A Comparative Study on AS-MAC and Crankshaft: The MAC Layer Protocols for Wireless Sensor Network

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ABSTRACT
Wireless Sensor Networks (WSN) is an emerging area of research in the field of wireless communication [1]. WSN applications include environmental monitoring, industrial process monitoring and target detection and tracking in an enemy terrain and many more. Though it has wide range of application domain, the basic constraint i.e. the power constraint of WSN still remains a challenge and a potential field of research.

MAC layer protocols play an important role in energy conservation. Being affected by the physical layer and providing services to the upper layer, many MAC protocols has been proposed for the smooth operation and to help reduce energy utilization in WSN. Many of these protocols are either contention based i.e. CSMA (Carrier Sense Multiple Access) or reservation based i.e. TDMA (Time Division Multiple Access). This paper compares two MAC layer protocols i.e. AS-MAC and Crankshaft with their characteristics and behaviors in the WSN environment. The comparative study presented in this paper may be used to find out the best suited MAC protocol for Wireless Sensor Networks.

Keywords
Sensor network, energy, CSMA, TDMA, MAC Layer.

1. INTRODUCTION
The recent developments in computing, communication and sensing technologies when merged together for environment monitoring using wireless media is known as Wireless Sensor Network (WSN) [1]. A WSN is generally formed by densely deploying the sensor nodes at the target application area. The application area of sensor network viz., environment monitoring, habitat monitoring, industrial process monitoring, target detection and tracking in an enemy terrain etc. The effectiveness of these application depends on reliability and efficiency of services that it performs for the WSN model. MAC layer acts as a backbone for providing the reliability and efficiency service to the WSN [1, 2, 6, 12, 13, 14, 15].

MAC layer is the layer which resides immediately above the physical layer and acts as a part of data link layer. The basic function of the MAC layer is to regulate the access to the shared channel among the sensor nodes. In other words, the duty of the MAC layer is to ensure that not a single node undergoes channel starvation. MAC layer protocols are responsible for channel access policies, scheduling, and buffer management [4, 12, 14].

WSN MAC layer protocol designers faced many challenges for designing MAC protocol especially while considering the energy management. The replacement of the sensor node battery which gets exhausted after deployment is almost impossible. Under this situation, it is important to develop MAC protocols which utilize the energy efficiently and reduce the wastage of sensor energy. Thus, WSN MAC protocols should be smart enough to conserve as much energy as possible during its tenure [3, 13, 14].

A good MAC protocol considers energy efficiency [4, 12, 13, 14, 15] and avoids redundant power consumption to preserve long lifetime of sensor node in the network. The following section mainly focuses on the reasons behind the energy wastage. The rest of the paper is organized as follows.section 3 reflects various classes of MAC protocols and section 4 describes AS-MAC protocol in detail with its functionalities. Section 5 focuses on working principle of Crankshaft protocol followed by comparative study in section 6. Finally section 7 concludes the paper.

2. REASONS OF ENERGY WASTAGE
In WSN it is almost impossible to change or replace exhausted batteries. The primary objective of a WSN is maximizing network lifetime by preserving energy resources. This is possible by minimizing unnecessary network communication while achieving the desired network operation.

The energy usage is not critical in wireless communications where dedicated power sources are present, but in battery powered WSNs, it is not acceptable as it severely decreases network lifetime.

Maximum sensor energies are wasted at medium access communication [4]. The following factors are responsible for energy wastage in MAC layer.

2.1 Collision
Network Collision [1, 4, 6] occurs, when more than one node transmit packets simultaneously using same channel then the packets are collided. Subsequently packets are dropped and senders of these packets retransmit the packets again. These retransmissions provide no guarantee of future collision of these packets, which leads to a lot of energy wastage. To solve this kind of collision issues, early MAC protocols adopted technique called duty cycling. In duty cycling a radio signal is placed in a low power sleep state when sensor nodes are not sending or receiving transmissions. Most of the modern MAC protocols also use this technique in a smarter way.

2.2 Over hearing
It is the situation where a node receives a packet which is intended for some other node [4, 5, 14]. In such a case the unnecessary transmission claims some extra pulse of energy.

2.3 Over emitting

This is also another reason of energy wastage in WSN which is caused by the transmission of a message when the destination node is not ready [6, 7].

2.4 Control Packets transmission

Many MAC layer protocols transmit control packets [2, 3] before actual data transmission. These control packets also leads to the wastage of energies.

2.5 Idle Listening

Idle Listening is a state where a sensor node continuously probes the idle channel when no transmission is occurring [2, 6, 10]. This continuous probing uses extra amount of energy.

3. CLASSES OF MAC PROTOCOLS

All the MAC protocols are classified into two broad categories viz contention based and reservation based depending on how they access a shared channel.

