Energy Efficient MAC Protocol for Wireless Sensor Networks-A Review

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Abstract: Wireless Sensor Networks is having broad area for researchers due to their wide range of application potential in areas such as target detection and tracking, environmental monitoring, industrial process monitoring, and tactical systems. In designing of Wireless Sensor Networks MAC protocols, conservation of energy is the main issue. Energy efficiency is a major consideration while designing wireless sensor network nodes. Lowering the energy consumption may result in increase of time delay from end to end in Wireless Sensor Network (WSN). To address the tradeoff between energy consumption and time delay, this paper proposes a MAC protocol based on sleep schedule of sensor node dynamic duty cycle. This paper propose that if any node is having data to send to the desired destination, it first checks the idleness of medium from where the data is to be sent and then sends an AWAKE signal to wake up the node for data reception. Else, all the nodes are kept in SLEEP state, so that energy conservation is more.

I. Introduction:

Recent advancements in scaling and low-power design put forward to active research in large-scale, highly distributed systems of small-size, wireless unattended sensors [1][2]. A sensor network consists of minute devices that are capable of probing the environment and reporting the collected data, typically using a radio, to the command center. Sensor networks can serve many military and civil applications such as disaster management, combat field surveillance and security.

In such applications, the sensors are usually powered using small batteries and replacing sensor's battery is not possible or not practical. Such energy constraints limit sensors' lifetime and thus makes it a real challenge for efficient designing and management of sensor networks. Therefore, a lot of the research related to sensor networks has focused on energy-awareness and minimization [1] [3] [4]. In this paper we concentrate on the minimization of energy consumption at the MAC layer through time-based arbitration of the sensor's medium access.

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Medium access is a major consumer of sensor energy, especially when the radio receiver is kept on all the time for long-range transmissions. Energy consumed for radio transmission is directly proportional to distance squared and can significantly increase in a noisy environment. Energy-aware routing typically follows multi-hop paths in order to optimize the energy of transmission [5]. On the other hand, time-based medium access control (MAC) saves transmission energy by limiting the potential for collisions and minimizes the energy consumed in the receiver by turning the radio off when it is idle [3][4]. Generally, an efficient MAC layer protocol for sensor networks should have the following attributes:

- The protocol should be scalable since most applications of sensor networks involve a large set of sensor nodes.
- Collisions among the transmissions of various nodes should be avoided. Collisions lead to packet drop and thus reduce throughput and cause energy wastage.
- Energy consumed by the radio circuit in idle mode is almost equal to that consumed in active state. Consequently, idle mode of operation and transmission overhearing among sensors should be minimized.
- To limit energy consumption during idle time, the sensors are typically switched to a sleep mode when not in use. However, active to sleep transitions and vice-versa consume considerable amount of energy. Therefore, an efficient protocol should minimize such transitions [4].
- Control packets overhead and active sensing of the medium, typically performed by contention-based protocols, are inefficient in terms of energy consumption. So, the protocol should not be contention-based.
- Packet drop due to limited buffer capacity should be prevented.
- The protocol should adapt to changes in the network topology and all sensors should have a fair chance of transmitting.

Unlike contention-based protocols, a Time-Division-Multiple-Access (TDMA) based MAC allows communication traffic to flow according to a preset schedule. Time-based MAC can minimize the energy consumption since the nodes can turn off their transmitters or receivers, unless they are expecting to receive or transmit a packet. It has been shown that turning off the radio receiver significantly reduces energy consumption and extends the life of wireless sensor networks [6] [7]. Also, collision among nodes can be avoided since each node has its own assigned time slots. However these advantages of time-based MAC are due to the deterministic operation, which requires communication time slots to be scheduled for both transmitting and receiving.

A. System Model

The system architecture for the sensor network is depicted in Fig. 1. In the architecture, all the sensor nodes are controlled by a single command node called the sink node which forms a cluster. Every cluster has a gateway node that manages sensors in the cluster. Clustering the sensor network can be either performed by the command node or collaboratively among the gateways and is beyond the scope of this paper [8]. Sensors are having the capability to communicate with radio based short-haul communication and are responsible for probing the clustering environment to detect a target/event. In this paper, we assume that sensor and sink (gateway) nodes are initially in idle state and all sensors in a cluster are within the communication range of the gateway of that cluster. The on-board clocks of the gateway nodes are assumed to be synchronized, e.g. via the use of GPS.

The sink node interfaces the command node with the sensor network through long-haul communication links. Sensors receive commands from and send readings to their gateway node, which processes these readings and transmits the fused information to the command node. Unlike sensors the gateways are significantly less energy consumption nodes. Hence the gateway is assigned the responsibility of organizing the sensors and routing generated data. Sensor organization refers to activating a subset of available sensors in the cluster to probe the environment based on the application and the sensor's capabilities. The gateway sets multi-hop routes based upon the current state of the network and sends route updates to the sensors. Route formation will designate some sensors to act as relays. The sensors then adjust their transmit power based upon their next hop neighbor.

