MOBILITY 2015

The Fifth International Conference on Mobile Services, Resources, and Users

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MOBILITY 2015

Foreword

The Fifth International Conference on Mobile Services, Resources, and Users (MOBILITY 2015), held between June 21-26, 2015, in Brussels, Belgium, continued a series of events dedicated to mobility-at-large, dealing with challenges raised by mobile services and applications considering user, device and service mobility.

Users increasingly rely on devices in different mobile scenarios and situations. "Everything is mobile", and mobility is now ubiquitous. Services are supported in mobile environments, through smart devices and enabling software. While there are well known mobile services, the extension to mobile communities and on-demand mobility requires appropriate mobile radios, middleware and interfacing. Mobility management becomes more complex, but is essential for every business. Mobile wireless communications, including vehicular technologies bring new requirements for ad hoc networking, topology control and interface standardization.

We take here the opportunity to warmly thank all the members of the MOBILITY 2015 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 MOBILITY 2015. 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 MOBILITY 2015 organizing committee for their help in handling the logistics and for their work to make this professional meeting a success.

We hope that MOBILITY 2015 was a successful international forum for the exchange of ideas and results between academia and industry and for the promotion of progress in the areas of mobile services, resources and users.

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

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Table of Contents

Dealing with Uncertainty in Context-Aware Mobile Applications

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***Abstract*—The exploitation of context-awareness, especially in mobile devices bears a huge potential. For example, mobile workers benefit from systems that adapt security settings to the current situation. However, context-aware computing strongly relies on raw data from various sources that might be neither trustworthy nor authoritative. In this work, we present a context model that explicitly reflects security and relevance of context information sources in order to improve context detection. We introduce a security rating denoting the trustworthiness of the context information, i.e., its vulnerability to forgery, and a relevance rating denoting the source's decisive impact on context detection.**

Keywords–Context-Awareness; Context-Modeling; Security

I. INTRODUCTION

Context-awareness of software applications is still in its infancy although it has been researched since the beginning of the nineties. Recently, the rise of mobile technologies introduced a new class of devices with various sensors providing context information. For such devices, context-awareness can be particularly useful to adapt user interfaces or security measures to the current situation. For example, context-awareness enables more flexible control by limiting the applicability of security measures only to situations where they are indispensable.

An important building block for enabling context-aware security is context modeling. The user's contexts (i.e., his current activity and situation) have to be determined by aggregating (low-level) contextual information, such as current location, battery consumption, or connectivity of his mobile device. In order to provide reliable decision support, context descriptions have to be trustworthy and accurate.

To leverage the full potential of context-awareness for IT security, it is essential to identify security-relevant contexts and to reliably detect these contexts. Thus, the context evaluation must furthermore consider information about how easy it is to counterfeit contextual information.

To this end, a methodology for eliciting and modeling contextual information is needed that yields reusable and comparable context descriptions. In particular, this method must support the identification of suitable context information sources and the aggregation of low-level pieces of context information into an overall context description.

In this work, we present our context model and context descriptions that explicitly include a relevance and a security rating for each context information source. This rating enables us to provide quality statements for the accuracy of context detections. Security decisions benefit from the quality statements within a context description, aggregated during runtime.

The paper is structured as follows: Section II addresses related work in the area of context definition and context information modeling. Our context modeling approach is presented in Section III, followed by Section IV addressing uncertainty of context information sources. In Section V, we apply our approach to an example scenario. Finally, Section VI provides a summary and an outlook on future work.

II. RELATED WORK

This section provides an overview of the state of the art in context-awareness and context-aware computing. More specifically, the term *context* and its early definitions are introduced and different context modeling approaches are described.

A. Definitions of the term "Context"

The notion of *context* emerged over time, the earliest definitions in our sense originate in the early nineties. All of them share similarities, but they also show differences. We will present the most prevalent and influential definitions.

In 1994, an early definition was provided by Schilit et al. [1], stating that a context is characterized by three aspects: where you are, whom you are with, and what resources are nearby. Therefore, Schilit et al. infer that context-aware systems have to depend on the location of use, nearby people, hosts, and accessible devices, as well as on changes over time.

In 1997, Brown and Bovey [2] describe context similar to Schilit et al. but include temporal attributes, such as time of day, season, and temperature, as additional contextual information sources. In addition, the authors propose to enrich context by using additional (user-provided) information to obtain more valuable information for their application.

Hull et al. [3] describe context as "many aspects of a user's situation", such as "user identity, location, companions, vital signs, air quality, and network availability". Franklin and Flachsbart [4] focus on intelligent environments observing their users. They state that context-aware computing should consider the observed situation of the user. A similar description can be found in [5]. Ryan et al. [6] state that context should include location as well as states of external and internal sensors of the computer itself. Hence, they also consider virtual context sources such as the state of the software running on the device. Pascoe [7] also considers virtual context sources, but describes them as the states of the application and its environment rather than states of the computer itself. Pascoe et al. [8] reveal the more rich and complex nature of context and that context can be complex. Furthermore, in accordance with other publications, they state that context is more than just location. Hofer et al. [9] partition context information regarding its origin and differentiate between physical, virtual,

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and logical context information. Physical context information, such as location, acceleration or light intensity, can directly be measured by sensors. Such physical measures are described as low-level context sources that are continuously updated. Virtual information stems from user data or internal system data. The latter context category, logical context information, is obtained by combining physical and virtual context sources according to some abstract logical rules.

Our work does not introduce a new context definition; rather, we use a combination of existing definitions and descriptions of context. Similar to [9], we partition context sources into virtual and physical information sources, depending on the origin of the information, and we logically link them. As this work focuses on mobile devices and their users, activities of the user are an important aspect, as well as the operational state of the device. Thus, we define context as:

> *Context is the state of all context information sources (including virtual and physical sources) that characterize the activity of the user and the operational state of the mobile device in a specific situation at a certain time.*

B. *Modeling Context Information*

Context-aware systems strongly rely on the quality of the context information, which is usually represented in a context model. The modeling and provision of context information is very important to fulfill the desired task. In this work, context awareness aims at the enforcement and adaptation of flexible security policies on the mobile device and its applications. Different approaches for modeling context information have been suggested. In [10] and [11], the authors survey the most relevant approaches and classify them into five categories:

Key-Value Models are the simplest model for structuring context information. As such models provide no structuring of information, they are easy to manage. They are often used, although they provide only limited support for more sophisticated modeling [10][11]. Key-Value models allow easy querying by simple algorithms matching the key value pairs. The querying can be enriched by Boolean operators or wildcards for the matching algorithm.

Markup Scheme Models use a hierarchical structure of markup tags containing attributes and their values. A well-known example is the eXtensible Markup Language (XML). A markup scheme has been proposed, for instance, in [12]. In contrast to key-value models, markup scheme models provide a mechanism for structuring context information.

Graphical Models can strongly vary in their representation. The best-known representative is probably the Unified Modeling Language (UML), which is also suitable for modeling context, as shown in [13] or [14]. Such models are easy to understand for human beings, but often lack formality (except for UML). Henricksen et al. [15] present a context extension for the Object-Role Modeling (ORM) approach. An interesting aspect of their model is the differentiation between static context information (i.e., facts that remain unchanged as long as the entities they describe persist) and dynamic context information. They distinguish between contextual information that can be treated as property or constant attribute and changing contextual information such as location.

Object Oriented Models provide their information as a collection of objects that contain context information. Such models can employ all object-oriented modeling techniques such as encapsulation, reuse, or inheritance. The objects can represent different context types and provide interfaces for the retrieval and processing of their context information. Hofer et al. used such object oriented models for the Hydrogen context framework [9].

Logic Based Models use formal methods to specify context information and rules that can be applied to them. Hence, they usually provide a high degree of formality. Typically, in the reasoning process new facts can be derived based on known facts and a given set of deduction rules. Albeit being very formal and precise, profound logic-based modeling is quite hard and modeling given facts can become very complex. One such approach has been published in 1994 by McCarthy and Buvac [16].

Ontology Based Models are used to represent concepts and interrelations. They are a very promising instrument for context modeling, especially with the option to apply ontology reasoning techniques and automatic derivation of new relationships. A representative of this class of models is the Aspect-Scale-Context (ASC) model, which is based on the Context Ontology Language proposed by Strang et al. [17].

For further details, the reader is referred to two surveys: Baldauf et al. [11] survey existing context systems and frameworks, including their respective context models. Another survey by Bettini et al. [18] describes the state of the art in context modeling and reasoning. In summary, the decision which kind of modeling approach to choose can only be made by investigating the underlying application scenario and the context to be modeled. Regardless of the presented approaches, none of them consider the uncertainty in context detection and are thus unsuited for security purposes. In our work, we use a combination of the presented context modeling approaches (hybrid approaches) and extend them with two quality attributes to deal with uncertainty.

III. CONTEXT MODEL

Our context model specifies relations between the context, the user, and the mobile device. Figure 1 presents a macroscopic view of the core parts of our model and their interrelations.

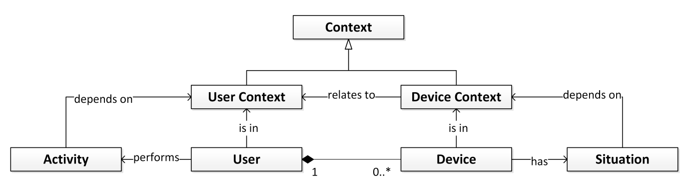

Figure 1. Context Model (Macroscopic Viewpoint).

A user can perform an activity at a certain time, and the user context depends on the performed activity. However, an activity change does not have to imply a context change. If we assume a user context such as *Traveling*, for instance, the user can perform several activities that belong to this context: *driving a car*, *riding a train*, *taking the plane*, or *walking*.

Hence, the relation between activity and user context depends on the granularity of the modeled user contexts and activities. Moreover, the technical abilities of the context information retrieval limit the detection options. In an ideal world, the user's activities and user contexts would always be congruent. However, the boundaries between certain activities are fluid and often cannot be determined by context information sources. Accordingly, the differentiation between activity and user context will persist. Hence, the context model has to cope with such uncertainties.

The situation of the device includes internal states of the device and attributes of the environment the device is in. Similar to the relation between activity and user context, device context and situation would always match in an ideal world. However, due to technical limitations, several distinct device situations lead to the same device context. It is apparent that the environment and internal states of the device can only be sensed by context information sources that are technically available. Thus, device context and user context must be detectable by existing context information sources, but are only approximations of the real world, neglecting unmeasurable information. In contrast, activity and situation strive to represent the world as it really is.

The core part of the context model is the context itself. The goal is to model the user and device context as an abstraction and aggregation of pieces of information obtained from various context information sources.

A. *Context Description Structure*

To model contexts, we use *Expressions* as generic statements that can be combined to form arbitrarily complex descriptions (see Figure 2). Expressions can be combined and nested in a way that the respective overall result is a Boolean value with additional ratings for security and relevance (see Section IV). We have a *GenericExpression* component that forms the basis for all other types of Expressions (arithmetic, comparison, and logic) and a *ConstantExpression* component holding a constant value. The Expression interface has a method for evaluating itself and a method for retrieving the return type. For type safety, it is important to have these type assignments, as a context description, at least in theory, could combine any expression type. However, there is a check whether the relation is allowed. For instance, a comparison between a Boolean type and a list of values would be rejected.

A specialization of the GenericExpression is the BinaryExpression, which allows exactly two subordinated expressions.

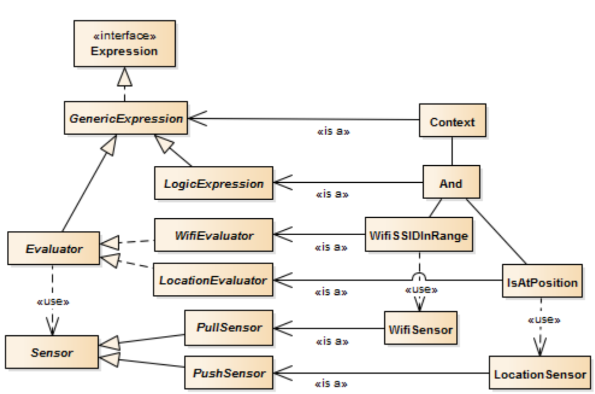

Figure 2. Excerpt Expression Model.

ComparisonExpressions, for instance, take exactly two sub-expressions for their evaluation.

ArithmeticExpressions are expressions for addition, subtraction, multiplication and division. For evaluating the expression, all assigned sub-expressions are joined by the appropriate operation. In general, ArithmeticExpressions can contain an unlimited number of nested expressions.

Similar to ArithmeticExpression, a *LogicExpression* can take an unlimited number of nested expressions for evaluation. For the moment, *and*, *or*, and *not* with their usual semantics have been implemented. Future extensions could include fuzzy logic or other evaluation capabilities.

The *EvaluatorExpression* can express various behaviors, for example, by using comparisons or arithmetic operations. The remaining task is to obtain concrete data from the system under observation. This is done by *Evaluators*.

Evaluators provide an abstract representation for context information sources, which usually deliver low-level information, such as the current coordinates of the Global Positioning System (GPS) or acceleration values. Each evaluator can be configured by several parameters that influence its behavior. Evaluators can be included as sub-expressions at arbitrary locations within the presented structure.

An evaluator encapsulates one or more context information sources. In general, we distinguish between push and pull behavior, based on the characteristics of the underlying sensors the Evaluator encapsulates. Some sensors can be configured to push new information as soon as new data is available (e.g., acceleration or location sensors). Other sensor information has to be pulled to obtain current information (e.g., mobile device settings, calendar). Hence, the configuration depends on the sensor type. Pull sensors contain a *scheduleInterval* parameter specifying the frequency of data updates. For example, wireless network information can be requested every five minutes.Push sensors usually contain parameters to configure conditions when data updates will be delivered. For example, the location sensor will only deliver new information if the mobile device location changed by at least a specified distance.

Our preferred format for a context description is XML (see Figure 3). The context id attribute is mandatory and has to be unique, as it is used to reference the context. In general, a configuration can contain several expressions of types arithmetic, comparison, or logic (future extensions could extend the list of available expression types).

The specification in Figure 3 includes two different evaluators: a GenericLocation evaluator for checking a specific location and a WiFiIsSSIDInRange-Evaluator to scan for specific wireless Service Set Identifiers (SSID). The location evaluator consumes the following parameters: location values (i.e., *latitude* and *longitude*), *distance* (specifying the data delivery and distance accuracy), *provider* (location information from network and/or GPS) and *maxAge* (allowed data age for evaluation). The wireless evaluator uses the parameter *ssid* to scan for this specific wireless SSID. The listing also shows an example of arithmetic expressions and comparisons. Evaluators may contain a relevance and a security rating, which are described next.

