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Abstract

Wireless sensor nodes are made up of small electronic devices which are capable of sensing, computing and transmitting data from harsh physical environments. These sensor nodes depend on batteries for energy, which get depleted at a fast rate because of the computation and communication operations these nodes have to perform. A well designed MAC (Medium Access Control) protocol can prolong the network life. A set of previously reported MAC layer protocols has abilities to achieve some energy efficiency. In this paper, we first describe some assumptions made for the specific application area of surveillance applications. Then, we compare a set of MAC protocols in terms of their suitability to be used in wireless sensor networks for this type of applications. In addition to energy efficiency, keeping the delays reasonably low is a crucial factor when sensing and reporting an event.

Keywords – *Wireless Sensor Networks, MAC protocols, real-time communication, Quality of Service, energy-awareness.*

1. Introduction

Advances in wireless communication made it possible to develop wireless sensor networks (WSNs) consisting of small devices, which collect information by cooperating with each other. Today, WSNs are more and more used in the commercial and industrial areas for e.g. environmental monitoring, habitat monitoring, healthcare, process monitoring and surveillance. Sensing and processing activities or communication with other nodes consumes a lot of energy. In many cases (e.g. in surveillance applications), it is undesirable or impossible to replace the batteries that are depleted of energy. In WSNs, the primary objective is to increase the network lifetime while keeping delays reasonably low. Many researchers are working on the development of power-aware protocols for WSNs in order to overcome energy efficiency problems. The combination of energy-awareness and Quality of Service (QoS) support, on the other hand, is not that well studied yet.

In this paper we are focusing on MAC protocols for surveillance applications. In section 2 we discuss the assumptions or requirements of surveillance applications. Further, in section 3, we talk about the reasons of energy waste. Furthermore, in section 4, we explain the MAC protocols and their performance in surveillance applications based on factors like energy awareness, QoS and latency. The conclusions from the survey are summarized in Table 1, and motivated in the protocol descriptions. We conclude the survey in section 5.

2. Surveillance Applications - Assumptions

In this paper, we make some assumptions for surveillance applications in WSNs, which are used as a reference frame in the further study.

- WSNs consist of a number of sensing nodes which are distributed in a wide area, according to the requirements of the application.
- The base station (sink), which collects data from other nodes, interacts with a user (someone interested in monitoring the activity). Sinks have more advanced features than sensing nodes in terms of data transmission and processing capabilities, memory size and energy reserves. There can be multiple sinks for a network so that there is no single point of failure.
- Energy dissipation is a major factor in WSNs during communication among the nodes. Energy should be saved, so that the batteries do not get drained quickly as these are not easily replaceable in a typical surveillance scenario.

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Table 1. Comparison of MAC protocols

Protocols	Energy Awareness			Contention based or Contention free	Quality of Service Support	Control Packet		Latency
	Low	Moderate	High			Required	Not Required	
SMAC	Low due to fixed duty cycle			Contention based	Low due to fixed duty cycle	Control Packet is required		High due to fixed duty cycle
TMAC	High when there is variation in traffic			Contention based	Decreases in heavy traffic	Required		Increases when traffic load is high
TEEM	High when traffic load is low			Contention based	Better when network is small	Required when any node wants to communicate		Increases in multi- hop networks
DEMAC	Low in high traffic			Contention free	Decreases in dense network	Control packet is required to elect the leader		Increases in high traffic
PACT	Moderate in large networks			Contention free	Improves QoS through passive clustering	Control packet is required to elect gateways and cluster heads.		Communication delay is reduced by using passive clustering
LMAC	Energy efficiency is low			Contention free	Provides low QoS	Control packet is required		Increases because a node has to wait for its time slot

- QoS tries to ensure efficient communication within bounded delays. Protocols should check for network stability and redundant data can be transmitted to increase reliability. It is also necessary to maintain certain resource limiting factors, such as bandwidth, memory buffer size and processing capabilities.
- The transmission mode plays an important role in WSNs. Nodes can take a single-hop or multi-hop path depending upon the type of network topology chosen for transmitting data to other nodes in the network.
- The sensor nodes can be mobile or static depending on the application.
- In surveillance applications, sensor nodes are often placed in unattended areas. Therefore, the network should be self-organizing and self-creating.

3. Reasons of Energy Waste

In WSNs, each sensor node can be in active (for receiving and transmission activities), idle or sleep mode. In active mode, nodes consume energy when receiving or transmitting data. In idle mode, the nodes consume almost the same amount of energy as in active mode, while in sleep mode, the nodes shut down the radio to save energy. A node's main waste of energy is due to the following factors [1].

- **Collision:** Collision can occur when two nodes transmit data at the same time and interfere with each other's transmission.
- **Idle Listening:** A node wastes its energy when it is listening to an idle channel waiting for traffic.
- **Overhearing:** A node wastes its energy if it hears a packet which is not destined for it.

- **Overmitting:** The energy can be wasted if a node sends data and the destination node is not ready to receive.
- **Protocol Overhead:** The contention-based protocols waste energy because nodes use control packets (RTS, CTS, ACK) before sending the data.
- **Traffic Fluctuation:** The fluctuations of the traffic load can lead to the waste a node's energy reserves. Therefore, the protocol should be traffic adaptive.

