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An Energy Efficient Medium Access Protocol for Wireless Sensor Networks

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Abstract *:* Wireless sensor networks have been widely used in many important fields such as target detection and tracking, environmental monitoring, industrial process monitoring etc. Since the nodes in wireless sensor networks consist of a limited power source, energy efficient operations of the nodes are very important. Although energy conservation in communication can be performed in different layers of the TCP/IP protocol suit, energy conservation at MAC layer is found to be the most effective one due to its ability to control the radio directly. For sensor nodes that are battery operated, it is sometimes difficult or impractical to charge or replace exhausted battery. The medium access protocol (MAC) for wireless sensor network must be energy efficient. This paper proposes a timeslot sharing medium access protocol for wireless sensor networks. The proposed scheme allows multiple sensor nodes to share a reserved or guaranteed timeslot for transmission. It allows more sensor nodes to transmit in the guaranteed timeslots and few sensor nodes to transmit in the contention slots. The goals of timeslot sharing protocol are to minimize the energy consumption of sensor nodes and to maximize the total number of nodes allowed in a network..

Key words : Energy efficiency, Time sharing, Wireless network, MAC protocol.

INTRODUCTION

Sensor networks consist of small, inexpensive, resource constrained devices that communicate using wireless multi hop network[1]. Each device is called as a sensor node. A sensor node cooperates with other nodes in the network to perform some useful operation for the end user, such as environmental monitoring or target tracking. Usually a end user desires to deploy several sensor nodes randomly throughout the target area . But some special cases may require the precise deployment resulting in a smaller network. Large sensor network applications require sensor nodes of marginal cost to keep the overall cost within reasonable bounds.

The communication in a sensor network takes place by forming a multi hop network to forward messages to the destination through the intermediate nodes, which may collect data for later retrieval by the end user or transfer the data over a dedicated communications link. Sensor nodes avoid direct transmission of data with the destination because of the high power requirements. In spite of using multi hop communication to reduce energy consumption for communication, the wireless radio consumes the largest amount of energy within a sensor node and provides the greatest potential for energy savings. The radio is the most power-consuming component of a sensor node. Large gains can be achieved at the data link layer because the MAC protocol controls the usage of the radio. Therefore, all the MAC protocols based on energy efficiency have been developed by taking into consideration the performance parameters like throughput, latency, and fairness to reduce the energy consumption and to maximize the lifetime of the network.

A good MAC protocol should have the following attributes. The first is the energy efficiency. Sensor nodes are likely to be battery powered, and it is often very difficult to change or recharge batteries for these nodes. Prolonging network lifetime for these nodes is a critical issue. Another important attribute is the scalability to the change in network size, node density and topology. Some nodes may die over time; some new nodes may join later; some nodes may move to different locations. The network topology changes over time. A good MAC protocol should easily accommodate such network changes.

Energy constraints of sensor networks have demanded energy awareness at most layers of the networking protocol stack. The radio transceiver unit considered as the major consumer of energy resource of the sensor node especially when the radio transceiver is turned on all time. A large amount of energy savings can be achieved through energy efficient media access control mechanisms. For this reason, energy consideration has dominated most of the research at MAC layer level in wireless sensor networks.

In this paper, a new energy efficient medium access control mechanism is proposed. This protocol allows multiple sensor nodes to share a reserved or guaranteed timeslot for transmission. It also allows more sensor nodes to transmit in the reserved or guaranteed timeslots and fewer sensor nodes to contend for the transmission. This reduces energy consumption in contention slot.

RELATED WORK

The medium access control protocols for the sensor networks can be classified broadly into two categories: Contention based and Schedule based.

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The contention based protocols relax time synchronization requirements and can easily adjust to the topology changes as some new nodes may join and others may die few years after deployment. These protocols are based on Carrier Sense Multiple Access (CSMA) technique and have higher costs for message collisions, overhearing and idle listening.

The IEEE 802.11[2] is a well-known contention based medium access control protocol which uses carrier sensing and randomized back-offs to avoid collisions of the data packets. The Power Save Mode of the IEEE 802.11 protocol reduces the idle listening by periodically entering into the sleep state. This PSM mode is for the single-hop network where the time synchronization is simple and may not be suitable for multi-hop networks because of the problems in clock synchronization, neighbor discovery and network partitioning.

Power Aware Multi-Access [3] is one of the earliest contention based MAC protocol designed with energy efficiency as the main objective. In this protocol nodes which are not transmitting or receiving are turned off in order to conserve energy. This protocol uses two separate channels for the data and control packets. It requires the use of two radios in the different frequency bands at each sensor node leading to the increase in the sensors cost, size and design complexity. Moreover, there is significant power consumption because of excessive switching between sleep and wakeup states.

