A survey of an Energy-Efficient MAC protocol for wireless sensor Networks

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Abstract— Wireless sensor network (WSN) is the combination of sensor, microelectronic and net communication technologies, which is widely applied in environment monitoring, military, industry, human health care and medical treatment and so on. However, WSNs are different from typical computer networks in that individual nodes have very limiting constraints in memory and processing power. The energy constraint is typically considered paramount for wireless sensor networks, and so many MAC protocols have recently been designed that tailor themselves specifically to the characteristics of sensor networks. The major sources of energy inefficiency in WSN are collision, overhearing, idle listening, and control packet overheads. According to the four sources of energy waste, researchers have proposed different types of MAC protocols to improve energy consumptions so that the WSN can have a long lifetime. In this paper we present a survey of the recent typical MAC protocols regarding energy efficiency for WSN.

Keywords— **MAC Protocol, S-MAC, T-MAC, LEACH**

I. Background

Since the terminology for wireless sensor networks is often used with different meanings in the literature, a single, common set of definitions is necessary to prevent confusion.

1. **MAC Layer:** The IEEE802 LAN (local area network) and MAN (metropolitan area network) defines medium access control (MAC) as a sub layer of the data link layer presented in the OSI model. The MAC layer main functions are frame delimiting and recognition, addressing, transfer of data from upper layers, error protection (generally using frame check sequences), and arbitration of access to one channel shared by all nodes. MAC layer protocols for WSNs must be energy efficient to maximize lifetime. Additionally, protocols must be scalable according to the network size and should adapt to changes in the network such as addition of new nodes, death of existing nodes, and transient noise on the wireless channel.

2. **Sleep**: Node state where the radio is turned off.
3. **Frame:** Data unit containing information from a MAC layer protocol and possibly from upper layers.
4. **Packet**: Data unit with information from a network layer protocol and possibly from upper layers.
5. **Collision:** Event where two or more frames are received at the same time, damaging the resulting signal. All information is lost.
6. **Overhearing:** To receive a packet whose destination is any other node. Overhearing results in wasted energy.
7. **Idle Listening:** Another source of wasting energy occurs when a node has its radio on, listening to the medium while there are no transmissions.
8. **Over emitting:** To transmit a message when the destination is not ready for receiving it. Energy for sending the message is wasted.
9. **Control Frames Overhead:** All frames containing protocol information and not application data. Energy for transmitting and receiving these frames is considered to be wasted.
10. **Capture Effect:** Phenomenon present in some analog modulation schemes, such as frequency modulation (FM). Two signals with different amplitudes arrive at a receiver and go through the pass band filter at the same time. The lower amplitude signal is greatly attenuated at the demodulator output, so the stronger signal is successfully received.
11. **Broadcast**:
Sending a message to all nodes in the network.
12. **Clock Drift:**
Most clocks in networking equipment use quartz oscillators, which change with age, temperature, magnetic fields, and mechanical vibration. As the oscillator changes, the time presented by the clock also changes and this is called clock drift.

II. Introduction

Wireless sensor network is considered to be one of the most influential technologies of the current century. WSN can be deployed for many applications ranging from agricultural, environmental, healthcare delivery, military, security, surveillance, home automation and so forth. Such a network normally consists of a large number of distributed nodes that organize themselves into a multi-hop wireless network. Each node has one or more sensors, embedded processors and low-power radios, and is normally battery operated. Typically, these nodes coordinate to perform a common task.
Due to low power support for sensor nodes, energy efficiency becomes one of the core problems. From analysis on the sensor nodes, the communication module is the part consuming most energy, which is the main optimization goal. The Medium Access Control (MAC) protocol directly controls the communication module, so it

has important effect on the nodes' energy consumption. The major sources of energy inefficiency in WSN are collision, overhearing, idle listening, and control packet overheads. According to the four sources of energy waste, researchers have proposed different types of MAC protocols to improve energy consumptions so that the WSN can have a long lifetime. Figure 1 shows the position of MAC within he protocol stack.

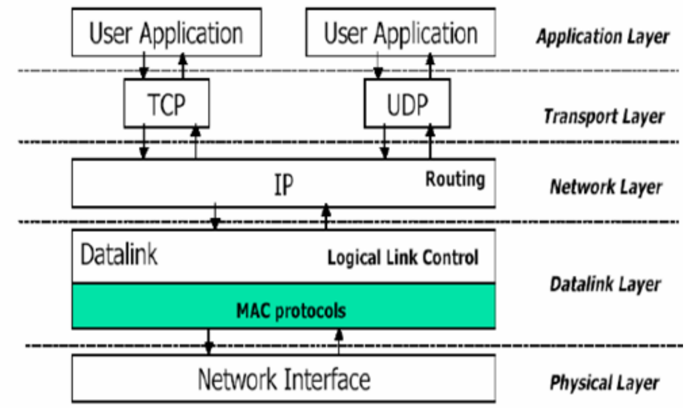

Fig.1 Position of MAC within Protocol Stack

Like in all shared-medium networks, medium access control (MAC) is an important technique that enables the successful operation of the network. One fundamental task of the MAC protocol is to avoid collisions so that two interfering nodes do not transmit at the same time. There are many MAC protocols that have been developed for wireless voice and data communication networks. Typical examples include the time division multiple access (TDMA), code division multiple access (CDMA), and contention-based protocols like IEEE 802.11.