3.1 Reservation Based MAC Protocols

This approach requires network topology knowledge. This helps to establish a schedule for each node to access the channel and communicate with other nodes. The schedule may have various goals such as ensuring fairness among nodes, reducing collisions, more access to the channel and transition at the same time. TDMA [6] (Time Division Multiple Access) is a representative scheme for reservation based approach.

In TDMA, time is divided into frames and each frame is divided into slots. During a frame, each node is assigned a unique slot during which it has the right to transmit. As a consequence, transmissions do not suffer from collisions, and guarantees finite and predictable scheduling delays. This also increases the overall throughput in highly loaded networks. TDMA schemes ensure fairness among nodes, as each node is assigned a unique slot in each frame.

Although TDMA schemes have many interesting features, they have some disadvantages i.e., their dependency on network topology and time synchronization. Asynchronous Schedule MAC protocol (AS-MAC) is one of the Reservation based MAC protocols, the details of which are discussed in detail in section 4.1.

3.2 Contention Based MAC Protocols

This approach is fairly simple as compared to reservation-based protocols, mainly because neither global synchronization nor topology knowledge is required. In a contention-based approach, nodes compete for the use of the wireless medium. The winner of this competition is allowed to access to the channel and transmit [6, 10]. CSMA (Carrier Sense Multiple Access) [6] are representative schemes of contention-based approaches.

In CSMA, for instance, a node having a packet to transmit first senses the channel before actual transmitting. Whenever, the node finds the channel busy, it postpones its transmission to avoid interfering with the ongoing transmission. If the node finds the channel clear, it starts transmitting (after possibly having waited a random time). CSMA does not rely on a central entity and is robust to node mobility. This characteristic makes it a good choice for networks with mobility and dynamicity [6, 9].

4. AS-MAC

The Asynchronous Scheduled MAC Protocol [7, 8], tries to reduce overhearing. This is done by assigning unique different time slots to nodes in which they listen for packets. As per the AS-MAC specification each node stores synchronization information about all of its neighbor's nodes in the network. This information determines when a node should wakeup for transmission or to receive packets.

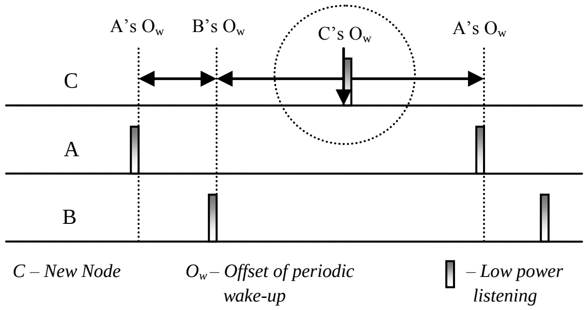

Figure 1: Choosing a Wake-up Slot in AS-MAC [8]

4.1 Functions of AS-MAC Protocol:

- In this architecture, MAC protocol is divided into two phases; the initialization phase and the periodic listening & sleep phase.
- During the initialization phase, a node listens for a pre-determined amount of time for "hello" packets, which contains neighbor's information.
- The neighbor's information includes the wake-up interval, the hello packet interval for that neighbor, and the wake-up offset for that neighbor.
- New node after listening for neighbor's hello packet completely, builds a table from the received information. Then it determines a unique wake-up offset for it. It then transmits this offset to all of its neighbors.
- After wake-up offset, the node enters the periodic listening and sleep phase.
- A node periodically wakes up in its given interval also called hello interval, and performs a Low power Listening (LPL) to detect an incoming message.
- If the node detects a busy channel, it then starts listening for an incoming message. On the other hand, the receiving nodes transmit the hello packet before receiving a message.
- In order to send data the senders must be aware of the time when the receiver is transmitting a hello packet. The scenario is depicted in Figure 2.

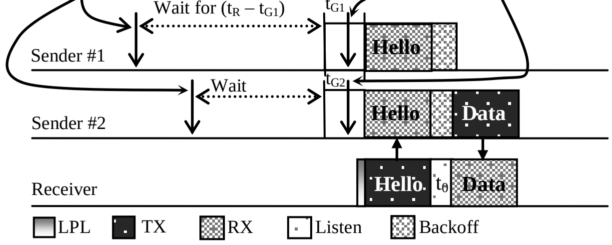

Figure 2: Transition of data in AS-MAC at Hello Time [8]

In Figure 2, both the senders, sender I and sender II wish to transmit to a single receiver. The receiver wakes up at its scheduled time and transmits a hello packet, which is received by both the senders. The senders then contend for the channel exclusively, and if for an example, the second sender gets an exclusive right to the channel, it transmits its data to the receiver.

The major disadvantage associated with AS-MAC is the memory overhead for maintaining a neighbors' table. In a dense network, maintaining neighbors' table claims a huge amount of overhead. Another disadvantage of this protocol is the transmision of hello packets. Although this approach permits new nodes to enter the network dynamically, however the non application related hello packets claims extra amount of resources such as energy and bandwidth. In addition to this inefficiency in broadcasting messages is also noted in AS-MAC. It is because each neighbor has a unique wake-up time, a node wishing to send information to all of its neighbors must send individual messages to each neighbor. This makes broadcasting more expensive as the density of the network increases.

