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Performance and Comparison of Energy Efficient MAC Protocol in Wireless Sensor Network

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Abstract** – **Energy efficiency is the kernel issue in the designing of wireless sensor network (WSN) MAC protocols. Energy efficiency is a major consideration while designing wireless sensor network nodes. Most sensor network applications require energy autonomy for the complete lifetime of the node, which may span up to several years. These energy constraints require that the system be built such that Wireless sensor networks use battery-operated computing and sensing devices. A network of these devices will collaborate for a common application such as environmental monitoring. Each component consumes minimum possible power, ensure the average successful transmission rate, decrease the data packet average waiting time, and reduce the average energy consumption. Influencing by the design principles of traditional layered protocol stack, current MAC protocol designing for wireless sensor networks (WSN) seldom takes load balance into consideration, which greatly restricts WSN lifetime. This paper proposes a new MAC protocol called Energy-Efficient MAC (E^2MAC) focuses mainly on achieving good performance in packet delay and packet delivery rate while being operated on very low level of energy consumption. E^2MAC is designed based on a previously defined MAC protocol called S-MAC & T-MAC with the addition of adaptive wakeup time and next awake node first packet scheduling features. We compare the performance of S-MAC & T-MAC with E^2MAC. The results show that E^2MAC exhibits superior performance particularly in dense/high load networks.

1. INTRODUCTION

A wireless sensor network (WSN) is a wireless network consisting of spatially distributed autonomous devices that use sensors to monitor physical or environmental conditions. These autonomous devices, or nodes, combine with routers and a gateway to create a typical WSN system. Each node consists of processing capability (one or more microcontrollers, CPUs or DSP chips), may contain multiple types of memory (program, data and flash memories), have a RF transceiver (usually with a single omni-directional antenna), have a power source (e.g., batteries and solar cells), and accommodate various sensors and actuators. The nodes communicate wirelessly and often self-organize after being deployed in an ad hoc fashion. Systems of 1000s or even 10,000 nodes are anticipated. Such systems can revolutionize the way we live and work. A WSN system is ideal for an application like environmental monitoring in which the requirements mandate a long-term deployed solution to acquire water, soil, or climate measurements. For utilities such as the electricity grid, streetlights, and water municipals, wireless sensors offer a lower-cost method for collecting system health data to reduce energy usage and better manage resources. In structural health monitoring, you can use wireless sensors to effectively monitor highways, bridges, and tunnels. You also can deploy these systems to continually monitor office buildings, hospitals, airports, factories, power plants, or production facilities.

At the MAC layer, several sources of energy waste are identified including collisions, overhearing, control overhead and idle listening [1]. Packet collision and overhearing naturally occur in a shared medium such as the wireless channel. Similarly, frequent control packets represent an unavoidable protocol overhead that is important for many purposes including organizing nodes association, nodes synchronization and data transactions. Further, idle listening is an operating mode during which a wireless node wastes energy without receiving any packets. Any energy-efficient MAC targets reducing the energy waste in one or more of the aforementioned sources.

This paper introduces E^2MAC as a new energy-efficient MAC protocol for WSNs. E^2MAC is an asynchronous protocol in which each node has its own wakeup and sleep schedule but nodes share their expected wakeup time for communication coordination. E^2MAC further introduces an adaptive wake-up duration algorithm and a novel next awake node first (NANF) packet scheduling technique. The performance of EEMAC is evaluated using simulations in NS2. E^2MAC improves the energy consumption but also strikes a good compromise for normalized performance metrics such as network throughput and packet delay. These gains are attained while maintaining a simple implementation required for low price WSN nodes.

1.1 MAC Layer Protocol:

In a wireless sensor network the MAC Layer protocols are supposed to perform the following tasks:

1. To create an infrastructure and establish link for data transfer.

2. To share network communication resources between sensor nodes. The MAC layer is responsible for access to shared

medium. It assists nodes to decide when to access the shared medium.

The MAC Protocols [4] can be classified as follows:

1. Scheduled: This is based on Time Division Multiple Access (TDMA) protocol. In this mechanism the channel is divided into fixed time slots. A complete cycle of these slots is called frame. TDMA Protocols are inherently energy conserving as they reduce wastage due to Collision, Idle Listening and Overhearing.

