ENERGY EFFICIENT MAC PROTOCOL FOR WIRELESS SENSOR NETWORKS

By

Hesham Sherif Mohammed Elhelw

A Thesis Submitted to the
Faculty of Engineering at Cairo University
in Partial Fulfillment of the
Requirements for the Degree of
Master of Science
in
Electronics and Electrical Communications Engineering

FACULTY OF ENGINEERING, CAIRO UNIVERSITY

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Energy Efficient MAC Protocol for Wireless Sensor Networks

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MAC; wireless sensor networks; energy efficiency; adaptive wakeup time; transmission buffer sorting

Summary:

Wireless sensor networks (WSN) are gaining more potential from research community due to the large spectrum of their applications. Energy efficiency is one of the most important aspects of WSNs. This thesis proposes a new medium access control (MAC) protocol for WSNs called E^2MAC which focuses on energy efficiency enhancement. E^2MAC focuses mainly on decreasing the time WSN node needs to stay awake for idle listening with minimal impact on throughput and packet delay by using, among other features, duty cycle fashion of sleep/active pattern of operation with dynamic active time that extend or shorten in run time based the traffic load.

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To my life journey partner and dear wife DOAA

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Elhelw, Hesham Sh, Ahmed H. Zahral, and Khaled F. Elsayed. "E2MAC: An Energy-Efficient MAC protocol for wireless sensor networks." *In proceedings of the 31st National Radio Science Conference (NRSC, 2014)*, pp. 244-251. IEEE, 2014.

List of Abbreviations

ACK	Acknowledgement
ASMAC	Adaptive Scheduling MAC
BMAC	Berkeley MAC
CAP	Contention Access Period
CCA	Clear Channel Assessment
CFP	Contention Free Period
CTS	Clear To Send
CSMA-CA	Carrier Sense Multiple Access – Collision Avoidance
DWMAC	Demand Wakeup MAC
E^2MAC	Energy Efficient MAC
EMMAC	Efficient Multichannel MAC
FFD	Full Function Device
GTS	Guaranteed Time Slot
IEEE	Institute of Electrical and Electronics Engineers
LPEAS	Long Preamble Emulation with Acknowledgement after local Synchronization
LR-WPAN	Low Rate – Wireless Personal Area Network
MAC	Medium Access Control
MPDU	MAC Protocol Data Unite
NAV	Network Allocation Vector
PHY	PHYsical layer
PMAC	Pattern MAC
PWMAC	Predictive-Wakeup MAC
RFD	Reduced Function Device
RTS	Ready To Send
SMAC	Sensor MAC
SCPMAC	Scheduled Channel Polling MAC
TDMA	Time Division Multiple Access
WA	Wakeup Acknowledgement
WiseMAC	Wireless Sensor MAC
WR	Wakeup Request
WSN	Wireless Sensor Networks

Abstract

Wireless sensor networks (WSN) are gaining more potential and focus from research community by time and especially in the last decade due to the large spectrum of their applications and the increasing dependence on them in many fields like industry [21] [22], military [23], home automation [24] and many other fields. Energy efficiency is one of the most important aspects which are tackled by recent researches in the field of WSNs since most of the WSNs applications devices are operated on batteries and for many cases changing or recharging the devices batteries frequently is not practical.

This thesis proposes a new medium access control (MAC) protocol for WSNs called energy efficient MAC (E^2MAC) which focuses on energy efficiency enhancement. Since idle listening is one of the main sources of energy waste in WSNs, E^2MAC focuses mainly on decreasing the time WSN node needs to stay awake for idle listening with minimal impact on throughput and packet delay by using, among other features, duty cycle fashion of sleep/active pattern of operation with dynamic active time that extend or shorten in run time based the traffic load.

E^2MAC is evaluated using Castalia simulation tool and results are shown in comparison to IEEE 802.15.4, long preamble emulation with acknowledgement after local synchronization (LPEAS) and TMAC. Results show that E^2MAC is more efficient than the three MAC algorithms in energy consumption especially in dense/high traffic networks without much impact and even in some case also enhancing both packet delivery delay and packet delivery success rate.

