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Strategies for Reducing Energy Consumption in Wireless Sensor Networks

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Abstract: Wireless sensor networks (WSN) consist of nodes that are usually battery powered and have restricted amount of energy. Energy consumption of nodes has to be reduced in order to increase the network lifetime. Hence energy management has become critical issue in WSN. This paper presents strategies to reduce energy consumption of nodes at communication and sensing level. We propose an optimized TDMA based MAC layer protocol-OLMAC (Optimized Lightweight Medium Access Control) protocol. This protocol exploits the inherent features of TDMA to avoid the main sources of energy wastage like collision and re-transmission, idle-listening, overhearing etc. A light sleep mode is introduced in OLMAC in order to reduce the switching energy consumption of nodes. This paper also discusses energy management strategy to reduce energy consumption of sensing unit in nodes. The strategies presented in this paper intend to reduce energy wastage in WSN and thus increase the network lifetime.

Keywords: WSN; MAC; TDMA; OLMAC; Energy consumption; communication unit; sensing unit; hierarchical sensing.

I. INTRODUCTION

A wireless sensor network (WSN) [14] consists of sensor nodes deployed over a geographical area for monitoring physical phenomena like temperature, humidity, vibrations, seismic events etc. Nodes in a WSN have the ability to collect and disseminate environmental data. WSNs have applications in a variety of fields such as environmental monitoring, military purposes and gathering sensing information in inhospitable locations etc.

Energy consumption of nodes is a crucial factor affecting the life of a sensor network because usually sensor nodes are driven by battery and have very low energy resources. In order to prolong a WSN lifetime, it is required to reduce the energy consumption of the nodes as much as possible [5, 14].

Typically, a sensor node contains three basic components: a sensing subsystem for data acquisition from the physical surrounding environment, a processing subsystem for local data processing and storage, and a wireless communication subsystem for data transmission and reception. In addition, a power source supplies the energy needed by the device to perform the programmed task [5]. Most of the energy is consumed by communication unit and sensing unit of the node.

Main reasons for energy wastage at communication level are collision and re-transmission, idle-listening, overhearing, control packet overhead and switching of nodes between states/modes. A node basically has states like active state in which the node can transmit and receive data, idle state in which the node listens to channel for possible incoming traffic and lastly the deep sleep state which consumes the least energy. Considerable amount of energy is consumed when a node switches from deep sleep to active state.

Medium access control (MAC) protocol [3] deals with when and how to access medium by a node, and how to transfer the data safely when there is more than one node accessing a single wireless channel simultaneously. Communication of sensor nodes is more energy-consuming than their computation, so it is a primary concern that the communication is minimized while achieving the desired network operation. Since the MAC protocol directly controls the communication module, it has important effect on the nodes' energy consumption. Thus there is a need to have a MAC protocol which reduces the main sources of energy wastage.

In some cases the energy consumed by sensing unit is almost same as that of communication unit [13]. Hence effective energy management strategies are required which reduce energy consumption at sensing level.

II. RELATED WORK

A. *Time Division Multiple Access (TDMA):*

Time division multiple access (TDMA) [3] is a channel access method for shared medium networks. In case of TDMA, time is divided into frames and each frame is divided into time-slots. Each time slot can be owned by one user. TDMA allows several users to share the same frequency channel. The users transmit in rapid succession, one after the other, each using its own time slot. This allows multiple stations to share the same transmission medium (e.g. radio frequency channel) while using only a part of its channel capacity.

B. *Lightweight Medium Access Control Protocol (LMAC):*

LMAC [2, 8, 11] is based upon TDMA. Time is divided into *time slots*, which nodes can use to transfer data without having to deal with energy wasting collisions. During its time slot, a node will transmit a message which consists of two parts: *control message* and a *data unit.* Since a time slot is

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controlled by a single node, the node can communicate *collision-free*.

