases of smart grid services from their textual descriptions based on reference models in order to obtain a reusable modeling framework as a basis to analyze and evaluate alternative implementations of a smart grid service. We start from use cases' textual descriptions based on smart grid architecture from International Telecommunication Union Focus Group on Smart Grid, and goal descriptions based on European Conceptual Model for the Smart Grid. We apply our previous results on goals and scenarios modeling methodology. A case study of building energy management systems services from the Customer domain is given. We work to complete the proposed framework with all detailed use cases for the Customer domain's functions, and to present scenarios on reusing this framework for transition of information system from an existing legacy architecture to a new smart grid-driven architecture.**

Keywords-smart grid reference models; smart grid services; BEMS; use case models; goals and scenarios; BUSITEV; URN.

I. INTRODUCTION

Smart Grid is a complex system of systems, as well a network of information networks, for which a common understanding of its major building blocks and how they interrelate are broadly shared. Smart Grid [1] services are related to energy bulk and distribution enabled by information technologies, whose objectives are the consumption-oriented generation and the generation-oriented consumption. Smart grids evolve by collaborative work of many organizations among financial options of distributed energy generation and consumption, in order to promote energy efficiency with quality and security of supply and safety.

Our focus is on goals and strategies of smart grid services, and on functional modeling them for effectiveness of their management at the customer side. We follow goal and scenario modeling technologies for use case modeling to obtain functional description of strategies, processes, environment properties which needed to support integrated change with simulation of goal satisfaction and risks reduction analysis.

To develop or to understand smart grid services, developers need to model and analyze interactions between those systems, which are involved in exchanges of goods and services. The International Telecommunication Union Telecommunication Standardization Sector (ITU-T) Focus Group on Smart Grid (FG Smart Grid) published the smart grids architecture and services use cases [3] based on smart grid standards issued by collaboration of international companies and institutes [1], [2].

The goals and strategies in order to promote energy efficiency, we find in the European Community's Smart Grid Energy Efficiency Directives (2006/32/EC, 2009/72-73 EC) [1], which regulates the dynamical interoperation for decentralized energy distribution networks cooperation.

The rest of this paper is organized as follows. Section II describes the smart grids viewpoints, Section III describes our research position for goal and functional modeling of smart grid' uses cases. Section IV addresses the related works. The acknowledgement and conclusions close the article.

II. SMART GRIDS VIEWPOINTS AND APPLICATIONS

The Smart Grid is a complex system of systems. At present, there are many activities running in parallel which are related to the field of smart grid standardization, with some overlapping and duplication of activity and opportunities for learning from the work of others. The main initiatives are presented in [1] from which we follow the Smart Grids European Technology Platform [1] and ITU-T FG Smart Grid [2] reference models. The key of standardization is interoperability, which can be achieved through standardization of communications in terms of interfaces, signals, messages and workflows.

A. Smart Grids European Technology Platform (2006/32/EC, 2009/72-73 EC)

The European Technology Platform (ETP) Smart Grids [1] was set up in 2005 to create a joint vision for the European networks of 2020 and beyond. It has identified clear objectives and proposes strategy for the Smart Grids vision about Europe's electricity networks that must be flexible, accessible, reliable, and economic.

ETP identified the services that Smart Grids are expected to offer to all electrical network users in Europe over time. The implementation of the services allowed by functionalities must be deployed and assessed at National level, taking also into account the initial status of networks and their "smartness".

ETP for SGs starting from Community objectives for SGs has introduced 6 groups for high-level services of SG with 33 functionalities, which are detailed for their intra actions with SG infrastructure and actors. An important tool is the ETP M/441 mandate for smart metering [1] to improve information and services to customers and enable customers to better manage their consumption.

Smart grids deployment will be a continuous learning process. The acceptability of new services by the customers is a main concern. ETP recommends encouraging member states to address communication and education of citizens involving all types of customers: industrial, commercial and residential consumers. To include residential customers in the energy efficiency improvement process, smart metering systems are a key factor with the functionalities as defined in mandate M/441.

B. NIST Smart Grid Conceptual Reference Model

The National Institute of Standards and Technology (NIST) coordinates the development of a framework of standards for Smart Grid [2] to propose use cases and architectures for the SG information networks and identified industry. The NIST Smart Grid Conceptual Reference Model identifies seven domains to analyze use cases: bulk generation, transmission, distribution, markets, operations, service provider, and customer. Main stakeholders are Consumers (residential, commercial, and industrial), Electric transportation and utility stakeholders, Electricity and financial market traders, Information and communication technology (ICT) Service Providers and Application developers, and others.

C. ITU-T Reference Models for Smart Grid

ITU-T Focus Group on Smart Grid (ITU-T FGSG) works for defining clear the common objectives of a Smart Grid, and to analyze *the ICT perspective* and identify *requirements and architectural considerations*.

The ITU-T FGSG architectural view [2] highlights the fact that Smart Grids are formations through ICT, and expands the NIST framework with communication domain, defining the SG architecture as formed from Energy and Service/Application planes according to their functionalities, and controlled and connected by Communication plane functionalities. ITU-T FGSG introduced more than 90 power-related and communication–related definitions and more than 60 abbreviations, for defining a smart grid *architecturally*, starting from the NIST Conceptual Reference Model [3]. FGSG defined 12 high level and 82 detailed level use cases [2].

III. Smart Grid Services and Applications Modelling Framework Based on SG Reference Models

We present our research position on a reusable modeling framework for Smart Grid Services and Applications (SGSAMF). We implemented the framework for Smart Grid (SG) customer services use cases to provide benefits for the configuration management of SG systems. The underlying MDE methodology applied it pushes people to think about the actual energy usage state, and to concentrate on outcomes and results before an eventually implementation of changes of management and infrastructure. This helps decision makers to invest accordingly in information systems and other aspects of changes. In this paper we provide case study for building energy management services use cases.

The BUsinesS and IT EVolution (BUSITEV) methodology [4][6] we applied to provide tools and concepts [7-10] for stakeholders to construct and maintain their proper Smart Grid Services and Applications Modeling Framework (SGSAMF) to serve as a basis:

- to analyze and evaluate alternative implementations of an SG architecture;
- to support planning for transition from an existing legacy architecture to a new smart grid architecture.

A. Generic goal models for EC TFGS high-level services and functionalities

Conforming to the European Conceptual Model for the Smart Grid, each stakeholder today has a different view on smart grids. Our work is related to customers' view.

Our focus is on functionalities from E and F groups defined for consumer related services numbered from 20 to 33 [1]. Fig. 1 shows a Goal-oriented Requirements Language (GRL) [7] partial model of goal-oriented requirements specification for EC TFSG high-level services and functionalities. The detailed services for F group of high-level services are modeled as actors, goals, soft goals decomposed on their realizations by tasks and resources. Relationships used are contributions, logical operators (And/Or). For modeling intents the content of this goal graph is captured from EC TFSG Studies Group 1 report at pages 6-19 in [1], which are textual description of objectives and high-level functionalities, and detailed services for SGs.

B. Generic models for Building Energy Management System (BEMS)

Our focus is on the 16 detailed use cases of Customer domain defined by ITU-T FGSG, which cover the functionalities of Building Energy Management System (BEMS).

BEMS is a system technology for managing the building facility and component operation focused specially on energy improved by sensing, metering and controlling devices based on ICT hardware and software technology [2].

The Customer system is technically formed by in-home displays (IHD), programmable communicating thermostats (PCT), direct load control devices (DLC), and web portals. *Information technologies* provide customers with the opportunity to manage their electricity consumption by providing them with data about, their electricity consumption and costs through mobile devices, IHDs, and web portals. *Control technologies* provide customers with the opportunity to manage their electricity consumption through load control devices, such as PCTs. Smart meters are fundamental components which allow electricity consumption information to be captured, stored, and reported in intervals of 60 minutes or less to both utilities and their customers.

Smart energy services in building domain are supported by introducing the smart grid infrastructure technology into building domain and it configuring for communication with the BEMS system technology. The in-building SG infrastructure includes detailed metering, detailed electricity control, Energy Service Interface (ESI), Distributed Energy Resource (DER) and electric vehicle (EV).

 ISBN: 978-1-61208-363-6

C. BEMS functionalities

BEMS manages electric usage for building operation and maintenance by dynamic pricing information transfer to BEMS through ESI. When external public grid needs to reduce demand by consumer with reaching to peak demand is realized a DR (demand signal) message transfer to BEMS through ESI, and BEMS controls the usage conform BEMS energy management algorithm and policy. Based on the DR message and/or dynamic pricing information from utility BEMS is able to control any energy consuming component intra building area through ESI. Based on some information including dynamic pricing message and/or DR message from utility, BEMS is able to control charge/discharge of EV's.

Fig. 2 shows the BEMS processes supported by SG services modelled into Use Case Maps (UCM) [7] scenario-based functional model. The model elements are expressed with usual basic workflow signs and the elements required to structure the business process model with regards to information passing and modularity in root-map and sub-map diagrams. The process flow takes place along directed path. Loops and circles are allowed in the path direction. We can provide their consistency with structure division by stubs (diamond), and with conditions during validation.

The textual requirements which cannot be built in functions, activities or conditions are collected by categories and are shown as notes with reference to stubs. Organizational cross-cutting events are highlighted by bounded path with components (rectangle), which model actors and divisions. For quality expectations we can give idioms for timing, pairing, constraints, limits and asynchrony-synchronic functions suported by User Requirements Notation (URN) tools [8].

The checking of the wellness of processes and concrete use cases take place with simulations in the form of scenarios supported by URN technologies [7-9].

Textual description of use cases is from the pages 53-57 in Appendix III. Use Cases for Building Management in "Use Cases for Smart Grids" from Smart-O-31Rev.7, ITU-T FGSG, Geneva, 18-21 December 2011, published at [2].

IV. RELATED WORK

Smart Grid-enabled applications present several examples of use cases to include real-time consumer control over energy usage; controls for large-scale energy storage; mobile billing for charging electric vehicles. Görbe et al. [11] propose user related services to apply EV batteries. Wang et al. [14] propose energy management modeling based on interpreted Petri Nets formalism for smart grid communication between buildings and public grid. Peruzzini et al. [13] propose an information management model to make an extended virtual enterprise to provide energy-control services. Kato et al. [12] provide a Home EMS for integrating of information and energy which aims to analyze user behavior to provide life-support services appliances. Those and other publications not provide help and reusable models for assessing services from SG reference models.

We applied the BUSITEV Framework [4], [6] based on MDE technologies and URN [7] mapping techniques that assure quality and improve testability. This way the modeling of the business processes results in the optimization of the processes and the changes of the organization at the same time as well as the required software maintenance for the problem generating change management. Applying this framework to design of SG services framework [6] provides to control and assess the conformance to the standards and reference models.

V. CONCLUSION

This position paper proposes a Smart Grid Services and Applications Modeling Framework (SGSAMF). Goals and scenarios models built following smart grids' reference models support valid domain-specific architectural decisions, and form a traceable library for business process models with reusable repositories of use cases for SG Customer Domain. This help decision makers and developers to apply European Reference Models for SG and ITU-T SG reference Architecture [1], [3].

As is shown in Section 3 the smart grids deployment will be a continuous learning process, when supporting standards and their appliances are crucial.

Our previous work on BUSITEV Framework [4] offers a good basis for modeling SG strategies and use cases to manage services strategies for smart grid developments and support the stakeholder's communication

Future work needs to complete the SGSAMF Framework with all detailed use cases for Customer domain's functions to support services management development. This framework support end-users trainings for customer acceptance of smart grids in order to make self-configuration of their usage strategies in home energy management systems.

ACKNOWLEDGMENT

We acknowledge the financial support of this work by the Hungarian State and the European Union under the TÁMOP-4.2.2.A-11/1/ KONV-2012-0072 project.

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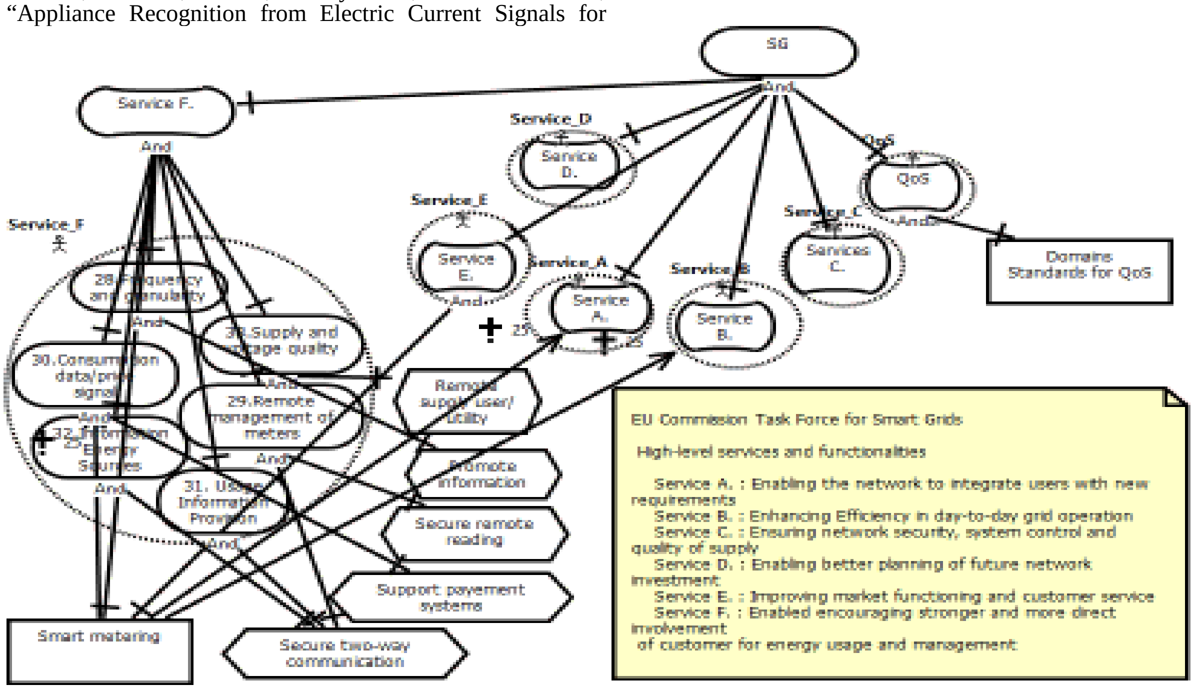

Figure 1. GRL goal-oriented requirements specification of TFSG high level services and functionalities (F group of ECTF for Smart Grids)

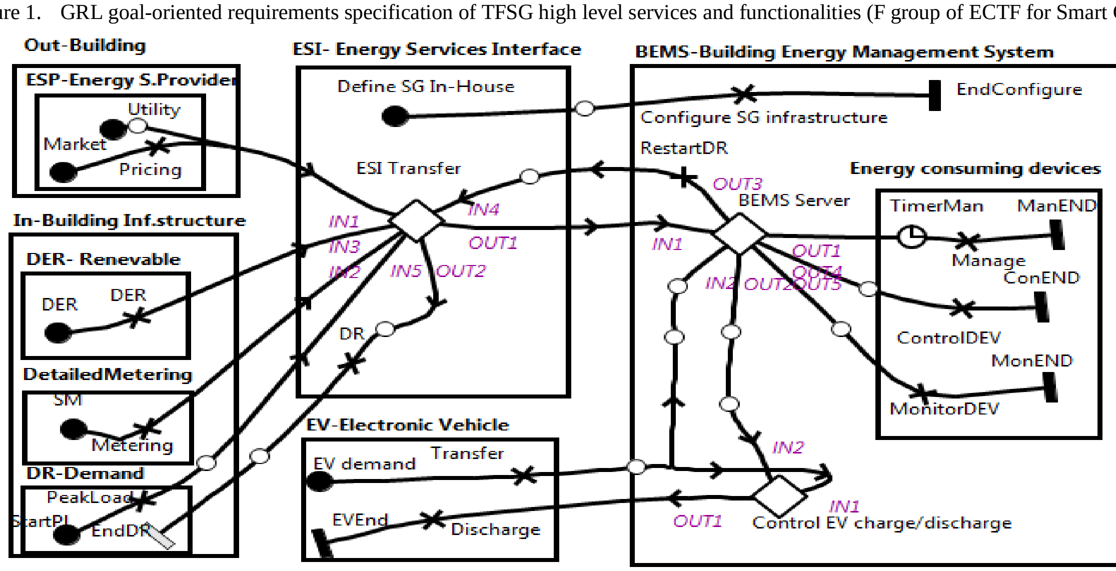

Figure 2. UCM functional model for BEMS processes supported by SG services defined at ITU-T FGSG

A Fast WiFi Direct Device Discovery with Caching Discovery Schedules for Seamless N-Screen Services

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***Abstract*— We propose a novel device discovery scheme in order to accelerate device discovery procedures in the Wi-Fi direct networks. In the proposed scheme, neighboring devices capable of caching the scheduling information are utilized to provide the cached scheduling information while a device in their vicinity is in search of another device(s).**

Keywords - WiFi direct, device discovery, seamless services.

I. INTRODUCTION

Thanks to the proliferation of smart-phones, we are experiencing totally novel services which we have never seen before. Indeed, smart-phones are expected to fulfill more promising services by accommodating bleeding-edge technologies. Particularly, the N-Screen services providing multimedia services with multiple screens are attractive ones among the feasible services which the smart-phones can provide now.

Typically, the smart-phone screens are small enough to be held by a hand. In contrast, the TV screen sizes become wider while their prices are plunging more sharply. Obviously, such trend stimulates the desire to watch multimedia contents on a well-mounted wide screen, and hence the desire could be a sufficient reason why the multimedia contents on a smart-phone should be transferred and displayed on a wider TV screen.

Meanwhile, we can perceive fast evolution of the 802.11 Wireless Local Area Networks (WLANs). Recent advent of the 802.11ac makes it possible that smart-phones are serviced with high data rates of more than a few Gbps. Such high rates are sufficient to provide satisfactory High Fidelity (HD) multimedia services. Besides, the emerging Wi-Fi direct mounted on top of the 802.11 WLAN protocol stack enables smart-phones to transfer directly HD multimedia data to their connected devices without passing through an Access Point (AP) [1].

In fact, it is already realized that recent smart-phones can be used for the N-Screen services with the help of proper peripherals equipped with the WiFi interface. For instance, the Google announces the Chromecast for wireless services. The Chromecast establishes wireless connections between smart devices including smart-phones and a HDMI-enabled display such as TVs and monitors. The Chromecast receives multimedia streaming data through WiFi interface and forwards it to its connected display via the High-Definition Multimedia Interface (HDMI) while a smart-phone sends the user-selected multimedia contents to the Chromecast. In this way, a smart-phone user can enjoy the multimedia services on a wider screen [2]. The Digital Living Network Alliance (DLNA) technology is another way to enjoy N-Screen services. The smart-phones can display their own multimedia contents on a wide screen via DLNA connections. Recently, more and more Smart TVs and monitors tend to adopt the DLNA standard for better contents sharing services.[3].

As we can see from the examples of the Chromecast and DLNA technology, it is necessary to manage wireless connections and data transfers between smart-phones and displays for proper N-Screen services. The Wi-Fi direct is designed for this purpose. Various N-Screen related technologies are already built on the WiFi direct technology. It is expected that more sorts of the N-Screen services are realized by adopting the Wi-Fi direct in near future.

A device with Wi-Fi direct should conduct a device discovery procedure first during its initial connection establishment. The device discovery takes two or more seconds to be completed which may incur service disruptions while a smart-phone tries to change displaying screen [4]. Let us imagine the following service scenario. When a user watching a movie on a smart-phone wishes to transfer the movie to a nearby Smart TV. The user obviously wants to keep watching the movie without any disruptions. Then, the smart-phone tries to find a near Smart TV in order to migrate the streaming service display on the smart-phone's screen to a newly found Smart TV immediately after it detects user's intention. Given this case, it is strongly recommended that a device discovery time should be reduced as possible as it can since it heavily affects service disruption times.

Therefore, we design a fast device discovery scheme to reduce the service disruptions when displaying screen is changed for N-Screen services. We consider neighboring devices in the vicinity of the smart-phone providing an N-Screen service for a user since we are in a huge trend that many consumer electronics, which could be potentially neighboring devices, such as TVs, phones, audio components, and even refrigerators are equipped with Wi-Fi interface. Those consumer electronics may give a help to the device conducting device discovery procedures although they are not capable of displaying the multimedia

 ISBN: 978-1-61208-363-6

contents. In the proposed scheme, those neighboring devices cache the information regarding device discovery schedules for the devices conducting WiFi direct device discovery procedures. Then, they will inform another devices trying device discovery procedures of the cached scheduling information if needed.

This paper is organized as follows: Firstly, Section II describes background on the N-Screen services. Then we explain the proposed Wi-Fi device discovery scheme in Section III. In Section IV, we discuss expected performance evaluations of the proposed scheme since this work is still in progress. Finally, Section V concludes the paper.

II. BACKGROUND

Figure 1 shows a Remote User Interface (RUI) framework designed by the ETRI [5], [6].

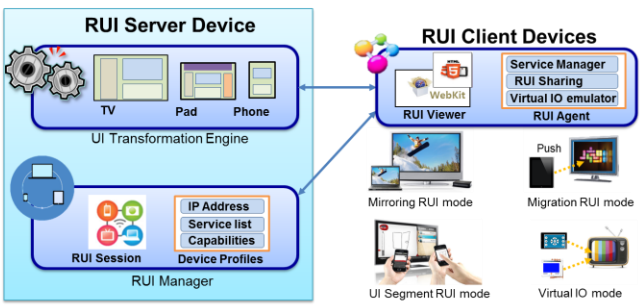

Figure 1. The structure and functionalities of ETRI's scalable RUI framework.

The RUI framework supports home networked smart devices to collaborate each other for the RUI services using migratable UIs. The UIs of RUI based application are implemented with the HTML5 language. They are composed of several UI segments, which can be moved to other devices according to user's requests. The core functionalities of the ETRI's RUI framework are summarized as follows:

- **UI transformation**: The UI transformation engine optimizes the UIs of RUI applications according to the device profiles including the information about resolution, screen size etc.
- **Mirroring RUI**: Users can share local UIs with multiple devices using duplicated UI documents. The duplicated UIs are synchronized according to invoked user events.
- **Migrating RUI**: When a user wants to display local UI on bigger screen than a local device, the user can push the local UI to a remote device. The local device can be used as input devices using I/O emulators.
- **Collaborative RUI**: A user can pull UI segments from a remote device to control remote RUI based services using their sub-UI displayed on the local screen.

Virtual I/O: A user can use local devices as virtual input devices to control remote devices or RUI services instead of a physical remote controller. The I/O emulators are embedded in the devices as Web applications composed of physical input device-like UI and functionalities. The emulators send invoked user events to a remote device through RUI framework, and the transmitted events are controlled by remote services.

The RUI framework is designed to work in the IP-based home networks. Therefore, all devices working on the same RUI framework should be connected to the same AP. However, the devices may not work correctly due to packet losses or delays while users move around at home. For example, an input event invoked by a virtual mouse often arrives too late to control remote services during the recovery procedures for packet losses caused by user's movement. In order to solve the problems, we are trying to expedite the operations regarding the RUI framework by revising the Wi-Fi direct protocols.

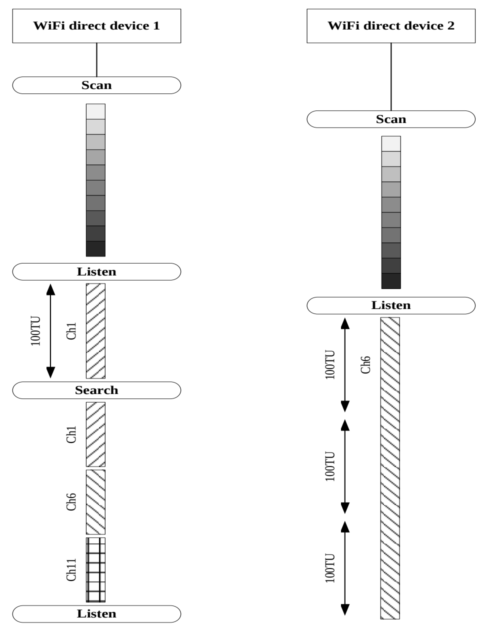

Figure 2. An Example of Wi-Fi Device Discovery Procedure.

The Wi-Fi direct announced by the Wi-Fi alliance is a protocol specification facilitating wireless Device-to-Device (D2D) communications in the 802.11 WLANs. It works on the top of Medium Access Control (MAC) layer of the 802.11 WLANs. Once a device with Wi-Fi direct is turned on, it begins to search another Wi-Fi direct device in order to establish a connection. For this purpose, the devices should follow device discovery procedure.

Figure 2 illustrates an example of the device discovery procedure. In this figure, *device-1* is first turned on, and then conducts the 802.11 active scanning. The active scanning is a typical 802.11 procedure to find new APs. An active scanning device sends *Probe Request* messages and waits for *Probe Response* messages for a while in each available channel in turn. Empirical measurements show that active scanning may take several hundred milliseconds so that extensive studies have been carried out to accelerate the active scanning procedure [7]-[14].

 ISBN: 978-1-61208-363-6

If the *device-1* fails to find a new AP with the active scanning, it enters device discovery procedure. Prior to the device discovery entrance, the device selects one channel as a home channel among three social channels, of which numbers are 1, 6, and 11. The device discovery procedure consists of two phases. The first phase is *Listen* phase. In *Listen* phase, Wi-Fi direct device camping on its home channel stays listening to *Probe Request* messages which another Wi-Fi direct device may transmit. The listening time can be arbitrarily chosen from one of three options, 100 Time Units (TUs, 1 TU is 1.024 milliseconds), 200 TUs, and 300 TUs.

If none of devices are found during the *Listen* phase, *device-1* begins *search* phase. In *search* phase, *device-1*sends *Probe Request* messages and waits for *Probe Response* messages. It repeats this procedure in each social channel in turn. In case when it cannot find a new device with this message exchanges, it tries *Listen* phase again. The device with device discovery procedure conducts this procedure until it finds a new device. Once a device succeeds in finding a new device, they form a network. When a Wi-Fi direct network is created, a group owner elected by comparing devices' intent value takes the role of an AP.

III. PROPOSED DEVICE DISCOVERY

A. Operation Scenario for N-Screen Services

Figure 3 shows an example for our scenario regarding the operation while a user with a smartphone moves from the TV at location A toward the TV at location B. For simplicity, we call the TV at location A and B as TV-A and TV-B, respectively. In this scenario, the smartphone is initially connected with the TV-A via Wi-Fi direct. It sends multimedia traffic for the streaming service so that the user with the smartphone can watch the TV enjoying multimedia service. Then, the user moves toward the TV-B while he/she is still watching the TV-A. During user's movement, the Wi-Fi direct connection may be lost due to weak wireless signal strength, and then the smartphone should search a new TV for continuous multimedia service.

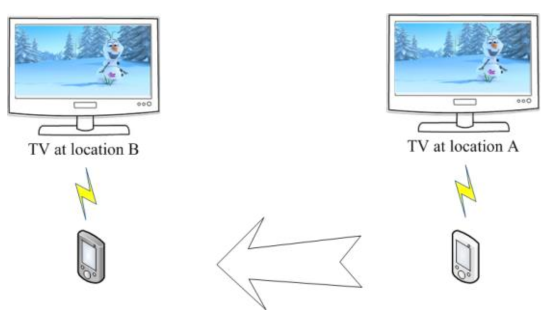

Figure 3. An Exemplary Service Scenario.

There can be one of two possible cases to cope with this situation. (1) The service on the TV-A seamless migrates to the TV-B when the smartphone successfully finds the TV-B. The smartphone should control overall procedure for the seamless migration. (2) Otherwise, the service should be provided in the smartphone temporarily until the smartphone finds a new TV. If it succeeds in finding a new TV, the service is switched to the newly found TV, e.g., the TV-B in this service scenario. If not, the service continues to be serviced in the smartphone.

In either case, the smartphone should try to find a new TV for continuous multimedia service so that the device discovery procedure should be done as early as possible. However, as reported in [4], the Wi-Fi direct device discovery may take longer than two or three seconds to be completed. Such a long device discovery procedure may disrupt the multimedia service thus deteriorating service quality seriously. For this reason, we propose more efficient device discovery procedure depending on the existence of neighboring devices capable of taking over ongoing services in the subsequent subsections.

B. Device Discovery with Neighboring Devices

We assume that the TV-B does not have any connection with other device. Therefore, the TV-B periodically conducts device discovery procedure.

Typically, the device conducting Wi-Fi direct device discovery broadcasts *Probe Request* messages and thereafter waits for *Probe Response* messages for a while in a social channel. Neighboring devices receiving the *Probe Request* messages reply with *Probe Response* message when they can provide the services which the searching device wants to be served.

Additionally, we add scheduling information to the *Probe Request* message. The scheduling information includes the time when the device revisits to the social channel in near future. Neighboring devices should cache the information even though the neighboring devices are not what the device conducting device discovery wants to find. It implies that the device caching the scheduling information does not need to reply if the Probe Request messages are not relevant to its capability. The cached information is conveyed to another device if what the device is searching matches the cached information. Then, the device can utilize the information to find a new device in its vicinity.

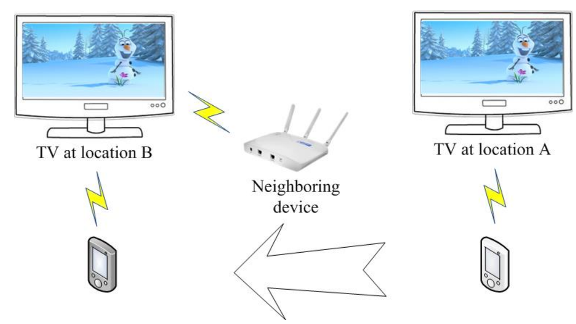

Figure 4. An Example for the Proposed Device Discovery with the Help of a Neighboring Device.

Figure 4 shows an example for this proposed procedure. In this figure, the AP neighboring to TV-B caches the scheduling information of the TV-B. The smartphone begins to move toward TV-B. However, it cannot find the

TV-B since the TV-B is far from it. Instead, the smartphone can obtain the scheduling information from the AP in advance. Therefore, the smartphone can wait for the TV-B in the social channel by referring to the scheduling information in the AP's vicinity. For better cache hit ratio, the AP can estimate the smartphone's movement so that the AP sends replies for only case when the smartphone approaches to it.

C. Device Discovery without Neighboring Devices

It is possible that there are none of neighboring devices, which can help the smartphone. In order to resolve the situation, we consider two candidates as follows:

(1) As explained earlier, each device has its own home channel. From this fact, we design the device to have its own time schedule, in which the device should stay definitely at the channel. The time schedule should repeat so that another device can estimate the future schedule with the current schedule. In the service scenario shown in Fig. 3, a smartphone may happen to pass by the TV-B and the TV-A in order. Therefore, the smartphone can cache the scheduling information of the TV-B, and then transfer it to the TV-A. In this way, the scheduling information may propagate to the TV-A. Later, a new smartphone may approach to the TV-A. Then, the TV-A gives the scheduling information of the TV-B to the smartphone. For this reason, the smartphone can utilize the information to predict future scheduling information and try to find a new device, i.e., TV-B with the scheduling information.

(2) We consider globally predefined time schedule. By using this schedule, devices should stay at a globally defined home channel for a given period. However, this scheme need to be polished more since it has many issues to be solved such as global synchronization, device discovery latency etc. Consequently, two proposed schemes still need to be refined for better efficiency.

IV. Expected Performance Evaluation

The proposed device discovery procedure is under development with the Odroid XU boards [15]. The boards are equipped with the Wi-Fi module manufactured by Realtek [16]. For our service scenario, we assume that TVs and smartphones run in the Android environments. Therefore, we utilize the Wi-Fi direct source code in the Android devices for the practical system developments in both sides of the TV as well as the smartphone.

We plan to conduct experiments with complete implementation of the proposed schemes. For our experiments, we will employ several neighboring devices and measure the lost packets during the proposed device discovery procedure and the existing device discovery procedure, respectively. After that, we will show the comparison results.

V. Conclusion

We propose a feasible device discovery scheme accelerating Wi-Fi direct device discovery procedure. The proposed scheme will be evaluated with practical implementations. We expect that our work is certainly helpful for the work regarding N-Screen services since these services become prevalent with Wi-Fi direct in near future.

Acknowledgments

This work was supported by the IT R&D program of MKE/KEIT, [I2905-13-1018, Smart TV platform built using a multi-device collaboration gateway].

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Towards Tactile Alarms Systems for Increased Awareness in Smart Environments

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Abstract—**Alarms are an important part of automation systems that raise user awareness in emergency situations. However, research shows that existing audible and visual alarms are ineffective. Failure to deliver alarm signals leads to lack of awareness that results in accidents. This paper presents a work in progress on a wearable tactile device application for smart alarm systems. We describe our hypotheses that tactile alarms can decrease user resistance and deliver more focused awareness with directional hints. In this paper, the prototype of a wearable tactile belt is described and its future improvements are analysed.**

Keywords–tactile; belt; alarms; wearable computing; wireless sensor networks.

I. Introduction

In many complex environments, the outcomes of critical situations depend on user awareness. If necessary emergency information is delivered on time, many accidents can be avoided. Our research focuses mainly on the maritime domain: offshore operations and ships in general. Offshore operations and navigation involve multiple complex tasks and cooperative work between people located in different physical locations. In addition, ships are also complex systems consisting of numerous subsystems. Ship accident reports show that many accidents happen due to lack of timely awareness of dangerous system states. Operators either do not perceive existing alarms [1], misinterpret them [2], or have turned them off due to inefficient and too frequent distractions [3].

In addition to maritime operations, we identify other environments in which smart systems with increased awareness are important. This might include control rooms of other complex systems such as oil rigs, and nuclear reactors that require constant monitoring. It can also be relevant for property night watch officers who monitor possible break-ins, as well as-for other alarm systems in general. All of the above scenarios involve human operators in protracted routine tasks where highly active periods are rare. This can lead to high risk situations for operators where fatigue plays a significant role and the operator can fall asleep. Effective alarm systems are necessary that can wake up sleeping watch officers.

Traditional alarm systems consist of two parts. User attention is attracted by audible alarms that are able to deliver signals to users regardless of their position and orientation of their head. A detailed explanation of the alarm source and type is presented as visual information: light indicators with different color codes in simpler cases and textual displays in more complex systems. However, accident reports [1][2][3] show that existing alarm systems are not efficient, and identify the need for improved alarm systems that:

- Deliver alarms on time and in an easily perceivable manner.
- Minimize distractions during insignificant errors.
- Deliver alarms focused on the responsible persons, and not directed to the general population.

In this paper, we present a novel alarm system based on wearable sensor and actuator networks that delivers tactile stimuli. We propose an approach, system architecture, and its advantages in Section III. We have built a prototype of a wearable tactile belt, described in Section IV. Its preliminary evaluation and need for optimization is described in Section V. Substantiation of our hypotheses require significant future work that we discuss in Section VI.

II. Related work

Improved emergency detection has been proposed previously [4]. We focus on alarm delivery in this paper, rather than detection. Tactile cues have been explored previously. Recognition ability has been proved for tactile cues [5]. Multiple tactile wearable devices have been proposed, including belts [6], vests [7] and wristbands [5]. Measurements show that resolution of tactile stimuli is around 24mm [8]. We utilize existing knowledge, but apply it to a different application: dissemination of alarms. Conclusions will be reached only after extensive field studies. Nevertheless, description of the system design process is an important step for both engineers and researchers.

III. Tactile alarm system architecture

We envision a smart alarm system that extends beyond audible and visual stimulation. We want to challenge the notion of traditional alarms that are obtrusive and render users resistant to technology. Wearable tactile devices provide a novel approach to solve traditional alarm system inefficiency. This paper describes a work in progress with the following hypotheses on the advantages of tactile alarm system:

- Tactile devices can better raise awareness of tired and sleeping users regardless of their location and position.
- User resistance (and system turn-off probability) can be mitigated by providing different levels of alarms and deliver them in a more focused manner.
- Tactile (compared to audible) cues can be more efficient in directing user's attention to the desired location and providing hints on the type and source of error.

We set the following design rules for tactile alarm system development:

1) **Simplicity**. The system should be easy and fast to don.

 ISBN: 978-1-61208-363-6

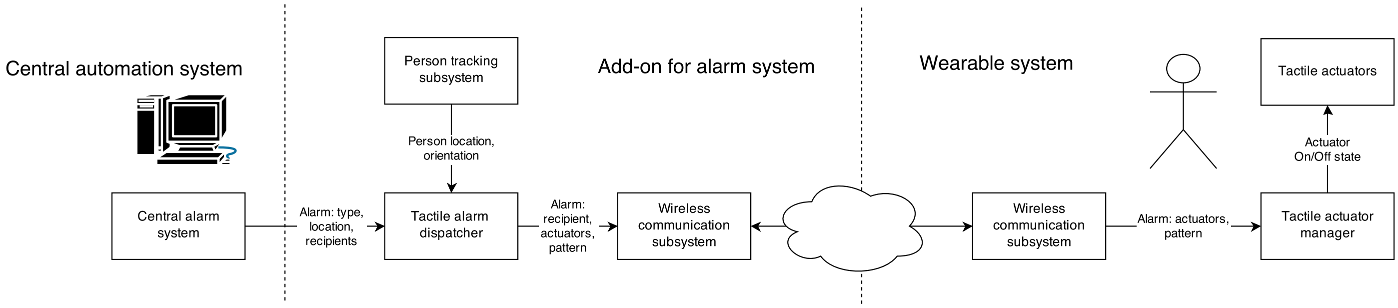

Figure 1. Proposed system architecture. Central automation system disseminates alarms that are translated to tactile cues by the wearable device. Wireless communication exists between the two parts of the system.

2) **Adaptability**. The system should be interchangeable and adaptable for persons with different bodily structure and age.
3) **Comfort.** The system should be lightweight, small, and not disturb the performance of daily activities and maritime operations.
4) **Robustness**. The system should be waterproof, and withstand high pressure and temperature changes that might occur during maritime operations. In addition to tasks on the ship bridge, operators should be able to move to the deck. It should not expose fragile parts, including wires and sensors.
5) **Accuracy**. The system should be able to deliver all required signals with acceptable latency while also not generating false alarms.
6) **Longevity**. The system should be able to operate without changing batteries for at least 24 hours. In the ideal case the system should be able to operate for 7 days (168 hours).

The proposed system architecture is depicted in Figure 1. The system consists of three parts. First, a central automation and alarm generation system is considered. This paper focuses only on alarm delivery, not detection or generation. Therefore, it is assumed that this part is already provided. The second part represents an add-on for the central automation system that is responsible for monitoring of the whole environment and raising alarm events accordingly. This component translates system conditions into tactile alarms that incorporate actual scene and user information. This sub-system is domain-specific and must be specified per application. The third part consists of a wearable sensor and actuator device that tracks users and delivers physical tactile stimuli to them, according to commands from the central system. The wireless sensor network approach is used for communication between the two parts of the system. Both parts of the system are independent and interchangeable as long as common communication standards and protocols are used, such as Bluetooth or 802.15.4.

In addition to attraction of user's attention, tactile systems can also deliver directional cues and focused alarms. Pointers and hints of focus can be given to specific users who can react on a particular event. Human location, pose and orientation tracking must be used to keep the system informed of the actual user state. Although localization techniques depend heavily on the environmental constraints and no generic technique can be provided, existing knowledge of indoor localization can be used to develop custom solutions.

The main advantage of the proposed approach is the interoperability of the components that are interchangeable. The wearable system can be seen as another user interface peripheral device, much like a remote headset or wireless keyboard. It can even be implemented as an external speaker that is able to translate specific sound patterns into tactile cues.

IV. SYSTEM PROTOTYPE

There are several options for device types to be used for our proposed system. The authors of this paper selected a tactile belt as the most appropriate. Ideally, this would be a smart belt that humans wear as usual during their daily activities. But in these first iterations this device will consist of a stretchable add-on-type belt. It can be worn over the regular belt or situated individually around the abdominal region. Its main advantages: close contact with the user, naturalness (immersiveness) that leads to low human resistance, ability to follow the user 24 hours a day (during service hours), and ability to provide accurate directions.

The tactile alarm system presented here is a sensor-actuator network, although the first implementations might seem otherwise. Although the main focus of the system is actuation, not sensing, in further, more advanced revisions, the system would contain sensor modality, such as position and pose estimation with inertial sensors, in combination with external vision-based user tracking. In this experimental phase, the authors have assembled only one prototype belt, yet for deployment at least two belts are required for cooperative operators, such as dynamic positioning and anchor handling operators on offshore vessels. In general, offshore vessels would require one belt for the captain and optional belts for other crew members. Continuous connectivity would require a wireless base station and router infrastructure that is able to provide two-way communication with the mobile, wearable devices in the environment that might be harsh in terms of interference and signal attenuation.

As can be seen in Figure 1, the device consists of three components: tactile actuators, actuator manager, and wireless communication. All of these components are independent and can have different implementations, as long as the interaction protocol is followed. For example, wireless communication can be implemented using WiFi, BlueTooth, ZigBee or other standards; AVR, MSP430 or other microcontrollers can be used as actuator managers; and different vibrating motors are supported.

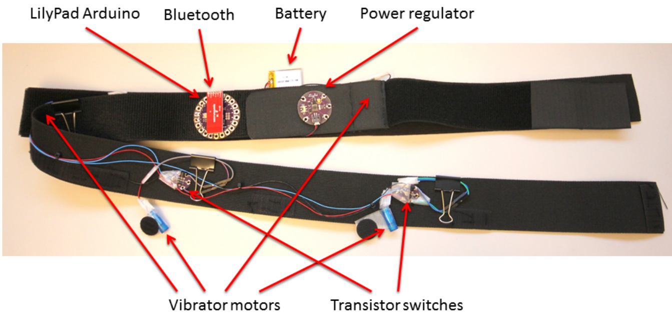

Figure 2. Tactile belt prototype.

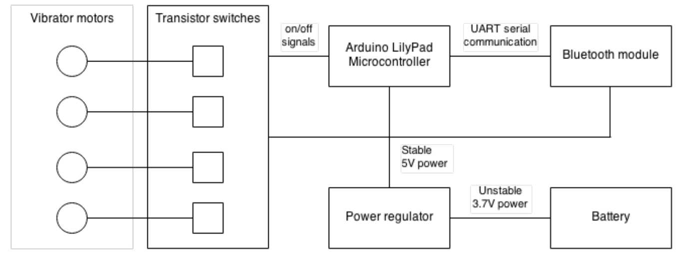

Figure 3. Tactile belt architecture.

We have created a hardware prototype, shown in Figure 2. Its structural diagram is shown in Figure 3.

A. Hardware components

The belt consists of the following components:

- Bluetooth radio module acting as a wireless bridge between the belt and external alarm system. Bluetooth Mate silver is used for the prototype, consisting of a Roving Networks RN-42 Bluetoth Class 2 module.
- 4 vibrating motors generating tactile cues. These are situated across the abdominal region of the user: one motor in the front, one in back, one on the left side and one on the right side. Literature studies show that users can distinguish between 8 evenly spaced locations on a tactile belt [9], yet we assume that four will be sufficient at this early investigative stage. The architecture is flexible: additional motors can be added later if necessary. A switch circuit with a transistor is added for each motor so that it can be controlled by a microcontroller. Precision Microdrives 307-100 Pico Vibe 0mm-25mm vibrating motors are used in the prototype with switch circuits consisting of BC368 NPN transistor, 1N4148 diode, and a resistor mounted on a LilyPad Small Protoboard.
- An Arduino LilyPad microcontroller acting as the manager: parses wirelessly received messages and sends commands to motors.
- A Lithium Polymer (LiPo) battery powering the whole belt. A 400mAh battery weighting 9 grams (0.32 oz) is sufficient to supply the system for about 8 hours. A 2000mAh battery (36 grams or 1.27 oz) would last about 40 hours.
- A power regulator module transforming unstable 3.7V battery voltage to a stable 5V power source.