2. Random: This is based on Carrier Sense Multiple Access (CSMA) protocol. In random access protocols, the channel is allocated to nodes on demand. i.e. the nodes contend for channel and if they find the channel free, starts transmission else postpone the transmission until the channel becomes idle and sense the channel to grab the chance to transmit the channel.

1.2 ATTRIBUTES OF GOOD MAC PROTOCOL

In the wireless sensor networks, for designing high-quality MAC protocol, these attributes are
to be measured [4].

- Energy Efficiency: Energy efficiency are the first attribute. Battery powered consist in The sensor nodes and it is often extremely complicated to change or recharge batteries for these sensor nodes. Sometimes it is helpful to replace the sensor node rather than recharging them.
- Latency: The second is latency. Latency requirement basically depends on the application. the detected events must be reported to the sink node in real time In the sensor network applications, so that the suitable action could be taken immediately.
- Throughput: With different applications the throughput requirement also varies. A few sensor network application require to sample the information with fine temporal resolution. In such sensor applications it is better that sink node receives more data.
- Fairness: In several sensor network applications when bandwidth is limited, it is compulsory to confirm that the sink node receives information from all sensor nodes fairly. However along with all of the above aspects the energy efficiency and throughput are the key aspects. By minimizing the energy wastage energy efficiency can be increased [4]

2. BACKGROUND AND RELATED WORK

The design of energy-efficient MAC protocols for wireless sensors is a very active area of research. The literature is rich with survey papers for energy efficient MAC protocols for WSNs. This section highlights some relevant proposals for WSN energy-efficient MAC protocols.

1) Sensor-MAC (S-MAC)

Locally managed synchronizations and periodic sleep, listen schedules based on these synchronizations form the basic idea behind the Sensor-MAC (S-MAC) protocol [2]. Neighboring nodes form virtual clusters to set up a common sleep schedule. If two neighboring nodes reside in two different virtual clusters, they wake up at listen periods of both clusters. A drawback of S-MAC algorithm is this possibility of following two different schedules, which results in more energy consumption via idle listening and overhearing. Schedule exchanges are accomplished by periodical SYNC packet broadcasts to immediate neighbors. The period for each node to send a SYNC packet is called the *synchronization period*. Figure 1 represents a sample *sender-receiver* communication. Collision avoidance is achieved by a carrier sense, which is represented as CS in the figure. Furthermore, RTS/CTS packet exchanges are used for unicast type data packets. An important feature of S-MAC is the concept of message-passing where long messages are divided into frames and sent in a burst. With this technique, one may achieve energy savings by minimizing communication overhead at the expense of unfairness in medium access. Periodic sleep may result in high latency especially for multi-hop routing algorithms, since all immediate nodes have their own sleep schedules. The latency caused by periodic sleeping is called *sleep delay* in [2]. Adaptive listening technique is proposed to improve the sleep delay, and thus the overall latency. In that technique, the node who overhears its neighbor's transmissions wakes up for a short time at the end of the transmission. Hence, if the node is the next-hop node, its neighbor could pass data immediately. The end of the transmissions is known by the *duration* field of RTS/CTS packets.

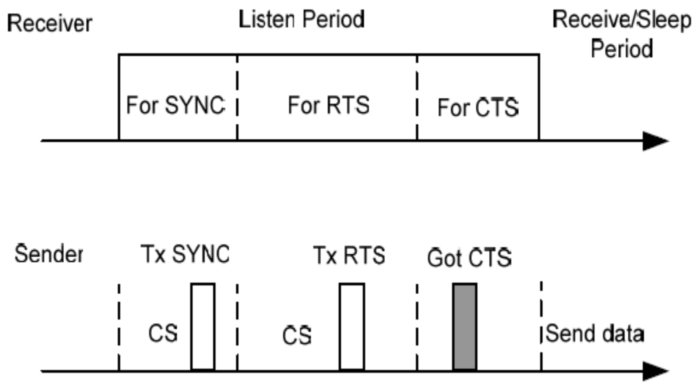


Figure 1. S-MAC Messaging Scenario

Advantages: The energy waste caused by idle listening is reduced by sleep schedules. In addition to its implementation simplicity, time synchronization overhead may be prevented with sleep schedule announcements.
Disadvantages: Broadcast data packets do not use RTS/CTS which increases collision probability. Adaptive listening incurs overhearing or idle listening if the packet is not destined to the listening node. Sleep and listen periods are predefined and constant, which decreases the efficiency of the algorithm under variable traffic load.