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```
<context id="example-context">
  <logic:and>
    <logic:or>
      <evaluator name="GenericLocation" relevance="5">
        <param name="latitude" value="49.431479"/>
        <param name="longitude" value="7.7520288"/>
        <param name="distance" value="15.0"/>
        <param name="provider" value="0"/>
        <param name="maxAge" value="3600"/>
        <param name="resultType" value="boolean"/>
       </evaluator>
       <evaluator name="WiFiIsSSIDInRange" relevance="3">
         <param name="maxAge" value="60"/>
         <param name="keepEnabled" value="true"/>
         <param name="scheduleInterval" value="15"/>
         <param name="ssid" value="wlan-home"/>
         <param name="resultType" value="boolean"/>
        </evaluator>
    </logic:or>
    <!-- Arithmetic demo: 2*2*4 >= 10+(36/6) -->
    <comparison:greaterEqual>
      <arithmetic:multiply>
        <constant type="double" value="2"/>
        <constant type="double" value="2"/>
        <constant type="double" value="4"/>
      </arithmetic:multiply>
      <arithmetic:add>
        <constant type="double" value="10"/>
        <arithmetic:divide>
          <constant type="double" value="36"/>
          <constant type="double" value="6"/>
        </arithmetic:divide>
      </arithmetic:add>
    </comparison:greaterEqual>
   </logic:and>
</context>
```

Figure 3. Evaluator Example.

IV. Dealing with Uncertainty

We introduce two quality metrics to address uncertainty of contextual information: a *security rating*, denoting the difficulty for an adversary to counterfeit the measurement of the context information source and a *relevance rating*, expressing the value of the context information source for the identification of the overall context.

A. Security Rating

Every evaluator has a security rating assigned to it. The rating takes the values from one (very low) to five (very high). Basically, the security rating denotes the trustworthiness of the context information, i.e., its vulnerability to forgery. The security rating within our work is defined as follows:

> *The Security Rating is a global indicator expressing difficulty and challenge for an adversary to counterfeit a context information source.*

The following guidelines are used to rate an evaluator. A security expert or group of experts have to perform this task when an evaluator is developed. The experts have to assess the necessary preconditions for a successful counterfeit context information source:

(i) insider knowledge or configuration details
(ii) special expertise or knowledge to perform the operation
(iii) special software or application
(iv) special hardware or equipment
(v) influence on information source (backend or environment change)

Based on these prerequisites, the metric to determine the rating for every evaluator is defined as follows:

- **1 (very low)**: 0 out of 5 prerequisites needed
  It is easy to counterfeit the measured values (e.g., just change or enter the value). An example for such a rating is the time of the mobile device or calendar entries of the user.
- **2 (low)**: 1 out of 5, but not prerequisite (iv)
  The manipulation of the sensed value can be done with little effort. An example is to simulate a high light intensity with a torch or to shake the device to forge acceleration values.
- **3 (medium)**: 2 out of 5 OR 1 out of {(iii), (iv), (v)}
  Some preparations are required, but they are not really challenging. An example would be faking the SSID or BSSID of a WiFi hotspot, which can directly be done by using a second smart mobile device.
- **4 (high)**: 3 out of 5 OR 2 out of {(iii), (iv), (v)}
  The required measures are challenging for an adversary, and without special knowledge, it would not be possible to perform the attack. An example is to simulate that the device is connected to an encrypted (mobile) network.
- **5 (very high)**: 4 out of 5 OR 3 out of {(iii), (iv), (v)}
  Forging of context information sources requires deep knowledge about the internal configuration and significant expertise; moreover special equipment is needed, such as software and hardware. An example is the GPS sensor or cell phone tower information, for which an attacker would need special hardware and knowledge how to use it.

The security rating has to be defined once, and it has a global scope for every instantiated context tree. However, it is possible to manually change the rating by explicitly setting it in the evaluator tag of the context description. For example, the security rating of a virtual context information source can vary according to its trustworthiness. A read-only enterprise calendar will be much harder to counterfeit than the personal calendar maintained by the user itself. Hence, we can manually assign a higher security rating to the evaluator using the read-only enterprise calendar.

B. Relevance Rating

Every evaluator has a second rating assigned to it, expressing the contribution of the context information source to the overall context identification. Similar to the security rating, it accepts values from one (very low) to five (very high). The rating represents whether the provided information tends to be decisive or has a less authoritative impact on context detection. The relevance rating is defined as follows:

> *The Relevance Rating is a local indicator expressing the correlation of a context information source with an activity, or situation.*

This rating depends on the modeled context, but also on the quality of a sensor and cannot be specified by just following generic guidelines. The retrieval of the relevance rating is part of the automatic derivation of context descriptions [19]. Essentially, we use different statistical methods to correlate

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sensor data with activities and use the results (e.g., a correlation matrix) to determine the relevance of a sensor for the characterization of an activity or situation. Furthermore, we use the calculated results to define the structure of our context descriptions.

C. Context Evaluation

The evaluation result of a context is obtained by evaluating the tree structure of the context description. The logical operators have their standard meaning.

- **OR**-relation: $A \vee B$ is true if A is true, or if B is true, or if both A and B are true.
- **AND**-relation: $A \wedge B$ is true if A is true and B is true.
- **NOT**-relation: $\neg A$ is true if A is false.

The calculation of the relevance and security rating for a context is as follows:

- **AND/OR**-relation: All fulfilled quality attributes of the elements in an AND/OR group affect the overall relevance or security rating. They are summed up to the denominator. The quality attributes of all evaluators that are actually fulfilled in the system under evaluation are summed up to the numerator.
- **NOT**-relation: The quality attribute of the element is propagated to the parent node, if the subordinated expression is false.

The quality attributes ensure that the fulfillment of those evaluators with highest relevance or security rating has the strongest impact on the overall result. The security policy specification bears responsibility for defining suitable thresholds for the security and relevance ratings that are sufficient to trigger a change of the security settings. Furthermore, the decision strongly depends on whether to tighten or to ease security restrictions.

V. Application Scenario

Our approach has been applied in a company which administrates mobile devices via the mobile device management (MDM) solution *MobileIron*. Via MobileIron, they adjust security settings (e.g., to impose password restrictions or storage encryption, to install or revoke certificates for virtual private networks, or to disable camera or microphone), and perform actions such as sending messages to the user or wiping the device. However, these settings and actions are rather static and cannot be adapted according to the current operational state of the device or the user activity. In this setting, context-awareness can provide more flexibility. For example, camera and microphone usage can be prevented within company premises, but allowed elsewhere. However, when used for security purposes, context detection has to be accurate and reliable in order to comply with company regulations.

MobileIron provides different types of policies and a label mechanism to assign policies to mobile devices. *Security policies* control security behavior such as password restrictions of the mobile device; *lockdown policies* limit the use of the mobile device such as disabling Bluetooth, camera, or microphone. We specified two security policies ($security1$ and $security2$) and three lockdown policies ($lockdown1$, $lockdown2$, and $lockdown3$), which are shortly described in the following.

TABLE I. Security Policies

	security1	security2
Maximum Inactivity Timeout:	30 min	2 times
Maximum Number of Failed Attempts:	3 min	5 times

TABLE II. Lockdown Policies

	lockdown1	lockdown2	lockdown3
Bluetooth:	Disable	Enable (Audio only)	Enable
Camera:	Disable	Enable	Enable
Microphone:	Disable	Enable	Enable
NFC:	Disable	Enable	Enable
Screen Capture:	Disable	Enable	Enable
Lockscreen Widgets:	Disable	Enable	Enable
USB Debug:	Enable	Disable	Enable

In Table I, $security1$ has higher priority than $security2$. Hence, if both policies are activated, security1 would be used. In Table II, the lockdown policies have the following priorities: lockdown1 $>$ lockdown2 $>$ lockdown3.

Despite the policies, we specified multiple labels: $default\_label$, $work1\_label$ (tighten security), $work2\_label$ (ease security) and $home\_label$. The assignment of policies to labels is depicted in Figure 4.

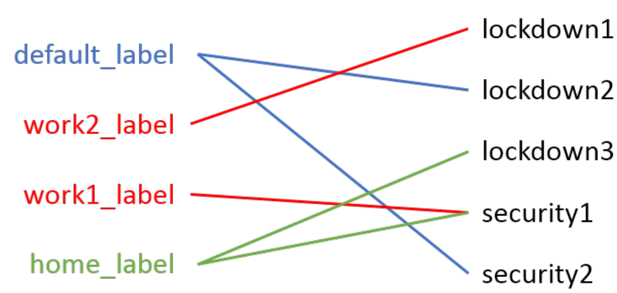

Figure 4. Mapping between Labels and Policies.

In the described setting, two contexts are of relevance: “Home” and “Work”. Both contexts are modeled by using wireless, location, calendar, and time evaluators. Figure 5 illustrates the context tree for the “Work” context c_1, including all assignments for the security and relevance ratings. As the security rating has a global scope for each evaluator type, the value does not change within the same type of evaluator. In contrast, the relevance rating changes, depending on the results from the statistical calculation.

For example, the wireless network *wlan-staff* has the highest statistical significance (correlation result), followed by *wlan-guest* and *wlan-extern*. This is reflected in the final relevance ratings of the wireless evaluators. *wlan-staff* is the employer’s wireless network and has the highest relevance. The calendar seems to be a relevant context factor, but as users usually do not schedule their entire working day in the calendar, the calendar evaluator has the lowest relevance. Similar behavior holds for the time evaluator. The company has flexible working hours, but the core working hours are between 09:00am to 4:00pm. Hence, users arrive earlier or stay longer at work, to reach their daily working time. Nevertheless, the time evaluator is more relevant than the calendar evaluator.

The company has defined several policies assigned to the

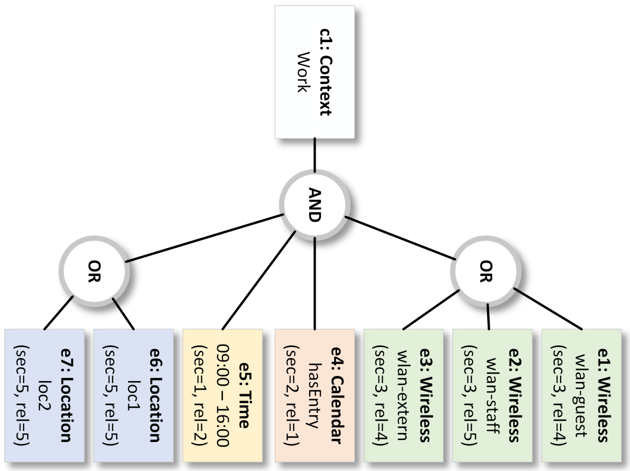

Figure 5. Context Tree Example for Context “Work”.

“Work” context, on which we focus in the following. On the one hand, there are policies easing security restrictions of the mobile device at work (in favor of usability). For example, the company increases the display timeout at work to thirty minutes for usability reasons ($work1\_label \rightarrow security1$). On the other hand, there are policies tightening the security at work. For example, the company prohibits the usage of camera, microphone, etc. at work to meet organizational policies ($work2\_label \rightarrow lockdown1$). The idea is now to define appropriate thresholds to reflect company needs.

To tackle this, we calculated the following cases:

- Context c_1 is $true$ with highest relevance $\rightarrow 1.00$
- Context c_1 is $true$ with lowest relevance e_1, e_4, e_5, e_6 are $true$ $\rightarrow 0.46$
- Context c_1 is $false$ with highest relevance $e_1, e_2, e_3, e_5, e_6, e_7$ are $true$ $\rightarrow 0.96$
- Context c_1 is $false$ with lowest relevance $\rightarrow 0.00$

Hence, the relevance range for c_1 $is\ true$ is between 0.46 and 1.00, and for c_1 $is\ false$ is between 0.00 and 0.96. Analogously, we calculated the security rating for c_1. Figure 6 shows our policy state chart and the state change criteria to activate and deactivate the policies. To change the states by using the relevance and security rating, as well as the fulfillment of the context, allows us to model hysteresis behavior. For example, changing from the state $work1\_label$ (inactive) to $work1\_label$ (active) is harder than changing from the state $work1\_label$ (active) to $work1\_label$ (inactive).

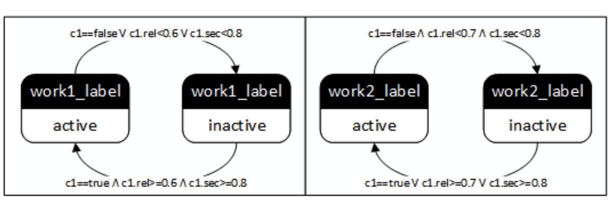

Figure 6. Policy Statechart.

For instance, assume that $work1\_label$ is inactive, the evaluators e_1, e_4, e_5, e_6 are true, and the evaluators e_2, e_3, e_7 are false. This results in context c_1 to be true. However, the relevance is only 0.46 and the security is only 0.50, which would prevent the change from inactive to active. Hence, we need at least one more evaluator changing its state to true for reaching the relevance threshold and even one more for reaching the security threshold. Vice versa, let us suppose that $work1\_label$ is active and the evaluators have the same state as before. Although c_1 is still fulfilled, we would make the change as the ratings are below the defined thresholds of 0.60 (relevance) and 0.80 (security).

A. *Lessons Learned*

The practical application was performed by two of our internal researchers, as they had to manually observe the mobile devices. For our case study, we used a Samsung Google Nexus 10 running Android 5.1 and a Samsung Galaxy Tab (SM-P600) running Android 4.4.2. Both devices were added to the MDM solution. We made several observations in our practical application, which we describe next.

Some sensors have uncertainties and inaccuracies in their measurements. In our scenario these are the location and the wireless sensors. We configured the wireless sensor to scan for specific wireless networks every five minutes. However, the sensor occasionally misses some wireless networks although the networks are available. If we measure for a specific wireless network ten times, the sensor will miss this specific network one to two times. Hence, we have a failure rate of 10 to 20 percent in our measurements. Let’s assume our context “work” c_1 is fulfilled and $work1\_label$ is active as well as $work2\_label$ is active. The affected wireless evaluators are e_1, e_2, e_3. All other evaluators are assumed to be fulfilled, i.e., working correctly. As they are in OR-relation, all three have to provide a wrong measurement to yield an overall evaluation result of c_1 that is wrong, which did not happen during our evaluation period. Evaluator e_2 has the highest impact on the relevance and security ratings. If the evaluation of e_2 fails, the relevance rating is at 0.81 and the security rating is at 0.86. Both ratings are above the specified thresholds to trigger a state change for the labels $work1\_label$ and $work2\_label$. The failure of an additional wireless evaluator, for instance e_1 or e_3, puts the ratings to 0.65 (relevance) and 0.73 (security), which are below the thresholds. Such ratings result in a change of $work1\_label$ from active to inactive, which is uncritical as it tightens our security settings. Regarding $work2\_label$, we will stay in the active state, as the overall context c_1 is still true, which is also uncritical. To trigger a state change, we would need all three evaluators to fail, which did not happen during our evaluation period, as already mentioned.

Regarding the location evaluation, we observed that we have some uncertainties in the location evaluation of e_6 and e_7 when people are entering the specified locations. Such location changes usually happened in the morning, when people arrived at work, and after noon, when people came back from lunch outside the company. The reason for detection failures is the inaccurate location fix after a location change. The Android location services return a coarse grained location, which is outside our specified locations for the evaluators. Let’s assume our context “work” c_1 is not fulfilled and $work1\_label$ is inactive as well as $work2\_label$ is inactive. The affected wireless evaluators are e_6, e_7. All other evaluators are assumed to be fulfilled, i.e., to work correctly. To trigger a state change, both evaluators have to be evaluated to true. Regarding

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$work1\_label$, it is uncritical as we are remaining in the high security settings; however, $work2\_label$ is critical. As we configured to receive a location fix latest every five minutes and after location changes greater than fifteen meters, we may stay five to ten minutes in a wrong state. However, as the Android location services pushes new information after the location fix, we observed to stay less than five minutes in the wrong state.

We modeled all evaluator groups in AND-relation, which was a bad decision regarding the time and calendar evaluators. As the working hours was given between 09:00am and 04:00pm, e_5 was also configured to be true in the specified interval. However, people usually do not completely stick to these working hours. We observed that $work1\_label$ stayed too long in state inactive (starting working before 09:00am) or changed from active to inactive too early (working longer than 04:00pm). Similar observations were made for the calendar evaluator e_4. We learned to model evaluators lower relevance rather in OR-relation than in AND-relation. However, we have to gain more experience to make a final decision.

VI. Conclusion and Future Work

We presented a model for representing security-relevant contexts as context descriptions. The model contains a security rating for each evaluator to quantify the overall trustworthiness of the context description during runtime. In addition, the model provides a relevance rating expressing the conduciveness of a context information source to the overall context. The context descriptions enable context-aware security decisions by referencing them as a decision criterion in security policies.

Future work will investigate potentials to return additional data types as an overall context result. Enriched context types facilitate the use of contextual information in the decision making process and improve expressiveness for security policy specifications. Presently, context descriptions are specified manually before being activated and are therefore rather static. Future work will investigate how context descriptions can be parametrized at runtime. This may include the use of context results as parameters for other context descriptions.

Regarding the security and relevance rating, we will further extend our evaluation criteria. We realized that faking the presence of contextual information can be easier in some cases then faking its absence (e.g., it is easier to simulate the SSID of a wireless access point than jamming the beacons from an existing one). Finally, we will explore the inclusion of accuracy information into our model as an additional quality attribute for judging the reliability of context information.

Acknowledgment

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Position Estimation for People Waiting in Line Using Bluetooth Communication

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***Abstract*—Unpredictable wait time at such places as bus stops, banks, and amusement parks is likely to create frustration to people in line. So far, efforts have been focused on estimating and displaying the wait time of users or customers in line. In most cases, the time has been estimated by counting the number of people waiting in line. It is not cost-efficient, however, as the method requires human resources or installation of expensive equipment. Moreover, the method can only provide the wait time for the last person in line, and cannot deal with such problems as fluctuations caused by wait time due to the latency of service. Therefore, it is desirable to extract the wait time corresponding to each person's position in line, without relying on human resources and equipment. This paper proposes a position estimation method based on the relative positions of users in line, using mobile terminals and a position management server. The devices held by the users are classified into groups depending upon their positions. Specifically, the device at the front of the line detects other devices using Bluetooth communication, and then places them into a second group. In the same way, devices in the second group detect the following devices and assign them to a third group. When this process has been repeated, the relative positions of terminals are identified. In addition, the Received Signal Strength Indicator (RSSI) values are also collected from Bluetooth communication to restrict the number of devices in each group. While generating smaller, subdivision groups, the nearby devices are picked out from the closest ones having strong RSSI values. As a result of experiments, the terminal's position has been estimated with an accuracy of 94.2% in a typical scenario.**

Keywords–Relative Positioning; Mobile Phone; Bluetooth; Location; Waiting in Line.

I. INTRODUCTION

In a crowded urban city, there are many occasions when waiting in line might increase frustration of people in their everyday lives. Lines form constantly at entrance gates to amusement parks, security gates at the airport, department store doors during sales, or occasionally at train stations and bus stops. Companies and stores that provide products and services are also concerned about wait time, as it is one factor affecting customer satisfaction. Houston states that there is a strong negative correlation between waiting time and a customer's evaluation of the quality of a service [1]. Maister addresses the fact that customer waiting at the store is the most important factor affecting customer satisfaction, and states eight rules regarding waiting time [2]. He states that customers are likely to be stressed and feel that the wait time is longer than the actual time if the wait time is unpredictable.