The choice of components was motivated by requirements of rapid prototyping. Therefore, most of the components are simple and available off-the-shelf modules, not necessarily the best choices in terms of energy efficiency and performance.

B. Software components

The software is designed as a master-slave (or client-server) system where tactile devices act as slaves/clients receiving commands from a central computer. In deployment, the central computer is represented as a module in the central alarm system, while in test scenarios this can be any personal computer or any other device capable of connecting to the tactile device wireless network. Wireless communication involves reliability issues potentially causing the alarm signals not to reach their target. However, this is out of the scope of this paper and will be researched further at a later stage in this project.

Client devices are programmed using the Arduino Integrated Development Environment (IDE) [10]. The server application was developed in Java, using the RXTX serial communication library.

The motors are activated by sending a `MotorCommand` message from the server to the client. The client responds with an `Acknowledgement` message. If the server receives no `Acknowledgement` within a certain period of time after sending a `MotorCommand`, it should resend the `MotorCommand` message. Timeouts and number of retries are system-specific and are not defined here.

V. Optimizations

The following problems have been identified for the prototype implementation:

- **Short network lifetime**. The devices are not able to operate autonomously for the desired period of 7 days. There are multiple reasons for this, including energy-inefficient hardware and task scheduling.
- **No multi-hop communication support**. While single-hop communication is reasonable for tactile alarm dissemination in a single room, it prohibits the implementation of alarm forwarding to watch officers in other facilities.
- **No multitasking**. One can implement all required processes (motor control, data reception, data transmission, and sensor sampling) in a single thread, yet this would involve the creation of a state machine with inefficient and error-prone polling strategies.

These drawbacks can be mitigated by following the wireless sensor network design rules proposed by Strazdins [11].

A. Network lifetime extension

The majority of energy is spent in radio listening mode. Customized MAC protocols that allow changing the radio duty cycle can help to reduce energy consumption significantly. For example, if the radio transmission is activated every 5 seconds for a 250ms period (it takes around 100ms to send a 46-byte packet [12]; 250ms is enough for two-way communication), this results in a 20% duty cycle.

The current Bluetooth module does not allow control of MAC protocols. Therefore, a more efficient radio module must be selected. In addition, the Arduino board with AVR ATMega328 microcontroller is also not the best option in

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terms of energy efficiency: it consumes around 25mA in active mode, and additional 25mA for Bluetooth radio, the total consumption of the platform is more than 50mA, or less than 8 hours of operation from a 400mAh battery.

Vibrator motor energy consumption cannot be accurately predicted in the absence of a particular scenario. However, the motor energy consumption in a realistic scenario is insignificant, compared to consumption of the rest of the system.

Selection of an energy-efficient wearable sensor-actuator node increases the lifetime dramatically. Let us take a TelosB-compatible platform with MSP430F1611 microcontroller and CC2420 radio, such as TMote Sky, as an example. The whole platform consumes 20-23mA during active radio transmission or reception. With a 20% duty-cycle this would result in less than 5mA average consumption. This is a tenfold increase in energy efficiency, compared to the existing implementation. Mercury is an example of a low-power wearable wireless sensor network with average consumption below 5mA including accelerometer and gyroscope sensors, and wireless communication [13]. To conclude, a solution that supports custom MAC protocols, TelosB-compatible platform, and low duty-cycle, would lead to significant lifetime extension of the device.

B. Multi-hop communication

To implement a deployable system, alarm dissemination is also required outside a single room, and 24-hour stable operation is required. Multi-hop communication between the alarm generation system and tactile wearable devices is an essential part of this requirement. The solution can be implemented in multiple different ways: either the conventional automation system's network (TCP/IP or other) is used to create a backbone network and connect tactile devices using gateway nodes attached to each backbone network router, or a mesh network of wearable devices and corresponding sensor network routers (802.15.4) can be installed in the environment and connected to the automation system's network using a single (or multiple redundant) gateway nodes.

C. Multitasking support

There are multiple logical tasks running concurrently on the wearable device: motor control, data reception, data transmission, and sensor sampling (no sensors attached at the moment, but these could be required in future deployments). Support of multi-tasking by providing API for separate thread creation is necessary for different reasons. First, it is correct to separate and encapsulate threads with different responsibilities and resources. It is logically more correct and makes the code easier to maintain and expand. Second, correct multi-tasking can improve the efficiency of the application in terms of time-sharing: threads wait when they have no operation to perform and start running whenever the expected event has occurred. An operating system such as Contiki OS [14], permitting multitasking, is essential part of maintenance improvement for wearable systems.

VI. Conclusion and future work

This paper presents a work-in-progress research study on tactile device evaluation for alarm systems. We present an architecture and a prototype device, and we analyse its drawbacks and optimizations. Several further activities are planned as future work to finish this research study. A field study must be executed to collect both qualitative user feedback and quantitative data on reaction time and accuracy of directional cues. Two challenges are identified. First, it is difficult to simulate real emergency situations, because long idle periods are involved in such scenarios. Second, a trade-off between unobtrusiveness and alarm redundancy must be maintained. Studies in maritime operation simulators (an environment similar to one used in [15]) are planned using the tactile belt as an alarm delivery mechanism to attract user attention to particular areas of the ship bridge. In synergy with other local research activities [16], eye trackers will be used as quantitative tools for reaction accuracy and latency measurement. In the case of positive results, this research study can serve as an important milestone for discussion involving industry, academia, and standardization institutions.

Acknowledgment

This study is as a sub-project supported by Norwegian Research Council (NFR) Grant in Marine Technology, Nr. 208530/O70 (2011-2014).

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Stability Improvement Solution of the Smart Power Grid by an Analysis of Voltage Variation in Intelligent Buildings

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Abstract — **This paper describes an approach to minimize the uneven effect of voltage and power in smart buildings and on electrical networks. The analysis is performed by considering diverse scenarios in smart power grids. The idea is to calculate the actual power consumption and power reserves of selected Smart Homes. In a second step, the effect of voltage variation on intelligent buildings and on electrical networks is investigated. In the last part, the control application of Next Generation Network (NGN) and stationary storages for improving the stability, especially those with a high percentage of in-feeds from renewable energy sources (RES) are discussed and evaluated. We consider intelligent buildings or Smart Homes based on Next Generation Network (NGN) components. The NGN components are applied as a communication and integration platform between the smart phone of smart home owners, the home automation and building control system as well as the energy suppliers of the smart power grid. Smart Home appliances based on the KNX bus, the Session Initiation Protocol (SIP) and the Presence Service are used to build a well performing and scalable system based on open source software.**

Keywords - Energy Management, Home Automation;Smart Power Grid, NGN, Presence Service.

I. INTRODUCTION

Intelligent power grids are the core of the future power supply. As a part of smart cities, smart buildings (facilities or houses), smart appliances, smart thermostats, smart meters, real-time dynamic pricing and next-day energy information feedback to electricity users play an important role in this intelligent management infrastructure. Every part of our environment will be connected to each other and can be controlled with the given rights from central points, and to exchange both energy and information. The actual intelligence is the IT-supported structure and control tactics especially to match fluctuating Smart Grids, which are supposed to guarantee stable power supplies within the European Norms. For the stability of a system with a Smart Grid, there are two main criteria: First, the generation has to match the demand at any time and has to hold a reserve (battery storage) for immediate outages. Second, the grid has to provide sufficient capacity for the voltage stability at every portion. According to our particular status and main problems, all countries need to simplify the Smart cities and adjust it to fit their own features. The purpose and relevance of this paper is to describe energy management mechanisms and tactics that include manual and automated control of equipment from uncertain energy sources, and to investigate various issues regarding energy instabilities of the smart building systems. In our consideration, our Smart Homes make use of Next Generation Network technologies (NGN), based on the Session Initiation Protocol (SIP) and the Presence Service [1]. By this way, a near-real-time push solution is realized, using the IP Multimedia Subsystem (IMS) to remotely monitor and control Home Automation systems via mobile devices with open source software. This is described in our previous work [1][2]. According to the latest report by GTM Research, the U.S. home energy management market is forecasted to be worth over 4 billion USD by 2017[3]. This forecast shows the business opportunities and relevance of the proposed document for home control and energy management services. According to this source, the sectors with the biggest potential for saving energy are buildings and mobility.

II. STRUCTURE OF THE PAPER

Following the introduction, Section III shows related work for the suitability of our previous idea to apply a control solution based upon NGN technology. In Section IV, the general concept is outlined and important use cases are presented. The overall system design is described in Section V. The calculation is discussed and evaluated in Sections VI and VII. The components used to analyze the solution are presented in Section VIII. Section IX concludes the paper and gives an outlook of future work.

III. RELATED WORK

Many companies and institutions are working on solutions for energy efficient management for buildings. In our previous work, [1], [2], [13], [17], we presented the detailed idea and hands-on work on operational tools and calculation experiments done on our prototype. The primary idea is to connect the technology of Next Generation Networks (NGN) to Smart Homes. The next step is to use SIP with all its benefits as the main communication protocol and connect it with a bus system standard, in this case KNX [4]. For the home appliances (sensors, actors), a signaling gateway between the KNX home automation and building control system [5] and SIP, allowing communication of mobile devices with KNX sensors/actors using existing SIP infrastructure, is applied.

The focus of this document is to analyze the power instability of NGN based smart homes. In order to meet today's power system requirements; it is the upholding of the voltage regulation within the permitted voltage range in distribution grids on the low voltage and middle voltage level. The consumption of electrical power causes the voltage to drop at the junction point of the smart buildings, whereas injection of power will make it rise. This overshoot-and-dip-effect increases with the power and the distance of the smart buildings to the substation. If the voltage drop or rise gets too high, the distribution system operator has to take counter measures. This is because the end users' appliances and electrical devices are designed for a certain voltage range defined by European norms EN50160:2007 [16]. The amplitude of the supply voltage is defined in the Norm and given in Table I.

TABLE I. TABLE I. AMPLITUDE OF SUPPLY VOLTAGE

Voltage Magnitude	LV: U =230V MV: "by convention"
Voltage Magnitude variations	LV, MV: ±10% for 95% week

It is defined in these norms that the magnitudes of the low voltage and high voltage should be in the given range.

IV. USE CASES OF SMART ENERGY MANAGEMENT

In this section, the uneven effect of two typical use cases of smart energy management, electric load balancing and regulating are discussed.

A. *Use case (UC1): Insufficient or lack of renewable energy*

In our previous work [1], [2], we discussed that in use case (UC1), the power consumption and load in the city reaches its maximum level. During the same time frame, the feed-in of renewable energy is diminishing to the minimum, e.g., because of wind calm or the lack of sun radiation. Figure 1 illustrates this situation.

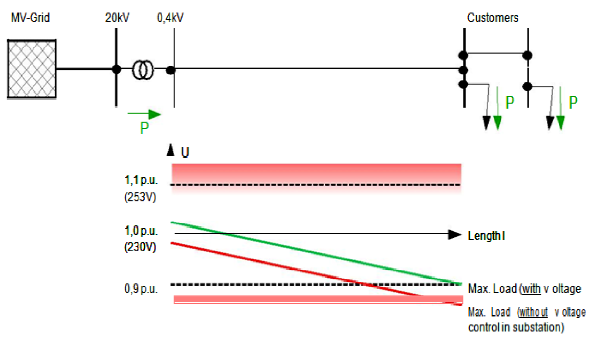

Figure 1. Maximum load scenario

After further analysis on this topic, we have found that in times of high load, the voltage at the terminals might fall below 0.9 p. u. (red line) equivalent to 207 V, which is a supplied or consumed voltage level violation according to European Norm EN50160:2007. This dip effect increases with the power and the distance of the smart houses to the substation. If the voltage drop gets too high, the distribution system operator has to take counter measures. The typical instrument to counteract this effect is the application of tap-changer transformers, because the end users appliances and electrical devices are designed for a certain voltage range defined by European Norm. This lack of electric power shall be balanced with an optimum approach at least partly by the intelligent buildings of the city. In order to do that, the lack of energy is signaled by the power providers towards the owners of intelligent buildings in the city by means of usual communication technologies. The house owners can then react by turning off domestic appliances (e.g., white goods), set air conditioning units or heat pumps into eco-mode and deactivate charging stations for electric cars and vehicles. Therefore, the energy supply within the city could be balanced in a better way by the swarm behavior of the intelligent consumers by de-activating power loads.

B. *Use case (UC2): Surplus or excess of renewable energy*

In our previous work [1], [2], we also discussed that in (UC2), the power consumption and load in the city reaches its lowest level. During the same time frame, the renewable energy is fed into the power grid at maximum levels because of strong winds or strong sun radiation. Figure 2 illustrates this situation.

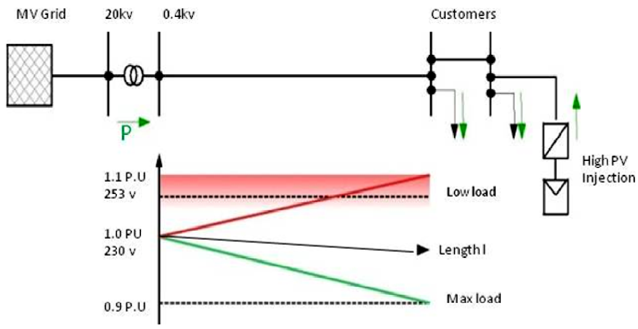

Figure 2. Low load scenario

In times of high Photo voltaic (PV) injection and low load, this is likely to occur in the morning hours. High Photo Voltaic (PV) injection shown here is just to sketch the idea of getting more power from the grid to the consumer. Injection of power may make the voltage at the terminals rise up to 1.1 p.u. (red line), equivalent to 253 V, which is also a possible voltage violation according to European Norm. This overshoot effect increases with the power and the distance of smart houses to the substation. If the voltage rise gets too high, the distribution system operator has to take counter

 ISBN: 978-1-61208-363-6

measures, because the end users appliances and electrical devices are designed for a certain voltage range only (as above). Again, this surplus or excess of electric power shall be used with optimum approach by the intelligent buildings of the city. In order to do that, the surplus of energy is again signaled by the energy suppliers towards the owners of intelligent buildings in the city. In this case, a smart phone app is used. The house owners with a smart phone application can react by turning on additional power loads such as domestic appliances (e.g., white goods, air conditioning units or heat pumps), as well as electric cars and vehicles. Also in this case, the energy supply within the city could be balanced by the swarm behavior of the intelligent consumers.

V. CONCEPT AND OVERALL SYSTEM DESIGN

The core concept is to minimize the uneven effect of smart buildings on electrical networks and on the smart power grid, by analyzing and controlling the load profile of the intelligent buildings. The use of information technology allows to improve how the electricity travels from the power grid with power system stability to consumer consumption integration. The basic idea is to balance loads in power grids by using KNX-enabled Smart Homes and a communication infrastructure based on NGN technologies and the Presence Service. The advantages of Next Generation Networks are used to build a communication platform between mobile devices and an intelligent building with a Home Automation solution.

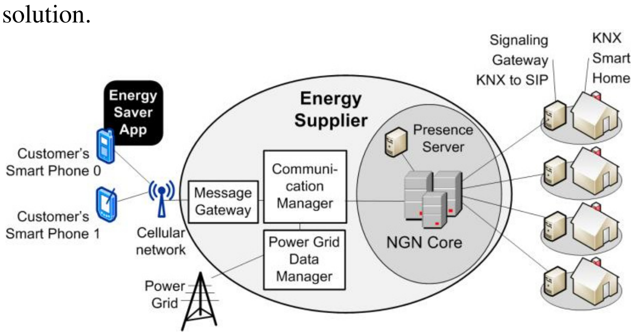

Figure 3. Control system with smart loads L9.....L20

Figure 3 depicts the smart loads and their control system architecture. For simplicity, the loads are named L 9, 10, 19, 20. To analyze the facts related to smart homes and power networks, an integrated engineering tool is used for the power system calculations. The following features are provided by “Dig SILENT Power Factory” [10]: It has been designed as an advanced integrated and interactive software package dedicated to electrical power system and control analysis in order to achieve the main objectives of planning and operation optimization. Some of these functions are load-flow, stability calculation and modal analysis.

To design a Distribution model of a smart home electrical network and a power grid, the following steps have been applied which include the external grid, transformers, bus-bars etc. (see Figure 4.) At first, an external grid (medium voltage) was connected to the bus-bar (B1). The specific bus-bar was connected to a transformer (step-down), the parameters being 120/20 kV. The low-voltage side was connected to the bus-bar (B2). Transformer T1…T3.20/0.4 kV (step-down), the high-voltage end was connected to B2, and the low-voltage end connected to B3. A specific transmission line, one end connected to B3 and the other end to consumer (load), was set up, the Line-Line voltage being 400V and 230 V Line-Ground. There is a total of 12 smart houses and 23 normal houses, resp. Loads (1.14 kW each), power factor 0.95 to bus-bar B3. The transmission line of B3 is 5 km in length. The resistance value for each kilometer of B3 is 0.2215 Ohm, with a reactance of 0.037 Ohm. When voltage is applied to the transmission line (B3), due to different loads, the voltage sags from 400 V to 343 V. The voltage 343 V is not according to the European norms. According to the norms, there can be ±10% voltage magnitude variation of the reference voltage. The distribution grid model consists of five transmission lines, three transformers 0.4 kV, four photo voltaic generators (PV cell) and one motor (battery). Every load at the consumer could be 1 to n number of customers. Three transmission lines are connected to one bus-bar, which is connected to one transformer (20/0.4 kV). The other two transmission lines are connected to a separate bus-bar, which is connected to another transformer (20/0.4 kV). Now, there are mainly two tasks: Energy balancing and operational control. Both tasks

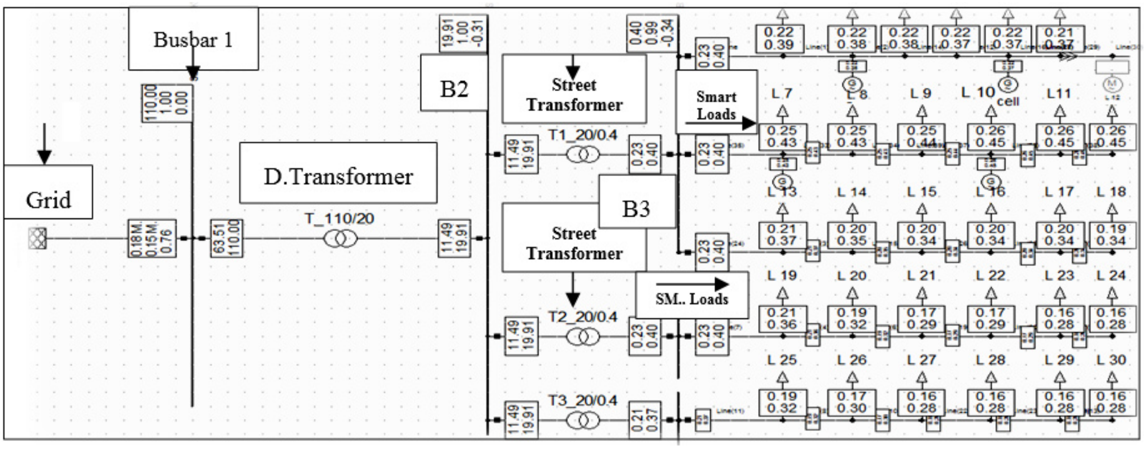

Figure 4. Transmission from Grid to distribution network and transmission from distribution to consumer end

are closely linked, since the power which is generated at different places and times in the grid must be evacuated and transported. According to the German Energy Industry Act, the power from internal Renewable Energy Sources (RES) generators must be evacuated [6]. For further coverage of 30% RES, contracts for RES outside the grid have been made. However, forecast and reality do not always match, neither on the generation nor on the load side [11].

VI. EVALUATION AND ANALYSIS OF THE OUTPUT PLOTS

The scenario being displayed in Figure 5 shows the high load connection. It shows a voltage dip after each load.

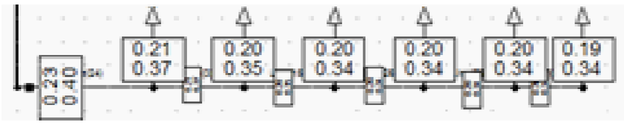

Figure 5. Transmission line with max load smart homes

In Figure 6, the scenario being displayed is high load.

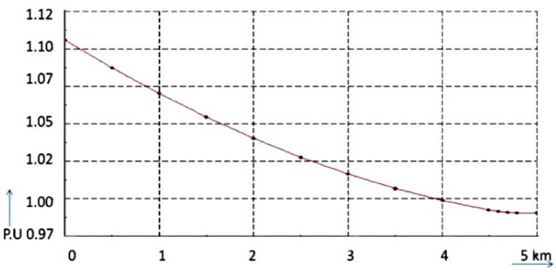

Figure 6. Plot: Voltage drop across supply line, high load at terminals

Given that the voltage has dropped from 1 p.u to 0.97 p.u, equivalent to 207V, at the end of the line. The graph shows that when smart high load is connected on a transmission line, there will be a voltage drop at the consumer end and the effect is increasing when the distance to the substation is increasing. Line-to-Line and Line-to-Phase voltages are reducing drastically. At the end, the voltage variations are violating the Norms. According to EN50160:2007, it should be within the 10% range. Usually, tap-changer transformers are used by distribution system operators as the typical instrument to counteract this effect. The technique is to choose another tap winding, so that the voltage in the substation increases, also affecting the terminal voltage. However, they can only be operated in load-less state which is a great disadvantage. If the voltage is supplied from the grid, the feed-in of renewable energy is diminishing to the minimum and the consumer is in the high load state. The voltage at the transmission line is decreased which has to be improved to a standard according to the Norms. Electrical appliances can be damaged if the voltage levels are not kept within the Norms. The electrical appliances at households cannot bear such decreases in voltage. More current will be drawn by appliances, causing more expenses and affecting the efficiency of these appliances. In the following, the second high Photo voltaic (PV) injection scenario is described (Figure 7). Each load is connected to bus-bar B3 (0.4 kV). Every alternate load is connected via a generator to smart houses.

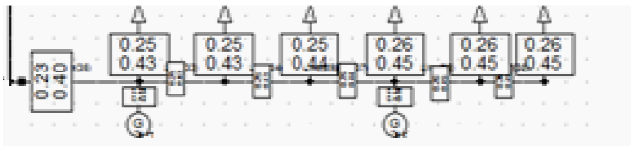

Figure 7. Transmission line with surplus power smart homes

In Figure 8, the scenario being displayed is high integration of in-feed, high Photo voltaic (PV) injection.

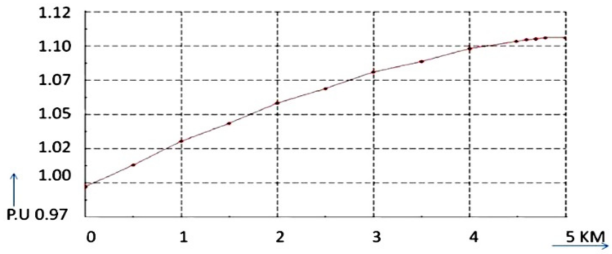

Figure 8. Plot: High Photo voltaic (PV) generation violates voltage criteria

Figure 8 shows the results, in which the voltage increases from 1.0 p.u to 1.10 p.u equivalent to 253 V, at the end of the line. Due to the power injection by the generators (PV panels) on the specific loads, which are connected to that generator, the effect will be distributed and the voltage is increased after every kilometer. Due to this injection of power, the transmission line voltage went high. The system voltage shows an overshoot from normal range, therefore violating the Norms, when excess power is available. Then, compensation should be made. The Photovoltaic (PV) generators (roof of house) are replaced with asynchronous generators, just to implement the idea. The active power of each generator is 0.0045 MW, the reactive Power is 0 MVAr, and the consumer is considered to be a household. If the voltage is now supplied by the grid and the generator injection is applied with the consumer having less load state, the voltage at the transmission line is increased (overshoot), which has to be lowered to a standard according to the Norms. The electrical appliances at households cannot bear such increase in voltage. Damage can be caused to the appliances. Also, the efficiency of these appliances can be affected.

VII. CALCULATION AND EVALUATION

The purpose of this calculation is to find the actual power which is needed to minimize the uneven effect of our smart houses, so an optimal control and balancing technique [1] can be applied. Voltages with U=230V are used as reference. Concerning the given voltage magnitude variations, the admissible voltage range for the LV consumer is 207 V < ULV < 253 V. The terminal voltage is subject to the line impedance R, X and the apparent power, as shown in Figure 9.

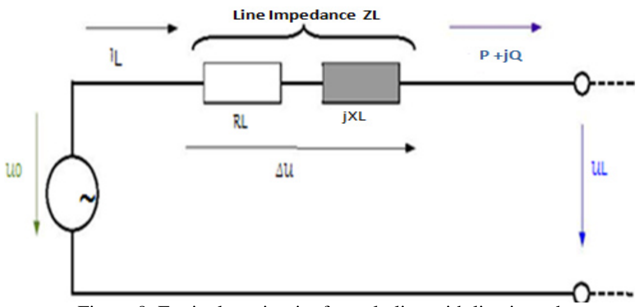

Figure 9: Equivalent circuit of supply line with line impedance

Figure 9 shows the equivalent circuit of a supply line with the voltage U0 at the substation and UL at the junction point to the load. The apparent power S = P + jQ is injected and flowing towards the junction point. The voltage ΔU drops across the line impedance ZL = RL + jXL and can be defined as [12]:

$$U = U_0 - U_l = I \ R_l \ jX_l \qquad (1)$$

Figure 10 shows the voltage across a supply line in the low voltage grid. The flow of the active power P is directed from the MV-Grid downwards through the MV/LV transformer, over a stub line towards the customers. In the following, a calculation of different scenarios (high/low load, high/low PV injection) is presented.

Figure 10. Single line distribution

Apparent power: $S = P + (j \cdot Q)$ (2)

Let Q = 0, then S = P. Number of smart loads = 12.

P/Customer = 1.14 $kW \cdot 12 = 13.68\ kW$

Voltage at Load: $U_a = U_0 \pm U_K$ (3)

Deference Voltage $= U_k$

Voltage at Customer End: U_a = ?

Supply Voltage U_0 = 230V Line-Earth

P [W] = U [V] · I [A]

Current: I = $\frac{P}{V}$ = 13.68 kW / 230 V (4)

I = 0.0594 kA = 59.4 A

Change in Voltage: $U_k = I \cdot Z_k$ (5)

$U_k = I_k \cdot Z_k$

$Z_k = R_k + (j \cdot X_k)$

Resistance = 0.207 Ω / km,

Reactance X_k = 0.0804 Ω/km, Distance = 5 km.

$$Z_k = \sqrt{0.5748} = 0.758155 \cdot 5 = 3.79\ \Omega \qquad (6)$$

$$U_k = I_k \cdot Z_k = 59.4 \cdot 3.79 = 225.17\ V \qquad (7)$$

Calculations of specific power:

$$U_k = I_k \cdot U = I \cdot Z_k$$

$$U_a = U_0 \pm U_k = 230V - 225.17\ V = 4.83\ V$$

$$Psp = 4.83 \cdot 59.4 = 286.9\ W \qquad (8)$$

This power is needed to stabilize the transmission line (Figure 11).

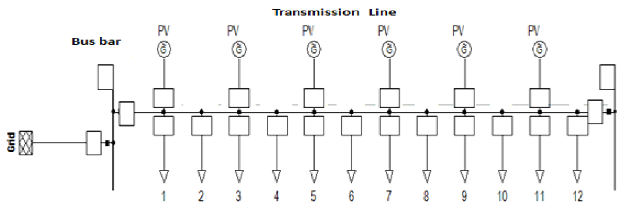

Figure 11.Unloaded Transmission line

Calculation of the excessive and deficit of power as follows:

$$U_a = U_0 \pm U_k = 230\ V - 205\ V = 25\ V = P = 1.485\ kW \qquad (9)$$

$$U_a = U_0 \pm U_k = 230\ V - 253\ V = -23\ V = P = -1.366\ \text{kW} \qquad (10)$$

Figure 12 defines the balanced load profile. Low load and high load scenarios are balanced by increasing or reducing power.

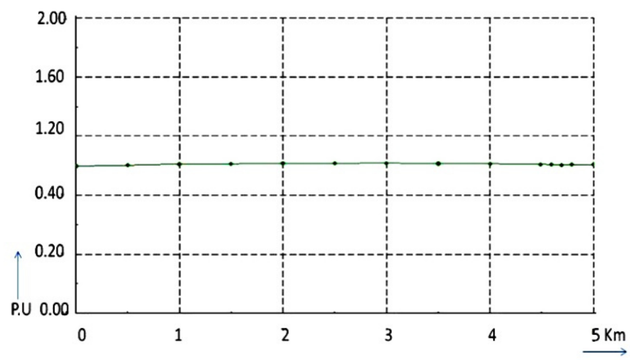

Figure 12. Stabilized Voltage scenario

VIII. COMPONENTS

The following section introduces the components which are needed for the proposed analysis and calculation. The following parts of the workspace are visible: The distribution grid (Figure 13) is fed by an external grid element. The transmission grid has a load element in the middle which represents the distribution grid, as depicted by the red arrow.

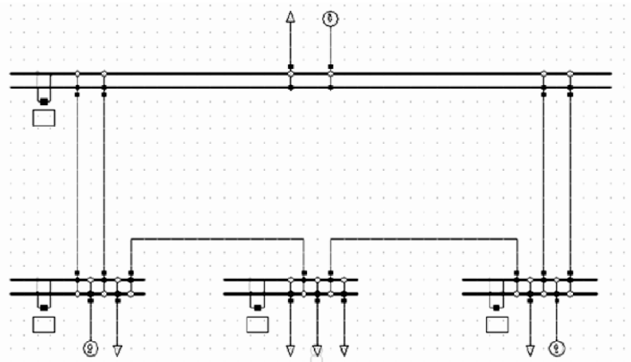

Figure 13. Transmission grid single line diagram

In order to connect the two grids, we have to remove the external net object in the distribution grid, and the middle load element in the transmission grid.

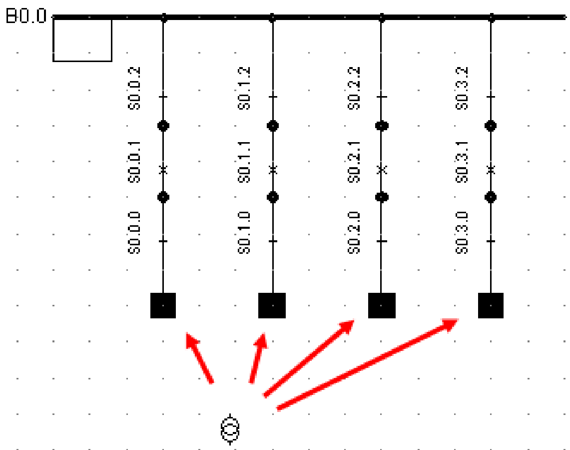

Figure 14. Transformer connected to the single busbar system

To create a 110/33 kV transformer and to connect the 110 kV double bus bar system with the 33 kV bus bar. The terminals (bus bars) of the substations are to be connected with two winding transformers to draw the first transformer, the upper terminal at the position is suggested by the background pattern.

The transformer is now connected graphically to the terminal at that position. The middle terminal makes the second connection (see Figures 14 and 15).

C. Performing a Load Flow Calculation

A load flow calculation may be started from the main menu. For this load flow, the following options need to be set: Calculation Method = AC Load Flow, balanced, positive sequence. All other options on the basic options page need to be disabled [10].

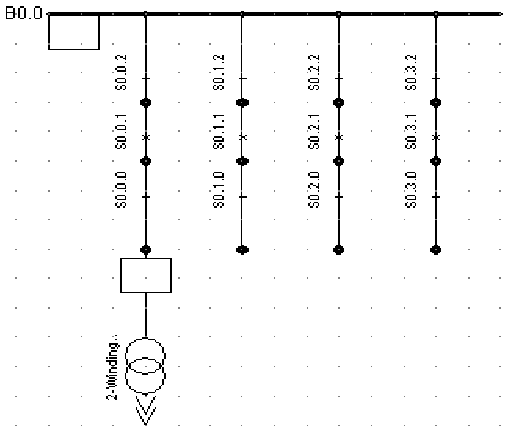

Figure 15. Two Winding Transformer Connection

The load flow calculation is not executed to resolve the error, one should first find the element for which the error was reported. With the Power Factory output window, the error can be corrected and the load flow calculated again.

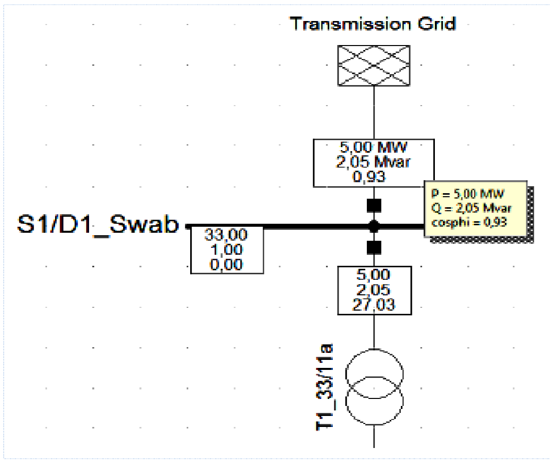

Figure 16. Results of the load flow calculation

Then, the calculation shows that the load flow solving algorithm has found one area (separated area) in the whole system and chosen the external grid element as a reference element. The single line graphic in Figure 16 shows the results of the load flow in the result boxes.

IX. CONCLUSION AND FUTURE WORK

The presented solution enables to analyze the uneven effect of smart houses under the conditions of high voltage and low voltage, when they are not according to the given standard of the EU Norms. Our results evaluate the following important conclusions:

In case of high load and lack of power, and in case of excessive power and low load, we have to manage the certain amount of power which can balance the effect. This could be done by reducing or raising the load with our load management and control solution.

According to our previous work, there is a need of a fully automated appropriate control and load management application with near-real-time push properties, which can respond in real time. This methodic approach could balance the existing smart buildings. Advancements are required in the existing power management systems [18].

An interesting alternative is the integration of battery backup systems. Already a proven technology for uninterrupted power supply (UPS) units, they become increasingly interesting for applications in power systems. They cannot only be used for energy balancing purposes, but can also serve as primary and secondary control reserve. Actually, this concept is not new: A battery-based system was built in Germany for voltage and frequency stabilization for the supply of the island network used in West Berlin 1986. The 17 MW plant / 14 MWh [13] was to going through an entire charge and discharge cycle twice per day.. Keeping in view of the fact if emerging renewable energy sources act as separate generation, they cannot balance the existing energy demand [14]. It is necessary that RES will be integrated in the existing power grid. Due to this integration, the power demands will be balanced at the peak time duration in the grids. This idea will be addressed in future work.

The software being used in this work is a limited version in which only small networks can be analyzed. For future work, voltage variations are to be looked upon at larger scales. This will be done with an extended version of the software, allowing designing a whole city grid model. The number of transmission lines will be increased as well as the number of parameters for the distribution grid. Thus, we will have the knowledge to give an intelligent idea within this remarkable field of study.

ACKNOWLEDGMENT

This work has been performed within the project "Smart Home Control" at Hochschule Darmstadt (University of Applied Sciences). The authors would like to acknowledge the support of the Energy Lab at the University for Access to the Dig Silent software and Albrecht JUNG GmbH & Co. KG for their contribution of KNX actors, sensors and other KNX home automation devices and kind support.

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Hand Posture Control of a Robotic Wheelchair Using a Leap Motion Sensor and Block Sparse Representation based Classification

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***Abstract*—In this study, a gesture and posture recognition method which is based on the Block Sparse, Sparse Representative Classification, and its use for a robotic wheel-chair control are explained. A Leap Motion sensor is used to capture the postures of the left hand. There are five postures mapped to the control commands of the power wheel-chair. These commands can be expanded as the posture recognition commands can deal with high number of classes. The MATLAB functions used in the computations are compiled into .NET programing environment. We tested the hand posture control in a hall where are occupied by tables and chairs. The navigation experiments were successful.**

Keywords*—*Robotic Wheel-chair control, Gesture and Posture Recognition, Compressed Sensing, Block Sparse Recovery, Sparse Representation based Classification.

I. Introduction

The trends in computing technologies are evolving towards the systems and algorithms that can sense the environment and make smart decisions to provide the users with more intuitive user interfaces. These smart interfaces pave the way for Human Machine Interfaces (HMIs) that aim to decrease the physical and cognitive loads of the users. As the machines and computing technologies get more compact and include variety of tiny sensors, their use by ordinary people becomes more difficult with the increasing functionality. Because of these developments, we need more intuitive and easy to use interfaces. These complex systems can be difficult even for ordinary users, but even more so when elderly or people who have some form of disability are concerned.

In this study, we explain a novel gesture and posture recognition algorithm and its deployment on a robotic wheelchair as a replacement of a conventional joystick control. The postures of left hand are captured via a Leap Motion sensor which can report the palm position, velocity and orientation values with the sub-millimeter accuracies.

The gesture and posture recognition algorithm is an implementation of the well-known Sparse Representation based Classification (SRC) algorithm [1] which has proven to be robust and highly accurate method in the case of face recognition research [1–3]. Based on this approach, Boyali et al. [4][5] extended the use of the SRC algorithm for gesture recognition and reported high classification accuracies. We further extend the SRC based gesture and posture recognition algorithm proposed by Boyali et al. in [4][5] by incorporating the Block and Group Sparsity approach which enhances the recognition accuracy as well as the speed of the algorithms.

The robotic wheelchair, on which the SRC based gesture and posture recognition algorithms are tested, is equipped with obstacle avoidance and path following systems which make the wheelchair fully autonomous [6].

This is an initial study of an end-user power wheel-chair control interface which will allow the people with severe mobility impairment to command the wheelchair with their residual and voluntary muscle movements. We employed a Leap Motion sensor to capture the postures of a hand to test the SRC based gesture and posture recognition algorithm, as the Leap Motion sensor has recently been introduced to the market. In future studies, we will utilize other means of sensors and systems with the introduced gesture and posture recognition algorithm.

Gesture or posture recognition based control of a power wheelchair has long been investigated by the researchers. There are several studies on the more intuitive user interfaces, to enable the people with severe mobility impairment and restricted muscle movements to command a power wheelchair. That is because the conventional joystick control of power wheelchairs may not be operated by those who are quadriplegics, handicapped children or people suffering from progressive Parkinson disease [7].

The remainder of the paper is organized as follows. In Section II, a brief literature review of alternative control interfaces for power wheelchair is given. The proposed BS-SRC based gesture recognition method is explained in Section III. Section IV is dedicated to the system and software architecture. In Section V, the implementation and simulations are detailed. The paper ends with the Conclusion Section.

II. Previous Studies

The alternative methods to conventional joystick wheelchair control are cluttered around different modalities. The most common modalities seen in the related literature are speech, gesture, gaze recognition and bio-signal control.

The voice and speech recognition systems suffer from the ambient noise and the accuracy rate depends on speech dexterity and pronunciation [8]. In the bio-signal based studies, Electromyography (EMG) [9–11], Electroencephalography (EEG) [12–14], Electrooculography (EOG) [15][16] are utilized to capture the occupant's intention for the power wheelchair control. In addition to the long bio-signal capturing time requirement and slow response, these studies also report more than 8-20 % mis-classification rates that render the proposed systems less appropriate for the real-time applications.

The gesture and posture recognition methods proposed by Jia et al. [7] and Rofer et al. [17] are based on the template

 ISBN: 978-1-61208-363-6

matching and Finite State Machine methods. In the study by Jia et al. [7], the head of the occupant is monitored by a camera and the position of the head and possible head gestures are evaluated to find out whether the occupant intents to give a navigation command to the wheel-chair. The accuracy of the camera based studies highly depends on the varying illumination, indoor and outdoor environments, cluttered background and shadow. The studies by Rofer et al. [17] and Teymorian et al. [18] utilize the Finite State Machine method which relies on the experimentally defined threshold and deadzone values. The state transitions are based on these manually defined values which limit the free motion of the tracked body parts. The bio-signal and head-joystick based systems require attached or worn devices which may disturb the wheel-chair occupant.

The proposed approach in this study is easy to implement, highly accurate and does not bring about any limitation to the free motion of the tracked hand. It is also robust to the illumination variations and there is almost no mis-classification error.

III. Block Sparse, Sparse Representation based Classification

The BS-SRC algorithm is based on the Sparse Representative based Classification algorithm which was originally implemented for face recognition [1]. The idea is simple. For a given collection of samples, which are stacked as a column vector in a matrix $A = [A_1, A_2, \ldots, A_n] = [v_{1,1}, v_{1,2} \ldots, v_{k,n_k}] \in \mathbb{R}^{mxn}$, the observed pattern $y \in \mathbb{R}^m$ is assumed to be represented by the linear combination of the samples stacked in the dictionary matrix. Accordingly, the vector $x_0 = [0, \ldots, 0, \alpha_1, \alpha_1, \ldots, \alpha_k, 0, \ldots, 0] \in \mathbb{R}^n$ which represents the linear span coefficients are obtained by solving the equation $y = Ax + v$ where $v \sim \mathcal{N}(0, \sigma^2)$ is the white noise. In the solution, the compressed sensing principles and ℓ^1 minimization methods are utilized. Once the solution vector is recovered by using a few linear measurements, the class label r_i is defined by finding the minimum reconstruction residual using equation (1).

$$\min_i \quad r_i(y) = \|y - A\delta_i(\hat{x_1})\|_2 \tag{1}$$

Boyali et al. [4][5] adopted the SRC method for the gesture recognition and reported very high accuracy rates. The authors take the Discrete Cosine Transform (DCT) of the two dimensional gestures which consist of only x and y coordinates to construct the dictionary matrix.

The recently introduced and highly effective approach in compressed sensing literature is the block or group structure assumption in seeking a sparse solution [19–21]. In this approach, the sparse solution has a structure in which the elements of the groups become either collectively zero or take non-zero values.

Several solutions have been proposed for the block sparse problems, such as Block Sparse Bayesian Learning (BSBL) [22], Dynamic Group Sparsity (DGS) [19] and Block Sparse Convex Programming (BS-CP) [23] which exploit the group sparsity of the solution.

In the SRC method, the observed pattern is assumed to be represented by all the samples stacked in the dictionary matrix and the coefficients of the unrelated class samples are also computed during the optimization. The block sparsity approach eliminates these extra computations, thus yielding a faster solution.

When the SRC method is concerned, there is indeed a structure in the sparse solution x, since the samples from the classes are put in the dictionary matrix in a structured form. The sparse solution, when obtained via Block Sparsity methods, contains the coefficients belonging to the corresponding class only.

We made use of the three methods BSBL, DGS and BS-CP for two different gesture sets given in the studies by Boyali et al. [4][5]. The experiments and simulations gave more accurate results than those reported in the previous studies in which only the SRC method is used. Besides, the block sparsity approaches make the algorithms faster than the classical sparsity assumptions, making the algorithms good candidates for real time implementations.

