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MAC protocols for Wireless Sensors Networks

Introduction

A 'Wireless Sensor Network' (WSN) can be described as a network of sensors which communicate with each other wirelessly. These sensors may be installed in an unattended environment with limited computation and sensing capabilities. Hence, they need to be tolerant and reliable so that maintenance requirement is less. Since sensors are often deployed in remote applications like forest-fire monitoring and structural health monitoring, the battery cannot be replaced frequently due to inaccessibility of sensor nodes. To prolong network lifetime, energy spending should be minimum. An approach is to design energy efficient MAC protocols. Various MAC protocols have been designed to address this issue.

According to a survey [1] on Wireless Sensor Networks, major sources of energy waste at medium access communication are:

- a) collision - which requires retransmission of collided packets
- b) overhearing - where a node receives a message meant for another node
- c) control packet overhead - where energy is consumed in exchange of control packets used for control data transmission
- d) idle listening - which means that node is listening to idle channel and then over-emitting by sending packets when the destination node is not yet ready.

Among all reasons mentioned above idle listening is a major cause of energy waste. So it is important to design a suitable MAC protocol which can reduce or prevent above energy wastes. There are four techniques to avoid idle listening - static sleep scheduling, dynamic sleep scheduling, preamble sampling, and off-line scheduling. Based on these techniques, many MAC protocols based on CSMA(contention based), TDMA(scheduling based), hybrid(contention and scheduling based) and cross-layer optimizations were introduced.

1. MAC protocols based CSMA

The MAC protocols behave differently under different network scenarios with respect to energy consumption and throughput. So there is a need of an efficient comparative study of these protocols. In this work, we evaluate CSMA based MAC protocols.

1. 1. SMAC

Sensor-MAC (SMAC) is a contention-based protocol that regulates sleep periods in a sensor network to conserve energy and improve network lifetime. This protocol represents the baseline of sleep-oriented, energy-efficient WSN MAC protocol designs. Out of four techniques for avoiding idle listening: static sleep scheduling, dynamic sleep scheduling, preamble sampling, and off-line scheduling, SMAC adopts

static sleep scheduling for preserving the energy. SMAC divides the time into frames. Every frame is divided into an active and a sleep period as shown in Figure 1. In active period, the transmitter-receiver is switched on and it is switched off during sleep period. The active period is further divided into Time Synchronization period and data transfer period. Time Synchronization is required so that receiver remains awake when sender sends the message. In Time Synchronization Period, first step in setting the sleep schedule for a node is to listen for a SYNC packet from a neighbour. The SYNC packet contains the sleep schedule and indicates that the sender is going to sleep after 't' seconds. Once the node receives its neighbour's sleeping schedule, it adopts that schedule and re-transmits the schedule for other neighbouring nodes to adopt. If a node does not receive a SYNC packet within a pre-decided timeout period, the node will set and broadcast its own schedule.

