Developing Cognitive Strategies for Reducing Energy Consumption in Wireless Sensor Networks

Elena Romero, Alvaro Araujo, Javier Blesa, Octavio Nieto-Taladriz
Electronic Engineering Department
Escuela Técnica Superior de Ingenieros de Telecomunicación
Universidad Politécnica de Madrid
Madrid, Spain
{elena, araujo,jblesa,nieto}@die.upm.es

***Abstract*— Due to Information and Communication Technologies, wireless data traffic is growing with a rate higher than 25% annually. Wireless Sensor Networks (WSNs) represent nowadays one of the most rapidly expanding sectors in wireless networks. In this context, applying reducing power consumption in WSN scenarios is a great challenge to face in order to make this kind of networks sustainable. In this paper, we present some work in progress ideas about different opportunities in power consumption reduction for WSN taking advantage of the opportunities presented by applying Cognitive Radio (CR) capabilities to WSN. Cognitive characteristics provide some features that make WSNs different to Cognitive Wireless Sensor Networks (CWSNs). However, cognitive capabilities entail extra power consumption too. Therefore, the design of strategies must be a task that involves the overall design across all layers of the communication protocol and not only specific improvements without considering consumption in a holistic way.**

Keywords - WSN; Power management; Cognitive radio; Network optimization

I. INTRODUCTION

Global data traffic in telecommunication annually grows with a rate higher than 50%. While the growth in traffic is stunning, the rapid adoption of wireless technology over the complete globe and the penetration through all layers of society is even more amazing. Over the span of 20 years, wireless subscription has risen to 40% of the world population, and is expected to grow to 70% by 2015. Overall mobile data traffic is expected to grow to 6.3 exabytes per month by 2015, a 26-fold increase over 2010 [1]. This expansion leads to an increase of the energy consumption by approximately 10% per year.

A major portion of this expanding traffic has been migrating to mobile networks and systems. This increasing demand for wireless communication presents an efficient spectrum utilization challenge. To address this challenge, Cognitive Radio (CR) has emerged as the key technology, which enables opportunistic access to the spectrum. Briefly, CR is defined as a wireless radio device which can adapt to its operating environment via sensing in order to facilitate efficient communications [2]. Moreover, it can facilitate multimode radio interfaces that can operate in multiple standards with its adaptation property.

Adding cognition to the existing WSN infrastructure will bring many benefits. In fact, WSN is one of the areas with the highest demand for cognitive networking. In WSN, node resources are constrained in terms of battery and power of computation but also in terms of spectrum availability.

Regarding spectrum scarcity, most WSN solutions operate in unlicensed frequency bands. In general, they use ISM bands, like, the worldwide available 2.4 GHz band. This band is also used by a large number of popular wireless applications (Wi-Fi, Bluetooth, Zigbee and IEEE 802.15.4). For this reason, the unlicensed spectrum bands are becoming overcrowded with the increasing use of WSN based systems. As a result, coexistence issues in unlicensed bands have been subject of extensive research [3][4] and in particular, it has been shown that IEEE 802.11 networks can significantly degrade the performance of Zigbee/802.15.4 networks when operating in overlapping frequency bands [4].

In this scenario, Cognitive Wireless Sensor Networks (CWSN) emerge as a new paradigm that can help mitigate very important problems like spectrum scarcity, interferences or reliable connections. Due to the number of nodes, its wireless nature, and its deployment in difficult access areas, CWSN nodes should not require any maintenance. In terms of consumption, this means that the sensors must be energetically autonomous and therefore the batteries cannot be changed or recharged. In this kind of scenarios lifetime of the nodes ranges typically between 2 and 5 years, making power consumption a dramatic requirement to establish [5].

Considering all these points, it is extremely important to optimize every step of wireless communications (ranging from the manufacture of equipment for basic functions). Thus, green networks and communication approaches require a holistic approach to energy optimization in communication systems inspiring a new research field.

The structure of this paper is organized as follows: Section II present the related work in CWSNs and some efforts related to reduce energy consumption. Section III focuses on the power consumption challenge in CWSNs. Section IV presents a group of strategies for power consumption reduction for CWSN sorted by the cognitive feature chosen for developing the strategy. Finally, conclusions and future work are presented in Section V.

II. RELATED WORK

In this section, state of the art on Cognitive Radio from a low-power WSN communication perspective is provided.

CWSN is a young technology and we can find few works about CWSN in a generic way [6]. Most of works introduce the idea of CWSN and promoting the research on this topic. Along the same line, [7] presents an overview of CWSNs,

 ISBN: 978-1-61208-197-7

discussing the emerging topics and the potential challenges in the field. The main advantages are discussed and possible, but vague, solutions to the problems are suggested. In [8], the main design principles, topologies, algorithms, sensing and decision techniques, advantages, application areas and architectures of CWSN are exposed. In [9], the vision and advantage of a holistic approach to cognition in sensor networks is provided. In [10], a methodology, a theoretical framework, and some novel ideas on performance modelling are presented.