The BSBL approach is chosen for the posture recognition and its real-time implementation in this study. There are two algorithms proposed in the BSBL method, the BSBL-EM in which the optimization problem is solved by Expectation Maximization (EM), and the BSBL-BO which utilizes the Bound Optimization method for the solution. The latter one is faster then the former.

In the BSBL method, the sparse solution:

$$x = [\underbrace{x_1, \ldots, x_{d1}}_{{x_1}^T}, \ldots, \underbrace{x_{d_{g-1}+1}, \ldots, x_{d_g}}_{{x_g}^T}] \in \mathbb{R}^n \tag{2}$$

consists of concatenated g blocks and each block, $x_i \in \mathbb{R}^{d_i x 1}$ is assumed to be generated by a parametrized multivariate Gaussian distribution:

$$p(x_i; \gamma_i, B_i) \sim \mathcal{N}(0, \gamma_i B_i) \quad i = 1, \ldots, g$$

with a non-negative parameter γ_i which controls the block sparsity of x and a positive definite correlation matrix B_i, which maintains the correlation structure of the i^{th} block.

The parameters are estimated by a type-II maximum likelihood procedure [24] after the parameters, γ_i, B_i and the standard deviation of the measurement noise λ, the posterior mean and covariance matrices are updated by using the EM or BO methods.

IV. System Architecture

The robotic wheel-chair used in the study was previously designed at The National Institute of Advanced Industrial Science and Technology (AIST) laboratories (Fig. 1). It has an autonomous mode, by which the wheel-chair can travel between two pre-defined points [6]. In this mode, since the occupant's hands become free, the hand postures and gestures can be utilized to add additional functionalities to the system. We use free motion and postures of a hand captured by an integrated Leap Motion sensor to command the wheelchair. An additional modality also improves the safety while traveling. In this configuration, the Leap Motion sensor is located on the left side of the wheel-chair.

Figure 1. Robotic Wheel-Chair and Leap Motion Sensor

There are five navigation commands, including, but not limited to, ”Go Straight, Turn Left, Turn Right, Stop, and Reverse” on the wheel-chair navigation mode (Fig. 2). The algorithm has no limitations for adding more posture classes into the dictionary matrix, and the number of the posture classes can be increased when necessary.

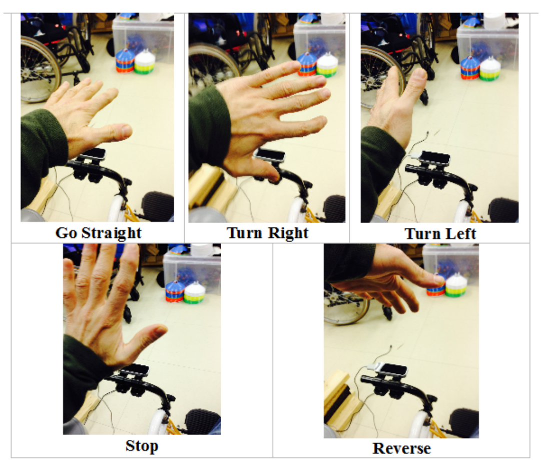

Figure 2. Hand Postures Mapped to Wheel-chair Navigation Commands

The posture recognition module is located on a different computer and the recognized commands are sent to the main computer on which the obstacle avoidance, and autonomous navigation modules reside, via a network cable (Fig. 3).

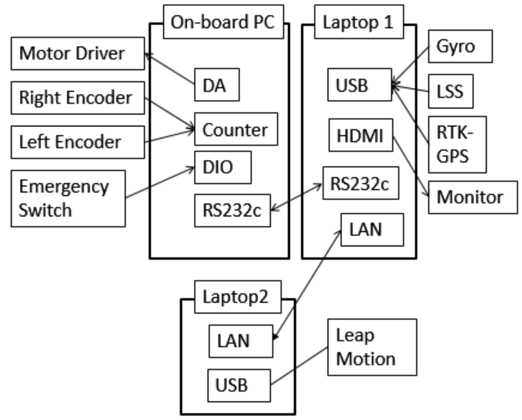

Figure 3. System Architecture

The Leap Motion sensor is a new device consisting of infrared cameras (Fig. 4) which can detect hands or pointers and reports the position, orientation and velocity of the tracked object at a frequency around 80 Hertz. The effective tracking volume is of a pyramid form, the height of which is about 47 cm from the center of the leap motion to the base of the pyramid.

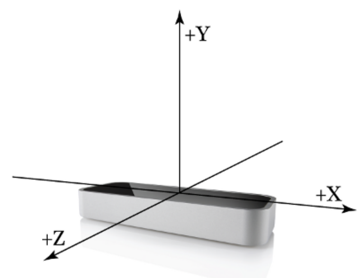

Figure 4. Leap Motion Sensor and Its Coordinate System

The angles of view along the z and x axes are 2 and 2.3 radians, respectively. The tracking volume is sufficient for this study. As the left hand is supported by the wheel-chair arm, it is always visible to the system when a posture based mode is active. The posture control mode is activated when the Leap Motion sensor detects a hand in the viewing volume. If there is no visible hand, the system enters the autonomous or joystick mode.

Although the Leap Motion sensor provides many variables, such as the number of fingers, finger direction, their relative positions to each other, finger and palm velocities as well as some internal recognized gestures by the frame object, we only utilized the palm orientations; roll, pitch and yaw angles, the direction of the normal vector of the palm and the palm velocities for posture recognition.

The MatLeap MATLAB Mex interface [25] is used to analyze the Leap Motion data in MATLAB environment, as the proposed BS-SRC based gesture recognition algorithm written in MATLAB. The MatLeap Mex interface contains of only a few functions and receives a few variables from a Leap Motion sensor. We added functions to the MatLeap interface to read the variables related to the tracked palm. The detected postures of the hand are then used by the BS-SRC algorithm for classification.

The algorithms and codes are converted to a dll file using the MATLAB's deployment toolbox to be able to use the available solvers and the implemented codes for posture recognition in the CSharp programming environment.

V. Implementation and Simulations

When the gesture and postures are mapped to a certain number of states, the common method is to use Finite State Machines (FSM), if the number of features is limited to a few dead-zone or threshold values which do not limit the freedom. Using the FSM approach may be a valid decision when the boundaries can be strictly separable by deadzones. However, the uncertainties naturally exist in the complex signals such as bio-signals which are required to be collected for relatively long periods of time. Similarly, as the Leap Motion sensor reports the features at a high frequency, and posture and gesture recognition requires a certain number of data samples, the boundaries between the postures cannot be set by FSM methods in a feasible way.

The BS-SRC based gesture recognition method yields highly accurate results which are more than 99% for different kinds of gesture sets. We tested the BS-SRC method for posture recognition and obtained more accurate results than the gesture recognition studies.

The first step in posture recognition is to construct a dictionary matrix $A = [A_1, A_2, \dots, A_n] = [v_{1,1}, v_{1,2} \dots, v_{k,n_k}]$ in which the samples from five postures are stacked as the column vectors. The DCT coefficients of the matrix are then computed.

Each posture signal vector v_{k,n_k} consists of the palm roll, pitch and yaw angles and the direction of the palm normal vector in the three axes x, y and z. The left hand is kept at the specified posture for 30 seconds and the palm roll, pitch and yaw, as well as the palm normal vector direction values are recorded. We reduced the sampling frequency from 80 Hertz to 50 Hertz. Each posture sample has a length of a half second, which corresponds to 25 measured values from each feature. There are 30 snapshots of each postures in the dictionary matrix $A \in \mathbb{R}^{150x150}$.

These sample postures are put in the dictionary matrix, the rest of 30 posture samples from each class are used for verification. In total there are 150 test postures and the BS-SRC based algorithm yields 100% recognition accuracy for the test samples (Fig. 5).

In the real-time implementation of the posture recognition algorithm, there are transition states between the postures. These transition states which can be considered as gesture, have a very short duration when compared to the postural states. Each transition states or gestures differ in length. During the transition, the hand posture can only be either of one of the involved states, and the algorithm chooses one of them.

Only a few false spikes occurred in the simulations. As shown in Fig. 6, the algorithm gives two instances of false recognition, while the hand repeatedly switchs between the Go Straight and Turn Right states.

We eliminate these rarely seen false recognitions by applying a very simple signal filtering method which incurs a short delay to the system. The delay is acceptable to make sure we produce a robust implementation of the algorithm. In most cases, there is no need to use such a filter. The figures (Figures 7 and 8) show the unfiltered simulation results. We can also use a low rank matrix recovery method to detect if the measured instance is a posture or gesture. For this approach, in every time instance, we add the received values to the dictionary matrix as the 151^{th} column and separate the matrix into two components; low rank dictionary and the outliers matrix. We use Direct Robust Matrix Factorization (DRMF) [26] algorithm to detect whether the current measurement is a posture or a gesture. Since the gesture states are not represented in the posture dictionary, the DRMF algorithm gives higher residual error for these states. There is an alternative approach we have been working on. In this approach, once the transition states are detected by the low rank matrix factorization method, we can employ a second dictionary which only consists of the gesture classes. The difficult part of this approach is to spot exemplar gestures from the streaming signals.

The algorithm buffers 25 samples from each of the features, concatenates them in a column vector to build the dictionary matrix. The recognized postures are numbered one to five and sent to the Laptop-1 (Fig. 3) computer via a network cable.

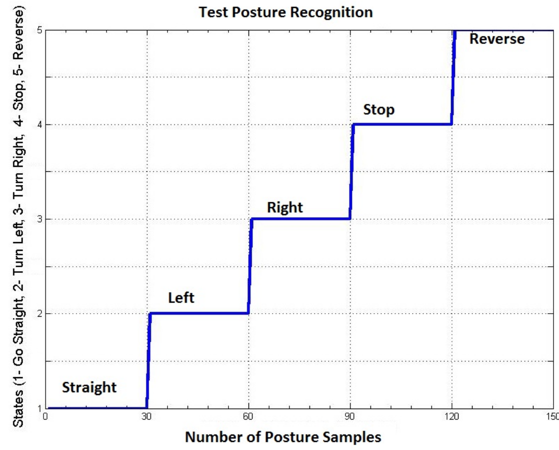

Figure 5. Test Postures and Recognized States

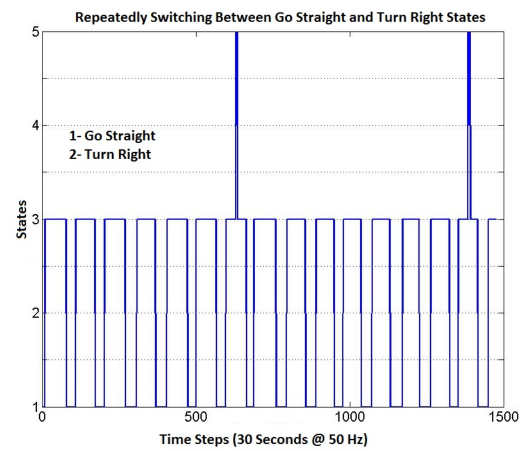

Figure 6. Switching Between Turn Right and Go Straight Postures

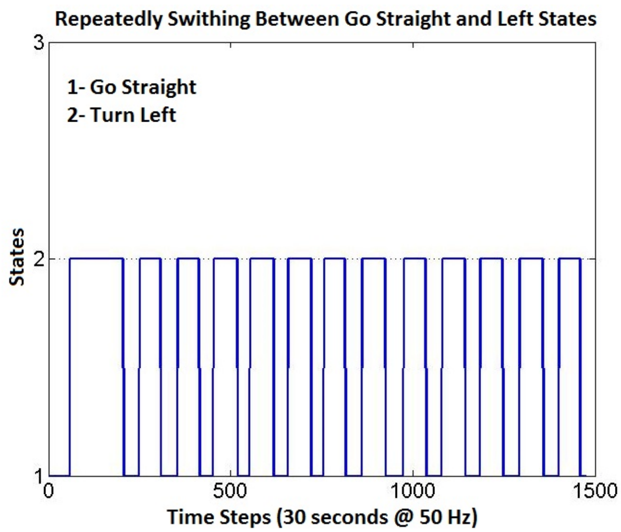

Figure 7. Switching Between Turn Left and Go Straight Postures

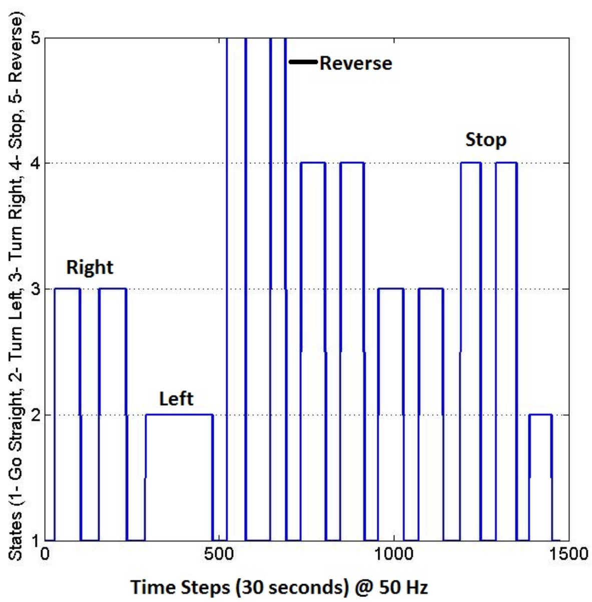

Figure 8. All States Visited

The receiving computer sends commands to the on-board PC to control the electric motors for a given navigation method. We tested the real-time performance of the power wheelchair. The tests were performed in a hall where there were tables and chairs and we navigated in this crowded area by controlling the wheelchair hand postures only.

VI. Conclusion and Future Works

This study is aimed to test the real-time performance of the BS-SRC gesture and posture recognition method on a power-wheelchair. The hand postures are captured via a Leap Motion sensor by collecting the palm roll, pitch and yaw angles as well as three palm normal direction vector at each time instance, then the concatenated features are evaluated by the BS-SRC method. The method yield highly accurate and robust

Figure 9. Test Hall

recognition rates.

The BS-SRC method is tested originally for two different gesture sets and we received higher accuracies and faster recognition when compared to those of the studies [4][5] in which only the SRC method was used. We will design an additional dictionary matrix, the column vectors of which will only consist of the gestures. Since the Leap Motion reports observations in a streaming signal form, the difficulty in this approach is to spot the beginning and end points of the gestures for a proper construction of the dictionary matrix.

We tested the posture recognition algorithm for only the Leap Motion sensor. We aim to repeat the experiments by using a pressure distribution sensor by which we can detect the seating postures, to track the change of weight center of the occupant and Microsoft's MYO gesture bracelets which is still in development phase and is not introduced to the market yet.

Acknowledgment

This study is supported by the Japan Society for the Promotion of Science fellowship program.

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An RFID-based Smart Cage for Animal Behavior Analysis

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***Abstract*—An innovative tracking system based on passive Radio Frequency Identification technology in Ultra High Frequency band, able to perform behavior analysis of small laboratory animals, is presented in this work. The proposed smart system consists of both hardware and software components and it is able to extract main behavioral parameters exploiting raw animals tracking data captured by a Radio Frequency Identification reader system. The proposed solution allows overcoming some limits of typical analysis methods commonly used in research laboratories for the same purposes, such as systems based on video technology and human observations, while providing the same information content. It is cheaper and guarantees better performance even in case of strong similarity among animals and in poor lighting conditions. Different tests were carried out in order to demonstrate the feasibility and effectiveness of the proposed system using laboratory mice. The software component is able to provide, via Web, a user-friendly tool containing main animal behavioral information such as statistical analysis and graphs regarding animal displacements, indication about the locomotor activity and detection of specific conditions including isolation and aggregation phenomena.**

Keywords-animals behavior; animal tracking system; Radio Frequency Identification; UHF; Web application.

I. INTRODUCTION

The animal behavior analysis is a very important research area, which involves several scientific disciplines, such as biology, physiology, pharmacology, toxicology, and so on. It is used to analyze neuropsychiatric diseases or to test the effects of new drugs and vaccines before being placed on the market. The traditional method to collect this information exploits video recordings that can easily gather information about many aspects of the situation in which animals interact with each other or with the environment. In addition, the video recording makes offline research possible by a skilled operator that observes the video and annotates the animal behavior manually. This is a time and labor consuming process and the analysis results may vary among different observers that can introduce subjective interpretations.

For this reason, the study of animal behavior supported by automatic system based on video technology has become increasingly popular. The use of visual systems, equipped with proprietary software tools, enables automatic analysis of information acquired by video in order to obtain statistical data and behavioral information. However, these software solutions are often very expensive and the usability is generally restricted to basic functions.

In the literature, several works propose solutions able to automatically collect behavioral information using the Radio Frequency Identification (RFID) technology, which allows the identification of a tag when it is in the region covered by an electromagnetic field generated by an RFID reader antenna system. A significant example is presented by Kritzler et al. [1], in which Low Frequency (LF) RFID systems are used and a semi-natural environment is reproduced. Nevertheless, mice are forced to follow obligatory paths in order to detect their movements. In addition, LF band does not allow simultaneous reading of a lot of tags because it is not compatible with the EPC Class1 Gen2 standard [2] and it is only able to guarantee a very limited reading range, i.e., less than 1 cm distance between tag and reader antenna.

The RFID technology in High Frequency (HF) band is used by Aguzzi et al. [3] to capture the behavior of marine animals. Also in this context, HF band does not allow simultaneous reading of a lot of tags and, consequently, it cannot be used to track simultaneously a lot of animals in order to identify social behaviors.

In this paper, an innovative RFID-based tracking system able to overcome some limits previously described is presented. This smart system uses the passive Ultra High Frequency (UHF) RFID technology and it is able to track an entire animal colony. In fact, unlike the LF or HF bands, the RFID technology in the UHF band is compliant with the EPC Class1 Gen2 standard, allowing a reading of about 100-1500 tags/s. Furthermore, the proposed system is able to summarize, in terms of graphs and statistical dashboards, the behavior analysis of each laboratory animal. To make this possible, a passive Near Field (NF) UHF RFID tag must be implanted in every animal (e.g., mouse, rat, etc.). For such a reason, a strong effort has been dedicated to the implant technique in order to allow the RFID tags to keep on working in the time and not to procure distress to the animal. Some results of these experimental tests on laboratory mice are presented by Catarinucci et al. [4] and confirmed in this paper through an analysis of the implanted mice performed long time after the date of the tag implantation. Instead, the main results obtained in the tests performed on the hardware component (i.e., on the prototypal reader antenna system) and reported by Catarinucci et al. [5] allowed to establish the proper distance between two adjacent antennas and between the RFID tag and the reader antenna plane in order to guarantee a correct tracking of the animals in the cage.

In addition to long-term analysis on the implanted tags, the tests presented in this work had two major goals. The first goal was to demonstrate the scalability of the proposed system. To achieve this goal, the system should be able to effectively work regardless of the hardware configuration (i.e., the number of reader antennas) and of the number of RFID tags involved in tests (i.e., the number of mice in the smart cage). The second goal was to prove that the RFID system is able to extract correct behavioral information useful to support the operator work. In order to prove this capability, the results obtained by the proposed system were compared with a video analysis performed by a skilled operator.

The paper is structured as follows. In Section II, the architecture of the proposed smart system is presented whereas details regarding the test procedures are reported in Section III. The results of the performed tests are discussed in Section IV. Finally, the conclusions are drawn in Section V.

II. Animal Tracking System Architecture

The architecture of the proposed smart cage, shown in Figure 1, is a hybrid (i.e., hardware and software) system composed of two main components.

The hardware component is mainly based on a NF antenna system working in the UHF bandwidth (i.e., 860-960 MHz). Such a system is composed of a matrix of antennas each one able to univocally localize the animal in an elementary cell as large as 12 cm x 12 cm. In order to

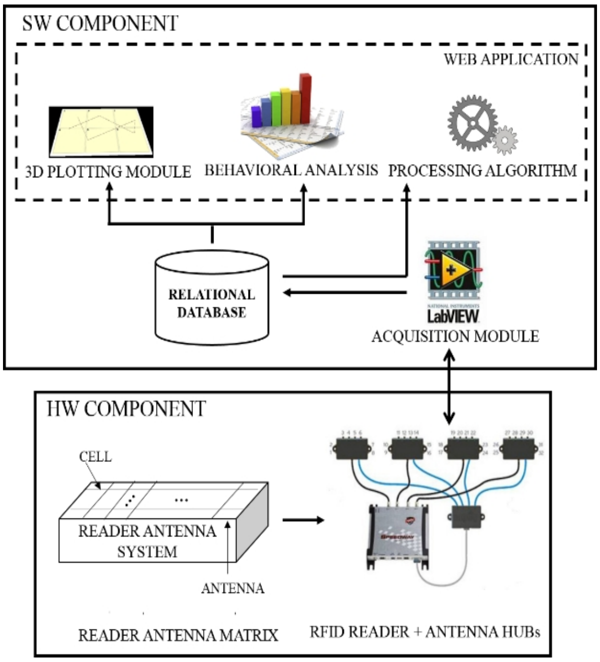


Figure 1. System architecture.

guarantee an accurate identification and localization of the animals moving within the cage, each single antenna satisfies specific requirements fulfilled through the design of optimized segmented loops: first, it irradiates a magnetic field as confined as possible in the related cell. Moreover, it guarantees a uniform magnetic field within the cell in order to minimize the localization uncertainty. Finally, it minimizes the far field radiation in order to avoid potential spurious readings of tags located in different cells. Such a system is thought to be positioned right below the cage in correspondence of each elementary cell and is connected to the RFID reader through a multiplexer allowing the management of up to 32 reader antennas. In this way, even large environments can be monitored and the behavior study of many animals at the same time can be performed. Let us observe that there are no obligatory paths for animal movements. The reader antenna system was widely tested and validated by the same authors [5].

Instead, the software component consists mainly of two modules: (i) the acquisition module, described and validated by Catarinucci et al. [6], developed by using the graphical programming environment LabVIEW [7] and responsible for managing the hardware component and collecting the raw readings coming from the reader antenna system, and (ii) the Web application able to support the researchers in animal behavior analysis.

The Web application is able to extract raw data, stored in a MySQL [8] relational database, in order to provide the end-users with an effective analysis that summarizes main behavioral parameters. The choice to adopt a Web solution is motivated by the need to guarantee a behavioral data access from anywhere by using a simple Internet access. In addition, different operators can access the same data from different locations. In particular, the Web application firstly processes the raw data by using the three phases of the RCP (RSSI Chebyshev Ping-pong) algorithm able to discriminate the correct mouse position. In fact, when only one of the reader antennas reads an RFID tag, the animal position is uniquely individuated. Nevertheless, if several reader antennas read the same RFID tag, a position ambiguity occurs and the RCP algorithm works to solve it by using the following three processing phases:

1. Identification of simultaneous readings and data discrimination based on the Received Signal Strength Indication (RSSI) value.
2. Check of adjacent cells exploiting the Chebyshev distance [9] method.
3. Removal of the "ping-pong" effect, which occurs when a tag is positioned between two cells. This generates a continuous alternation of the position between the two involved cells.

The pseudo-code of the proposed algorithm is shown in Figure 2.

The Web application provides the end-user with several information about the behavior of each mouse in the smart cage in the form of tables or graphs. This feature was obtained using the JFreeChart [10] Java library. This open source library can dynamically create graphs starting from

```
for each tag ID{
    for each sampling interval{
        PHASE 1:
        store the sample with max RSSI value
  and all samples with RSSI value in the
  interval(RSSImax – RSSI) in List1.
    }
    PHASE2:
        for each sample in List1{
            if distance [i , i+1] ≤ 2
                add i+1 sample in List2;
            else if distance [i + 1, i + 2]>2
                     discarded i+1 sample;
                         else add i+1 sample in
List2;
        }
        PHASE3:
        for each sample in List2{
            if i ≠ i+1{
                if i-1=1+1
                    discarded i sample: ping-
pong effect!;
                else add i sample in List3;
            else add i sample in List3;
            }
        store all sample in List3 in the
database
        }
```

Figure 2. The pseudo-code of the proposed RCP algorithm.

the source data stored in the database. The Web application adopts a client-server architecture and is developed by using Struts2 [11]. This framework, distributed by Apache, is completely based on Java. In order to manage the Web pages, SiteMesh framework [12] was used. It offers an important support for the Web pages decoration and layout, by effectively managing the navigation and allowing the generation of composed pages. Finally, a tracking module allows the user to show a screen in which the smart cage surface is replicated in order to provide information about the displacement of each mouse in the cage (Figure 3.a). In this way, it is possible to track and evaluate animal behavior and reactions to particular solicitations (e.g., drugs or vaccines administration). The Web application also provides a 3D video that reproduces the mice movements in the cage. The user can manage the video reproduction by using the Play, Stop and Restart buttons. Furthermore, the user can insert several objects in the experimental scene (i.e., cage) reproducing accurately the real scene. In this scene, a sphere of a different color that moves in the cage represents each mouse (Figure 3.b). In order to develop the 3D component, the WebGL [13] technology was chosen because it is able to generate and manage three-dimensional graphics directly on Web pages, allowing the interaction with the 3D environment.

From the computational point of view, it is worth highlighting that the acquisition module was designed and implemented separately from the others components in order to guarantee effectiveness and scalability. In fact, in this way, the acquisition module and the processing module may evolve independently allowing, for instance, different processing systems to be associated with the same acquisition system. Furthermore, this choice relieves the computational load of the acquisition module.

It is worth noting that the implantation of an RFID tag in each mouse represents a decisive procedure. For this reason, much time was spent in this direction. First, a careful technological scouting was performed in order to select, among all the commercial tags, those most suitable to be implanted in laboratory mice, characterized by small size and high performance. Then, the best tag implantation technique in laboratory animals was evaluated through some tests carried out by using mice.

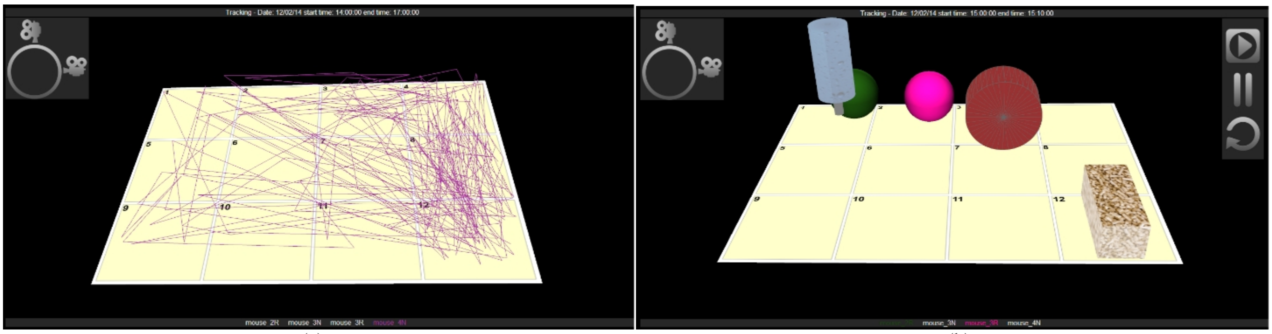
In particular, the choice of the better tag to implant in the mouse took into account the main requirements reported below: (i) to guarantee a long-term readability of implanted tags, and (ii) not cause discomfort to the animals or changes in their behavior.

III. MATERIALS AND METHODS

In this section, details regarding the test procedures and the proposed goals for each test are reported.

A. *Tags implantation procedure*

The first phase of this work focused on the choice of the best passive UHF RFID tag able to satisfy the stringent requirements such as high tolerance to mechanical stress, high reading performance in presence of liquids, and low cost. Preliminary tests, presented by Catarinucci et al. [4], were carried out in order to select the best candidate tag able to ensure high performance for a long time after its implantation in laboratory mice. Furthermore, a feasibility



(a) (b)

Figure 3. Screenshots of the tracking module: (a) displacement of a mouse in the smart cage; (b) 3D reconstruction of the smart cage.

study on the tag implantation methodology in the animal was performed. As result of these preliminary tests, the tag with higher performance has a layout characterized by an antenna size of 15 mm x10 mm, die-cut size of 19 mm x14 mm, an Impinj Monza4D chip, and a PVC plasticization with thickness of 80 μm per side. The plasticization preserves the tag conservation, protects it from corrosion due to animal tissue composition, and ensures the reliability of the implanted tags in the time. The first tests, performed to select the best tag, lasted for about a month. Instead, the tests presented in this study are long-term analysis and covered a period of about one year. In this regard, the long-term analysis concerned several mice in each of which the selected tag was implanted. In order to evaluate the readability of all implanted tags, each implanted mouse was placed in proximity of the reader antenna for 30 seconds. Then, the ratio between the number of readings performed by the system and the total number of expected readings was calculated in different time instants starting from the implantation date (i.e., 1, 3, 6, and 12 months after the implantation date). Because the system, in a configuration with a single reader antenna, is able to intercept about twelve readings per second, and the considered time interval was 30 seconds long, the total number of expected readings is 360. Finally, for each time instant, the performance of the tags was evaluated as the percentage of the average readings.

The surgical tag implantation required multidisciplinary skills and this task was executed in cooperation with the Istituto Superiore di Sanità (Italian National Institute of Health) in Rome, which made possible the testing of passive UHF RFID solutions in laboratory mice. The surgical implantation details are reported by Catarinucci et al. [4]. All procedures involving animals were approved by the Service for Biotechnology and Animal Welfare of the Italian National Institute of Health and authorized by the Italian Ministry of Health, according to Legislative Decree 116/92, which implemented the European Directive 86/609/EEC on laboratory animal protection in Italy.

B. RFID devices

The proposed tracking system consists of a 4-port Impinj Speedway Revolution R420 reader connected to an Impinj GPIO adapter via one HD15 cable. The GPIO adapter allows for the connection up to four Impinj Antenna Hub, acting as multiplexers, each of which accepts up to eight reader antennas. Each Antenna Hub is connected to the GPIO adapter via a straight Ethernet cable and to the reader with a SMA-male to R-TNC-female coaxial cable. Each reader antenna is connected to its Antenna Hub via a SMA-male to SMA-male coaxial cable. The reader antennas are powered in time division through the four ports of the RFID reader. More specifically, at a generic time, only a single antenna is powered, thus reducing potential array effects and energy wasting. In such a context, the multiplexing system allows a switching time between reader antennas inferior to 200 μs and a switching time between two Antenna Hubs amounted to 25 ms. This means that, even in presence of the worst computational case (i.e., with 32 reader antennas), a time distance between two consecutive interrogation of the same antenna is inferior to 6.4 ms, which is about eight times less of the minimum time required for a mouse to cross a cell. This ensures an accurate tracking, without loss of positional information. If all 32 reader antennas are connected based on a 4x8 matrix, the size of the arena can reach about 48 cm x 96 cm, enabling the testing of a high number of animals.

C. Tests setting for system scalability and animal behavior

In the test aimed at evaluating the scalability of the proposed system, different system configurations were used, as reported in Table I. In each cell, in correspondence of each reader antenna, two RFID tags were placed: one was placed in the center of the cell and the other tag was placed randomly on the cell. The power transmission of each reader antenna was set to 27 dBm and, for each system configuration, the test was 30 minutes long and was repeated five times. Then, the percentage of incorrect tag localizations was calculated before and after the data processing carried out by the RCP algorithm. The percentage of incorrect localizations was calculated as the ratio between the number of localization errors and the total number of readings detected by the RFID system.

A final test was performed in order to evaluate the effectiveness of the proposed system to correctly detect animal behavior. In this three hours long test, a system configuration, consisting of twelve reader antennas according to a 4x3 matrix and four implanted mice, was used. The test environment is shown in Figure 4. A cage of dimension 36 cm x 48 cm was used and on the bottom of the test cage, the sawdust was placed in order to absorb mice feces and urine. The transmission power of the reader

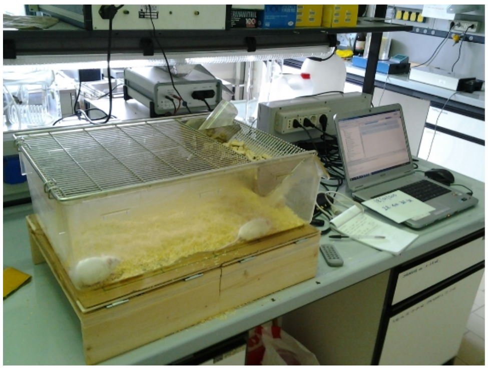


Figure 4. The proposed system during a test performed by using laboratory mice.

TABLE I. SYSTEM CONFIGURATIONS USED IN THE SCALABILITY TEST

Number of cells	*Number of tags*
3	6
6	12
12	24
24	48
32	64

 ISBN: 978-1-61208-363-6

antennas was set to 30 dBm. The behavior of the mice in the cage was monitored by using both the proposed RFID system and a video camera (i.e., a Canon MVK 460). In this way, it was possible to compare the results obtained through the proposed system with those obtained by a video analysis performed by a skilled operator. The operator, by using a stopwatch, measured and recorded how many seconds the mice spent alone, manifesting an isolation attitude, or in group of at least two mice, manifesting an aggregation attitude. In particular, an event was considered an isolation phenomena if a mouse remained alone in a cell cage for at least 100 seconds. Vice versa, an event was considered an aggregation phenomena if at least two mice remained in the same cell for at least 25 seconds. The correlation between the results obtained through the two methods was measured by using the Pearson correlation coefficient (r). It measures the strength of a linear association between two variables, where the value r = 1 means a perfect positive correlation and the value r = -1 means a perfect negative correlation.

IV. RESULTS

All tests reported in this paper were performed in order to ensure statistically relevant results, with a confidence interval of 95% and a maximum relative error of 5%.

Before analyzing the results obtained in the tests aimed to evaluate the scalability of the proposed system and its capability to detect behavioral information, it is worth highlighting the high performance of the selected RFID tag. In fact, one year after the surgical implantation, all implanted tags were still readable. Table II shows that the average percentage of readings is 100% one month after the implantation date (i.e., all tags are still readable) and it is not below 98% even one year after the implantation date. This is a very interesting result that demonstrates not only the robustness of the RFID technology in the UHF band for animal tracking purposes, but also that the tag implantation does not cause pain or discomfort to the mice. In fact, after one year, the mice had not removed the tag and did not suffer from health effects. Regular checks on the implanted animals carried out by the researchers of the Italian National Institute of Health in Rome, Italy, demonstrated that this surgical practice does not affect the animals' behavior. In fact, implanted mice behavior is not different from that of sham operated mice as well as their health conditions.

The results regarding the system scalability are reported in Figure 5 where, for each system configuration, the average percentage of incorrect localization, before and after data processing performed by the RCP algorithm, are reported. It is possible to notice that, before the data processing, the percentage of incorrect locations varies between 33.74% (in the system configuration with three cells) to 58.73% (in the system configuration with six cells). These localization errors were caused by tags positioned between two cells, which were read simultaneously from more than one antenna, leading to an ambiguity of their position. After the data processing, the percentage of incorrect localization was less than 0.4% in all system configurations. These results prove the effectiveness of the RCP algorithm and that the system is scalable because it works well regardless the number of considered cells and involved tags.

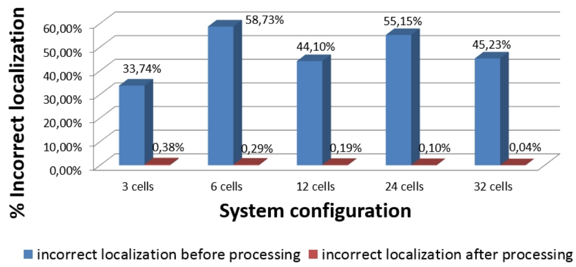


Figure 5. Percentage of incorrect localizations before and after the RCP algorithm processing for different RFID system configurations.

In Table III, the results of the comparison between the proposed system and the operator analysis in the test aimed to evaluate the ability of the RFID system to detect animal behavior are reported. In particular, the values represent the average isolation time and the average aggregation time detected during the test by both the RFID system and the operator analysis. The Table III shows as the results obtained using the two methods are very similar to each other and prove that the proposed system is able to correctly detect the animal behavior. These considerations are also proved by the correlation graphs, reported in Figure 6. In fact, the correlation values are 0.97 and 0.92 in the detecting of isolation phenomena (Figure 6.a) and aggregation phenomena (Figure 6.b), respectively. This reveals a strong positive correlation between the two compared methods and indicates that high values of the isolation (aggregation) time detected by the RFID-based system corresponds to high values of the isolation (aggregation) time detected by the operator video analysis (and vice versa). The RFID system extracts higher values compared those recorded by the operator because the proposed system is able to provide measurements that are more accurate.

TABLE II. AVERAGE PERCENTAGE OF READINGS FOR ALL IMPLANTED TAGS 1, 3, 6, AND 12 MONTHS AFTER THE IMPLANTATION DATE

Observation time	% reading
1 month	100%
3 months	99%
6 months	98%
12 months	98%

TABLE III. SOCIAL INTERACTIONS TESTS, DETECTION OF THE ISOLATION AND AGGREGATION EVENTS

	RFID-based system	Skilled operator
Isolation time [s]	231.80[a]	192.5[a]
Aggregation time [s]	31.3[a]	28.75[a]

a. Data are reported as mean of the values obtained using four mice in 3 hours test.

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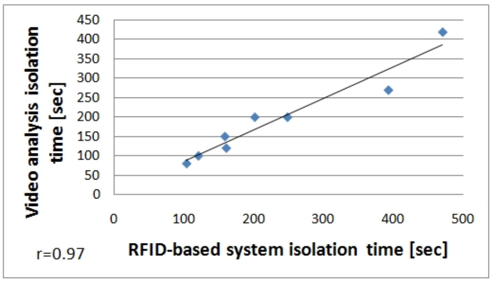
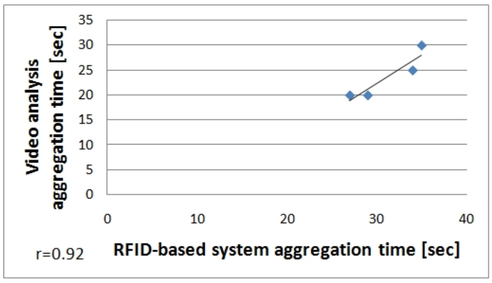


(a)



(b)

Figure 6. Graphs of the correlation between the proposed RFID system and the operator video analysis: (a) detecting of the isolation time; (b) detecting of the aggregation time.

V. CONCLUSION AND FUTURE WORK

In this work, an innovative and complete UHF RFID-based system able to extract behavioral analysis of small laboratory mice is presented.

Although RFID technology in LF or HF (Near Field Communication – NFC) bands allows the simultaneous reading of tags, the number of tags that can be read at the same time is limited. RFID tags in LF or HF band are generally used for proximity applications or when the distance and the population of the tags are not excessive. Instead, the UHF RFID technology allows reading many tags simultaneously, making it the ideal candidate for the study of colonial animals' behavior. Although some materials (e.g, liquids or metals) may absorb or reflect the waves, altering the conditions of writing and reading of UHF tags, the results obtained in tests on the proposed system shown that the use of this technology is effective for the declared purposes.

The proposed smart cage allows overcoming some of the inherent limitations of methods commonly used in research laboratories for the same purposes, such as systems based on video technology and human observations by using a hybrid system consisting of hardware and software components.

Different tests were carried out in order to demonstrate the feasibility of the proposed system, its scalability and its efficiency in terms of detection of social events involving the observed animals. The performed tests demonstrated the feasibility of implantation of a small RFID tag in a mouse and the effectiveness of the RFID technology for the behavior analysis of laboratory mice. Moreover, the proposed system offers a low-cost, user-friendly and time-saving solution to support the researches in the animal behavior analysis.

Currently, the RFID system is under evaluation at the Italian National Institute of Health, Rome, Italy, where skilled operators are testing it in real-world scenarios.

ACKNOWLEDGMENT

The authors thank Prof. Luca Catarinucci and Dr. Riccardo Colella of the University of Salento, Lecce, ITALY, for their precious support in the realization of the prototypal reader antenna.

This work partially fulfills the research objectives of the PON 02_00563_3470993 project "VINCENTE - A Virtual collective INtelligenCe ENvironment to develop sustainable Technology Entrepreneurship ecosystems" funded by the Italian Ministry of University and Research (MIUR).

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A Novel Authentication Framework Based on Biometric and Radio Fingerprinting for the IoT in eHealth

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***Abstract*—Patient monitoring outside the hospital environment is one case for Internet of Things (IoT) in healthcare. While remote patient monitoring may improve healthcare, patient authentication is a challenge in this scenario. Authentication mechanisms that require the user to present credentials only initially do not verify the claimed identity of the patient after the initial authentication. We propose a novel authentication framework based on biometric modalities and wireless device radio fingerprinting. The framework is capable of verifying that the monitored data belongs to the correct patient during the entire session, it also ensures the integrity and trust of the received data. We analyse our framework in view of some issues for the IoT in eHealth such as context and location awareness, resource constraints, and dynamic environment.**

Keywords*—*Internet of Things; eHealth; biometric authentication; radio fingerprinting.

I. INTRODUCTION

The current Internet is rapidly evolving towards the Internet of Things (IoT) environment where different objects communicate and exchange information with each other for improved functionalities and performance. While monitoring patient's health parameters with on-body sensors, the IoT may allow the patient to be at different locations such as home, office, public place, or in a vehicle but medical sensors still connected and transmitting information to the doctor's office.

The healthcare system can get many benefits by using flexible Remote Patient Monitoring (RPM) in the IoT for eHealth such as patient monitoring with chronic disease, monitoring of elderly people, and monitoring of athletes fitness [1]. The main objective of the RPM system is to assist the existing healthcare system by monitoring the vital signs of patient's health data in real time.

A. Research questions

With a RPM scenario as a basis, we address the establishment of trust in the received data in two parts: 1) how do we know that the data monitored during the entire session in the RPM system belongs to the correct patient, i.e., data origin authentication; 2) how do we ensure the *integrity* of the received data.

More specific for a health scenario, we address two parts: 1) how can we know if the patient is suffering from a heart attack or other acute conditions; 2) how can we locate a patient that is suffering from some acute incident.

B. Security challenges for the IoT in eHealth

Transferring a patient's health data to a remote medical server opens for security threats such as interception, interruption, modification, and fabrication [2]. These threats may impact on a patient's privacy, confidentiality of data transmission, integrity of received data, and data availability.

Authentication is a key aspect in terms of establishing trust in the system. Although, trust can be defined for different purposes and application areas in several disciplines [39], our criteria to determine trust in the RPM system is simple. If we establish a mechanism capable of ensuring that the received data is coming from a correct device and patient, then it can serve the purpose of trust establishment. If the sensors are used by someone else except the actual patient, the authentication mechanism should be capable of detecting the imposter at any time during the monitoring session. The capability to detect an imposter not only increases the effectiveness of system security but also maintains the trust level in the system.

C. Biometric and radio fingerprinting

The continuous RPM requires continuous verification of monitored data to establish trust. In order to ensure that the received data is coming from the correct patient and is correct, verification of data origin and integrity are important elements in the RPM system. For this purpose, one can use authentication mechanism to ensure the correctness of data origin before the data is used for medical diagnosis. Authentication mechanisms based on credentials such as secret keys, password, and tokens possess vulnerabilities for the RPM system. One of the reasons is that if a third party gets access to the credentials, then he can impersonate the actual patient causing data fabrication and data integrity issues. Also, after initial authentication using these credentials, there is no guarantee that the data is still coming from the authenticated patient throughout the session. The RPM system demands continuous monitoring of the patient which also implies that the monitored data should be validated on a continuous basis until the session ends [3] [4]. The RPM system should ensure not only that the monitored data belongs to the actual patient during the whole monitoring period but also that it is sent using the correct device. This may be achieved using biometric and radio fingerprinting since they have direct association with the user and the device.

