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Energy Efficient Cognitive MAC for Sensor Networks under WLAN Co-existence

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ABSTRACT

Energy potent has been the driving force behind the design of communication protocols for battery-constrained wireless sensor networks. The energy potent and the performance of the proposed protocol stacks, however, degrade dramatically in case the low-powered wireless sensor networks are subject to interference from high-power wireless systems such as wireless local area networks. In this paper we propose Cognitive Medium Access Control, a novel cognitive medium access control scheme (MAC) for Institute of Electrical and Electronics Engineers 802.15.4-compliant wireless sensor networks that minimizes the energy cost for multi-hop communications, by deriving energy-optimal packet lengths and single-hop trans-mission distances based on the experienced interference from Institute of Electrical and Electronics Engineers 802.11 wireless local area networks. We evaluate Cognitive Medium Access Control by deriving a detailed analytic model for its performance and by comparing it with previous access control schemes. Numerical and simulation results show that a important decrease in packet transmission energy cost, up to 66%, can be achieved in a wide range of scenarios, particularly under severe wireless local area network interference. Cognitive Medium Access Control is, also, lightweight and shows high robustness against wireless local area networks model estimation errors and is, therefore, an effective, implementable solution to reduce the wireless sensor networks performance deterioration when coexisting with wireless local area networks.

INTRODUCTION

The upgrading number of different wireless technologies sharing the open spectrum bands, such as the 2.4GHz. ISM band, demands for a take another look of the protocols regulating the spectrum access. As the medium access control (MAC) schemes are precisely designed for one given technology, they are not anymore able to achieve the objective of potent and "fair" sharing of the wireless resources when functioning under resistance from heterogeneous technologies. In this paper we consider the particular case of the coexistence of Institute of Electrical and Electronics Engineers 802.11 wireless local area networks and Institute of Electrical and Electronics Engineers 802.15.4-compliant wireless sensor networks. Both technologies apply carrier sensing-based medium access control with collision avoidance. In addition, wireless sensor networks try to locate the narrow frequency band with less harmful resistance for their operations. Unfortunately, all these techniques do not avoid high resistance and frequent packet losses in the wireless sensor networks, which are mainly caused by the importantly different transmission bandwidths and powers of the two technologies competing for the same resource. Therefore, they are blind to the narrow-band, low-powered wireless sensor networks transmissions, and do not defer channel access, due to the overlapping wireless sensor networks packet transmission. In all this, the wireless local area networks transmissions remain basically unaltered by the low wireless sensor networks interference, while wireless sensor networks packets are lost. Fortunately, measurement results show that the wireless local area networks transfer is rather discharge with long white spaces, when the channel is idle because all wireless local area networks users are inactive. Therefore, in order to maximize its performance, the wireless sensor networks should be able to transmit in these long interference-free times, thus, being cognitive of the radio environment as imposed by the wireless local area networks activity.

In this paper we propose and evaluate a new cognitive MAC (COG-MAC) protocol for wireless sensor networks, which extends the carrier sense-based MAC and aims at minimizing the energy loss due to unsuccessful transmissions over the interfered channel. Our paper provides the following contributions. 1) We give a characterization of the wireless local area networks channel usage patterns as seen by the sensor nodes, taking into account the nodes' limited channel estimation capabilities, and propose techniques for distributed wireless local area networks usage pattern estimation. 2) Based on these resulting wireless local area networks channel usage characterization we design COG-MAC that optimizes the packet length and the transmission distance, and performs wireless local area networks activity-aware channel access to ensure that wireless sensor networks nodes transmit in the long wireless local area networks white space periods. 3) We provide an accurate analytical model that describes the probability of COG-MAC packet transmission success. We use the model to optimize the wireless sensor networks packet size and the single-hop wireless sensor networks transmission distance to minimize the normalized energy cost metric, which we explain as the energy required successfully transmitting and receiving a unit of information over a unit of distance. 4) We show that all the basic components of COG-MAC are essential for achieving the objective of energy potent communication, and COG-MAC, compared to previous access schemes, reduces the normalized energy cost up to 66%, and can importantly decrease the end-to-end energy cost in a multi-hop wireless sensor networks without increased delay. The rest of the paper is organized as follows. It describes the networking scenario and the interference and sensing models and gives the wireless local area networks channel activity model. We describe the proposed protocol stack, followed by its mathematical analysis. We present a numerical evaluation of COG-MAC along with a comparison with traditional wireless sensor networks MAC schemes, while a simulation study is presented.

2.1 MEDIUM ACCESS CONTROL PROTOCOLS FOR WIRELESS SENSOR NETWORKS

The MAC protocol improves energy well-organized in wireless communicating sensor networks by increasing sleep duration and decreasing all the basis of energy wastage. These Medium Access Control protocols can be broadly classified as schedule based and assertion based schemes. The schedule based protocols involve time synchronization requirements but the assertion based protocols relax time synchronization requirements.

