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Wireless Sensor Networks:Delay Guarentee and Energy Efficient MAC Protocols

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Abstract— **Wireless sensor networks is an emerging technology that serves as environment monitors in many applications. Yet these miniatures suffer from constrained resources in terms of computation capabilities and energy resources. Limited energy resource in these nodes demands an efficient consumption of that resource either by developing the modules itself or by providing an efficient communication protocols. This paper presents a comprehensive summarization and a comparative study of the available MAC protocols proposed for Wireless Sensor Networks showing their capabilities and efficiency in terms of energy consumption and delay guarantee.**

Key Words: MAC (Medium Access Control), SEA (Simple Energy Aware), WSNs (Wireless Sensor Nodes or Networks) RTS (Request To Send), CTS (Clear To Send), SYNCH (Synchronize), NS2 (Network Simulator 2).

I. INTRODUCTION

A sensor network is an infrastructure comprised of sensing (measuring), computing, and communication elements that gives an administrator the ability to instrument, observe, and react to events and phenomena in specified environment.
With its origin in the early nineties, the subject of wireless sensor networks has seen an explosive growth in interest in both academia and industry. In just the past eight years a lot of researches have been done on the subject (figure (1) example of a sensor node).

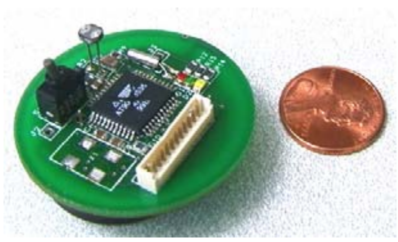

Figure (1) Berkeley Mote

Wireless sensor networks promise an unprecedented fine-grained interface between the virtual and physical worlds. They are one of the most rapidly developing new information technologies, with applications in a wide range of fields including industrial process control, security and surveillance, environmental sensing and structural health monitoring.
There are four basic components in a sensor network: (1) an assembly of distributed or localized sensors; (2) an interconnecting network (usually, but not always, wireless-based); (3) a central point of information clustering; (4) a set of computing resources at the central point (or beyond) to handle data correlation, event trending, status querying, and data mining. In this context, the sensing and computation nodes are considered part of the sensor network; in fact, some of the computing may be done in the network itself. Because of potentially large quantity of data collected, algorithmic methods for data management play an important role in sensor networks.
Yet the energy constrained miniatures must operate in a way that keeps fair consuming between sensor nodes to reach efficient network productivity. In practice, it will be necessary in many applications to provide guarantees that a network of unattended wireless sensors can remain operational without any replacements for several years. Hardware improvements in battery design and energy harvesting techniques will offer only partial solutions. This is the reason that most protocol designs in wireless sensor networks are designed explicitly with energy efficiency as the primary goal. Naturally, this goal must be balanced against a number of other concerns.

II. MAC PROTOCOLS FOR WSN

There are a lot of protocols for MAC layer. For wireless sensor networks the literature provided a lot of protocols and divided it into two major categories:

1. **Contention Based MAC Protocols (CSMA carrier sense multiple access)**: the wireless nodes here contend to enter the medium of connectivity (which is the wireless medium in case of WSNs) and the winner node reserves the medium to itself until it finishes its operation. Examples for this kind of protocols are: the popular 802.11 [1], S-MAC [1], T-MAC [3], R-MAC [12]... etc.
2. **TDMA (time division multiple access) Based MAC Protocols**: the medium here is divided into time slots each node knows its time slot when to enter the medium and do its operation. Maybe the most popular TDMA based MAC protocol for WSNs is ALOHA [7].

MAC protocols have challenges to overcome when it is meant to be designed for WSNs:

1. Reliable end-to-end data delivery.
2. Low latency data delivery.
3. Scalability and Adaptability.
4. Energy efficient consumption in wireless nodes.

Ioannis Mathioudakis et al, presented the most energy wastage sources in MAC protocols for WSNs [19]:

The first source is caused by collisions, which occur when two or more nodes attempt to transmit simultaneously. The need to re-transmit a packet that has been corrupted by collision increases the energy consumption.

