Energy Saving Mechanisms in Hybrid Media Access Control Protocol for WSNs

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Abstract:
The Layer 2 Medium Access Layer (MAC) in Wireless Sensor Networks (WSNs) has been predominantly favorite to the researchers to save energy since it has all the tasks regarding distribution, communication, channel access and management, collision avoidance and handling, clustering, and various other house-keeping chores. The sensor nodes have to work with limited battery life, and energy expensive radio communication. This paper outlines the attributes that are crucial for the design of MAC layer protocols; discusses various prevalent hybrid MAC protocols for WSNs, underlining their strengths and weaknesses. Then, comparison of hybrid MAC protocols on the basis of various attributes. It provides a comprehensive and evaluating study in which, the energy-saving mechanisms proposed and applied in the WSN MAC protocols are thoroughly discussed. The paper also ascertains the canonical methods for improving energy-efficiency of the WSN MAC protocols and paves the future endeavors.


INTRODUCTION

Improvements in various technologies like MEMS (Micro-Electric Mechanical Systems) were the development in the progress of WSN. It has resulted in low-cost sensor nodes, which are composed of extremely small chips integrating electrical circuits and mechanical processes to both record and process data in a single chip, a processor, and a transceiver, a number of sensors, such as temperature, moisture, and vibration sensors, and a power source. WSNs have many applications in both military and civilian such as battlefield surveillance, habitat monitoring, healthcare, traffic control etc.

These Wireless Sensor Networks have severe resource constraints and energy conservation is very essential. The Figure 1 depicts the basic model of a sensor node and interconnection of different employed modules.

The sensor node’s radio in the WSNs consumes a significant amount of energy. Coverage and communication range for sensor nodes compared to other mobile devices is limited due to low power capacities of sensor nodes. Unlike other wireless networks, it is generally difficult or impractical to charge/replace exhausted batteries. That is why the primary objective in wireless sensor networks design is maximizing node/network lifetime, leaving the other performance metrics as secondary objectives.

The high energy cost of radio usage has motivated research in energy-efficient MAC protocols. Several sources of energy waste exist in WSN radio communication, such as idle listening, overhearing and collisions. MAC is an important technique that ensures the successful operation of the network. Early solutions to the problem of conserving energy at the MAC layer can be split into two categories: TDMA-based and CSMA-based protocols. Carrier Sense Multiple Access (CSMA) technique, has higher costs for message collisions, overhearing and idle listening [25]. Many MAC protocols viz. Sensor Mac (S-MAC), Time-out (T-MAC), Adaptive Energy Efficient MAC(AEEMAC) have been proposed using these two traditional mechanisms. The contention based protocols relax time synchronization requirements and can easily adjust to the topology changes by joining some new nodes. They schedule transmit & listen periods, thus avoiding collisions, overhearing and idle listening. However, TDMA gives much lower channel utilization than CSMA under low contention as nodes can only transmit during their scheduled slot. But
CSMA performance decreases under high contention in terms of both energy consumption and channel utilization. So the recent research got concentrated on the development of hybrid mechanisms i.e. the necessity to design efficient MAC protocol for Wireless Sensor Networks heads to the development of hybrid MAC protocols. They combine the strengths of both TDMA and CSMA protocols and offer high energy savings, better scalability and flexibility than any of the contention-based MAC or TDMA-based MAC protocols [21]. Hybrid techniques aim at achieving lower power consuming WSNs while establishing the equilibrium, by providing adaptive capabilities to the network so to readily switch between CSMA and TDMA phenomenon, which save significant amount of energy. Thus the main ill-factor of hybrid mechanisms is their complexity that limits them to serve only a limited variety of applications.

Important Attributes for Efficient MAC Protocol
The WSN has a large number of nodes. So, to achieve the effectiveness in the MAC protocol, the following attributes are to be addressed well while designing a MAC protocol.

- **Energy Efficiency**: Energy efficiency is a major concern of Wireless Sensor Networks due to sensor nodes with limited battery life and energy expensive short-range radio communication. Various applications require all time monitoring resulting in energy consumption. Therefore, energy efficient MAC protocol is the primary need for the longevity of node’s life.

- **Latency**: Latency requirement basically depends on the application. In real time, it is necessary to report the sink about the detected events in the shortest possible time, so the actions can be taken immediately.