2) ***T-MAC*** [3]

In T-MAC all the messages are transmitted in a burst of variable length and there is gap between the bursts called sleep/sleep time. This is to reduce the idle listening. The node awakes periodically to communicate with neighbors and it uses RTS and CTS, Data Acknowledgement (ACK) scheme, which provides both collision avoidance and reliable trans-mission. In this the messages are stored in a buffer and then a frame is made to transmit containing messages during the active time as shown in fig. The active time ends when there is no active event for a time period TA and the node goes to sleep mode. At the time of high load nodes communicates continuously without sleeping.

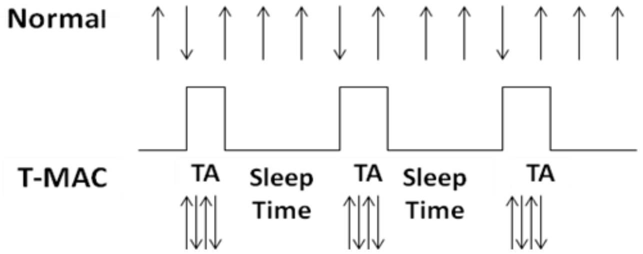


Figure 2: T-MAC Messaging Scenario

The major disadvantage with this technique is "The early sleep problem". i.e. the node goes to sleep mode even if it its neighboring node have something to send to it. It has been found from previous research papers that T-MAC is more efficient than the traditional protocols, Pendulum and Leach protocol.

3. MAJOR ISSUES OF ENERGY WASTAGE

The reason of wastage of energy in a MAC protocol for wireless sensor networks are the following [5].

1. Idle listening

When nodes have nothing to send or receive, the nodes still remain in active state and do idle listening to the network. This process consumes equal amount of energy as during transmitting or receiving process. Thuse resulting into wastage of energy.

2. Collision or Corruption Normally collision may occur when neighboring nodes contend for free medium and lossy channel will result in corruption of transmitted packets. When either of two cases happens corrupted packets should be retransmitted, which increases energy consumption.

3. Overhearing Sometime nodes can pickup which are destined to other nodes. These also leads to unnecessary consume of energy.

4. Control Packet Overhead Exchanging control packets between sender and receiver also consumes some energy. Reducing the energy wasted idle listing protocols like SMAC and TMAC can be used. SMAC Traditional wakeup scheduling approach which uses fixed duty cycle [4].

Duty Cycle =Listen Interval/ Frame Length

4. ENERGY EFFICIENT MAC DESIGN AND IMPLEMENTATION

E^2MAC introduces two new features to S-MAC and T-MAC including the adaptive wakeup time and next awake node first (NANF) packet scheduling.

A. Adaptive wakeup Time

The adaptive wakeup time feature enables E^2MAC to change its activity to accommodate the network varying load. By this addition, each E^2MAC node may remain idle for TA seconds unless it receives packets destined to it. On receiving packets, E^2MAC extends its wakeup time for another TA and this behavior repeats until a complete TA passes without receiving any packet.

B. Next Awake Node First Scheduling

Typically, the packets are serviced in a first-in-first-out (FIFO) order in the MAC queue. In our proposed next awake node first (NANF) scheduling, the MAC would schedule the packets according to the expected wakeup order of receiving nodes independent of their arrival order from higher layers. Figure 3 illustrates the impact of the proposed next awake node first on the performance. Hence, node 1 would wake up for one cycle without receiving any packet even though the network contains packets destined to it. Such behavior increases both energy consumption and average packet delay in the system. When using NANF, E^2MAC would schedule the packet transmission according to the activity of receiving nodes. Each time E^2MAC receives a packet transmission request from the application layer it sorts its transmission buffer in an order corresponding to the destination wakeup time. Using such design enables E^2MAC to transmit node 1 packet first although it received node 2 packet first from application layer. Hence, E^2MAC would maintain a lower packet delay and energy consumption profile in comparison with S-MAC.