Chapter 1. Introduction

Advances in modern technology enabled fabrication of small sized and low cost sensor nodes with a wireless module for communicating their measurements wirelessly. This eliminates wiring difficulties especially when the required area to be covered is significantly large. Distributing a large number of nodes for measurements brings wireless sensor networks into existence. Wireless sensor networks (WSNs) have many applications such as health, security, military and industry and the demand on wireless sensor networks is increasing by time. Energy efficiency represents a main aspect when designing a MAC protocol for WSNs due to the nature of the applications since in many applications of WSNs the nodes are distributed in the field where reaching them and changing their batteries frequently is not a realistic usage pattern.

1.1 Wireless Sensor Networks Overview

Wireless sensor networks consist of sensor nodes distributed over field to measure several physical values like temperature, humidity, pressure, etc. WSNs are used in several applications like environment monitoring, defense, scientific applications, target tracking, and climate control. Sensor nodes in WSNs generally operate on batteries with limited capacity. Hence, nodes have to limit the communication coverage resulting in the need of several nodes to cover the field area. As shown in Figure 1.1, WSNs nodes communicate together in different defined patterns to deliver their readings to a sink that receives all collected measurements and performs necessary calculations and processing over the measured values taking the corresponding decisions or actions [1].

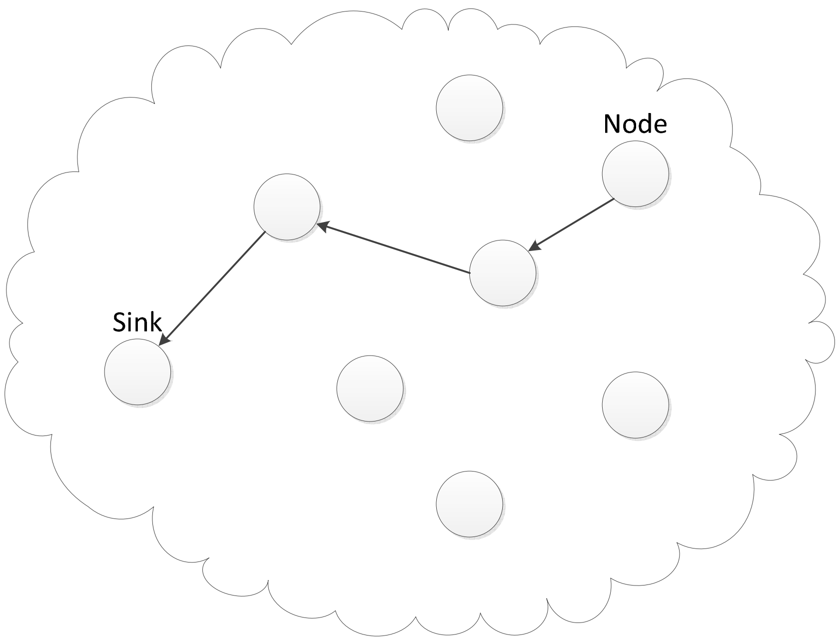

Figure 1.1: Wireless sensor networks field

A WSN node consists mainly of 5 modules: sensing, communication, processing, memory and power supply modules. The sensing module is responsible for measuring a physical parameter intended by the WSN node. Most of the sensors take samples of measurements periodically. The communication module is responsible for delivering the measured values to the network sink, relaying data packets between nodes till reaching the network sink. It is also common that the nodes relay control packets from a network control unit to change sensing periodicity for example. The processing unit is responsible for handling measured values by the sensing module making any required filtering on them before sending them to the sink node through the communication module. Also processing module is responsible for controlling the used communication protocol and the power saving algorithms to reduce power consumption by WSN node for a long life operation. The memory module is mainly a flash memory used to store the application code used by the node and RAM for application execution. The power supply module is used to supply the four modules described above with required energy which is mainly based on batteries. Although all WSN node modules consume energy, the most energy consuming module in the node is the communication module either by transmission and reception operations or by idle listening [2].

Due to the nature of WSNs, it is not possible to connect nodes to power means or even recharge them frequently since most of time WSN nodes are distributed in a field on large area and sometimes in critical locations which make it hard to reach them frequently.