- **Throughput**: The data passing through a network from sensor nodes to the sink over a period of time is throughput. A few sensor network applications require sampling the information with fine temporal resolution. In such sensor applications it is better that sink node receives more data.

- **Scalability**: The wireless sensor networks grow according to the conditions and requirements of the applications. More sensor nodes are added to make sensor networks efficient. So WSN requires flexible MAC protocol which should be adaptable to these changes.

- **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. Moreover all transmission intended nodes get fair time to transmit. 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 up to maximum.

RELATED WORK
The authors in [24] analyzed and compared the application specifics of the existing Hybrid-MAC protocols depicting the effect of the inefficient behavior of these protocols if imposed on some other applications’ scenarios.

The channel access policies are classified into [23] four categories: contention-based, TDMA-based, hybrid, and cross layer protocols. The paper [22] discusses the recent energy efficient MAC protocols for WSN and presents a classification of the various approaches pursued. The four main categories explored are scheduling based, collision free, contention based and hybrid schemes. Here, we are focusing on the power saving mechanisms used by different protocols with their advantages. Here shortcomings are also focused in the design of various hybrid MAC protocols.

The comparative study of each protocol is also shown, pointing towards the improvements of hybrid MAC protocols in the field of Wireless Sensor Networks.

HYBRID POWER SAVING MECHANISMS
In recent years several hybrid MAC protocols have been proposed like TFMAC [16], ERMAC [17], Cluster-based (HC) MAC [18], TDM-FDM MAC [19], CAT based MAC [20] etc. They combined the features of contention based and schedule based protocols [21] with the aim to include the benefits from both of them. All these protocols divide the access channel into two parts. Control packets are sent in the random access channel, and data packets are transmitted in the scheduled channel. The control channel schedules the data access.

The work flow of hybrid MAC protocol has to go through several phases [26]. In neighbor discovery phase the nodes find adjacent or two hops neighbors and prepares database for neighbors. During slot assignment phase the neighbors list is used to assign the slot to every node using slot assignment algorithm. The nodes opt the period i.e. time frame to use a time slot for transmission, and every node has to synchronize its time frame during transmission. The intensive global synchronization of all nodes takes place. During the transmission control, nodes will transmit based on the nodes set, which might be contention based depending on traffic conditions. Nodes will use their assigned slot whenever nodes want priority over their traffic and will otherwise work in contention-based mode.

Z-MAC (Zebra-MAC)
In Z-MAC [2] a node can be in one of the two modes: LCL (Low Level Contention) or HCL (High Level Contention). In LCL, any node can compete to transmit in any slot, but in HCL only the owners of the current slot and their one-hop neighbors are allowed to compete for the channel access. Hence lower collision. For neighbor discovery it uses DRAND [9], an efficient scalable channel scheduling algorithm to allot slots to nodes. A time frame is decided by the local framing and synchronization. A node which is assigned with a slot called “owner” and others are called “non owners” of that slot. A node can transmit in any of the time slots of Z-MAC but an owner node gets an advantage in accessing channel. Hence, when several nodes detect events and contend for the channel,
Z-MAC automatically behaves like TDMA, leading to much better higher channel utilization. It is robust to dynamic topology changes and time synchronization. It’s good for applications where expected data rates and two hop contentions are medium to high. However, it run global clock synchronization at the setup phase, which is complex and consumes lots of resources. Scalability is also an issue because of network wide deployment of TDMA schedule.

A-MAC (Asynchronous MAC)
A-MAC [1] aiming at providing collision-free, non-overhearing and less idle-listening transmission services. TDMA is considered as baseline MAC while CSMA is used to enhance the accessibility of a wireless channel. It allocates unique number of time slots within two-hop neighbors. Nodes are notified using advertisement period (ADV) where all the nodes broadcast their transmission schedules. Every node wake up during ADV period, while in other times only receiver/sender needs to be active for data transmission. With this method, energy wastage is avoided on overhearing and idle listening. Basically, A-MAC allocates each node a certain number of unique time slots within its two-hop neighbors. Nodes then make use of these pre-assigned time slots to transmit the data packets without interference with others, hence no collision. Only receiver nodes have to wake-up for the whole transmission time. This saves lot of energy of Wireless Sensor Networks. The nodes are notified in advance when they will be the receivers of packets. However, control packet overhead is large due to the advertisement of schedules. The latency is high due to the transition between two mechanisms.