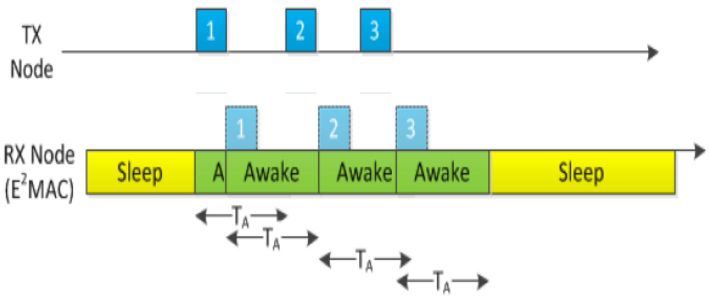


Figure 3: Adaptive wakeup time feature

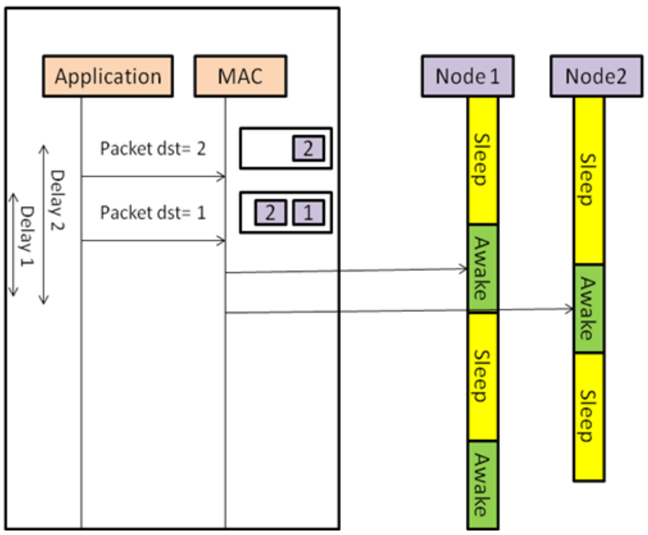


Figure 4: Next awake node first feature

5. PERFORMANCE EVOLUTION

In this section performance metrics are used to evaluate performance of E2MAC protocols and data dissemination

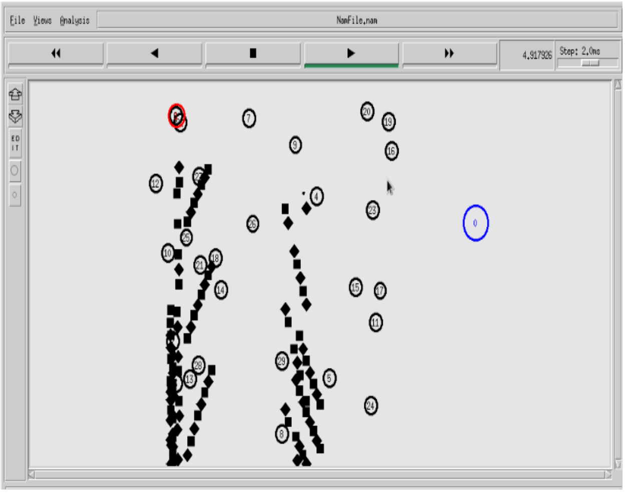


Figure 5: NAM visualization with More Dropping Packet to Node, In S-MAC

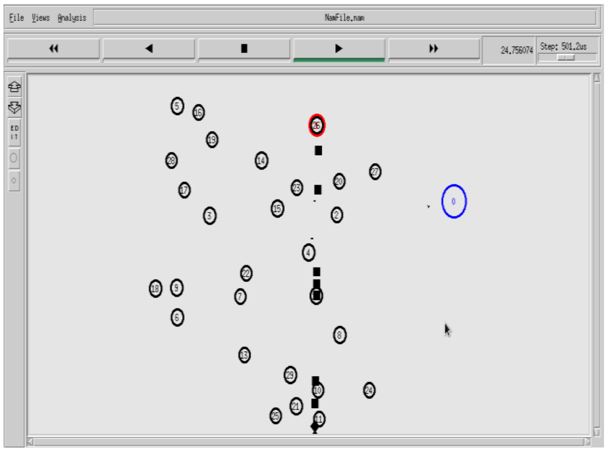
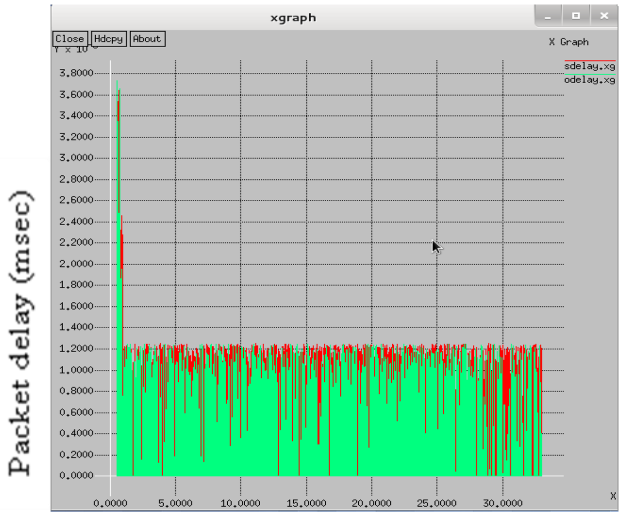