1.2 Wireless Sensor Node Energy Consumption

As illustrated in Section 0, wireless sensor nodes have mainly 5 modules and each module of them needs energy to operate properly. Overall energy consumption by the WSN node is the summation of all the 5 modules energy consumption. So, minimizing energy consumption of each module of the 5 modules minimizes the overall energy consumed by the WSN node.

One of the main sources of energy consumption in WSN node is the energy used by the sensing module to measure the environmental or body value intended by the WSN node to measure. Usually this module consumes energy only while being active for measurements. Since most of the WSN applications require measuring environmental or body values in periodic manner or in trigger based approach, optimizing sensing module energy consumption can be easily achieved by switching on the module only when measurements are required to be samples then switch it off till next measurement sample acquisition.

Another source of energy consumption in WSN node is the operating system and application execution on the processing and memory modules. Like sensing module, optimizing energy consumption for processing module can be achieved by putting the processing module in sleep mode whenever no calculation are required.

The communication module is also one of the energy consumption sources in the WSN node. Communication modules are responsible for delivering measured values to the measurements collection entity in the network through either point-to-point or multi-hop communication techniques. Energy consumption optimization for communication module is not as simple as energy consumption optimization in other modules of the WSN node since there are many sources of energy consumption in communication module that are illustrated later in next section. Usually, communication module consumes most of the energy in any WSN node. Hence, this thesis focuses on energy consumption in providing an energy efficient MAC protocol for WSN nodes.

1.3 Energy Consumption Sources in Radio Modules

Any wireless node radio module consumes energy on transmitting packets, receiving packets and also idle listening to the radio channel. SMAC [4] authors specify four major sources of energy waste. First packet collision triggers packet retransmission and hence consumes more energy and also adds to the packet delay. The second source of energy waste is overhearing, which means that wireless node receives packets from other nodes that are not destined to it. The third source of energy waste is the control packets overhead, WSNs are used to deliver data packets carrying measured values where control packets are used just to manage and maintain this transmission process active so efficiency of the network is measured by percentage of data packets to the total number of packets exchanged in the network. Hence, as exchanged control packets in the network increases, more energy is wasted because it is not used in the main target of WSN. The fourth and last major source of energy waste as defined by SMAC authors is the idle listening, idle listening is the time in which sensor node is turning on its radio module and listening to the radio channel waiting for receiving control or data packet destined to it. Idle listening is time wasted waiting for packets reception and since this time is usually large enough to achieve low packet delay, it is considered a major source of energy waste.

1.4 Thesis Contribution

In this thesis a new energy efficient MAC protocol for WSNs is introduced called E^2MAC. E^2MAC is based on LPEAS [8] MAC which is based on IEEE 802.15.4. E^2MAC targets energy efficient performance of WSN nodes without causing a large impact on both throughput and packet delay taking into considerations at the same time the simplicity of the protocol implementation to be suitable for low-priced WSN nodes.

E^2MAC is an asynchronous protocol that integrates adaptive awake time feature from the TMAC protocol [5] into LPEAS [8] and adds novel scheduling technique for transmitted packets based on the destination node wakeup time. In order to evaluate E^2MAC compared to LPEAS, IEEE 802.15.4 and TMAC; we used Castalia where we added both E^2MAC and LPEAS implementations to it.

1.5 Thesis Outline

Chapter 2 discusses related work to E^2MAC like the SMAC, TMAC, PWMAC, EMMAC, IEEE802.15.4 and LPEAS. It also provides classification for the different MAC protocols based on their features. In chapter 3 the E^2MAC protocol is described in details including the changes added on top of LPEAS protocol to enhance the packet delay and throughput. Adaptive awake time and transmission buffer sorting features which represent the main modifications to LPEAS in E^2MAC are also described in details. Chapter 4 includes the evaluation of E^2MAC with comparison to IEEE 802.15.4, LPEAS and TMAC. Castalia simulation tool is used in this evaluation for its focus on WSN simulations. Energy consumption, packet delivery rate and packet delay are the three key performance indices measured to evaluate the four MAC protocols. Chapter 5 concludes the thesis and presents possible future work directions.