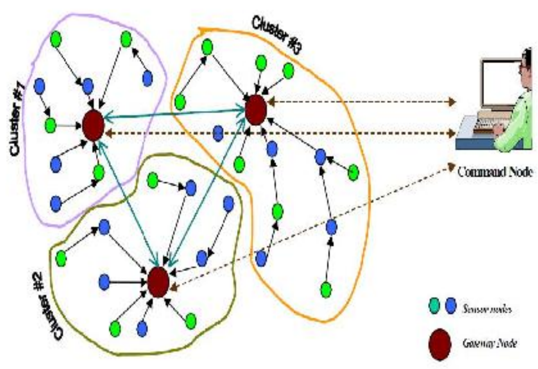

Fig. No. 1 WSN Cluster

Radios are assumed to have the ability to operate in four different modes transmit, receive, idle and sleep. The energy consumed in idle mode is almost equivalent to that in receive mode [16]. The energy consumed by the radio is:

$E_{radio} = N_{tx} [P_{tx} (T_{on}\text{-}t_x+T_{st}) + P_{out} T_{on}\text{-}t_x] + N_{rx} [P_{rx} (T_{on}\text{-}r_x+T_{st})]$ …… (1)

Where N_{tx}/r_x is the average number of times per second, the transmitter/receiver is used. T_{st} is the transition time from sleep to active mode. $T_{on}\text{-}t_x/r_x$ is the ON time of the transmitter/receiver. Pout is the output transmission power. $P_{tx/rx}$ is the power consumed by the transmitter/receiver [8].

II. Major Issues of Energy Wastage:

1. Idle listening

When nodes in the cluster have nothing to transmit or receive, the nodes still remain in active state and do idle listening to the network. This process consumes same amount of energy as in the transmission or receiving process, that lead to wastage of energy.

2. Collision or Corruption

Normally collision may occur when neighboring nodes assert for free medium and faulty channel will leads to corruption of transmitted packets. When either of two cases happens corrupted packets should be retransmitted, which increases energy consumption.

3. Overhearing

This happens when a node receives some packets that are actually sent to other nodes.

4. Control Packet Overhead

Some energy is also consumed when there is exchange of control packets between sender and receiver.

III. S-MAC (Sensor-MAC)

In wireless sensor network, the Sensor S-MAC protocol is a contention based MAC protocol. It is an improved version of IEEE 802.11 protocol .The sensor node periodically goes to the fixed sleep cycle for the MAC protocol. The time frame is divided into two part: one for a sleeping session and the other for a listening session In SMAC, the sensor node are capable to communicate with additional nodes and they send some control packets like SYNC,RTS (Request to Send), CTS (Clear to Send) and ACK(Acknowledgement) are only for listen period. By a SYNC packet exchange all nearest nodes can synchronize collectively and using RTS/CTS switch over the two nodes can communicate with each other. The Fig. 1 describes the basic s-node scheme where transmission of data from node 1 to node 2 is shown. Even IF there is no reception/transmission a lot of energy is still dissipated in this protocol during listen period as the sensor will be in AWAKE state.

If node sleep for half second and wake up for other half second so energy saving is 50%.

Schedule Exchanging-:

SYNC packets are exchanged periodically to maintain schedule synchronization.

SYNC Packet

Sender Node ID	Next Sleep Time

Synchronization period: Period for a node to send a SYNC packet. Receivers will adjust their scheduled counters immediately after they receive the SYNC packet. Each node maintains a schedule table that stores schedules of all its known neighbors. For initial schedule: A node first listens to the medium for a certain amount of time (at least the synchronization period). If it does not hear a schedule (SYNC packet) from another node, it randomly chooses a schedule and broadcasts its schedule with a SYNC packet immediately. This node is called a synchronizer. If a node receives a schedule from a neighbor before choosing its own schedule it follows this neighbor's schedule becomes a Follower. It waits for a random hold time and broadcasts its schedule to the cluster. Border node having different SYNC packet from Synchronizer node. It will wake up for all schedules it knows, so it consumes more energy

Overview

The S-MAC protocol is designed with the primary goal of reducing energy consumption from various methods. It is obtained by periodically putting nodes into a sleep state. Each node sleeps for a specified amount of time, then wakes up and listens to see if any other nodes want to communicate. During the sleep time, the node turns off its radio and sets its timer to wake up. A complete listen and sleep cycle is called a frame. Nodes are free to choose their own listen and sleep schedules. Nodes announce their schedules to their neighboring nodes by broadcasting SYNC packets. A group of nodes following the same schedule forms a virtual cluster. As shown in Fig. 2, nodes A, B, C, D and E form a virtual cluster following one schedule, and nodes F,G,H, and E form another virtual cluster following another schedule. Node E belongs to two clusters, and follows two different schedules. It becomes a border node and has two listen intervals in a given frame to support inter-cluster communication. When two neighboring nodes follow two different schedules where two listen intervals are not overlapped, they may never find each other. The Periodic neighbor discovery (PND) is introduced to solve this problem. During PND, each node periodically listens for an entire synchronization period, the period for each node to send a SYNC packet. The following rules govern each node when selecting its schedule and creating its schedule table which stores the schedules of all known neighboring nodes and its own. Also the AWAKE/SLEEP signal is introduced in this to set the state of node.