III. CATEGORIZATION OF MAC PROTOCOLS FOR WIRELESS SENSOR NETWORKS

MAC protocols presented in the literature can be classified in three groups according to the approach used to manage medium access: 1.contention based 2. schedule based and 3, Hybrid MAC. All protocols presented in this paper assume no mobility in the network, only one radio available in each sensor and bidirectional links (meaning if node A can listen to node B, node B can listen to node A).

3.1. Contention Based

Contention-based MAC protocols are mainly based on the Carrier Sense Multiple Access/ Collision Avoidance (CSMA/CA). Contention-based protocols require no coordination among the nodes accessing the channel. Colliding nodes will back off for a random duration of time before attempting to access the channel. Medium access is distributed; there is no need for central coordination for the nodes to use the medium. The typical contention-based MAC protocols are S-MAC, T-MAC.

(a) Sensor MAC (S-MAC)

S-MAC is a medium-access control (MAC) protocol designed for wireless sensor networks. Wireless sensor networks use battery-operated computing and sensing devices. A network of these devices will collaborate for a common application such as environmental monitoring. We expect sensor networks to be deployed in an ad hoc fashion, with individual nodes remaining largely inactive for long periods of time, but then becoming suddenly active when something is detected. S-MAC was proposed for energy efficiency based on IEEE 802.11 aiming at saving energy. It divides the time into frames whose length is determined by applications. There are work stage and sleep stage in a frame. S-MAC adopts an effective mechanism to solve the energy wasting problems, that is periodical listening and sleep. When one node is idle, it is more likely to be asleep instead of listening continuously to the channel to saving energy. The neighbours nodes reduce the idle listening by constructing a virtual cluster through consistency sleep schedule of negotiate mechanism; it reduces the transport delay by adopting traffic adaptive listening mechanism; uses beacons to reduce retransmission and avoid listening to unnecessary data; reduce the control packet overheads and packet delay through message division and burst transmission.

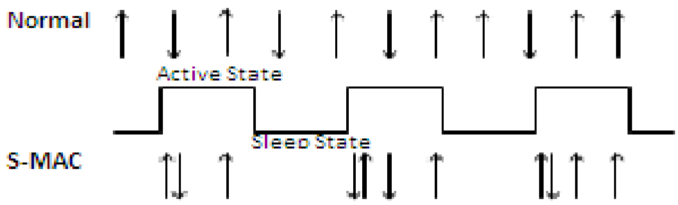

Fig. 2 S-MAC protocol

Advantages — The energy waste caused by idle listening is reduced by sleep schedules. In addition to its implementation simplicity, time synchronization overhead may be prevented by sleep schedule announcements.

Disadvantages — The period length is limited by delay and cache size; the active time depends on message transmission rate; the active time must adapt to highest traffic load to guarantee reliable and timely message transmission; the idle listening will relatively increase when traffic load is low.

(b) Timeout MAC (T-MAC)

Timeout- MAC (T-MAC) is proposed to enhance the poor results of S-MAC protocol under variable traffic load. T-MAC is the protocol based on the S-MAC protocol in which the active period is pre-empted and the sensor goes to the sleep period if no activation event has occurred for a time. The event can be reception of data, start of listen/sleep frame time etc. The T- MAC protocol introduces the idea of having an adaptive active/inactive (listening/sleeping) duty cycle to minimize the idle listening problem and improve the energy savings over the classic CSMA and S-MAC fixed duty cycle-based protocols. Although T-MAC gives better results under these variable loads, the synchronization of the listen periods within virtual clusters is broken. This is one of the reasons for the *early sleeping* problem.

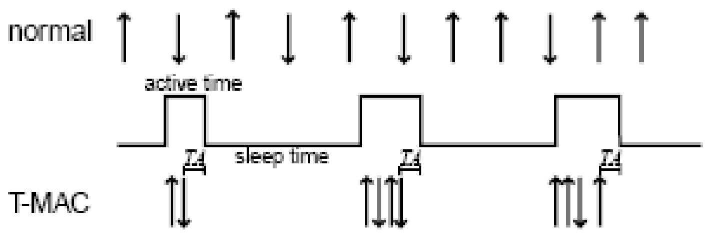

Fig.3 T-Mac protocol

Advantages - T-MAC gives better results under these variable loads, the synchronization of the listen periods within virtual clusters is broken.
Disadvantages – T-MAC Suffers from early sleeping problem –node goes to sleep when a neighbour still has messages for it.