All these Medium Access Control protocols consist of acknowledgement messages and impart through which better reliability can be achieved. Although traditional MAC protocols achieve low-power process, they use only a single channel which limits their performance. Therefore several multi-channel Medium Access Control protocols for Wireless Sensor Networks have been recently proposed. Hence a high quality MAC design provides a well-organized utilization of limited amount of energy as its primary concern.

2.2 MMDQS MAC: MULTIHOP MULTI-CHANNEL DISTRIBUTED QOS SCHEDULING MAC

The Multi-hop Multi-Channel Distributed Quality of Service Scheduling Media Access Control scheme improves the network performance of Wireless Sensor Networks by selecting the best channel for an individual wireless sensor node. The overall network performance of Wireless Sensor Networks is increased here by decreasing the chance of collisions and intrusion. MMDQS Medium Access Control protocol utilizes parallel transmissions and also supports short packet transmissions under low traffic networks. This scheme improves the performance of aggregate throughput, probability of successful transmission, packet delivery ratio, energy consumption and average end-to-end delay. When the medium is busy, all available multi-channels are utilized to reduce the channel access time of a sensor node and hence improve the Wireless Sensor Networks performances. The multi-channel Medium Access Control schemes employed here increase the capacity of wireless access control mechanisms. These multi-channel access mechanisms maintain different transmissions in wireless links active at the same time without collision. Such multi-channel scheduling Medium Access Control assignment can eliminate the interference among different channels and therefore, no collision in the Medium Access Control layer. In this protocol, each sensor node is equipped with directional antennas and the size of Medium Access Control layer packet is very small.

The primary objectives of MMDQS-Medium Access Control are maximum aggregate throughput, interference-free communication and guaranteed Quality of Service. There are three assumptions regarding the sensor nodes used in this protocol: All sensor nodes are equipped with directional antennas, all sensor nodes are stationary and Sensor nodes can choose arbitrary transmits power for data transmission. The frame structure of MMDQS-Medium Access Control protocol consists of a Contention Period and a Non Contention Period. The beacon frames are transmitted during Contention Period to perform time synchronization periodically. In the MMDQS-Medium Access Control protocol, the Contention Period is of fixed length frames composed of a specified number of time slots and the period of Non Contention Period is dependent on the contention resolution of Contention Period.

3. RELATED WORK

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Energy efficient communications have been extensively studied for standalone WSNs. The key idea for energy efficiency in sensor networks is to minimize idle listening, by letting the sensors turn off their radios whenever idle, controlled by duty-cycling, or by wake-up radios.

It is recognized, however, that cross-network interference can have significant effect on the network performance, as it is shown for coexisting WSNs in and for WLAN and Bluetooth interference in. WSN multi-channel operation aims at avoiding this cross-network interference by tuning to the best available band for communication. These solutions are efficient as long as there exist channels with no or low interference, but lose effectiveness when all considered channels suffer from interference with similar statistical behavior. Therefore, as wireless channels are getting densely populated, it is important to design protocols that can work efficiently even in the presence of cross-network interference.

Many of the proposed solutions build on the known characteristics of the interfering networks. Employs narrowband sensing, with additional HW cost, to identify and utilize the channels, where the wide-band device can effectively coexist with narrow-band transmissions, while in, the sensors force the WLAN to back off by sending frequent (one per DIFS), high power jamming signals during their packet transmission, which needs complex PHY layer and leads to increased energy consumption in the WSN. Instead, the effect of interference is minimized without changing the WLAN behavior in and introducing WSN packet header and payload redundancy.

Recent works investigate how to avoid WLAN interference by employing channel availability predictions. The case of a non-saturated single WLAN AP is studied in, modeling the packet arrivals at the users as a Bernoulli process. In a Poisson arrival process is considered, and WLAN output buffers are modeled as M/G/1 queues, resulting in sub geometric idle period distribution.

4.1 APPLICATIONS

Wireless LANs have a great deal of applications. Modern implementations of WLANs range from small in-home networks to large, campus-sized ones to completely mobile networks on airplanes and trains.

Users can access the Internet from WLAN hotspots in restaurants, hotels, and now with portable devices that connect to 3G or 4G networks. Oftentimes these types of public access points require no registration or password to join the network. Others can be accessed once registration has occurred and/or a fee is paid.

4.2 PERFORMANCE AND THROUGHPUT

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WLAN, organized in various layer 2 variants (IEEE 802.11), has different characteristics. Across all flavors of 802.11, maximum achievable throughputs are either given based on measurements under ideal conditions or in the layer 2 data rates. This, however, does not apply to typical deployments in which data are being transferred between two endpoints of which at least one is typically connected to a wired infrastructure and the other endpoint is connected to an infrastructure via a wireless link.