TH-MAC
TH-MAC [3] is a traffic pattern aware MAC protocol inspired from Z-MAC, customized and improved for clustered sensor networks. It uses A-DRAND as slot assignment algorithm, an improved version of DRAND. Each node is assigned with one slot but at the same time it employs on-demand empty slot reassignment to allot more slots to cluster heads and coordinators. The time frame is divided into two parts: a reserved part and a non-reserved part. If a node is a normal sensor, it can only selects a slot from the non-reserved part which is not yet selected by none of its one-hop or two-hop neighbors. However, if the node is a cluster head or a coordinator, it can get a slot, not only from the non-reserved part but also from the reserved part. It improves channel utilization, throughput and energy efficiency. Slot reassignment does not influence existing slot allocation for cluster members and subjects little overhead. This approach has a benefit that only part of nodes and part of slot numbers need to be reallocated when the cluster head and coordinator changes.

CT-MAC (Contention-based TDMA MAC)
CT-MAC [4] is a contention-based TDMA hybrid protocol that based on a contention/doze and communication/dormancy duty cycle. The mechanism used is extended RTS/CTS handshake operates under the protocol interference model,

\[
\begin{align*}
\{ d(i, j) & \leq \gamma \\
(1 + \eta) \times d(i, j) & \geq d(k, j) \\
(1 + \eta) \times d(i, j) & > d(k, j)
\end{align*}
\]  

\( \text{for } \gamma, \eta > 0 \)

where \( d(i, j) \) denotes the Euclidean distance between node \( i \) and \( j \). The parameter \( \gamma \) denotes transmission range, and \( \eta > 0 \) models the situations where a guard zone is specified by the protocol to prevent a neighboring node from transmitting on the same sub-channel at the same time. Contention based on extended RTS/CTS scheme. The given frequency is divided into multiple channels to enhance channel utilization and reduces collisions. A node can send RTS even after overhearing RTS/CTS from other node if its intending transmission link is not interfered with that link. The node-pairs gained their intending channels will turn off the radios earlier to doze mode to save energy. It allows all nodes to enter into dormancy mode much earlier either because, no data transmission is expected to occur or for the reason that these nodes cannot transmit in that period under the restriction of the protocol interference model. Smart doze/dormancy mechanism reduces the energy consumption. It directly contributes to the improved network throughput. Extended RTS-CTS and distributed MNLS detection lowers the end to end delay. It can solve both the hidden and the exposed terminal problems, and hence greatly enhances the channel utilization.

HMAC (Hybrid MAC)
In HMAC or Hybrid MAC [5], time is organized into frames. Each frame contains multiple short wakeups slots and multiple data slots. It employs two basic procedures: self-organization for wakeup slot assignment and data transmission. Each node carrier sense in the beginning of each wakeup/data and chooses one wakeup slot. It notifies all its neighbors of the wakeup slot number. A sender must wake up the next-hop receiver using receiver’s wakeup slot before data transmission. Each sender randomly picks up a data slot for transmission and announces its slot number and the receiver’s ID. A slotted frame structure together with a wakeup mechanism helps to improve energy efficiency, reduces the event latency and collisions when the traffic load increases. It is simple and scalable since each node only needs one-hop information. Slots used for data transmission can be shared by the nodes on-demand basis, which significantly increases the channel utilization.

HyMAC
HyMAC [6] is a hybrid TDMA/FDMA MAC protocol. The communication period comprises of a Firefly based hardware synchronization is used. Scheduled node communicates in an energy-efficient collision free manner turning off its radio when it is not necessary. Each node randomly selects one slot to send a HELLO message to the base station. On the other hand, all of the unscheduled nodes like the ones which have just joined the network only operate in contention slots sending the HELLO message in a similar way. Consequently, every node will be able to send DATA messages to its parent using its assigned slot and frequency in a way that maximizes the network throughput and minimizes the overall uplink delay. HyMAC is the first sensor-net MAC protocol that schedules the network nodes in a way that eliminates collisions and provides small bounded
end-to-end delay and high throughput. However, it requires hardware based costly synchronization.

**IEEE 802.15.4**
IEEE 802.15.4 [7] is a hybrid protocol for low-rate Wireless Personal Area Networks (LWPAN). It can have two modes: beacon-enabled and non-beacon-enabled mode. In the former mode, nodes use unslotted CSMA/CA for transmitting frames, while the slotted CSMA/CA is used in the beacon enabled mode. A superframe structure is used in beacon-enabled mode, which is bounded by beacon transmissions from the coordinator [10]. It comprises of an active part and an optional inactive part. The active part has further divided into CAP (Contention Access Period) and CFP (Contention Free Period).