Sensor – MAC [4] a contention based MAC protocol is modification of IEEE 802.11 protocol specially designed for the wireless sensor network. In this medium access control protocol, the sensor node periodically goes to the fixed listen/sleep cycle. A time frame in S-MAC is divided into two parts: one for a listening session and the other for a sleeping session. Only for a listen period, sensor nodes are able to communicate with other nodes and send some control packets.

Timeout T-MAC [5] is the protocol based on the S-MAC protocol in which the Active period is preempted and the sensor goes to the sleep period if no activation event has occurred for a particular time period. The event can be reception of data, start of listen/sleep frame time etc. The energy consumption in the Timeout T- MAC protocol is less than the Sensor S-MAC protocol. But the Timeout T-MAC protocol has high latency as compared to the S-MAC protocol.

The schedule based protocol can avoid collisions, overhearing and idle listening by scheduling transmit & listen periods but have strict time synchronization requirements.

The traffic adaptive medium access (TRAMA) [6] is a Contention based protocol that has been designed for energy efficient collision free channel in WSNs. In this protocol the power consumption has been reduced by ensuring collision free transmission and by switching the nodes to low power idle state when they are not transmitting or receiving.

SMACS [7] is a schedule based medium access control protocol for the wireless sensor network. This MAC protocol uses a combination of TDMA and FDMA or CDMA for accessing the channel. In this protocol the time slots are wasted if the sensor node does not have data to be sent to the intended receivers. This is one of the drawbacks of this MAC scheme.

Low Energy Adaptive Clustering Hierarchy (LEACH) is a Energy Aware Scheduled Based MAC [8] protocol assumes the formation of clusters in the network. The cluster head manages each of the cluster sensor nodes. The cluster head collects the information from the other sensor nodes within its cluster, performs the data fusion, communicates with the other cluster head and finally sends the data to the control center. The cluster head performs the assignment of the time slots to the sensor nodes within its cluster. The cluster head inform the other nodes about the time slot when it should listen to other nodes and the time slot when it can transmit own data.

Hybrid MAC protocols combine the strengths of scheduled and unscheduled MAC protocols while compensating their weakness to build more efficient MAC schemes. Hybrid protocols use different techniques to conserve sensor battery power; some protocols differentiate between small and long data messages. Long data messages are assigned scheduled slots with no contention, whereas small periodic control messages are assigned random access slots. Other hybrid techniques adjust the behavior of MAC protocol between CSMA and TDMA depending on the level of the contention in the network. The greatest advantage of the hybrid MAC protocols comes from its easy and rapid adaptability to traffic conditions which can save a large amount of energy, but this advantage comes at the cost of the protocol overhead and complexity caused by the TDMA structure which limits the scalability and applicability range of the protocol.

PROPOSED TIME SLOT SHARING MEDIUM ACCESS PROTOCOL

In wireless sensor networks for synchronization and network management, time is partitioned into periodic intervals called superframes [9]. A superframe is usually partitioned into a beacon period (BP) and a data period (DP). The data period is partitioned into a contention free period (CFP), and a contention access period (CAP). The following figure illustrates the superframe structure.

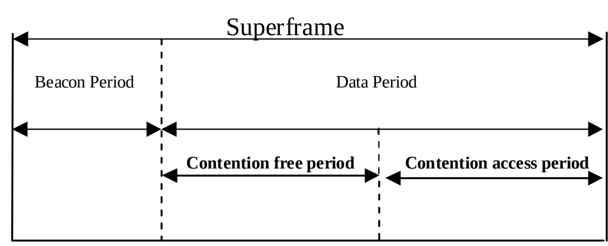

Fig 1: Super frame structure.

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Every superframe consists of number of timeslots. Depending on the specific network requirements, the numbers of timeslots and the length of each timeslot in BP, CFP and CAP varies. During the BP, network control parameters are transmitted, i.e., network identifiers, transmission rates, logical channels, start of the CFP, the start of the CAP, the access schedule for the CFP, etc. The BP may consist of multiple timeslots [10] or a single timeslot [11]. During the CFP, sensor nodes uses allocated timeslots to transmit data. During the CAP, sensor nodes use the contention techniques to transmit the data.

In conventional medium access protocols, a timeslot in the BP or CFP is allocated to a specific node. In the case of the BP, the timeslot is referred as a beacon slot and in the case of the CFP, the timeslot is referred as a guaranteed timeslot. During a timeslot in BP or CFP, only the node that has been allocated to the timeslot is allowed to transmit beacon or data, even if the duration of the transmission is only a fraction of the timeslot or there is no transmission. Other nodes are not allowed to use that timeslot unless the timeslot is reassigned to it. The timeslots in CAP are not allocated to any particular node. All nodes in the network are allowed to transmit in CAP by using the contention access mechanism defined for the given network.