Considering these circumstances, if the waiting time in line is provided to the customer, it might be possible to reduce stress and raise customer satisfaction. There are various approaches to extract the waiting time. For example, by considering the number of people in line or the time taken to provide the service. The number of people can be calculated by counting them while in line, or estimating the number of people from the length of the line. There are also methods to estimate the wait time employing special equipment. Queuing time estimation system [3], for example, calculates the wait time automatically by extracting the length and moving speed of the line from the images of surveillance cameras. It is not cost efficient, however, as it requires human resources to count the number of people and the installation of special equipment on site. Moreover, the wait time can change due to the latency of providing the service. Furthermore, it can only estimate the wait time of the last person in line, and cannot easily estimate the wait time for all customers in the line.

Two points must be considered in order to estimate wait time according to location in line: estimating the position of customer in line, and estimating the time for providing the service. Here we focus on estimating the position of each person in line. The location of each person in line can be estimated by generating groups of terminals according to the Received Signal Strength Indicator (RSSI). RSSI is extracted from wireless communication hardware of customers' mobile terminals, and groups are assigned sequentially. Bluetooth has been used as the wireless communication technology in our work; however, the authors believe that the proposed algorithm works with other communication technologies as well. Note that the geographical locations of people are not determined absolutely, but rather we determine their relative location within the line. An experiment has been conducted to verify the effectiveness of the proposed method.

This paper is organized as follows. Section 2 describes the estimation of wait time in line and relative location using Bluetooth communication. The method for estimating the location in line is presented in Section 3. Section 4 presents the evaluation results and discussion, and Section 5 concludes the paper and suggests future work.

II. RELATED WORKS

Related work concerns the estimation of wait time and user location for lines of people.

A. Wait Time Estimation in Line

Most existing work on estimating the wait time or monitoring the line are conducted by installation of fixed devices such as cameras [4], infrared sensors [5] and floor mats [6] on site. These systems focus on macroscopic movement of pedestrians in both single or multiple lines, and usually require preparation and installation of single or multiple special devices. Such systems can provide information such as the length of the entire line, the average wait time, and the fastest lane among multiple lines. This overall line information is only useful for passengers before deciding to wait in line. Those already waiting in line are more likely to appreciate information about

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their precise location in line and the time it will take until the service is provided.

Other research has focused on estimating the wait time from the user's mobile terminal instead of installing special devices or using human observers. LineKing [7] employs the users' carry-on devices and a data aggregation server, and estimates the wait time by measuring the number of people in line. The number of people is estimated by observing the terminals within a radius of 50m–100m of the line, and terminals that leave the area. To determine the terminal location either GPS, or the distance from a base station or access point, is used. However, errors of predicted wait time may occur as the estimated number of people differs from the actual number of people in line, because this method detects all terminals within a radius of 50m–100m. To reduce the rate of error, it is necessary to measure the wait time beforehand. The error can be reduced to between two and three minutes if the measured wait time and the detected data are used together, but it requires effort to measure the wait time before the system is launched. The order of people waiting in line cannot be extracted. Therefore, it is difficult to obtain the wait time for a specific location in line.

Wang [8] investigates smartphone WiFi signals to track people waiting in line by installing a fixed monitoring device near the service area. Some experimental scenarios and analyses show that monitoring WiFi signals from a fixed device enables estimating total wait time in a queue and distinguishing different phases such as waiting, service and leaving periods. If the line is not too long, WiFi communication distance may be wide enough to cover the entire line, however, this method cannot estimate the location and wait time for each individual in line.

B. Estimation of Relative Location

Some work has focused on the features of Bluetooth RSSI to estimate the relative location of users. Maekawa estimates a train user's car number and the congestion of the train by extracting the RSSI from the user's personal devices [9]. They look at the changes of RSSI due to train doors, distance, and intervening people in order to determine whether or not the user is in the same car as other users. Other work recognizes relative location by aggregating RSSI and user movement traces at gathering places such as special event sites [10]. Exploiting the fact that weak signals beyond 6km will not be detected, they classify nearby and distant devices with high accuracy. This work estimates relative location from the features of RSSI fluctuation caused by obstacles, but the situation of people waiting in line is not considered.

Luciani and Davis have performed experiments to find a correlation between RSSI values and distance in a grassy field, on a concrete surface, and in a hallway with various elevations [11]. There seems to be a tendency for RSSI value to decrease proportionally with increasing distance. However, the variance of the RSSI tends to increase considerably with an increase of distance. The RSSI value for 1m to 2m indicates a strong signal that settles in the range of −60dBm to −80dBm, while the RSSI values for distances over 2m are widely scattered in the range of −80dBm to −100dBm. Thus, it seems difficult to deal with the entirety of long lines since the RSSI value is not a reliable measure of large distances. However, it seems highly accurate to measure short distances

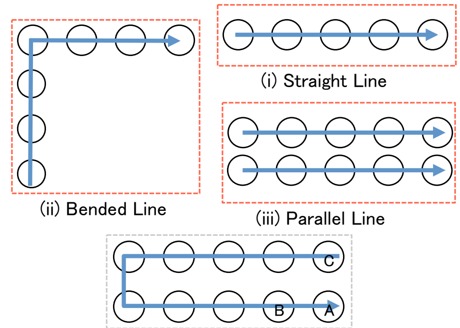

Figure 1. Types of Line Formation

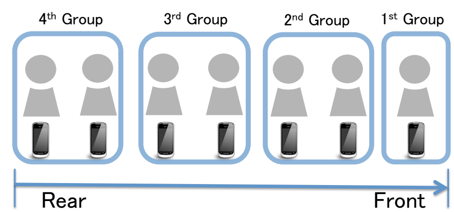

Figure 2. Groups Subdivision for Location Estimation in Line

up to approximately 2 meters, which is sufficient to detect the device of a person in front or behind.

In this paper, we explore a method to estimate location considering RSSI and the relative positions of people waiting in line. The proposed method is not intended to extract the geographic location of users, but rather deals with their relative locations.

III. Location Estimation in Line

This section describes our method to estimate location in line and its implementation.

A. Environment Settings

There are various types of line, as shown in Figure 1, such as: (i) a straight line, (ii) a curved or bent line, (iii) two parallel lines, and (iv) a line that turns back upon itself. In (iv), the RSSI of terminals B and C, as received by A, are almost the same when the distance to those terminals is the same. The proposed method generates groups using the RSSI between pairs of terminals, thus it is difficult to estimate locations for the line in (iv). We therefore focus on lines which do not turn around, such as in (i)–(iii).

The proposed method uses Bluetooth communication to detect devices in the line. Therefore, all of the Bluetooth devices in the line are assumed to be in Discoverable mode, which allows other devices to detect them.

B. Location Estimation Method

The location estimation is performed with user terminals and a location management server. The relative location is determined by dividing terminals into groups, from the front to the rear, as shown in Figure 2. The location estimation method to determine the relative location is shown in Figure 3. The first terminal in line determines the base of location estimation.

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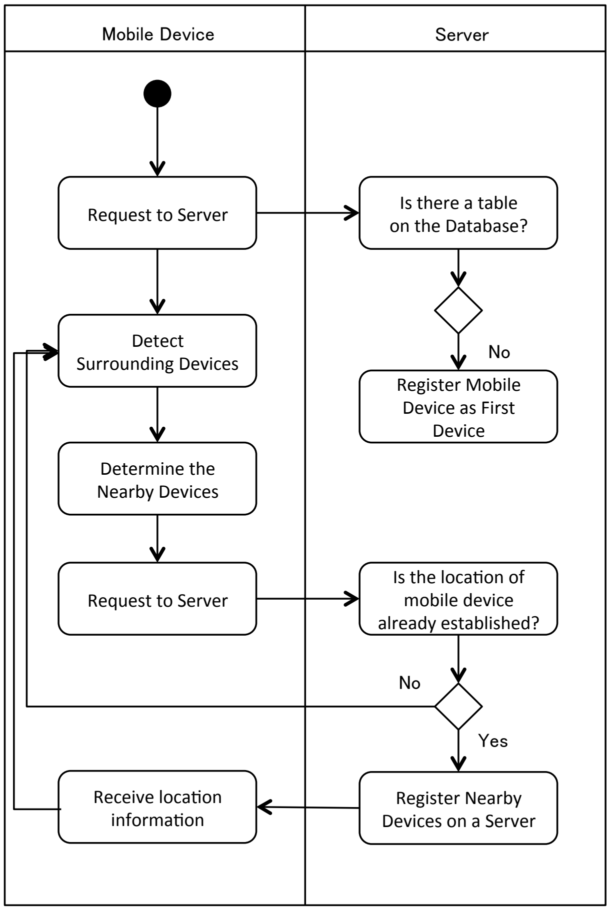

Figure 3. Location Estimation Method

It is assumed to be the first terminal to join a server in which no other terminals with location information are yet registered. Next, the first terminal detects nearby terminals, and registers them on the server as a second group. Then, the second terminal group performs the same process, and registers a third group. This process is performed repeatedly, until the relative locations of all terminals have been determined.

Bluetooth is used to detect nearby terminals. The maximum value for signal strength is determined by each device's Class, and the approximate range of communication is known for each Class, as shown in Table I. The approximate distance is calculated from signal strength. Mobile terminals usually fall into class Class 1 or Class 2. Devices within approximately 5m can be detected even though there are human obstacles. However, if all of the detectable terminals are registered as the next group, the group will have too many terminals and location accuracy might fall. Therefore, it is necessary to classify detected devices as 'nearby devices' and 'other devices', and register only the nearby devices as the next group.

C. Classification of Nearby Devices

The RSSI between pairs of terminals is used in order to distinguish nearby devices from other devices, and the nearby devices are added to the next group. RSSI has the following features.

TABLE I. REACHABLE DISTANCE OF BLUETOOTH COMMUNICATION

	Class 1	Class 2	Class 3
Reachable Distance	100m	10m	1m

RSSI value generally decreases proportionally to the square of distance, but human obstacles and the surrounding environment can greatly weaken the signal strength. In addition, the RSSI differs depending upon the types of user terminal (e.g., mobile phone brand). As the Bluetooth Class indicates the maximum RSSI value, the user terminal will be classified with an appropriate Class with according to the RSSI value irrespective of the type of terminal. Some terminals in the same Class have different RSSI values. Therefore, it is impossible to determine whether or not the terminal is within the designated distance shown in Table I or to assign the threshold of RSSI in such situations.

In this paper, we aim to identify the nearby devices from the RSSI. The signal of terminals in a line can be received several times, and the average RSSI calculated. The terminals with a relatively large RSSI are assigned as nearby devices. This process limits the number of terminals in each group, and enables accurate determination of location.

D. Experiment Settings

There are several steps in our method, namely, detecting the surrounding terminals, choosing the Nearby Devices among the detected terminals, and designating the terminal's location in line.

Detection of Surrounding Terminals

Bluetooth functionality is used to scan for the surrounding terminals. When a new terminal is detected, the Bluetooth MAC address, RSSI, detection time and detection count are registered in the database (SQLite) installed in users' terminals. If the detected terminal has already been registered, the RSSI and detection counts are updated.

Let $AvgRSSI$ be the average RSSI, $Count$ be the number of times a device has been detected, and $InRSSI$ be the incoming newly-received RSSI value, then the average RSSI is calculated by equation (1), and the database is updated.

$$AvgRSSI = \frac{(AvgRSSI \times Count) + InRSSI}{(Count + 1)} \quad (1)$$

After the detection of terminals in range, the next step separates nearby devices from other devices.

Determination of Nearby Devices

Nearby Devices are chosen among all of the detected devices one minute after the first detection. A one-minute interval is necessary because without the interval only a few values of RSSI may be sampled, which is not enough to decide whether or not it is a nearby device. The four devices having the highest average RSSI are assigned as Nearby Devices. In other words, the two terminals in front of and behind each terminal are assigned as Nearby Devices. The first terminal, however, has no terminal in front of it and therefore only the top two terminals are assigned as Nearby Devices. After

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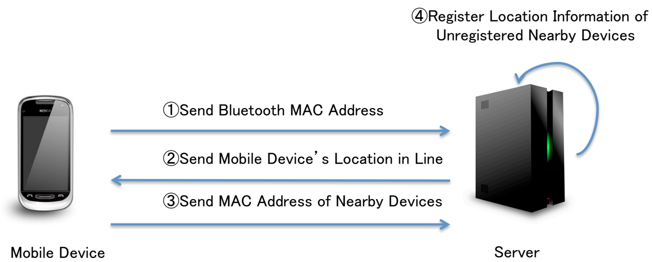

Figure 4. Process for Designating Location in Line

the assignment of Nearby Devices, the next step identifies locations.

Designation of Location in Line

The location management server stores the MAC address of terminals, and their locations once determined. The process for determining location is shown in Figure 4.

Terminals send their MAC addresses to the server. If the location of the terminal is known then the server responds with the terminal's location in line; otherwise the server registers the MAC address but does not yet respond. When a terminal receives its location information it responds to the server by sending the MAC addresses of its Nearby Devices, which allow the server to determine the location information of the following group. Any of these Nearby Devices that do not yet have a location must be behind the terminal in the line (those in front have already been assigned a location) and belong to the following group. The server therefore assigns that location to those terminals and informs them about their location. They in turn respond with their Nearby Devices, and the process repeats continuously to determine sequentially the location of all terminals in the line.

IV. Evaluation of our Proposed System

An experiment has been conducted in order to verify the accuracy of the location in line, by comparing the actual location and the location determined by the proposed method.

A. *Method of Experiment*

All of the terminals are assumed to be in Discoverable mode, as explained in Section III-A. Under such conditions, if there is an existing terminal running the system within the detectable range of Bluetooth, the location can be estimated even though not all of the terminals are running the system. However, this experiment has been conducted in a desirable situation in which all of the terminals are running the system, in order to verify the efficiency of the proposed method. As shown in Figure 5, the experiment has held in an outdoor environment, where six users holding an Android terminal stand in line at intervals of 0.5m. We cannot prepare the same model of Android terminal, so different terminals were used as listed in Table II. The first person in line runs the system and registers as the first terminal on the server, and then the other terminals run the system consecutively. The experiment concludes when all of the location information of the terminals has been registered by the server. The experiment was performed seven times.

Figure 5. Experimental Environment

TABLE II. TYPES OF TERMINALS USED FOR EXPERIMENT

Terminal Number	Terminal Model
1st terminal	Galaxy Nexus
2nd terminal	Nexus 5
3rd terminal	Xperia A
4th terminal	Nexus S
5th terminal	Galaxy Nexus
6th terminal	Galaxy Nexus

TABLE III. THE RESULT OF CHOSEN NEARBY DEVICES

Loss Count	False Detection Count	Number of Trials
4	10	35

TABLE IV. THE RESULT OF NEARBY DEVICES FOR EACH TERMINAL

	1st	2nd	3rd	4th	5th
Loss	0	0	1	3	0
False Detection	0	1	1	5	3

B. *Experiment Results*

It is important to choose the Nearby Devices correctly in order to estimate locations accurately. Thus, the results are analyzed in two ways: for correctness of choosing Nearby devices and for accurate estimation of location.

1) Correctness of Choosing Nearby Devices: The two devices in front and behind are examined to verify the correctness of choosing Nearby Devices. We examine the correspondence between the Nearby Device information aggregated on the server and the actual nearby terminals. The first five terminals chosen as Nearby Devices are analyzed in this experiment.

The correspondences are shown in Tables III and IV. Table III shows the overall result of terminal information aggregated on the server, and Table IV shows the result for each terminal individually. "Loss" refers to terminals which were supposed to be (but were not) identified as Nearby Devices, and "false detection" refers to incorrect detection of a remote terminal that was more than two terminals away.

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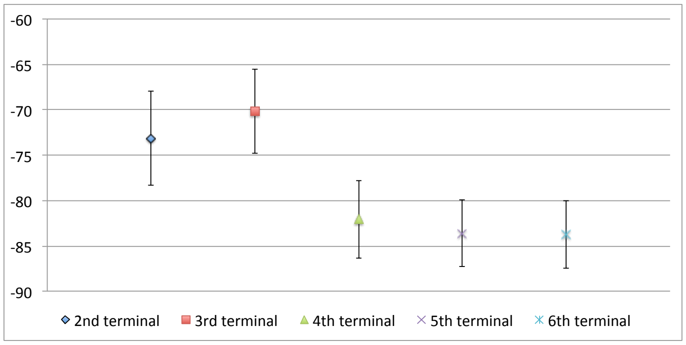

Figure 6. Average RSSI Received by the 1st Terminal

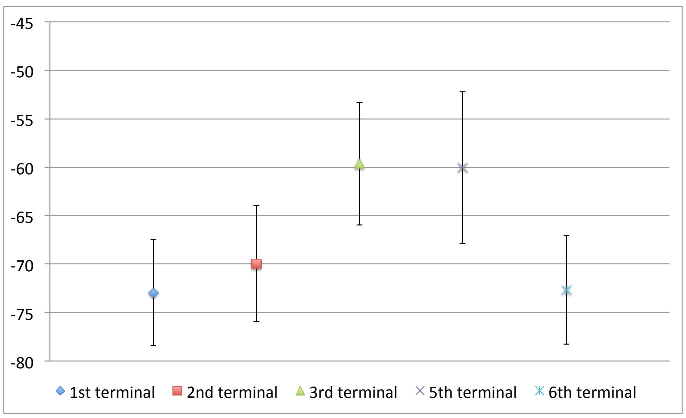

Figure 7. Average 4th Terminal RSSI Received by the Other Terminals

The RSSI values received from each terminal are also analyzed, as they are used to pick out the Nearby Devices. The average RSSI values that the first terminal received for the other five terminals in line are shown in Figure 6. The fourth terminal in the line was the one most often incorrectly detected as a Nearby Device by the other terminals; Figure 7 shows the RSSI of the fourth terminal as received by the other five terminals in the line.

2) Location Estimation Accuracy: When the proposed method is properly performed, the groups are classified as shown in Table V and the sequential order for each terminal can be assigned. The correct location (Table V) and the location determined by the server are compared in Table VI. The result for the first terminal is omitted as it is automatically registered by the server as the first group and the first terminal in line. The number of trials for the 2nd and 3rd Groups differs from that of the 4th Group because the number of terminals included in a Group varies.

The result shows that the 2nd and 3rd Groups are formed correctly. However, the 4th Group was incorrectly included in the 3rd Group twice, because a 2nd Group terminal determined the last (6th) terminal as a Nearby Device. The overall result shows that the proposed method determines location with an accuracy of 94.2%.

TABLE V. GROUPING OF PEOPLE IN LINE

Groups	Terminals
1st Group	1st Terminal
2nd Group	2nd and 3rd Terminal
3rd Group	4th and 5th Terminal
4th Group	6th Terminal

C. Discussion

The experiment has shown that the proposed method can estimate the relative location in the line with high accuracy, but false location estimation can occur when the Nearby Devices are incorrectly chosen.

Table IV shows that the 4th terminal had low accuracy when choosing Nearby Devices. The 4th was supposed to choose the 2nd, 3rd, 5th and 6th terminals. However, it sometimes choose the 1st terminal as a Nearby Device. This occurred probably because the average RSSI of the 1st terminal was approximately the same as that of the 6th terminal, even though the 1st terminal was located 0.5m farther away than the 6th terminal, and its signal attenuated by one additional intervening person. The incorrect choice of Nearby Device by the 4th terminal increased the number of terminals in another Group and adversely affected the accuracy.

D. Applicability to the Real Environment

Further issues relating to deployment in a real environment are discussed in this section.

Terminal Conditions in Line

In the proposed method, all terminals are assumed to be in Discoverable mode. In real situations, on the other hand, not many terminals are in Discoverable mode, because of security vulnerabilities and increased energy consumption. However, this situation may start to change as security and energy consumption are improve [12], and several services with low energy consumption have been developed. Thus, owing to these improvements, we believe that the number of users who would set their terminal to Discoverable mode will increase.

Signal Strength Depending Upon the Terminal's Brand

The signal strength and accessible range of Bluetooth may differ depending upon the types of user terminals. A distant terminal emitting a strong signal can be recognized as a Nearby Device and consequently affect the accuracy of location estimation. Such problems can be reduced if terminals and the server work cooperatively to determine the Nearby Devices. The server, which aggregates the RSSI received from multiple terminals, designates the strong signal terminal by comparing the values of RSSI and then determines the closest terminal as the Nearby Device. The location accuracy can be improved by excluding distant terminals with strong signals.

Distinguishing Other Devices from Those in Line

When people are waiting in line or moving forward, the signals of their terminals are detected in a consistent pattern. If some of them leave the line, the strength of their signals will be gradually weakened and may eventually disappear. By checking the detection count of terminals in the line, the signals of people leaving the line can be detected. For

TABLE VI. LOCATION ESTIMATION RESULT

	Successful Counts	Num. Trials	Accuracy
2nd Group	14	14	100%
3rd Group	14	14	100%
4th Group	5	7	71.4%
Total	33	35	94.2%

people outside of or away from the line, the signals from their Bluetooth devices can also be falsely detected and chosen as Nearby Devices. Thus, it is necessary to distinguish these devices from those of people in the line. People who are standing still, or moving towards or away from the line, will have terminals transmitting in an inconsistent pattern different from those picked up from the line. The terminals distributing the consistent patterns are thus classified as Nearby Devices to perform location and wait time estimation in line.

Reduction of RSSI due to Obstacles