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- After being deployed, a node listens for at least one synchronization period to hear the existing schedules from neighboring nodes. If it does not hear any schedules, it starts its own schedule, announces the schedule by broadcasting
- SYNC packets periodically and becomes a synchronizer. If it hears a schedule from its neighboring node before choosing its own schedule, it follows the received schedule and becomes a follower.
- After choosing and announcing its own schedule, a node has two choices when it hears a different schedule from a neighboring node. If the node has no other neighboring nodes with different schedules, it discards its old schedule and follows the new schedule from the neighboring node. If it has one or more neighboring nodes with different schedules, it adopts all schedules and becomes a border node.

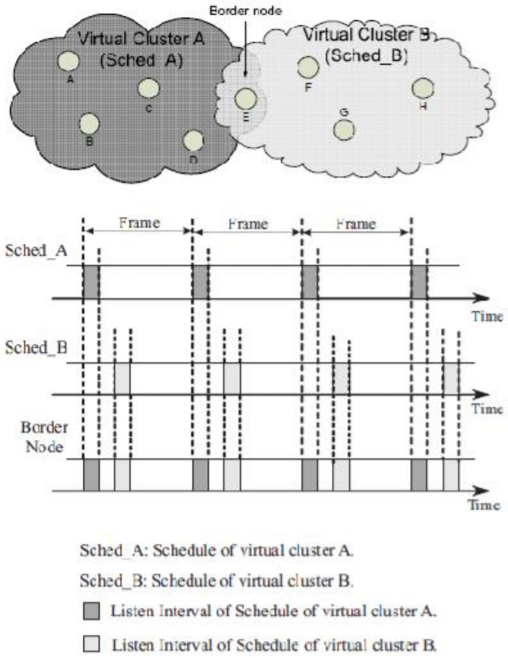

Fig No. 2 Scheduled based network

A border node following multiple schedules has relatively large power consumption because it transits into the listen state more than once in each frame and relays the data packets between the virtual clusters. It makes border nodes to reduce lifetime. The eventual death of the border node ceases the communication between neighboring virtual clusters. Therefore, after some time, a sensor network covering a wide area and consisting of tens of thousands of sensor nodes is divided into several isolated virtual clusters due to the death of border nodes

IV. Comparative study of existing MAC Protocols:

Table 1 compares the different MAC protocols by taking parameter scheme used, energy savings, advantages and disadvantages. [9]

NAME OF THE PROTOCOL	SCHEME USED	ENERGY SAVINGS	ADVANTAGES	DISADVANTAGES
SMAC	Fixed duty cycle, Virtual Cluster, CSMA	Power savings over CSMA/CAMAC	Low energy consumption when traffic is low	Sleep latency, problem with broadcast
BMAC	LPL, Channel assessment software interface	Better power savings, latency and throughput than SMAC	Low overhead when network is idle, consumes less power	Overhearing, bad performance at heavy traffic, long transmission latency
TMAC	Adaptive duty cycle, overhearing, FRTS	Use 20% of energy used in SMAC	Adaptive active time	Early sleeping problem
WISE MAC	Minimized preamble sampling, schedule	Better than SMAC and low power listening	Energy consumption both at sender and receiver and at non target receiver increase latency at each hop	Low power for low traffic, do not incur overhead due to synchronization
TRAMA	TDMA	Utilization of classical TDMA	Higher energy efficiency and throughput	Time is divided in to random access period
DMAC	Converge cast communication	Low latency	Energy saving and low latency	Aggregate rate is larger
CMAC	Aggressive ack. anycast, convergent packet forwarding	Consume less energy than existing solutions	High throughput, low latency and consumes less energy	Not yet found

Table 1: Comparative study of energy efficient MAC protocols

V. Conclusion:

Designing a MAC protocol which can improve energy efficiency to extend network lifetime in Wireless Sensor Networks is a challenging problem. It is mainly due to stringent resource constrains both in sensor nodes and wireless media. Sensor-MAC (SMAC) and their comparative study with different protocols have been proposed in this paper. 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 choices will, in-general, be application dependent, which means that there will not be one standard MAC for WSN's.

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