5. CRANKSHAFT

The basic drawback of the AS-MAC protocol leads to the development of Crankshaft MAC protocol. The Crankshaft protocol [6, 8, 11] aims to reduce overhearing of neighboring nodes in a dense network, which is an important cause of inefficiency of AS-MAC protocol in dense network. The basic principle of the protocol is that nodes are awake to receive messages only at fixed offsets from the start of a frame.

5.1 Functions of Crankshaft Protocol:

- The Crankshaft protocol divides time into frames, and each frame is divided into slots. Slots further divided in broadcast slots and unicast slots.
- During a broadcast slot all nodes wake up to listen for an incoming message. Any node that has to broadcast message contends with all other nodes to send their message. A frame starts sending message with all the unicast slots, followed by the broadcast slots.
- Each node also listens for one unicast slot of every frame. During that slot a neighboring node can send a message to that listener node, provided it wins the contention. The MAC address of the receiver node determines the slot that it listens to [6, 8, 10, 11]. Therefore, before sending any messages a sender node must knows precisely in which slot the receiver wakes up. This protocol uses a Data/Ack sequence for unicast messages, and the slot length is long enough for the contention period, maximum-length data message and acknowledgement message [8].

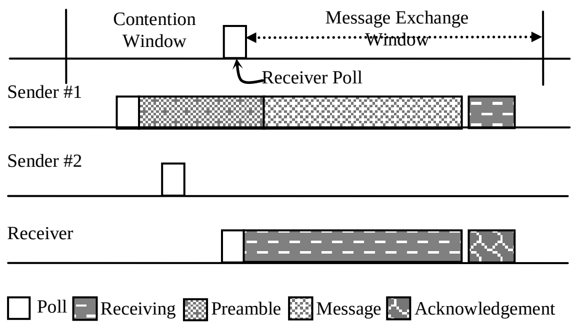

Figure 3: Contention and Message Exchange in Crankshaft [9]

A node acts as a sender as well as to receiver if it loses contention for sending data.

In crankshaft, synchronization is used to achieve better energy efficiency. The nodes need not wake up for the whole slot, but only for a small time at a fixed offset from the start of the slot (Figure 3). The intermediate period between the start of the slot till the moment a node starts listening, the radio is turned off to resolve contention. A node chooses a moment in the contention window, to send a message in a particular slot. The sending node listens for a short amount of time just prior to its selected moment to detect other nodes contending for the same slot. If no other nodes are transmitting, the sending node starts transmitting a preamble to notify other nodes of its intention to send. As soon as the receiving node is known to wake up, the sending node transmits the start symbol and then the actual message.

6. COMPARISON & ANALYSIS

AS-MAC differs from Crankshaft in the following number of ways -.

- In AS-MAC, there are no broadcast slots, and this makes broadcasting inefficient whereas Crankshaft has a sufficient amount of broadcast slots for dense sensor networks.
- The number of unicast slots in Crankshaft is also programmable, which is independent on the number of nodes in the network. This means that depending on the number of unicast slots provisioned, it is possible for the multiple receivers to wake up during the same slot, which is not possible in AS-MAC [6, 8, 9].
- The major difference between Crankshaft and AS-MAC is the absence of a time synchronization mechanism in Crankshaft. AS-MAC uses hello packets for introducing new nodes into a network as well as to align node clocks [6,8,9].
- Crankshaft has no special provisioning for clock alignment, and instead relies on an upper layer to manage this [6,9,11].
- The Crankshaft protocol introduces MAC layer acknowledgments, functionality which is not introduced in AS-MAC.

Table 1. Summary of comparison of AS-MAC & Crankshaft

Parameters	AS-MAC	Crankshaft
In dense network	Performance degrades.	Performs consistently well
Multiple receiver wakeup	Not Possible	Possible
Time Synchronization Mechanism	Present	Absent
Broadcast Slot	No Broadcast Slot	Sufficient number of broadcast slot
MAC layer acknowledgement functionality	Absent	Present
Time Division	Frames	Frames and slots

It is clear from the above set of comparisons given in Table 1 that Crankshaft protocol out performs AS-MAC protocol in many ways.

7. CONCLUSION

This paper presents a comparative study of two MAC layer protocols in Wireless sensor networks. The MAC protocols viz AS-MAC and Crankshaft are compared with respect to various parameters such as the number of broadcast slots and unicast slots, time synchronization mechanism, clock alignment and MAC layer acknowledgement. It has been observed that Crankshaft out performs AS-MAC in almost all respects. It is also seen that the protocols based on preamble sampling consume lesser energy. The advantages and disadvantages of these two protocols in scenario of high and low traffic are also discussed. Such analysis may help to configure the network as per the user requirements.

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