An Energy-Efficient MAC Protocol to Conserve Energy in Wireless Sensor Networks

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ABSTRACT

Wireless Sensor Network (WSN) nodes are widely used in various sectors nowadays. WSN nodes experience a lot of problems that impact on battery life for sensor node such as, overhearing, collision, hidden node, idle listening, schedule drifts, and high latency. Moreover, WSN nodes are strongly dependent on its limited battery power, and replenishing it again is difficult as nodes are deployed in an ad-hoc manner. Energy consumption is the most important factor to determine the life of a sensor network because usually sensor nodes are driven by low battery resources. An approach to conserve energy in WSN nodes is to carefully design its Medium Access Control (MAC) protocol. Several previous work has been carried out to mitigate many problems that impact on battery life for sensor node such as overhearing, collision, and hidden node. This paper attempts to design Energy-Efficient MAC (EE-MAC), a hybrid energy-efficient protocol to address the energy issues that are related to WSNs nodes. This protocol aims to reduce idle listening times as well as lowering the latency time thus reducing the energy consumption. The proposed protocol has been developed and analyzed using the ns-2 Simulator. A mathematical model was used to prove the efficiency of the proposed protocol. We have compared our proposed EE-MAC protocol with the existing contention-based IEEE 802.11 PSM protocol. The simulation results illustrate that the EE-MAC has achieved better energy conservation than the IEEE 802.11 PSM protocol.

Keywords: EE-MAC, WSNs, Medium Access Control, Energy-Efficiency, ns-2, IEEE 802.11 PSM protocol.

I INTRODUCTION

WSN nodes are compact-sized, low power autonomous devices with wireless communication capabilities that are widely used in various real world applications today. These nodes are used in various sectors among others, are deployed in a sensor field to measure environmental conditions such as temperature, pressure, humidity, movement, etc.

WSN nodes are powered by limited power sources and often exhibit strong dependency on battery life making replenishment an arduous or impossible task as most nodes are deployed in an ad-hoc manner. Energy in WSN node, though often insufficient and limited in supply, is the most important parameter that determines the WSNs lifetime.

In a WSN node, the radio interface is distinguished as a major source of the energy consumption(Jang, Lim, & Sichitiu, 2013).In WSN operation, energy can be dissipated by either "useful" or "wasteful" means. For example, as a part of useful operation, node requires energy to transmit or receive data messages, and processes query requests through which energy is consumed. On the opposite, energy consumption by means of overhearing, retransmitting due to harsh environment, dealing with the redundant broadcast overhead messages, as well as idle listening to the air interface are wasteful energy consumption (Chhabra & Sharma, 2011; Saharan & Pande, 2013).

Three main activities involved in energy consumption are distinguished in sensor node, namely sensor sensing, computation and radio operations. The radio operation is the biggest contributor to energy loss. In the radio operation, besides transmitting, receiving and scanning the air interface for communication can consume a significant amount of energy (Riaz, Qureshi, & Mahboob, 2013).A sensor node is useless without energy. Operations of sensor nodes on limited battery power justify that energy usage is an important concern in WSN design.

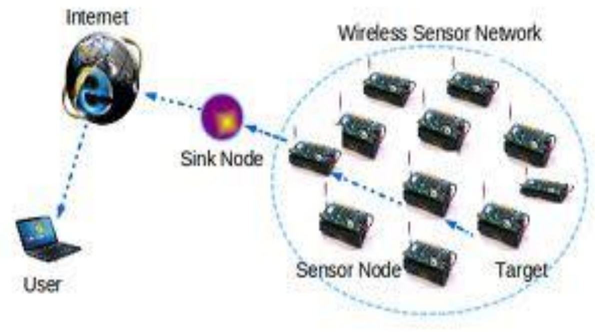

Figure 1.A Typical Wireless Sensor Node And Its Architecture (Dubey & Agrawal, 2013).

In this paper, an energy efficient MAC protocol is designed. The protocol is experimentally analyzed and the performance metrics of the EE-MAC protocol is compared against the existing contention-based protocol of IEEE 802.11 PSM MAC. Our simulation show that the EE-MAC performs better when is compared to existing contention-based MAC protocol. Figure 1 shows a typical WSN node.