 ISBN: 978-1-61208-363-6

D. *Contribution*

The goal of our work is to develop a more reliable authentication system that can prevent the misuse of the RPM for the IoT in eHealth. Our main contribution in this paper is to propose a novel authentication framework for the IoT in eHealth. More specifically, a patient is authenticated by the following tuple:

(P, B, F), where P is patient's physiological biometric, B is patient's behavioral biometric, and F is patient's smart phone radio fingerprint.

In contrast to existing techniques that use only biometric modalities, our approach binds together the biometric modalities and radio fingerprinting technique as a unique identifier to not only authenticate the patient but also the device transmitting health parameters. However, biometric and radio fingerprinting used separately for authentication in the RPM pose some shortcomings. For example, using radio fingerprinting only, the device can be authenticated but not the patient. Using biometric only, the patient can be authenticated but the authenticity of the transferring device may be questioned. We therefore propose a novel authentication framework that binds them together for the said purpose. The authentication method comprised of biometric modalities and radio fingerprinting has not been investigated to date.

In order to incorporate the issues and concepts discussed earlier, Section II discusses authentication techniques using biometric and radio fingerprinting. Section III presents the proposed authentication framework. Related work is highlighted in section IV. Section V analyses our authentication framework. Section VI concludes the paper and addresses future work.

II. AUTHENTICATION TYPES

A. *Biometric Techniques*

Authentication is a necessary requirement in any information system to ensure the availability of information to authorized users only. The authentication mechanisms are developed using passwords, secret keys, tokens, and biometric features. The verification is performed based on credentials such as something we know (password, passphrase, personal identification number), something we have (tokens, cryptographic keys), something we are (physiological and behavioral characteristics such as fingerprints, face, iris, palm prints, voice, hand geometry, Deoxyribonucleic acid (DNA), Electrocardiography (ECG), keystroke dynamics, gait, and signature).

Authentication systems may require use of one of these factors (knowledge, possession, and inherence) when an entity presents evidence for its identity. A common solution to reduce the risk of an entity presenting false evidence is to use different factors in combination, yielding multi-factor authentication. Biometric authentication is considered much stronger when compared to password or token based authentication [5] because the biometric characteristics of every human are uniquely identifiable, non-transferable, and non-reproducible. Multi-factor authentication is considered stronger than single factor authentication. Authentication mechanisms can be divided into two categories: static and continuous authentication methods [6]. Static authentication mechanisms authenticate the user initially but do not monitor post authentication session to detect if it is the same user accessing the system [7]. However, some systems can use periodic static authentication as well for re-authentication using same static credentials. Continuous authentication methods monitor a system during the lifetime of a session to detect if it is the same user accessing the system [8].

Continuous authentication mechanisms are an obvious choice for the RPM scenario because they have the potential to answer the fundamental question of patient verification during the entire session of remote monitoring. We can also use more than one biometric trait or use static and continuous simultaneously to verify the patient and increase the trust level on the received data.

B. *Radio Fingerprinting Technique*

The radio fingerprinting technique uses the hardware properties of the wireless devices and their signal characteristics for the purpose of unique identification. The radio fingerprints are generated by analysing the properties of radio signal and are determined by extracting device specific features that are caused by hardware impairments. The radio fingerprints are extracted by analysing the received radio signal for specific properties such as frequency, amplitude, and phase [14] [15] [16]. Radio fingerprinting is comprised of pre-processing, detection, feature extraction, and classification processes phases [9]. The purpose of radio fingerprinting is to uniquely identify the transmitter independently of any identifier in the data payload that can be forged easily. Radio fingerprinting can be used to identify cellular phones or other wireless devices, and to prevent fraud and cell phone cloning [10] [11]. The successful identification of wireless devices can potentially allow other applications such as intrusion detection system and forensic data collection to use radio fingerprinting [12] [13].

Radio fingerprints allow us to compare and distinguish different wireless devices with each other [17] and can be used in an authentication mechanism similarly to human biometric authentication. The radio fingerprinting method is composed of enrolment and verification operations [18] [19] [20]. Radio fingerprinting can be used in message authentication because it helps against message replay attacks [16].

III. PROPOSED AUTHENTICATION FRAMEWORK

We assume a mobility scenario where the patient does not need to stay at static locations. Hence, the patient can be at various locations including (i) at home, nursing home, or office; (ii) at public places such as library, café, playing sports; (iii) in transport such as car, ambulance, bus, and train; (iv) hospital that includes waiting room, intensive care unit, and surgery room. The RPM scenario for the IoT in eHealth is depicted in Fig. 1. We base the mobility scenario on previous work [40].

We propose an authentication framework composed of three phases to ensure the correctness of patient's physiological characteristics, patient's device, and patient's behaviour on continuous basis. Note that medical sensor to smartphone authentication is an important issue that is not treated here.

We assume that the medical sensors are paired with the patient's smartphone earlier during an issuing procedure. Hence, the patient uses only such medical sensors that have already been paired with the smartphone. The pairing procedure can ensure that the smartphone only connects with pre-approved medical sensors. Beyond this, the three phases of authentication are:

- Patient to smartphone authentication
- Smartphone to network authentication
- Patient to remote medical server authentication

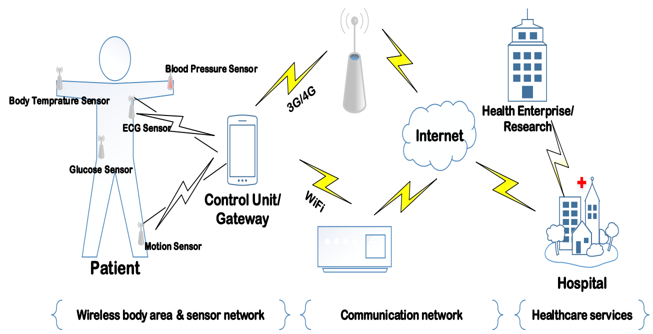

Figure1. Remote Patient Monitoring (RPM) Scenario

A. Patient to smartphone authentication

This phase ensures that the smartphone collects the data from a correct patient or the patient uses correct device to transfer medical data. We propose to use built-in sensors in the smartphone to authenticate the patient, e.g., smartphone biometric fingerprint identification sensors, face recognition using camera, voice recognition using microphone, and gait recognition using accelerometer. The authentication process for this step is depicted in Fig. 2.

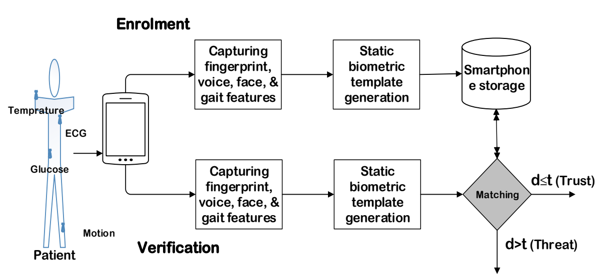

Figure 2. Patient to smartphone authentication process

The patient to smartphone authentication phase based on static biometric is composed of enrolment and verification processes. During the enrolment process patient's fingerprints, voice, face, or gait features are extracted to create a biometric template that is stored in smartphone for future comparison. Later on, the template is used for authentication. During the verification process, the patient's biometric characteristics are captured and verified against the stored template. A distance *d* indicates the tolerance of variation for the matching. The predefined trust threshold *t* indicates the limit for accepting or rejecting the authentication. If (d ≤ t) the patient is authenticated and trust is established. Otherwise (d > t) the user will be required to try again. Repeated failures will be treated as a possible threat. In an adaptive security setting [41], the trust threshold *t* might be varied dynamically depending on the current user environment and risk level.

B. Smartphone to network authentication

We propose this authentication phase to incorporate the idea of using an authenticated device. The process is depicted in Fig. 3.

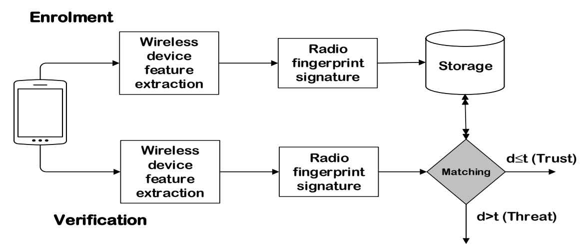

Figure 3. Smartphone to network authentication process

The device to network authentication phase based on radio fingerprints is comprised of enrolment and verification. The device specific features are extracted in the enrolment process to create the radio fingerprint of smartphone. The signatures are stored at wireless access point and mobile operator end for future comparison. Later on, when smartphone wants to access the medical server, first the radio fingerprint is checked at the access point or at the mobile operator end. A match will allow the connection but the request will be blocked on a mismatch. Our solution assumes that the access point and mobile operator network are configured to only let through traffic from matching devices. Note that the mobile network operators do not provide such service to date.

C. Patient to remote medical server authentication

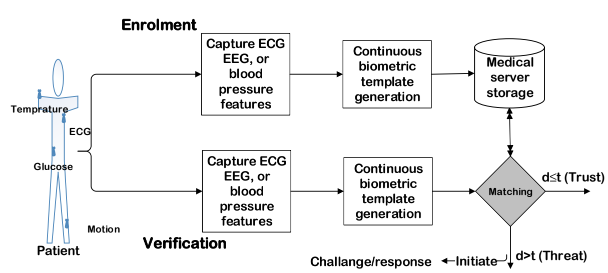

Figure 4. Patient to medical server authentication process

The process for continuous biometric authentication consists of enrolment and verification as depicted in Fig. 4.

During the enrolment process the patient's ECG, or blood pressure features are extracted to create a biometric template that is stored at medical server for future comparison. Later on, the template is used for authentication. During the authentication process, the patient's biometric characteristics are captured and verified against the stored template. If the comparison verifies the patient based on matching score, then the patient is authenticated and trust is established. Otherwise in case of a non-match, the server will keep receiving data marked with reduced trust level.

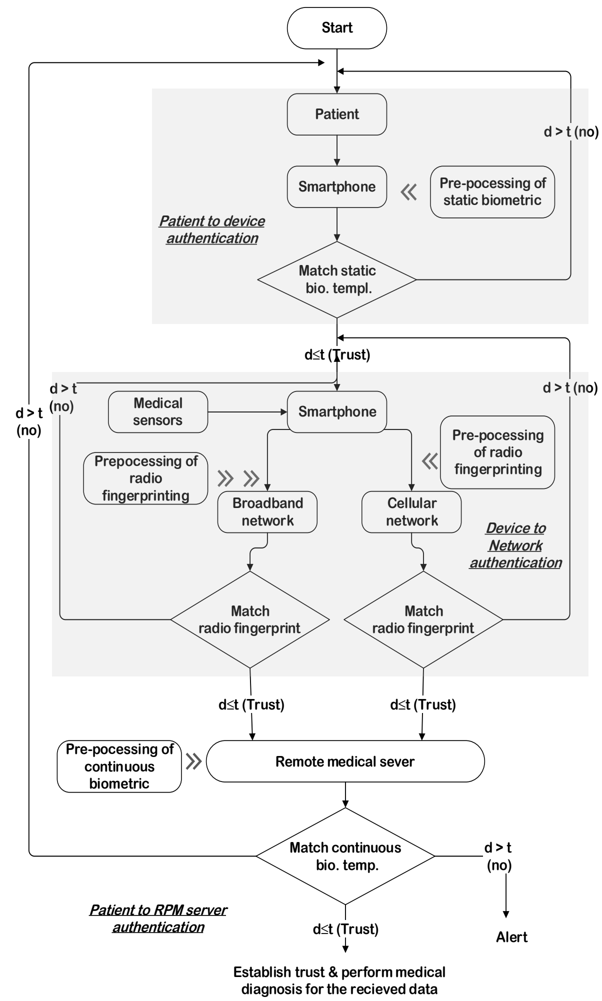

Figure 5. Authentication framework

As mentioned earlier, the overall authentication framework is composed of three phases depicted in Fig. 5. The three phases are combined to provide the required level of authentication. At first, the preprocessing of the static biometric template is performed and the signature is stored in the smartphone. The patient to device authentication phase ensures that the correct patient access the smartphone. The process is repeated when non-match occurs, otherwise patient is verified as a genuine user when match occurs and the next phase—device to network authentication—starts. Once the patient has been authenticated, the smartphone starts to collect data. Based on the patient's current location, either a wireless access point or the mobile network operator first verifies smartphone fingerprint signature against preprocessed stored template. The patient's data is forwarded to the medical server when the template is matched, otherwise the phase is repeated. During the next phase—patient to medical server authentication—apart from medical diagnosis the received data is used for feature extraction to create template that is matched against a preprocessed stored template. If the templates match the patient's data it is used for medical diagnosis, otherwise either the overall process is repeated or an alert is generated to initiate a response mechanism from medical staff. Table 1 summarises the phases of the authentication framework. The marks indicate the locations involved in the corresponding phases.

TABLE 1. AUTHENTICATION FRAMEWORK PHASES

	Locations			
Authentication type	**Patient**	**Smartphone**	**Network**	**Medical server**
Static biometric	✓	✓		
Radio fingerprint		✓	✓	
Cont. biometric	✓			✓

IV. RELATED WORK

The proposed authentication framework integrates static biometric, wireless device fingerprinting, and continuous biometric to provide an overall authentication solution. In this section, we briefly present related work to show that research in these domains is promising and that it is viable to these mechanisms for identification and verification in our scenario.

Biometric modalities such as voice, face, and fingerprinting recognition are emerging as an alternative authentication choice for smartphone users [21]. Also, some researchers have developed algorithms for voice and face recognition on mobile phones [22] [23]. Mobile phones with biometric fingerprint identification capability are already available in the commercial market.

The viability of authentication using wireless device fingerprinting has been proposed and demonstrated by some authors in different settings such as distributed ad hoc networks [24], infrastructure type networks [12] [25], and sensor networks [16]. A recent Internet draft [26] discusses the scope of radio fingerprinting for wireless device authentication. The identification for source of transmission by cellular operators has been addressed in the literature [16] [27]. Ureten et al. [9] demonstrated the use of radio fingerprinting to enhance the security of the 802.11 standard communications. Moreover, identifying wireless devices through fingerprinting technique has been published by various authors such as identifying unique devices through wireless fingerprinting [28], using radio device fingerprinting for the detection of impersonation and Sybil attacks in wireless networks [29], secure authentication in wireless networks using RF fingerprints [30], forensic identification of GSM mobile phones [14], practical RF fingerprints for wireless sensor network authentication [31], and AGC-based RF fingerprints in wireless sensor networks for authentication [32].

Patient authentication using ECG in biometric recognition has been presented in many recent studies [33] [34] [1]. The authors not only demonstrated the ECG data collection while the patient is at rest but also during the different activities phases. The RPM system utilizing sensors such as ECG, Electroencephalography (EEG), and Electromyography (EMG) attached to a patient's body, aiming to collect signals and then transferring them to a remote medical server is also explained in the literature [35] [2]. The use of a patient's physiological or behavioural characteristics in body area sensors network to solve identification and verification problem [4], physiological biometric for continuous authentication in ubiquitous environment [36] [5], and physiological characteristics of the patient for identity recognition have also been published in the literature [37] [38].

V. DISCUSSION

Some characteristics of the devices in the IoT environment are resource constraints, heterogeneity, distributed environment, uncertainty, context and location awareness, and ubiquity. In this section, we analyse our proposed mechanism in the context of these characteristics.

A. Resource constraints

Resource constraints such as limited power in sensor nodes are an important factor in the RPM system. Increased activity beyond the necessary collection and transmission of patient's data may drain the power of sensor nodes. An authentication mechanism for such environment should not consume significantly more resources than what is already the case. The proposed mechanism impose only minor extra processing burden on devices during different phases of authentication. For instance, patient to device authentication using static biometric requires only the patient's physical characteristics template to be locally stored at smartphone consuming little storage. Similarly, device to network authentication requires the wireless device fingerprint template to be stored either at the wireless access point or at the mobile network operator consuming no storage at the device. Patient to remote medical server authentication utilise the continuous biometric technique where the matching template is stored at the server end. The received data is used at the hospital site to authenticate the patient without requiring sensors to do any extra processing. Thus, devices with limited energy are not required to perform any extra processing. The framework does not impose any extra burden in terms of storage, processing, and power. In fact, the patient's own physiological and behavioural characteristics, the device specific characteristics, and the monitored data that is to be collected anyhow serve the authentication purpose.

B. Distributed/heterogeneous/dynamic environment

The devices in the IoT imply a distributed environment. As discussed in the scenario, the patient may be present at various locations but medical sensors can still send data to the medical server. We propose to use wireless device fingerprinting for broadband and cellular network infrastructures. Therefore, our framework is usable in such environments.

C. Context and location awareness

The proposed framework uses patient's behavioural characteristics for continuous biometric authentication. The patient behaviour can change when he is suffering from a heart attack. While authenticating a patient during a heart attack, the biometrically received data will not match the stored template. The non-match will trigger an alarm at the medical server requiring a response. For example, the response may include calling the patient on the smartphone, where in case of no answer an ambulance will be dispatched. In this case, radio device fingerprinting can serve another useful purpose. Since there can be uncertainty about the patient's current location, the device fingerprints and location service at that point of time can help in locating the patient.

D. Security

We analyse the security of our proposed framework from availability, integrity, and confidentiality aspects. The biometric and radio fingerprints templates are vulnerable to theft. At first, the patient can always report immediately for such an instance. However, if the imposter uses the stolen device for sending data to the medical server, while the patient to device authentication and device to network authentication may succeed, the continuous biometric authentication template will not match. The non-match will trigger an alarm at the medical server implicating that either it is an imposter or the patient is suffering from an attack. The authentication mechanism triggers an alarm that requires response by medical staff. Also, if someone gets access to the biometric templates and tries to use them for sending fabricated data to the medical server, then the imposter will not be able to compromise the system because biometric features of every human are unique and non-transferable. During the transfer of data to the medical server there is a risk of data interception which may impact the patient's privacy and confidentiality. We recommend using lightweight cryptography to prevent clear text data transmission to the medical server.

VI. CONCLUSION & FUTURE WORK

Our proposed authentication framework comprised of three phases ensures that the received data at remote medical server belongs to correct patient and identifies the fabricated data. The framework is resource and energy efficient requiring no extra processing for authentication purpose except the initial pre-processing of biometric and radio fingerprinting templates. While suffering from a heart attack or other extraordinary medical condition during the remote monitoring session, the patient's location can be determined using smartphone radio fingerprints.

In future, we want to evolve our framework towards adaptive and context aware authentication mechanism. The framework will be validated using simulation scenarios [40]. Incorporating context awareness and adaptive security in our framework are challenges because a non-match between stored and given templates always can not be treated as a threat to the system, rather there can be situations where environmental or system's context can assist us in decision making. Adaptive security can make template matching more flexible and we can adjust security level instead of blocking transmission during no-match due to the changed context. Thus, we will develop models of context awareness and adaptive security for our proposed authentication framework.

ACKNOWLEDGMENT

The work presented here has been carried out in the research project ASSET – Adaptive Security for Smart Internet of Things in eHealth (2012–2015) funded by The Research Council of Norway.

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 ISBN: 978-1-61208-363-6

Smart Mobility for Reducing School Gate Congestion in Europe

Innovating Smartphone Walking School Buses for Children of Primary Age

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Abstract **- In this paper, we report research on the impact of a Smartphone enabled 'Walking School Bus' Application (WSB App) on parental waiting experience, with a view to influencing a reduction in school gate traffic congestion in European cities. The core concept of the WSB App is to enable parents to track - real-time - the arrival of their child's WSB. This is through use of a moving icon representing the WSB as it sets off from the start and progresses along designated stops towards school, guided by an adult WSB coordinator. Our research aim was to understand how the cognitive appraisal of the waiting experience of the parents differed with and without the intervention of the WSB App. A sample of 46 parents were recruited from 6 primary schools in North West England, and baseline data were collected on their waiting experience either in the experimental (n=24) or control (n=22) group. Preliminary analyses involving a comparison between conditions showed no significant difference on perception of duration of wait or perception of punctuality. In addition, using 'thematic' analyses, three-quarters of respondents reported benefits; in particular, the timing and child use of the WSB were identified as beneficial. The wider implications of application of real-time information systems to modes of active transportation are discussed.**

Keywords-Smart Mobility; Walking School Bus; Application; Mobile Technology; Children

I. INTRODUCTION

In 2013, the most congested European cities were Brussels, London, Antwerp, Rotterdam, Stuttgart, Cologne, Milan, Paris, Ghent and Karlsruhe [1]. In Brussels – the worst affected - drivers can expect to spend as much as 83 hours per year waiting in their cars [1].

Increasingly problematic to most European urban centres in peak travel time is the increase in car use in the morning school run, resulting in congestion around school drop-off zones. Evidence suggests that in the UK around 43% of primary school children travel to school by car compared with 37% a decade ago [2]. This increase in traffic, combined with decreases in 'active transport' (cycling and walking) to school in primary school children has raised associated concerns about impact of air quality, child health-related fitness and independent mobility.

Children of primary school age are on the cusp of becoming independently mobile, and soon to be making decisions about modes for future commutes. Significantly, we know that from a life course perspective that habit uptake in early life, in the area of active transportation is likely to inform children's future mobility behaviors [3], and there is a call for sustainable and convenient transport experience to influence future choice decisions. Today's primary children are the commuters of the future. And with projected birth rate trends in some European countries – for example, the population of UK pupils in state funded schools is projected to rise 18% by 2020 [4] there is a need to provide convenient alternatives to car travel in the future.

Collectively, these trends make it timely to consider alternatives in transport, such as walking school buses

 ISBN: 978-1-61208-363-6

(WSB) to be promoted as a sustainable and convenient choice to shape future travel behavior [5].

The concept of a WSB was innovated in Australia [6] to enable children to get to school walking as a group, supervised by young people or adults. Traditionally, WSBs have involved leaders or coordinators using an informal timetable where there is some indication of a clock-time when a bus is expected to arrive at a particular stop. Whilst the innovative idea has been recognized by those who have adopted it - particularly in New Zealand, USA and Australia [5] - there is still scope to understand the barriers to choosing the WSB over other (less sustainable) modes of transport.

One potential barrier to uptake is the extent of visual access to the WSB's progress and arrival at stops on the way to the destination, particularly the case where the local highways are non-linear or when the WSB route changes orientation. The uncertainty in waiting times or confidence in arrival may influence parents/guardians uptake of a WSB use. It could be argued that if children and parents had a method to visually track the WSB as it leaves the start and travels along scheduled stops until it reaches the school, as with a smartphone enabled WSB, this may help break down these barriers.

In this paper, we report on the innovation of the Smartphone enabled WSB which exploits a real-time information system, to make travel to school a potentially more convenient initiative for parents and children.

A. *Real Time Information System for Promoting Smart Mobility*

In the domain of public transport, real time information systems have long been used with the intention to encourage commuter confidence in the reliability of services. Previous research of the impact of real-time information systems on public transport systems found increased information about accurate arrival time results in a more cognitively satisfying wait [7]. In addition, the more confidence that a user has in the reliability of a service, the more likely a mode of transport is to be perceived as convenient and usable, particularly in adverse weather conditions.

By understanding the influence of waiting experience and confidence in service, we hope to unpick the barriers to choosing sustainable transport in travelling to school and overcome the potential worsening of congestion and non-sustainable travel choices in Europe and further afield.

The WSB application involves using the tracking ability available in Smartphones to give the WSB new temporal visibility to users and potential users (parents, children, and walking bus coordinators) to optimize fluidity across scheduling boundaries between the morning school run and morning work start times, reducing some potential barriers to WSB use such as waiting time information and confidence in WSB arrival and punctuality.

This quest is timely in the context that between 2012 and 2013 the proportion of the global population using smart phones increased from 16% to 20.2%, with a further projected rise to 24.4% in 2014 [8]. In the UK, the ownership of Smartphones increased from 30% to 45% of the population within 2011 alone [9]. On the basis of this rising ownership, any issue around digital inclusion did not seem a barrier to the access to the innovation.

In the current study, we investigate the extent to which real-time information systems can be utilized to promote perception of a quality waiting experience, thereby facilitating parents to uptake this service. Specifically, this research explores the potential impact that Smartphone enabled WSB intervention as a smart mobility choice, and focuses on the extent to which this real-time information is effective in making a difference to user's waiting experience.

In this paper, we examine the extent to which this innovative smart mobility impacts on the perceived waiting experiences of parents using the WSB App. Specifically, we investigate the extent to which perceived waiting time - as measured by duration - is altered as a result of the use of the App. Second, we look at any differences in perceived punctuality. Finally, we elicit comments from the parents on their experiences of using the WSB App.

B. *Features and Architecture of the Smartphone Enabled Walking School Bus Application*

A 'parent' view of the WSB interface, showing the WSB icon and the pick-up points is show in Figure 1 below. Parents are able to track the movement of the WSB along the route displayed. They are able to add their children to their chosen WSB stop to allow coordinators to expect/know not to expect their child. Once the WSB coordinator has pressed 'start tracking' – see Figure 2 below - real time movement alerts and predicted arrival times are provided for each stop.

The WSB application is compatible for all iOS devices version 5.0+. Lancaster University hosts the centralised web service on a virtual machine cluster. The application downloads the pre-established pickup points and displays it to the user. It then used the Google Maps Directions Service to create a route for the user. The WSB coordinator uses their application to push their location to a central web service every 5 seconds. The web service then queries the Google Maps Directions service to retrieve real-time prediction information for the user. This web service then disseminates this geo-location and prediction information to all other parent devices.

The architecture components in Figure 3 shows the publish-subscribe architecture designed for the system. The native iPhone application is connected to the WSB server back-end through a REST-ful web service. The coordinator device publishes its location in a web request to the centralised service. When it receives a request it interprets the call and stores the pushed information into the database. The parent side of the application then sends requests to the centralised web service to retrieve the location of the coordinator. The back-end database stores the consistent state of the WSB system.

The devices cache local copies of all the data they receive as objects in a SQLLite database. When the system makes a change to this data a sync flag is checked and periodically objects are sent back to the server. This allows the devices to function and provide useful information to the user without having to hear from the server for substantive periods.

The application can also be used by parents to add their children to the Walking School Bus. The child's information is anonymised, encrypted and sent to the web service. This can then be downloaded by the coordinator to view the children they need to pick-up at each stop.

The WSB application developed is an open and secure platform which has been created based around the smartphone that will enable people to better visualize the activity of other people and things relative to their own immediate and future movements.

Figure 1. Parent view of WSB app user interface

Figure 2. WSB coordinator view of WSB app user interface

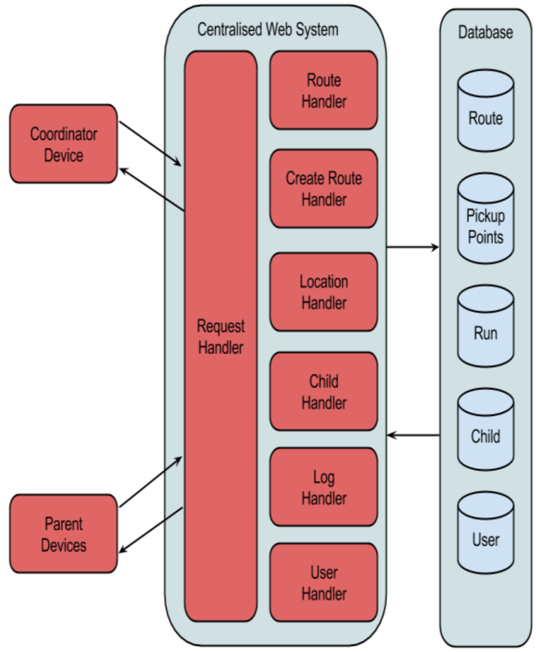

Figure 3. Architecture components of WSB App

II. Study Method

A. Design

Between May 2013 and July 2014, an experimental cross-sectional ‘between groups’ design was adopted to compare the perceived waiting experience of parents either assigned to the intervention of a smartphone WSB Application, or those in a ‘control’ condition who used the WSB as they would normally. A between groups design was adopted to reduce practice effects. Further, the intervention was a one-day intervention trial, due to the focus on assessing the impact of technology on ‘time perception’. Two sets of measures were taken, pre- and post-test of the perceived waiting time duration and perceived confidence of the arrival of the WSB. In addition, participants were asked brief question about their experience of waiting for the WSB.

B. Sample

A total of six established WSB’s from primary schools in the North West of England were recruited which involved 46 parents (24=experimental; 22=control group) from a range of low-mid socio-economic demographics. Institutional ethical approval was obtained.

C. Procedure

Following the ethical process of informed consent, parents completed 'baseline' questionnaires about their perceptions of waiting experiences using the 'traditional' WSB. Following this, their waiting experiences were compared before and after using the intervention. The intervention alsted one day. All parents in the intervention group received a demo of the WSB Application.

III. OUTCOMES

The quality of the parental waiting experience was assessed according to three approaches. The first measure was according to perceived waiting time duration. Our preliminary data analyses of the sample collected until November 2013 shows that on a 'traditional' WSB, the perception of 'typical' waiting time is mean of 4 minutes (s.d. = 2.82, n=32). On the basis of a comparison between conditions, there was no significant difference on this measure.

Second, the same trend occurred for perception of punctuality. In the rating of 'typical' punctuality, the mean score was 4.4 on a Likert scale where '5' is very punctual.

Finally, according to participant perceptions of the waiting experience, three-quarters of respondents reported benefits, in particular around the timing and/or visibility of the WSB. Table I shows representative quotes. Three quarters of participants valued the use of the WSB App, whereas three participants reported issues with the functionality of the WSB App.

IV. CONCLUSIONS AND FUTURE WORK

Overall, the findings showed that there was no adverse impact on either the perception of duration of either waiting experience or punctuality based on adoption of a 'quantitative' analysis of perception of waiting times. This is important because it shows that there was no disadvantage of using this real-time information smart technology, which clearly matters in the context of getting children to school punctually.

In contrast, the adoption of a thematic analysis showed - even on one day trials - explicit evidence of positive attitudes by three quarters of parents towards the experience of using the WSB Application. In particular, both 'time' and 'child use' were cited by participants as reasons for the perceived benefits of use. These outcomes are relevant to the planning of the future uptake of the WSB App.

It is also relevant to note that in an earlier phase of the research, user attitudes to privacy around future use of the WSB App were examined through interviews with Headteachers, WSB coordinators and parents/guardians. Only a minority of those interviewed from a range of socio-demographic groups had concerns, and it has not limited longer trials.

One limitation is that these were outcomes from the basis of a one day trial and it remains to be seen whether perceptions remain stable across five week trials.

TABLE I- THEMATIC ANALYSIS FROM EXPERIMENTAL GROUP (N=19)

Theme:	n	**Representative Comment:**
Positive		
'Time'	6	"Being able to track the WSB meant we were able to leave the house just before it reached us, cutting down the waiting time."
Child use	4	"The children enjoyed following the bus (on App) learning about where the signal came from." "It was an interesting experience for both my child (name removed) and myself."
Visibility of WSB	2	"Felt App useful as I was able to see where WSB was. Also I was able to see when they arrived at school."
Generic	2	"The Application was great."
Negative		
Usability on the day	2	"Bus app did not work so we left early to make sure we did not miss it"
'Time'	1	"The bus arrived later at 8:17hrs when its latest time is 8:17hrs, I was anxious."
Other	2	"I don't really wait when my children are ready as they just knock the door .."
Total	19	

 ISBN: 978-1-61208-363-6

On the basis of preliminary analyses from one day trials, these findings show that although smart mobility devices can consciously be perceived as convenient and enjoyable by users this is not necessarily associated with any reduction in perceived waiting time as assessed by duration. However, this may be because one day trial is not sufficient for altering human cognitive processes. In future research we propose to explore the extent to which perception of waiting time is reduced on the basis of a longer trial. The study of the interrelationships between real time information systems of smart mobility and human cognitive processes – specifically perception of waiting time – will be inform the design of future smart mobility systems, particularly those that are user centered.

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 ISBN: 978-1-61208-363-6

Beyond the 'Smart' City: Reflecting Human Values in the Urban Environment

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***Abstract*—The paper presents a work in progress that will develop a tool for mapping and reflection upon human values within the context of the 'smart' city. As the rise in 'smart' city initiatives and implementation of technologies within the urban environment become more evident, citizens face irrevocable changes to their environment and their lives within the city. Such a reliance upon technological strategies to fix cities' ills and a drive for constant innovation within the 'smart' city is largely being driven by technology companies and city leaders. Citizens must live with the consequences of such strategies which have the potential to change their environments in momentous ways. In order to develop new technologies within the urban environment Living Labs are becoming increasingly prevalent, enabling designers of technologies to engage with multiple stakeholders, including citizens, in the design and implementation of new products. We present a work in progress that develops a tool for the mapping of and reflection upon, human values in order to avoid unnecessary technologies being imposed upon citizens. Furthermore, we seek to engage those currently driving the 'smart' city agenda in envisioning an alternative future where consideration of citizen's values and the effectiveness of the city takes priority over technology implementation for the sake of efficiencies. We present the need for this new tool as it goes further than existing methods in its potential for enabling citizens to develop clear understanding of the values present in the 'smart' city environment.**

Keywords–urban areas; social factors; appropriate technology

I. INTRODUCTION

The contemporary city is a progressively complex entity, with issues such as increasing populations, sustainability and the need for greater efficiency becoming the focus for city leaders and technology companies. As examples of 'smart' cities increase and the implementation of urban, mobile and ubiquitous computing within this environment become more apparent, the landscape of the city is becoming redefined in a seemingly irreversible race toward autonomous operation of the urban sphere [1].

Physical environments impact upon human psychology and behaviour [2], yet there is little evidence to demonstrate the human aspects of what makes a city are considered when leaders or technology companies begin to consider transformations to make a city smart [3]. Currently there seems to be a focus on the 'smart' rather than the 'city', with a bias toward technological solutions [4]. Although cities are making some advances in dealing with major issues such as increases in population, decreases in funding and pressure on existing services, this is not done in a holistic and integrated manner. This results in the neglection of human factors [3][5] and too much reliance upon technology to fix existing and future ills [6].

There is little consensus as to what exactly defines this emerging paradigm between 'smart' cities across the globe, many differing approaches to their development currently exist [4][5][7]. "A city can be called a 'smart' city when investments in the human and social capital and traditional ICT based infrastructure fuel a sustainable economic growth and a high quality of life, with wise management of natural resources" [8].

This definition can be contrasted with the following statement, taken from a white paper on "Smart Cities and the Internet of Everything" [9].

"Smart cities are a future reality for municipalities around the world. These cities will use the power of ubiquitous communication networks, highly distributed wireless sensor technology, and intelligent management systems to solve current and future challenges and create exciting new services" [9].

The first definition places 'human and social capital' before 'ICT based infrastructure', whereas the second definition talks exclusively of technological based solutions. It is this conflict, between the significance of human and technological drivers within 'smart' cities, that forms the basis of this paper.

Within the context of the 'smart' city, Living Labs [10] have sought to involve 'users' in the development of technologies, with a broad aim of demonstrating a "user-centric open innovation approach for fostering everyday life innovation in users' real life context" [10]. As with 'smart' cities, there is no consensual definition of a Living Lab, but they are increasing in numbers globally, engaging in user-centric research relating to technology but not exclusively within the 'smart' city context.

The paper is structured as follows; the introduction (section I) presents the context of the 'smart' city and Living Labs, section II presents a discussion of Living Labs and their role in shaping 'smart' cities, using the particular example of the UrBan Interactions (UBI) programme in Oulu, Finland. This is followed by the introduction of human values and technology, a justification for their consideration within this discussion, and an example of values based HCI approaches in section III. In section IV we present a discussion of technology in the urban environment and in section V we introduce the Value Reflection Map, a tool through which values can be evaluated within Living Labs in relation to 'smart' cities. This forms the basis for the next stages of the research development. Section VI concludes the paper with proposals for future work.

II. THE RISE OF THE LIVING LAB IN THE SMART CITY.

Living Labs are increasingly considered to be effective sites through which to engage citizens in the development of technologies deployed within cities [11]. As sites of innovation,

 ISBN: 978-1-61208-363-6

they began development in the 1990s as a method to test new technologies in a home-like environment at MIT Medialab. More recently they have developed a more user-centric, open innovation approach across many technological fields. They can be found in cities across the globe with differing scopes and different funding models, sharing no unified methodology or framework. Although no unified framework or definition is available, they tend to share the ethos of user-centred approaches [10] with the broad aim of enabling citizen based innovation for the development of new technologies.

New networks such as the European Network of Living Labs (ENoLL) [12] aim to develop a more coherent and connected approach, using the following definition; "A Living Lab is a real-life test and experimentation environment where users and producers co-create innovations. Living Labs have been characterised by the European Commission as Public-Private-People Partnerships (PPPP) for user-driven open innovation." ENoll consider Living Labs to adopt four main activities; co-creation, exploration, experimentation and evaluation. [12]

Oulu, a member of the ENoLL network and situated in northern Finland, offers an example of a partnership operating across public and private organisations. It seeks to integrate technology into all aspects of city life and to place itself as a leading archetype of the 'smart' city and living lab movements. The city has the largest regional research and design spending per capita in Finland and fifth largest in Europe, providing 14000 jobs in the ICT sector. In the late 1990s Oulu was ranked as the world's third "silicon valley" in Wired Magazine and the area has the youngest population average in Finland and Europe [13].

Ubidisplays are currently deployed outdoors and indoors in Oulu city centre, in order to experiment and test technologies and applications 'in the wild'. Displays are implemented, deployed and evaluated in a 'real world setting atop an open urban computing testbed' [14][15]. This approach marks a response to criticisms that technologies designed and tested in labs do not account for 'real world' environments or applications [16]. The UrBan Interactions (Ubi) programme is joint sponsored by the City of Oulu and Nokia, with a budget of e6 million.

The hypothesis for the deployment of Ubidisplays states "by deploying new technology and services in the urban space we make it a 'better' place for people" [17]. Without a description as to what 'better' is, the hypothesis suggests a place is enhanced by the deployment of technology, in this case the Ubidisplays. In literature relating to the project there appears to be little consideration of the environment in which the displays are being deployed, or evidence that citizens are engaged prior to the design process. This also suggests that deploying a piece of technology enhances a space, without surveying the environment or indeed the need or desire for having such a display within the public arena. Through the mapping of human values within the urban environment, our research aims to establish the appropriateness of a technological fix to perceived problems within the 'smart' city. Such an approach fundamentally questions the current methods of user-participation methodologies and highlights the need for value elicitation and reflection tools.

III. Human values and technology

It is widely accepted that human values become manifest in the design and use of new technologies [18], and as such are a vital component of our research. Human values have long been recognised as important in disciplines such as anthropology, sociology and psychology [19]. Values in psychology are conceptions of desirable ways of behaving or desirable end states, characterised as relatively stable, transcending specific situations [18][19]. Empirical evidence demonstrates that all values are held by all people, across cultures all of the time, but their importance is ranked differently within each individual. [19]. Within more technology-based disciplines, communities such as CSCW and Participatory Design have also long embraced overarching human values such as cooperation, participation and democracy in their design methods [20]–[22].

An important and co-dependent relationship exists between human values and design as a result of their fundamental shaping of the human condition and people's attitudes towards technology [18]. Values are also a fundamental component of the design process, as has been recognised in the field of Human Computer Interaction (HCI). In this particular case, we take the 'smart', technologically mediated city as the context. Citizen's experiences will be affected by the design and implementation of such technologies to their everyday environment, therefore it is essential to take into account their values and ensure they are not negatively affected.

A design tradition which has placed values at the heart of its practice is Participatory Design (PD) [22] , in that it considers stake-holder participation in the design of technology as fundamental. The inclusion of values within the core design criteria of PD echoes a similar approach within Value Sensitive Design (VSD), a theory aiming to offer a principled and comprehensive framework for accounting for a set of (universally held) human values of ethical import throughout the design process [23]. The field of HCI has acknowledged the need to respond to human values, echoed by Sellen et al [24], who believe that greater finesse will be required in order to determine and understand values in the context of large systems and sets of systems that users operate within. They state "Much effort also needs to be expended on determining what is desirable within a place, an institution, or a society" [24].

IV. Technology and the urban environment

Within the field of HCI methods do exist to work with values during the design phase of the development of new technologies, however there is a lack of tools allowing users role to actively define their own contextualised values within the design process [18]. Values are not explicit and easy to discuss, leading to interpretation issues between users and designers. The lack of existing tools is acknowledged by Kujala and Väänänen-Vainio-Mattila [18], who call for further research and the development of a toolkit which will enable this to occur more effectively. However, the toolkit has not been developed, leaving a space for the development of a Value Reflection Mapping tool (VRM). The tool will enable greater understanding and development of user's values in two ways. Firstly, the VRM will enable citizens or organisations to map values for new technology designs and the urban space into which they might be placed. Secondly, it encourages questioning of the suitability of new technologies and whether they are needed, rather than jumping immediately to a technological solution.

Introducing technology into the urban environment, as can

 ISBN: 978-1-61208-363-6

be seen with the 'smart' city paradigm, changes the nature of place. As a result the city is transformed into a digitally augmented physical space, and therefore can be considered as 'hybrid'. In this respect, we can understand the intention to augment a physical space with technology as a means of attempting to improve that particular space, as can be seen in the example of Oulu's Ubidisplays and their aim of making the space 'better'.

At present there are too few theoretical and methodological approaches which examine the effects of technologies upon physical spaces and subsequently the human relationship to them [25][26]. A need for new ways of understanding physical spaces with respect to their digital augmentation is required. This is a view held by Ciolfi, [26], particularly in terms of how their "features support and affect our physical presence and further experiences with the environment...in order to shape the way in which a system will be embedded in the space itself."

Deployment of technology within the city might be the solution to some important issues affecting citizens, but without considering the value environment in which such issues exist and active engagement with all citizens, it is not possible to determine if it is necessarily the most appropriate answer. By beginning with human values and mapping layers of values within the urban environment, suitability emerges and will enable a 'bottom up', human approach. Human values are certainly present within technologies and urban environments but often remain hidden to both citizens and those developing new technologies within the urban environment.

V. The Value Reflection Map

A prototype tool, the Value Reflection Map (VRM), was developed as part of a short research project with one city based stakeholder in Lancaster, UK, in order to assess the viability of such an approach. As an independent retailer and café owner, the stakeholder has engaged in projects seeking to introduce a variety of digital interactions within his business spaces [27]. The starting point was to question the approach taken by Oulu in order to evaluate the environment into which a new technology might be placed. Central to this study was the question of how human values can be made manifest within a physical space and objects within that space.

We began by questioning whether design processes considered the spaces where interactions were being placed, furthermore whether human values were taken into account in such a process. Through eliciting contextualised values of the stakeholder, we sought to investigate how consideration of values might enable designers to question whether introducing new technologies into a space was appropriate and if so, how values might be designed into such technologies.

The method employed to develop the VRM consisted of three stages, with the output being a paper based map of colour coded values elicited from the physical environment and objects contained within. Schwartz's value model [28] was taken as a starting point, where the stakeholder answered questions from the European Social Survey (ESS) [29]. This survey was chosen due to it being based upon empirically established questions, which seek to elicit values of individuals across different cultures. Other models could have been employed, but for the purpose of the initial short research project it was useful to use an example with existing surveys and against which answers could be modelled.

We built upon the ESS in the next stage through conducting a contextualising interview with the aim of elaborating on the information gained from the values survey. In order to discover values held by the stakeholder which were made explicit within the physical space the interview was coded and specific values identified. The third step, artefactual analysis, was conducted in order to interpret how the stakeholders values were embedded and communicated within the environment. Using an image of The Hall, we systematically identified the stakeholder's values for each object within the space, colour coding each value. Areas of particular value density were identified that helped the stakeholder visually aware of where his values were manifest within the space.