The conventional medium access protocols impose the certain limitations on the wireless networks: The allocated timeslot is not fully utilized when the node does not have enough packets to transmit, which decreases the network efficiency. The destination node(s) need to stay awake for receiving in the reserved timeslots even if source node does not transmit any packet, and that results in idle listening. The total number of nodes that are allowed to transmit during the CFP is limited by the number of timeslots in CFP, which in a network with large number of nodes, forces more nodes contend for medium access during CAP, which in turn results in decrease of bandwidth efficiency due to the higher probability of collision. The retransmission caused by collisions also increases the energy consumption. So the conventional medium access protocols do not fully explore the characteristics of the wireless sensor networks. The proposed timeslot sharing medium access protocol for wireless sensor networks overcome the limitations imposed in conventional medium access protocols. The proposed timeslot sharing protocol achieves both energy and bandwidth efficiency.

Timeslot Sharing in Beacon Period

The beacon is a special type of control packet transmitted by a node. In some sensor networks, all nodes are required to transmit their beacon in a superframe. The period where beacons are transmitted is defined as beacon period. Beacon slot sharing decreases the number of beacon slots and enables more time for data transmission, and therefore increases the efficiency of the network. Beacon slot sharing also allows nodes to save energy used to listen to and process unnecessary beacons. The principle of beacon slot allocation is to make use of beacon slot as efficient as possible and leave more time for data transmission.

In a wireless sensor network, one or more nodes are designated as network coordinator(s). The network coordinators are responsible for network management and resource allocation. Beacon transmission nodes request beacon slots from network coordinators during the process of network setup or joining network by sending their beacon transmission patterns to the network coordinators, which allocate beacon slots to beacon transmission nodes according to the beacon transmission needs of the requesting nodes. The network coordinators can allocate a single beacon slot to multiple beacon transmission nodes if there is no beacon collision. The network coordinators inform each of the nodes that share a beacon slot when and how to transmit beacon. Figure 2 shows an example of beacon slot sharing. Node A and node B share a beacon slot with node A transmitting beacon every four superframes and node B transmitting beacon every two superframes. Beacon transmission nodes are required to send their new beacon transmission patterns to the network coordinators when their beacon transmission patterns change. The network coordinators can change beacon slot allocation if it is necessary.

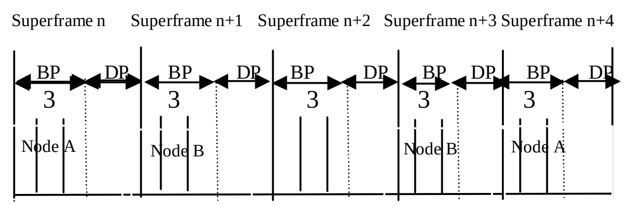

Fig 2: Node A and Node B share beacon slot 3

In a distributed wireless sensor network without network coordinator, beacon transmission nodes share the responsibility to manage beacon slot allocation. A beacon slot is said to be occupied if one or more nodes transmit beacons in that beacon slot. A node that transmits beacon announces its beacon transmission pattern in its beacon. A beacon transmission node first scans for an occupied beacon slot for sharing by listening to other nodes' beacons. If there is no occupied beacon slot satisfying its need it then selects an unoccupied beacon slot. To share an occupied beacon slot, a node needs to scan for beacon transmission in the shared beacon slot for a sufficient number of successive superframes to determine when it transmits beacon. For example, if node A selects an unoccupied beacon slot #10 and transmits beacon every two superframes. Node B that also transmits beacon every two superframes can share beacon slot #10 with node A. To locate its turn for beacon transmission, node B has to monitor beacon transmission in beacon slot #10 for at least two consecutive superframes.

In such a distributed network, the beacon transmission nodes can detect beacon collision by skipping its beacon transmission periodically. If a node that skips beacon transmission receives beacon in its beacon slot when it is its turn to transmit beacon, a beacon collision occurs. The node has to resolve the beacon collision by selecting a new beacon

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slot or new beacon transmission turn. A node can also change its beacon transmission pattern or beacon slot selection at any time and re-select or join a desirable beacon slot to transmit its beacon. A node can also change its beacon slot if it reduces the number of the occupied beacon slots or the length of beacon period, as long as a desirable beacon slot is available.