3.2. Schedule Based

Protocols arbitrate medium access by defining an order (called schedule) for nodes to transmit, receive, or be inactive. Generally speaking, each node communicates during specific time slot(s) and can be inactive the rest of the time. Schedule-based protocols use a variety of approaches, as illustrated below.

(a) Low-Energy Adaptive Clustering Hierarchy (LEACH)

IT is a hierarchical clustering algorithm for sensor networks, called Low Energy Adaptive Clustering Hierarchy (LEACH). LEACH arranges the nodes in the network into small clusters and chooses one of them as the cluster-head (CH). Node first senses its target and then sends the relevant information to its CH. Then the

CH aggregates and compresses the information received from all the nodes and sends it to the base station. The nodes chosen as the CH drain out more energy as compared to the other nodes as it is required to send data to the base station which may be far located. Hence LEACH uses random rotation of the nodes required to be the CH to evenly distribute energy consumption in the network. After a number of simulations by the author, it was found that only 5% of the total number of nodes needs to act as the CH. TDMA/CDMA MAC is used to reduce inter-cluster and intra-cluster collisions. This protocol is used were a constant monitoring by the sensor nodes are required as data collection is centralized (at the base station) and is performed periodically. The diagram below shows the architecture of LEACH.

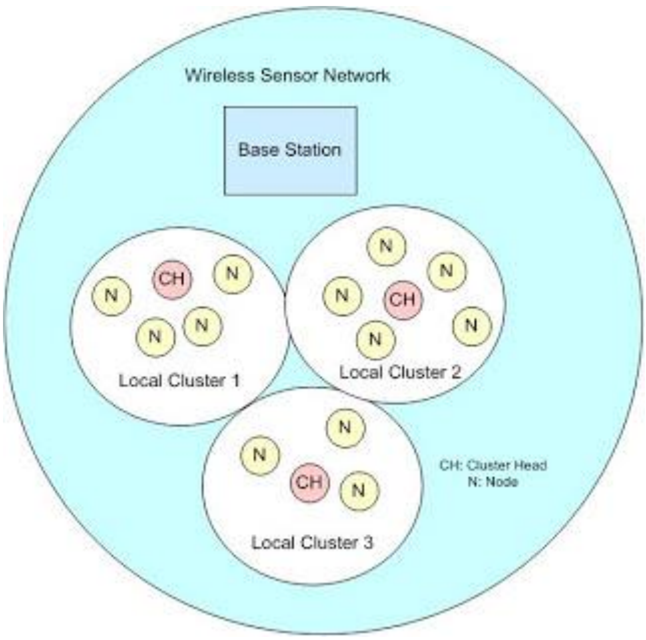

Fig.3 Architecture of LEACH

Advantages: LEACH include saving energy through sleeping. CH rotation extends the lifetime of the network by balancing the rate of energy usage over all nodes, so any one node takes longer to exhaust its energy resources. Including several other networking layers in the protocol design benefits the whole communication scheme by reducing energy usage due to inefficiencies between layers.
Disadvantages: LEACH include overhead associated with the death of a CH. When a CH dies, the whole cluster becomes inactive during the remaining steady-state phase, even if several nodes inside the cluster have enough energy to function. Also, LEACH assumes one-hop communication between the nodes and the CH and also among the cluster heads and the BS, something that is not easily achieved in a randomly deployed network. DSSS increases the complexity of the hardware. LEACH requires tight synchronization (for the TDMA schedule and for using DSSS) which is not included as part of the protocol and will require additional energy and overhead to accomplish.

(b) TRAFFIC ADAPTIVE MEDIUM ACCESS PROTOCOL (TRAMA)