4. MAC Protocols and Their Performance in Surveillance Applications

A properly designed MAC protocol allows the nodes to access the channel in a way to save energy and support QoS. Here we will discuss MAC protocols by keeping in mind the surveillance assumptions explained above. The conclusions from the survey are summarized in Table 1, and motivated in each protocol description below.

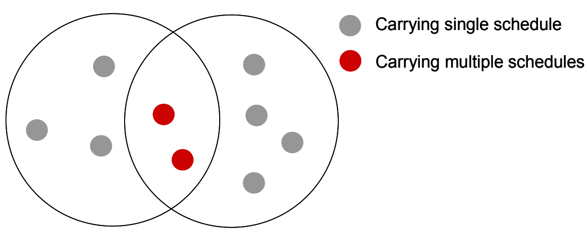

Figure 1: Virtual cluster.

Sensor-MAC (SMAC)

The SMAC protocol [2] uses periodic listening and sleeping schemes to prolong the network lifetime. In SMAC, nodes use 'sync' packets to exchange their schedules.

The neighbouring nodes build virtual clusters to reduce the communication delay (see Figure 1). In a virtual cluster, nodes have the same schedule and the nodes which exist in more than one cluster carry multiple schedules. Due to the different schedules, the probability of wake-up of these nodes becomes higher than for other nodes which results in energy wastage.

SMAC uses a fixed duty cycle, but in surveillance applications the occurrence of events can vary. Due to the fixed duty cycle, a node will consume most of its energy in idle state when the traffic load fluctuates. If we change the duty cycle with respect to high traffic load and the network experiences low traffic load, the node will waste its energy in idle listening (see Figure 2). While on the other hand, if we adapt the duty cycles to low traffic load and the traffic load then increases, the communication delay will increase too, which leads to a decrease in QoS. The protocol is most suitable when the traffic load remains constant.

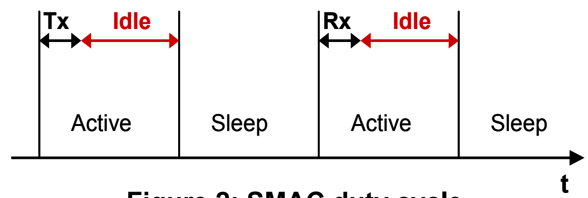

Figure 2: SMAC duty cycle.

Timeout-MAC (TMAC)

As stated above, the SMAC protocol does not work well when the traffic load fluctuates. To overcome this problem, the TMAC protocol [3] introduces the time-out value to finish the active period of a node (see Figure 3). If a node does not hear anything within the period corresponding to the time-out value, it allows the node to go into sleep state.

TMAC follows the SMAC protocol in terms of synchronization and virtual clustering schemes. The TMAC protocol solves the early sleeping problem, introduced in SMAC, using two methods: *"Future Request To Send"* (FRTS) and *"Taking Priority on Full Buffers"*. The performance of TMAC in surveillance applications is better compared to SMAC when there is fluctuation in traffic loads. In TMAC, the nodes send their queued packets at the beginning of each frame which increases the traffic load. At high traffic loads, the transmission suffers from delay and network QoS decreases because multiple nodes try to access the channel and the loosing nodes have to wait for the entire frame.

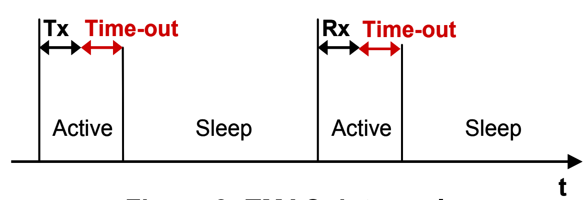

Figure 3: TMAC duty cycle.

Traffic Aware Energy Efficient MAC (TEEM)

TEEM [4] uses the same technique to save energy as used in SMAC but instead of a fixed duty cycle, it makes the duty cycle adaptive according to the traffic information. The SMAC protocol divides the listen period into three parts Sync, RTS and CTS, while in

TEEM, the listen period consists of *Syncdata* and *Syncnodata*. The first part of the listen period in TEEM contains data while the other part contains no data. Both parts are used for synchronization. Each node will listen in the first *Syncdata* part of its listen period whether someone has data to transfer or not. If there is no data in the *Syncdata* part then it will send its own sync packet in the *Syncnodata* part. The TEEM protocol combines the Sync and RTS packets into one packet called *SyncRTS*. Whenever a node wants to communicate with another node, it sends the *SyncRTS* packet in its *Syncdata* part. The destination node receives the packet and starts the communication, while the other nodes synchronize themselves with a *SyncRTS* packet and go into sleep mode. If we look at this protocol with respect to our assumptions for surveillance applications, it gives more sleeping time to nodes than SMAC and TMAC. On the other hand, it provides one hop forwarding per transmission cycle. This may increase the transmission delay in multi-hop networks and decrease the network's QoS. TEEM MAC is a good choice in small networks because there are fewer chances of retransmission.

