COGNITIVE RADIO USAGE IN 6LOWPAN WIRELESS SENSOR NETWORKS

Gün Demirbaş and Bülent Gürsel Emiroğlu
Department of Computer Engineering
Başkent University, Ankara, Turkey
gundemirbas@gmail.com, emiroglu@baskent.edu.tr

ABSTRACT

Wireless Sensor Networks (WSNs) are becoming more and more important every last day. In order to integrate to the Internet, WSNs should communicate with Internet protocol as Internet runs on IP. IPv6 offers a big address pool which is suitable for WSNs which are needed to be accessed remotely. IPv6 over Low Power Area Networks (6LowPAN) helps us to link WSNs to the Internet. Wireless networks use RF technology and share a constrained media with security, military and licensed commercial applications. Through the limitations it is hard to maintain a robust RF spectrum which provides secure and reliable connection. In addition, sensor nodes must drain very low power while communicating over RF technology because WSNs are battery powered or non-powered. Despite the limitations and constraints in radio communication technology, RF traffic in WSNs spectrum is increasing steadily as a result of embedded device usage increase over the Internet. Cognitive Radio (CR) concept is a way to manage radio traffic over RF spectrum. Cognitive Radio helps managing the radio traffic and offers adaptive techniques which result in power consumption reduction. In this work we propose a network model that considers Cognitive Radio usage in 6LowPAN architecture.

KEYWORDS

WSN, CR, CRSN, 6LowPAN, 802.15.4, IPv6

1 INTRODUCTION

Wireless sensor networks consist of distributed autonomous devices which monitor environmental conditions and embedded actuators which are dedicated for specific actions. Those devices work in a cooperative manner, they communicate, decide and act based on information that they share. With the development in embedded technologies, power consumptions and hardware costs decreased, many applications such as, wide area monitoring, critical real time surveillance gained acceleration in usage.

Wireless technologies and Internet grow in a great pace by increasing usage of smart phones, PDA’s and computers. Also embedded smart devices which use IEEE-802.11, WiMAX, 3G and 4G network technologies are becoming a part of the Internet. The 6LoWPAN concept originated from the idea that "the Internet Protocol could and should be applied even to the smallest devices" [1], and that low-power devices with limited processing capabilities should be able to participate in the Internet of Things [2].

As radio communication increased and reliable radio spectrums are licensed for commercial applications a radio spectrum shortage raised upon. To provide a solution for limited and constrained radio spectrum problem the idea of Cognitive Radio (CR) was first introduced and described by Mitola [3]. By implementing CR techniques on WSNs a new research area called Cognitive Radio Sensor Networks (CRSN) has been born. There are researches which focus on merging WSNs into the Internet cluster.

There are also researches on CR and Software Defined Radio (SDR) applications in WSNs. An interesting research on CRSN, Akan at al. [4] discuss CR usage principals over WSNs and state CR usage requirements on WSNs. Our motivation is based on principal that WSNs should use CR yet they should also join the Internet over stable and open protocol like IP. So we propose a new 6LowPAN CRSN model which considers CR principals and acts upon Internet Protocol that wireless sensor and actuator devices can easily join the Internet.
The main contribution of this work relies on the novel sensor network model that we proposed. The novelty of our architecture is the implementation of CR oriented WSN using 6LowPAN technology. The proposed concept focus on interoperability between sensors and embedded Internet devices while considering CR approaches to form a WSN. Proposed network model is based on Open System Interconnection model.

The remainder of the paper is organized as follows: In Section 2, we briefly describe WSNs and show useful application areas. In Section 3, we provide brief background information about 6LowPAN architecture and underlying adaptation layer technologies. In Section 4, we discuss CR and CRSNs. We propose a cognitive radio sensor network model that uses 6LowPAN architecture in Section 5. We conclude in Section 6.

2 WIRELESS SENSOR NETWORKS

Embedded devices that communicate over RF transceivers which have acting or sensing capabilities form WSNs. A basic sensor node shown in Figure 1 should have a controller or a sensor, a power supply, RF frontend and a processing part.

2.1 WSN Characteristics

WSNs are generally spatially distributed and they can have mobile sensor nodes. Nodes are generally miniature hardware sensors which have a radio and battery. They are designed for long-term large area deployments for unattended operations. They have limited power and disruptive communications.