As a short and initial research project, we produced a paper artefact that mapped one particular space with the values of one person. One very encouraging aspect of this technique, as identified from the initial test with the stakeholder, is the ease in their understanding of the Value Reflection Map. Through employing a visual map the stakeholder was able to clearly identify value clusters within the space where he was considered the introduction of digital interactions.

Insights from the initial research included feedback that the stakeholder is immediately able to identify with the physical space and objects. We also discovered use of imagery rather than text led to a clear and unambiguous reflection of values. A further reflection was that a paper based artefact widens potential access to citizens who do not engage with technology, either through choice or circumstance. By developing the VRM further it will enable the values of multiple people within multiple spaces to be considered and reflected. Further development of this tool will require the creation of a new methodology, as it is vital to engage citizens and investigate their experiences within the built environment.

The term 'mapping' is embedded within the practice of cartography, but is often used when information is being visualised. We employ this term in order to enable citizens and organisations to use the map as a way-finding and sense making tool in order to elicit their own values and those of the designers of technologies. Human values are not always easy to discuss, even though we all hold them, we do not necessarily make connections between what we value and the expression of those values. We believe a primarily visual tool will facilitate more effective elicitation of values within the environment.

Existing methods and tools have created some interesting and challenging approaches to mapping emotions or charting citizen unrest within urban environments. PanoRemo [30] enables designers to map user's emotions onto a variety of panoramic images, employing emotional design and market research techniques in order to evaluate how people feel about a particular environment. The Centre for Urban Pedagogy (CUP) [31] work with stakeholders in cities, most often disadvantaged or marginalised groups. They develop information brochures that are of particular use to that community, employing analogue techniques and community led design. A variety of different techniques for making visible issues that are hidden are included in The Atlas of Radical Cartography. The most notable example featured is iSee [32], an online initiative where citizens log and map surveillance such as CCTV throughout the city, meaning they can then plot their routes through the 'path of least surveillance'. The VRM does build upon the principles of making information visible and

 ISBN: 978-1-61208-363-6

community led design, but the point of departure is that it is not a digital tool, nor will it be employed for market research as Panoremo. It also differs from the work carried out by CUP, in that the aim of the VRM is for citizens to discover information and values for themselves, rather than relying upon organisations to do so.

VI. Conclusion and Future Work

The aim of this initial investigation was to identify the potential effectiveness a visual approach to representation and reflection of values might have and if the VRM was a valid starting point for further work. Through questioning current approaches taken by cities such as Oulu, we intend to develop a longer term research project. Based upon the position we have taken regarding the current focus upon the 'smart' within cities, we believe the VRM tool will be effective if employed within contexts such as Living Labs. Furthermore it will enable the visualisation of citizen's contextual values before the design of any technology occurs.

Distinct opportunities exist in cities as technological environments, such as improvements in health care, education and sustainability [33], however these need to be realised in balance with the potentially negative consequences produced by the introduction of such technologies as big data, ubiquitous and mobile computing. At present the balance within the 'smart' city paradigm favours efficiencies rather than effectiveness, which does not always provide the optimal environment for citizens.

Key to the next stage of research is the engagement of Living Labs involved in the development of new technologies within the 'smart' city. In order to develop the Value Reflection Map further, we intend to use such sites as case studies, to enable us to begin developing the new methodology through engaging with real world practices within the city.

A crucial strength of the Value Reflection Map will lie in the visual representation of values, enabling designers and citizens to clearly identify important values. Visual representation of values within spaces will ensure connection of citizens, space, objects and values, leading to more informed decisions regarding implementation of technology in the city. It is through the deployment and use of this tool that we intend to ensure focus on citizens within the city is valued more highly than focus on the 'smart'.

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Online Geodatabases as a Source of Data for a Smart City World Model Building

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***Abstract* — Online geodatabases have been growing increasingly as they have become a crucial source of information, with increasing social networks providing location-related features to their users. The aim of this study is twofold. On one hand, as our main contribution, we make an overview of the most significant online geodatabases which aims at understanding what data they contain, how they are managed and updated and who are the major consumers of their data. On the other hand, we shortly describe our previously developed world model and propose a new type of data feeds coming from place-based social networks and online geodatabases. So far, this symbolic world model has been fed with data coming from manual editing and automatic sensor-based updating. We believe that the aggregation of these additional sources of data will provide a more rich description of places of interest in a city and will enable an automatic creation of topological and other types of relations between those places.**

Keywords-online geodatabases; place-based social networks; symbolic world model.

I. INTRODUCTION

The ever more increasing use of social networking applications where the users may add location data to their posts, comments and pictures, created the need for geographic data repositories providing complete and correct data freely, with points of interest, monuments, companies, bars, stores, hotels and restaurants, among others. Currently, there are several online databases providing data about millions of places all over the world. Some of the examples are GeoNames [1], LinkedGeoData [2] and Factual [3]. Social networking applications, such as Facebook, Google+ and Foursquare use their own repositories in addition to the above mentioned; they also provide tools for creating new places, for editing the existing ones [4], adding more details, ranking and so on, all aiming at the construction of the most complete, the most correct, the supreme database of places in the world.

We have been working on a symbolic world model that acts as a repository of data about places people visit or know [5]. This model is built similarly to the human mental model of space in which places are represented by nodes of a graph and there are topological relations among them [6]. Each place is further described by a set of attributes. Each relation also owns a set of attributes if adequate and necessary. Our model not only allows topological relations; it also allows custom types of relations.

In our previous work [7], we showed how this model can be constructed manually by the user through a web application and also how it can be updated automatically by a set of processing modules connected to a WiFi network. Now, we are interested in developing applications that interact with Foursquare and/or directly with one or more online geodatabases to help user to construct and update their symbolic world model. The final step in our project will be the integration of all the three data sources, manual, automatic from sensor networks and semi-automatic from online geodatabases, with our system architecture and further study of the most appropriate implementation for the data repository for which we have identified already a set of challenges.

The remaining of this paper is organized as follows. Section II presents an overview of the most significant online geodatabases and discusses some of their aspects. Section III introduces the symbolic world model and describes two developed modules to act as new sources of data for the world model. Section IV concludes and makes an outlook.

II. ONLINE GEODATABASES

Geography has always been important to the human race. Stone-age hunters anticipated the location of their target, early explorers lived or died by their knowledge of geography, and current societies work and play based on their understanding of who and what belongs where. Applied geography, in the form of maps and spatial information, has served discovery, planning, cooperation, and conflict for at least the past 3000 years of our history [8].

Web mapping systems have gained substantial popularity in the last 15 years, and have been rapidly expanding since the release of OpenStreetMap [9] back in 2004, followed by Google Maps in 2005, Wikimapia in 2006 and Microsoft Silverlight in 2007. Latest releases include improved navigation, Google Fusion Tables, Google Maps Mobile and Wikitude Drive (2010) [10].

It is important to note that map coverage did not only become more widespread in recent years; it has also become significantly more accessible to the average user. Early maps that were restrained to commercial and data providers via satellite images rapidly expanded to the combination of road networks, panoramic street-level imagery such as Google Street View and massive collaborative systems such as

OpenStreetMap. Geographic Information Systems (GIS) represent a jump from paper maps like the computer from the abacus [11]. Within the last thirty years, GIS technology has evolved from single purpose, project-based applications to massive enterprise systems [12]. Such systems are currently being used by businesses, institutions, industry, local governments and the private sector to provide services to clients, manage resources, and to address multiple issues concerning to health and human resources, transportation, public safety, utilities and communications, natural resource, defense and intelligence, retail and many more.

With such a development, new concepts and technologies have arisen over the years. 3D Desktop applications, detailed and interchangeable layers, public data, map makers, map integration with social networks and mobile mapping have also appeared. The existing services have attracted several millions of users, both desktop and mobile. The scope of web mapping applications has widened from purely easy to use consumer-oriented tools to highly specialized applications with GIS functionalities that help solving and optimizing problems in several domains. Despite the advances of web mapping within the last few years, there is still a lot of potential to collaborate, to elaborate, to tell stories with creative new methods and to use the data in useful and interesting new ways [10].

Presently, vast quantities of geospatial data and information at local, regional and global scales are being continuously collected, created, managed and used by academic research, for spatial decision support and location based services. A key aspect to any geospatial solution is to support efficient data maintenance and analysis in a heterogeneous operating environment. This requires highly scalable, highly available and secure database management systems. One of the biggest challenges is integrating time into database representations, another is integrating geospatial data sets from multiple sources (often with varied formats, semantics, precision and coordinate systems) [13].

Current GIS applications, which are optimized to store and query data that represent objects defined in a geometric space, often utilize online geospatial databases as sources of their data. Most spatial databases allow representing simple geometric objects such as points, lines and polygons and can operate with varied data structures, queries, indexes and algorithms. These can support several operations such as spatial measurements (computing line length and distances between geometries), spatial functions, geometry constructors and observer functions (queries which return specific information regarding features such as the location of the center of a circle). They also allow remote querying of results via an Application Programming Interface (API) or even integration with other existing geo databases (such as the LinkedGeoData initiative).

Some examples of online geodatabases include OpenStreetMap (OSM) project [9], the GeoNames project [1], and Factual [3]. The main difference between these is that OSM and GeoNames are both open-source projects, accepting data from thousands of users, while Factual, usually, only maps out missing attributes or adds new ones. OSM features the largest collection of data (over 1 billion nodes), which surpasses other services in this regard.

A. Factual

Factual, launched in October 2009, is an open data platform developed to maximize data accuracy, transparency, and accessibility. It provides access through web service APIs and reusable, customizable web applications. Factual features data sets about local place information, entertainment and information derived from government sources. At the current date, and according to their website, Factual contains data of over 65 million places, which are updated and improved in real-time by Factual's data stack. Factual's API allows for remote access to stored data, through the use of queries. Access to the API server must be requested first with an OAuth authorization standard API key and secret, and has existing frameworks for several programming languages such as C#, Java, PHP, Python and Ruby. Results can also be obtained through HTTP GET requests. According to the factual developer site, it is possible to make different types of queries, based on text or points of interest, direct and reverse geocoding, geo filters, data submission and matching queries with provided information. It can also clean and resolve data as results are submitted into the database, and afterwards connect it to other sources of factual data, or external sites (such as Facebook or Twitter) relating to the same coordinates, and further enhance this by delivering contextually relevant content, experiences and ads based on where mobile users are located.

B. GeoNames

GeoNames is another global geodatabase initiative. According to their website, the GeoNames database contains over ten million geographical names corresponding to over 7.5 million unique features. All features are categorized into one out of nine feature classes and further subcategorized into one out of 645 feature codes. Beyond names of places in various languages, data stored includes latitude, longitude, elevation, population, administrative subdivision and postal codes. However, implementing its own semantics schema can be a barrier to future interoperability with other geospatial databases and sources of information [14]. It operates on a low level, semantic schema with no set of constraints on the domain and range of attributes, which can be a barrier to the consistency of the data set. GeoNames also features a functional API call server, which allows for querying of information on a programming level in several programming languages (such as C# or PHP). Results can be returned via XML or JSON objects. As described on their website, GeoNames API allows for full-text based searches, postal code search, place name lookup, nearby postal codes, reverse geocoding, nearby populated places as well as providing other services such as recent earthquakes or weather status lookup.

C. OpenStreetMap

OpenStreetMap is a collaborative geospatial project that aims at creating a free editable map of the world created by

Steve Coast in the United Kingdom in 2004. Since then, it has experienced a growth of up to 1 million users (in 2013) who collect all kinds of high quality data from various sources, such as Global Positioning (GPS) devices, aerial photos, sea travels, and government files. Like most Internet projects, most users are casual or inactive, with a small dedicated minority contributing the majority of additions and corrections to the map. The database now contains over 1 billion nodes, 21 million miles of road data and 78 million buildings [15]. OSM features a dynamic map where every urban or natural feature is built by the community, resulting in accurate, high quality data representations [16].

The OSM project facilitates complete, regularly updated copies of its database, which can be exported and converted to several GIS application formats through various frameworks. The data is stored in a relational database (PostgreSQL backend) which can be accessed, queried and edited by using a REpresentational State Transfer (REST) API, which uses HTTP GET, PUT and DELETE requests with XML payload. Data collection is acquired by GPS traces or by manual map modeling.

OSM uses a topological data structure with four data primitives: nodes (geographical positions stored as coordinates), ways (ordered lists of nodes which can represent a polygon), relations (multipurpose data structure that defines arbitrary relationships between 2 or more data elements which may be used to represent turn restrictions on roads), and tags (arbitrary metadata strings, which are mainly used to describe map objects). Each of these entities has a numeric identifier (called OSM ID) and a set of generic attributes defined by tags. For example, the natural tag describes geographical features which occur in Nature and has a wide set of values {bay, beach, … , wetland, wood} [16]. Further tags are used to specify time zones, currencies [17] and alike.

According to previous studies [18], the volunteered geographical information submitted to OSM is fairly accurate, with more than 80% of overlap between other specialized datasets, and often with more correct references in several countries around the world.

D. LinkedGeoData

LinkedGeoData (LGD) [2] is an effort to add a spatial dimension to the Semantic Web. It utilizes the information collected by the OpenSteetMap project and makes it available in Resource Description Frtamework (RDF) knowledge. The Semantic Web eases data and information integration by providing an infrastructure based on RDF ontologies, which are interactively transformed from OSM data. This procedure is believed to simplify real-life information integration that requires comprehensive background knowledge related to spatial features [17]. LinkedGeoData offers a flexible system for mapping data to RDF format, improved REST interface and direct interlinks to GeoNames and other geospatial data projects.

The data acquired from OSM is processed in different routes. The LGD Dump Module converts the OSM planet file into RDF and loads the data into a triple store. This data is then available via the static SPARQL endpoint. The LGD Live Sync Module monitors and loads change sets to the RDF level in order to update the triple store accordingly. The Osmosis is a community developed tool, which supports setting up such a database from a planet file and applying change sets to it. For data access, LGD offers downloads, a REST API interface, Linked Data and SPARQL endpoints [17]. The REST API provides limited query capabilities about all nodes of OSM.

LGD does not only contain linked data to OSM, but to other data services as well. It currently interlinks data with DBPedia and GeoNames [17], which is done on a per-class basis, where all instances of a set of classes of LGD are matched with all instances of a set of classes of other data sources using labels and spatial information. Since a vast amount of data is changed on OSM every few minutes, several filtering and synchronization procedures are used to ensure the data is kept relevant. Converting relational databases to RDF is also a significant area of research that LDG heavily depends on. These enhancements may further contribute to new semantic-spatial search engines to enable more linked data applications, such as geo-data syndication. However, certain limitations are still in the way of a more robust and scaling service, such as a lack of aggregating ontologies between OSM and the filtering system.

E. Discussion

Next, we discuss some aspects of online geodatabases that have been in the focus of the current research, namely, crowdsourcing, reliability and interoperability.

1) Crowdsourcing

A recent trend in neogeography has emerged by complementing information to geodatabases via several outside sources, namely social networks [19], shared media websites, and user's GPS contributions, known as Volunteered Geographical Information (VGI). The potential of crowdsourcing is that it can be a highly exploitable activity, in which participants are encouraged to contribute to an alleged greater good. For example, in Wikipedia, well over 99.8% of visitors to the site do not contribute anything [18]; yet, this does not deter the contributors from doing most of the work.

Since geospatial databases typically contain vast amounts of data, it is important to create mechanisms that can assist and verify the user-generated data submissions, which aim at improving internal data quality and resolving data conflicts between sources. These conflicts can be identified at the syntax (representation), structure (inconsistency), semantic (ambiguity) and cartographic (accuracy) levels [20].

Crowdsourcing in GIS has the following advantages:

- Make datasets accessible by non-proprietary languages and tools;
- Introduce formal semantics to make data machine learning possible, so the process can be automated between sources;
- Enrich existing data with other sources in a combined way, therefore increasing location precision;
- Allow cross-referencing and querying of multiple data sources simultaneously;

- Automatically detect on-going events and new places of interest from media and social networks.

However, there are several obstacles to this approach: data conflicts must be carefully managed, and proper conversion methods must be employed to ensure consistency (e.g., different names and tags for the same places in different sources), as well as other mechanisms to verify data integrity from user submissions (data validation). Outdated sources of information must also be filtered. A layer structure by Multi-Providers cRowd-Enhanced Geo linked Data (M-PREGeD) has been proposed [20] to improve data quality by involving the users in the selection process. This practice adopts the use of shared vocabularies and links to help increase semantic consistency and accessibility among sources of data.

In this case, results are stored in a local database and further enriched with matching Linked Geo Data nodes, which are verified and corrected by the Linked corrections layer, and only after that become available to the web applications layer. The user-generated matches are acquired by several applications, such as UrbanMatch [20], which is a game with a purpose for matching points of interest and photos, running on mobile geo-located services. The player is given a set of photos and is asked to match them with each location. The output is gathered from the players, verified and correlated and finally used to generate trusted links. A high number of similar answers are used to identify patterns of information and determine the accuracy of provided data.

This process can be defined in 3 layers: the Linked Geo Data layer which contains unprocessed data from several sources, the Linked Connections layer that is composed of all verification methods, such as the UrbanMatch game. Finally, this data is submitted to the web applications layer to the general audience.

Another process is done by analyzing metadata and tags from photos over different social media websites (such as Flickr and Twitter), by discovering associations between the media and the owner's geographical position, and is also possible to populate geo-sets with news data collected from other sources by employing extraction and retrieving systems [21].

These experiments not only help increasing spatial accuracy for existing places, but can also be used to discover new points of interest. Conflicts can be detected and resolved by automatic procedures, and expanding these techniques is an on-going process, especially when certain errors can occur [19] due to old or mislabeled data, incorrect semantic relationships, or simply by geographic evolution overtime. For example, there is a high correlation between places of interest like restaurants and a number of photos containing tags such as "food", "dinner" and "eating" being uploaded on the same location. This quantitative evaluation consists of very specific statistical and data mining methods with several levels of precision. In recent studies [19], several new places in London were found with the help of these methods that were not present in GeoNames or Foursquare. Since different database providers are constructed in different ways, this procedure takes into account how different places are submitted and represented internally, and tries to aggregate similar results into a location vector, which creates a classifier that calculates the likelihood that a given location contains a place in particular. Closer examinations detected conflicts or mislabeled data such as misleading Tweets and incorrect or semantically ambiguous tags, and this allowed excluding potential outliers based on standard deviation in the dataset. Using this method, new places of worship, schools, shops, restaurants and graveyards were found that did not yet exist in LinkedGeoData and GeoNames. With finer iteration it becomes possible to detect new places of interest with higher precision, such as extending OpenStreetMap to indoor environments [22]. This approach aims at increasing the detail of geo data by adding new tags to inner structures, such as airports, museums or train stations by employing a 3D building ontology. Again, such data is likely to be supplied voluntarily by individuals at those places of interest. This kind of non-profit projects greatly enhances user participation.

2) Reliability

The proliferation of information sources as a result of networked computers has prompted significant changes in the amount, availability, and nature of geographic information. Among the more significant changes is the increasing amount of readily available Volunteered Geographic Information, which is produced by millions of users. However, many of these results are not provided by professionals, but by amateur users; therefore, they do not follow the common standards in terms of data collection, verification and use, this creates an issue which is very frequently discussed and debated in the context of crowdsourcing activities. Several studies [18] [23] [24] [25] have analyzed the systematic quality of VGI in great detail, and claim that for the most part results can be fairly accurate compared to other private or governmental entities, and represent the move from standardized data collection methods to data mining from available datasets.

Evaluating the quality of geographical information has received the attention of surveyors, cartographers and geographers many years ago, which have carefully deliberated a number of quality standards [18]:

- Lineage: the history of the dataset;
- Positional accuracy: how well the coordinate of an object is related to reality;
- Attribute accuracy: how well an object is represented with tag attributes;
- Logical consistency: the internal consistency of the dataset;
- Completeness: measuring the lack of data for a particular object;
- Semantic accuracy: making sure an object's representation is correctly interpreted;
- Temporal quality: the validity of changes in the database in relation to real-world changes and also the rate of updates.

Several methodologies were developed to quickly determine the data quality, from statistical comparison (using average standard deviation between different databases to calculate positional accuracy, object overlap percentages, tile boards, road length comparison among maps [25] and spatial

 ISBN: 978-1-61208-363-6

density among urban areas) to more empirical methods (visual density representations, road comparison). The results [25] state that there is an approximate overlap of 80% of motorway objects, roughly located within about 6m of distance recorded between OpenStreetMap and other proprietary map types in London, as well as less than 10% of total road length difference between OSM and TeleAtlas.

3) Interoperability

The growth of geospatial industry is stunted by the difficulty of reading and transforming suitable spatial data from different sources. Different databases have unalike conventions, classes, attributes and even entirely different semantic structures, which makes it difficult to interconnect and correlate data from different sources [26]. As billions of dollars are invested worldwide in the production of geospatial databases, it becomes imperative to find other alternatives for data translation and open, collaborative frameworks. As most GIS use their own proprietary format, translating this data into other formats can be a time consuming and inefficient process. Transformations between formats can also result in loss of information because different formats support different data types. Data translation also takes up a large amount of secondary storage and can be costly to develop. Other providers sometimes restrict access by repackaging products for a particular GIS.

There have been several solutions in the past to alleviate the issue, such as object oriented open frameworks and open architectures. Other approaches consist in interpreting other formats through the use of a universal language (such as, the Open Geospatial Datastore Interface (OGDI)). As the translation process is a long and difficult progress, OGDI is based on reading different geospatial data formats directly, without translation or conversion [10]. In essence, it works as a comprehension tool instead of translation. This allows for different formats to be queried from a uniform data structure, as well as transparent adjustment of coordinate systems and cartographic projections. Such data structures can be implemented via simple object oriented concepts, such as point features instantiating a coordinate, line features being composed of 2 or more coordinates in the same directional vector, and area features consisting of several line features forming a closed ring. This transient vector structure is the backbone of the retrieval functions, and allows for transparent adjustments and understanding of multiple coordinate systems. OGDI also uses an API that can validate parameters and sequences, transform coordinates and projections and provide an entry point to OGDI functions for each driver.

The multinational and multilevel initiatives, such as Open Geospatial Consortium (OGC) [27] and Defence Geospatial Information Working Group (DGIWG) [28], have been supporting and fostering the development of Digital Geospatial Information (DGI) standards that make spatial information more accessible to application developers.

III. SYMBOLIC CITY

In our previous work, we introduced our system architecture and the main structure of a symbolic world model. The world model we proposed is based on human mental models of space. It consists of objects, attributes, relations and relation attributes. The objects represent places and are further described by a set of attributes. Relations represent any kind of topological or other connection between places and also can be further described by a set of attributes. As such, our model can be visualized as a graph in which objects are nodes and relations are edges. A simple example is given in Figure 1.

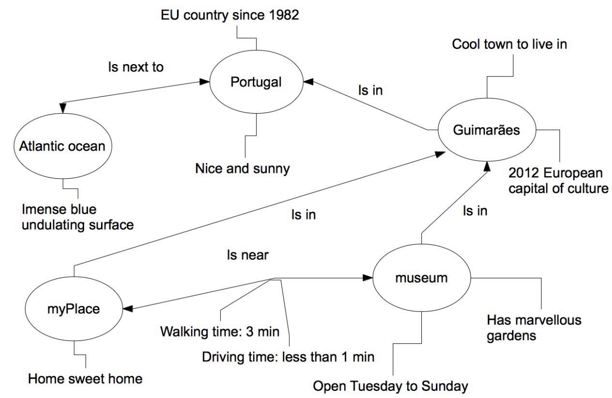

Figure 1. An exemple of a world model where places are nodes and relations are edges of a graph

Figure 2, in turn, shows how the symbolic model is integrated in the system architecture which supports different sources of data: manually introduced data, using a web application (SC Space Editor), automatically retrieved, by physical sensors and obtained on demand by software modules that communicate with online geodatabases and Place-Based Social Networks (PBSN).

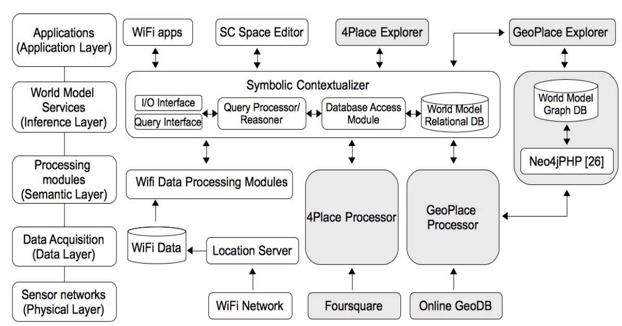

Figure 2. General system architecture

In the scope of the first type of interaction, the user can insert, modify, remove and query all the objects represented in the world model. In the second case, a set of processing modules was developed to extract data from WiFi networks, process them and insert them automatically in the model. Finally, the third type of interaction with the symbolic model is based on data from online geodatabases and PBSN, namely Foursquare. This type of data feed can be considered semi-automatic, as it requires some user intervention, as we will further explain.

We envision an application called Symbolic City that is based upon our world model and provides a new way of looking at places of interest in a city, as shown in Figure 3.

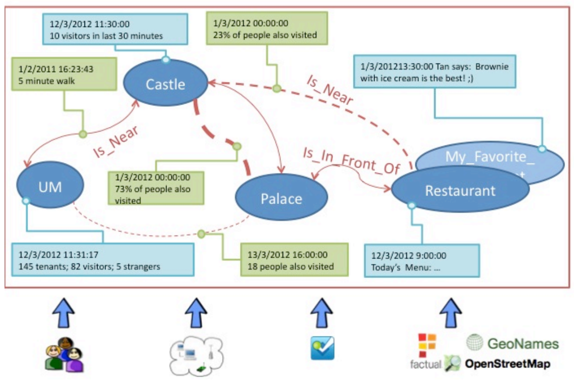

Figure 3. Symbolic City service concept

In order to achieve this kind of data crossing, we propose several sources of data and a set of processing modules that feed the model and allow for inference of place attributes that change with time, the creation of relations between places and user world model customization. The editing application was object of our previous work as well as the modules corresponding to WiFi data analysis. In the following subsections we describe the two remaining modules.

A. 4Place Explorer

Location integration in social networking applications provides means for people to share in real time places they or their friends and acquaintances visit as well as look for tips, comments and ranks of Points Of Interest (POIs) or places they intend to visit. Foursquare, Google+ and Facebook users are able to share their present location through the check-in mechanisms and comments about these places. Currently, these three applications are most commonly used in the scope of location sharing.

4Place Explorer is a PHP module we implemented to allow for the integration of the available data from Foursquare and Google Maps (for the purpose of route finding between two places) with the world model data. It uses Foursquare API. OAuth standard is used as it provides the access to most of the API functions with a user account.

In the current version of this module, the user searches for a place by its name. Data about that place are fetched from Foursquare in JSON format. The user chooses the matching place and a query in the symbolic model is made to check if that place already exists. If it exists, only the new attributes and new relations are inserted in the model, if there is any. If it does not exist, a new object is created with a set of attributes and a set of relations. The attributes that are extracted are the following: name, category, address, coordinates, city and country. The current number of *check-ins* may act as an indicator of how many people are visiting a place and it also may be added to the model. Currently, three types of relations are created automatically: Is_In, between an object and a city or a country; Is_Near, based on the distance between two places, calculated in a given range from the found object; and Is_Accessible_From, if a route can be obtained from Google Maps.

The purpose of this module is to provide a new perspective over the places that are represented in the two sources of geographical data, Foursquare and symbolic world model. The implemented mechanisms allow for automatic creation of new objects in the model as well as connecting objects with relevant topological relations.

The existence of relations transforms a set of dispersed places to a graph of interrelated places, providing not only proximity of points of interest, but also inviting the visitor to nearby locations and contributing to a better publicity, be it for tourism or for commercial purposes.

B. GeoPlace Explorer

Current version of the GeoPlace Explorer application allows for creating new places manually and searching for a place by name in Factual, GeoNames and OpenStreetMap geodatabases. After the search results are shown, the user choses the object to be created in the database. Objects have default attributes such as name, category, latitude and longitude. The user that creates an object becomes its author. The online geodatabase source from which the object was retrieved is also registered. An object may have other free attributes specified during its creation. Objects belong to one of six basic categories (city, island, building, country, road and ocean) and can have relationships (with corresponding attributes) to one or more objects. For example, the object of category "city", named Funchal can be related (relation "Is_In") to the object called Madeira of category "island", which, in turn, is related to the object Portugal, of category "country".

Our database is modeled in Neo4j [29], one of the most popular graph database models. The object creation and manipulation is done by a series of PHP files that interact with the database by the means of the Neo4j client library called Neo4jPHP [30] using Cypher queries.

The purpose of this module is twofold: to learn and test a graph database as a possible solution for our world model repository; and to analyze APIs and data about POIs from three different online geodatabases. So far, the main findings were that graph databases are farther more flexible and scalable than the relational databases as they do not require a rigid predefined structure and that using the three studied online geodatabases is advantageous as the existing data may be complementary.

IV. CONCLUSION AND FUTURE WORK

In this paper, we presented an overview of the most popular online geodatabases and discussed their main characteristics and strengths. Crowdsourcing has shown to be the most significant way of maintenance of large spatial data repositories, be it directly, as in OSM, be it through social networking, as in Foursquare. We introduced a symbolic world model as a repository of spatial data created manually by the user through a web application as an image of their mental model of space, and automatically by a set of processing modules that interact with sensors, place-based social networking applications and online geodatabases.

The envisioned Symbolic City application is related with spotting not only the POIs in a city, but also the relations that exist between POIs and that are inferred automatically by the developed modules. We believe that the users may get more details about POIs of their choice by adding them to their own personal models by combining several different sources of data. We expect to achieve this as the integration of the SC Space Editor, the 4Place Explorer and the Geo Explorer may follow in the near future.

However, there are still several challenges that we face in our present stage of research. They are related to the social and collaborative aspect of our application, with the choice of a database implementation (transition from a relational to a graph database or a hybrid solution), system distribution over several servers, and so on. There are already some promising solutions for each of these challenges, so in the near future we expect to obtain some new and exciting results.

ACKOWLEDGMENT

This work has been supported by FCT – Fundação para a Ciência e Tecnologia within the Project Scope: PEst-OE/EEI/UI0319/2014.

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Smart City as an Integrated Enterprise: A Business Process Centric Framework Addressing Challenges in Systems Integration

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***Abstract*— Smart city is emerging as a response to mitigate the problems of fast urbanization and unpredictability of standards, policies, and citizens' needs in urban areas. For a city to be smart, integration of city systems is essential in order to provide flexibility and access to real-time information for creation and delivery of efficient services. Business Process Change (BPC) is essential for systems integration in smart city development. Similar to BPC in Enterprise Systems Integration (ESI) for the private sector, changing business processes for smart cities encompasses a number of challenges and opportunities. This research-in-progress considers a city as an enterprise and attempts to develop a framework to address the business process-centric challenges in smart city development. ESI approaches, techniques, and tools will be utilized in this context. Thus, the proposed framework will identify and address BPC challenges in all steps of BPC for smart cities, using BPC tools, techniques, and approaches in ESI.**

Keywords-Enterprise systems integration; ESI; Smart city; Business process change; BPC; Smart city challenges.

I. INTRODUCTION

More than half of the world's population now lives in cities [1]. Around 70 per cent of the world's populations is likely to live in cities by 2050 [2]. Livability of these fast growing cities depends upon our ability to address the challenges that include human health, transport, infrastructures, waste management, and air pollution [1]. In order to address these challenges and respond to changing citizens' needs, all systems of a city should communicate with each other accurately and use each other's resources timely and speedily [3].

Similarly, today's unpredictable and competitive business environment needs real-time information to make timely decisions by enterprises. This is achieved by integration of all systems, applications, and information, normally referred as Enterprise Systems Integration (ESI), which includes a massive change within the enterprise [4]. ESI is the most important and useful change within the organization to provide real-time information, make timely decisions, and provide cheaper, quicker, and high quality services [5]. One of the most imperative actions for ESI is Business Process Change (BPC) that is defined as analyze, redesign, and improve existing business processes to achieve a competitive advantage in performance [6].

Hence, ESI and smart city development have very similar characteristics especially in their aim and objectives. This research-in-progress considers a city as a large-scale enterprise and focuses on challenges and approaches in changing business processes within city systems. Therefore, similar to enterprise systems, integrating all city systems is necessary, and this will be accomplished during the development of a so-called smart city [7][8].

This section describes the research gap, contribution to knowledge, and the aim and objectives of the proposed research. The next section provides an overview of the context in both areas of ESI and smart city. Then the methodology for undertaking the research will be explained.

A. Research gap

By considering a city as an enterprise and the necessity of systems integration in this large-scale enterprise, BPC will be the main meta-process in smart city development. Similar to BPC in ESI, developing a smart city by integrating city systems and processes/services comprises a number of challenges and opportunities that have been discussed by some researchers. For instance, Vojdani [8] argued that flexibility and agility of BPC for smart city, are two challenges in dealing with the unpredictability of the urban environment. These challenges also strengthen the necessity of systems integration for smart city. Moreover, Nam and Pardo [9] have discussed the business process related challenges for smart city by analyzing service delivery in two cities. They have explained the challenges like interoperability of technology, budgetary constraints, and interdepartmental collaboration in the three categories of technology, organization, and cross-organization.

Nevertheless, there is insufficient academic research, which particularly and comprehensively describes the challenges of BPC in smart city development. In addition, no research has discussed the usefulness of ESI solutions for smart city. Likewise, no academic literature has specifically prioritized the BPC challenges and their solutions in ESI and smart city development. The limited research that has been conducted [10][11], has emphasized major BPC challenges in ESI without addressing the priority issue. Many researchers like Chourabi et al. [1] and Nam and Pardo [11] still talk about the lack of academic literature in the smart city subject. Yet, research on the concept, challenges, and BPC for smart city has commenced. Liu and Peng [7] believe that smart city development still blindly persists on the technological layer, and further studies are required specifying policies and standards in order to reduce process integration issues. As stated by Chourabi et al. [1], they have

 ISBN: 978-1-61208-363-6

started filling the knowledge gap regarding the challenges of smart city development by providing a framework for the principles and success factors of smart city initiatives, but they have focused more on the technology perspective. This study will continue the previous attempts and will take a step forward closing the gap in the literature regarding BPC for smart city. Thus, more findings especially from primary research are required. This research will also benefit from exploring the BPC challenges and potential solutions in ESI, in order to address the BPC issues for smart city.

B. *Aim and objectives of the research*

The aim is to explore and address the BPC challenges in smart city development using tools, techniques, and approaches of BPC in ESI.

The proposed objectives are as follows:

- Identify the challenges of BPC in ESI
- Identify the challenges of BPC for smart city
- Compare and prioritize identified challenges in ESI and smart city development
- Examine process change solutions, tools, and techniques for ESI and assessing (qualitatively) their usefulness and effectiveness for smart city in order to address the challenges
- Develop a framework to address BPC challenges in smart city development

II. CONTEXT

This section demonstrates the empirical foundation of the research-in-progress including the two main fields of ESI and smart city, as well as the relationships between them, by critically analyzing the previous investigations leading up to our proposed aim and objectives.

A. *Enterprise Systems Integration (ESI)*

ESI represents a progressive and repetitive unification of technologies, human performance, operations, and knowledge of the enterprise as a whole [12]. Thus, it is critical to improve all aspects of the business key drivers, which are processes, people, technology, and flow of information amongst them. Technology is only an enabler and allows people to manage BPC [13]. The flow of information through all of these elements is also necessary especially when technology is inserted for BPC [14]. Therefore, BPC is the main area of activities in ESI, and enterprises should shift from functional-oriented integration to process-oriented integration [22][23]. In addition, BPC addresses some issues in other areas of ESI.

BPC is a complex task and includes many challenges, such as inter-dependencies between processes, departments, stakeholders, their attributes, and applications [16]. Moreover, redesigned and new business processes should deal with continuous change. Therefore, flexibility and complexity are two imperative issues of BPC that can be addressed by effective Business Process Management (BPM) [13]. Additionally, BPM as a systematic approach can address inter-relationship issues in BPC [18]. Furthermore, choosing an accessible Business Process Modeling (BPMo) tool, such as Event driven Process chain Mark-up Language (EPML) addresses the issues of interoperability in BPC [19]. In addition, BPC challenges are involved with "people" and "technology" aspects of business change. For instance, "ability of employees to learn" and "cultural readiness" are major factors in BPC that are directly related to People. Moreover, "IT influence in BPC" is a technology related challenge that needs to be tackled by an appropriate systems integrator [17].

B. *Smart city*

Liu and Peng [7] signify that two factors of "Urbanization" and "Industrialization" cause today's so-called "city disease". Birmingham city council [20] has classified urbanization related issues into six categories of economic, well-being, mobility, environmental, digital inclusion, and the need for an integrated approach ("Joined-Up approach"). Unpredictability of a city's environment and continuous change in city policies, standards, and residents' needs are the main urbanization related challenges for local governments. Thus, access to real-time data and flexibility in city systems is required in order to create and deliver services [8]. To promote sustainable living, it is necessary to change the traditional urban activities and functions. In other words, the managers and authorities have to manage their cities in a smarter way [1]. In addition, local governments face issues related to different sectors, such as multiple stakeholders, high interdependency, cross-sectoral cooperation, and inter-departmental coordination [9]. Moreover, Liu and Peng [7] present interconnectivity through various sectors of a city as a significant issue for city leaders. As a result, full integration of city systems is required in order to enable access to real-time data by all sectors [9].

Table I provides some definitions for smart city in various aspects:

TABLE I. SMART CITY DEFINITIONS.

Smart city definition	Significant focus	Study
A place for utilizing technology to process large amount of data to produce real time information, knowledge, and intelligence	Technology	[2]
An integration of technology & strategies to improve quality of life, economy & sustainability	Technology	[21]
"A city well-performing in a forward-looking way in various characteristics, built on the smart combination of endowments and activities of self-decisive, independent and aware citizens"	Visions of well-being in the future (People)	[22]
A place in which there is enough communication between people and city's systems, enough mobility, and no excess of consumption	- People - Systems integration	[23]
"A city that monitors and integrates conditions of all of its critical infrastructures"	Technology	[24]
A larger system that integrates elements of physical & technological infrastructures enabling ubiquitous use of mobile and virtual technologies, and human infrastructures.	- Technology - People	[25]
The use of smart technologies to build and integrate critical infrastructures and services to increases in efficiency, effectiveness, transparency, convenience, and sustainability	- Technology - Process	[26]

These explanations emphasize some principles, such as "systems integration", "efficiency of services", and "access to real time information", but they mostly concentrate on technology perspectives. This research, adapts these principles by focusing on the business process viewpoint and defines "smart city" as an integration of the systems within a city and change their business processes in order to provide access to real time information and knowledge by all sectors and enhance communication between them. In this environment, agile and efficient services are delivered at real time and with a lower cost. This is a process-centric definition and indicates that the integration of city systems and their services is a necessity for a city to be smart.

C. *City as an enterprise*

In order to address the challenges for local government in creation and delivery of smart services, this research-in-progress considers a city as a large-scale enterprise, which includes all of its elements (Figure 1).

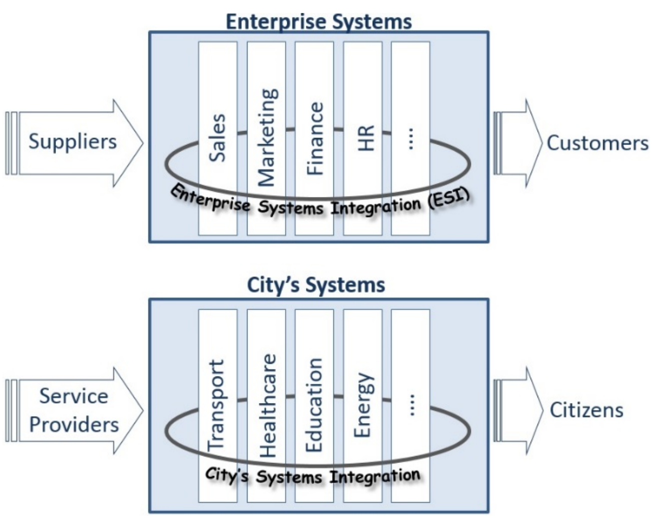

Figure 1. City as an enterprise.

As shown in this figure, service providers are considered as suppliers, citizens are customers, and local government/authorities are the managers and leaders of the enterprise. Moreover, any enterprise consists of systems such as finance, human resources, and sales. Likewise, a city encompasses a number of sectors/systems such as transport, health care, energy, and education.

III. RESEARCH METHODOLOGY

The methodology to undertake the proposed research is based on a mixture of gathering data from literature, questionnaire, and interview; discussion and comparison of gathered data; as well as development and evaluation of the main research outcome, which is a framework to address BPC challenges for smart city.

Firstly, following datasets (combination of secondary and primary data), must be collected for this research:

- Dataset-1: Challenges of BPC in ESI and prioritization
- Dataset-2: BPC tools and techniques to address BPC challenges in ESI
- Dataset-3: Challenges of BPC in smart city development and prioritization

The first two datasets will be gathered through a comprehensive literature review to identify the challenges related to changing business processes for ESI. These data collection phases will be supported by some theories such as system thinking theory [27] and systems theory [28] to underpin the concepts of system, enterprise systems, and ESI; business process change management theory [29], which identifies and categorizes some BPC challenges in various ways; and contingency theory, which emphasizes that a variety of challenges need to be addressed for a successful change [30].

Then, primary research through questionnaire is carried out to prioritize the BPC challenges in ESI. The questionnaire will be responded by enterprises that have already implemented an ESI solution (e.g. government agencies and commercial organizations), as well as ESI implementers and solution providers for enterprises. These data groups will help to generate information and knowledge to address BPC challenges in smart city development.

Dataset-3 will be predominantly gathered through primary research by undertaking interviews as a way to properly understand the specific issues, which are faced by smart city developers in real-life. City authorities, which are initializing smart city projects, as well as, solution providers for Smart Cities will be interviewed for this data collection phase. The prioritization part will be performed during interview and by utilizing prioritization results from dataset-1.

By considering smart city as an integrated enterprise, the results from dataset-3 will be compared with dataset-1, in order to apply tools, techniques, and approaches for addressing BPC challenges in smart city development. This is also underpinned and upheld by complexity theory [31] and organization as system theory [32]. At the end of this phase, a preliminary framework for service transformation in smart city development will be formulated and will be incrementally adjusted to achieve the research outcome. All theories outlined above as well as the BPC model that has been theorized by Kettinger et al. [32] and the business process improvement model developed by Lodhi et al. [16], will be utilized in order to design and develop the framework, which demonstrates tools, techniques, and approaches for addressing the challenges in every BPC step.

The final updated framework will be evaluated and possibly modified through an expert discussion in three areas as follows:

- Contents and structure of the framework
- Identified solution(s), tools, and techniques to address the BPC challenges in smart city development
- Implementability of the framework

This will be accomplished by analyzing and discussing the framework with smart city experts from academia, authorities (smart city developers), and industry (smart city solution providers).

IV. CONCLUSION

From the literature, it has been demonstrated that very few researchers have discussed the concept and the challenges of smart city development, especially in BPC perspective. In addition, there is no academic research regarding usability of ESI approaches, tools, and techniques to address the BPC issues for smart city. Likewise, no academic literature has set priorities for all BPC challenges in ESI and smart city development. Hence, comprehensive research including gathering data from secondary and primary sources is necessary to close the gap in the literature and in response to the increasing demand with respect to the above subjects.