Talking about reduce power consumption in general CN, there are several approaches. In a bottom-up review of low-power design, the first level can be focused on circuit choices (error correction, rake parameters, and drive currents). Second level is system parameters such us modulation, coding, carrier, filtering, sample rate or algorithms. Third level is radio knowledge of consumed power and final level is the application development. Most of the research works focus on achieving power-efficient spectrum use. In [11], a transmission power management is proposed to minimize interference with primary users and to guarantee an acceptable QoS level for the cognitive transmission. A method of spectrum sharing with multi-user cognitive network based on interference temperature limits model is proposed in [12]. Taking into account the channel occupancy probability is possible to develop a variable power-bandwidth efficiency strategy. Reducing the bandwidth efficiency by 50% can increase the battery life by 400% [13]. In [14], the power constraint is integrated into the objective function named power efficiency.

If we move to the specific area of consumption reduction in CWSN, there is still much work to do. Focusing on low-power networks, Gür and Alagöz [15] notice the importance of CR features to improve power consumption, as in [8] where it is noted that CR could be able to adapt to varying channel conditions, which would increase transmission efficiency, and hence help reduce power used for transmission and reception.

Some advices are given in [6] as “implementing spectrum sensing in all nodes in a WSN may not be efficient in terms of energy consumption”. In [9], two main problems related with energy consumption are listed: network lifetime maximization and energy efficient routing.

A routing scheme optimizing size of transmitted data and transmission distance is proposed in [16], while [17] focuses on reducing power consumption in the sensing step. It is noted the importance of carrying out this task adopting a cross layer approach for spectrum sensing and optimizing the sensing procedure with respect to energy consumption.

In [10], Bdira and Ibnkahla remark that energy-aware routing studies do not use to address application layer constraints (distributed or centralized processing of information, whether information relayed is urgent or essential) even though recent literature is rich in cross-layer optimization suggestions.

Even the research in this area looks to be very interesting (as the references prove), the use of Cognitive Radio to improve energy consumption in WSN is not a mature research area. Some ideas are given, but real proposals and improvements are missing. In this scenario, CWSN has much potential to provide. In this paper, we propose different approaches to improve power consumption strategies with cognitive features.

III. COMSUMPTION CHALLENGES IN CWSN

Cognitive Radio emerges as a new paradigm that allows the use of techniques and can help to mitigate very important problems like spectrum scarcity, interferences or reliable connections. We can say that CR is an intelligent wireless communication system that is aware of its surrounding environment, and adapts its internal parameters to achieve reliable and efficient communication (in terms of power consumption too) [18].

CRs open up new control dimensions for reducing energy consumption with their agility and adaptation properties. However, the cognitive technology will not only provide access to new spectrum but also provides better propagation characteristics. CR networks could achieve a wide variety of enhancements by adaptively changing system parameters like modulation, transmission power, carrier frequency, data rate and constellation size. This will certainly improve power consumption, network life and reliability in a WSN.

With these capabilities, a CWSN node can select the best strategy meeting its goals. A CWSN node could decide on the most appropriate strategy and acts accordingly. For this purpose each node has an optimization module that manages various parameters to decide the best policy in each case. The energy efficiency should be one of these optimization policies embedded in the optimization module.

However, there are intrinsic challenges related to the CR capabilities such as hardware complexity, algorithmic problems, and design problems. Indeed, the added complexity of the nodes to enable cognitive capabilities makes nodes have higher energy consumption. Sensing state, collaboration among devices (that requires communication) and changes in transmission parameters are not free in terms of consumption.

In this way, all steps must be taken into account for a holistic optimization. Reducing power consumption requires optimization across all the layers of the communication systems. This paper addresses the different options provided by CR in the design of low-power WSN.

IV. ENERGY OPTIMIZATION STRATEGIES

As mentioned above, the reduction of power consumption is a task that involves the overall design across all layers of the communication protocol. Focusing layer by layer, several strategies for optimizing the consumption can be listed for each level, but we believe that due to CR characteristics, address the problem of consumption in a holistic approach has more advantages.

Our proposal is to divide the opportunities to optimize energy consumption in 3 aspects, namely those that obtained through the sensing of the spectrum, those related to the capability to change transmission parameters and those that depend on the ability to share knowledge of the network. The first two aspects derive directly from the cognitive capabilities added to the WSN nodes. However, the third aspect, related to the communication between devices, although essential for CR, is one of the basic characteristics of WSN, now enriched with cognitive information.

A. Ability to sense the spectrum.

Related with the ability of being conscious at any time of the spectrum features and changing the transmission parameters dynamically we can list the following optimization strategies.

- Use less noisy channels implies less number of retransmissions: Often in WSN scenarios, due to congestion of the network and low power transmission, some packets are lost forcing retransmissions. CR provides the ability to sense the spectrum and change transmission parameters according to them. Thus, if in sensing step a less noisy channel is found may be optimal to change the transmission to this channel in order to avoid duplicate transmissions and reducing the global consumption of the network.
- Use less saturated channels implies lower transmitted power: In the same way as in the previous case, cognitive features provide the ability to transmit in less noisy channels. If the transmission is made through a channel less saturated we can reduce the transmission power by ensuring that messages reach their destination. Taken into account that communication is one of the most energy expensive tasks, reduce power transmission saves power to the network
- Use less noisy channels provides the possibility of using more efficient modulations: Power consumption could be reduced by using less robust modulations with lower consumption. More energy can be conserved by dynamically adopting the modulation according to instantaneous traffic load and congestion of channels [13].

