MAC Layer Protocols for WSN-Comparison and Performance Improvement Strategy

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Abstract—*In this paper authors have elaborated on objective of MAC protocol, energy efficiency of MAC protocol and comparison of MAC layer protocols such as S-MAC and D-MAC for WSNs. The primary goal of the S-MAC design is to improve energy efficiency while maintaining good scalability and collision avoidance. To achieve this goal, S-MAC tries to reduce energy consumption from all the major sources that causes inefficient use of energy. D-MAC protocol was proposed to address the data forwarding interruption problem in multihop data delivery and its primary goal is to achieve both energy efficiency and low latency. Authors have tried to explain how D-MAC is more energy efficient than S-MAC and also elaborated on how performance of D-MAC can be improved using single or multiple mobile element based data gathering Technique.*

Keywords*: Energy efficiency, Energy consumption, Data forwarding interruption, Data gathering.*

1. INTRODUCTION

a. Wireless Sensor Networks (WSN)

Wireless Sensor Networks (WSNs) have been widely considered as one of the most important technologies for the twenty-first century [1]. Enabled by recent advances in micro electronic mechanical systems (MEMS) and wireless communication technologies, tiny, cheap, and smart sensors deployed in a physical area and networked through wireless links. A WSN typically consists of a large number of low-cost, low-power, and multifunctional sensor nodes that are deployed in a region of interest. These sensor nodes are small in size, but are equipped with sensors, embedded microprocessors, and radio transceivers, and therefore have not only sensing capability, but also data processing and communicating capabilities. They communicate over a short distance via a wireless medium and collaborate to accomplish a common task, for example, environment monitoring, battlefield surveillance, and industrial process control.

2. OBJECTIVES OF MAC DESIGN

The basic function of a MAC protocol is to arbitrate access to a shared medium in order to avoid collisions from different nodes. In addition to this basic function, a MAC protocol must also take into account other factors in its design in order to improve network performance and provide good network services for different applications. In WSNs, these mainly include energy efficiency, scalability, adaptability, channel utilization, latency, throughput, and fairness [2].

a) **Energy Efficiency***:* It refers to the energy consumed per unit of successful communication. Since sensor nodes are usually battery powered and it is often very difficult or impossible to change or recharge batteries for sensor nodes, a MAC protocol must be energy efficient in order to maximize not only the lifetime of individual sensor nodes, but also the lifetime of the entire network.

b) **Scalability:** Scalability refers to the ability to accommodate the change in network size. In sensor networks, the number of sensor nodes deployed may be on the order of tens, hundreds, or thousands. A MAC protocol must be scalable to such changes in network size.

c) **Adaptability:** Adaptability refers to the ability to accommodate the changes in node density and network topology. In sensor networks, node density can be very high. A node may fail, join, or move, which would result in changes in node density and network topology. A MAC protocol must be adaptive to such changes efficiently.

d) **Channel Utilization***:* Channel utilization refers to the bandwidth utilization for effective communication. Due to limited bandwidth, a MAC protocol should make use of the bandwidth as efficiently as possible.

e) **Latency:** Latency refers to the delay from the time a sender has a packet to send until the time the packet is successfully received by the receiver. In sensor networks, the importance of latency depends on different applications. While it is true that latency is not a critical factor for some applications

f) **Throughput:** Throughput refers to the amount of data successfully transferred from a sender to a receiver in a given time, usually measured in bits or bytes per second. It is affected by many factors, for example, the efficiency of collision avoidance, control overhead, channel utilization, and latency.

Like latency, the importance of throughput depends on different applications. Among all these factors, energy efficiency, scalability, and adaptability are the most important for the MAC design of sensor networks.

3. ENERGY EFFICIENCY IN MAC DESIGN

Energy efficiency is of primary importance in WSNs. In general, energy consumption occurs in three aspects: sensing, data processing, and data communication, where data communication is a major source of energy consumption. Sensor node consumes 3 Joule of energy to transmit 1-Kb data over a distance of 100 m [2]. For this reason, it is desired to reduce data communication as much as possible in a sensor network. Thus, sensor nodes can use their processing capability to locally perform simple data processing, instead of sending all raw data to the sink(s) for processing, and then transmit partially processed data to the sink(s) for further processing. On the other hand, an efficient MAC protocol can improve energy efficiency in data communication and prolong the lifetime of a sensor network. To design energy-efficient MAC protocol, it is important to identify the major sources of energy waste in sensor networks from the MAC perspective. Energy waste comes from four major sources: collision, overhearing, control overhead, and idle listening [3].