This research proposes that BPC is essential in the integration of city systems for smart city development. Similar to ESI, there are many challenges in BPC for smart city. The proposed research considers a city as an enterprise and attempts to develop a framework to explore and address BPC challenges in smart city development, using BPC tools, techniques, and approaches in ESI.

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From Smart Metering to Smart City Infrastructure

Could the AMI Become the Backbone of the Smart City?

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***Abstract*— The paper presents a study and preliminary field results concerning the use an Advanced Metering Infrastructure (AMI) based on the standard protocol Wireless Metering Bus (WMBus) mode "N" (169MHz), also for smart city services. The paper shows how such an infrastructure is suitable for metering services, but it has some limitations when dealing with services requiring either more bandwidth or more frequent communication.**

***Keywords*— metering; MBus; urban infrastructure; short range; 169MHz.**

I. INTRODUCTION

Smart City services could drive the boost of Internet of Things (IoT) since over 50% of world population lives in cities (>3.3bn), growing to 70% of total world population by 2050 [1]. On the other hand, governments, through regulation [2], pushes for a new and strong sensitivity to sustainability, will ensure the creation of a mass market of IoT application in the "Green Economy" area. Smart Metering and Smart Grid are often mentioned as some of the applications integrated into the Smart City even if the two big worlds of "Smart City" and "Energy" seem to proceed in parallel without strong degree of synergy among them. Even if a strong effort has been made by EU Government in order to encourage standardization for the IoT [3][4], still plenty of communication technologies are available on the market. The choice of the right wireless technology for a specific application service, is not easy since different constraint such as range, datarate, power, latency and cost should be taken into account and a satisfactory tradeoff shall be identified. If the same technology platform should be used for different application services, the choice becomes even more difficult to take.

The paper presents the attempt to use a standard European wireless protocol (WMBus mode "N" [5]), that has been chosen for a smart gas metering massive roll-out in Italy, for managing other typical services of the smart city framework.

In 2008, the Italian Authority for Gas and Electricity prescribed the use of Smart Meters for the gas distribution network (about 21 million meters) [6]. The roll out plan states that 60% of «consumer» gas meters (about 18 million) shall be replaced by 2018 and 100% of «commercial» and «industrial» gas meters by 2024. General Packet Radio Service (GPRS) solutions for «commercial» and «industrial» gas meters has been proposed and is being deployed on the field, while Point to Multipoint solutions based on a European standard short range protocol (WMBus 169 MHz) will be used for «consumer» gas meters. Since the project implies a huge investment (around 4-5 billion Euros) and some studies [7][8][9] showed how the business case is very uncertain, in 2012 the Authority for Energy recommended [10] gas DSO to evaluate the possibility to extend the usage of the gas smart metering network to other services including other metering applications, such as water metering and other smart city applications.

In Section II of the paper an introduction to the WMBus protocol is given. In section III the analysis and results on the protocol from different perspective are given. In section IV a Case Study where the results of the analysis are applied to a specific case, are shown. In section V conclusions and further steps to be taken are mentioned.

II. WIRELESS MBUS MODE "N"

MBus is a European communication protocol that has been specified for metering applications (the "M" of MBus stands for "metering"). Mode "N" has been specified in order to allow communication at higher range than the typical home area situations; in this case a lower frequency (the 75kHz band between 169.400 and 169.475 MHz has been identified). This frequency band has been reserved by European Telecommunication Standardisation Institute (ETSI) EN 300 220-1 [11] for metering applications allowing a maximum Equivalent Isotropically Radiated Power (EIRP) of 500mW (27dBm) with a maximum duty-cycle of 10%.

The standard is developed within the CEN (the European Committee for Standardization) also in response to the EU mandate 441 [2]; the "N" mode has been proposed by France and Italy since in both countries a wireless network based on 169MHz frequency will be adopted for gas metering. The wireless protocol is narrowband and it uses a Gaussian Frequency Shift Keying (GFSK) modulation at different data-rates according to 6 different channels; those channels are spaced by 12.5 kHz and have a bit-rate either of 4.8 kbps (channels 1a, 1b, 3a, 3b) or of 2.4 kbps (channels 2a, 2b). Mode N2g (different channels grouped together to get a higher data-rate) that uses a 4GFSK modulation, has been reserved for "relaying" type of communication nodes. Different service classes are defined within the standard and in the higher class a minimum level of sensitivity -115dBm shall be guaranteed at a Packet Error Rate (PER) < 10^{-2}. The protocol allows power saving and bidirectional communication, made possible by the implementation of two communication mechanisms: Access Timing and Synchronous Transmission. At application level, it is possible to use specific data objects but also tunneling of Device Language Specification (DLMS/COSEM) data objects.

III. ANALYSIS OF A MULTISERVICE NETWORK BASED ON WIRELESS MBUS MODE "N"

The analysis has been made breaking down the problem into many independent sub-problems, which are easier to deal with; for each of the analyzed aspects, a simulation model was created, to provide preliminary and qualitative estimations of the performances achievable by the system (traditional and detailed network simulators such as Network Simulator (NS-2) were not used because of the poor maturity of the WMBus mode "N" specifications at the time the analysis was done). Each model was then merged into a simplified network-like simulator, that through a set of parameters, can be adapted to represent a replica of a real scenario. Feedbacks given by this tool may be useful to evaluate the feasibility of new projects.

A. Channelisation aspects

Since WMBus is a narrowband protocol (75kHz in total, 12.5kHz each channel), it is likely that more channels will be used in parallel to increase the amount of data that can be transmitted in particular in a multiservice perspective; WMBus is a Frequency Division Multiplexing (FDM) [5] protocol and hence is affected by Adjacent Channel Interference (ACI). A Simulink model was created to assess the theoretical impact of ACI on the transmission; the effect was obtained introducing an interfere source and increasing the power of this interferer until a significant degradation on the channel adjacent to the interferer one, can be detected. In Fig. 1, the Bit Error Rate (BER) for different channels, at different interferer power is shown. The influence of the interferer depends on the used modulation and the 4.8kbps channels seems to be the most sensitive.

In order to confirm the results of the analysis, some measurements were made using commercial transceivers implementing WMBus 169MHz; on average, the noise generated by an undesired GFSK 2.4 kbps signal source on the adjacent channel is 64 dB lower with respect to the power generated on the central frequency of the true transmitting channel. There is a 20dB difference when compared to the theoretical analysis; the difference is caused by the filters used in the commercial transceivers that mitigate the effect of ACI.

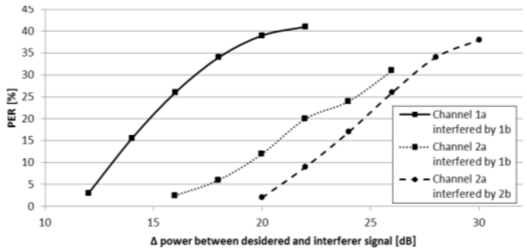

Fig. 1. Simulink ACI analysis.

ACI interference, when continuous, can be compared to a noise floor that limits the sensitivity of the devices; in order to understand what is the minimum power level of the desired signal to obtain a good transmission quality, some additional measures were made. The results showed how the desired signal should have a strength of at least 5-6 dB more than the noise floor caused by the interferer. In summary, to obtain a satisfactory communication when different systems are transmitting in uncoordinated way on different channels, it is important that at the receiver, the difference between the received signal on the serving channel and the one received on an adjacent one is less than ~58 dB.

B. Energy Consumption

Energy saving is certainly among the primary objectives in the design of a metering network, since meters are usually not powered by the electricity grid. Therefore, in order to enable remote reading functionalities, it is necessary to install batteries in such devices. With the purpose of minimizing as much as possible the maintaining costs, WMBus has been designed to achieve high energy efficiency. The calculation of the power absorbed by a meter, is a prerequisite to estimate the battery lifespan. Many variables have to be considered in such a computation, coming both from the devices and battery physical characteristics. Considering the usage of real apparatus (already available in the market), some assumptions have to be taken. Let us suppose to equip meters with 19Ah batteries: we must also consider battery self discharge, that leads to decrease its nominal capacity year after year. Consumptions related to metrological functionalities in a meter is normally the smaller part and it depends on the hardware design of the meter; assuming an additional consumption equal to 5 uA (this hypothesis was shared with some meter manufacturers) and degradation equal to 5%/year, it is possible to obtain the graph presented in Fig. 2, which shows battery lifespan as a function of synchronous transmission frequency. Two different Tx-Rx boards differing only for different maximum output power (64mA @ 14 dBm for Device1 and 320mA @ 27 dBm for Device2) are also compared.

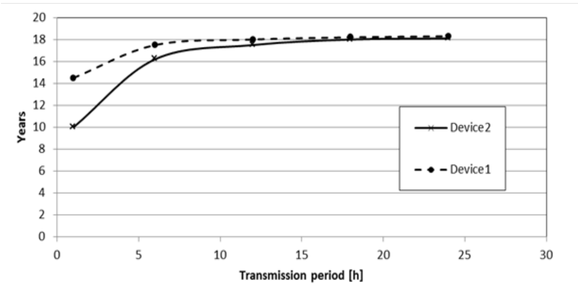

Fig. 2. Meter battery life estimation.

Under the above assumptions, it was possible to estimate that a meter life span could be around 18 years, when the period between subsequent transmissions is 24h. This result is aligned with an assessments made on real devices in [12]. On the other side, comparing the two boards, it can be observed that differences in battery life tend to converge for increasing transmission periods. This kind of behaviour happens because when data sending events are very distant from each other, the only relevant factors that would affect battery duration, are metrological consumptions and capacity degradation.

C. Radio coverage

One of the main advantages of the WMBus mode N protocol is the use of a low transmission frequency, which should make it possible to achieve greater Line of Sight (LOS) distances and less sensitivity to attenuation due to obstacles. In a typical scenario, gas meters are installed in concrete niches protected by metal cabinets. The goal is to define some objective parameters that allow to perform, with good approximation, some large scale estimations taking into account those challenging radio propagation aspects.

Although the majority of the meters are placed at ground level, in some cases, devices such as water meters, are located in the basement.

In case of a multiservice network, one data concentrator should be deployed to serve not only gas meters, but different services with their own radio propagation specific issues. In such a case, the radio coverage assured by the data concentrator (i.e., the maximum communication range) should be studied according to the most critical path that could be present between the concentrator and the meters. Some laboratory tests have been conducted in order to estimate the loss due to such obstacles in the LOS.

It has to be noticed that the objective of this analysis, was not to define a new propagation model, but to have a flavor of the performance of this protocol, by tuning available propagation models with some experimental result, since most of the pre-existing models do not fit properly with this context either for the positioning of the “mobile station” or for the adopted bandwidth.

The analysis has taken into account two different positions of the data concentrator, at street level (2m -microcellular) and at mobile station position (30m -macrocellular). Some preliminary and not massive on-field radio coverage test has been conducted, using the two boards already mentioned above (Device1 and Device2). Results coming from experimental test have been compared to some of the already available mathematical models, such as Okumura [13] and Hata [14] (only applicable when transmitting data from an height higher than 30 m).

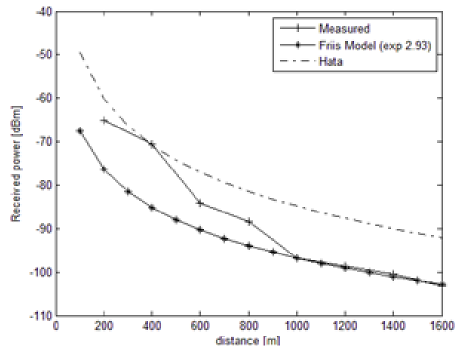

Fig. 3. Measured vs Predicted received power as function of distance in suburban area when Concentrator is installed on a tower

In Fig. 3, it can be noted that Hata does not predict, with an acceptable approximation, the measured radio field, in particular at growing distances. On the other side, Friis model [15], with a modified exponent, seems to model more effectively the real behaviour of the signal. In particular, a value of 3.2 for the exponent, seems to work properly for a *Micro Cellular* positioning of the concentrator in a *Urban* environment and a value of 2.9 for a *Suburban* environment; in case of *Macro Cellular* positioning of the concentrator, the value of the exponent in the Friis formulation to be considered for a *Suburban* environment is 3.0. The analysis was made on data coming from test campaigns on a limited number of sites (no enough data points were collected to tune the exponent in case of *Macro Cellular* in *Urban* Environment), hence further massive test campaigns should be made to validate these preliminary results.

D. Network capacity

Aspects, such as maximum number of users and coexistence between different services, are way more important than data throughput or delays, when analyzing metering networks performance. Given the lack of media access control methods in WMBus, the standard just allows to prevent systematic collision through a cyclic access number that, randomly initialized on each device, allows to slightly vary the time between two subsequent transmissions.

In the most typical scenario, meters have transmission period scattered throughout the day; by approximation, this phenomenon can be seen as a random variable uniformly distributed over 24 hours. A simple Matlab model has been built, capable of simulating the periodic data transmission coming from a set of meters. Communication takes place according to the following rules: first transmission of each meter is made at random time within the day, the next, with periodicity T, are determined using the de-synchronization system implemented by the standard. Sometimes, due to maintenance or control reasons, concentrator may need to transmit some information to meters, in this case a bidirectional exchange of data may occurs. The abbreviation CMD in the graph of Fig. 4 represents the probability that each day, a data exchange between the concentrator and the meter occurs (the hypothesis is that a sequence of 12 message are exchanged, 6 from the meter to the concentrator and 6 is in the reverse path) . For sake of simplicity, collisions do not require retransmissions.

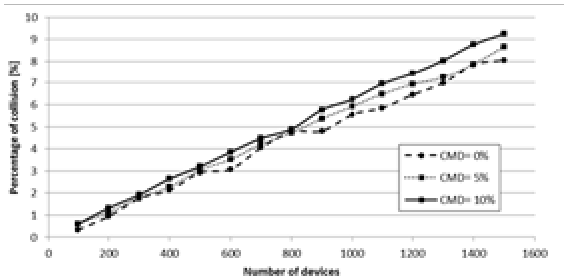

Fig. 4. Percentage of collision in a WMBus network composed by gas (49%), water (23%), heat (7%) and monitoring (21%) meters

Under the above listed hypothesis, the main aspect that influences collision probability is the number of meter in the coverage area of each concentrator. For example, if the maximum acceptable probability error is 5%, no more than 800 devices should be active in the same collision domain. CMD parameter has just a little impact on performance, since collisions are mostly related to the presence of many synchronous messages (due to lack of media access methods).

IV. A CASE STUDY

In order to evaluate how the different network aspects influence each other and to understand what are the network performances of this communication protocol in a multiservice scenario, a model simulating a real network deployment has been created. The model allows the user to configure a set of parameters for each of the drivers that influence the network performances, such as range (e.g., Rx and Tx power and related antenna gains, positioning of the data concentrator, attenuation of obstacles), energy consumption (e.g., type of battery, self-discharging factor, non tx consumptions) and network capacity (e.g., length of data packets, duty cycle, bit-rate, etc.). The parameters can be set and customized for each of the services to be delivered. Due to those different characteristics of each service, the model estimates different "cell" size, according to each service; but when the number of total data concentrator to be deployed for a multiservice network is calculated, the range of the most "difficult" (in terms of radio propagation) service and hence the shortest, is used. On the basis of this range all the other parameters (e.g., collision probability, battery duration, etc.) are estimated.

As an example, in the following list, the results of simulation of a multiservice network (gas, water, heat cost allocators and pollution monitoring) for a small city is shown; the hypothesis is that all the meters are distributed in the city in a uniform way; each of the service have been characterized in terms of propagation aspects, battery and network capacity and in order to reduce the collision probability, 2 different channels have been used. Here the simulation results are presented:

- **Area to be covered:** 20.5 Km^2
- **Data Concentrator (DC) range**: 450m
- **Coverage area of each data concentrator:** 0..64 Km^2
- **Collision Domain**: Ch 2a: 1.20Km^2, Ch 2b: 3.05Km^2
- **# of DC to be deployed**: 32
- **# of meters under each DC**: Ch 2a: 254, Ch 2b: 2983
- **Collision Probability**: Ch 2a: 2.9%, Ch 2b: 7%
- **Battery Duration (years):** Gas: 16 ,Water: 17, Heat: 6, Monitoring: 5

In the case of multiservice, the estimated number of data concentrator is bigger than in the case of gas only network, because heat cost allocator and water meters are even harder than gas to be reached by the radio signal. The probability of transmission errors is critical (up to 7%) even in the case of usage of two different channels. The first outcome of this simulation is that, in order to implement this scenario, either not all the 4 services should use the same network infrastructure, or a more efficient mechanism should be foreseen at physical and MAC layer of the protocol to manage access to the channel and to manage flexible allocation of channels and different data rates.

V. CONCLUSION AND FUTURE WORK

Wireless MBus mode «N» (169MHz) seems to guarantee adequate performance in terms of range when applied to a single metering service with low data rate requirements (e.g., gas, water). The usage of the same communication infrastructure, for additional services, is sustainable only if the additional service does not require high data-rates, if the number of additional sensors is not too big and the sensors do not communicate too frequently. When the number of sensors in the area of the same data concentrator increases from hundreds to thousands, the reliability of the communication decays rapidly. A more flexible management of the physical layer (e.g. carrier sense multiple access with collision avoidance and dynamic management of multiple channels) could limit transmission errors, due to the narrow band of the protocol, only very limited data rate services could co-exist in this network (in this perspective, in recent draft updates of the Italian gas metering standard companion for WMBus, LBT was introduced). In order to guarantee a minimal level of synergy among different services network without limiting too much the range of managed services, a multimode mode network (double frequency band e.g., data concentrators with 868MHz and 169MHz radio) [16] might be a more reasonable tradeoff. Further analysis and test should be done in order to confirm the preliminary results of the study and to evaluate if a scenario where the IoT communication platform can be based on clusters of technologies also exploiting different bandwidths. Those further investigation should also evaluate which bandwidths are the most appropriate for the different kind of services; each cluster of technologies could be based on a specific communication protocol and can provide a set of services (e.g., a cluster based on WMBus 169MHz could enable gas and water metering, insuring longer distance coverage, another cluster based on either 868MHz or 2,4GHz protocols such as ZigBee could enable services that requires more frequent communications, such as parking services) . The different clusters then, could share part of the communication infrastructure in order to reduce costs and to harmonize at least at management level, through a set of standard Application Programming Interface (API), the access to those network clusters.

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Effective Context-based BIM Style Description (BSD) of Query Results

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***Abstract*—The purpose of this study is to develop an effective Building Information Modeling (BIM) query visualization style description and a method for utilizing it based on context. Such BIM would influence usability in visualizing query results according to a user's use case context after querying the objects required from a BIM database. This study proposes a context-based structure for BIM style description (BSD) of query results and a language that defines it effectively. The proposed BSD is demonstrated through a case study, and conclusions are derived.**

Keywords-BIM; Query Language; Context; Visualization Style; BSD.

I. INTRODUCTION

Building Information Modeling (BIM) technology is a 3D-based building object database (DB) modeling and utilization technology specialized for the architecture, engineering, and construction (AEC) industries. BIM can be actively applied to unstructured building designs and building member prefabrication.

Recently, BIM technology has been used to conduct various studies on building Facility Management (FM), Building Automation Systems (BASs), Building Energy Management Systems (BEMSs), and Geographic Information Systems (GISs) for Smart Building and Urban Management (SBUM). This is because problems that cannot be solved by existing FM, BAS, BEMS, and GIS systems could be effectively addressed if 3D building object DB information from the BIM were well converged.

For BIM-based SBUM, BIM DB information must be queried effectively, and the queried results must be visualized according to the use case context for users. In particular, processing and visualizing the queried results according to the use case context can influence the usability of the BIM-based SBUM system. However, few studies related to this area have been conducted because BIM technology is relatively new, and FM, BAS, and BEMS, as well as technologies for integration and utilization of their information have emerged within the last two to three years.

This study proposes a context-based BSD structure that can effectively visualize queried results obtained from the BIM DB by a user according to the use case context, and a language that can define the structure effectively. The proposed BSD is demonstrated through a case study, and conclusions are derived.

Here, context-based BSD refers to a method for displaying queried information effectively in various application contexts based on BIM. For example, in some applications, only important query results among all results are preferred to be displayed on a screen. Furthermore, a representation mode (color, visualization style, etc.) for certain results may be emphasized depending on the context in which a user searches the virtual space. The context-based BSD mode supports these features, so that it can help users to recognize query results effectively in BIM information that includes a large number of BIM objects and make a decision.

We described the content for BSD research as follows.

1.The Introduction section describes research background and motivation.
2.The Study methodology section describes the study workflow.
3.The Related literature review surveys the recent research.
4.The Development of the BSD query result structure section describes the BSD method design.
5.The Implementation case study section develops the prototype to validate BSD.
6.The Discussion section describes the benefits of BSD
7.The Conclusion and future work section explains the results of our study and draws conclusions.

II. STUDY METHODOLOGY

The research scope of this study is the development of a context-based BSD structure. The study's conclusions are derived through case studies.

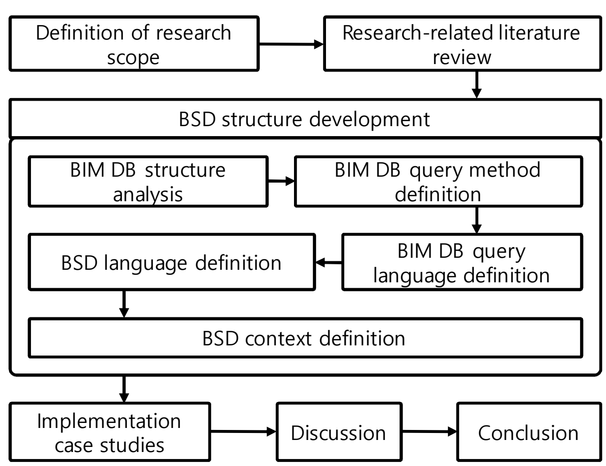


Figure 1. Research flow.

The study method is shown in Fig. 1. The differentiation of this study can be derived by reviewing the research scope and related literature. For BSD structure development, first, the Industry Foundation Classes (IFC)-based BIM DB structure is analyzed, and a simplified BIM query language structure is developed.

Then, the context-based BSD language is defined and conclusions are derived via the implementation of case studies.

III. RELATED LITERATURE REVIEW

Studies related to BIM DB queries were conducted to develop query methods in accordance with their utilization purpose, and they are based on the IFC DB proposed by buildingSMART alliance [8] or on commercial building modeling system DBs, such as Autodesk Revit [11] and Graphisoft ArchiCAD software [12].

Research on object interaction query [1] proposed a Query Volume (QV) method that is specialized for the purpose of building design. Research on automated extraction from and querying of the BIM DB [2] proposed a building component query, location query, and space query for the BIM DB query operations, and implemented them. Research on spatio-semantic consistency checking for the BIM DB [3] proposed a semantically queryable measure for building spaces. Research on the spatial query language [4] defined the operators for space query of GIS and building objects, and developed a viewer that can perform space queries with regard to objects represented by CityGML [9]. Research on construction-specific spatial information [5] proposed a query language that can check constructability from the designed building model information. Another study on the GIS model information representation proposed online mapping [6] using HTML5. In that study, GIS model information was represented graphically using HTML5. In a study on theme-based mapping and graphical representation of GIS model information [7], the direction for the concept of the Extensible Markup Language (XML) theme-based graphic symbol creation and its extension were proposed. Many studies related to this are based on GIS.

The literature review related to the present study shows that most research focused on query methods and language development for building object query, design intention check, space check, and constructability. However, few studies have been conducted on a method for effectively visualizing queried results from the BIM DB according to the use case context, and there is no related tool to perform this. In addition, the development of BIM technology is still underway. Nonetheless, few studies have been done on how to express query results for BIM shape and attributes effectively.

IV. DEVELOPMENT OF THE BSD QUERY RESULT STRUCTURE

A. *Analysis of the BIM DB structure*

The BIM DB in this study is based on the IFC [10]. The IFC is a BIM international standard file format that can represent a building structure as relationships among building objects, such as building, story, slab, floor, column, door, and window. The IFC is stored in EXPRESS or XML mode, and verification rules are defined for each object class in order to conduct object information integrity checks. Recently, buildingSMART presented IFC4 that improved the extendibility of file formats and removed ambiguity.

The IFC can search an entire IFC object hierarchy structure and extract required information using the IfcProject object that defines a building project. Each object can search topological information in relation to the corresponding object through the IfcRelationship of the IfcObjectDefinition. The IfcRelationship is redefined as it is derived into classes of IfcRelAggregates or IfcRelContainedInSpatialStructure, depending on the type of relationship with the objects. These classes represent whole/part and reference relationships between objects. The relationships that are used most to search the IFC objects are Relating/Related, Decomposed, Contained, and Referenced.

The building space and member objects have an inclusion relationship with each other. For example, IfcBuilding that includes IfcProject includes an aggregate relationship of IfcBuildingStorey using the IfcRelAggregates object. Conversely, IfcBuildingStorey references objects, in which they are included, as an inverse relationship (INV). IfcBuildingStorey manages IfcProduct using the relationship object called IfcRelContainedInSpatialStructure. Fig. 2 shows the IfcBuilding class relationship.

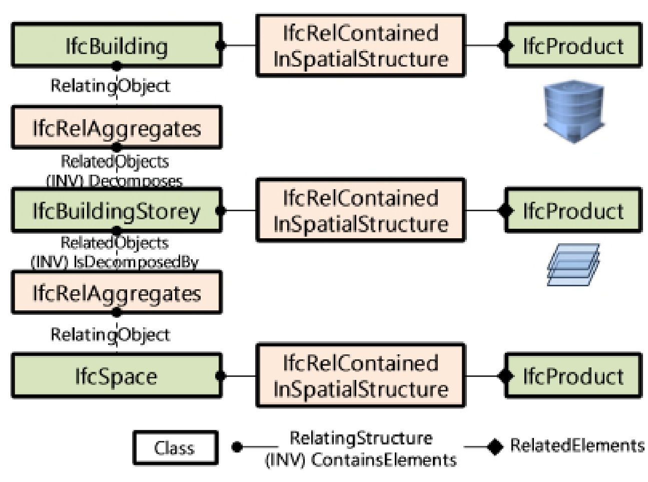


Figure 2. IfcBuilding classes relationship [10]

The IFC stores building information as shape information and attribute information. The shape information is recorded in boundary representation (B-Rep) format or parametric-based primitive format. If the IFC

 ISBN: 978-1-61208-363-6

shape information is analyzed, space-based objects can be queried.

The attribute information is provided via IfcPropertySet in association with objects. An object can be related to multiple attribute sets. IfcPropertySet has IfcProperty which manages individual attributes. Therefore, an attribute value of a particular object can be acquired via access to IfcProperty; in addition, an object with a specific attribute value can be searched.

In IFC2x3, the IFC structure consists of more than 700 classes based on extendibility. This is highly complex because it defines relationships between classes semantically. In this paper, the Simple BIM (SBIM) DB structure shown in Fig. 3 was designed to make querying of IFC DB information more convenient.

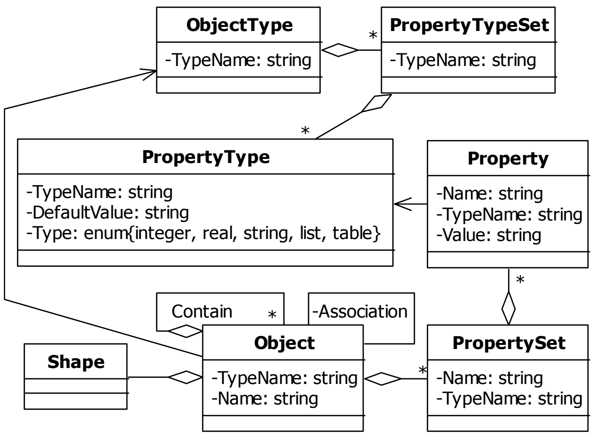


Figure 3. Simple BIM DB architecture.

B. Definition of the BIM DB query method

For a BIM DB query, IFC is parsed to be stored in the simple BIM DB structure. Building classes such as slab, wall, and window are mapped to objects, whereas types of building classes are mapped to ObjectType. A Whole/Part structure of an object is represented by a Contain Relationship. Other relationships can be represented by an Association Relationship.

Since Object classes and ObjectType classes have a Dependency relationship, a specific building element can be queried. In addition, Object classes include PropertySet classes such that objects with a specific attribute value can be searched. Searching according to object relationships can be done using the Contain and Association relationships. Fig. 4 shows the BIM DB query process, including BSD processing.

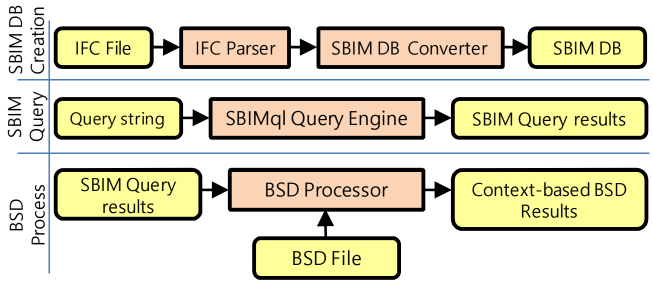


Figure 4. BIM DB query process.

C. Definition of the BIM DB query language

In this study, Simple BIM DB Query Language (SBIMql) is developed to define an information query format for SBIM DB. SBIMql uses a token analyzer and a parser generator such as LEXical analyzer (Lex) or Yet Another Compiler Compiler (YACC) in order to check syntax errors automatically. The language structure is defined as being similar to that of Structured Query Language (SQL). The SBIMql definition for YACC is as follows:

```
Variable
   : PROPERTY_NAME

Value
   : STRING

ConditionOP
   : '=' | '<' | '>' | '<=' | '>='

Func
: IsIn
| IsCross
| IsOut

SimpleExpression
: Variables ConditionOP Value

LogicOp
: 'AND'
| 'OR'

Expression
: SimpleExpression
| SimpleExpression LogicOp Expression
```

Using SBIMql, the following query can be defined syntactically.

```
SELECT * FROM IfcObject WHERE
     Type=IfcWindow AND Name='Window xyz'
```

Figure 5. SBIMql process algorithm.

The semantics of this query statement is for querying all the objects of Type IfcWindow and the Name attribute value of Window xyz. Fig. 5 shows the algorithm of the SBIM query engine that processes SBIMql.

D. Definition of the Context-based BSD structure

In order for a user to recognize query results effectively, it is highly important to support features that provide color schema according to attribute values based on the use case context while visualizing the query result. It is also important to emphasize specific objects and specific values of objects, which influences usability directly. To implement this feature, context-based BSD language is defined to display SBIMql query results effectively based on the use case context. The BSD must support a variety of use case contexts for users.

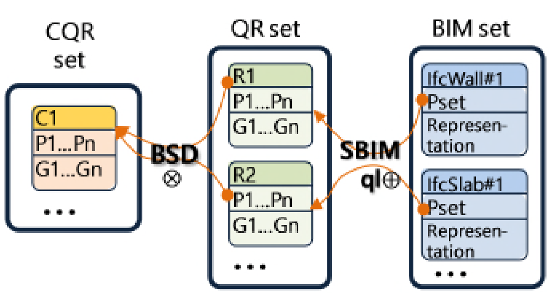


Figure 6. Set Mapping from QR to CQR.

The issue described in the previous paragraph can be defined as a problem of mapping elements in the query results (QR) set into the context-based QR (CQR) described by the context-based BSD, as shown in Fig. 6. As can be seen from Fig. 6, BSD plays a role as a conversion function between sets.

The BSD consists of a number of BIM styles (BSs) of query results that define the view style of the query result. Depending on the context in which the BS is applied, an attribute and shape style are applied to the BS. The context consists of specific style application conditions under which the style is applied. The condition has filters that define detailed conditions to process the attribute or shape styles in accordance with the context. The attribute style defines how to represent the attribute values in the query result to a user, whereas the shape style defines the materials that are used to visualize the object shape in the query result. The material can define color, transparency, and texture. For example, if the context is a space program, the color schema can be developed and applied accordingly. Table 1 describes the context-based BSD definition.

$$BSD = \{BS*\}, BS = \{BS_{Arg}, C*\}, \quad (1)$$

$$BS_{Arg} = \{Ctx, Desc\}, Ctx = Context, Desc = Description, \quad (2)$$

$$C = \{C_{Arg}, F*\}, C_{Arg} = \{T, N\}, \quad (3)$$

$$F = \{F_{Arg}, L\}, F_{Arg} = \{Var, V, V_{From}, V_{To}\}. \quad (4)$$

TABLE I. CONTEXT-BASED BSD DEFINITION

Element	*Description*
BSD	BIM query results Style Definition
BS	BIM Style Definition
BS_{Arg}	Arguments of BIM Style like below Ctx = Context name Desc = Description
BS_{Arg}	BIM Style Definition Arguments
Ctx	BSD Context Definition
Desc	BSD Description
C	BSD Context Condition Definition
C_{Arg}	BSD Context Condition Arguments
T	Context-based Condition Type
N	Context-based Condition Name
F	Context-based Condition Filter Definition
F_{Arg}	Filter Arguments that have a variable, value, and equation.
L	BSD Condition Logic script to describe the BIM Property and Geometry Transformation depending on Context
Var	Context-based Condition Filer Variable such as Type, DistanceFromCameraToObjectCenter and OrderIndex
V	Filter Variable value
V_{From}	'From value' to evaluate the Filter condition
V_{To}	'To value' to evaluate the Filter condition

Fig. 7 shows the algorithm related to rendering the query results considering BSD.

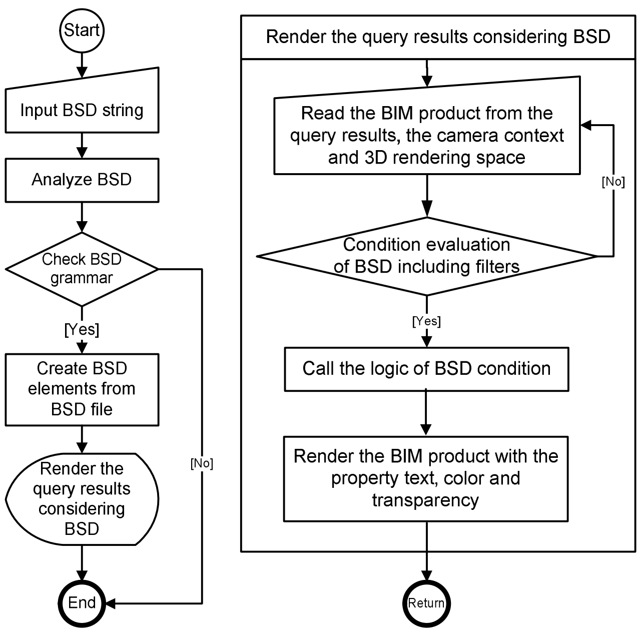


Figure 7. BSD process algorithm.

Fig. 8 shows the BSD elements class diagram. It consists of conditions which can contain the filters. The filter contains the other filter or the logic to represent how to render the queried BIM product. The filter consists of Var, V, V_{From}, and V_{To} to evaluate the condition. This logic can be executed when the condition including the filters is satisfied.

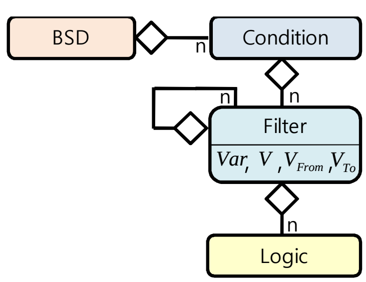


Figure 8. BSD elements class diagram in Unified Modeling Language (UML).

The following code is an XML definition example to visualize the BIM query information in the context of the Space Program Management using the proposed BSD.


```
<BSD>
 <BS Context="Facility management"
      Desc="Information highlight">
   <Condition Type="Property" Name="Length of object">
    <Filter Var="Type" Value="IfcWallStandardCase">
      <Filter Var="DistanceFromCameraToObjectCenterPosition"
           FromValue="0" ToValue="10">
        <Logic>
           Value = string.format("Length of %s = %.2f",
               Property.PSet("Name"), Property.PSet("Length"))
           TextHeight = 30.0 -
               DistanceFromCameraToObjectCenterPosition
        </Logic>
      </Filter>
    </Filter>
   </Condition>
   <Condition Type="Geometry" Desc="Object highlight">
    <Filter Var="Type" Value="IfcWallStandardCase">
      <Filter Var="SortIndex" Value="0">
       <Logic>
        Color = RGB(0.0, 1.0, 1.0, 1.0)
       </Logic>
      </Filter>
    </Filter>
   </Condition>
   <Condition Type="Geometry" Desc="Transparent schema">
    <Filter Var="Type" Value="IfcWallStandardCase">
      <Filter Var="DistanceFromCameraToObjectCenterPosition"
           FromValue="0" ToValue="10">
        <Filter Var="SortIndex" ValueFrom="1"
             ValueTo="infinite">
         <Logic>
          Ratio = (QR.Count - SortIndex) / QR.Count
          Color = RGB(0.0, 1.0, 0.0, Ratio)
         </Logic>
    </Filter></Filter></Filter>
  </Condition>
 </BS>
</BSD>
```


V. IMPLEMENTATION CASE STUDY

SBIMql and the BSD were implemented using the open-source eXtensible Building Information Modeling (xBIM) Toolkit for this case study via the context-based BSD implementation. Note that xBIM is an open-source-based software development BIM tool that supports IFC read-and-write as well as mesh processing using Open CASCADE, and visualization via a 3D rendering engine for IFC shape visualization.

Fig. 9 shows a result that performs the SBIMql query statement "SELECT * FROM IfcWallStandardCase WHERE IfcWallStandardCase.Length > 5000." Fig. 9 shows the model before (above) and after (below) the SBIMql query.

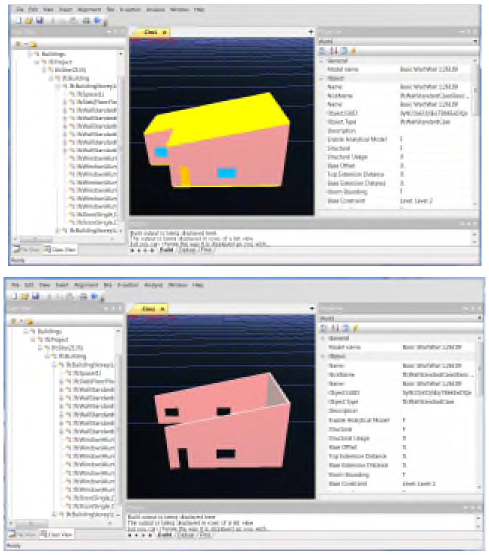


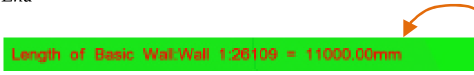
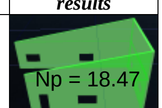
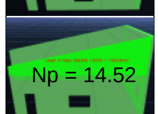
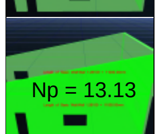
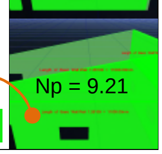
Figure 9. SBIMql query and results.

The following code shows the result of applying the context-based BSD according to the use case context. It was verified that the query result was effectively visualized using the BSD according to the use case context.

```
SELECT BSD(*, 'Context-based BSD.xml') FROM IfcWallStandardCase WHERE IfcWallStandardCase.Length > 5000' ORDERBY IfcWallStandardCase.Length
```

Table 2 lists the BSD results for how the SBIMql-processed result can be different depending on the context condition.

TABLE II. CONTEXT-BASED BSD RESULTS

Context-based BSD Condition and BSD Logic Script	***SBIMql+BSD results***
Var = DistanceFromCameraToObjectCenterPosition Np = Near distance from camera to object center position *If* $(0 \le Var < 15)$ → Value = string.format("Length of %s = %.2fm", Property.PSet("Name"), Property.PSet("Length")) TextHeight = 30.0 - DistanceFromCameraToObjectCenterPosition Color = RGB(0.0, 1.0, 0.0, 0.8) *Else* → Value = "" Color = RGB(0.0, 1.0, 0.0, 0.3) *End* 	

Context-based BSD Condition and BSD Logic Script	***SBIMql+BSD results***
Var = *SortIndex* *If* $(Var = 0)$ → Color = RGB(1.0, 1.0, 0.0, 0.0)	
Var = *SortIndex* *If* $(0 \le Var < \inf)$ → Ratio = (QR.Count - SortIndex) / QR.Count Color = RGB(0.0, 1.0, 0.0, Ratio)	
Var = *Length* *If* $(0 \le Var < 10000)$ → Color = RGB(0.0, 1.0, 0.0, 1.0) *If* $(10000 \le Var < 12000)$ → Color = RGB(0.0, 1.0, 1.0, 1.0) *If* $(12000 \le Var < 15000)$ → Color = RGB(0.0, 0.0, 1.0, 1.0) *If* $(15000 \le Var < \inf)$ → Color = RGB(1.0, 0.0, 1.0, 1.0)	

VI. DISCUSSION

To evaluate the usability of the BSD, a five-point scale Likert survey was conducted with three BIM practitioners and three ordinary persons by asking them how much they understood the query intentions after showing the results of SBIMql and SBIMql+BSD.

TABLE III. CONTEXT-BASED BSD RESULTS

Usability Item	***SBIMql***	***SBIMql+ BSD***	***Difference***
Understanding (U) – easy to understand the query result.	1.7	3.7	2.0
Search (S) – required objects can be searched quickly.	1.7	4.0	2.3
Recognition (R) – information on the screen can be recognized comfortably.	1.7	3.7	2.0

The interview participants provided positive answers for the BSD usability, shown in Table 3, which distinctively demonstrate the difference between the two groups of SBIMql and BSD. Particularly, respondents recognized that the improved ability to search for a needed object within the queried objects results set.

The participants suggested that an increased variety of operators is required for the BSD, and that more improvements are needed in terms of queries on the BIM objects and BSD processing performance. There were the discussions related to BSD results such as the meanings and effects as described below.

First, there are meanings when the BSD is used for the object classification between the BIM products which have similar shapes but different property values.

Second, the query results can be understood as representing an object by using BSD intuitively. It is possible to validate the query results regardless of whether the search result is correct.

Third, the BSD can be used to represent the color schema depending on the property value of the BIM product.

Forth, the query results can be visualized considering the navigation context including the variables such as the camera distance from the observed object in the 3D rendering space.

However, there were some issues as described below.

First, if there are many objects in a BIM model, it seems that the BSD query process performance is slow. In case of this, it is necessary to improve the performance.

Second, the various BSD operations such as "touch", "in", and "out" between BIM products are needed to represent the query results considering the model space context.

In addition, to satisfy the suggested opinions, optimization and efficient space indexing for SBIMql and BSD processing are required.

VII. Conclusion and Future Work

For context-based BSD structure development, the IFC-based BIM DB structure was analyzed, and a simplified BIM query language structure was developed. The BSD proposed in the implementation case study showed the feasibility of visualizing query results based on the use case context of a user.

By using the proposed BSD method, tools that can increase the usability of query results can be provided to the AEC industries according to various use case contexts, such as SBUM.

The survey results cannot be verified statistically, because the number of the samples was small, which is the limitation of this study. This limitation will be overcome in the subsequent study. Moreover, we will extend the mapping operators for the proposed BSD and study how to analyze the information graphically in the future.