2.1 WSN Application Areas

WSNs are used in many critical or noncritical applications areas like data acquisition systems, environmental monitoring systems, in house control systems, inventory tracking and logistic applications.

Figure 1. Simple Wireless Sensor Node

3 6LOWPAN

3.1 Why IP

Dunkels et al. [3] define the term The Internet of Things: IP for Smart Objects. They point out that the underlying networking technology must be based on solid standards to support innovations as the application space grows. Scalability and interoperability are very important factors for smart objects to support the large number of applications. IP is an open and flexible standard. IP runs over 4G, 3G, 802.11, 802.15.4, Ethernet and more networking standards. More over IP is light weighted, versatile, scalable, manageable, and stable an End-to-End protocol which has been proved useful in many applications. IPv6 also brought us more opportunities like larger addressing pool, different hierarchical addressing mechanisms that remove unnecessary network address translation processing and offers better quality of service mechanisms.

3.2 IEEE 802.15.4

The IEEE 802.15.4 standard describes a Low Rate Wireless Personal Area Network (LR WPAN). IEEE 802.15.4 also attempts to achieve several goals like extremely low cost networks, short range operation with a reasonable battery life. Two major parts of the standard define the PHY communication layer and the MAC communication layer. These two layers are the common foundation layers of the OSI model and are found in almost all other communication protocols. IEEE 802.15.4 Standard physical layer radio characteristics are illustrated in TABLE I.
Table 1. IEEE 802.15.4 Radio Characteristics: Binary phase-shift keying (BPSK), Amplitude-shift keying (ASK), Quadrature-quadrature phase-shift keying (Q-QPSK)

<table>
<thead>
<tr>
<th>Frequency</th>
<th>Channels</th>
<th>Data Rate</th>
<th>Output Power</th>
</tr>
</thead>
<tbody>
<tr>
<td>868-868.6 MHz</td>
<td>0</td>
<td>BPSK at 20 kb/s</td>
<td>30 dBm, 1 W</td>
</tr>
<tr>
<td></td>
<td></td>
<td>ASK at 250 kb/s</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Q-QPSK at 100 kb/s</td>
<td></td>
</tr>
<tr>
<td>902-928 MHz</td>
<td>1-10</td>
<td>BPSK at 40 kb/s</td>
<td>&gt; 10 dBm</td>
</tr>
<tr>
<td></td>
<td></td>
<td>ASK at 250 kb/s</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Q-QPSK at 250 kb/s</td>
<td></td>
</tr>
<tr>
<td>2400-2483.5 MHz</td>
<td>11-26</td>
<td>Q-QPSK at 250 kb/s</td>
<td>20 dBm, 100 mW</td>
</tr>
</tbody>
</table>

3.2.1 Node Types

802.15.4 Standard defines two types of nodes which are Full Function Device (FFD) and Reduced Function Device (RFD). FFDs can serve as the coordinator of a personal area network or a relay of a network or a common node. RFDs are simple devices that do not act like coordinator and generally only communicates with FFDs.

3.2.2 Topologies

There are two main network topologies namely, star network and Peer-to-Peer network. In Start networks FFD device declares itself as a coordinator. After choosing a PAN identifier other RFD nodes can join that network. Peer-to-peer networks can form arbitrary patterns of connections. These networks meant to serve as the basis Ad-Hoc networks capable of performing self-management and organization.

3.3 6LowPAN Adaptation Layer

The 6LowWPAN is an open standard than enables IP communication over IEEE 802.15.4 PHY and MAC layers. While operating over 802.15.4 seems a straightforward approach to the development of a packet data wireless network or wireless sensor network, there are incompatibilities between IPv6 format and the formats allowed by IEEE 802.15.4.

IPv6 requires the maximum transmission unit (MTU) to be at least 1280 bytes in length. This is longer than the IEEE802.15.4's standard packet size of 127 octets which was set to keep transmissions short and thereby reduce power consumption.

To overcome the address resolution issue, IPv6 nodes are given 128 bit addresses in a hierarchical manner. The IEEE 802.15.4 devices may use either of IEEE 64 bit extended addresses or 16 bit addresses that are unique within a PAN.