II MEDIUM ACCESS CONTROL PROTOCOL

There have been a significant number of researches that revolve around minimizing the use of energy by sensor node. Short network lifetimes can cause significantly negative effect on the performance of the application. The lifetime of sensor network is determined by the number of active nodes and connectivity of the network. Therefore, efficient use of energy by possibly reducing energy consumption is the solution to maximize the lifetime of WSNs(Yick, Mukherjee, & Ghosal, 2008). In this study, we focus mainly on the MAC protocols.

The basic function of MAC protocol is to organize access to a shared medium over the network. Recent efforts have been carried out within the MAC protocol to conserve energy. This include MAC protocols which regulate the duty-cycle of the radio interfaces on a WSN node, whereby a radio interface will switch into active, idle or sleeping mode depending on the network conditions.

Generally, the MAC protocols used in WSN node can be categorized into three; contention-based protocols, scheduled-based protocol and hybrid-based protocol.

A. Contention-based Protocols

In a contention-based protocol, nodes transmit or receive data whenever the medium is idle. This scheme however, leads to collisions as two or more nodes may transmit at the same time. The collision problem had received wide attention and many techniques for immediate mitigation if not total eradication have been proposed. One prominent technique for mitigation of collision is known as Carrier Sense Multiple Access (CSMA). CSMA requires a node to 'listen' to the channel before transmitting data. Data is transmitted if the channel is idle, otherwise the node will have to wait for a period before transmitting. In the event of a collision, nodes need to retransmit at a random interval known as the back-off mechanism. There are two different approaches to minimize the collision of transmission of data in CSMA, which are Carrier Sense Multiple Access/ Collision Detection (CSMA/CD) and Carries Sense Multiple Access/Collision Avoidance (CSMA/CA)(Younis & Nadeem, 2006).

B. Scheduled-Based Protocols

Scheduled-based MAC protocols controls the duty-cycle of nodes. A WSN node is scheduled to be only active at a specified time to access the channel. Through this approach nodes possess equal time for receiving or transmission of data. An example of the scheduled-based protocol is Time Division Multiple Access (TDMA) which is prominent in the earlier wireless communications.

C. Hybrid-Based Protocols

The prime function of hybrid-based protocol is to integrate the contention-based and schedule-based protocols by giving the recognition to their strength and provide solutions to their existing weaknesses. The related aspect is the hybrid-based MAC protocol is one of the functions of hybrid MAC protocol is that it integrates the merits of contention-based MAC and the schedule-based MAC together. The hybrid MAC introduces two types of packets namely the control packets and the data packets. The control packet is always introduced into the random access channel. The random access channel is used for synchronization purposes only while the data packet performs the function of transmitting the scheduled channel. Hybrid protocols are known provide better scalability and flexibility than both contention- and schedule-based protocols.The rest of this section discusses four kinds of hybrid MAC protocols.

i. Zebra-MAC (Z-MAC) Protocol

Z-MAC is defined as a hybrid technique that requires lower traffic for running CSMA and switches to TDMA at higher traffic (Bachir et al., 2010). Like CSMA, Z-MAC is capable of obtaining combination of high channel utilization and low-latency with little contention. Z-MAC is found with attributes of having high channel utilization with high contention as shown by TDMA. The work of Z-MAC depends on the DRAND (Distributed Randomized) algorithm to assigns a slot to each node. The Z-MAC algorithm ensures the integration of slots in such a way that hidden nodes collisions are avoided when even a node and the two-hop neighborhood share the like time slot occurs (Rhee, Warrier, Aia, Min, & Sichitiu, 2008).