Acknowledgment

This research was supported by a grant from the "BIM/GIS Platform-based Construction Spatial Information Integration Operation Technology Development" project, which is one of the main projects in 2014 of the Korea Institute of Construction Technology.

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A Combination of MCLT Peak-Pair Based Audio Fingerprinting and Spatial Audio Reproduction

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***Abstract*—This paper proposes a spatial audio reproduction system connected with the audio fingerprinting for providing an immersive experience to the music user. The proposed system combines the audio fingerprinting and the spatial audio processing. In the proposed system, a salient audio peak-pair fingerprint based on modulation complex lapped transform improves the accuracy of the audio fingerprinting in real noisy environments and spatial audio using diffusion metadata gives a listener a sensation of being listening to the sound in the space, where the sound is actually recorded.**

Keywords-audio fingerprinting; spatial audio reproduction; diffusion metadata; modulation complex lapped transform

I. INTRODUCTION

Recent advances in computation, displays, and networking technology have brought about many new interactive multimedia applications. Most of these applications strive to provide an immersive experience to the user, e.g., improve image quality by providing high resolution displays, improve audio quality by providing three-dimensional audio spatialization system, improve responsiveness by adopting powerful CPU/GPUs, enlarging network bandwidth and shortening network delay, improve system robustness by having quality monitoring and management, content-based multimedia information retrieval, security solutions, etc.

Thanks to these technology advances and trends, digital music has evolved in the form of new services. Recently, technologies of music identification and spatial audio reproduction have received wide attention independently of each other.

Audio fingerprinting techniques [1] are meant for successfully performing content-based audio identification even when audio signals are distorted. Common uses include query-by-example music or advertisement identification [2] [3], broadcast monitoring [4], copyright detection, and automatic audio content library organization [4][5]. A good fingerprint should capture and characterize the essence of the audio content. More, specially, the quality of a fingerprint can be measured in four dimensions: discriminability, robustness, compactness and efficiency.

Various methods [6] have been proposed to satisfy several practical requirements for a successful audio fingerprinting system. Among various algorithms, the system developed by Wang [7] has been considered as a commercially successful and widespread work. Besides, the robust hash algorithm proposed by Haitsma et al. [5] is also a well studied content-based music identification or retrieval technique. In practice, it still needs further improvement to be used in a real environment.

Spatial audio-related techniques [8] in general attempt to deliver the impression of an auditory scene where the listener can perceive the spatial distribution of the sound sources as if he or she were in the actual scene. The audio spatialization system renders a virtual sound image in order for the listener to feel as if the signals were emitted by a source located at a certain position in 3D space [9][10]. Either headphones or a small number of loudspeakers (two in our system) can synthesize such spatialized audio effects, though the latter is often more appealing in immersive applications since it does not require the user to wear headphones.

Spatial audio has been developed for many years by reproduction techniques such as ambisonics [11], wave field synthesis [12], amplitude panning [13], and binaural synthesis [14]. The wave field synthesis renders a whole sound field to the room through a large number of loudspeakers. Nevertheless, such a solution is expensive and non-scalable. Ambisonics and amplitude panning are widely used panning techniques. In both methods, the virtual sound source is rendered at various locations by controlling the output amplitude of the loudspeakers. When two loudspeakers are available, however, they can only reproduce virtual sources in the line segment between loudspeakers. In addition, results degrade significantly if the user gets closer to one of the two loudspeakers. Binaural synthesis is capable of placing the virtual sound beyond the loudspeakers' boundaries due to the use of the head related transfer functions (HRTF) that faithfully represents the transfer function between the sound sources and human ears.

Until now, audio fingerprinting and spatial audio coding techniques have been developed independently of each other.

In this paper, we propose a spatial audio reproduction system connected with the audio fingerprinting for providing an immersive experience to the music user. The proposed approach used in this paper has two advantages: (1) The proposed algorithm improves robustness of the audio fingerprinting in various noisy environments; (2) The spatial audio encoding and reproduction of diffuse sound delivers

 ISBN: 978-1-61208-363-6

high spatial impression in multichannel surround sound systems.

This paper is organized as follows. Section II describes our proposed method. Section III discusses the experimental results. Finally, section IV presents our conclusion.

II. THE PROPOSED SYSTEM

The proposed system using a combination of audio fingerprinting and spatial audio reproduction is illustrated in Figure 1.

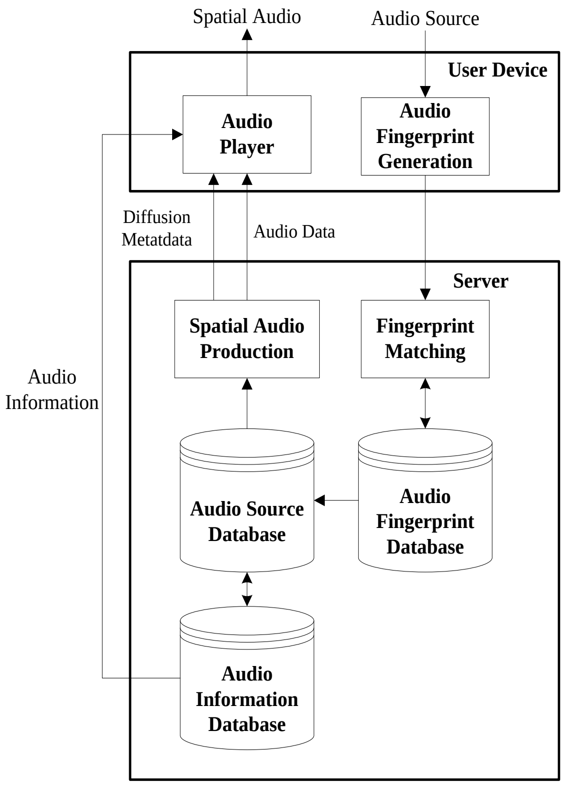

Figure 1. Block diagram of the proposed system.

The system is comprised of several modules: audio fingerprint generation, fingerprint matching, spatial audio generation, and spatial audio playback.

First, a fingerprint client, such as portable consumer device captures an audio clip that is a few seconds-long, and then extracts a robust fingerprint and submits it to the server. The extracted fingerprint is then used to query the audio fingerprint database and is compared with the stored fingerprints. If a match is found, the resulting track identifier is retrieved from the audio source database and used again as query for searching user reviews in the audio information database. If the user wants to hear the retrieved music, audio tracks are compressed and transmitted from the server to the user device in connection with synchronized spatial metadata representing diffusion and preferably mix and delay parameters. The separation of audio stems from diffusion metadata facilitates the customization of playback at the receiver, taking into account the characteristics of the local playback environment.

A. *MCLT peak-pair based audio fingerprinting*

For the robust fingerprint extraction against noise and distortion, we propose to use modulation complex lapped transform (MCLT) [16] based peak-pairs. MCLT is a cosine-modulated filter bank that maps overlapping blocks of a real-valued signal into complex-valued blocks of transform coefficients. Thus, MCLT basis functions are found in pairs to produce real and complex parts separately. These basis functions are phase–shifted versions of each other. Since MCLT has approximate shift invariance properties

As shown in Figure 2, the robust MCLT peak-pair-based fingerprint extraction method is composed of six main blocks.

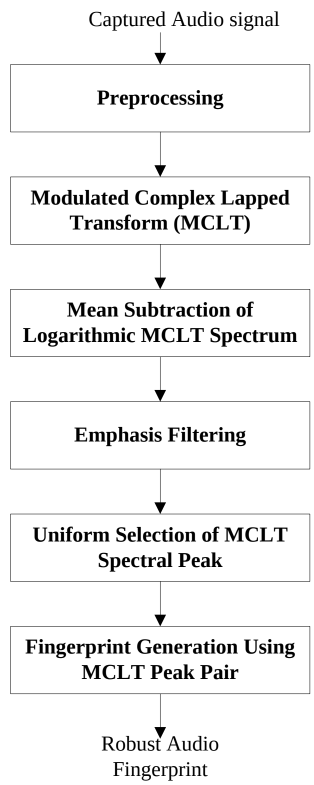

Figure 2. Block diagram of the robust audio fingerprint extraction.

First, a stereo audio signal captured by a user's mobile phone is converted into mono and then downsampled to 16 kHz. The converted signal is divided into overlapping frames by the application of a Hanning window function (each of which contains 512 overlapped samples). In order to find the spectral peaks, an MCLT is then applied to each frame (1024 samples), given by

$$S_{MCLT}(k,l) = \sqrt{V(k,l)\cdot V(k,l) + V(k+1,l)\cdot V(k+1,l)} \quad (1)$$

using

$$V(k,l) = b(k,l)\cdot U(k,l), \quad (2)$$

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$$U(k,l) = \sqrt{\frac{1}{2N}} \sum_{n=0}^{2N-1} x(n + lM) h(n) \exp\left(\frac{-j2\pi kn}{N}\right), \quad (3)$$

$$b(k,l) = W_8(2k+1,l) \cdot W_{4K}(k,l), \quad (4)$$

$$W_T(r,l) = \exp\left(\frac{-j2\pi r}{T}\right) \quad (5)$$

where k is the frequency bin index, l is the time frame index, h is an analysis window of size N, M is the framing step, and $U(k,l)$ is the normalized $2N$-point FFT of input audio signal.

A log spectrum is generated by taking the log modulus of each MCLT coefficient. From the logarithmic MCLT spectrum, a frequency-time averaged MCLT spectrum is calculated and subtracted, thus yielding a normalized logarithmic MCLT spectrum.

To increase the local spectral peaks of high frequencies against attenuation distortion, an emphasis filter is applied to each normalized logarithmic MCLT spectrum.

The emphasis-filtered MCLT spectral peaks are fed into a uniform selection step shown in Figure 3, where the salient peaks are selected by applying appreciative forward and backward filtering using a dynamic peak-picking threshold.

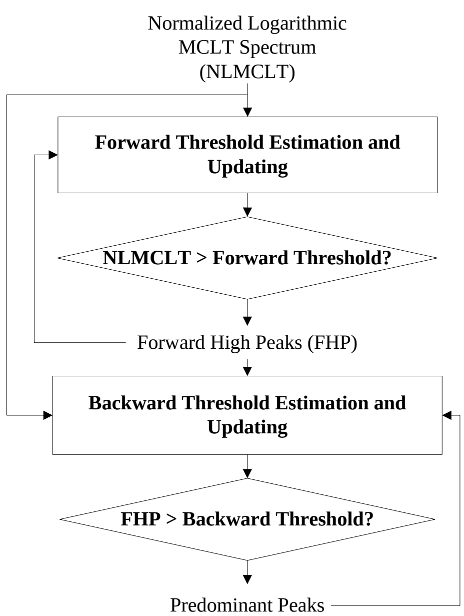

Figure 3. Block diagram of forward and backward filtering.

In a local target area of the frequency-time plane, nearby salient MCLT peaks are combined into a pair or landmark. Landmarks are 4-tuples of the start time, start frequency, end frequency, and time difference, and are converted into hashes with a start time.

Assuming that $P_b(k_a,l_a)$ is the anchor point and paired with another landmark point $P_b(k_p,l_p)$, its landmark L is obtain by:

$$L = (l_a, k_a, k_p, l_p - l_a) = (l_a, \Delta k, \Delta l) \quad (6)$$

All k (in frequency bins) and l (in frames) are integers with a fixed higher bound, so each landmark point generates a fixed number of pairs. Due to the horizons, Δl is limited to a lower value than l_p.

And then, k_p, l_p and Δl are combined into a 32-bit hash

$$hash = k_a \cdot 2^{(m+n)} + \Delta k \cdot 2^n + \Delta l \quad (7)$$

using

$$m = \log_2 \Delta k \text{ and } n = \log_2 \Delta l \quad (8)$$

The robust fingerprint generated in consumer devices is submitted to the server for content-based identification.

When building the audio fingerprint database at the server, a database index is created by a fingerprint hash, and a track ID and time offset of the hash are stored according to the hash value to facilitate fast processing.

In retrieval or identification processing, the similarity searches of audio are performed in the fingerprinting domain. A query signal is fingerprinted in the user's mobile phone, and the resulting hashes are compared against the hashes stored in the database hash table. After the entire matching hashes are found, a candidate set of match segments can be obtained by combining the track ID stored in the database and the time offset of the hash in the query audio. If the files match, matching hashes should occur at similar relative offsets from the beginning of the matching file.

B. Spatial audio generation and playback

One of the primary objectives of spatial audio reproduction technique is realistic perception of the delivered contents by the consumer. The structure of our system is based on Jot's approach [16], which processes multi-channel audio by encoding, transmitting or recording audio tracks in synchronous relationship with time-variable metadata controlled by a content producer and representing a desired degree and quality of diffusion.

The spatial audio reproduction system is mainly divided into two blocks: spatial audio generation in the server side and spatial audio playback in the receiver side.

1) Spatial audio generation

Figure 4 is a system level schematic diagram of the spatial audio generation and encoding aspect.

Audio source data are converted into digital audio signals by multi-channel microphone apparatus. A metadata production engine processes the audio signal data under control of mixing, acoustic reflections, perceived direction and distance of signals via input device using multi-channel microphone apparatus, monitoring decoders, and monitoring speakers.

The metadata generated by the metadata production engine includes a representation of reverberation parameters, mixing coefficients, and inter-channel delay parameters. The metadata will be time varying in increments with the frame metadata pertaining to specific time intervals of the corresponding audio data. The time-varying audio data is encoded by a multichannel spatial audio encoder [17], to produce the encoded audio data in a synchronous relationship with the corresponding metadata pertaining to the same times.

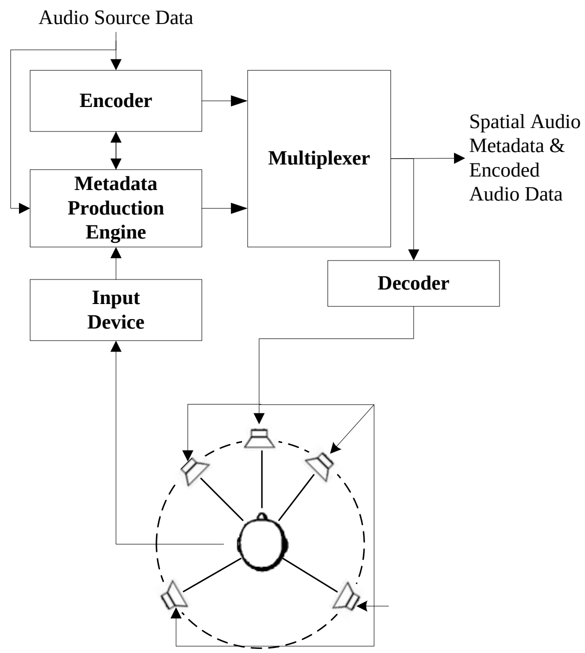

Figure 4. Block diagram of spatial audio generation.

Both the metadata and the encoded audio signal data are multiplexed into a combined data format by multi-channel multiplexer and transmitted to the spatial audio playback module of the user device. In order to permit monitoring during the production process of the spatial audio metadata, the monitoring decoder demultiplexes and decodes the combined audio stream and metadata to reproduce a monitoring signal at speakers. The monitoring speakers are arranged in a standardized arrangement such as ITU-R BS 775. The monitoring system allows a listener at the user device to perceive the effect of the metadata and the encoded audio.

2) Spatial audio playback

Figure 5 is a system level schematic diagram of the spatial audio decoding and playback aspect.

The metadata decoder receives and separates the encoded, transmitted data in a multiplexed format into metadata and audio signals data. The spatial audio decoder [17] receives the encoded audio signal data and decodes it by a method and apparatus complementary to that used to encode the data. The decoded audio is organized into the appropriate channels and output to the environment engine. The environment engine includes a diffusion engine in series with a mixing engine and operates in a multi-dimensional manner, mapping N inputs to M outputs.

The diffusion engine conditions N channel digital audio from the decoder in a manner controlled by and responsive to the metadata to add reverberation and delays, thereby producing direct and diffuse the audio data in multiple processed channels. The multiple processed channels are then mixed in a mixing engine to produce mixed digital outputs. The mixing engine mixes the N audio input channels by multiplexing and summing under control of a set of mixing control coefficients to produce a set of M output channels for playback in a user device.

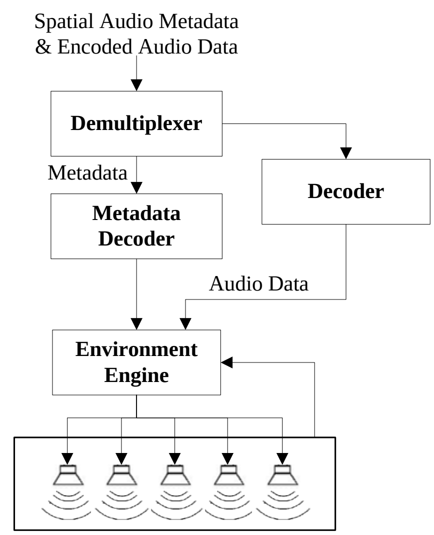

Figure 5. Block diagram of spatial audio playback.

A dedicated diffuse output from the mixing engine is differentiated for reproduction through the dedicated diffuse radiator speaker.

The multiple audio channels are then converted to analog signals, amplified by amplifiers. The amplified signals drive an array of speakers in a listening environment.

III. EXPERIMENATAL RESULTS

In this subsection, the performance of the proposed MCLT peak-pair fingerprint extraction algorithm is evaluated. Additionally, the performance of the algorithm is compared with the modified implementations of three previous methods. Method 1 is an STFT-based peak-pair fingerprint extraction method proposed by Wang [7], while Method 2 is an audio fingerprint extraction based on the masked audio spectral keypoints [18]. Method 3 is a local feature extraction from adaptively scaled patches of the time-chroma representation of the audio signal [19].

For experiments, two test database types were selected: (1) Set I consists of a database of 7,000 songs from different genres such as pop, hip-hop, jazz, and classical. (2) Set II is a database containing 4,000 TV advertisements with total time amounting to 740 hours, and each advertisement ranging from 10 to 15 minutes in length. All of the audio data are stored in PCM format with mono, 16-bit depth, and 16 kHz sampling rate converted from real audio data in consideration of portable devices such as mobile phones. Audio query clips with lengths of two, three, four, and five seconds were captured using mobile phone, which was placed 5 meter from a 2.1-channel loudspeaker connected to a TV. With the randomly created 3,000 queries, query sets are created by adding various types of noise of different levels. Five different types of noise (babble noise, moving car noise, white noise, street noise, and computer fan noise) have been artificially added to different portions of the database at signal-to-noise (SNR) ratios ranging from clean to 12 dB, and 6 dB.

Table I depicts the experimental results of the four methods when a 5-second-long query from Set I was used. MW, MC, MX, and MCLT denote Method 1, Method 2, Method 3, and the proposed method, respectively. The recognition results under the five different noisy environments are averaged for the evaluation.

TABLE I. COMPARATIVE PERFORMANCE FOUR SCHEMES WITH SET I.

SNR	Averaged Recognition Rate (%)			
	MCLT	**MW [6]**	**MC [7]**	**MX [8]**
clean	97.3	95.5	94.8	93.5
12 dB	96.8	93.7	89.6	78.9
6 dB	93.6	88.4	77.5	63.8
0 dB	80.7	73.6	61.7	57.6
Total	92.1	87.8	80.9	73.5

As shown in Table I, the best recognition accuracy was 97.3% for query-by-example music identification, which was obtained with the proposed MCLT. The recognition rate of MW was slightly lower than those of MCLT. MX yields the lowest identification rate, and provides worse results at SNR 0 dB.

Table II presents the results of the advertisement identification performed on a Set II database.

TABLE II. COMPARATIVE PERFORMANCE FOUR SCHEMES WITH SET II.

SNR	Averaged Recognition Rate (%)			
	MCLT	**MW [6]**	**MC [7]**	**MX [8]**
clean	95.5	93.6	93.5	92.6
12 dB	94.3	90.5	86.2	75.4
6 dB	91.6	85.4	74.6	60.2
0 dB	77.5	70.8	58.5	53.4
Total	89.7	85.1	78.2	70.4

As shown in Table II, the recognition accuracies for advertisement identification are not better than those of Table I for music identification, because some advertisements in Set II contain silent segments. The query was captured frequently from the silent segments and used for the matching. Also, the proposed MCLT yields better performance than MW, MC, and MX.

Table III shows the recognition performance of the MCLT scheme for when the query length was changed.

TABLE III. PERFORMANCE EVALUATION ACCORDING TO QUERY LENGTH.

SNR	Averaged Recognition Rate (%) By Query Length			
	2 sec	**3 sec**	**4 sec**	**5 sec**
clean	76.8	91.5	95.1	97.3
12 dB	71.5	90.7	94.3	96.8
6 dB	63.3	84.7	91.8	93.6
0 dB	55.6	76.5	81.7	80.7
Total	66.8	85.9	90.7	92.1

This result shows that the performance increases as the length of the query increases. Also, the proposed scheme shows satisfactory performance with 4 and 5-second-long queries, showing a recognition rate above 90%.

Figure 6 presents the simulation results of the spatial audio generation and playback.

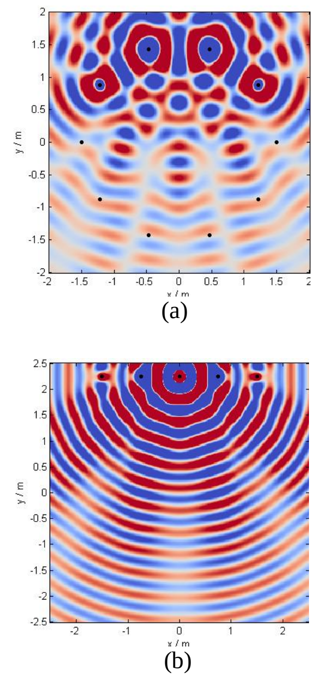

Figure 6. Simulation results of the spatial audio generation and playback.

Figure 6 (a) shows the simulation result of the spatial audio effects, when 10 speakers are arranged in a circle. Figure 6 (b) depicts the simulation result of the spatial audio effects, when 5 speakers are arranged in a line.

We performed a Mean Opinion Score (MOS) test on music quality. The listening tests were arranged in an acoustically isolated listening room. A total of 12 listeners participated in the test. The MOS scores for music playback are in the range of “excellent” to “good”.

IV. CONCLUSIONS

In the new combination of the audio fingerprinting and spatial audio reproduction, the MCLT peak-pair based audio fingerprint improves the accuracy of the audio fingerprinting system in a real noisy environment. And spatial audio reproduction on the multi-channel loudspeaker setup improves the realism of the spatial sound experience.

ACKNOWLEDGEMENT

This research was supported by the MSIP(Ministry of Science, ICT & Future Planning), Korea, under the ITRC(Information Technology Research Center) support program (NIPA-2014-H0301-14-1019) supervised by the NIPA(National IT Industry Promotion Agency)

This research was supported by Basic Science Research Program through the National Research Foundation of Korea (NRF) funded by the Ministry of Education, Science and Technology (NRF-2013R1A1A2007601)

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 ISBN: 978-1-61208-363-6

Energy Monitoring in Smart Buildings Using Wireless Sensor Networks

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***Abstract*—In this work, we present the implementation and deployment of a wireless sensor network for the monitoring of electric energy uses in smart buildings. This wireless sensor network is based on our newly-developed *Granular Radio EnErgy-sensing Node* (GREEN), which consists of a micro-controller, a radio, a battery and a giant magnetoresistive (GMR) magnetic field sensor. The GREEN node can be easily attached to a current-carrying conductor for proximity-based electric current measurement. The intent of this article is to fully disclose the information regarding the design, fabrication and implementation of this GREEN-based wireless sensor network used as an electric energy monitoring system. It should be noted that the wireless sensing platform is not limited to energy monitoring, but can also be well adopted in other applications and deployment settings.**

***Keywords*–Smart Building, Wireless Sensor Networks, Energy Sensing**

I. Introduction

Energy efficiency in smart buildings relies on a reduction in overall usage and also Demand Response (DR) to offset non-essential peak energy usage. These economic goals then depend on information about the energy usage of individual appliances. Retrofitting existing systems for commercial buildings and households requires that voltage and current sensing devices be as non-intrusive as possible for ease of integration and ease of deployment. Presently, buildings are retrofitted by installing clamp-on submeters into circuit breaker panels to monitor the electricity usage in each individual circuit. However, the installation of such systems is very expensive as it requires the use of certified electricians and a scheduled shutdown of electrical services. In our previous work [1], [2], we proposed a stick-on submetering system that allows the electric currents going through the circuit breakers to be measured from multipoint magnetic field measurements on the surface of breaker panels (also see in Fig. 1). Since the sensors can be easily attached on the surface of panels, the installation cost of this system is one-tenth the cost of any clamp-on meters. There are many commercially available wireless platforms [3], [4], [5], [6], [7] that can be used to establish a wireless sensor network for transmission of data collected from the circuit breaker stick-on sensors. However, as the available space on the circuit breaker panels is often limited, the footprint of the entire wireless sensor node is desired to be as small as possible and none of the commercial platforms has so far met this requirement. Therefore, a compact wireless sensor node, called “The Granular Radio EnErgy-sensing Node (GREEN)” was designed and fabricated. With a footprint of only $1cm^2$, it allows for easy installation and more accurate placement, which in turn allows for increased granularity of measurements of the electric currents [8]. This paper presents complete information on the operation and programming of the nodes. It can be seen that they can be used widely in smart building applications and many other “smart environments”. The remainder of the paper is structured as follows, Sec. II presents the specific wireless technology that we’ve developed for the smart buildings. In Sec. III, we describe the wireless sensor networks and the lightweight mesh networking. In Sec. IV, we show an example of the wireless monitoring and the stack of prototypes it employs to transmit the data. Lastly, in Sec. V, we summarize our findings and show directions of future work.

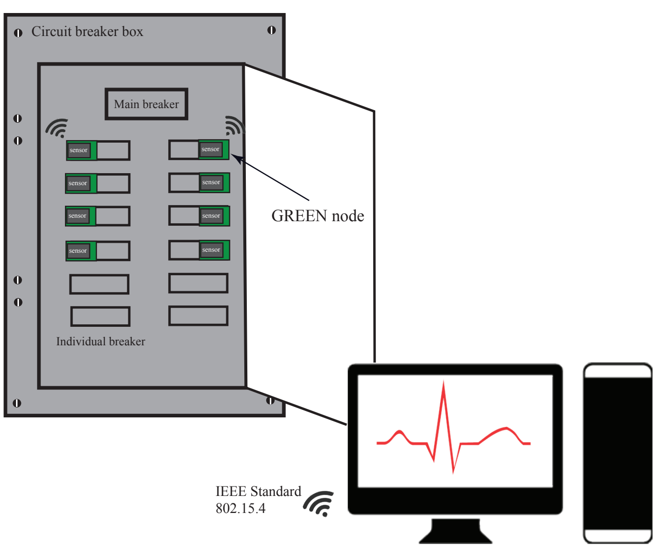

Figure 1: Schematic of a GREEN-based stick-on electricity monitoring systems for circuit breaker panels.

II. Specific Technology to Support Smart Buildings

Granular Radio EnErgy-sensing Node (GREEN, see Fig. 2) is a $0.56cm^3$ wireless stick-on node for non-intrusive energy monitoring applications [3]. Our target application is to wirelessly monitor the electricity usage from electrical circuit

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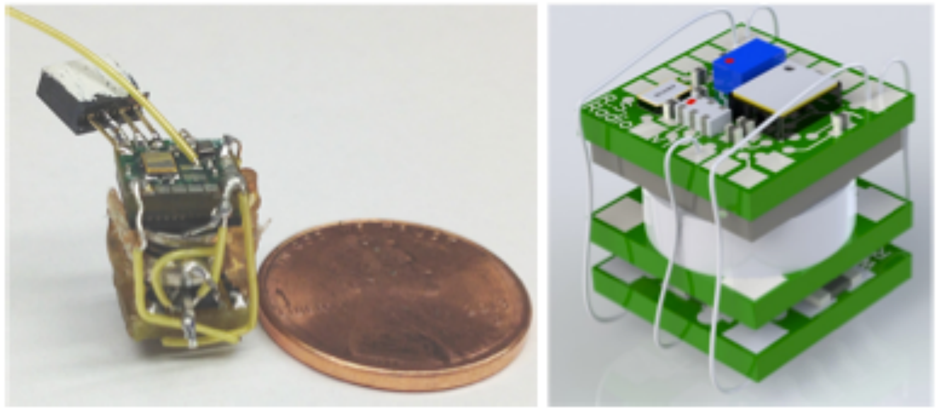

Figure 2: GREEN beside a 1-cent coin (left) and GREEN 3D model [8]

breaker panel, power cords of any device (lighting, appliances, electric vehicles, etc.), and critical loads on distribution and transmission cables. Shown in Fig. 3 are GREENs three

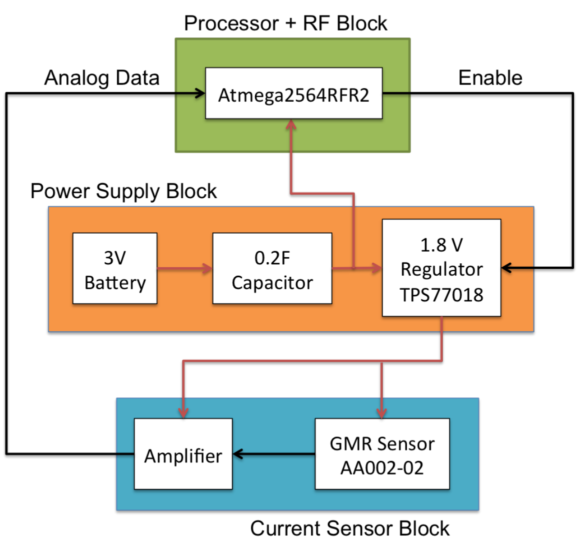

Figure 3: GREEN block diagram

main blocks along with the components that comprise each block. An analog AA002-02 GMR (Giant Magnetic Resonator) sensor from NVE Corporation is the main component of the Current Sensor block. This is interfaced to an Atmel Atmega2564RFR2 microcontroller with integrated Zigbee-compliant radio. The sizes of these two main component chips together with a $3V$ coin cell battery and a capacitor allowed the GREEN node to have a very small form factor, as shown in Fig. 4. Despite its size, the GREEN microcontroller/radio board (Fig. 4) managed to contain the common digital serial communications (I2C, SPI, USART) that are available in the Atmega2564RFR2 chip. One port is readily available for analog input, but the 4-pin programming port can also be configured for analog interfaces, if needed. All ports can also be used as basic digital input/output interfaces. This makes

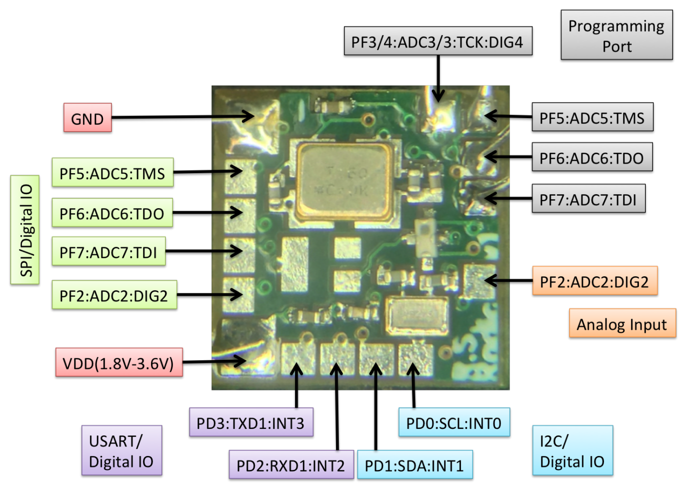

Figure 4: GREEN microcontroller/radio board pin layout

the microcontroller/radio board flexible to be interfaced with different types of sensors and configurable for other types of applications.

III. Wireless Sensor Networks (WSN) & Lightweight Mesh

Fig. 5 shows an example of the wireless sensor network (WSN) deployed in our work on smart buildings. In deploying a wireless sensor network using GREEN, we used the Lightweight Mesh (LWMesh) software stack [9], [10] provided by Atmel. BitClouds Zigbee Pro Stack [11] could also be used, but it requires some porting since the Atmega2564RFR2 is not readily supported. LWMesh software stack has provided programming templates in C for peer-to-peer and basic wireless sensor mesh networks. In this implementation, we used the wireless sensor network configuration. The provided projects are already arranged as project files for the Atmel Studio IDE. Although the templates are configured for Atmega256RFR2, the same can be used for Atmega2564RFR2 (used in GREEN) since they are both practically in the same family. To create a

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wireless sensor network using LWMesh, three types of nodes are created: non-routing nodes (end devices), routing nodes (routers) and coordinator. End devices can receive or transmit data when in range, but may not be available all the time (in sleep modes, limited power). Nodes with routing capabilities usually have continuous power and they relay the data coming from other router nodes or an end device to a coordinator. Coordinator/gateway nodes usually have continuous power and directly interface with a server machine (computer). The software stack can theoretically accommodate up to 65,535 nodes in one network. The address space is divided to non-routing and routing nodes. For routing nodes, 0x0001 to 0x7FFF addresses can be assigned, while 0x8000 to 0xFFFF are used for end devices. Address 0x0000 is used for the coordinator node. The current state of GREEN requires the use of Atmels JTAGICE 3 (or compatible programmer) to effectively program and configure the individual nodes. Future works would include the use of On-the-Air (OTA) programming for firmware update and easy online reconfiguration, when needed, especially if a very dense network is deployed. A native routing algorithm is already present in LWMesh. This made our work easier to test the capability of the GREENs in building a sensor network. Routing tables are automatically created and updated when data is being routed. The routes created by the algorithm may not be optimal.

IV. WSN Monitoring and Protocol

LightWeight Mesh follows the IEEE 802.15.4 standard frame format, but not the protocol stack itself. LightWeight Mesh cannot receive and process IEEE 802.15.4 command frames. Fig. 6 shows the general LightWeight mesh frame format used by each node.

For the current setup, the data received by the coordinator node is passed to the server (PC) via serial port. Fig. 7 shows the data format sent by the coordinator to the server. User programs able to access serial ports can now interpret this data. For the network topology visualization, we used the WSNMonitor software program from BitCloud. This monitoring software can show the real time topology formed network and the sensor readings received by each node. It can also show the RSSI and LQI for each link. Fig. 8 shows a sample screenshot of the WSNMonitor Software, depicting the nodes and links formed by the network.

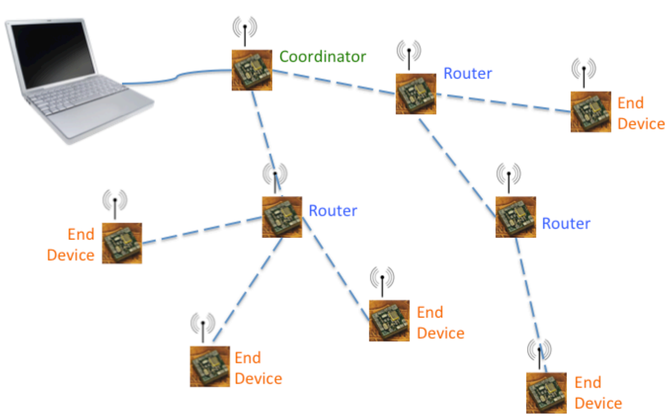

Figure 5: A sample wireless sensor network

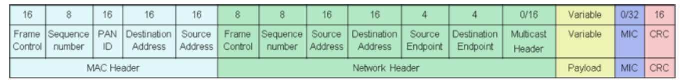

Figure 6: LightWeight mesh frame format

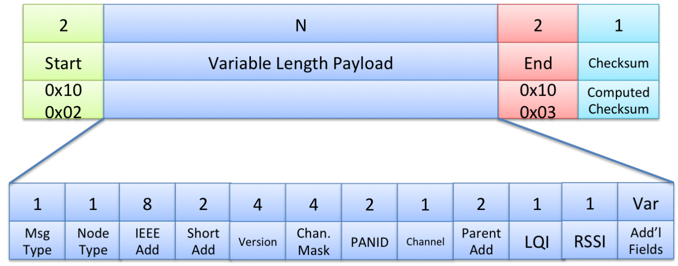

Figure 7: Data format

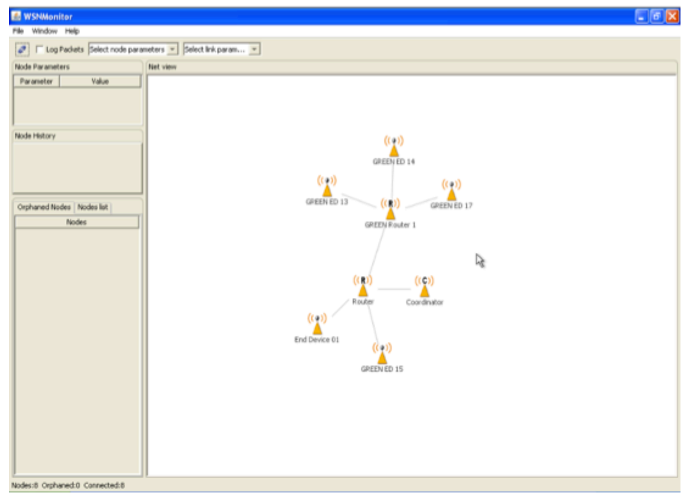

Figure 8: An example of the WSNMonitor Software

A logging program using Python to monitor the battery

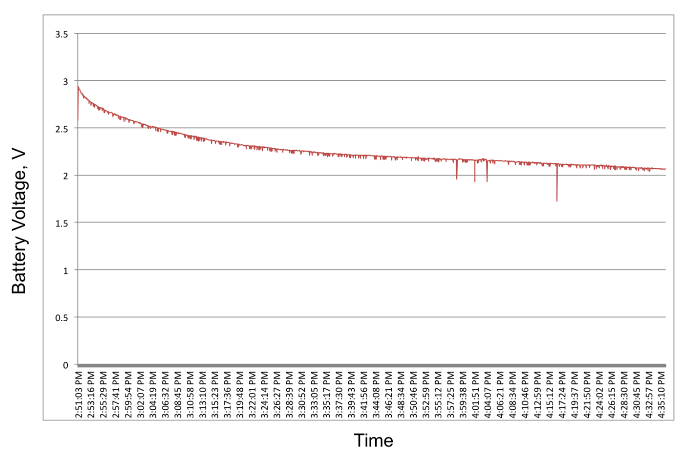

Figure 9: Battery discharge curve: a coin-cell battery is able to sustain the operation of the GREEN node continuously for about 1 hr and 45 mins.

 ISBN: 978-1-61208-363-6

voltage of end nodes was also created. Fig. 9 shows a sample battery voltage profile of an end node. The node is transmitting data every two seconds using the default format of the LightWeight mesh stack (approximately 10ms) and then goes to deep sleep mode. The node lasted for about 1 hour and 45 minutes in this example.

V. Conclusion and Future Work

The GREEN device is not limited to sensing magnetic fields and currents, although this is an excellent demonstration. Any sensor that interfaces via analog, serial, I2C, SPI or digital I/O can be connected to the controller/radio. The only requirement is that the sensors must be very low power so the battery is able to provide a reasonable runtime. Even with this restriction, the device has many potential applications in "smart buildings, ranging from instrumenting the heavy equipment in a machine room to monitoring environmental conditions. The main advantage of the GREEN is that it presents an extremely small, mesh networkable radio platform that is capable of interfacing with a wide variety of input devices.

The future work of this project will focus on the large-scale deployment of this wireless sensor network into buildings to perform condition-based air quality and energy consumption monitoring.

Acknowledgment

The Public Interest Energy Research Program of the California Energy Commission funded the research. The University of the Philippines, ERDT and BCDA-PCIEERD programs provided funds for the first author as part of an expanding research agreement with UC Berkeley. We thank all these organizations for support and many other students and colleagues in the College of Engineering, Berkeley.

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Smart-Grid Control

Adaptive Multi-Agents Architecture

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***Abstract*—This article is about the control and management of smart-grid and new generation of electrical systems. In fact, most of the advanced technologies and systems depend on energy, especially electrical energy; even the daily activities of simple consumers, their tools and equipments are based on electric power. The developed solutions remain within the boundaries of existing and limited systems and do not meet the requirements of the future generation of the electrical networks, such as including intermittent energy resources, and electric vehicles. In this research, we present a solution based on the use of an adaptive multi-agents architecture to control and manage smart-grid. The main output of this paper is an explanation of our solution, the most important points, and the main parts of the proposed architecture.**

Keywords-smart grid; multi-agent system; multi-agent adaptive model; auto-organization mechanism.

I. INTRODUCTION

The management and control of electrical systems presents an issue with many facets. In fact, such important topic involves several stakeholders, including states and governments, consumers, environmental interest groups and local officials etc., to discuss and interchange points of view [1].

The discussions focus on two main issues and challenges. The former is on how to design the best system that meets all requirements in quality and quantity [2], while the latter is on how to migrate the existing networks to a smarter system, especially with the current aged infrastructure.

The importance of the smart-grid concept lies in the fact that it is the best choice to meet the requirements of the near future electrical system [3].

To satisfy the smart grid requirements, there is a need for a lot of investments, new energy markets, policies and pricing, and appropriate legislation. In addition to these issues, there are many scientific challenges, such as the introduction of new Information and Communication Technologies (ICT) and the development of models and standards [4][5].

Our approach focuses on the information and data management with consideration of other aspects, such as physical and electrical components, business objectives and market policies. The idea is based on the use of multi-agent architecture for the management and control of smart-grid with adaptive functionality.

The main questions discussed in this paper concern the choice of an agent-based architecture [6], the interest of its adaptive nature [7][8][9], and the skeleton outline of the solution developed.

This article is intended to answer these questions and try to makes a pathway that helps smart-grid designers to design and model adaptive multi-agents architectures by defining a minimum basic architecture that can be extended later, according to the smart-grid specifies to design and manage. In future work, the solution will be implemented on a micro grid to test, evaluate and optimize it. Additionally, the solution will focus on some aspects that are considered the most important, e.g., real-time processing of information, self-healing, and system security.

The rest of this paper is structured as follows. Section II presents studies and works on smart-grid elaborated by committees and different stakeholders. Section III briefly explains the utility of the proposed approach. Section IV presents in more detail the principles of adaptive multi-agent architectures. The proposed approach is explained in Section V. Section VI presents advantages of the developed architecture. Finally, a conclusion summarizes the main aspects illustrated.

II. STATE OF THE ART

The electrical smart systems attract more and more the interest of nations, laboratories, academics, economists and all types of electricity customer (commercial buildings, industrial factories and residential consumer). Several studies and approaches are proposed to find effective solutions to smart-grid challenges, namely, the model developed by the National Institute of Standards and Technology (NIST) [10], the European Union, which proposes a Smart Grid Architecture Model (SGAM) [11], the Institute of Electrical and Electronic Engineers (IEEE) proposition [12] and the International Electrotechnical Commission (IEC) one [13]. All these models give just standards and models to design architectures for smart-grid and do not propose detailed and practical solutions. However, these models play an important role and invite designers and researchers to complete the work based on their results.

 ISBN: 978-1-61208-363-6

Other solutions exist and benefit from advanced technologies, such as cloud computing [14] or market-driven approaches [15]. Although they are agent-based solutions, they do not explain and fully address the concept of adaptability and the basic agent structure, which represents the basic building block of the multi-agents architecture.

We pointed out in our approach the importance of the system adaptability with unexpected scenarios and its capacity to pass critical situations. We also present the structure and behavior of the architecture core component (the agent).