The second source of energy wastage is idle-listening, where a node listens for traffic that it is not sent. This energy expended monitoring a silent channel can be high in several sensor applications.

The third source of waste is overhearing, which occurs when a sensor node receives packets that are destined for other nodes.

The fourth is caused by control packet overheads, which are required to regulate access to the transmission channel. Sending and receiving control packets consumes energy too, and less useful data packets can be transmitted.

The fifth source is over-emitting where the destination node is not ready to receive during the transmission procedure, and hence the packet is not correctly received.

Finally, the transition between different operation modes, such as sleep, idle, receive and transmit, can result in significant energy consumption. Limiting the number of transitions between sleep and active modes leads to a considerable energy saving.

The next section will demonstrate most of the recent proposed MAC protocols for WSNs.

III. RELATED WORK

A. Contention Based MAC Protocols:

The most known MAC protocol for wireless networks is IEEE 802.11 which is the standard now for WLAN applications [1]. IEEE 802.11 performs well on terms of latency and throughput but it is very unwanted in terms of energy consumption because of the (idle listening) problem issued with it. When the node is in idle listening state it is been proved that the node consumes energy equivalent to the receiving energy that is why this protocol is not preferred for WSNs applications.

Wei et al, presented sensor-MAC (S-MAC), a contention based MAC protocol designed explicitly for wireless sensor networks [1]. While reducing energy consumption is the primary goal in the design, the protocol also has good scalability and collision avoidance capability. It achieves good scalability and collision avoidance by utilizing a combined scheduling and contention scheme. It achieves efficient energy consumption by using a scheme of periodic listen and sleep reduces energy consumption by avoiding idle listening. It uses synchronization to form virtual clusters of nodes on the same sleep schedule. These schedules coordinate nodes to minimize additional latency. The protocol uses the same mechanism to avoid the overhearing problem and hidden channel problem that is used in IEEE 802.11 MAC protocol. S-MAC has a problem of latency because of periodic listen and sleep scheme which is fixed depending on the duty cycle.

Tijs van dam et al, introduced T-MAC, a contention-based Medium Access Control protocol for wireless sensor networks [3]. Applications for these networks have some characteristics (low message rate, insensitivity to latency) that can be exploited to reduce energy consumption by introducing an active/sleep duty cycle. To handle load variations in time and location T-MAC introduces an adaptive duty cycle in a novel way: by dynamically ending the active part of it. This reduces the amount of energy wasted on idle listening, in which nodes wait for potentially incoming messages, while still maintaining a reasonable throughput. T-MAC uses *TA* (time out) packet to end the active part when there is no data to send/receive on the node. It compromises between energy efficient consumption and latency efficient throughput because of the scheme of burst data sending.

Changsu suh et al, focused on the contention-based MAC protocol and present a novel scheme, named as TEEM (Traffic aware, Energy Efficient MAC) protocol [6]. The proposed TEEM is originally inspired by S-MAC [], probably the most often cited contention-based MAC protocol for sensor networks with the concept of periodic listen and sleep modes. The protocol achieves energy efficient consumption by utilizing ‘traffic information’ of each node, achieving a significant decrease in power consumption. Thus, the listen time of nodes can be reduced by putting them into sleep state earlier when they expect no data traffic to occur. Two important modifications TEEM protocol makes over the existing S-MAC protocol: firstly by having all nodes turn off their radios much earlier when no data packet transfer is expected to occur in the networks, and secondly by eliminating communication of a separate RTS control packet even when data traffic is likely to occur. Still it lacks on latency efficiency it subjected to energy efficient operation.

Tao Zheng et al, proposes a new MAC protocol, called PMAC, where the sleep-wakeup times of the sensor nodes are adaptively determined [5]. The schedules are decided based on a node’s own traffic and that of its neighbors. Experimental results show that in comparison to SMAC, PMAC achieves more power savings under light loads, and higher throughput under heavier traffic loads. The improved performance of PMAC suggests that ‘pattern exchange’ is a promising framework for improving the energy efficiency of the MAC protocols used in sensor networks. Because of the (*pattern*) approach PMAC has the computation overhead by using Markov chain approach as a probability check.