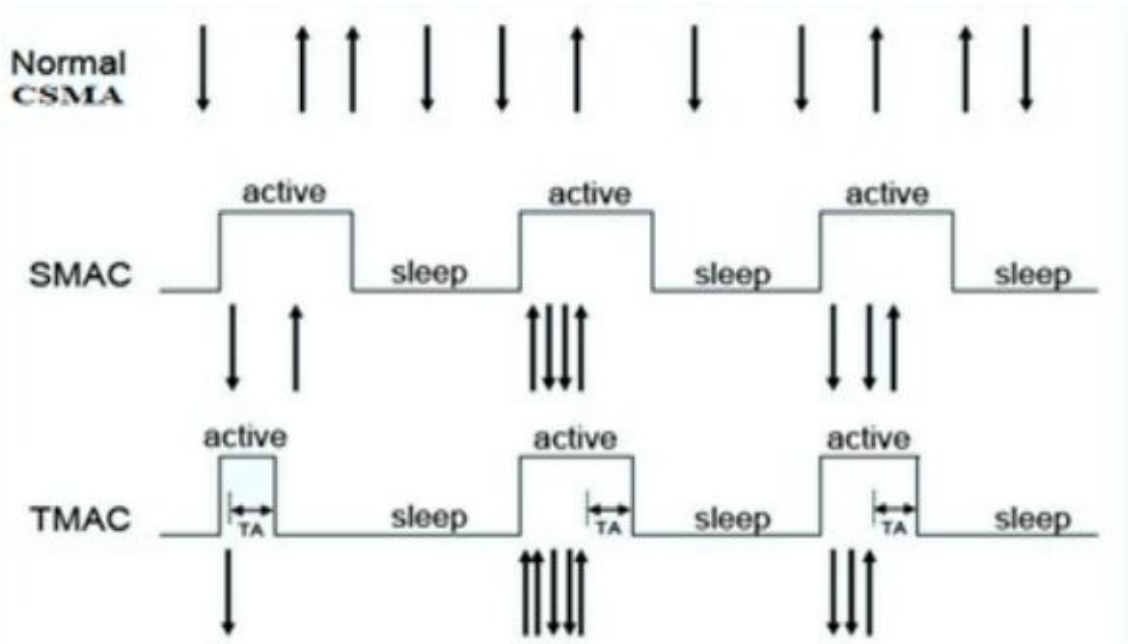


Figure 1: Sleep and wake-up cycles in SMAC and TMAC

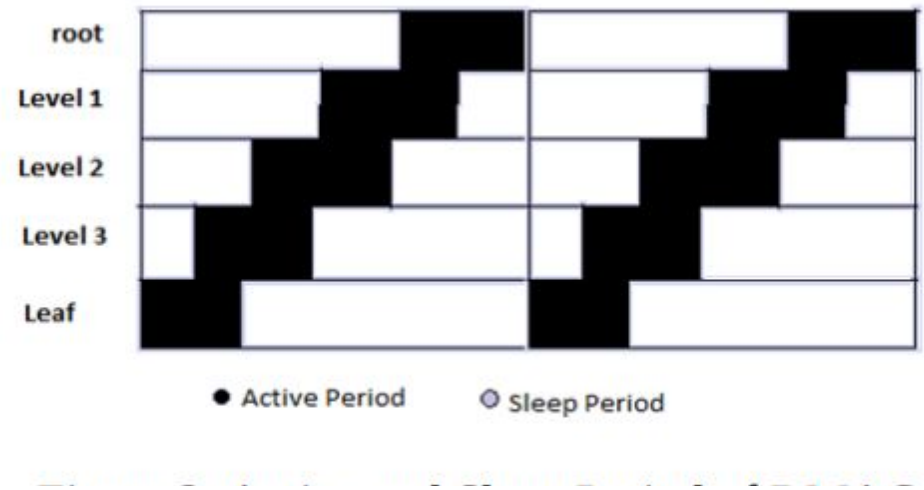
1. 2. TMAC

Timeout-MAC is also a contention-based, MAC layer protocol that is based upon the basic features of SMAC in optimizing power efficiency by sleeping during periodic network inactivity. TMAC allows the nodes to sleep after sometime when all network traffic has completed. The end of traffic is signalled after monitoring an idle channel for an adaptive timeout (TA) period. If no activity occurs for this TA time duration, node switches off its radio and goes to sleep state. The TA period should be large enough to overcome the early sleeping problem (a node goes to sleep state when a neighbour still has packets to be sent). TMAC also introduces a FRTS (Future request to send) mechanism and full buffer priority, to avoid early sleeping problem for converging type of data communication. When a node which has a data to send overhears a CTS packet, it broadcasts a FRTS. The duration of the data is stored in FRTS packets. The recipient of FRTS sets its NAV and goes to sleep. After the communication, node again wakes up to receive the data the sender of FRTS.

1. 3. DMAC

D-MAC is a protocol which aims at real-time delivery of data, still being energy efficient. It adopts a staggered wake-up pattern to forward the data packets to the base-station as shown in Figure 3. Nodes

are considered to be present at different levels of data-gathering tree.



All the nodes at one level would wakeup simultaneously to receive the data. This receiving period, μ, is followed by the transmitting period (μ) in which they forward data to higher level. The nodes at next level wake-up just after the receiving period of the lower level. So, active period is a staggered wake-up pattern, where active period of one level partially overlaps with that of lower level as shown in the figure.