The goal of the TRAMA protocol [6] is to provide a completely collision free medium access and thus achieve significant energy savings. It is primarily a scheduled based MAC protocol with a random access component for establishing the schedules. TRAMA relies on switching the nodes to a low power mode to realize the energy savings. The Protocol has different phases or components namely: Neighbor Protocol (NP), Schedule Exchange Protocol (SEP) and Adaptive Election Algorithm (AEA). NP uses the random access period to gather the one-hop and two-hop neighbor information. SEP helps establishing the schedules for a given interval among the one-hop and two-hop neighbors. Finally, AEA decides the winner of a given time slot and also facilitates the reuse of unused slots. TRAMA derives from the idea proposed in the Neighbor- Aware Contention Resolution (NCR) to select the winner of the given time slot in a two-hop neighborhood. For every one-hop and two-hop neighbor, a node calculates a MD5 hash of the concatenation of the node-id and the time slot t. This gives the priority of a node for a given time slot. The node with the highest priority is chosen to be the slot winner. After the Neighbor Protocol has gathered the neighbor information using the signaling packets in a random access mode, the node computes a certain SCHEDULE_INTERVAL. This is the duration in which a node may transmit data and is based on the rate at which packets are generated from the application layer. The node further pre-computes the priorities to identify its own winning slots for the duration of SCHEDULE_INTERVAL. These schedules are announced in a schedule packet. Instead of including the receiver addresses in the schedule packet, a bitmap is included for its every winning slot.
Advantages: Higher percentage of sleep time and less collision probability are achieved, as compared to CSMA-based protocols. Since the intended receivers are indicated by a bitmap, less communication is performed for the multi- cast and broadcast types of communication pat- terns, compared to other protocols.

Disadvantages: Transmission slots are set to be seven times longer than the random-access period. However, all nodes are defined to be either in receive or transmit states during the random-access period for schedule exchanges. This means that without considering the trans- missions and receptions, the duty cycle is at least12.5 percent, this is a considerably high value. For a time slot, every node calculates each of its two-hop neighbours' priorities on that slot. In addition, this calculation is repeated for each time slot, since the parameters of the calculation change with time.

3.3 Hybrid MAC

Hybrid MAC scheme, for sensor networks that combines the strengths of TDMA and CSMA while offsetting their weaknesses. The main feature of Z-MAC is its adaptability to the level of contention in the network so that under low contention, it behaves like CSMA, and under high contention, like TDMA. It is also robust to dynamic topology changes and time synchronization failures commonly occurring in sensor networks.

(a) Z-MAC (Zebra MAC)

Z-MAC combines the strengths of TDMA and CSMA while offsetting their weaknesses. The main feature of Z-MAC is its adaptability to the level of contention in the network so that under low contention, it behaves like CSMA, and under high contention, like TDMA. It is also robust to dynamic topology changes and time synchronization failures commonly occur- ring in sensor networks. Z-MAC has the setup phase in which it runs the following operations in sequence: neighbor discovery, slot assignment, local frame exchange and global time synchronization. These operations run only once during the setup phase and does not run until a significant change in the network topology (such as physical relocation of sensors) occurs. The idea is that the initial upfront costs for running these operations are compensated by improved throughput and energy efficiency during data transmission. In this section, we first describe how we implement these setup phase operations and then discuss how they are integrated with the main transmission control of Z-MAC. In Z-MAC, a time slot assignment is performed at the time of deployment - higher overhead is incurred at the beginning. We use DRAND, an efficient scalable channel scheduling algorithm .After the slot assignment, each node reuses its assigned slot periodically in every predetermined period, called frame. We call a node assigned to a time slot an owner of that slot and the others the non-owners of that slot. There can be more than one owner per slot because DRAND allows any two nodes beyond their two-hop neighborhoods to own the same time slot.

(b) **B-MAC (Berkeley Media Access Control)**

B-MAC Berkeley Media Access Control for Low-Power Sensor Networks employs an adaptive preamble to reduce idle listening, a major source of energy usage in many protocols. When a node has a packet to send, it waits during a back off time before checking the channel. If the channel is clear, the node transmits; otherwise it begins a second (congestion) back off. Each node must check the channel periodically using LPL (low-power listening); if the channel is idle and the node has no data to transmit, the node returns to sleep. The B-MAC preamble sampling scheme adjusts the interval in which the channel is checked to equal the frame preamble size. As an example, if the medium is checked every 100 ms, the preamble of the packet must last 100 ms as a minimum, in order for the receiver to detect the packet. Upper layers may change the preamble duration, according to the application requirements.
Advantage: B-MAC in WSNs is that it does not use RTS, CTS, ACK, or any other control frame by default, but they can be added. Additionally, it is one of the few specialized MAC protocols whose implementation was tested in hardware. No synchronization is required, and the protocol performance can be tuned by higher layers to meet the needs of various applications. The main

Disadvantage: The preamble creates large overhead. One example presents 271 bytes of preamble to send 36 bytes of data.

<u>Conclusion</u>

The medium access control is a broad research area, and many researchers have done research work in the new area of low power and wireless sensor networks. This paper reviewed MAC protocol for WSNs, sources and causes of energy inefficiencies and their consequences on the network. This paper presents a new MAC protocol for wireless sensor networks. It has very good energy conserving properties com- paring with IEEE 802.11. Another interesting property of the protocol is that it has the ability to make trade-offs between energy and latency according to traffic conditions. The protocol has been implemented on our tested nodes, which shows its effectiveness.

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