4 COGNITIVE RADIO SENSOR NETWORKS (CRSN)

4.1 Software Defined Radio (SDR)

SDRs implement changes in radio frequency, modulation, output power and any other parameter that is required during radio communication. SDRs use software instead of hardware for handling necessary changes. SDRs should dynamically adapt to their environment more easily than traditional hardware implemented radios.

Having software at physical communication layer allows creating more intelligent and situation aware radio communication systems. But software processing costs additional energy consumption. To reduce energy consumption software processing should be handled carefully.

4.2 Cognitive Radio (CR)

CR is a new networking technology that adaptively changes radio parameters for more efficient communication. CRs can automatically detect available channels in RF spectrum and tries to improve radio operating behavior and provides a way for concurrent usage of limited spectrum resources. CR uses a number of technologies including SDR and Adaptive Radio where systems monitor and modifies its own performance.

There are two types of CR which are called Full CR and Spectrum-Sensing CR. Full CR considers every possible parameter observable by a wireless network and Spectrum-Sensing CR only considers the radio frequency spectrum.
4.3 Cognitive Radio Sensor Networks (CRSN)

Akan et al. [4] state that it is conceivable to provide wireless sensor networks with the capabilities of cognitive radio and dynamic spectrum management. This defines a new sensor network paradigm CRSN. In general, CRSN can be defined as a distributed network of wireless sensors, which sense an event signal and collaboratively communicate their readings dynamically over available spectrum bands in a multi-hop manner ultimately to satisfy the application-specific requirements. CRSN objectives are listed below:

1) WSNs should find a robust channel and reserve that channel for burst communication. This reservation must be done and released adaptively.

2) WSNs should have access RF spectrums dynamically. Radio communication must be cooperatively done between different frequency channels.

3) WSN should be adaptively changing their characteristics for low power consumption. Devices should intelligently sleep if there is no activity going on.

4) WSNs should work concurrently with overlaid deployment of multiple WSN. Network design should be open for network coverage extensions.

5) WSNs should access to multiple channels to conform different spectrum regulations. Networks should operate like a bridge between regulated spectrums.

5 6LoWPAN CRSN MODEL

Our cognitive 6LowPAN sensor network model consists of three main parts. In part one, we describe a network topology. In part two, we describe necessary communication implementations over OSI layers. Finally, we introduce existing open source solutions which implements IEEE 802.15.4 and 6LowPAN standards.

5.1 Topology

Our system shown in Figure 2 is structured in a clustered mesh topology. To this end border routers carry their cluster information through a different frequency cluster or network. Border routers have a 2.4 GHz IEEE 802.15.4 physical layer device, a 2.4 GHz IEEE 802.11 physical layer device and a 3G compatible communication device.

5.2 Communication

Table 2 illustrates a comparison between OSI communication layer model and 6LowPAN network communication stack. Cognitive radio usability in each layer is described in the following paragraphs.

5.2.1 Physical Layer

A CRSN node should reconfigure its operating frequency, modulation, channel coding and output power without replacing hardware. To provide this operation ability SDRs are used as physical layer device. 6LowPAN uses IEEE 802.15.4 standard in physical layer. IEEE 802.15.4 physical layer operation frequencies and data rates are given in TABLE 1. Consequently SDRs used in required nodes should operate in given frequency bands.
5.2.2 Data Link Layer

Data link layer functionality is known to be a reliable transmission between physical layer hardware. CRSNs should follow the principles of dynamic spectrum management in an energy-efficient manner. 6LowPAN uses IEEE 802.15.4 MAC layer as data link layer. IEEE 802.15.4 has utilities like CSMA/CA and provides solutions for energy efficiency. Hence 802.15.4 lacks dynamic spectrum management utilities we use border routers that acts as a secondary user of a primary network.

5.2.3 Network Layer

CRSN also faces network layer problems like WSN. CRSNs provide multi-hop networking and energy efficient routing. Existing CR routing algorithms provide joint spectrum and routing decisions but do not consider resource constraints. On the other hand WSN routing protocols aim to minimize energy consumption and do not handle dynamic spectrum access. 6LowPAN uses Routing Protocol for Lossy networks (RPL) which handles energy consumption minimization. In order to provide CR abilities to our network model we build a mesh structure which uses Internet Control Message Protocol.