Sangheon Pack et al, proposed a task aware MAC protocol for WSNs [10]. As a kind of cross layering approach, TA-MAC protocol determines the channel access probability depending on a node’s and its neighbor nodes’ traffic loads through the interaction with the data dissemination protocol. TA-MAC protocol can reduce energy consumption and improve the throughput by eliminating unnecessary collisions. The TA-MAC protocol is feasible because it can be integrated with other energy efficient MAC protocol (e.g., SMAC). This is because the TA-MAC protocol focuses on the determination of channel access probability that is orthogonal to the previous MAC protocols for WSNs.

Shu Du et al, another approach for efficient MAC protocol called RMAC (the Routing enhanced MAC protocol), that exploits cross-layer routing information in order to avoid the common problems without sacrificing energy efficiency [12]. Most importantly, RMAC can deliver a data packet *multiple* hops in a single operational cycle. During the SLEEP period in RMAC, a relaying node for a data packet goes to sleep first and then intelligently wake up when its upstream node has the data packet ready to transmit to it. After the data packet is received by this relaying node, it can also immediately forward the packet to its next downstream node, as that node has also just woken up and is ready to receive the data packet. The mechanism is implemented using a packet called (Pioneer) this packet travels to all sensors in down-stream to synchronize the duty-cycles of the nodes to guarantee a multi-hop packet delivery. This protocol achieved latency efficient operation.

Sung-Chan Choi et al, proposed PS-MAC (Probability Sensor-MAC), a time slotted MAC protocol like S-MAC but unlike S-MAC in which all nodes have the same synchronized and periodic listen and sleep cycle, in this protocol, different transmitter and receiver node pairs have asynchronous and non-periodic listen and sleep schedules [11]. Each sensor node uses a pseudo-number generator and determines its listen and sleep schedule randomly based on its pre-wakeup probability and seed. Yet it could produce over emitting problem because of the asynchronous probability so to avoid this problem the neighboring nodes exchange their pre-wakeup probabilities and seed numbers. The protocol provided an energy efficient operation with a decent throughput because of asynchronous scheduling which out-performs S-MAC on heavy load situation.

Miguel A. Erazo et al, developed S-MAC to SEA-MAC a protocol aims for energy efficient operation for WSNs for environment monitoring [13]. The protocol assumes only the base station node has the time synchronization schedule. Sensor nodes suppose to be active only when there is a sample to be taken from the environment which decreases the duty-cycle of the node and preserves energy.

Another approach is produced by *Farid Nait-Abdesselam et al*, O-MAC a protocol which aims to decrease energy consuming and provide high throughput in WSNs Its design is mainly based on two major ideas [14]. First, it adopts a locally scheduled algorithm on a CSMA protocol which will prevent possible collisions among the neighboring contending nodes. Second, it allows the nodes in the vicinity of a transmission and that are not concerned by the data being sent the possibility to sleep during the duration of one transmission and to inform their neighbors of their ultimate entry into sleep mode to prevent them from sending data wastefully during the sleep period. Still this protocol has packet overhead because it has to utilize another to control packets OTS (Order To Sleep) and NTS (Node To Sleep).

Yanjun Sun et al, produced DW-MAC (Demand-Wakeup) [18]. DW-MAC is a synchronized duty cycle MAC protocol, where each cycle is divided into three periods: Sync, Data, and Sleep. DW-MAC assumes that a separate protocol is used to synchronize the clocks in sensor nodes during the Sync period with required precision. The basic concept of DW-MAC is to wake up nodes on demand during the Sleep period of a cycle in order to transmit or receive a packet. This demand wakeup adaptively increases effective channel capacity during a cycle as traffic load increases, allowing DW-MAC to achieve low delivery latency under a wide range of traffic loads including both unicast and broadcast traffic.

Qingchun Yu et al, introduced LL-MAC (Low-Latency) MAC protocol, which improved the problem of the conflict between energy efficiency and low-latency [16]. This scheme uses asynchrony (ASYNC) message package to broadcast the schedule information between neighbor nodes instead of SYNC package in S-MAC, and brings in a stagger active schedule which derives from DMAC [16], it ensures the sender and the receiver node will be both active for one packet transmitting time, which avoids the data forwarding interruption problem and reduces the transmission latency.