1. 4. B-MAC

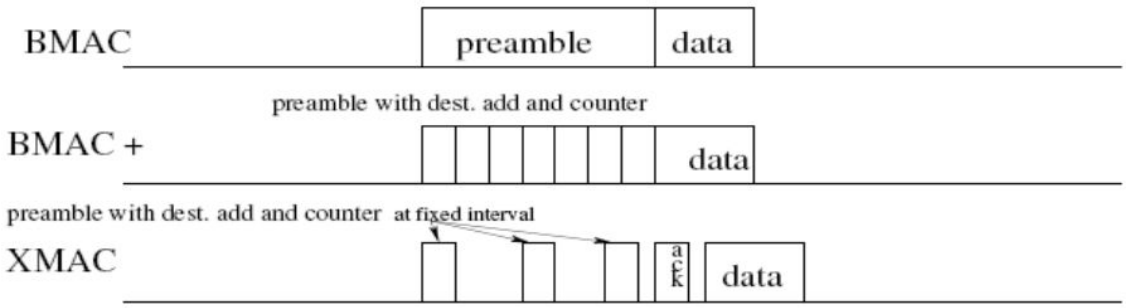
Berkley Media Access Control (BMAC) is a MAC level protocol for Wireless Sensor Networks which uses adaptive preamble sampling scheme. This technique consists of sampling the medium at fixed time intervals. Sampling the medium means to listen to the channel for some activity. In this scheme, every node samples the medium at fixed intervals to check whether any node is willing to communicate. If any node has a packet to send, node (sender) sense the medium if it is free, takes a small back-off and then sends a long wake up preamble followed by data packet. The goals of BMAC protocol are low power operation, effective collision avoidance and efficient channel utilization at low as well as high data rate. BMAC can be scaled to a large network. It is re-configurable by networks and its implementation is simple and requires small RAM size. BMAC protocol uses concepts of media access functionality. It uses clear channel assessment (CCA) and back offs for channel arbitration, acknowledgments for reliability, and low power listening (LPL) for low power communication.

1. 5. BMAC+, XMAC and WISE-MAC

BMAC+ is an extension of BMAC protocol. BMAC+ tries to reduce waste of energy due to long preamble of BMAC. Standard MAC protocols such as BMAC use long preamble before data to wake up receiver. This preamble scheme was enhanced in BMAC+ to reduce power consumption. In BMAC receiver turns its radio off after getting preamble but still sender continue to send remaining part of preamble which results in waste of energy and also introduces excess latency.

In 2006, these problems were solved when **XMAC**, a low power MAC protocol was introduced. XMAC introduces a shortened preamble approach that retains the benefits of low power listening such as low power communication, simplicity and decoupling of transmitter-receiver sleep schedules. XMAC introduces a series of short preamble packets, each packet containing the destination address and remaining number of preambles.

WISE-MAC is a medium access control protocol for WSNs which is based on non-persistent CSMA and uses preamble sampling technique to reduce power consumption. WiseMAC tries to use minimum sized wake preamble. WiseMAC requires no setup signalling, no network-wide synchronization and is adaptive to traffic load. WiseMAC like BMAC is based on sampling technique where a node listens to the channel for a short duration. All sensor nodes sense medium at the same constant period 'TW' independently.



In general, X-MAC performs better than all other CSMA MAC protocols considered. Protocols based on preamble sampling consume lesser energy than protocols based on static or dynamic sleep schedule.

2. MAC protocols based TDMA

The other class of MAC protocols are based on reservation and scheduling: TDMA-based protocols. TDMA protocols have a natural advantage of energy conservation compared to contention protocols because the duty cycle of the radio is reduced and there is no contention-introduced overhead and collisions. However, using TDMA protocol usually requires the nodes to form real communication clusters, like Bluetooth, and LEACH. Managing inter-cluster communication and interference is not an easy task. Moreover, when the number of nodes within a cluster changes, it is not easy for a TDMA protocol to dynamically change its frame length and time slot assignment. So its scalability is normally not as good as that of a contention-based protocol.

Each node maintains a TDMA like frame, called super frame, in which the node schedules different time slots to communicate with its known neighbors. At each time slot, it only talks to one neighbor. To avoid interference between adjacent links, the protocol assigns different channels, i.e., frequency (FDMA) or spreading code (CDMA), to potentially interfering links. Although the super frame structure is similar to a TDMA frame, it does not prevent two interfering nodes from accessing the medium at the same time. The actual multiple access is accomplished by FDMA or CDMA. A drawback of the scheme is its low bandwidth utilization.

Conclusion

Although there are various MAC layer protocols proposed for sensor networks, there is no protocol accepted as a standard. One of the reasons behind this is the MAC protocol choice will, in general, be application-dependent, which means that there will not be one standard MAC for sensor networks. Another reason is the lack of standardization at lower layers (physical layer) and the (physical) sensor hardware.

The majority of MAC layers are using CSMA / CA (random access), that can be combined with frequency division and frequency hoping. But still, this global study demonstrated that all types of MAC layers have both their advantages and disadvantages that made each one suitable to a certain kind of application.

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