To access the channel, two CCAs (Clear Channel Assessment) will be done in two successive back off periods to assure the channel is completely idle. If both CCAs report that the channel is idle, packet transmission may begin in CAP or a node can request for GTS allocation by sending a request GTS request command. Due to its GTS allocation scheme, it provides fairness in transmission but with a low arrival rate that has allocated a GTS (Guaranteed Time Slots) may only partially use it. This leads to under utilization of the GTS bandwidth resources. IEEE 802.15.4 is low cost and low power consumption due to its duty cycle controlling scheme. However, deferred transmissions reduce the utilization of the medium. It also suffers from collision problem, Congestion of data requests, and collision of data requests with deferred transmissions several fixed time slots. In each cycle, the beginning slots are scheduled slots and remaining slots are contention slots.

**EQ-MAC**
EQ-MAC [8] is quality of service and energy aware hybrid MAC protocol. It differentiates between short and long messages; long data messages are assigned scheduled TDMA slots (only those nodes, which have data to send are assigned slots), while short-periodic control messages are assigned random access slots. This technique limits message collisions. First it chooses cluster heads on the basis of clustering algorithm [13]. The channel access is composed of two sub-protocols: Classifier MAC (C-MAC) [14], and Channel Access MAC (CA-MAC) [15]. C-MAC classifies packets based on their importance and stores them into the appropriate queue. The source node knows the degree of importance of each data packet it is sending, which can be translated into predefined priority levels. CA-MAC provides scheduled slots with no contention (based on TDMA) for data messages and random access slots (based on CSMA/CA) for periodic control messages. The protocol gives higher priority to process the real time traffic, and assigns any remaining slots to the non-real-time traffic. EQ-MAC enables access to channel, only to those nodes which have a data to transmit to according to their traffic priority levels; this avoids wasting slots by excluding those nodes which have no data to transmit from the TDMA schedule.

**ER-MAC (Emergency Response MAC)**
ER-MAC [27] adopts a TDMA approach to schedule collision-free slots. Nodes only wake up for their scheduled slots, else switch into sleep mode for power saving. It constructs a tree using a simple flooding mechanism. During topology discovery setup a routing tree to find neighbors as well as to track changes in the tree. The base station generates a TOPOLOGY_DISCOVERY message, which consists of hop_count, new_parent_id and old_parent_id. Each node records its hop count to the base station, its parent ID, a list of its children and its one-hop neighbor list. Uses bottom-up approach for TDMA slot assignment, so as to flow of communication towards base node. ER-MAC manages local time synchronization using parent-children broadcast synchronization similar to the root-neighbors synchronization of FTSP [11]. When an event of interest occurs, nodes that participating in the emergency/real-time monitoring change their MAC behavior by pushing contention in TDMA slots to achieve high delivery ratio. ER-MAC offers a synchronized and loose slot structure to allow nodes to join or leave the network. It consumes less energy because the owner of the slot does not need to contend to access the channel. It is flexible to adapt traffic and topology changes. Good for emergency WSN applications. It provides higher delivery ratio with lower energy consumption. It has synchronized and loose slot structure. However, it is not scalable for large density.

<table>
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<tr>
<td>ER-MAC</td>
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<td>Low</td>
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</tbody>
</table>

Table 1. Hybrid Energy Efficient Mac Protocols
CONCLUSIONS
Due to sensor nodes mostly supported by battery with constrained power, energy efficiency is crucial for applications of WSN, and the MAC protocol is the major determining factor in WSN energy performance. So how to design an energy efficient MAC protocol is an important issue. In this paper, it has been discussed the hybrid MAC protocols integrating the two kind of mechanisms are better in energy efficiency than pure MAC using single mechanism. However hybrid MAC protocols are usually complex in transition mechanisms between contention-based and TDMA-based, in addition, these protocols are usually complex in implementation. However, hybrid method could significantly increase the design complexity and diminish the disadvantages of conventional methods so it needs extensive research. Nowadays with WSN applications and hardware evolving rapidly, how to achieve better energy efficiency in MAC for WSN is still a critical issue and need more research.

REFERENCES
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