a) **Collision:** Collision occurs when two sensor nodes transmit their packets at the same time. As a result, the packets are corrupted and thus have to be discarded .Retransmissions of the packets increase both energy consumption and delivery latency.

b) **Overhearing:** Overhearing occurs when a sensor node receives packets that are destined for other nodes. Overhearing such packets results in unnecessary waste of energy and such waste can be very large when traffic load is heavy and node density is high.

c) **Idle Listening***:* Idle listening occurs when a sensor node is listening to the radio channel to receive possible data packets while there are actually no data packets sent in the network. In this case, the node will stay in an idle state for a long time, which results in a large amount of energy waste.

d) **Control Overhead:** A MAC protocol requires sending, receiving, and listening to a certain necessary control packets, which also consumes energy not for data communication.

4. MAC PROTOCOLS FOR WIRELESS SENSOR NETWORKS

MAC protocols for WSNs, including contention-based protocols, contention-free protocols.

1) Contention-Based Protocols

Contention-based MAC protocols are S-MAC and D-MAC for WSNs.

A. Sensor-MAC (S-MAC)

The sensor-MAC (S-MAC) protocol proposed by Ye et al is an energy-efficient MAC protocol specifically designed for WSNs. The primary goal of the S-MAC design is to improve energy efficiency while maintaining good scalability and collision avoidance. To achieve this goal, S-MAC tries to reduce energy consumption from all the major sources that cause inefficient use of energy. But the drawback is, it allows some performance degradation in latency. To reduce idle listening, S-MAC introduces a periodic listen and sleep mechanism to establish a low-duty-cycle operation on each node. With this mechanism, each node is periodically put into a sleep state for some time, and then wakes up and listens to see if it needs to communicate with any other node. A complete cycle of listen and sleep periods is called a frame. Each frame begins with a listen period, during which a node can communicate with the other nodes, followed by a sleep period, during which a node sleeps if it has no data to send or receive, or remains awake if it has data to send or receive, as shown in Fig.1. A duty cycle is defined as the ratio of the listen duration to the whole duration of a frame. The listen period is further divided into smaller intervals for sending or receiving SYNC, RTS, and CTS packets. The duration of the listen period is normally fixed depending on physical-and MAC-layer parameters, for example, the radio bandwidth and the contention window size. The duration of the sleep period can be changed according to different application requirements, which actually changes the duty cycle. To reduce control overhead, however, neighboring nodes coordinate their sleep schedules and try to adopt the same schedules to listen and sleep, rather than randomly sleep on their own. To establish coordinated or synchronized sleep schedules, each node exchanges its schedule with other nodes by periodically broadcasting a SYNC packet to all its immediate neighbors and maintains a schedule table that stores the schedules of all its known neighbors for listening and sleeping.

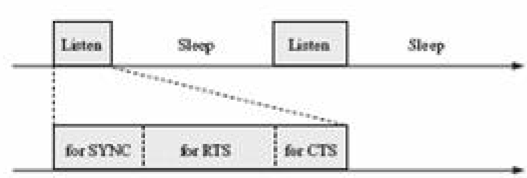

Fig. 1: Periodic listen and sleep in S-MAC[17]

The SYNC packet is very short and contains the address of the sender and the next sleep time of the sender. The collision avoidance mechanism used in S-MAC is similar to that in the IEEE 802.11 DCF [3]. To avoid collision, S-MAC uses the RTS/CTS mechanism to address the hidden terminal problem.