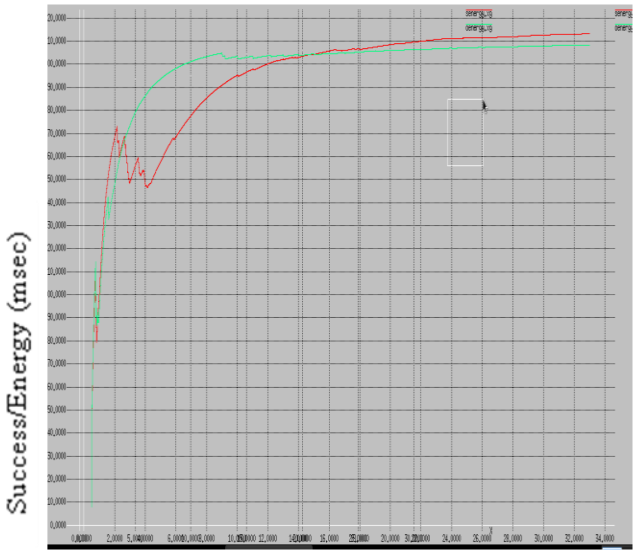
Figure 6: NAM visualization with Dropping Packet to other not visited token Node 1,In E^2MAC.

a) Packet Delivery Ratio (PDR): The ratio between the number of packets that are received and the number of packets sent.



Simulation Time

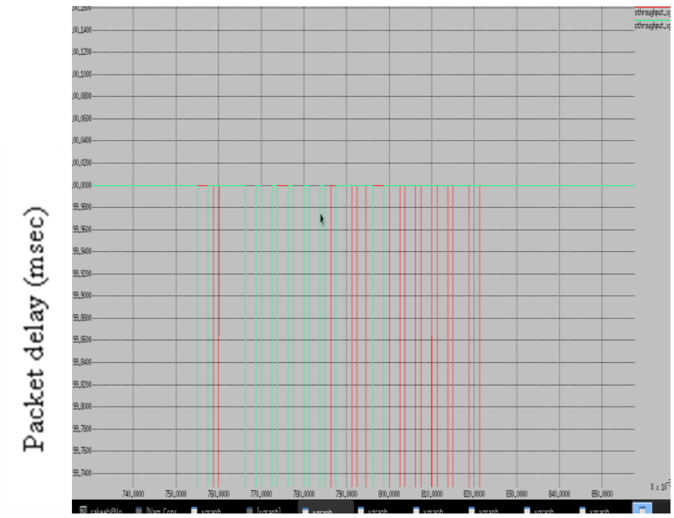
Figure 7: Packet Delivery Ratio In S-MAC & E^2MAC
The packet delivery ratio from 30 node in high load network.



Simulation Time

Figure 8: The S-MAC & E^2MAC protocols of WSNs with Respect to Energy. Average Consume energy with changing input packet rate.

c) Throughput : Throughput is the total of all bits (or packets) successfully delivered to individual destination over total–time / total-time (or over bits-total/total time) and result is found as per KB/Sec



Simulation Time

Figure 9: In S-MAC & E^2MAC protocols of WSNs with respect to Throughput.

6. CONCLUSION AND FUTURE WORK

This paper produces a new MAC protocol, Energy Efficient MAC, in MAC by adding two main features; adaptive wakeup time and next awake node first (NANF) scheduling. Energy Efficient MAC shows good energy consumption without impacting packet delay and packet delivery success rate but even enhancing them especially in the dense/high load networks. Performance is compared with S-MAC and the results show that lower delay and success rate per consumed energy are attained by Energy Efficient MAC particularly in dense/high load networks. As a future work, we are considering analyzing how to enhance energy efficiency in light load networks. One solution can be changing TA adaptively in run-time to be short in light traffic networks and large in heavy load networks.

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