Z-MAC however poses a problem known as the schedule drift. Data transmission sometimes exceed the time slot allocated thus encroaching into time slots meant for other nodes. This will result in another node switching into awake node, and possibly result in collisions.

ii. Wireless Sensor MAC (WiseMAC) Protocol

WiseMAC uses a preamble approach to achieved minimisation of energy during the idle listening (Hurni & Braun, 2008). Besides, mitigation of energy consumption in WiseMAC becomes visible through the use of the preamble sampling approach. Also WiseMAC allows an ultra-low average power consumption with low traffic conditions and provides high energy efficiency in accordance with high traffic conditions (Demirkol et al., 2006; El-Hoiydi, Decotignie, Enz, & Le Roux, 2003; Saharan & Pande, 2013).

WiseMACperforms optimallyon the WSN nodes only when it is applied on single-hop networks. In high traffic conditions, WiseMAC is prone to consume more energy as the nodes need to sample the medium more frequently, resulting in idle listening.

iii. Crankshaft

Crankshaft is a hybrid MAC protocol, which is mainly made for expansion of WSNs (Cano Bastidas, 2011). The Crankshaft protocol divides time into frames while each of the frames is divided into slots. Besides, the slots are classified into two namely broadcast slots and unicast slots. The communication in a slot is contention-based and in the event of a collision, the node computes a random back-off for retransmission. A node chooses a moment in the contention window in order to be able to transmit message in an exact slot. The Crankshaft utilizes a DATA/ACK sequence for unicast messages while the lengthen slots tenable to accommodate them. Therefore, a designated allocation is made for base-station or sink nodes which would listen to the unicast slots (Halkes & Langendoen, 2007; Kaan & Yang, 2008).

Though the Crankshaft focuses on expansion of sensor networks, it is non-scalable and not statistically allocated resulted in poor performance. Furthermore, the frequent shift to active mode to listen to the air interface causes idle listening.

iv. Asynchronous Scheduled MAC (AS-MAC) Protocol

AS-MAC asynchronously coordinates the wakeup times of neighboring nodes to reduce overhearing, contention and delays unavoidable in synchronous schedule-based MAC protocols. Therefore, AS-MAC adopts duty cycling in order to prevent idle listening and Low-Power-Listening (LPL) (Anwar & Lavagno, 2010). AS-MAC protocol is grouped into the initialization phase and the periodic listening and sleep phase (Jang et al., 2013).

The initialization process begins whenever a new node joins a WSN that produces information that enable the neighbor table and possess information about the neighbor.

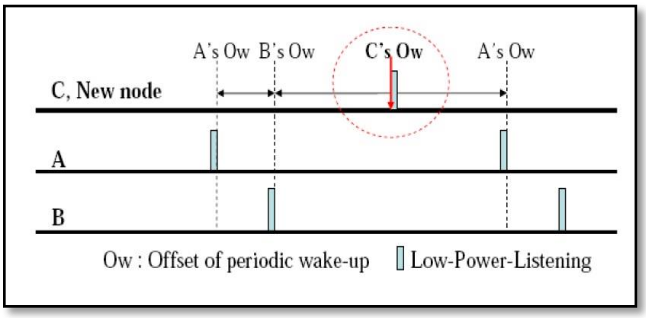

Figure 2.Initialization Phase Finding Its Offset (Jang et al., 2013).

In the Periodic Listening Phase (PLP), the receiving node wakes up periodically perform PLP. A node in active state will shift into sleep state after data is successfully transmitted.

The problem with the schedule-based MAC protocol AS-MAC is the sudden switch to active mode when the time slot arrives, which results in energy leakages if the circuitry is not properly designed.

III ENERGY EFFICIENT MAC

This section describes the proposed Energy-Efficient MAC (EE-MAC) protocol. In a sensor networks where energy is alimited resource so that energy consumption must be minimizedwhile satisfying given scheduling requirements.

Generally, the total energy consumed by a wireless sensor node is given as below:

$$\sum E_{total} = E_{Active} + E_{Idle} + E_{Sleep} \text{ ……………..(1)}$$

whereE_{Active} is the amount of energy consumed when the node is in its active mode. E_{Idle} is the amount of energy consumed when the node listens to the air interface for incoming messages, while E_{Sleep} is the amount of energy used basically for circuitry purposes when the node is in its sleep mode.