5. NETWORK SIMULATOR VERSION 2

Network Simulator (Version2), widely known as NS2, is simply an event driven Simulation tool that has proved useful in studying the dynamic nature of communication networks. Simulation of wired as well as wireless network functions and protocols (e.g., routing algorithms, TCP, UDP) can be done using NS2. In general, NS2 provides users with a way of specifying such network protocols and simulating their corresponding behaviors. Due to its flexibility and modular nature, NS2 has gained constant popularity in the networking research community since its birth in 1989. Ever since, several revolutions and revisions have marked the growing maturity of the tool, thanks to substantial contributions from the players in the field.

Among these are the University of California and Cornell University who developed the REAL network simulator the foundation which NS is based on. Since 1995 the Defense Advanced Research Projects Agency (DARPA) supported development of NS through the Virtual Internetwork Test bed (VINT) project .Currently the National Science Foundation (NSF) has joined the ride in development. Last but not the least, the group of researchers and developers in the community are constantly working to keep NS2 strong and versatile.

5.1 BASIC ARCHITECTURE

The Figure 5.1 shows the basic architecture of NS2. NS2 provides users with executable command ns which takes on input argument, the name of a Tcl simulation scripting file. Users are feeding the name of a Tcl simulation script (which sets up a simulation) as an input argument of an NS2 executable command ns. In most cases, a simulation trace file is created, and is used to plot graph and/or to create animation.

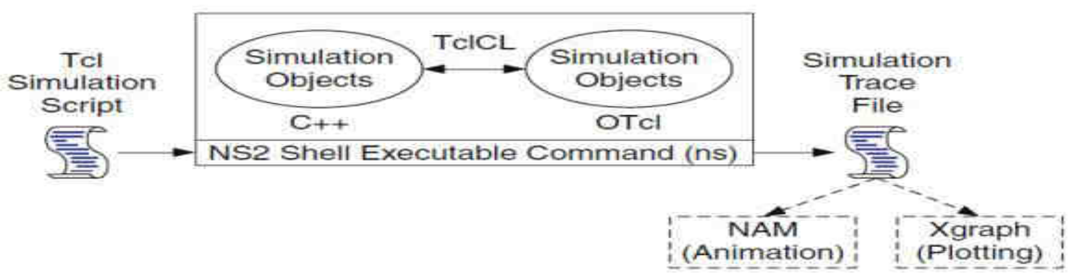

Figure 5.1Basic Architecture of NS.

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NS2 consists of two key languages: C++ and Object-oriented Tool Command Language (OTcl). While the C++ defines the internal mechanism (i.e., a backend) of the simulation objects, the OTcl sets up simulation by assembling and configuring the objects as well as scheduling discrete events (i.e., a frontend). The C++ and the OTcl are linked together using TclCL. Mapped to a C++ object, variables in the OTcl domains are sometimes referred to as handles. Conceptually, a handle (e.g., n as a Node handle) is just a string in the OTcl domain, and does not contain any functionality. Instead, the functionality (e.g., receiving a packet) is defined in the mapped C++ object (e.g., of class Connector). In the OTcl domain, a handle acts as a frontend which interacts with users and other OTcl objects. It may define its own procedures and variables to facilitate the interaction.

Note that the member procedures and variables in the OTcl domain are called instance procedures and instance variables, respectively. Before proceeding further, the readers are encouraged to learn C++ and OTcl languages. this refer the readers to for the detail of C++, while a brief tutorial of Tcl and OTcl tutorial are given in Appendices A.1 and A.2, respectively. NS2 provides a large number of built-in C++ objects. It is advisable to use these C++ objects to set up a simulation using a Tcl simulation script. However, advance users may find these objects insufficient. They need to develop their own C++ objects, and use an OTcl configuration interface to put together these objects. After simulation, NS2 outputs either text-based or animation-based simulation results. To interpret these results graphically and interactively, tools such as NAM (Network Animator) and Graph are used. To analyze a particular behavior of the network, users can extract a relevant subset of text-based data and transform it to a more conceivable presentation.

5.2 DIRECTORIES AND CONVENTION

5.2.1 Directories

Suppose that NS2 is installed in directory nsallinone-2.30. Figure shows the directory structure under directory nsallinone-2.30. Here, directory nsallinone-2.30 is on the Level 1. On the Level 2, directory tclcl-1.18 contains classes in TclCL (e.g., Tcl, Tcl Object, Tcl Class).