B. Dynamic-MAC

D-MAC is an energy-efficient and low-latency MAC protocol by Lu et al. [4] for data gathering in WSNs. This protocol was proposed to address the data forwarding interruption problem in multihop data delivery and its primary goal is to achieve both energy efficiency and low latency. To deliver data from a source sensor node to the sink through a multihop path, most MAC protocols that use active-sleep duty cycles (e.g., S-MAC) suffer from a data forwarding interruption problem, where some nodes on the multihop path cannot be aware of the on-going data delivery. For example, in an implicit duty-cycle adjusting mechanism, a node remains active when it overhears ongoing transmissions in the neighborhood [5]. Since the overhearing range of a node is limited by its radio sensibility, a node that is out of the overhearing range of both the sender and the receiver of a data transmission cannot be aware of the ongoing data transmission and thus goes to sleep until the next cycle. As a result, the data forwarding process will be interrupted at a node whose next hop toward the sink is out of the overhearing range. The data packet has to wait in the queue until the next active period, resulting in sleep latency. For an explicit duty-cycle adjusting mechanism, it uses duty-cycle adjusting messages to directly adjust the duty cycle. Since the adjusting messages can only be forwarded a limited number of hops in an active period, a node out of the range goes to sleep after its basic duty cycle, leading to the interruption of the data forwarding as well. To address this problem, D-MAC employs a staggered wakeup schedule to enable continuous data forwarding on a multihop path. In WSNs, the primary traffic is for data gathering from sensor nodes to a sink. The data delivery paths from multiple sources to one sink constitute a data gathering tree, in which flows are unidirectional and all nodes except the sink forward the packets they receive to the next hop. To enable continuous data forwarding on a multihop path, D-MAC staggers the schedule of the nodes on the multihop path and allows the nodes to wake up sequentially like a chain reaction, as shown in Fig.1. In the schedule, an interval is divided into three periods (or states): receiving, sending, and sleeping

1. In the receiving period, a node is expected to receive a packet and send an ACK packet back to the sender.
2. In the sending period, a node tries to send a packet to its next hop and receive an ACK packet.
3. In the sleeping period, a node turns off its radio to save energy.

The receiving and sending periods have the same length of μ, which is long enough for transmitting and receiving one packet.

Depending on its depth d in the data gathering tree, a node sets its wake-up schedule ahead from the schedule of the sink. With the operation like a multihop chain, each node periodically goes into the receiving, sending, and sleeping states. As a result, when there is no collision, a packet will be forwarded sequentially along a multihop path to the sink without sleep latency. However, when a node has multiple packets to send at a sending slot, it needs to increase its own duty cycle, and has to request other nodes on the multihop path to increase their duty cycles as well. For this purpose, D-MAC employs a slot-by-slot renewal mechanism, where a more data flag is piggybacked in the MAC header to indicate the request for an additional active period with little overhead. Before a node transmits a packet, it first sets the more data flag in the packet if either its buffer is not empty or it received a packet with a more data flag from its previous hop. The receiver will check if the more data flag is set in the received packet, and if the flag is set, it will also set the more data flag of its ACK packet to the sender. With this slot-by-slot renewal mechanism, D- MAC can adaptively adjust the duty cycles to the traffic load. In addition, D-MAC employs a data prediction mechanism to solve the problem when each single source has a traffic rate low enough for the basic duty cycle to handle, but the aggregated rate at an intermediate node is larger than the basic duty cycle can handle. When multiple children of a node have packets to send in the same sending slot, data prediction is used to request active sending slots. When multiple nodes on the same level of the data gathering tree with different parents compete for the channel, the data prediction mechanism is unable to handle the interference. In that case, an explicit control packet called More-to-Send packet is used to adjust the duty cycle under the interference.

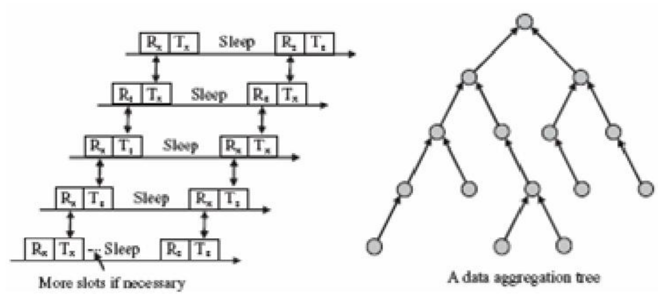

Fig. 2: An aggregation tree in D-MAC[18]

5. SUMMARY AND FUTURE DIRECTIONS

Medium access control plays an important role in improving energy efficiency and network performance of WSNs. In this paper a comparison has been made between both S-MAC and D-MAC and it shows that D-MAC is more energy efficient than S-MAC.

In future one can make use of single mobile or multiple mobile element based data gathering techniques to further improve energy efficiency of D-MAC by providing scalability, incorporating elimination of redundant data, elimination of buffer overflow and by making sensor nodes collaborate with each other in an energy-efficient manner to enhance the network lifetime.

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