The amount of energy consumed by a node in active mode can further be divided into $E_{Tx,}$ the amount of energy consumed for data transmission, and $E_{Rx.}$is the amount of energy consumed for data receipt.Equation (1) can therefore be expanded and written as

$$\sum E_{total} = E_{Tx} + E_{Rx} + E_{Idle} + E_{Sleep}$$

……………….(2)

The energy requirement for data transfer is far larger than the combined amount of energy required for data receipt, scanning the air interface and in the sleep mode. However, most nodes are in idle mode most of the times and a significant amount of energy is wasted during this period. We argue therefore important that the amount of time a node remains in idle mode is reduced so as to reduce the energy consumption. By reducing the $E_{Idle,}$ the total energy consumed can be reduced.

In the following section, the scheduling mechanism in EE-MAC is discussed to illustrate how to reduce the idle listening in WSN nodes.

A. *Scheduling*

Scheduling is a technique used in most schedule-based MAC protocols. Each node is assigned a specific slot of which it can receive and transmit data. Similar technique is employed in EE-MAC. During initialization, all nodes are active to receive a synchronization message from the sink node. The time slot assigned for each node is divided into two slots, one for notification of data arrival, and another for the nodes to transmit to the sink. If a node has data to transmit, it transmits during the time slot assigned, otherwise it switches to sleep mode immediately. The procedure of EE-MAC is illustrated in Figure 3.

The steps below demonstrate the EE-MAC procedure:

Step1: Initialize: In the initialization step, all nodes are awake to receive synchronization message from the sink node.

Step2: Send synchronization message Nodes receive synchronization message from sink node.

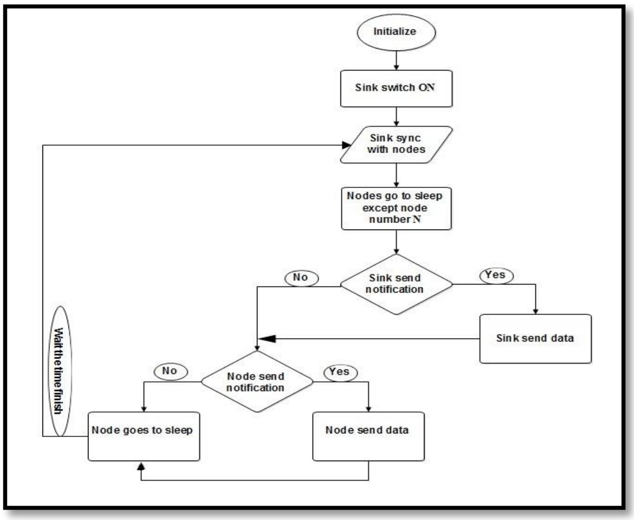

Figure 3.The EE-MAC Procedure

Step3: Synchronize with sink: Nodes synchronizes with sink. Nodes know the slot they are assigned to

Step4: Nodes go to sleep except node number N: All nodes, except node N switches to sleep mode. Node N is ready to receive data

Step5:Sink send notification: Through this step, sink notifies node number N if it has messages to send.

Step6: Sink sends data: Sink node sends messages to Node N.

Step7: Node send notification: If the sink has message to send, then Node N notifies the sink if it has data to send. Otherwise node N goes to sleep immediately.

Step8: Node send data: In this step node N will send data after receiving accepted the notification from Step 7. Node N will sleep when it finishes data transfer of the time slot expires.

Step9: Node goes to sleep: Node goes to sleep under the following circumstances: (i) None N has no data to be sent, (ii) Node N finished sending data, or (iii) Node N's time slot expires.

Figure 4 shows the scheduling procedure.