5.2.5 Transport Layer

CRSNs uses transport layer for End-to-End reliable delivery of events while considering quality of service. After detection of an event, readings must be reliably delivered to destination. If multi-hop limit is exceeded this packet should be discarded to preserve energy. Therefore transport layer has to achieve a delegate balance between reliability and energy efficiency. 6LowPAN uses IPv6 as transport layer. IPv6 provides UDP for connectionless and energy efficient communications and TCP for connection based reliable communications. We use TCP for important hop limited events and UDP for non-critical and periodic readings.

5.2.4 Application Layer

Application layer algorithms generally provide events and signals to the destination for monitoring purposes. Application layer processes provide services for sensor queries. IPv6 provides interoperability between applications and the Internet. By using IPv6 we can easily provide query service and runtime update solutions over existing application layer protocols such as HTTP, FTP and RSS. We use BSD socket [5] interface for creating application layer processes in our network model. Using existing protocols and socket interface grants us reliable and energy efficient service oriented sensor monitoring in our model.

Table 2. OSI Layer Model 6LoWPAN Stack: Carrier sense multiple access with collision avoidance (CSMA/CA), Physical layer (PHY), Multiple Access Control layer (MAC)

<table>
<thead>
<tr>
<th>ISO/OSI Layer Model</th>
<th>6LoWPAN Stack</th>
</tr>
</thead>
<tbody>
<tr>
<td>Application Layer</td>
<td>6 Low PAN Specific Applications (Using Socket Interface)</td>
</tr>
<tr>
<td>Presentation Layer</td>
<td>Not Explicitly used</td>
</tr>
<tr>
<td>Session Layer</td>
<td>Not Explicitly used</td>
</tr>
<tr>
<td>Transport Layer</td>
<td>TCP/UDP</td>
</tr>
<tr>
<td>Network Layer</td>
<td>IPV6 and Adaptation Layer for routing, fragmentation/reassembling</td>
</tr>
<tr>
<td>Data Link Layer</td>
<td>IEEE 802.15.4 MAC (unslotted CSMA/CA)</td>
</tr>
<tr>
<td>Physical Layer</td>
<td>IEEE 802.15.4 PHY</td>
</tr>
</tbody>
</table>

5.3 Software Components

6LowPAN adaptation layer stack called SICSLowpan and lightweight IP stack called uIP are open source software for WSNs. These software implementations are included in Contiki [6] an open source embedded operating system for WSNs. Contiki also has a lightweight multitasking kernel. We use Contiki as the key software element in our network model. Necessary drivers for IEEE 802.15.4 compliant radio devices and 802.15.4 MAC layer implementation are also provided by hardware manufacturers.
Linux-wsn project brings 802.15.4 raw socket interface and 6LoWPAN features to Linux kernel. Mainline Linux kernel supports IEEE 802.15.4, IEEE 802.11, WiMAX, 3G and 4G devices natively. Mainline Linux kernel also includes routing algorithms and TCP/IP stack. For border router implementations between network clusters and between different radio bands embedded Linux is selected.

6 CONCLUSION

As new wireless technologies such as 4G and WiMAX spreads, more wireless sensor and embedded wireless actuators will be a part of the Internet. Interoperability between licensed bands will be needed in order to populate smart objects existence to remotely control embedded networks. To achieve this interoperability between different frequency network clusters CR and SDR approaches are going to be used more widely. Border routers and network coordinators must operate cooperatively 802.15.4, 802.11, 802.16 and 802.20 IEEE standards.

Standardization and layered open architectures are important factors for unifying different technologies. Sensor networks and embedded devices are the key components of artificial intelligence supported autonomous systems and will be the essential parts of next generation technologies. There are organizations like IPSO (IP for Smart Objects) Alliance those help embedded devices and wireless communicating sensors connect to the Internet.

Proposed architecture allows efficient usage of radio spectrum and interoperability between different wireless network technologies on existing international standards. 6LoWPAN and Cognitive Radio are promising research areas thus we need to focus on using these technologies more coherently. Our future work will be focused on realizing our concept model in a real world example. Small scale example of the model will be set up for gathering performance and efficiency metrics.

7 REFERENCES