In our experiment, users held the terminals in their hands. However, terminals are more likely to be placed inside pockets or in bags, which may cause inaccurate selection of Nearby Devices. It is necessary to consider these points by investigating the RSSI values in order to enhance the method of choosing the Nearby Devices.

Number and Distance between People

The experiment was held with a limited number of people, but there are usually more people waiting in line. It is necessary to examine the applicability of our method in such situations. The location estimation accuracy may improve if the distance between the devices increases, as the difference of RSSI will be more pronounced.

V. CONCLUDING REMARKS

We have presented a method to estimate the location of terminals of users waiting in line. In the proposed method, employing the user's terminal and a server, the relative location between users has been assigned in order starting from an initial user (the first in line). Bluetooth RSSI from mobile terminals was used to determine the Nearby Devices to enable more detailed location estimation. An experiment was conducted to verify the effectiveness of the proposed method with the result that the user terminal location was estimated with high accuracy. However, false detection of Nearby Devices has caused the grouping process to overestimate the number of terminals, which reduced the accuracy of location estimation.

In the recent social trend, the use of Bluetooth technology has been declining due to the evolution of new radio technologies such as D2D, M2M, mmWave, and Massimo MIMO. However, iOS devices are installed with iBeacon which uses Bluetooth Low Energy (BLE). Furthermore, deployment of iBeacon technology to OS X, Android and Windows Phone devices implies that it is not the end of Bluetooth technology. Therefore, it is necessary to watch for the wave of future consumers. Whichever wireless communication technology is used, the necessity of the proposed algorithm will remain. Further planning is necessary to investigate the feasibility of the proposed algorithm to these other radio technologies.

WiFi technology is currently being used very often as it is widely deployed in everyday environments at home, school, company, office, and so on, since it is convenient to connect smartphones in such an environment. Recent work shows good detectability of WiFi packets emitted from smartphones in public transportation [13]. Our next target will be application to WiFi technology in conjunction with other new radio technologies.

Identifying terminals leaving the line, locating coordinates of user terminals, terminals emitting different signal strengths, and energy consumption issues other than the use of BLE are currently not considered. For future work, these issues and the characteristics of RSSI need to be examined in order to explore the application of our method in real environments.

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Bridging Location-based Data with Mobile Practices

Introducing a Framework for Mobile User-Studies

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***Abstract*—Increasingly, mobile services are using location-based information provided by GPS sensors. Especially HCI research deals with a growing interest in how people make sense of location-based information while on the move. Mobile user-studies can help to address this black box and provide the opportunity to combine location-based data with context related content of the mobile practices being performed. In this study, we address this relationship and ask how spatial information should be visualized in order to explore mobile contexts. We conducted a qualitative study to learn about the usage and interpretation forms of spatial information and further translated these findings into a basic framework for mobile user-studies, concluding with an evaluation.**

Keywords-mobile user-studies; location-based services; mobility; user studies; framework.

I. INTRODUCTION

Nowadays, mobile phones accompany most of us every day and everywhere we go. They have opened up new possibilities for the investigation of human behavior [31]. In particular, mobile, intelligent, and GPS-enabled smartphones allow for and demand an integrated view of location-based information and the mobile contexts in which the particular mobile practices are performed [14] [21]. HCI research has is greatly interested in how people make sense of location-based information while on the move. Currently, more and more mobile user-studies are being conducted to answer this question e.g., [11][26]. However, the relationship between spatial information and mobile practices is still underexplored.

In order to shed light on this question, we ask in this paper how spatial information and mobile practices (and their relationship) should be addressed in order to support mobile user-studies in an appropriate manner. The challenge herein is to map the geo-location data (referring to time, longitude and latitude) with the cultural and meaningful dimension of space to inform a framework for mobile user-studies. To do so, we conducted a context study with 19 users who allowed us to track their movements over three weeks. At a later date, we provided them with GPS-based paths of their own movements, which enable them to follow their movements on a map over the time. This alienated mobility data triggered narrations about mobility, i.e. the users were encouraged to report freely about the mobile contexts they identified. These mobility narrations allowed insights into how spatial information was used, referenced and interpreted when reporting on mobile practices. In particular, we discovered three main requirements from the interviews to inform mobile user-studies: (1) the visualization of movements, (2) the visualization of paths and places and (3) the integration of interpretation spaces. We continued by building a framework for mobile user-studies around these identified findings. We then evaluated the framework and concluded with a discussion regarding future enhancements.

II. STATE OF THE ART

In the following, we introduce current tools for mobile user-studies that can be clustered into three groups: (1) *experience-based studies*, (2) *location-based studies*, and (3) *integrated studies*. We will discuss the current approaches with regard to their ability to explore how people use location-based information, and state the necessity for a framework that allows this question to be addressed.

A. User-Studies in the mobile contexts

Fostered by the rapid dissemination of mobile devices and their ever-increasing role in our everyday lives, the field of HCI has yielded new approaches to capture peoples' behavior and actions with regard to location-based data by observing the use of mobile devices.

1) Experience-based studies

Early on (mobile) diary studies [1], as well as the experience sampling method [8] were viewed as appropriate methods for capturing users' behavior directly in a specific situation [17]. Both facilitate user-driven reporting of one's own behavior in mobile contexts. In diary studies, users– based on previous instructions by the researchers – decide when and which information is worth reporting. Forms of voice-based diaries or photo-based diaries [4] as well as combined methods have been designed for specific mobile contexts [9]. In all these studies, the diary entries have to be reported manually [6]. Brandt et al. [2] present variations called snippets, which are short diary notes recorded in specific situations and which allow the users to complete the entry later. These traditional paper-based diary studies include fields for writing down the location of an activity and are comparable to the experience sampling method, the main difference being that in experience sampling, participants are given a signal at a specific time to report details about his/her current situation. One Shortcoming of both diary studies and experience sampling is the effort needed to document the relevant data. Further location-data is not systematically addressed as a basis for interpretation, and as a result users lack proper support to reflect on locations [21][23].

2) Location-based studies

Beside these more qualitative approaches, quantitative logging approaches are being used increasingly to gather detailed information on mobile behavior. Life-logging is one such approach which aims to record user behavior automatically via "the continuous capturing of personal data, such as photos from one's field-of-view, location, audio, biometric signals and others, with the aim of supporting the later recall and reflection on one's life events and experiences" [12]. Data logging in general means that usage data, which would otherwise be very hard and time-consuming to capture, is automatically collected by a device with no user interaction whatsoever [11]. Due to the fact that mobile devices have become highly personalized tools for virtually everyone, they are more or less present and on hand at any time and place [10]. Mobile-data logging therefore represents a significant part of life-logging, allowing users' spatial footprints to be traced. Hence these services do not offer the integration of the user's-perspective.

3) Integrated studies

Further, approaches that combine experience-based studies with automatic data logging are coming increasingly into existence. The current stance of literature is dominated by a space-related understanding of mobility [15]. One characteristic of this research stream is strong sensor orientation which allows mobility patterns, like routines and mobility modes [19] to be discovered, thus enabling mobility systems to be improved [28], or sustainable mobility behavior to be fostered [3][22]. One example is given by driver logbooks that allow drivers to report information about certain journeys [21][24], or Froehlich et al's [11] system that combines the logging of phone data with mobile experience sampling by triggering surveys at specific moments of interest. They show that the acceptance of such a mobile system in everyday life requires both robust performance and non-intrusive data collection. Liu et al. [23] argue that such mixed methods are required to gather appropriate information about users' behavior. A major challenge of this research line is identifying encounters for temporal and spatial mobility patterns [20], and interpreting this data as forms of mobility activities. This can be addressed by using location-based data collected from social media applications (e.g. Foursquare or Twitter) [14], or mixed-method research using questionnaires, surveys or interviews that aim to describe the purpose of the activities, the means of transportation and personal details [5][16]. However, these complex frameworks do not look in detail at how location-based data is actually interpreted by users in particular mobility contexts.

B. Motivating a framework for mobile user-studies

We showed that researchers can benefit from the new options to capture, track, simulate, mimic and shadow the many interdependent forms of people's intermittent movement [30]. Hence, we do not move in an empty space but through streets and places. We go home, to work, to a restaurant, visit a friend or the sports club. Often we have a special preference within the selected transport mode, the company we choose for our journeys, types of coordination, or the selected route. In order to focus on such issues, we cannot refer to locations as being stated only objectively. Moreover, we have to ask how users can be supported in interpreting spatial data to re-construct the specific meanings of places that influence our movements and daily mobility [26]. Hence, mobile user-studies should not only take the objective spatial dimension into account but should also support the user in an appropriate manner to reflect on the actual mobility [7][13]. Yet there is very little going on in terms of trying to understand the role of real world context in relation to understanding, building or evaluating interactive mobile user-systems [18][26]. This leads us to the challenge of finding new ways to support people with their mobile phones to not only track spaces, but to allow the users to remember and interpret concrete mobility situations.

III. CONTEXT STUDY

In the following, we introduce the study conducted in order to discover how users make use of and interpret spatial data.

A. Method

We conducted an empirical study with 19 users. The user group was selected from a wider project, aimed at assisting elderly people with modern mobility support systems. The initial contact with participants was made through various local organizations for senior citizens. We selected a heterogeneous group of socially active seniors (N=19, 14 female and 5 male), in relation to age (between 57 and 80 years old, and an average of 69 years), local infrastructure (10 in high density areas and 9 in more low density areas), and also in relation to the transport systems typically used. The idea behind this selection was to obtain a wide spectrum of mobility experiences. We worked with the seniors in a participatory design-orientated Living Lab setting [25]. We provided all users with a modern smartphone and guided them in its usage. In regular schooling sessions that took place weekly over a period of about two years, the users improved their technological skills and increased their knowledge of mobile mobility services. Hence, although we were dealing with older adults, at the time of investigation all interviewees were skilled in handling mobility-related application services.

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Mobility narrations were conducted in an interview-like manner with each of the 19 users. We asked them to interpret the prepared maps with the outlined GPS tracking data of their movements over the last two weeks. We provided all users with a Google account, which allows us to obtain GPS data produced by the participant's mobile phones in order to track their movements. Mobile behavior was recorded automatically by the Google service *Location History* [32]. During the trial, the participants led their daily lives routinely while the GPS mobile sensor was constantly tracking their outdoor movements. After two weeks of tracking we re-visited each participant and prepared the collected data for presentation. We used both paper-based as well as computer-based representations of the tracked mobility behavior as shown in figure 1. The picture shows the data of one day, as provided by the Google service. The digital version enables users to check the detailed travel times on demand and to zoom the map in and out. These forms of presentation provided information about the spatial movements in units of space and time gained from the mobile GPS sensors. With these representations, we triggered mobility narrations that led us back to elementary travel stories. These stories provided insights into how people read and make sense of their personal location-based data.

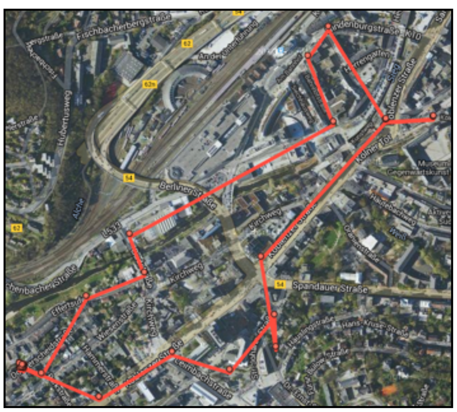

Figure 1. Shows the material provided to the users

Our study was conducted in a region in western Germany which has about 100,000 inhabitants and includes both urban and rural areas. All the workshops took place in participants' homes and lasted between 56 and 153 minutes. Pseudonyms have been used to ensure participants' anonymity and confidentiality.

B. *Identified Elements of locating practices*

In the following we outline the empirical findings from our study. The mobility narrations provide insights into how users align their mobile practices along the presented spatial information of past journeys. Three key elements which especially supported the users were (1) visualization of movements, (2) visualization of paths, and (3) interpretation spaces.

1) *Visualization of movements*

We started by asking users what they could see on the personalized maps lying in front of them. We made sure to ask open questions that leave participants space to explain using their own reference system. We obtained answers like the following example sequence #1:

Sequence #1: [locating mobile contexts]

> *I: So let's take a look at the details on the map.*
>
> *A: Yes, okay. It (the internet page) is just setting up. Goodness, that's amazing! What's this? Whereabouts was I then? Right here! I was in the internet café yesterday. As clear as day! Wow! […]And here. er. here I can see my way to my brother over there.*

In this sequence the maps are addressed as an important tool to help participants remember and identify their own past mobility practices as it is emphasized with expressions of joy: #1: *It (the internet page) is just setting up. Goodness, that's amazing! […] As clear as day! Wow!* Further, the geographic visualizations of their own GPS data was often used for orientation, to identify where the participants had actually been. However, although the users only see spatial references as red-lined GPS marks of their movements, they do not state purely geospatial descriptions. Instead, people refer to their mobile practices as if one could actually *see* them on the map ("*I can see what I have been doing*", or in "*I can see my way to my brother over there*" (#1)). Hence, people literally bridge the geographic data lying before them with their mobile practices. Coincidentally, both dimensions are connected through the narrative elements of "here" or "there" as their locutionary seat. The map with the referenced GPS coordinates was disengaged by the users in an interpretative process that turns geographic space into a meaningful area. Although the spatial character still exists within the indexical reference of the particles "here" and "there", the emphasis lies not on the geography but rather on the mobile practices performed. In other words, mobile contexts are easily identified by the users with the help of the maps and the referenced GPS locations, as the two examples (along with many others) show.

2) *Visualization of paths*

Additionally, it turned out that the visualization especially of paths supports the identification and interpretation of mobile contexts, as illustrated by the following sequences #2- 3:

Sequence #2: [categorizing located contexts]

> *I: Perhaps you could describe what you can see on the map?*
>
> *D: Well, for example, that's where I took the bill to Alfons. In the garden centre. It is only a short walk, I went on foot, because it is right here in the neighborhood.*

Sequence #3: [categorizing located contexts]

E: when I'm mobile I go to the gym, I go shopping, or go swimming with my neighbor, as you can see here below."

In these sequences not only the indexical character of the elements like "here" and "there" are addressed, but rather its deontic character that refers to a particular mobile practice. In sequence #2 it is paying a bill in a shop in the neighborhood, or in sequence #3 it is going home. Ascribing content to locations in this way is different from simply naming streets or areas of the city as it connects familiar meanings to the paths shown. In the excerpts, users refer explicit to these paths as "making sense". Within these ensembles, users are able to inscribe particular knowledge to the "geometrical" or the "geographical" space which makes it meaningful and socially readable. Thus, the paths drawn on the map work as preconditions to transform users' mobility practices into a legible form along the path that can be identified and described easily.

3) *Integration of interpretation spaces*

Further, in the course of the interviews it transpired that users locate their mobile practices within particular paths and places, as illustrated in the following sequence #6:

Sequence #4: [reading located contexts]

C: So I'm only here. From my place, I drove into Ludwig Street first.. This is Ludwig Street here. Then I went back and forth a bit, picked a friend up then went up [name of a village] to Berleburger Street and picked up another friend. And then we went to Giersberg (= area) to play cards here.

The user point out a "tour" of paths as a series of units (*Ludwig Street first, to. […]to Berleburger Street and […]to Giersberg (= area)"*. Although the drawings on the map outline not the "route" (there isn't one) but the "log" of peoples' journeys – users interpret the outlined marks as footprints of the successive events that took place in the course of the journey. In sequence #4 the speaker refers to an event which happened at a particular place. Within the stated mobility context of *playing cards* the related mobility practices are expressed within certain preferences. Hence, although we are dealing with an objective tool – the map - the reference to this tool is quite selective and subjectively motivated according to the stated mobility practice of playing cards. Therefore, the conducted mobility is stated in a particular manner, namely as a regular activity that is shared with friends. If the user had talked about the workplace or the home, these descriptions would probably have been different. We can imagine for example that the way-finding would be much more straightforward without picking up friends, or would rely on using public transport. Hence, the map is not used in order to reconstruct the prior paths and visited places but to reconstruct particular activities and events from mobile practices that can be located or related to paths and places. We could further observe that users start to annotate the maps, what identifies paths and places as useful units providing users with spaces in which to describe and exaggerate their journeys.

IV. CONCEPTIONAL FRAMING

The three identified elements of (1) visualization of movements, (2) visualization of paths and places, and (3) integration of interpretation spaces turned out to be basic needs, necessary to make use of and interpret spatial information. The study especially reveals that designers should provide users' starting points to empower them to make sense of geo-location data. We found out that designers need to understand how users refer to their performed mobility and provide an appropriate basis for the interpretation of mobile contexts.

This motivates the creation of a framework for mobile user-studies that empowers users to actively make sense of the mobile practices they performed. Hence, we identified the following issues that go along with the three findings:

(1) "Visualization of movements" refers to the need to collect spatial movements in situ.

(2) "Visualization of paths and places" can be translated as the users' need to be supported in identifying journeys places within performed trips.

(3) "Integration of interpretation spaces" refers to the need to allow users' annotations on the performed trips.

TABLE I. IDENTIFIED ISSUES, DESIGN CHALLENGE AND TECHNICAL IMPLICATIONS

No.	Identified Issue	Design Challenge	Technical Implications
1	Visualizing GPS/ time data on a map	Collecting spatial movements in situ	Users' mobile phones need to continuously log position and time
2	Visualizing the GPS/ time data as paths	Identifying trips and destinations as the points of beginning and ending a performed activity	Based on available sensorial data the system needs to be able to determine the start and end of trips
3	Integration of interpretation spaces	Collecting information within the performed journeys and places	Based on the recorded trips the system needs to provide features to annotate trips and to select context information

V. A FRAMEWORK FOR MOBILE USER-STUDIES

In the following, we introduce in more detail how the identified requirements are translated into a framework for mobile user-studies. This framework allows studying in rich detail how users make use of and identify mobile contexts while on the move.

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A. Addressing the challenge to locate mobile contexts

Collecting spatial movements in situ requires location data from the phones' sensors to be acquired. GPS immediately comes to mind as the most important sensor, but other sensors like wifi or Bluetooth signals can also be used to determine a users' location. In order to identify trips and destinations, it is necessary to analyze this data. In long-term studies, large amounts of location data are gathered which leads to high demands of computational power to process this data. E.g. we tested processing 1000 locations on a modern smartphone with clustering algorithms like DBSCAN. The computation of clusters took about 10 seconds. Yet for in-situ recognition of places and routes, such approaches are not suitable for processing a complete data set.

Thus these calculations need to be repeated at very short intervals to ensure in-situ recognition of trips. Further, the intensive workload on the devices would make them unusable due to battery drainage. Moreover, combining the GPS data with other sensor inputs like wifi or Bluetooth signals is problematic when using this approach. Thus we decided to gather location data and process the incoming stream according to predefined rules. This approach allows the researcher to define under which circumstances data should be stored and/or can be shown to users to ask for qualitative input like collecting information about a trip or destination.

We used a complex event processing approach (CEP) to implement a rule system on the client side. This has several advantages compared to performing statistical analysis of the collected location data. Firstly, using a CEP Engine (CEPE) allows the data to be processed stream-based. Thus only relevant, incoming location data is processed. The CEPE automatically filters relevant data (e.g. locations that were received within a given timeframe) based on the rules that were defined previously using a special event pattern language (EPL). Secondly, these rules can be (de-) activated or swapped easily without modifying the code of the application itself. Using CEPE on the mobile client allows on-the-fly modifications of data collection (e.g. triggering a questionnaire when a user leaves a spot that has been identified as relevant during the running study).

In our case, we used the Esper complex event-processing engine. Esper is an open source CEPE that has been ported to Android and is only about 6MB in size. Further we used the Funf framework to capture sensor data from more than 15 sources including location, wifi and running apps. This data is then sent to Esper. The patterns, which have been defined on the server, are downloaded via a REST API as soon as they are available. This API provides a JSON file, containing the EPL and the id numbers of the actions it should trigger, which in our case are surveys initially linked to particular places. To create such EPL patterns, knowledge of EPL syntax is required. To eliminate this necessity and to enable researchers without technical training to define EPL rules that allow for categorization locations, we created a graphical editor that is described in the following section.

B. Graphic rule definition to support categorization

As pointed out earlier, one of the main challenges is the collection of spatial information, and to react to this data e.g. by running questionnaires based on the user's mobility. Thus we developed a web-based editor that is based on the EPL and allows researchers to define events using a graphical user interface (GUI). The editor (Fig. 2) ensures that researchers formally define the situations which are relevant for the study in order to make them unambiguously recognizable by mobile devices equipped with the appropriate sensors.

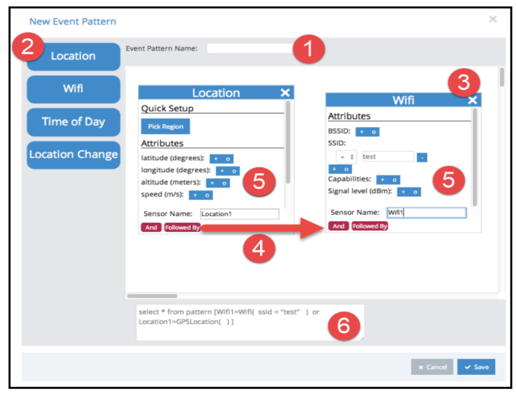

Figure 2. Web Based Editor for Event-Definition

This example shows how researchers can create event patterns that support the categorization of the participants' devices. Firstly (1) researchers name the patterns they are going to create. From the list of sensors (2) they can drag and drop different location-related sensor events to the canvas (3). The available sensor events are:

Location: Probably the most basic sensor event for location detection. This event will be triggered every time the device receives a location. This can also be specified in more detail by providing bounding areas of relevant locations (e.g. specifying that a questionnaire should be triggered when users are at a specific location, e.g. at university).

Time of Day: Basic sensor event to define a time. This event can be used to define rules that should only be matched at a given time of day (e.g. specifying that a questionnaire should be triggered at 3 PM on a Wednesday).

Location Change: This event detects a change of the geographic location without the need to specify a concrete GPS position. The researcher needs only to provide a time span and a distance. If there are location measurements in this time span that are further apart than the provided distance, the event is triggered.

Wifi: This can be used to determine if a user is connected to specified (or indeed any) wifi. This sensor can be helpful to detect if users are in a specific building (e.g.

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triggering a questionnaire when users connect to their home wifi).

Further, the framework allows these sensor events to be connected through "AND", "OR" or "Followed-by" connections. Per default, events are connected by "OR"; "Followed-by" and "`AND" connections are established by dragging lines between the events.

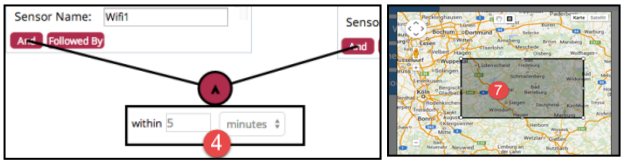

Figure 3. Left: Connecting two events - Right: Setting location attributes using "quick setup"

"AND"-connections imply that the criteria for the event is fulfilled simultaneously, e.g. the participant is at the specified location and connected to the specified wifi. "OR"-connections imply that one of the specified events has happened, e.g. the participant is connected to the specified wifi but is not at the specified location (or vice versa). "Followed-By"-connections refer to a sequential order, e.g. the participant happened to be at the specified location but left and connected to the specified wifi afterwards. For "AND" and "Followed-By" connections researchers can specify a timeframe for the occurrence of the involved sensor events (see (4) in fig. 3). For each of the sensor events, attributes can be determined (5) to further specify events. E.g., using the attribute SSID for wifi-events implies that events will only be triggered when the participants connect to a specific wifi network. It also demonstrates the "quick setup" of the location sensor to define attributes based on a selected geo region (7). The output of the event orchestration is shown below the canvas in fig. 3 (6). Here the generated EPL-snippet is shown. The snippet and the canvas are synchronized, thus any changes in one will be reflected in the other representation. These event pattern can be connected to actions (in our case triggering questionaires) that are executed when the event occurs. These EPL-snippets are pushed to the mobile devices along with their corresponding action. Principally this enables the researcher to specifiy or adapt his definition easily and to push it to the participants' devices immediately without changing any source code or adjusting settings.

C. *Interface design to support the analysis of location data*

After a survey has been started and data has been received from the users, researchers have to be able to view and analyze the collected qualitative and quantitative data. To enable this, we built a web-based route viewer (see Fig. 4), which allows researchers to inspect the routes, the participants' names for those routes, and the respective surveys. This enables researchers to comprehend the participant's thoughts on those routes, as participants name locations according to what they mean to them personally. The locations are managed in the route viewer. The route viewer provides a list of participants as shown on the lower left. If a participant is selected, all routes for this participant are listed to the right with the name designated by the participant. If a participant gives the same name to several routes, these routes are grouped together, thus facilitating the categorization of locations.

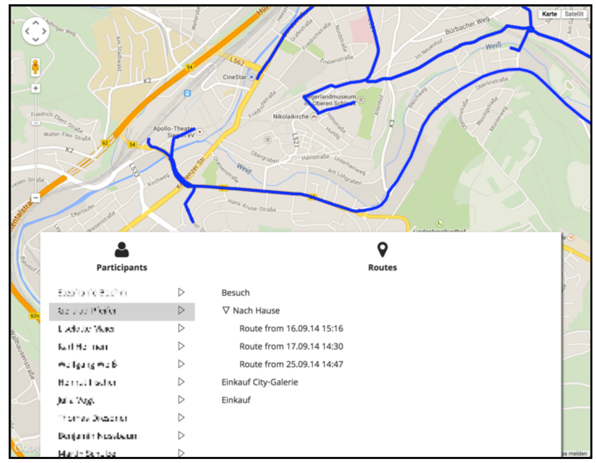

Figure 4. Web based route viewer

VI. EVALUATION

In order to evaluate the framework, we first conducted a test to check the its functionality by defining different events and testing whether the respective action is triggered. Secondly, we tested the web frontend with researchers to find out whether the identified issues were included properly.

A. *Technical evaluation*

Within the technical evaluation we equipped four students with mobile devices and pre-installed our framework. After this we defined several event patterns in the backend system. The first pattern was expected to trigger when the students were on campus. At first, we did not take into consideration that this event would be triggered each time a new location measurement is added to the CEPE. This resulted in two cases of students being prompted to fill out the same survey several times while they were present at the university. This was fixed by changing the event pattern definition slightly, so that it only triggers once a day. Next we defined a more complex event, intended to trigger when the student's phone detects a certain wi-fi network and switches on the screen of his phone. This was used as a way to detect precise in-door locations. This enabled us to define a survey which was triggered when the student was in the proximity of our offices and using the mobile phone. The problem with this approach was that the survey notification was triggered directly after the screen was turned on - a time when users usually want to accomplish a certain task. It would be possible to add a pause time after the event triggers in the CEPE, but our visual editor has not supported this feature yet.

B. Content evaluation

We further conducted a first content-orientated evaluation with five researchers from the field of information science and mobile media studies. Having introduced them to the framework, we let them use the described functions and conducted an interview afterwards that lasted about 30 minutes on average.

The participants confirmed that: (1) the implemented framework collects spatial movements in situ and visualizes them on a map; (2) Visualization of paths and places helps to identify journeys and important places; Further, (3) the participants used the annotation feature within the journeys performed in order to provide more detailed information about the trips conducted.

The five participants did however also name some critical issues: (1) Three of the users stated they would appreciate the option to annotate routes later, without the need to do it while being on the move. Participants pointed out that situations could potentially arise when one is pressed for time and therefore it would be more convenient to categorize trips later; (2) Further, we gathered initial insights into preferences concerning how to visualize trips on the map in order to support users in remembering and interpreting their mobile practices. Most of the participants strongly recommended visualizing single trips instead of cumulated routes. The clustering of trips where are annotated with the same categories was recommended; (3) Finally, participants stated that a time line is important for them, to help remember particular trips better. Two of the researchers stated their wish to view trips in a chronological order and to view trips of selective categories on the same timeline.

VII. Discussion and Concluding Remarks

In this paper, we argued in favor of mobile user-studies as a great approach to foster our understanding of mobile behavior. However, current services mostly address spatial information as fixed and restricted to longitude and latitude. We showed that location-based information is highly interwoven into sense-making processes and mobile routines. Therefore, mobile user-studies are needed to provide answers to how people actually use and interpret their performed mobility while actually being on the move.

In order to inform the design for a framework of mobile user-studies, we started with a context study to discover ways in which users make sense of spatial information in daily mobility. We especially gained insight about three requirements that were translated for building the framework: (1) visualization of movements, (2) visualization of paths and places, and (3) integration of interpretation spaces.

The evaluation showed major research issues for the future. The organization of trips was particularly stated to be a major issue. A future version should therefore be designed so as to assign collected content information within performed trips on maps that can be seen by both researchers and users. Moreover, the route viewer and the questionnaire editor are implemented as two separate applications. Currently, questionnaire data cannot be shown in the route viewer although it has the same access to the API. Hence in future we plan to integrate those two applications seamlessly.

The framework is openly and flexibly designed to allow researchers manifold options of collecting data on the move. Our challenge in the future is to find appropriate ways of integrating and making use of empirical data like questionnaires, open questions, photos etc. that can be selected in connection with a particular trip. Hence we have laid the basic groundwork that allows how people actually interpret their performed mobility to be studied, as well as making use of location-based information while on the move. But to answer this question in more detail, our second step has to be to build a graphic editor that visualizes what the framework can already achieve (by using the event pattern language): the integration of routes with user-interaction mechanisms.

Acknowledgment

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A Mobile Application for Supporting Surgical Workflow

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***Abstract*—This paper presents a mobile application to enhance safety and efficiency in the operating room. The application plays a crucial role in preparing the surgical personnel and gaining useful help as needed in real time. Seamless integration of information is implemented to support surgical workflow beyond spatial constraints.**

Keywords-mobile application; surgical workflow; operating room; information integration.

I. INTRODUCTION

It is reported that about 40% of the medical accidents occur in the operating rooms (ORs) and around 20% of them can be prevented in advance [1][2]. Since the OR is the most cost-intensive sector in the hospital, the optimization of workflow processes is of particular concern for health care providers, managers, and administrators [3]. In order to enhance safety and efficiency in the OR, a prototype system named Surgical Workflow Manager (SWORM) has been implemented as a surgery management platform capable of planning, recording, and adapting the surgical processes in regular sequence [4].

Timely communication between team members is crucial in such a complex and hectic environment as the OR. The SWORM is basically devised to run inside the OR, but all personnel needed do not always stay in the room. For instance, a circulating nurse may engage in more than one surgery at once, and other doctor who takes outpatients may be asked to give the surgical team advice on a certain situation. However, they face difficulty in grasping the current situation in the hallway or elsewhere. A mobile application is thus proposed in this paper to meet the demands of understanding and intervening in surgical workflow even outside the OR. This paper does not focus on the SWORM but its mobile application. The application makes the SWORM feasible around the OR by seamless integration of information.

The rest of this paper is organized as follows. Section II describes the service architecture and main functions of the mobile application briefly. Section III describes development environment and discusses the results of a case study. Section IV concludes this paper.

II. ARCHITECTURE AND FUNCTIONS

The surgical workflow should be summarized concisely and represented intuitively at the mobile application. The SWORM transmits the surgical processes and their selected information to the application in real time, and obtains feedback from the designated mobile users who are away from the OR during the intra-operative period. The application currently consists of three consecutive pages: surgery list, process list, and detail process information. The overall architecture is depicted in Figure 1.

The Surgery List page provides a brief summary of scheduled surgeries as shown in Figure 2(a). After browsing the list including surgery names, assigned ORs, and scheduled dates, the user can select a specific surgery to identify its patient, disease, surgeon, and scheduled time. The Surgical Process button leads the user into the Process List page. The EMR, Staff, and Resource buttons are intended to access the corresponding legacy systems, but not activated yet.

The Process List page shows planned surgical procedures with highlight on the ongoing one. If a profession is called or asked for feedback on any procedure, a message button labeled by profession appears beside the procedure to unfold the messages (e.g., S, N, and T for surgeon, nurse, and technician each). Each button is also distinguished by color: green means the message completed, red at hand, and yellow coming up. In Figure 2(b), for instance, a supervising surgeon outside the OR may skim through the list trying to make sure whether every procedure is performed without loophole. After finding the request on the Test Stimulation procedure, he/she can move into the Detail Process Information page to make a useful response.

The Detail Process Information page provides the overall status of a selected procedure as shown in Figure 2(c). The page not only displays formal indicators such as duration and parameters of the procedure, but also contains intra-operative records such as patient's state, operative photos, and compliance with the checklist. The user can give the team in the OR helpful advice and information by writing comments or uploading photos relevant to the given situation.

III. APPLICATION

The mobile application has been constructed in a hybrid app development environment. This app is written with web technologies (HTML 5, CSS, and JavaScript) and currently runs on Android only. At the server side, the SWORM uses HTTP and Ajax for I/O interfaces, and MySQL as a database. The data created by the SWORM and mobile application are stored in and retrieved from the database directly.

The application is applied to a real Deep Brain Stimulation (DBS) surgery for trial use, and evaluated by its developers and users. All of the functions are performed well as intended. While a supervising neurosurgeon and an anesthetist stayed outside the OR, they could intervene effectively in the surgery by monitoring its workflow, capturing the messages, and sending some advice. An X-ray (C-arm) technician received a call before needed, and she moved into the OR with the equipment on time. Even though limited, interviews from the users show that the mobile application would increase convenience, and consequently be useful in enhancing safety and efficiency in the OR.

IV. Conclusions

This paper proposed a mobile application for surgical decision support. Exchanging information between inside and outside the OR has been made by the phone calls mostly. Instead, this service enables a user outside the OR to monitor surgical workflow and intervene in the ongoing surgeries as needed. Usefulness of the service was evaluated restrictedly in the perspective of surgical safety and efficiency.

The usability test is expected to improve user interfaces and details of each function in the near future. For instance, when someone is needed, the application will send the selected user an alarm to notify the event, and then lead the user into the related page. The test results should be analyzed and evaluated quantitatively to ensure the performance of the application as well.

Acknowledgment

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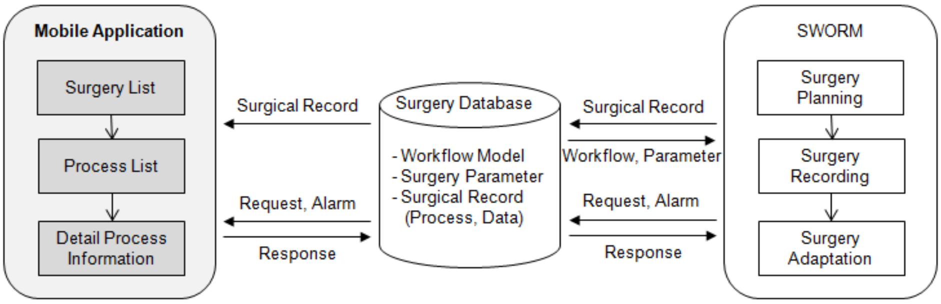
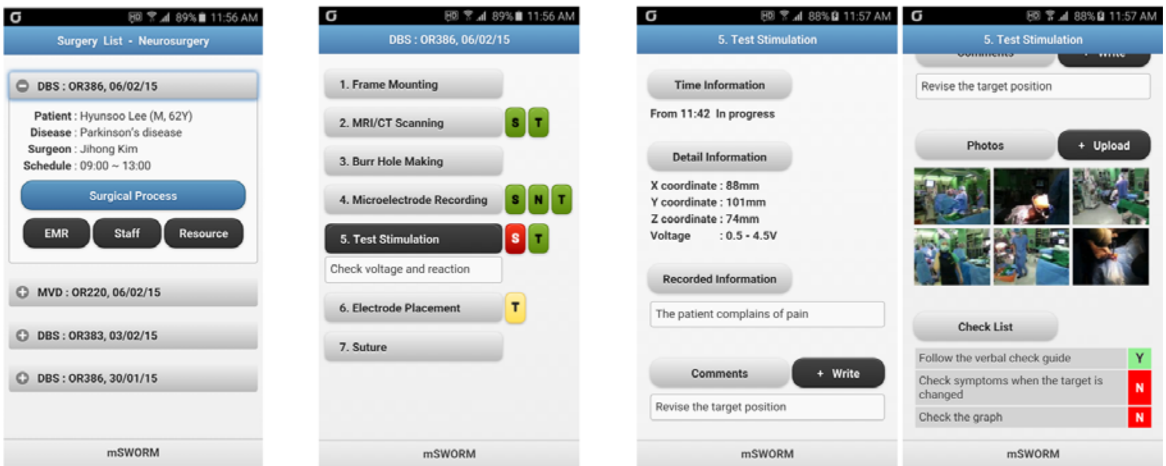


Figure 1. Overall architecture of a surgical mobile service.



(a) (b) (c)

Figure 2. Snapshots of the mobile application: (a) Surgery List page, (b) Process List page, and (c) Detail Process Information page.