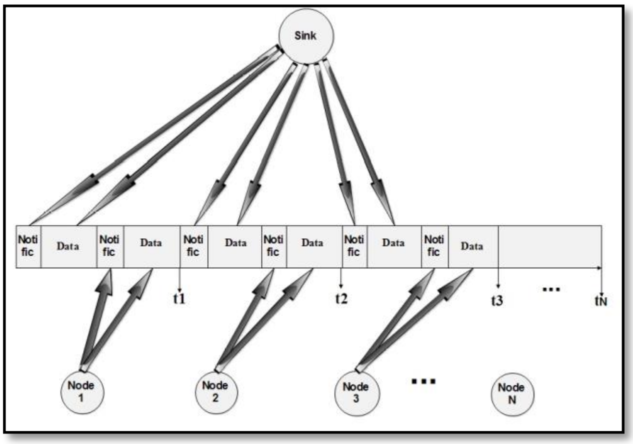

Figure 4.The EE-MAC Procedure

IV SIMULATION SETUP AND PARAMETERS

We have implemented the EE-MAC protocol using ns-2 simulator on Fedora OS. Through this exercise we intend to develop the proposed protocol, simulate the energy saving scheme and evaluate the performance of our (EE-MAC) protocol. ns-2 simulator mainly developed on Fedora OS to support sensor network simulations. The main advantageous of ns-2 is open source.

We have simulated the proposed EE-MAC protocol using ns-2 version 2.32. In our EE-MAC simulation, we have defined 100 nodes within a sensor field of 500x500 and the simulation time is set at 200 seconds. The EE-MAC is compared against the standard IEEE 802.11 Power Saving Mode (PSM). Briefly, the parameters of the simulation are as tabulated in Table I.

Table I: Simulation Parameters and Setup

Parameter	EE-MAC	IEEE 802.11 PSM MAC
Deployment zone	500m^2	500m^2
Number of nodes	100 nodes	100 nodes
Initial Energy	100 Joules	100 Joules
Tx Energy	0.02 Joules	0.02 Joules
Rx Energy	0.01 Joules	0.01 Joules
Idle Energy	<0.01 Joules	<0.01 Joules
Simulation time	200sec	200sec

V RESULTS & ANALYSIS

The EE-MAC simulation was carried out and compared against the IEEE 802.11 PSM. Performance matrices such as throughput, latency and most importantly energy consumption were captured. Table II below summarizes the simulation results.

Table II. Simulation Results.

Simulation metrics	Results of (EE-MAC) protocol
No. of packets sent	3100
No. of packets received	3085
No. of Packets dropped	15
Dropping-Ratio	0.483871
Packets delivery ratio	99.5161
Delay	2.51999
Throughput	84241.1
Jitter	0.0502109
Total Energy Consumption	105.2
Average Energy Consumption	1.052

The proposed EE-MAC performs better when is compared to the IEEE 802.11 PSM. Of the 3100 packets sent, only 15 packets were dropped, providing EE-MAC as delivery ratio of 99.5%. Figure 5 and Figure 6 depict the simulation result of EE-MAC pertaining to packets dropped.

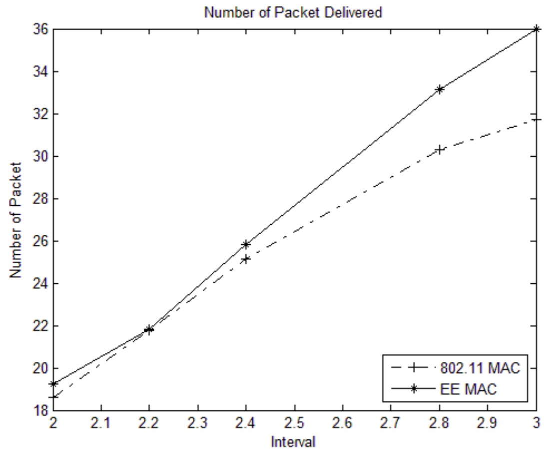

Figure 5: Packet Delivery

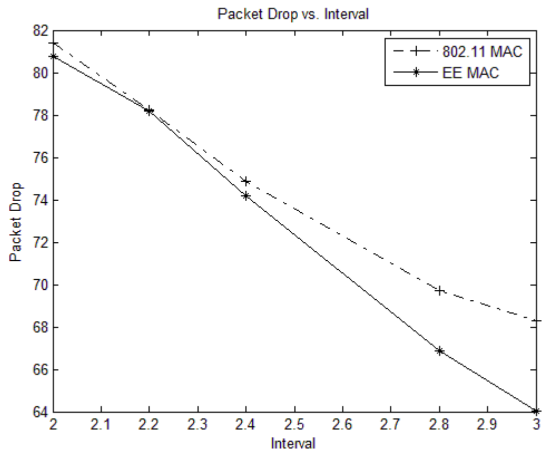

Figure 6: Packet Drop

EE-MAC also produced a higher throughput and a lower jitter when is compared against the IEEE 802.11 PSM as shown in Figure 7 and Figure 8.