B. TDMA Based MAC Protocols:

Rajgopal Kannan et al, introduced ER-MAC (Energy and Rate), the distributed energy aware MAC protocol is based on TDMA and hence possesses the natural ability of avoiding extra energy wastage [2]. The main advantages of a TDMA-protocol present in ER-MAC are the following:

1. Packet loss due to collisions is absent because two nodes do not transmit in the same slot. Although packet loss may occur due to other reasons like interference, loss of signal strength etc.
2. No contention mechanism is required for a node to start sensing its packets since the slots are pre-assigned to each node. No extra control overhead packets for contention are required.

ER-MAC uses the concept of periodic listen and sleep. A sensor node switches off its radio and goes into a sleep mode only when it is in its own time slot and does not have anything to transmit. It has to keep the radio awake in the slots assigned to its neighbors in order to receive packets from them even if the node with current slot has nothing to transmit.

Anirudha Sahoo et al, produced RT-MAC, a TDMA based MAC protocol that can provide delay guarantee [15]. TDMA based MAC protocols suffers from latency because of the assigning of time slots which takes much time relatively because of the number of sensor nodes deployed. Yet RT-MAC can overcome this by reutilizing the connection channel between two successive channel accesses of a sensor node. And RT-MAC allows sensors to go to sleep which preserves energy. Thu it provides delay guarantee, but it encompasses a lot of calculation that could exhaust the sensor node itself in some cases like clock drifting problem.

IV. SIMULATION AND RESULTS

We have simulated IEEE802.11, SMAC and SEA-MAC to show the efficiency of each protocol in terms of energy consumption. And we chose these protocols for:

1. S-MAC is the most popular in WSNs systems.
2. SEA-MAC is an improvement on SMAC.

The simulation scenario contains five nodes in straight line using the Network Simulator 2 [20] (NS2) version 2.29. Figure (2) shows the scenario.

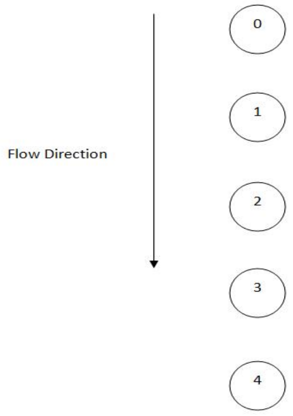

Figure (2) simulation scenario and flow direction

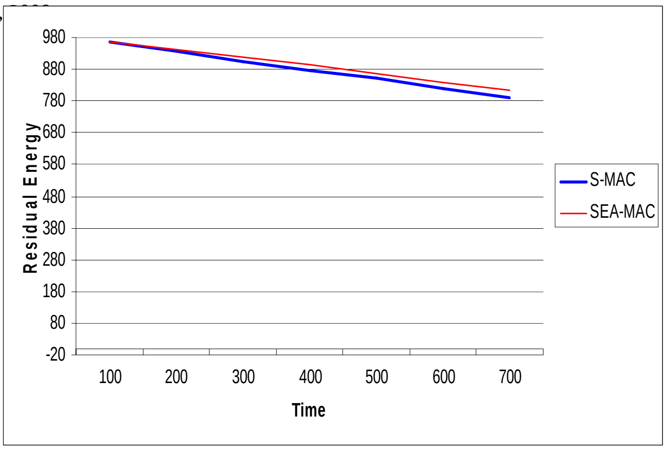

Figure (4) 25 % duty-cycle

The simulation procedure has been done first for (10%) duty-cycle and (25%) duty-cycle for the two protocols. As we see in figure (3) below:

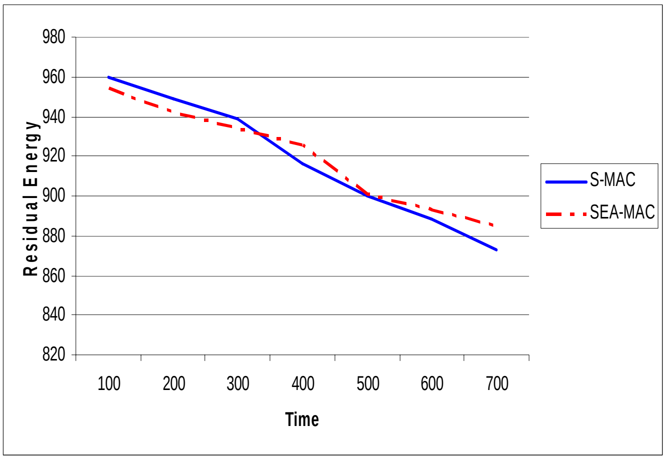

Figure (3) 10% duty-cycle (energy against time)

It is obvious that SEA-MAC has the lead in energy consumption that is because SEA-MAC has a fixed period while S-MAC Duty-Cycle dependent.

While when we increase the duty-cycle period to (25%) as in figure (4):

We observe that SMAC is losing energy more than SEA-MAC because in SMAC depends on duty-cycle period. While SEA-MAC is still consumes less energy than S-MAC because it is designed for high Duty-Cycle operation.

Note: the next figures (5, 6, 7, 8) are the results and the scenarios obtained from the source publications.

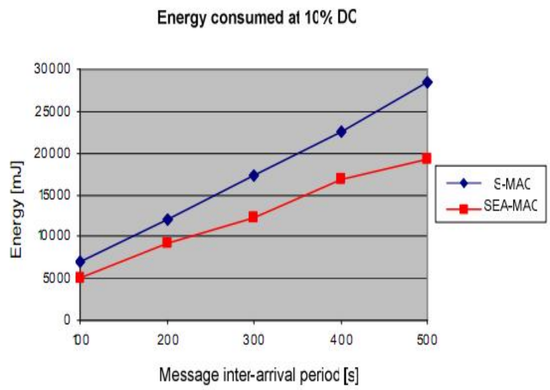

Figure (5) [13] SEA-MAC vs. S-MAC

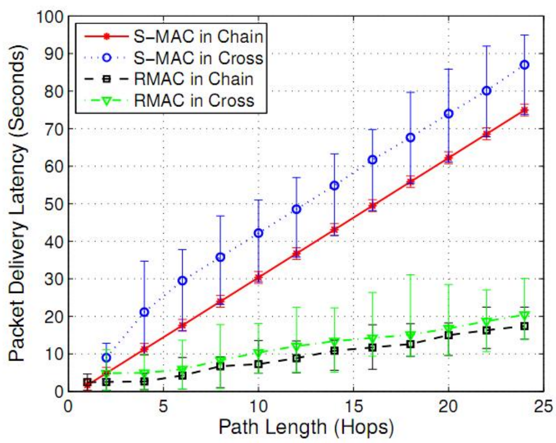

Figure (6) R-MAC [12] throughput performance

Figure (9) and (10) respectively shows the scenarios that R-MAC was implemented in:

Figure (7) [12] Chain scenario used for RMAC

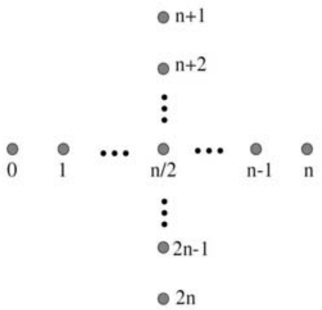

Figure (8) [12] Cross scenario used for RMAC

V. CONCLUSION

A lot of Contention-based MAC protocols provided in the literature because they are easy to implement and scalable in operation. While few protocols introduced for TDMA-based scheduling because of the overhead of time slot scheduling because of the large number of sensors that are deployed. Still there are more works to design MAC protocol based on TDMA scheme; they all share the same complexity in time slot assigning. There is no MAC protocol considered as a standard for WSNs because WSNs are application depended. That's why a lot of MAC protocols are provided in the literature for WSNs. Our future work is to define a new MAC protocol that can achieve both energy efficiency and delay guarantee.

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