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An Ant Colony Optimization Solution to the Optimum Travel Path Determination Problem in VANETS: A NetLogo Modelling Approach

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***Abstract*—A Dynamic Travel Path Optimization System (DTPOS) based on Ant Colony Optimization (ACO) for the prediction of the best path to a given destination is presented. The system is modeled in a multi-agent multi-purpose framework in NetLogo and experiments conducted on 100 test vehicles under different traffic scenarios. The test vehicles are released from a fixed location in the simulation environment and given a predefined destination. The route taken by the vehicles to reach the destination gives a measure of the intelligence in the system. Two variations of the system, DTPOS with ACO (DTPOS+ACO) and DTPOS without ACO (DTPOS-ACO) are investigated to establish the effect of ACO on the solution. For every vehicle which successfully makes it to the destination,the mean travel time is recorded. The results have shown that at all traffic densities the mean travel time of vehicles in DTPOS+ACO was always lower than those for DTPOS-ACO. Also it was shown that for the same percentage of vehicles arriving at the destination, DTPOS+ACO vehicles took less time than DTPOS-ACO vehicles.**

Keywords-Intelligent Transport Systems (ITS); Vehicular Ad hoc Networks (VANETS); Swarm Intelligence (SI); Ant Colony Optimization (ACO); Dynamic Travel Path Optimization System(DTPOS)

I. INTRODUCTION

Traffic congestion has been a serious problem on roads around the world ever since ancient Roman times, when the streets of Rome became so congested that all non-official vehicles were prevented from entering the city [1]. In recent times, traffic congestion has been responsible for problems like long delays, wasted time, and increased pressure [2], not only to drivers, but also to passengers and even to pedestrians.

In the United States for instance, research has shown that 4.2 billion hours are wasted daily just waiting in traffic; this converts to 2.8 billion gallons of fuel [3]. Similar results have been recorded in Europe, Japan, and Australia [4][5][6]. Research has demonstrated that lower speed vehicles emit more CO_2, for instance, vehicles traveling at 60Kph emit 40 percent fewer carbon emissions than vehicles traveling at 20Kph and vehicles traveling at 40Kph emit 20 percent fewer emissions than the 20Kph baseline [6].

Intelligent Transport Systems (ITS) provide attractive methods for reducing congestion, which involves the use of modern electronic information systems to control, manage, and regulate traffic flows according to inputs from traffic flow status prediction systems, through dynamic signal timings [7][8].

In this paper, we propose a Dynamic Travel Path Optimization System (DTPOS) which is an ITS solution to the traffic problem based on Ant Colony Optimization techniques. Ant colony optimization is a classic example of Swarm Intelligence (SI), in which case ants using pheromone relay information from one ant to the other to enable them determine the shortest and optimum path from a new food source to the nest. Initially, the ants travel on all possible paths while depositing pheromone on their trail. After some time when more ants use the shorter paths, more pheromone is deposited to act as positive feedback which quickly results in the shortest trail being selected as a better option due to its high pheromone concentration. The ACO algorithm mimics the behavior of ants foraging for food [9][10].

The remainder of the paper is organized as follows: Section II briefly looks at some related works; Section III mathematically models the ant colony optimization solution to the traffic problem; Section IV introduces the proposed ACO inspired DTPOS model and Section V touches on the simulation of the model by NetLogo and Section VI discusses the results. Finally Section VII presents conclusions on our key research findings.

II. RELATED WORKS

The first instance where an ant based system was used for dynamic problem solving was in [11]. Ant Colony Optimization (ACO) has been applied to dynamic path optimization in [12]. The authors in [12] have also demonstrated how the

ACO algorithm can be structured so as to adapt to changes in the initial constraints of the optimization problem. In [13] an optimum traffic system for the reduction of vehicular traffic congestion in an urban environment is proposed. The algorithm proposed in this system has the limitation of performing well only when the number of agents is above 100. A dynamic system for the avoidance of traffic jams (DSATJ) is also proposed in [14]. This system gives an alternative path whenever there is a traffic jam at any section of the road and resumes to the original route when the traffic situation gets better. An ant colony system for a dynamic vehicle routing problem has been proposed in [15], this system provides a means to route a fleet of vehicles with the objective of visiting a set of customers in minimum time. A hybrid ACO technique for dynamic vehicle routing is introduced in [16]. In [17], an improved ant colony optimization algorithm by Previous Path Replacement (PPR) which the authors term path crossover for optimal path planning is introduced.

In [18], a preference based shortest path determination using ACO is investigated. In this case, shortest path is obtained taking into consideration the preferred paths of the agents. In [19] ACO has been applied to a multi-criteria vehicle navigation problem. In this case an exact shortest path solution is not the ultimate objective but a compromised set of best solutions taking into consideration different preferences by different drivers.

ACO has been extensively applied to shortest path problems in [20]-[22]. In [23], the time for obtaining shortest path solution is shortened by using a modified version of the AntNet routing algorithm. In [24], a traffic congestion forecasting algorithm based on a pheromonal communication model is proposed. This algorithm allows vehicles to react to dynamically changing traffic situations through information disseminated in the pheromone model. A system for travel time prediction which takes into consideration past, present, and future traffic trends is presented in [25].

In our previous work in [26], we introduced a Distributed Intelligent Traffic System (DITS) which proposes a solution to the traffic problem using ACO. In that paper, we investigated how ACO reduces the global traffic situation through cooperation among the vehicles. In our recent work in [27], similar to the work proposed in this paper an optimum path prediction is proposed using ACO. The results are however limited to a single traffic density and traffic distribution. In this paper, we vary the traffic density as well as the traffic distribution and investigate the effect of ACO on the Mean Travel Time (MTT) as well as the percentage of vehicles arriving at the destination, and the time taken. To implement information relay among the vehicles in DTPOS we refer to our previous work in [28].

III. Mathematical Modeling of the ACO Solution to the Problem

In defining the path determination problem, we consider a minimization problem (S, f, Ω), where S is the set of candidate solutions, f is the objective function which assigns an objective function value *f(s,t)* to each candidate solution $s \in S$ and $\Omega(t)$ is the set of constraints. The parameter t indicates that the objective function, and the constraints can be varying with time. The goal is to find a globally optimal feasible solution $s*$ which is a minimum cost feasible solution to the problem.

In determining the candidate solution set S, we begin by first defining a solution set R such that $R = \{r_1, r_2, r_3...r_n\}$. The constraint Ω is such that *(s,d)* is the best path given a source to destination pair *(s,d)*. In building a complete solution S we begin from an empty set $\emptyset$ and then build a complete solution S stepwise by adding one new component $r_i \in R$ at every step.

The step by step decision depends on a stochastic decision policy (Π) which depends on a set of pheromone variables τ_{ij}. A policy in this context is a rule which links the resultant status to an action based on given constraints. The stochastic policy τ_{ij} is characterised by a distribution probability over all the likely actions. Each feasible action is connected to a selection probability. An action is therefore taken based on the selection probability for that action. τ_{ij} therefore gives an indication of how good the decision to use a particular path is. For example τ_{ij} can represent the desirability of having (r_i, r_j) in the anticipated solution sequence.

The ultimate objective is to get a good complete solution which satisfies the primary goal of having the best path from a source s to a destination d. τ_{ij} therefore represents the desirability of moving from s_i to s_j in order to reach a destination d such that the final path from a source s to a destination d is the optimum, given a list of candidate paths. The τ_{ij} values are used to calculate the selection probability P_{ij} of each solution.

If $N(r_i)$ is the set of all likely components in state r_i, then the probability of each $r_i \in N(r_i)$ is calculated as P_{ij}. The road network is represented as a directed graph G such that:

$$G = (N, E) \tag{1}$$

where N=(N_1,N_2,N_3,N_4...N_n) is the set of n nodes (i.e. junctions) and E is the set of directed edges as shown in Figure 1. The objective of the model is to route vehicles so that they reach their destination in the quickest time possible while avoiding heavy traffic portions of the road. The modeling of the problem is subject to the following limitations:

Let ψ represent the delay in vehicular movement and ϕ the congestion situation; it can clearly be seen that: $\psi \propto \phi$, however, even though other factors like road accidents and

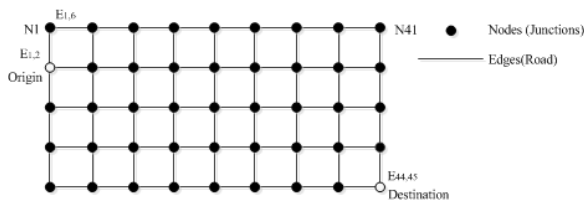

Figure 1. A typical road scenario for best path determination.

road works can also cause delays, traffic delays in this case are only limited to congestion. In this case all delays as a result of other factors are quantified in terms of congestion.

E_{ij} is characterized by the length x_{ij} and traffic T_{ij}. Each route in the network is represented by (2) below:

$$R = a_{ij} \tag{2}$$

where

$$a_{ij} = \begin{cases} 1, & \text{if node } j \text{ is visited after node } i \\ 0, & \text{otherwise} \end{cases} \tag{3}$$

where *i,j=1...n* and *n* is the total number of nodes in the route *R*.

We assume that time taken to traverse E_{ij} is independent of time taken to traverse other edges. Therefore the total transit time $T_m(R)$ for a route R is given by:

$$T_m(R) = \sum_{i=1}^{n}\sum_{j=1}^{n} a_{ij} x_{ij} T_{ij} \tag{4}$$

The objective is to choose a path to the destination which minimizes $T_m(R)$. Every path is assigned a score and the path with the best score is attained under the condition:

$$Best\,Score(S) = Score\,at\,min(x_{ij}T_{ij}) \tag{5}$$

The shorter the route the more traffic it attracts. The relationship between distance and traffic can therefore be represented as:

$$T_{ij} \propto \frac{1}{x_{ij}^{(R)}} \tag{6}$$

The ultimate objective is to get a solution which is a trade-off between minimum distance and traffic. We play around both parameters in arriving at the best solution to the problem. In moving from node *i* to node *j* the cars make a decision based on the probability below:

$$P_{ij} = \frac{T_{ij}^{\alpha} x_{ij}^{\beta}}{\sum_{h \in Q} T_{ih}^{\alpha} x_{ih}^{\beta}} \tag{7}$$

where α and β give the influence of traffic (pheromone) and distance on the solution and Q is the set of nodes not yet visited. The traffic (pheromone) update depends on the evaporation rate (the rate at which cars leave) ρ and the deposition rate Δ_{ij} (the rate at which cars arrive). The pheromone or traffic update is governed by the equation:

$$T_{ij} = (1-\rho)T_{ij} + \Delta_{ij} \tag{8}$$

Δ_{ij} depends on whether a car used the edge a_{ij} or not, ie whether a_{ij} or a_{ji} =1. The total amount of pheromone added or traffic added can be calculated as follows:

$$\Delta_{ij} = \sum_{k=1}^{N} \frac{a_{ij}^{(k)}}{t_m(k)} \tag{9}$$

$t_m(k)$ is the time taken by the car k in covering that section of the road and is a function of the speed of the car $v(r)$. *N* is the total number of cars in that section of the road

$$t_m(k) = \frac{x_{ij}}{v(k)} \tag{10}$$

Substituting equation (10) into (9) and (8) yields:

$$T_{ij} = (1-\rho)T_{ij} + \sum_{k=1}^{M} \frac{a_{ij}^{(k)}}{\frac{x_{ij}}{v(k)}} \tag{11}$$

Selecting α and β such that

$$\alpha + \beta = 1 \tag{12}$$

Equation (7) is reduced to:

$$P_{ij} = \frac{T_{ij}^{\alpha} x_{ij}^{(1-\alpha)}}{\sum_{h \in Q} T_{ih}^{\alpha} x_{ih}^{(1-\alpha)}} \tag{13}$$

At every junction, the car computes the probability P_{ij} in (13) and selects the junction with the highest probability. It continues until it gets to the destination, after which the travel time is computed. In testing the model, it is compared with a model that computes its probability by considering only the distance of the candidate paths with no knowledge of the traffic. In that case:

$$P_{ij} = \frac{x_{ij}}{\sum_{i=1}^{K}\sum_{j=1}^{K} x_{ij}} \tag{14}$$

where K is the number of candidate junctions. Before traffic begins to build up all other cars arriving at the junction choose their path based on (14). In that case, the path with the shortest distance to the next junction is selected, however; if the distances are the same, they all have an equal probability of being selected. Portions of the above mathematical model were introduced in [9] but the main difference between this approach and previous methods is the use of ABM techniques to investigate the effect of other agents on the global optimum path determination problem.

IV. DTPOS DESCRIPTION

The DTPOS proposed in this section is developed within the framework of a Multi Agent Multi Purpose (MAMP) system architecture to predict the optimum path to a predefined destination. The ultimate objective of DTPOS is to reduce the travel time by intelligently selecting the best path in terms of distance and traffic. The proposed system accomplishes this task by computing a selection probability P_{ij} for the best path at every traffic intersection. In this paper two variations of the DTPOS, DTPOS+ACO and DTPOS-ACO which differ only in the inclusion of ACO in one and its absence in the other are developed and simulated. The results are then discussed in later sections to get a better understanding of the effect of ACO on VANETs.

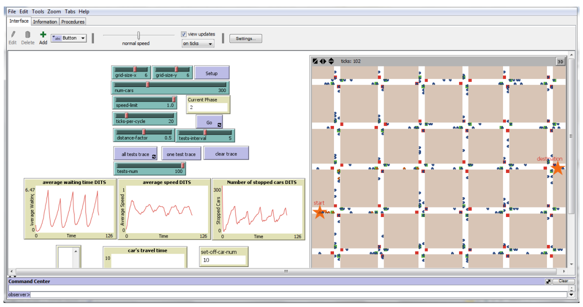

Figure 2. NetLogo GUI with 6x6 road network topology.

The use of agent-based models(ABMs) or individual based simulation models is growing rapidly in a number of fields. The Logo family of platforms is currently one of the most widely used ABMs. NetLogo is popular in this family because it offers the option of studying the behaviour of individual agents working in isolation as well as the effect of the agents working in a community.

1) DTPOS+ACO Description: The ACO inspired system relies on repeated sampling of multiple solutions to the optimum path determination problem. The solutions from these outcomes are used to update the value of pheromone variables in the model. The major difference between this system and ant behavior is that while ants choose the path with the highest pheromone concentration as the best path, the proposed system selects the path with the least traffic as the best path. As the traffic concentration increases, the probability of selecting a particular path reduces. Figure 2 shows the GUI of the NetLogo implementation of DTPOS+ACO.

The DTPOS+ACO mimics traffic behavior in an urban environment. The system has a control environment which permits the user to set the initial conditions for the experiment and an observation environment which gives a visual display of what is happening in the simulation environment. The system permits the number of cars, the maximum speed, the destination and the traffic controls to be set by the user. It relies on mobile agents which are vehicles in this case and stationary patches which represent the road network.

There are two breeds of vehicles in the system; these are test cars and passers. The test cars are assigned specific destinations and the time taken for them to maneuver their way through the traffic to reach their destination is recorded as the travel time. The second breed of vehicles, the passers, also travel within the study environment to create a traffic situation but they are not monitored as is done for the test vehicles. The system works in such a manner that when test cars get to the junctions and a decision has to be made as regards which path to take, the vehicles compute the probability P_{ij} as indicated in equation (13). The path with the best probability at that instance is selected by the vehicle. As soon as a test car arrives at its destination the travel time is recorded, and the vehicle dies out of the simulation environment. The stopping criterion for the simulation is for all the test cars to arrive.

2) DTPOS-ACO Description: The DTPOS-ACO is similar to Figure 2 shown above. The major difference between the two systems is in the way the selection probability is calculated. P_{ij} in this case is calculated only from the distance without taking the traffic into consideration as illustrated by (14).

V. SIMULATION FLOW DIAGRAM

In this section, the simulation flow diagrams for the two DTPOS systems are discussed to give a better understanding of how they are simulated. As has already been mentioned the systems are implemented in NetLogo. To have a fair comparison, both systems are simulated under the same conditions, and the results obtained are analyzed. The systems are simulated based on the simulation flow diagram shown in Figure 3. The simulation is initialized by choosing the size of the grid, the number of cars, the maximum speed of cars, the pheromone evaporation rate, the traffic duty cycle, and the recording time interval. The pheromone values are initialized to give a better picture of the traffic buildup as the simulation progresses.

The simulation terminates when all the test cars have arrived at a given destination. For every traffic density selected, five separate traffic distributions are considered and the simulation run until the stopping criteria is met. The simulation parameters are as shown in TABLE I. 100 test cars are made to travel a fixed distance under different traffic densities and the mean travel times as well as the percentage of cars arriving at the predefined destination are recorded and compared.

VI. SIMULATION RESULTS AND ANALYSIS

Let the time taken by a vehicle *i* to arrive at the predefined destination be t_i. Given that N vehicles successfully arrived at the destination, the mean travel time given N vehicles is given by:

$$t_t = \frac{\sum_{i=1}^{N} t_i}{N} \quad (15)$$

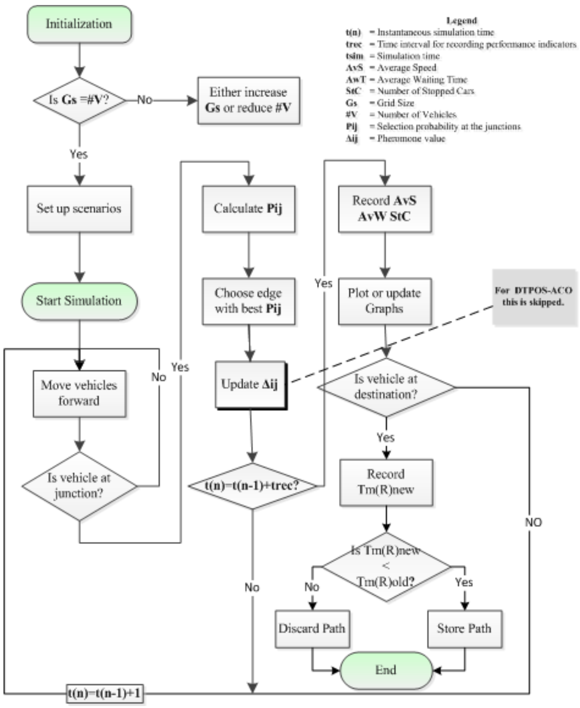

Figure 3. Simulation Flow Diagram for DTPOS.

TABLE I
SIMULATION PARAMETERS.

PARAMETER	SPECIFICATION
Model Simulator	NetLogoV4.1RC5
Total number of vehicles	200, 300 and 400
Total number of test vehicles	100
Road Topology	6x6
Maximum Speed	1.0(50Km/h)
Trace volatility rate(ρ)	8 percent
α	0.5
β	0.5
Terminating Criteria	All test cars to arrive

Also let the number of vehicles arriving at the destination be K and let T_K be the time taken for all the vehicles to arrive at the predefined destination. The time taken for all vehicles to arrive is calculated as a sum of the individual times. Hence the total time is given by:

$$T_K = \sum_{i=1}^{K} t_i \tag{16}$$

In the experiment, 100 test vehicles are set off and the mean travel time for every N vehicles arriving is computed using equation (15). The time taken for a percentage of the vehicles to arrive at the predefined destination is also recorded. Three different cases are defined for the experiment as follows:

- Case 1: 200 Vehicles in 6x6 topology;
- Case 2: 300 Vehicles in 6x6 topology;
- Case 3: 400 Vehicles in 6x6 topology.

The experiment is conducted for DTPOS+ACO and DTPOS-ACO to obtain t_t and T_K for three different traffic densities. t_t and T_K are measured in ticks which translates to seconds in the simulation. 1tick is equivalent to 1second in this simulation.

A. Case1: 200 Vehicles

Figure 4 shows the mean travel time comparison for DTPOS+ACO and DTPOS-ACO for a traffic density of 200 vehicles. It is evident that vehicles in the DTPOS+ACO case have shorter mean travel times than those in the DTPOS-ACO case. What this means is that vehicles in the DT-POS+ACO case spend less time reaching their destination compared to those in the DTPOS-ACO case travelling to a common destination. Figure 5 also shows the percentage of vehicles arriving at the specified destination and the cumulative time taken. As can be seen from the figure it takes about 50ticks for 50 percent of the vehicles to arrive in the DTPOS+ACO case and vehicles take 100ticks which is twice that time to get 50 percent of the vehicles arriving in the DTPOS-ACO case. The figures double in both cases to have 100 percent of the vehicles arriving.

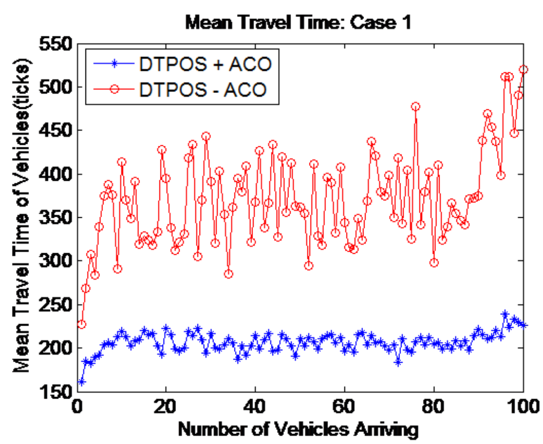

Figure 4. Mean Travel Time of Vehicles: Case 1.

B. Case 2: 300 Vehicles

Figure 6 shows a similar trend to what has been previously discussed with DTPOS+ACO showing lower mean travel times than DTPOS-ACO. The mean travel time figures however are much higher for the 300 vehicles traffic density than for the 200 vehicles.

Figure 7 also shows the percentage of vehicles arriving at the predefined destination and the time taken for all of them to reach their destination. For the case of 300 vehicles, it takes 100ticks for 50percent of the vehicles to arrive at the destination in the DTPOS+ACO situation and 200ticks for the same percentage to arrive at the destination in the

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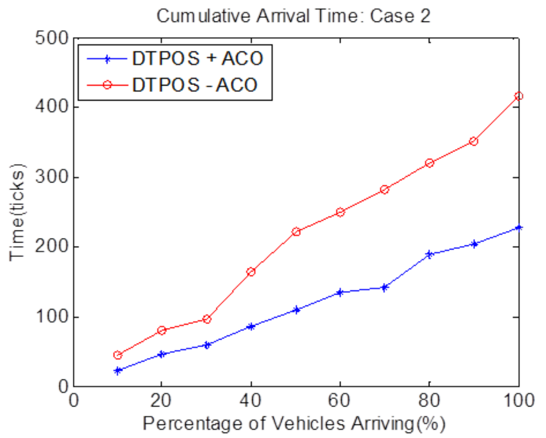

Figure 5. Percentage of Vehicles Arriving Vs Time: Case 1.

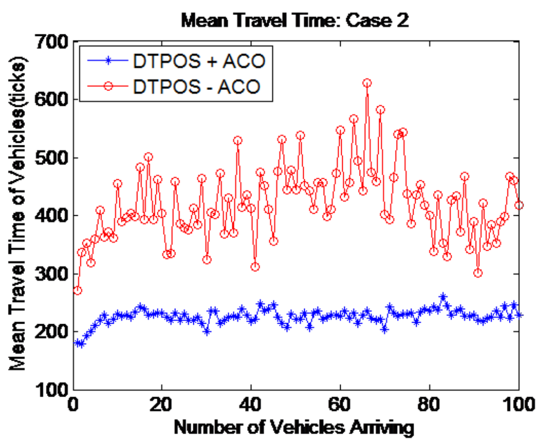

Figure 6. Mean Travel Time of Vehicles: Case 2.