B. Capability to change transmission parameters

Network can reduce power modifying several transmission parameters linked with sensed information. Examples of these parameters are: using less transmission power, using less memory, less microprocessor cycles, or an oscillator with lower frequency. For this challenge the following strategies could be used:

- Change communication parameters based on data rate requirements: Network devices can modify their communication parameters (modulation, channel, interleaving, etc.) to avoid a specific data rate with low power optimization. Network can use the most low power consumption wireless interface for a required data rate.
- Adaptative communication based on QoS requirements: because of the spectrum knowledge network can send more important packets using a better modulation, frequency channel or emitter power, but with a power penalty. Also, network can use crowd channels to transmit packets with low QoS requirements.
- Change transmission parameters according to spectrum: As it is said in section A, it is possible to change channel, power transmission or modulation parameters depending on the interferences found in the spectrum.

C. Ability to share knowledge of the network

CWSN paradigm allows modifying several parameters with influence in power consumption. These parameters belong to all stack levels, from application layer to physical radio interface. Spectrum knowledge, sharing information and collaboration are essential to achieve this goal. Strategies for achieving this goal are:

- Devices with higher consume could be switched off: One of the parameters that can be shared with other network nodes is the consumption of each node. In this way, the entire network could be aware of what nodes consumptions are higher or lower or in what circumstances (overcrowded channels) these values could vary. Thus, the network can be aware of the "black spots" and ensure that these nodes have fewer messages to be routed thus reducing the overall consumption of the network.
- Load balance could be used to take advantage of consumption and decrease overall consumption: Despite what is said in the previous point, sometimes load balance could be beneficial to reduce the overall consumption of the network even when using a priori nodes with higher consume. If nodes with the lowest consumption get stressed their batteries could be depleted, which would force in the future to pass all messages by nodes with higher consumption.
  Due to the ability of the network to share information about nodes consumption and remaining battery, this action could be taken.
- Transmitting with power enough to reach only some nodes: Taking into account that the network is aware of the topology, the packets could be sent directly to the destination if it is within range but if it is not the case, instead of increase transmission power, messages could be sent to intermediate nodes, which then forward the packet to other nodes until the destination is reached. This multi-hop transmission allows to take advantage of the exponential decrease in radiated power to save overall power consumption in the network by shortening the distance between nodes taking advantages of the density of nodes [5].
- Developing more energy efficient protocols and routing algorithms: Related to the above three points, there is a vast field of investigation related with routing schemes. It could be combined data from individual nodes consumption, load balancing, distance between nodes, number of hops to reach the destination, noise in channels, etc. In this area, several papers in WSN scenarios have published [19][20], but adding CR capabilities further enriches the possibilities for consumption reduction.
- Switching off the sensing state if it is no necessary: Knowing the behavior of the network and being

aware of the history, nodes can decide to turn off the sensing state to reduce individual consumption and thus also the overall consumption of the network.

- Change on/off/idle mode based on latency requirement: packets can be stored in a node for a long time, limited by latency limit. During that time the receiver can be switch off and to save power. Transmitter node gathers information for a more efficient communication.
- Decrease security depending of power constraints. Security processing is one of the most important microprocessor activities. Ciphering, key generation or other countermeasures are critical for power consumption. A cognitive algorithm could change security depending of power consumption.

V. Conclusion and Future Work

Due to the number of nodes, its wireless nature, and that they may be deployed in difficult access areas, power consumption in CWSN nodes is one of the more recurrent problems of this kind of networks. This work in progress presents some ideas in order to reduce power consumption for Cognitive Wireless Sensor Networks scenarios.

The introduction of Cognitive Radio capabilities in WSN provides a new paradigm for power consumption reduction but also implies some challenges to face. This reduction of consumption is a task that must involve the overall design across all layers of the communication protocol.

Our proposal is divided in three blocks depending of the opportunities to optimize energy consumption. These blocks are: 1) Strategies related to the sensing of the spectrum capability, 2) Strategies related to the ability to change transmission parameters and finally, 3) Strategies depending on the ability to share knowledge of the network.

As a preliminary test for these ideas, some scenarios have been implemented with very simple low power optimization algorithms. Results show as a simple cognitive radio strategy can reduce between 94% (changing the wireless interface accordingly to data rate) to 40% (choosing less noisy channels) amount of power. Also we can check other curious issues such as the opportunity of change data-packet size depending on the transmission context is very important to reduce energy consumption. These tests must be completed with more complex algorithms in order to be presented.

Current green wireless communications research directions have to consider Cognitive Radio capabilities to enable power reduction in Wireless Sensor Networks.

Acknowledgment

This work was funded by the Spanish Ministry of Science and Innovation through the Secretariat of State for Research, under Research Grant AMILCAR TEC2009-14595-C02-01, and through the General Secretariat of Innovation under Research Grant P8/08 within the National Plan for Scientific Research, Development and Technological Innovation 2008-2011.

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