All NS2 simulation modules are in directory ns-2.30 on the Level 2. Hereafter, it will refer to directories ns-2.30 and tclcl-1.18 as ˜ns/ and ˜tclcl /, respectively. Directory common contains basic modules related to packet forwarding such as the simulator, the scheduler, connector, and packet. Directories queue, tcp, and trace contain modules for queue, TCP (Transmission Control Protocol), and tracing, respectively. NS2 consists of two languages. Suppose that objects “A” and “B” are written in each language and correspond to one another. Then, “A” is said to be the shadow object of “B”. Similarly “B” is said to be the shadow object of “A”

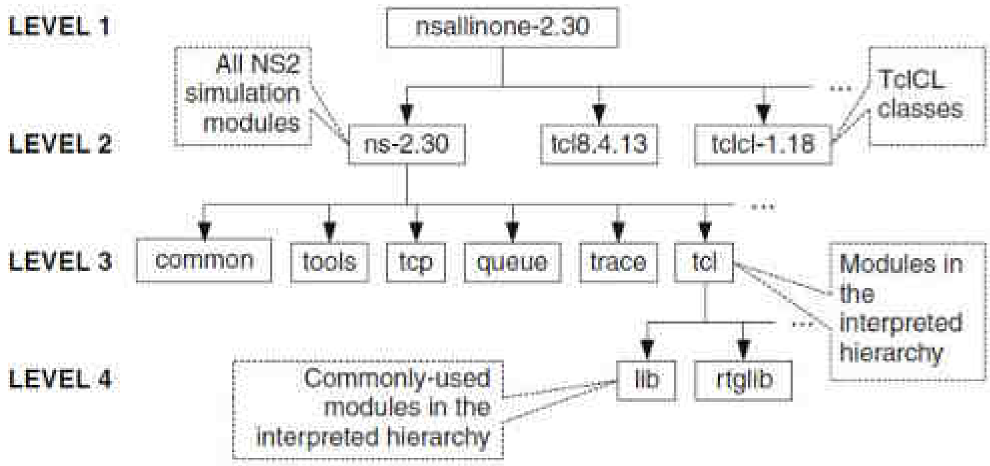

Figure 5.2 Directory structure of NS2

On Level 3, the modules in the interpreted hierarchy are under directory tcl. Among these modules, the frequently-used ones (e.g., ns-lib.tcl, ns-node.tcl, ns-link.tcl) are stored under directory lib on Level 4. Simulation modules in the compiled hierarchy are classified in directories on Level 2. For example, directory tools contains various helper classes such as random variable generators. Directory common contains basic modules related to packet forwarding such as the simulator, the scheduler, connector, and packet. Directories queue, TCP, and trace contain modules for queue, TCP (Transmission Control Protocol), and tracing, respectively.

6. COG MAC OPTIMIZATION

A novel cognitive medium access control scheme for IEEE 802.15.4. An effective implementable solution is to reduce the Wireless Sensor Networks performance impairment when coexisting with Wireless Local Networks. Minimizes the energy cost for multi hop communications. By deriving energy-optimal packet lengths and single-hop transmission exists. Distances based on the experienced interference from IEEE 802.11 Wireless Local Networks. Cognitive Medium Access Control is light weight and shows high robustness against Wireless Local Networks model estimation errors.

7. CONCLUSION

The proposed COG-MAC, a cognitive MAC scheme for energy efficient WSN operation under WLAN coexistence. The proposed scheme is based on controlling the interference from the coexisting WLAN by predicting its behavior with a smart channel sensing mechanism that takes into consideration the WLAN channel usage model. Energy cost minimization is achieved by optimizing the WSN single hop transmission distance and packet length, based on the estimated parameters of the WLAN channel usage model. To solve the optimization problem an analytic model for the successful single-hop WSN packet communication. Through numerical evaluation showed that COG-MAC significantly outperforms other MAC protocols, especially in case of severe WLAN interference. The evaluation also revealed that both COG-MAC optimization of packet size and transmission distance and smart channel sensing are key mechanisms for increasing energy efficiency.

The simulation results to demonstrate the accuracy of the analytic model and to show that COG-MAC achieves significant gains even in multi-hop environment. Consequently, COG-MAC provides a distributed solution that exploits existing functionalities available in current commercial sensor hardware, and archives energy-efficient communications in the presence of coexisting WLAN networks.

7.1. FUTURE ENHANCEMENT

Most protocols involving clusters use direct communication link between the cluster head and the sink. Research into using a more energy efficient multi hop communication protocol between the cluster heads and the sink will help conserve the energy, and accordingly extending the lifetime of the WSN. Most of the research on energy efficient controlled access protocol has come at a cost of control packets overhead. By investigating this research area further, an enhanced energy efficiency protocol may be developed that can revolutionize WSN's power consumption. Another challenge with CA protocols is that they are not scalable and this can be investigated further. Though CDMA involves complex computing, but also it can eliminate collision, developing a technique for wide application of this in WSN will boost energy efficiency, and hence, network lifetime of WSNs. This will be more so since processing consumes less energy than communication.

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