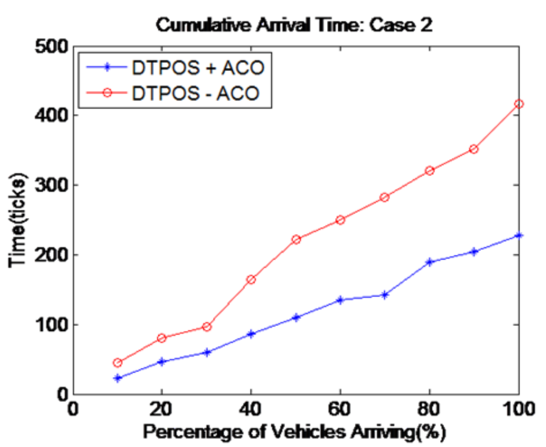

Figure 7. Percentage of Vehicles Arriving Vs Time: Case 2.

DTPOS-ACO situation. It takes twice as much time in both systems for all the vehicles to arrive. Once again it has been shown that vehicles in the DTPOS+ACO case use less time than those in DTPOS-ACO.

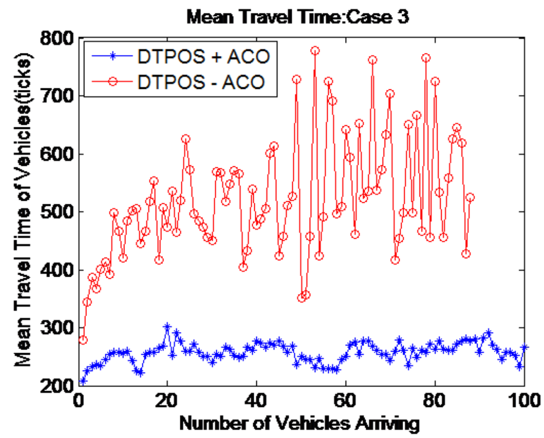

Figure 8. Mean Travel Time of Vehicles: Case 3.

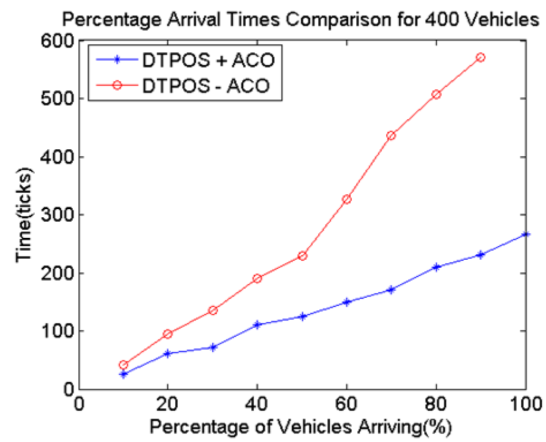

Figure 9. Percentage of Vehicles Arriving Vs Time: Case 3.

C. Case 3: 400 Vehicles

Figure 8 shows the mean travel time comparison of vehicles for the two systems with a traffic density of 400 vehicles. The trend remains the same with higher values of travel time as a result of the increased traffic density. Figure 9 however, shows an interesting trend when the percentage of vehicles arriving and their cumulative times are studied. It was realised that as the traffic density increases it becomes almost impossible for all the vehicles to arrive in the DTPOS-ACO case. For the 400 vehicles traffic density, it was realised that while it took about 220ticks for all the vehicles to arrive in the DTPOS+ACO case, it took almost 600ticks which is almost thrice the time for all the vehicles to arrive in the DTPOS-ACO case.

VII. CONCLUSION

In this paper, a dynamic travel path optimization system has been proposed. The system is implemented in NetLogo. Two cases of the DTPOS have been developed, one with ACO and the other without ACO. The two systems

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were simulated, and the results analyzed for comparison of performance. The performance indicators studied have shown that the DTPOS with ACO always gives results which are better than the case without ACO. At all traffic densities, the mean travel time of vehicles was always lower for the DTPOS+ACO than the DTPOS-ACO. Also, the percentage of vehicles arriving at the destination and their cumulative time were compared, and it was evident that DTPOS+ACO took less time for all the vehicles to arrive than DTPOS-ACO. It can therefore be inferred that Ant Colony Optimization solves the vehicular traffic problem by substantially reducing the travel time.

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User Acceptance Identification of Restrictions Caused by Mobile Security Countermeasures

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***Abstract*—The proliferation of mobile devices, especially smartphones and tablets, in people's daily life has motivated the enterprises to embrace mobility as an inevitable success factor in their business. However, integrating mobile devices into enterprises brings new security risks and challenges. Hence, security countermeasures must be applied to mobile devices to secure corporate data and segregate them from private data. Such countermeasures can restrict the usage of mobile devices, and mobile users consequently have to accept the restrictions arising by applying such countermeasures. The user acceptance of these restrictions must be considered. This work derives a set of such restrictions that limit the usage of mobile devices. It also presents the results of a questionnaire that investigates the user acceptance rate of these restrictions. The results of this study might help enterprises in their decision-making process about selecting proper security countermeasures by keeping a considerable balance between security and usability.**

Keywords-mobile enterprise applications; mobile devices; mobile security; user acceptance.

I. Introduction and Literature Review

Over the past few years, the evolution of mobile technologies and applications makes the ubiquitous communications (anywhere and anytime) a growing reality [1][2]. According to [3], mobile broadband connections are forecasted to continue growing worldwide to 5.3 billion in 2018, moreover, mobile users will steadily increase to reach 1.37 billion in 2017. In this paper, the mobile user refers to the employee who uses mobile devices (just smartphones and tablets) at work.

The rapid proliferation of mobile devices in people's daily life has triggered enterprises to consider the mobility as an inevitable part of their business and IT strategies to derive more revenue, enhance customer engagements, and being more competitive in the market. Smartphones and tablets became more integrated into enterprises' IT infrastructure. This integration solely represents the enterprise mobility concept by giving the employees better possibilities to work effectively while they are on move [4]. The reasons for this include location flexibility, time saving, portability, ease of research, etc. For example, sale persons can access their mobile Customer Relationship Management System (mobile CRM) to allow them updating their customer details while they are away from their offices.

Many companies provide corporate mobile devices to be used by their employees. Such devices can often be monitored and controlled. On the other hand, the employees can use their own personal devices for work. This concept is considered as a consumerization of IT or Bring Your Own Device (BYOD) [5][6]. In this sense, using corporate or personal mobile devices increases employee productivity and reduces business operational costs [7].

However, companies that allow using mobile devices for work have to pay more attention to the huge amount of new risks that differ clearly from Personal Computer (PC) risks. Smartphones and tablets are lightweight mobile devices. They have low technical capabilities in comparison to PC devices. This hiders these mobile devices from porting PC security technologies and standards [8][9]. Furthermore, mobile devices are small and portable and therefore, they can easily be stolen or lost.

Because of many different risks and risk sources in mobile environments [10]-[13], companies have to apply proper mobile security countermeasures to mitigate such risks. Applying security countermeasures on mobile devices may restrict their usage in a way that affects the mobile users' flexibility and productivity. This in turn influences the decision to use these mobile devices at work. Moreover, this can lead to lose the benefits of mobility. Therefore, companies have to consider such consequences on mobile users when applying new security solutions. One of the biggest barriers to reach a true mobile security is the user acceptance of corporate security policies. As enterprises move to mobile devices, their IT organizations are trying to keep the right balance between user enablement and data security [14].

In this paper, the current mobile security countermeasures are defined based on literature and best practices, and the user acceptance of the accompanying restrictions is investigated quantitatively (see Section IV). The work contributes to the security in mobile applications' research domain in the definition of user acceptance, creation a catalogue/list of the investigated restrictions (consequences) and then ana-

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lyzing them by investigating the relationships between these restrictions and the acceptance rate of the enterprises' users. These contributions might be of a great assist for enterprises in their decision-making process, especially when they select security countermeasures by keeping a considerable balance between security and usability.

This paper focusses on the user acceptance rate of mobile security countermeasures in business sectors, where the employees are allowed to use mobile devices for working purposes. The rest of this paper is organized as follows: Section II presents the related work. Then, Section III presents a list of security countermeasures along with their possible accompanying restrictions on mobile users. Section IV presents the results of a conducted questionnaire that measures the user acceptance rate of potential restrictions. Finally, the paper sums up with a conclusion in Section V.

II. Related Work

In order to investigate the user acceptance of new technologies, the Technology Acceptance Model (TAM) has been often conducted [15]-[17]. This model addresses why users accept or reject information systems and how the user acceptance can be affected by system design features [18]. User technology acceptance broadly refers to an individual's psychological state with regard to her or his voluntary and intentional use of a technology. It has been also identified as fundamental challenges to organizational technology adoption [15]. In [16], an extended TAM for mobile government systems has been proposed. However, in that work, the security was not taken as a factor that affects users' decisions to accept using mobile systems.

Another work that is located in this topic has investigated the user acceptance of a Privacy-Enhancing Technology (PET) that is called "Attribute-Based Credentials", or Privacy-ABCs [17]. This work considered the security and privacy as factors that affects the user acceptance of the PET without considering mobility.

In [19], a framework to design secure Mobile Enterprise Applications (MEAs) has been presented. That framework mainly supports the enterprises in decision-making process during designing secure MEAs, side by side in keeping a balance between mobile security and user acceptance. It is stated in that work that the companies have to check user acceptance of security countermeasures even in the design phase of adopting mobile applications. This can be determined through a questionnaire, in which, employees of the enterprise can respond about the potential restrictions.

These related works motivate the objective of this study in investigating the user acceptance rate on the restrictions that accompany the security countermeasures the enterprises enforce while allowing their users to use their mobile devices at work. This paper does not introduce a TAM extension. Rather it investigates the business user's acceptance of the restrictions that are caused by the applying security countermeasures on mobile devices. Such investigation has not been conducted in the related work in this domain so far.

III. Mobile Security Countermeasures and their Accompanying Restrictions

Enterprises need to implement suitable security countermeasures to mitigate the wide range of threats in the mobile environment and achieve a certain level of security on mobile devices. Applying security countermeasures to mobile devices can restrict the usability of those devices. In general, a high level of security on mobile devices can be achieved by setting a high level of restrictions, but on the other hand, this will reduce their usability. These restrictions negatively affect the satisfaction factors of the employees who want to use mobile devices in business sectors. Therefore, enterprises have to balance between the technical view (security solution) and the user view (user acceptance of the restrictions). Hence, a balance between security and usability have to be maintained [20]. The rest of this section goes through a number of mobile security countermeasures collected from literature and best practices. Furthermore, these countermeasures are classified in groups along with their potential restrictions.

A. Authentication and Authorization

Authentication involves identifying the mobile user who needs to have access on certain corporate data. This is usually based on one or a combination of the following types of credentials: something you have (certificate), something you are (fingerprint), something you know (password). In [21], a number of authentication methods for mobile devices has been presented and classified in groups (knowledge-based methods like passwords, Personal Identification Numbers (PIN) or pattern locks as well as biometrics methods like face recognition and voice recognition). In order to control the access to corporate resources, the authenticated mobile users should be also authorized through authorization process, which grants or denies specific permissions to each user.

In addition, mobile devices can be authenticated through continuous touch-based authentication, which continuously records touch data from mobile device's touch screen and then exploits user interaction data to authenticate users based on the way they perform touch operations [22][23]. However, this mechanism is not included in the conducted survey, because it is not widely known in the practice so far.

Consequences on Mobile Users. Strong authentication requires a strong password, which enhances the security on mobile devices. High restrictions can be applied on mobile devices by enforcing long alphanumeric passwords that will be required frequently and might lock the user after few wrong attempts. Such high restrictions enhance the security, but on the other hand, minimize the usability and reduce employees' productivity.

B. Encryption

Virtual Private Network (VPN) is one alternative to enable secure connection between an enterprise's internal network and mobile applications by installing a VPN client on mobile devices [24]. VPN is an alternative to secure sensitive business data "in motion" over unsecured network. In addition, to countermeasure the possible disclosure of sensitive

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data that stored on mobile devices (data-at-rest), mobile device's local storage has to be encrypted. Strong encryption mechanisms are used to protect the confidentiality and integrity of communications. By using these encryption and mutual authentication mechanisms, the risk from using unsecured mobile networks before transmitting any data can be mitigated [25].

Many mobile users use personal mobile applications (e.g., Dropbox, iCloud) to centrally store documents in cloud and synchronize them with their multiple computing endpoints. Such mobile applications can take corporate documents out of IT control if those documents are moved to such personal clouds. Therefore, mobility also needs data encryption while they are "in use", which includes maintaining encryption of whatever is being viewed in the file system while being used by a mobile application as well as data shared via Open In or Copy-Paste to another mobile application on the mobile device (i.e., opening an email attachment into a document editor) [14].

Consequences on Mobile Users. Excluding the slower performance that might be caused, no major consequences on mobile device usage have been found when applying encryption on data-at-rest and data-in-motion. In general, enabling security features affects the performance, regarding time and computational power to execute cryptographic algorithms, and users have to find a compromise while choosing ease of use and performance versus security [26].

Concerning data-in-use encryption, the mobile device's performance will be even slower than the case of encrypting data-at-rest and data-on-motion, due to full memory encryption. Anyway, if the data-in-use encryption is not implemented, the company may disallow their employees from using cloud services. This restricts the usage of third mobile applications on mobile devices. Otherwise, the company should have control on Open In and Copy-Paste functions [14].

C. Mobile Physical Security

Lost and stolen mobile devices are seen as the greatest security concern, due to the risk of compromising their data. Hence, mobile device's physical security should be given higher importance. When mobile devices are lost or stolen, the enterprises should not lose control on those devices. Such control can be done using Mobile Device Management (MDM) systems, which enables IT departments to remotely lock and reset mobile devices and wipe their data [27]. Furthermore, to mitigate the risk of compromising the data of lost or stolen mobile devices, a layered mitigation strategy can be conducted [25]. The first layer involves a required authentication before gaining access to the mobile device or corporate resource. The second layer involves either encrypting the mobile device's local storage, or not storing data on mobile devices at all (read only). The third layer involves mobile user training and awareness, which can reduce the frequency of risks related to mobile device's physical security.

Consequences on Mobile Users. Controlling mobile devices by remotely locking and resting has no consequences that can restrict the mobile devices' usage. However, if the layered mitigation strategy is conducted, restrictions can be set in the first layer during authentication (see Section III-A). In the second layer, the user can experience slow performance if the mobile device's local storage is encrypted (see Section III-B). Furthermore, a high level of mobile's physical security may require that no data will be allowed to be locally stored on mobile devices. Consequently, the user will not be able to access corporate documents offline on the mobile device. The third layer concerning the mobile user training will be presented in Section III-F.

D. Protection against Untrusted Applications.

The simplest way to protect mobile devices against untrusted third party applications is to enforce a policy that prohibits the installation of all third party applications. However, this way restricts the mobile device's usage and the mobile user's acceptance rate of such restrictions will be low (see Section IV-C). The alternative is the implementation of whitelisting to prohibit installation of all unapproved third party application. MDM systems utilize the whitelisting for allowing or blocking applications running on mobile devices [28]. Some enterprises implement a sandbox that isolates the corporate date and applications from third party applications on the mobile device. An application runs in a sandbox has file areas, which can only be accessed by the application itself [29].

Consequences on Mobile Users. The mobile user will not be able to install third party mobile applications on the mobile device if the enterprise applies a policy that prohibits the installation of all third party applications. Regarding the second alternative, if whitelisting is applied, the user will still be able to install third party mobile applications, which are approved and included in the whitelist. Finally, if a sandbox is implemented, the user should be able to install third party mobile applications.

E. Firewalls and Antivirus Protection.

To prevent data leakage via malware that is already installed on mobile devices, firewalls are also implemented on mobile devices to block or audit disallowed connections to or from mobile devices [30]. In the traditional desktops, firewalls can restrict access to system services and prevent applications on the system from leaking sensitive information to third parties. Regarding mobile devices, the firewalls can also restrict the network access to data-sensitive applications when not using Wi-Fi network. This is because network connections using mobile 3G/4G networks are usually either expensive or volume restricted [31]. Other way of protection is using antivirus software that can be installed on mobile device to detect malware.

Consequences on Mobile Users. Firewalls and antiviruses software protection can slow down the entire mobile system because these software's functions are always running in the background. The battery consumption can also be a big concern. The enterprises must have control on firewalls and antivirus software to keep them always enabled. However, an enforced firewall policy can affect the mobile users' satisfaction. The system slowness and high battery consumption are factors that make the employees avoid using mobile devices for work.

F. Conducting Security Awareness

Applying technical security countermeasures to mitigate risks can be insufficient as long as employees are not aware of potential security risks [32][33]. Furthermore, awareness of security risks can improve security countermeasures development (design and implementation) and performance (reduced deficiencies and greater efficiency) [34]. Hence, enterprises have to organize security awareness programs for their employees who want to use mobile devices at work.

Consequences on Mobile Users. Concerning mobile security awareness programs, which are complementary to the technical security solutions, no restrictions on mobile devices' usage has been found so far.

IV. METHODOLOGY

This part describes the research data, the measurement and the methods utilized in the data analysis process. In order to achieve the research objectives and to conduct that in a structured way, few research methodologies have been carried out in this research process. The focus of this study is mainly finding out the various mobile security countermeasures and their restrictions on the enterprises' users who use their corporate mobile devices. This is besides finding out the user acceptance level of these restrictions. For that, a quantitative approach is followed to describe and understand experiences, ideas, beliefs and values. Quantitative research concerns asking people about their opinions in a structured way so that facts and statistics can be produced to guide a study like the one presented in this paper. Briefly, this study analyzes the user acceptance level through observations in numerical representations and statistical analysis.

A. Measurement

For a quantitative measurement, an online questionnaire had been developed to study the perception of users' acceptance rate on the security countermeasures applied on their corporate mobile devices. The pros and cons as well as the reliability of this instrument were also part of the research objectives. The questions were prepared from the information collected from the available literature and best practices in this domain.

The circulated questionnaire had been divided into three main parts and consisted of 17 questions in total. The initial four questions were targeting the mobile device usage at work. The following list of questions targeted the mobile security awareness of users while using their mobile devices. The remaining set of questions were focusing on measuring the user acceptance level of the security countermeasures and their accompanying potential restrictions maintained by the organizations (to protect their data) and applied to the users' mobile devices.