Timeslot Sharing in Contention free Period

Generally, the sensor nodes do not have a large amount of data to transmit and are sleeping for most of time. A sensor node wakes up, performs its task, and goes to sleep again. A sensor node transmits its data in either an assigned timeslot in the CFP or in the CAP. Transmission in CFP allows a source node to wake up in the guaranteed timeslots and transmit data without contending for medium access. It also allows the destination node(s) to wake up in the exact timeslots and receive data without idle listening. In conventional MAC designs, once a timeslot is assigned to a node, it cannot be used by others regardless if the node has data to transmit. A node that uses the CAP for data transmission only needs to wake up if it has data to transmit. Transmission in CAP consumes more energy compared to CFP transmission due to two factors: (a) The random backoff forces both transmitting nodes and receiving nodes to stay awake for a longer period of time; (b) Collision occurs for CAP transmission, which results in retransmissions. So, to achieve high energy-efficiency in dense wireless sensor networks, more sensor nodes should transmit in CFP and fewer sensor nodes should transmit in CAP. But the number of timeslots in CFP is limited by the superframe period. The CFP timeslot sharing is designed to allow more nodes to utilize the limited slots in CFP in a sensor network. In a managed wireless sensor network, a node can request the guaranteed timeslots in CFP from a network coordinator to transmit data. The network coordinator can request a node to report its data transmission pattern to determine timeslot allocation scheme. The network coordinator may allocate the sharable timeslots to a node as long as there is no transmission collision. The network coordinator informs a node about timeslot sharing information and node's turn to transmission data. For example, a network coordinator can inform a node to transmit data in timeslot #10 every three superframes starting from next superframe. Once timeslot is allocated to a node, the network coordinator also informs destination node(s) to wake up for data receiving in the allocated timeslots. The network coordinator can transmit the timeslot allocation information to source node and destination node(s) in beacon or control packet. A node follows the timeslot allocation to transmit data in CFP. The network coordinator records each node's timeslot assignment and the nodes allocated to each timeslot in the CFP. Any node as well as the network coordinator can initiate a timeslot allocation change at any time based on node requirements or network conditions.

In a distributed wireless sensor network where a network coordinator does not exist, a node with data to transmit in CFP makes timeslot reservation by coordinating with destination node(s) so that the destination node(s) wake up to receive the data in the exact timeslot. The timeslot reservation information can be broadcasted in beacon or other control packets. The set of source node and destination node(s) that first reserves an unoccupied timeslot is called the initial set. The initial set broadcasts its data transmission pattern in the reserved timeslot. Other sets of nodes can join the initial set to share the reserved timeslot if that timeslot satisfies their data transmission needs. For example, if set A, initial set, announces that it transmits data in two of every three superframes, then a set B that transmits data in one of every three superframes can join the set A to share the timeslot with set A as shown in Fig 3.

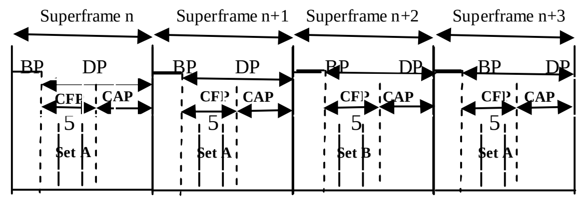

Fig 3: Set A and Set B share time slot 5 for data transmission

In such a distributed wireless sensor network, a node intending to transmit data in CFP first scans for beacon or control packets to find out the occupied timeslots for sharing. If there is no occupied timeslot satisfying its needs, it then reserves the unoccupied timeslots with coordination with the destination node(s).

A set of nodes that join other set(s) to share a reserved timeslot can broadcast their data transmission patterns in that timeslot. The data transmission pattern in a reserved timeslot is propagated to the network so that no data collision is caused. To join one or more sets and transmit data in a shared timeslot, the source node locates its turn for data transmission and informs destination node(s) so that the destination node(s) gets ready in the exact timeslot without wasting energy. A source node listens for data transmission in reserved timeslot for a sufficient number of successive superframes to determine its turn. For example, if the initial source node transmits data in a reserved timeslot every three superframes, the joining source node listens for data transmission in that timeslot for at least three successive superframes. If there is data transmission in that timeslot in each of three successive superframes, then that timeslot is not available for sharing. If the timeslot is idle in one or more superframes, the joining source node can take its turn and transmit data.

CONCLUSION

Wireless sensor networks have a wide range of potential applications such as target detection and tracking, environmental monitoring, industrial process monitoring, and hospital monitoring systems. Since sensor nodes have limited resources, minimizing energy consumption and maximizing the network lifetime is a common objective in a wireless sensor network,. The medium access protocol must be energy efficient. The timeslot sharing medium access

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protocol proposed in this paper allows more sensor nodes to transmit and receive data free of contention in the guaranteed timeslots and without idle listening for receiving data. The timeslot sharing medium access protocol can increase the lifetime of a wireless sensor network by minimizing the possibility of collision. It also decreases the control packet overhead, idle listening, overemitting and overhearing. The timeslot sharing is an efficient medium access protocol for wireless sensor networks. The proposed protocol is suitable for the sensor networks based on network coorcdinators like cluster heads and for the distributed sensor networks where there is no network coordinator.

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