Distributed Energy Aware MAC (DEMAC)

The DEMAC protocol [5] uses a TDMA (Time Division Multiple Access) scheme to access the medium. DEMAC treats the nodes with respect to their energy level and it gives more time slots to a node that has less energy than other nodes. The DEMAC protocol uses a threshold value for the energy level of a node. If a node's energy level decreases below the threshold value, it allows the node to go into a selection phase. In the selection phase, neighbouring nodes exchange their energy levels. The lower the energy level, the more time slots (in which it is allowed to sleep) are assigned to a node, which gives it more sleeping time than other nodes. If we look at this protocol from a surveillance point of view, it gives better QoS than contention-based protocols. It provides collision-free communication because each node has pre-assigned time slots. DEMAC uses an election process which can increase the delay in communication. The nodes which are near to the sink will get weaker than other nodes because they are more involved in processing or forwarding the data to the sink than others. In this situation, the election process will occur frequently, especially in a dense network with high traffic load, which decreases the QoS. In DEMAC, the energy consumption of a node can be increased because it has to wake up during the time slots of its neighbours so that it can receive the data, i.e. it can only sleep in its own time slots.

Power Aware Cluster TDMA (PACT)

PACT [6] is a TDMA-based protocol used for large multi-hop WSNs. PACT uses adaptive duty cycles with respect to the traffic load. It uses passive clustering [7] in which a small number of nodes participating in the data forwarding are called cluster heads and gateways (see Figure 4). These nodes are elected with respect to their energy level. Nodes which are members of more than one cluster can be elected as gateways. The gateway nodes allow communication between clusters while a cluster head interacts with member nodes and then transfer data to the sink. If we look at this protocol with respect to surveillance applications, it will show good results because it provides collision-free communication.

PACT uses adaptive duty cycles based on the current traffic density to decrease the energy consumption. It decreases the communication delay through passive clustering, which improves the QoS support. On the other hand, each node has to listen to mini slots or control packets from other nodes in order to get the control information. This may lead to some energy consumption.

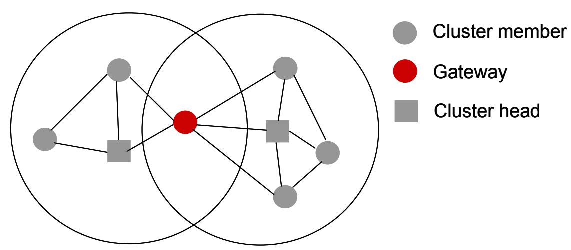

Figure 4: Passive Clustering.

Lightweight MAC Protocol

Lightweight Medium Access Protocol (LMAC) [8] is a TDMA-based protocol which tries to minimize the transceiver state switches (from low-power state to receive or transmit state) and adapt the switching-state to traffic fluctuation. It allows the nodes to sleep when there is no data to transfer. The LMAC protocol is based on Eyes Medium Access Protocol (EMAC) [9]. The EMAC protocol is a TDMA-based protocol in which each node has one slot to transmit the data in a frame. Similarly to EMAC, LMAC also allows the nodes one possible time slot in a frame. In the LMAC protocol, a time slot is divided into two parts: Control Message (CM) and Data Message (DM). LMAC is a contention-free protocol and uses a clustering scheme to handle multi-hop communication. Like EMAC, it gives one time slot to each node to control it. It provides collision-free communication by ensuring that no node can select the same time slots that are in use by its neighbours within a two-hop distance. If we apply this protocol in a surveillance application, it will not be very suitable because each node has to wait for its time slot, which increases the latency. Moreover, each node has to listen in the control section of each frame which may lead to waste of energy.

5. Conclusion

In this paper, we have presented a comparative survey of MAC protocols and their performance in surveillance applications. Table 1 shows the comparison of different MAC protocols based on the main requirements for surveillance applications - energy awareness and QoS support. If we look at the comparison table, the PACT protocol provides a reasonable solution in terms of QoS and low latency through passive clustering. It also uses an adaptive duty cycle with respect to traffic load, to increase the network life time. The LMAC protocol provides collision free communication but it allows only one time slot in a frame to a node, which can increase the latency. DEMAC takes the individual energy levels into account and therefore provides a superior solution in terms of energy awareness. Contention-based protocols like, SMAC, TMAC and TEEM, use the same scheme (periodic listening and sleeping) to prolong the network life time. The TEEM protocol provides more sleeping time to nodes compared to SMAC and TMAC.

In contention-based protocols transmission suffers from collisions because each node is allowed at any time to access the shared medium. The contention-based protocols waste energy in terms of collisions, leading to increased delays and reduced QoS support. In contention-free protocols, like LMAC, DEMAC and PACT, collision-free communication and increased QoS is provided. Each node has pre-assigned time slots to transmit the data but each node has to listen to the time slots of its neighbours in order to synchronize. This may increase the energy consumption. Contention-free protocols suffer from clock drift problems and require tight synchronization. The difficulty with contention-free protocols is the adaptation to topology changes.

Many existing MAC protocols deal with either the energy or QoS aspects of WSNs. Nevertheless, we believe that there still is a need for research on protocols that focus on a combination of both aspects to meet the required for typical surveillance application scenarios.

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