The questions were distributed to the respondents in form of multiple choices questions (using Likert scale items). Users were given the flexibility to choose more than one answer, and they were given space to add their own options.

B. Data Collection

This process focused on collecting the data through distributing the designed questionnaire on a set of targeted respondents who are using their mobile devices at work. The research objectives were achieved from the suggestions of users by targeting corporate areas. According to [35], it is well noted in the literature that managers would ultimately affect firms' practices. Therefore, middle and top managers from information and communication technology domain were considered in this study as main targeted respondents. The questionnaire was circulated in corporate offices and social networking websites. The respondents were given 10 days to complete the questionnaire.

Concerning the sample size, 130 potential respondents were targeted regardless of their age group. According to [36], sample sizes that are greater than 30 and less than 500 are appropriate for most researches and based on that, the selected sample size in this research is considered appropriate. All responses were checked for validity. The incomplete responses were considered invalid and had been excluded. The response rate was 79%. That makes 103 users who provided valid responses. Finally, the data were analyzed using Statistical Package for the Social Sciences (SPSS) statistics software package. Data analysis is explained in the following section.

C. Data Analysis and User Acceptance Rate

The responses to the provided questions had resulted in the following:

- The initial questions were related to mobile devices' usage at work. Around 30% of the respondents stated in this regard that they are allowed to use their mobile devices (own or corporate mobile devices) at work. Only 13% of the respondents were allowed to use only corporate mobile devices.
- Regarding the usage degree of mobile devices for various purposes, the respondents were able to use their devices for corporate purposes considering security as a major concern. The majority of the responses, who were allowed to use mobile devices at work, stated that they were using their mobile devices to access corporate emails (91%), performing work related tasks (52%), access corporate content (70%) and searching for information (69%). Each of these percentages was directly related to a response to a question in the questionnaire.
- When asked about security awareness of their mobile devices, 35% of the respondents had indicated that they have medium to no knowledge about mobile security concerns. This shows that security awareness, training and education were also very important in organizations to protect their data.
- As for dealing with their corporate data, 52% of the respondents answered that they never dealt with their enterprises' data on their mobile devices. Moreover, 30% of the respondents answered that they only dealt with non-

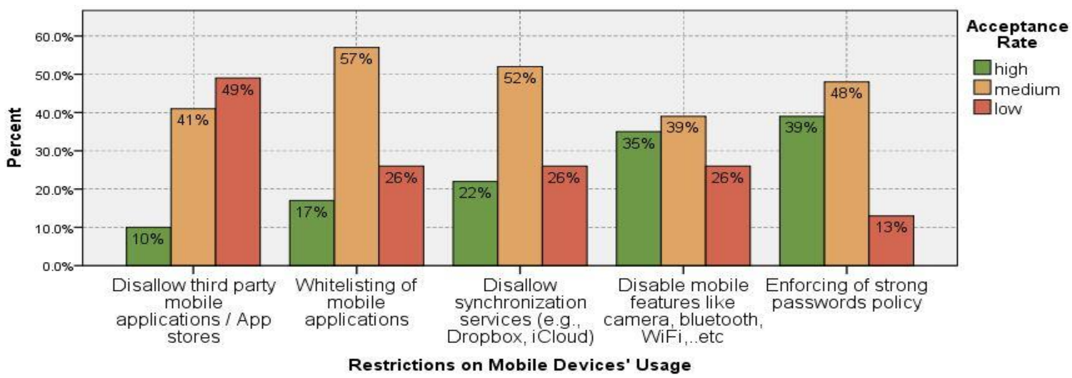

Figure 1. User Acceptance Rate of Restrictions on Mobile Devices' Usage

sensitive corporate data. This comes from several security restrictions applied to these data. An employee, who has to access sensitive corporate data (e.g., sales data, Human Resources (HR) data or policies) using mobile devices, might accept a wide range of restrictions. On the other hand, these restrictions might be not accepted by an employee, who deals only with non-sensitive corporate information.

- Regarding security countermeasures, the majority of respondents, who were allowed to use mobile devices at work, were enforced to apply countermeasures on their corporate mobile devices. The restrictions that arose from applying the aforementioned countermeasures vary from enforcing strong passwords to restricting installation and usage of third party applications reaching the enforcement of full memory encryption. This latter can result in a lower performance of mobile devices.
  The user acceptance rate was analyzed and an excerpt of the restrictions are depicted in Figure 1.
- After listing most of the restrictions the mobile users faced when using mobile devices at work, the last part of the questionnaire investigated whether the users are comfortable with these restrictions or not. Concerning flexibility and productivity, the results (see Figure 2) showed that around 43% of the respondents were not satisfied with the current security restrictions in their mobile working environments.

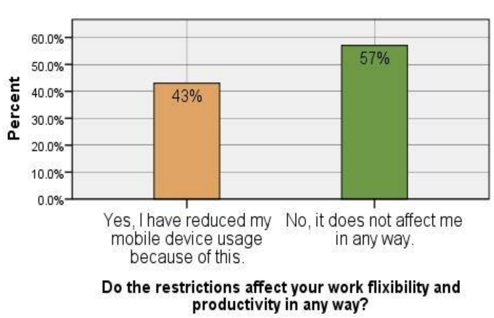

Figure 2. The Effect of Restrictions on Mobile Devices' Usage

D. Recommendations

The mobile user acceptance of the restrictions is a very important factor to be considered during the design phase of MEAs. Evidently, using a strong technical solution must not be on the costs of user's satisfaction. Rather, they have to be considered side by side.

As the enterprises data are usually classified into security levels, enterprises should carefully define the intended security level of their data on mobile devises. The security level should be defined to include three points of view, namely, business view, user view, technical view as depicted in Figure 3. These views are explained as follows: *Business View.* The enterprise defines the security requirements as a subset of its business requirements. *Technical View.* The security requirements are fulfilled by applying the security countermeasures. Implementing the technical solution is accompanied with potential restrictions. *User View.* The user acceptance of the restrictions should be considered as highly important when defining a security level. For instance, there are two alternatives to countermeasure the potential threats that can be caused by third party applications. The first alternative is to disallow the installation of all third party applications on mobile devices. The second alternative is to apply whitelisting. Figure 1 clearly showed that the user accepts the second alternative (whitelisting) more than the first one. This gives enterprises an indicator that the users will be more satisfied with applying whitelisting rather than preventing the installation of all third party mobile applications. In addition, the mobile security countermeasures and restrictions must be taken in such a way that it should not restrict the flexibility and productivity of users. A balance between mit-

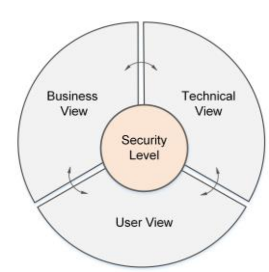

Figure 3. Security Level on Mobile Devices

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igating corporate risks and user acceptance has to be taken into account as well. In addition, security awareness programs for employees is a complementary factor for mitigating risks in the mobile environments.

V. CONCLUSION AND OUTLOOK

In this paper, mobile security countermeasures has been derived along with their restrictions on mobile devices' usage. Generally, from a technical point of view, a high security level on mobile devices can be achieved by setting a high level of restrictions. However, this decreases the mobile user satisfactions. A questionnaire has also been conducted to investigate the mobile user' acceptance of the potential restrictions. The user acceptance rate can affect the user decision to use mobile devices. If the user acceptance is low, the user will not be able to use the mobile device at work. Consequently, the company will lose the advantages gained from employing mobility. Having a general overview on the user acceptance rate will help the enterprises in selecting the needed security countermeasures side by side with keeping a balance between security and usability.

In this paper, the extension of TAM was out of the scope. However, the results presented in this paper was part of an ongoing research that will proceed to extend the TAM. This extension will include the applied mobile security countermeasures and their consequences as factors that can affect the user acceptance of using mobile business applications.

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A Reactive Inter-Domain Routing Protocol for MANETs

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***Abstract*—Mobile Ad hoc Networks (MANETs) were developed to support communication in an environment and places where the permanent availability of fixed infrastructure who maintains communication between different nodes cannot be assured. The first interest in mobile ad hoc networks was the simple routing between similar nodes. That's why researchers focused more on how to make routing efficient within a single domain. In last decade, the heterogeneity of mobile nodes increased dramatically and the need of the interconnection between MANETs in many situations, such as in battlefields or disaster recovery is more important because of diversity of "intra-domain" routing protocols in each domain. For this purpose, an inter-domain routing protocol was developed to support communication across different MANETs. In many researches, the mobile agent paradigm was used to perform routing in MANET. In this paper, a highlight of the use of mobile agents in ad hoc networks, and the application of them with bees' communication to design a reactive inter-domain routing protocol for MANETs. Our bees' communication-based proposal will helps to enhance the efficiency of the routing protocol and to reduce the battery use of the node.**

Keywords-mobile ad hoc networks; inter-domain routing; mobile agents; bees communication.

I. INTRODUCTION

In the twentieth century, the wireless ad hoc networks take an emerging aspect. Any fixed infrastructure or central administration needs to deploy this kind of networks. Most of researches concerning routing in ad hoc networks focused on routing in a single domain.

A research has been performed in the beginning of the 2007^{th} for routing between heterogeneous domains (different routing protocol and different technology of transmission can be employed in each domain). The protocol instances issued from this research [1][2] run in routers in a distributed manner. There are gateways in each domain used for routing packets from one domain to another until the destination is reached.

Nowadays, many protocols in the field of inter-domain routing in mobile ad hoc networks focused on the semi-proactive and proactive routing, but did not consider the reactive side. In this paper, we introduce a new reactive inter-domain routing protocol for ad hoc networks using bees' communication. The natural inspired metaheuristic algorithms take advantages on the design of the intra-ad hoc routing.

We present, in this paper, an overview of using mobile agents in inter-MANETs, then, their application in the context of bees' communication to design a reactive inter-domain routing protocol for MANETs. Bees' communication was introduced and developed for routing in a single MANET. Bees' communication will be a first use in the inter-domain routing for ad hoc networks. We use it to enhance the efficiency of the inter-domain routing and for reducing the battery use. The method used is inspired by the bee dance foraging principle to find food.

The rest of the paper is organized as follows. In Section 2, an overview of the related works that use swarm intelligence is presented. In Section 3, a description of the basic inter-domain routing protocol for MANETs. Section 4 outlines method bees employ to share food among them using dance language. Sections 5 and 6 provide details on our approach.

II. RELATED WORKS

The enhancement of routing in MANETs was based on swarm intelligence many times. The first routing algorithm related to the use of Ants' communication was the Ant-Colony based Routing Algorithm (ARA) [3]. The core of the algorithm is described in the ant-based routing algorithms (AntNet) [4] and (ABC) [5], two swarm intelligence routing protocols for fixed networks. Another routing algorithm designed for MANETs and based on AntNet (AntHocNet) [6], it is a hybrid routing protocol using both a reactive mode of operation (on-demand route discovery) and a proactive mode of operation (periodic route discovery). However, the routing overhead of AntHocNet is a disadvantageous factor [7]. The swarm intelligence method based on Ant Colony Optimization was also used in the inter-domain routing for MANETs. Dressler and Gerla [8] proposed to enhance inter-domain routing in MANETs, based on virtual cord for routing between a set of MANETs, by applying the ACO mechanism of the AntHocNet protocol to handle topology change. The result of their work showed that the proposed combination is efficient and had marginal overhead by applying ACO mechanism.

Bees' communication was first studied by Karl Von Frish in 1911 [9]. He spent his professional life studying the comportment of bees and won a Nobel Prize for his research. The application of bees' communication in routing data packets so far has only been introduced and developed for routing in a single MANET. Farooq et al. developed a protocol called BeeHive for fixed networks [10]. They claimed that the study of honey bees has revealed a remarkable sophistication of the communication capabilities as compared to ants. Their work on BeeHive demonstrated that it can be more energy-efficient than AntNet and deliver the same or better performance. BeeAdHoc [11] is an application of the principle of bees' communication to route packets within a single MANETs and it was proposed by the same researchers. BeeAdHoc uses fewer control packets as compared to AntNet and AntHocNet, which decreases the routing overhead, and distributes traffic to different paths proportional to their quality and capacity, which makes it an energy-efficient routing protocol. Based on early results, BeeAdHoc shows also that packet delay is lower.

As the use of Bees' communication shows more interesting results than the use of ants' communication for intra-domain routing in ad hoc networks, we will use bees' communication to perform an efficient and reactive inter-domain routing protocol for MANETs and compare it with the existing inter-domain routing protocol for MANETs [8] based on ants' colony optimization.

III. BASIC SCHEME INTERCONNECTING SEVERAL MANETS

The interconnection between groups of MANETs is maintained by gateways belonging to each MANET. When a node "a_1" from a certain MANET "A" want to reach a node "d_2" from an another MANET "D", firstly, it routes packets to a reachable internal gateway within MANET "A", using the underlying routing protocol; after that, packets are routed to an external gateway within external MANET using inter-domain routing protocol, and so, until the packets reach destination in domain "D".

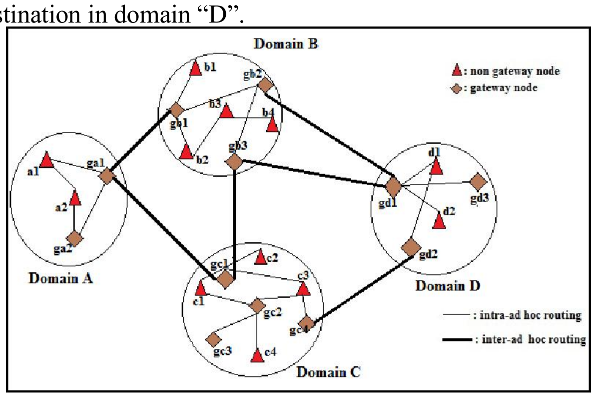

Figure 1. Interconnection of several MANETs.

The inter-domain routing protocol is proactive; thus, the external routing table of each gateway to different domains is known by at least all gateways.

IV. HOW BEES SHARE FOOD LOCATION

Bees are very organized and communicate in a very complicated manner through dances. When a food source is found by a bee, the other bees reach this location after some time; this is done by sharing the way to source using dance language done by the first discoverer bee. All information that other bees need to find food source are: its distance from the hive, its direction, and productivity. The dancing process is performed into two dances; see Figures 2 and 3.

A. *Waggle Dance*

This type of dance is performed when food is located at a long distance from the hive. At this state and taking as reference the direction if the sun, the movement of this dance resembles to the number "eight". In a typical dance, the bee moves in a straight line, for a short distance, moving its body from side to side approximately 13 to 15 times a second and return after to the beginning point from which it starts the dance tracing a half-circle.

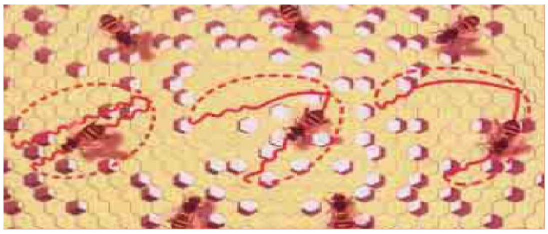

Figure 2. Waggle Dance [12].

By varying the angle between the waggling run and an imaginary line running straight up and down, the bee conveys the direction of the food source. If a line is drawn which connects the food source and the hive, and another line which connects the hive and the spot on the horizon immediately below the sun, then the angle formed by the two is observed to be the same as that of the angle in the waggle dance.

B. *Round Dance*

The round dance is a round movement of the discoverer bee, it turns around itself in a quick rhythm of eight to ten tour/second then make a half round in the opposite sense.

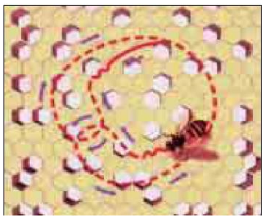

Figure 3. Round Dance [12].

The other bees, while observing this dance, know that source of nectar is near close to a radius of 50 meters.

V. EXTENDED APPLCATION OF BEES' COMMUNICATION TO THE INTER-DOMAIN ROUTING FOR MANETS

Our proposal is to design a reactive inter-domain routing protocol for mobile ad hoc networks. As mentioned earlier in the beginning of this paper, our idea is based on bees foraging principle. For instance, a discoverer bee starts searching food place, and when it finds it, it tells other bees the location of the food. It launches discovery process and when it discover the place, it tells the information about this

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place to the other bees; (for distance, we use PacketDelay, for direction, we use RouteLifeTime (because only nodes having a sufficient energy participate in the packets routing) and for productivity, we use AvailableBandwidth (the quantity of the food transported, is equal to the number of packets routed).

In our case, we use waggle dance since it will be applied for large scale interconnected MANETs.

We will use mobile agents to discover routes to a destination, and to transmit back results to the source node relying on three metrics, Packet Delay, RouteLifeTime, and AvailableBandwidth.

A. PacketDelay

It is the end-to-end packet delay for a discovered route between source and destination.

B. RouteLifeTime

It is the average remained battery of nodes composing a route between source and destination

C. PacketDelay

The bandwidth is the maximum data transfer rate of a network connection. It specifies how much data can be sent over a specific connection during amount of time. The available bandwidth then is the unused capacity of a network connection during a time interval. The available bandwidth along a path is the minimum available bandwidth of all traversed network connections.

VI. ALGORITHM DEFINITION

As mentioned in Section 3, a packet from a source S, traverses a path of intra-connected and inter-connected gateways until reach destination D. We will use three types of mobile agents, MA_D, MA_RL, and MA_AB.

MA_D: is the mobile agent responsible of packet delay computation. MA_RL: is the mobile agent responsible of RouteLifeTime computation. MA_AB: is the mobile agent responsible of available bandwidth computation.

A. PacketDelay Computation

From an intra-domain, a node requesting a high quality route to another intra-domain node does:

1) If the domain the source node belongs to uses proactive routing protocol then:

- The source node creates MA_D mobile agent for each gateway having connection to external domain.
- The mobile agents store the departure time from source node and are sent to the corresponding gateways.
- When arrival at the gateways nodes, they calculate difference between departure time and arrival time and store results in variable delay.
- After that, at each gateway the mobile agent is cloned and broadcasts to another connected gateway until the destination is reached.

2) If the domain the source node belongs to uses reactive protocol

- The source node launches a discovery process using underlying routing protocol. The discovery process is ordered to gateways having connection to the external domains.
- After the source node obtains the list of gateways having connection to the external domains, it uses the same procedure detailed above to perform computation of delay.

B. RouteLifeTime Computation

As done for packets delay, a source node creates mobile agent for each gateway having connection to the external domains and submit them to these gateways.

When mobile agents arrive to these gateways, they store the value of the remained battery energy in a structure containing (gatewayID, remainedbattery).

After that, a mobile agent is broadcasted to an external domain. It compares the stored remained battery energy to the remained battery energy of the current node.

- If the current node energy is less than a certain threshold (speed of average consumed energy per a degree of amount traffic) then, it returns to the source node with **routequalityfailed** message.
- Else, if the current energy is better than the stored one, then, the result is stored in the struct.

When mobile agent arrives to the destination, it calculates the average remained battery of the traversed path, and the result is send back to the source node.

C. AvailableBandwidth Computation

The available bandwidth can be calculated as: the total bandwidth of a network connection – consumed bandwidth
The consumed bandwidth (goodput): average data rate of successful data transfer per a slot of time, and can be taken by mobile agents from statics of the network device.

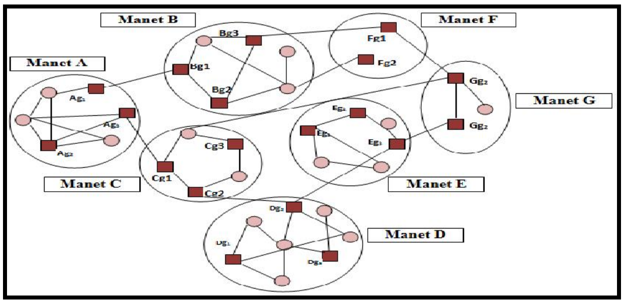

Figure 4. Proposed scenario to apply bees' communication.

When applying **routequality** request from node "a" in domain A, to node "e" in domain E (see Figure 4), node "a" will have routequality of all routes leading to node "e" so that it can choose the best one based on "minimum delay, maximum bandwidth, and maximum lifetime"

VII. CONCLUSION AND FUTURE WORK

With the proposed solution, mobile agents can contribute to minimise the energy of nodes and when the route quality to reach a node will be known, the overhead will be minimized. Future work will be to build the proposed solution for a large scale interconnected Mobile AdHoc Networks. We will use the network simulator ns-2.32 [13] with the integration of the mobile agent framework to perform the computation made by each gateway and to evaluate the performance and overhead of the given scheme.

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