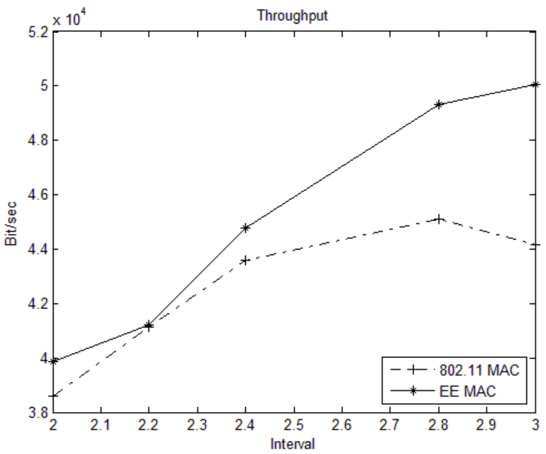

Figure 7: Throughput

The proposed EE-MAC have shown to be energy efficient when is compared against the IEEE 802.11 PSM.

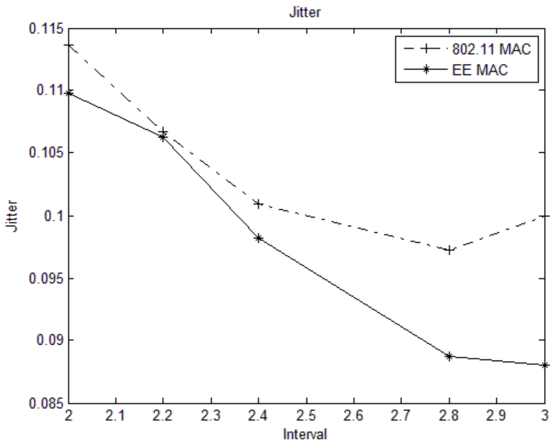

Figure 8: Jitter

The slot assignment mechanism as well as the reduction of idle times has improved energy consumption to more than 40%. This is a significant improvement on energy conservation. The simulation result is shown in Figure 9.

VI CONCLUSION AND FUTURE WORK

In this paper, we have designed, implemented and analyzed the hybrid EE-MAC protocol using ns-2 simulator. We have evaluated the performance of the EE-MAC protocol and compared it to the standard IEEE 802.11 PSM. In this study, the EE-MAC performs well in reducing the energy consumption, and maintained a high level of throughput, and packet delivery ratio. The energy conservation is due to the efficient scheduling mechanism used for reducing the idle listening times. This also addresses the shortcomings of schedule drifts. The contention-based characteristics on the other hand had resulted in a higher throughput which makes the EE-MAC more reliable.

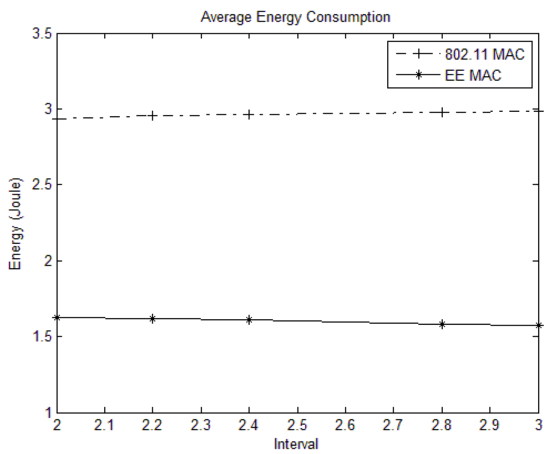

Figure 9.Average Energy Consumption.

In this study, we have only considered static sensor nodes. In future studies, node mobility will be considered, and we seek to address the energy issues related to mobile WSN that are deployed in many applications today.

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