III. NEED FOR NEW APPROACHES

The information systems of large and complicated projects, such as electrical networks, are characterized by a very advanced level of complexity. They have become increasingly difficult to manage because reference systems and emerging applications become progressively more distributed, open, handling large amounts of information and having new capabilities to work in cooperation and adapt their behavior with changes. On the other hand, administrators and electrical networks managers have an increased need for effective management and control systems with dynamic architecture. Added to the structure flexibility, the electrical network must be able to be managed as independent parts (case of several micro grids) with local processing of information and autonomous management units and components or in cooperation (case of entirely system) [14] with the ability to interchange data and messages. We chose agent-based architectures because it recognizes criteria and capacities to meet the complex and dynamic systems that need powerful and flexible approach and present an adequate field and environment for test and validation of Multi Agents Systems (MAS). This situation is almost the same for all systems, especially more complex systems, such as smart-grids. This heterogeneity, large scale and distributive architecture exclude all opportunities to express all necessary knowledge to manage and control the system, hence the necessity to develop an adaptive multi-agent model with the ability to change its behavior according to changes and environmental disturbances.

Such a model, which can adapt its behavior and its internal structure with the situation of the system, requires self-observation mechanism to detect emerging events.

IV. ADAPTIVE AGENTS -BASED ARCHITECTURES

A. *Adaptive Multi-Agens Systems*

Multi-agent systems come as a result of research evolving a set of theories, such as Artificial Intelligence (AI), Expert Systems (ES) and object-oriented systems to exceed their limits. Multi-agent systems are used to model complex, heterogeneous, nonlinear and especially dynamic and evolving systems. This requires adaptive agents capable of dynamically acquiring knowledge not introduced earlier by the designer or the system operator, enabling them to adapt their behavior at the individual level (agents) and collective level (organization of agents) [7][8][9].

B. *Differents Models and Architectures*

Multi-agent systems have started with two basic models: a first reactive agent [7] (used for cases of immediate response and not much individual intelligence; however, a collective intelligence is required) and a second cognitive agent that is smarter and has advanced processing and reasoning capabilities. This type of architecture is favored in cases of complex decisions.

The two models presented are subsequently emerged to find a new architecture that benefit from the speed of the reactive agent and the intelligence of the cognitive one. This new hybrid architecture traces a path between the two approaches by combining reactive and cognitive properties, typically implemented in different modules.

TABLE I. COMPARATIVE TABLE OF MULTI-AGENTS ARCHITECURES

Architectures	Advantages	Disadvantages
reactive	- fast response - simplicity of implementation	- limited to simple systems - not much intelligence
cognitive	- agents are intelligent can model complex systems	- expensive implementation for littre systems
hybrid	- undeniable qualities in software engineering respond to diverse spots	- does not resolve the issue of variable granularity [7]

Modular architectures [7] have passed the hybrid model. They make the agent as an open system benefit from the modularity introduced and the ability to exchange modules between agents.

Hybrid architectures (traditional) do not resolve the problem of granularity; in fact, they are not able to support a design system whose agents have varying granularities. This gave birth to a new generation of operational and generic architectures [7]. They are based on platforms with reduced core and basic features such as communication with other agents and environment entities. This idea is to have a basic building block for the development of a model of adaptive architecture that can be integrated into various systems.

This model allows the integration of all architectures, starting from a minimal agent, and then adding the desired functionality by successive refinements.

V. ADAPTIVE MULTI-AGENT SYSTEM APPROACH TO MANAGE AND CONTROL SMART-GRID

A. *Developed Approach*

As explained earlier in this paper, complex problems and computer systems require the modeling and design of computer systems, which become too complex.

Therefore, the trend is moving more and more towards the development of new approaches integrating adaptability and self-organization capacities [17].

To respond to the different objectives of smart-grid, the mechanism of self-organization is an interesting way to design an adequate management and control system. This enables the smart-grid to adapt its behavior to environmental changes in an unsupervised manner.

The idea developed in this paper presents an approach in this context designed for smart-grids. It is based on the concept of distributed and self-agents learning that are guided by a set of local decision rules that are refined continuously under the influence of the environment. This approach is based on several theories, mainly Adaptive Multi-Agent Systems (AMAS) [16][17]. Such a system is composed of several types of agents (load agent, generation agent, transmission agent, distribution agent, etc.) that are equipped with local knowledge and a representation of their environment. They make their decisions using this knowledge, their cooperative social behavior and adaptability skills and capacities (see Figure 1).

For example, the following agents are part of the proposed architecture:

- Load agent: responsible for the management and control of electrical appliances in homes, companies and factories. It has a dual role (two directions), it routes requests energy consuming from appliances to network controller and monitors the implementation of the political system.
- Generation agent: it manages one or more resources of energy and decides the amount of electricity to produce with reference to customer demand and the capacity of the resources. This agent is implemented in several forms, depending on the resources it manages. In fact, management of intermittent resources and current fossil-based resources is different, risk and danger of nuclear power plants is not the same in friendly- nature resources.

Therefore, each agent adapts its behavior according to its position in the network by choosing the features and the necessary means to fulfill (perform) the tasks entrusted to it.

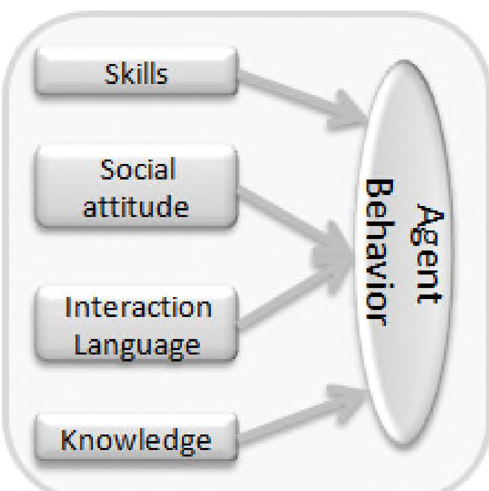

Figure 1. Agent Architecture [16].

The first step in the proposed bottom-up design approach is to identify the agents; then, to ensure that the local agent is or trying to be in cooperative interactions with other agents. Neural networks can be used to identify agents, which provide well-defined agents on a set of parameters and criteria defining each agent and specifying its architecture.

The second step is to define the agent's components, because each agent in this architecture is divided into several proactive components. This allows reusing of these components by different agents by instantiating them if necessary. It should be noted that each component can be reactive or cognitive, which allows building hybrid agents not only hybrid architectures, and this is one of the most important criteria of this approach inspired from the architecture Development and Implementation of Multi-Agent Systems (DIMA).

The components of an agent are always chosen around a core (main component that contains the component identifier (ID)). This main component is the only one that cannot be changed, all others can be modified or changed and these interactions (see Figure 2).

To present these components, the notation used is that of Unified Modeling Language (UML) [7]. It defines any component as a set of classes with their methods.

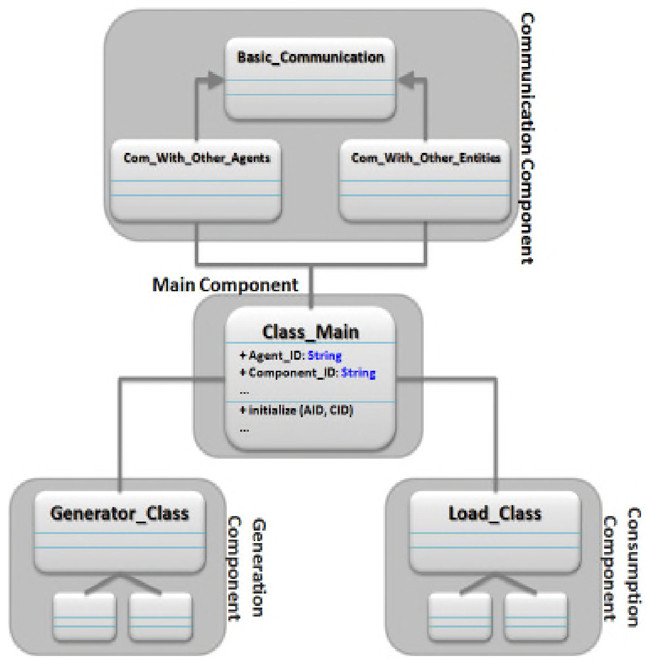

Figure 2. Agent Components

B. *Basic Agent Components*

1) Main Component: It contains the basic informations of the agent and the component such as their IDs, their statements, etc.

2) Communication Component: This component is essential in the architecture. This module will guarantee

 ISBN: 978-1-61208-363-6

reliable communication with other agents. It is responsible for the delivery of messages between agents according to the appropriate protocol conversation.

With this approach, the design of agents is operated in a relatively simple manner, starting with a minimal agent and adding the desired modules according to its mission.

Several modules (components) can be attributed to agents such as components controlling energy generators, consumers, network transmission or distribution, etc.

C. *Agent Communication Language*

Designing MAS requires coordination and cooperation between its agents to perform their tasks. So, designers should formalize how the agents coordinate themselves. In fact, like any community assembling several individuals, a common and conventional language must be specified to facilitate communication within this shared environment. This is the case in all communities (social, IT, scientific, etc.). To this end, the Foundation for Intelligent Physical Agents (FIPA) [19] has defined some specifications and standards for the use of multi agents systems.

Many languages have been created such as Agent Communication Language (ACL) [19] and Knowledge Query and Manipulation Language (KQML) [19] for use in MAS development.

ACL is a FIPA specification-based language. It is the most preferred in the development of multi-agent systems [18]. It defines a specific structure for the messages circulating between the agents. This structure includes attributes containing information about the agents involved in the conversation, i.e., the sender, receiver(s), the message content, etc. (see Figure 3).

An ACL message should contain the following parameters [18]:

- Communication type (performative): this parameter indicates whether the message is a request, a reply, a piece of information, etc.;
- List of the participants in the conversation: it contains information on the sender and the receiver(s), and reply-to fields, including the names of the corresponding agents;
- Message content;
- Description of the content: the used language, encoding and vocabulary (ontology);
- Conversation control parameters: such as a conversation identifier and protocol.

```
(REQUEST
:sender ( agent-identifier :name agent1@platform:1099/JADE )
:receiver (set ( agent-identifier :name agent2@platform:1099/JADE ) )
:content "Hello! How are you?"
:language FIPA-SL0
)
```

Figure 3. Sample ACL message, using the default ontology [18].

The example in Figure 3 presents a sample ACL message, but in complex conversations, using a common language may not be sufficient, so ontology (i.e., formal representations of knowledge) should be specified to define the vocabulary that agents use in their conversations.

D. *Inheritance Notion*

A set of generic classes (Framework) defined different types of agents and the services they provide. These generic classes are inherited by subclasses to detail the specifics depending on the role of this container agent. For example, classes of agents that control the electricity generators inherit a generic management generator class and redefine methods and may add new attributes and / or methods according to the characteristics of their resources (intermittent, un-intermittent, permanent, seasonal, etc.) hence the obligation to assign any agent an adequate adaptive design starting with the same generic model (class).

Figure 4 presents an example of inheritance relationship, in fact, classes Intermittent_RES and Permanent_RES inherit the standard methods of all generators of energy from class Class_Generator. Classes Intermittent_RES and Permanent_RES are in turn inherited by the classes Solar_Panel, Turbine_Wind, Fossile_RES, and NuclearPowerPlants which redefine the methods to their suit characteristics.

This property greatly simplifies the task to the designer who benefits from a framework containing almost all basic classes; otherwise, its task is reduced to mapping classes and redefining their methods.

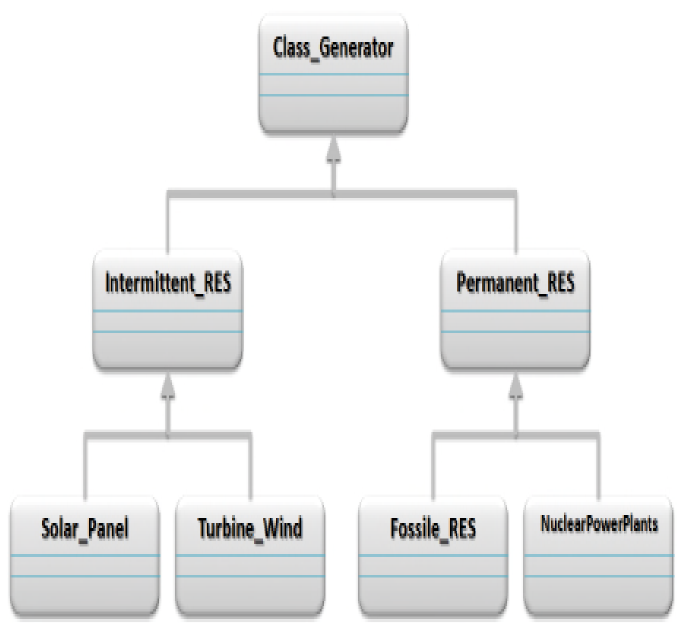

Figure 4. Example of inheritance between classes within a generation agent

E. *Decision-Making Structure*

In a smart-grid, like any complex and dynamic system, an agent may often be faced with dilemmas in the decision-making process. In fact, an agent must have a decision-making structure enabling it to evaluate the situation and decide what to do.

The proposed approach excluded the idea of predicting all possible cases for the simple reason: it is not feasible except for small systems and / or simple scenarios and of course this is not the case for smart-grid where different variations cannot be known a priori. The architecture of the agent, in this case, must provide the ability to easily adapt the decision-making process to the changing environment.

With its decision-making mechanism, an agent needs two sets: a first set of conditions to be used to test the context of the agent and a second set of actions (methods) that modify the state of agent and / or its environment.

The decision-making process can be described by a Petri network or Programmable Logic Controller (PCL) whose states are the situations that can take the agent (see Figure 5).

VI. Proposed approach advantages

The approach presented in this paper is based on the decomposition of smart-grid into subsystems managed by agents that have dynamic modularity. It benefits from the properties of adaptive multi agent systems such as:

- Multi-granularity: agents have different granularities;
- Dynamism and openness: the agents are dynamically created and destroyed. They often change their behavior and change their internal structures regularly by adding or removing modules (components) and services;
- Heterogeneity: the architecture includes different models of agents (reactive, cognitive, hybrid, modular);
- Real-time reflection: the system reacts to changes and events in a timely manner;
- Reusability: the same components can be used in several agents.

The solution differs from others [14][15][18] by a set of criteria which proves its high performances when we compared it with other solutions (see Table 2).

TABLE II. COMPARATIVE TABLE OF SOLUTIONS PERFORMANES

Performances	**Proposed solution**	**Other solutions**
Adaptability	Able to adapt to unexpected situations.	Don’t fully address the adaptive nature of the system.
Flexibility	Flexibility is witnessed at all levels namely the design, implementation, etc.	Some solutions [14][15] may be qualified by this adjective, others are static and rigid as current systems that are invariant.
Structure & modularity	Variable and modular structure, otherwise has a variable and dynamic granularity.	Static structure [14] [15] [18] defined from the beginning.
R eusability	Based on generic components that are used by different agents.	There is no re-use because of the lack of units and generic components equipped just with common services.
Clarty & simplicity	Clear and easy to understand even for non-specialists and simple in terms of implementation.	Clarity and simplicity are relative and vary from one solution to another.

VII. Conclusion and future work

The paper presents an agent-based architecture given as a solution for the problem of smart-grid management and tries to pass the boundaries of current solutions to a new dimension of autonomous steering (management, control) system. To achieve such a system, we must overcome many difficulties and challenges mainly modeling smart-grid and designing its information system that presents a delicate and crucial task. In fact, the theoretical model will define policies of the real networks.

In order to achieve a consistent system, it is strongly recommended to divide the system into subsystems easy to identify and model. This division must be justified and follows a systemic methodology. It represents our next object of work and it should provide the desired benefits to the proposed architecture.

Acknowledgment

The author is grateful to Mr. Samir Ben Ahmed (Faculty of Mathematics, Physical and Natural, Tunis) for his valuable help and encouragement during this work and university author-courses.

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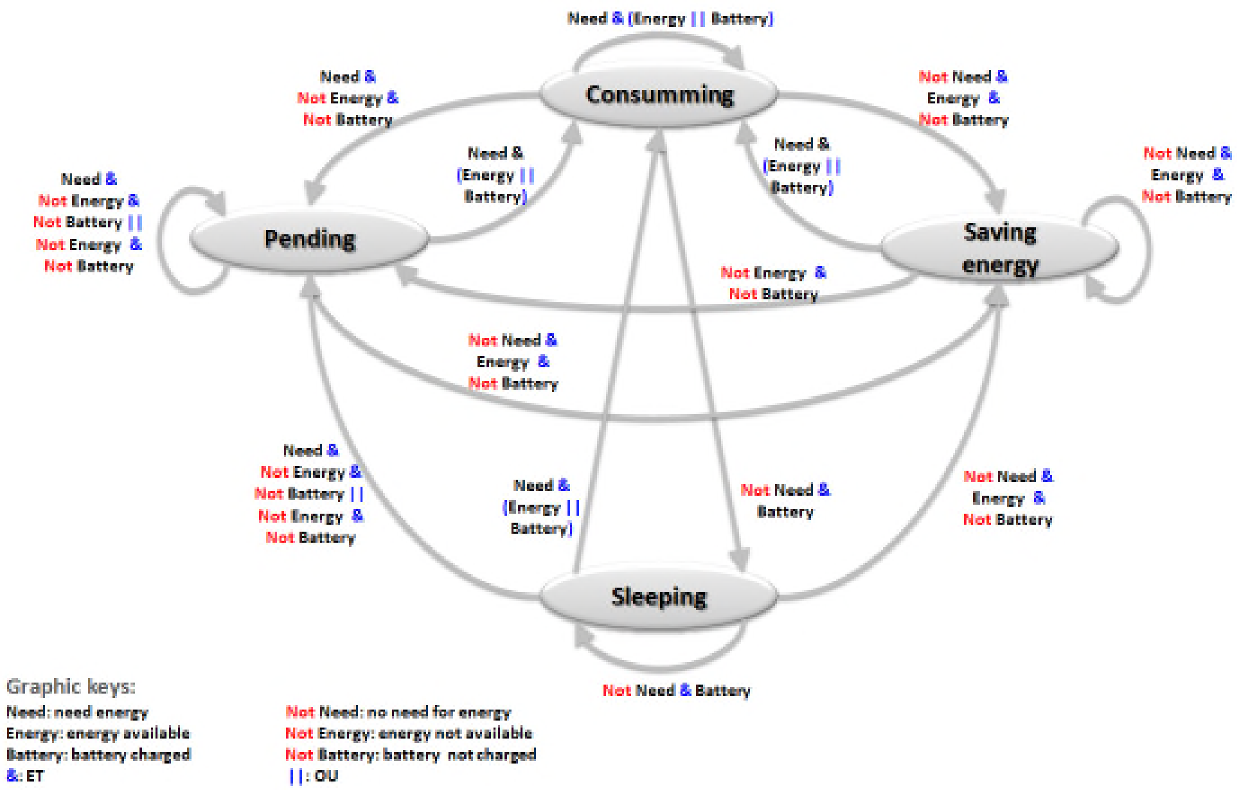

Figure 5. Example of PLC decision-making mechanism for a load agent

Comparing Low Power Listening Techniques with Wake-up Receiver Technology

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***Abstract*—One of the major challenges in wireless sensor networks is in reducing power consumption of the individual motes while not degrading the functionality of the network as a whole. With wireless sensor technology becoming more wide spread and larger deployments of this technology being rolled out post deployment issues such as battery replacements become a bigger issue. Reducing power consumption is essential in situations where it is infeasible or impractical to frequently replace batteries. Reducing the power consumption of the motes to a level where batteries can last years or where ideally to levels where energy scavenging becomes more feasible, resulting in battery-less operation of wireless networks, is a major research challenge. One of the main energy consumers on a wireless mote is the radio transceiver. Current approaches using low power listening techniques to reduce mote power while maintaining meshing capabilities and this paper compares the state of the art in low power listening (BOX-MAC 1 and 2) with the latest in commercially available wake up radio technology (Austria Microsystems (AMS) AS3933) to determine which approach is more efficient from an energy consumption view. A theoretical approach has been taken to compare achievable lifetimes of motes under different traffic situations using both Low Power Listening (LPL) methods and Wake up Receivers (WUR). This is then compared against empirical data. As this paper shows, when considering power draw of radios in different configurations, WURs consume up to 20 times less power compared to techniques, thereby enabling indoor energy harvesting (EH) solutions to become practical.**

Keywords*—*LPL; Wakeup Radio; BOX-MAC; BMAC; XMAC; Wireless sensor networks

I. Introduction

One of the main challenges in Wireless sensor networks (WSNs) to date is post deployment lifetime of the motes [8]. Batteries are often used to supply power to the wireless motes as supplying a constant power source would be infeasible, for example in outdoor locations where power infrastructure is non-existent [14].

Moreover, regularly changing the batteries would be impractical and also expensive, while the costs of the batteries are relatively cheap (sub 1 euro) the cost of maintenance staffs time to carry out the work is not. Because of this, reducing power consumption by as much as possible to either increase the time between battery changes or make the devices energy harvesting compatible is an important research topic.

Often, the most resource hungry device in a mote, for a WSN is the radio, consuming around 19mA in receive mode [12]; so, much work is put into reducing its on time. Two ways in which power used by the radio may be reduced are either using a duty-cycling media access control (MAC) protocol, or, using a low-power wakeup radio (WUR) [4], which consumes minute amounts of power while still being in a constant active or listening state.

Low power listening (LPL) protocols reduce power consumption by putting the radio into sleep mode with regular intervals in which it will wake up to sample the channel for activity. This introduces latency into the network which in some cases would be unacceptable ,e.g., a system controlling a solar panel or wind turbine where systems need to be shut down to prevent damage to them in a timely fashion.

Despite the advantages that WURs may offer their uptake in WSN applications to date has been limited, possibly due to them having lower receive sensitivities when compared with conventional radio frequency (RF) radios as well as much reduced range. While there are designs available that consume a few microwatts [1] while being able to receive data, their benefits vs. traditional low power techniques are still uncertain. If validated, WUR could pave the way for much longer WSN node lifetime.

I. Demirkol [4] have performed a previous comparison between low power listening modes and wake-up radios, they do not include a comparison of newer, more efficient, low-power listening protocols such as BOX-MAC [10]. Amre El-Hoiydi in [5] discusses that the development challenge of creating a WUR that consumes tens of µA necessitates the further development of protocols that rely on the main radio.

W.S. Wang et al. [15] discuss power levels that are attainable from various indoor based energy harvesting solutions. They determine that for a single solar cell in an indoor location, the maximum power attainable is 151.6 µW. This paper uses analytical work to show that with such a constrained power budget, using LPL methods would be insufficient for use in battery-less operation.

The rest of the paper is ordered as follows. Section II covers background work in the area of LPL MAC protocols as well as advances in WUR technologies, it also includes the limitations of wake up receivers compared to traditional radios utilising LPL methods. Section III will cover the analytical work done. Section IV outlines the experimental setup used to verify the theoretical work carried out in Section III. The results of analytical and empirical work are described in Section V. Conclusions are presented in Section VI and future work the authors wish to carry out in this space is listed in Section VII.

 ISBN: 978-1-61208-363-6

II. Background Work

A. Low power listening modes

The need to reduce power consumption for a device lead to the creation of LPL methods, indeed, if the radio is left on in listening mode constantly, the battery powering the mote could be drained in as little as 3 days [11]. Because of this, much research has been done on proposing new methods to reduce the duty cycle of radios. Early work in this field relied solely on information from a single layer in the protocol stack ,e.g., sensor-MAC(S-MAC) [16], Berkeley-MAC (B-MAC) [13], X-MAC [3], whereas newer techniques are starting to rely on information from multiple layers to achieve better efficiencies, example, BOX-MAC and WiseMAC [5].

1) S-MAC: S-MAC was designed with the reduction of energy consumption as its primary goal, other aims for the protocol were to provide good scalability and collision avoidance, and these secondary goals are achieved through the use of a combined scheduling and contention scheme. S-MAC is based on 802.11 MAC protocols. The authors of S-MAC identified four major sources of energy waste.

Firstly, collision occurs when corrupted packets that are discarded and need to be re-transmitted, this also has the unwanted effect of increasing latency in the network. Overhearing is when a node receives a packet that it is not meant to. Thirdly, the overhead that is required for control packets, and finally, idle listening of the channel can consume 50%+ of the energy required in receive mode [16]. S-MAC was created to tackle these issues; it relies mainly on the physical layer and has a fixed listening period of 115ms with a variable sleep period between checks to achieve different values for duty cycle [13].

2) B-MAC: B-MAC was created with the goal of increasing packet delivery rates, throughput, latency, and energy consumption compared to S-MAC. B-MAC uses clear channel assessment (CCA) and packet back offs for channel arbitration. Reliability is achieved through link layer acknowledgements, with LPL being used for low power communications. While S-MAC includes network and organization within the protocol, B-MAC does not include these functionalities (e.g., synchronization and routing), leaving it up to higher levels to implement such things. B-MAC is the default MAC protocol used by TinyOS and relies on the physical layer for channel sensing.

3) X-MAC: Contrary to the previous two protocols, X-MAC is primarily a link layer protocol. X-MAC aims to achieve better lifetimes by employing a shorter preamble and preamble sampling time when compared to protocols like S-MAC and B-MAC. X-MAC is an adaptive algorithm that dynamically adjusts the receiver duty cycles to optimize energy consumption per packet, latency, or both parameters. X-MAC has two proposed ideas to reduce energy consumption. First, embed addressing data inside the preamble, so that receivers which do not need to receive the packet can go back to sleep mode, saving power. The second idea is to use a strobed preamble; this allows a receiver node to interrupt the transmitter before an entire preamble duration, reducing energy losses on both transmitter and receiver side.

More modern MAC protocols, such as BOX-MAC have been introduced that use information in multiple layers to make more informed decisions about the state of the network, thereby, making more efficient use of the radio and reducing power consumption by up to 50% when comparing X-MAC with BOX-MAC [10], and up to 30% when being compared to B-MAC.

4) BOX-MAC: BOX-MAC was developed as an evolution of both B-MAC and X-MAC, while the earlier two protocols rely on a single layer for information to perform power savings, BOX-MACs 1 and 2 rely on information contained within both the physical and link layers to achieve the goals of LPL. Of the two versions of BOX-MAC, BOX-MAC-1 is a predominately physical layer protocol that incorporates link layer information, and BOX-MAC-2 is a packetized link layer protocol that incorporates physical layer information.

BOX-MAC-1 acts as an improved version of B-MAC, instead of B-MACs preamble, BOX-MAC-1 transmits a continual data packet. This allows nodes to save power by only staying awake for packets that are meant for them. BOX-MAC-2 improves upon X-MAC by first checking whether or not there is sufficient energy on the channel as opposed to waking up long enough to hear a complete packet. Because of this, BOX-MAC-2 reduces receive check lengths by a factor of 4 compared to X-MAC.

BOX-MAC-1 has been shown to be more efficient when network traffic is low and BOX-MAC-2 is better at high traffic applications. Because of this, and the base protocols they were derived from, WURs have been compared with B-MAC and BOX-MAC-1 in low traffic situations and with X-MAC and BOX-MAC-2 in high traffic situations.

B. Wake up radios

There are two types of implementation for wake up radios, namely an identity-based system and a range-based system. Range-based systems work by transmitting a wake-up tone which is then received by all nodes within range and triggers all of those nodes to wake up their processors. Identity-based systems work on the principle of a bit-sequence being received and then decoded and checked against a pre-set identity.

1) Range based systems: These systems are often charge pump based, and are realized using Schottky diodes [11] or MOSFETs [7]. Once sufficient activity is detected on a channel, the wakeup circuit will then trigger an interrupt on the sleeping micro-controller. The downside to this approach is that a correct wakeup signal is treated the same way as any other RF activity on that frequency, leading to an increase in false wakeups, triggering the main radio more often than necessary.

The attractive feature of these circuits is that they have very low power consumption and in some cases can be completely passive circuits [2], the caveat being that passive circuits have even less range than active receiver based circuits.

2) Identity based systems: Identity based systems are able to process information carried in the wakeup signal i.e. an address. This results in less false wakeups per mote as only motes that are actively being addressed will wake up the main radios to receive data. Data is clocked into a register and is compared against a pre-set value [4]. If the compared values are correlated, a wakeup signal is sent to the micro-controller

 ISBN: 978-1-61208-363-6

TABLE I: WUR SUMMARY

Radio	Active current draw	Sensitivity(dBm)	Frequency (Mhz)
[6]	6µA	-80	868
[9]	2.4µA	-71	868
[1]	1.37µA	-67	0.11 - 0.15
[12]	18800µA	-98	2400

and then the main radio is switched on to receive the data packet.

C. *Advantages and disadvantages*

Clearly, the reduced operational range of wake-up radios diminishes their suitability in networks that require large ranges between nodes while still maintaining a short latency interval. Additionally, adding in a wakeup receiver increases the complexity of hardware design on already constrained systems so careful consideration must be taken into account when designing such a system. The increased complexity and, therefore, the increased cost of the overall system may negate the yields gained from prolonged battery lifetimes.

The advantages of wake-up receivers include their much reduced operational power requirements (µA operating current versus mA for traditional radios). Also, as the wake up receiver is constantly receiving, the requirement to synchronise between sender and receiver is removed as it has become a purely asynchronous communications network.

III. Analytical Work

This paper aims to show that using WUR technology, energy savings can be made in compared against LPL techniques.

All calculations in this paper are based purely on the consumption of the radios as all other system components are assumed to be equal and that their energy usage will remain the same throughout all experiments, as a result of this, lifetimes presented in the results will be higher than those achieved in reality as the whole system will use more energy than is being calculated here.

For this paper, Chipcons CC2520 [12] radio has been selected to represent the main radio technology as it is widely used in WSN testbeds [11]. While many different possible WUR technologies can be used (shown in Table I), a device in the 110kHz ISM with a current consumption of 1.37 µA [1] to represent a WUR with a decent sensitivity. These radios are summarized in Table I. The lower sensitivity radios equate to an indoor range of approximately 30m [6], which should be sufficient to cover a typical office room.

Utilizing wake-up radios presents certain changes to the calculations [10] used for the time the radios perform various tasks; these changes are summarized in Table III.

For the analytical work, this paper assumes a standard time for transmission of valid packets of 4.1ms (802.15.4 payload transmission time) which remains equal for both LPL modes as well as WUR solutions. The reason for the added 0.5ms is that it takes this extra time to wake up the main radio from sleep to active mode. TCX in this case equals the number of milliseconds in a day as the radio is always listening.

These changes are reflected in Table III. Using the adjusted calculations from Table III, and a Schott Solar cell which is capable of generating up to 151.6 µW [15], a theoretical limit for number of valid wake up messages per hour using a WUR system was arrived at of 109 messages if using a single Schott Solar cell. This measure does not take into account sending messages back to a base station; further investigations will need to be carried out to determine the upper limit for communications in both directions.

Assuming that transmitting a response to a query would take approximately the same amount of power as receiving one packet, such a system would be able to achieve 55 asynchronous communications per hour. Using these equations from Table II and Table III, a graph was plotted to visualise average power consumed by each method for varying amounts of valid packets per hour, this is visualised in Figure 1.

IV. Experimental Setup

In order to validate the analytical calculations in III an experiment was devised to measure the power consumption of LPL and Wake up radios. The first step of the experiment was to measure power consumption on this platform in the following scenarios, the wireless platform consuming the minimum power possible to establish a baseline of power consumed by the MCU and radio in sleep mode.

Next, the state of the art in low power listening methods was measured for different values of receive check interval. The LPL techniques selected were the physical layer B-MAC, link layer X-MAC and the hybrid protocols BoX-MAC 1 and 2. No transmissions were carried out these measurements were

TABLE II: ORIGINAL ENERGY CALCULATIONS

Time spent on wake-up transmission deliveries	T_TX (box1, bmac)= D * T
	T_TX (box2, xmac) = D * (T / 2)
Time spent on incorrect radio packets	T_I (box1, box2, xmac)= I * 20ms
	T_I (bmac) = I * T
Time spent for valid radio packets	T_V (box1, bmac)= V * (T/2 + 4.1ms)
	T_V (box2, xmac) = V * 4.1ms
Time spent checking the channel.	T_CX (box1, bmac) = R * 0.78ms
	T_CX (box2) = R * 5.61ms
	T_CX (xmac) = R * 20ms
Time spent on idle power	TIDLE = Msec in day - (T_TX + T_I + T_C + T_V)

TABLE III: ADJUSTED CALCULATIONS FOR WUR

Value	Time spent per day
Time spent on wake-up transmission deliveries	T_TX = 0ms
Time spent on incorrect radio packets	T_I = I * 20.5ms
Time spent for valid radio packets	T_V = V * 4.9ms
Time spent checking the channel	T_CX = 86400ms
Time spent on idle power	T_IDLE = (86400ms - (T_TX + T_I + T_V))

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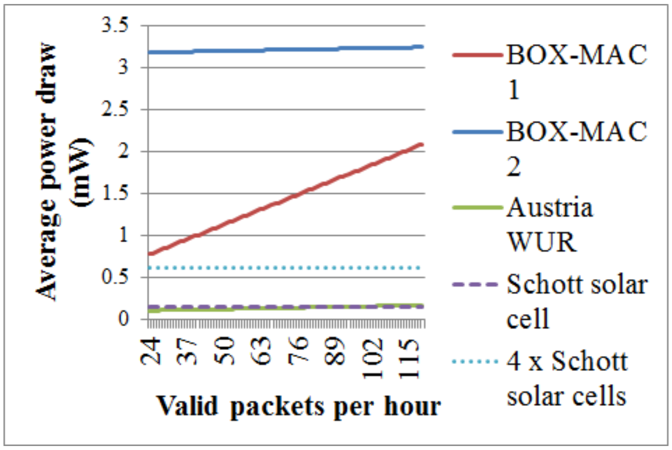

Fig. 1: Power draw calculations

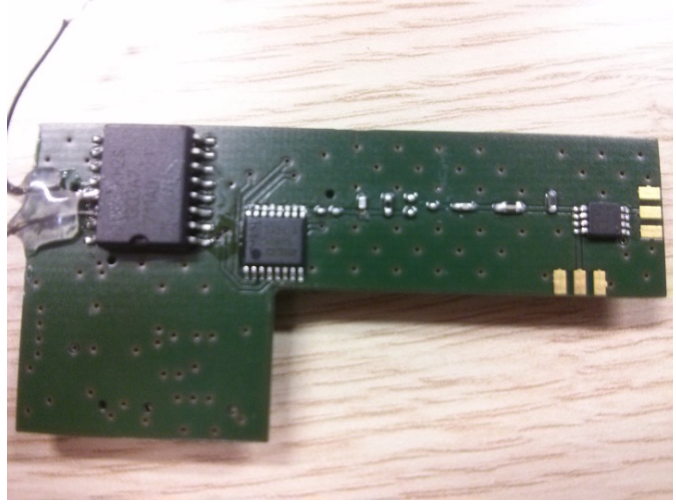

Fig. 3: Tyndall WUR expansion board

only used to get the baseline average power consumption of each LPL method.

For the hardware used in this setup, a wireless mote consisting of an MSP430F5437 microcontroller and a Texas Instruments CC2520 was chosen as the radio platform. The mote platform is shown in Figure 2. The mote is a credit card sized platform with expansion slots for additional peripheral devices (sensor layers, radios, actuators etc). The mote also has a number of jumper selectable options for power sources and power distribution allowing complete control of which sub components of the mote get powered up. For example the on-board FTDI chip can be enabled or disabled depending on the configuration required.

To take advantage of the modular nature of the platform, a daughter board was developed, pictured in Figure 3. This board has a 32 kHz crystal acting as an external clock source for an Austria AS3933 WUR. There is also a radio frequency passive network on the daughter board which is tuned for 2.4GHz signals.

The AS3933 WUR uses on off keying (OOK) modulation, while it is an identity based WUR it can also be setup as a ranged based WUR through register settings. The passive network performs a low pass filtering of the 2.4 GHz signal down to 125 KHz in a fashion similar to that used in [11], which is the frequency the WUR operates on.

To perform the power analysis, a DC Power Analyser from Agilent Technologies (N6705B) was used to provide power to the entire device via the red (positive) and blue (negative) wires seen in Figure 4. The entire setup is shown in Figure 5. 64k points of measurement over 4 seconds were taken using the scope view function and then exported into csv format. These individual points were then averaged to arrive at the figures displayed in Table IV.

V. Results

Setting the supply voltage at 2.5V, measurements were taken for low power listening methods when no packets are

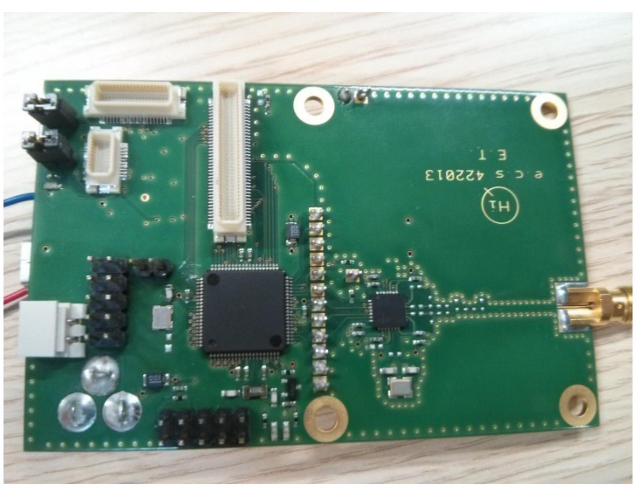

Fig. 2: Tyndall Mote

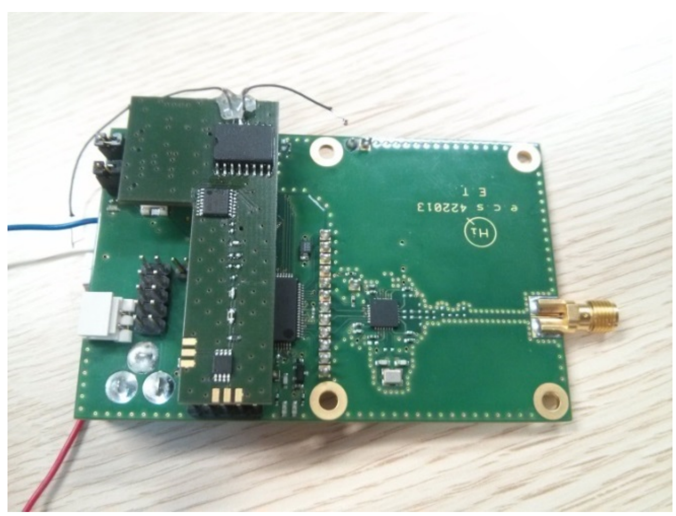

Fig. 4: Boards connected

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TABLE IV: POWER MEASUREMENT RESULTS

Protocol	Receive check interval	Radio duty cycle (%)	Average power (μW)
All sleep mode	0	0	15.7
WUR	0	0	54.1
BMAC, Box-MAC1	50ms	1.52	1113.5
	500ms	0.152	128.95
	1s	0.076	72.5
	2s	0.038	45
Box-MAC2	50ms	11.22	6128
	500ms	1.122	631.53
	1s	0.561	326.4675
	2s	0.2805	176.75
XMAC	50ms	40	22022.75
	500ms	4	2138.49
	1s	2	1080
	2s	1	549.345

delivered to determine absolute minimum power expended for each method. The results are recorded below in Table IV.

The MCU is in low power mode whenever it is not communicating with the radio chip, and the CC2520 is in the lowest power mode (LPM2) when it is not in receiving mode to listen for packets. The addition of the WUR to the base system imposes an additional 40μW requirement for minimal operations.

This base level requirement of 55μW is easily attained using Schott Solar cells that can generate up to 151.6 μW each [15]. Also from Table IV, for a single solar cell, LPL methods are unable to achieve a low enough average power draw while maintaining a low latency.

Comparing the LPL methods, XMAC consumes the most power because of its relatively large on time for the radio when performing a receive check. BMAC and BOX-MAC1 consume equal amounts of power because the main radio is receiving for equal lengths of time. The length of time the radio is on and in receive mode is listed in Table II.

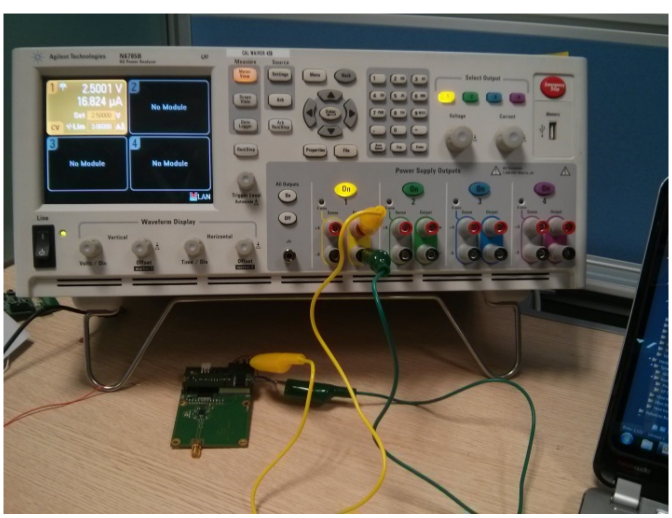

Fig. 5: Device under test

VI. CONCLUSION

From the analytical work done, it has been shown that WUR are much more suited to indoor battery-less solutions than LPL techniques. Furthermore, from the initial recorded measurements of power, the empirical data suggests that WURs offer a lower power consumption while still maintaining a lower latency over LPL methods. There are certain scenarios where WUR would not be suitable for a WSN, namely where a long range between motes is required while still maintaining a low latency in mote-to-mote communications, however, in situations where long range is not required but latency is not a crucial factor, WURs can still be employed to prolong the lifetime of motes in a WSN. Wake-up radios can reduce the energy usage of a system to a point where it would enable indoor, asynchronous communications powered by indoor based energy harvesting methods, which typically dont offer as much energy as outdoor solutions.

VII. FUTURE WORK

The first step in creating a battery-less bi-directional wireless sensor platform is to ensure the power consumption of the device is kept to an absolute minimum. Box-MAC1 when its receive check interval is set to 2s, achieves low power consumption (250uW). However, this figure still exceeds the power provided by a single solar cell making it unsuitable for an indoor EH solution that is based upon a single solar cell [15]. The authors propose to perform the following:

1) Integrate the mote platform (Figure 4) with Tyndalls in house energy harvesting platform [15], pictured in Figure 6.
2) Include a sensing layer on to the mote; employ asynchronous communications using the WUR.
3) Build large scale deployment of battery-less WSN platforms utilizing WUR technologies.
4) Using a large scale deployment, validate the usefulness of WUR in modern WSN deployments.

ACKNOWLEDGMENT

This work has been co-funded by the European Commission under the 7th Framework Programme , through the GreenCom project (http://www.greencom-project.eu/).

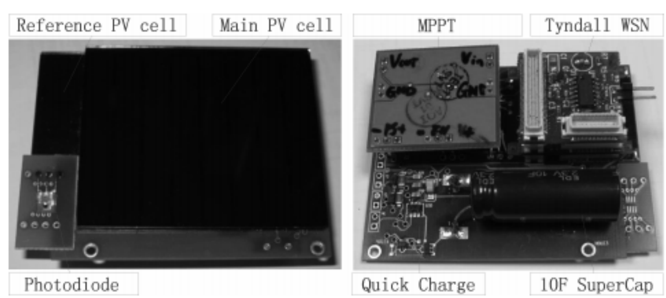

Fig. 6: Energy harvesting platform

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