The fixed sized control message is used for several purposes. It contains the *ID* of the time slot controller, it indicates the distance of the node to the gateway in hops for routing to a gateway in the network, it addresses the destination and reports the length of the *data unit*. The control data is also used to maintain synchronization between the nodes, so the nodes transmit the sequence number of their time slot in the frame. The control message contains fields like identification, current time slot number, occupied slots, distance to gateway, destination ID, and data size.

All neighbouring nodes receive the control messages of their neighbouring nodes. If the nodes are not addressed in that message, the nodes will switch off their power consuming transceivers and wake up at the next time slot. If a node is addressed, it will stay awake and listen to the data unit.

C. Enhanced Lightweight Medium Access Control Protocol (ELMAC):

Enhanced Lightweight Medium Access (ELMAC) [1, 7] control inherits the good features of LMAC. ELMAC is a TDMA based mechanism where time is constructed into a frame which is further divided into a number of timeslots. A node transmits a beacon packet at the beginning of its controlled timeslot. If there is a data to be transmitted, node notifies the destination node in the beacon packet. Otherwise, it turns to deep sleep mode in order to reduce the energy consumption. The destination needs to stay in the listening mode in order to receive the scheduled data. Nodes that are not needed for communication turn to deep sleep mode.

In ELMAC protocol, the process of obtaining a time slot by a sensor node is divided into three states: initial state, wait & discover state and active state as shown in figure 1.

When a new node enters a network, it starts the algorithm in *initial* state where node listens to the channel in order to find a beacon signal from its neighbourhood. Node turns into *wait and discover* state when it receives a beacon signal which enables it to start frame synchronization. Node waits for a random frame delay before selecting a free time slot and at the same time it also discovers its neighbouring nodes' status by collecting information from the received beacon signal. At the end of this state, the node uses equation (1) to find unoccupied time slot.

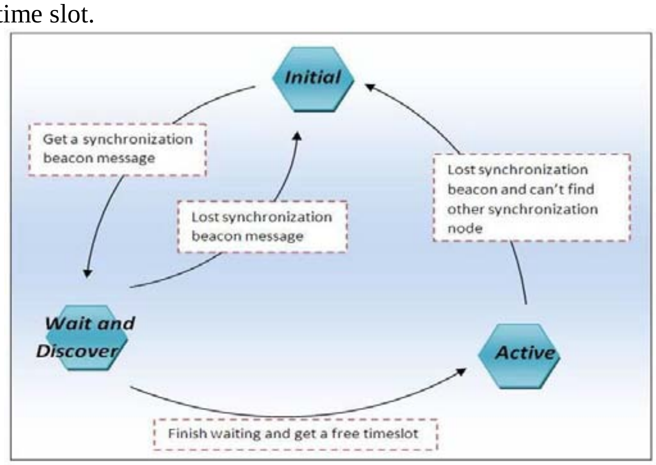

Figure 1: State diagram for time slot assignment in ELMAC [1]

$$Z_{OR}(x_1, x_2, \ldots, x_N) = x_1 \vee x_2 \vee \ldots \vee x_N \quad \text{--------} \quad (1)$$

In equation (1), the value of X_i is the i^{th} occupied time slot collected from the beacon message while $\vee$ is an OR operation. The resultant bitmap pattern from this operation will be in terms of 1's and 0's where 1's indicate occupied time slot, and 0's indicate the vacant ones. A node randomly chooses its time slot identification from the list of vacant ones (indicated by 0's). Node will enter active state when it has successfully selected a time slot. In this state, node will transmit a beacon message at the beginning of its time slot to indicate its allocated slot. It will also listen to the channel at the beginning of other time slots in order to listen for a beacon message from its neighbouring nodes. Node enters deep sleep mode in two scenarios. First, after transmitting a beacon message and no more data packet scheduled to be transmitted. Second, if it receives a beacon message from it neighbouring node indicating no incoming data packet.

D. Method for Assigning Timeslots:

Nodes in a WSN must be able to figure out autonomously which time slot they should control. The aim is to provide each node a time slot in which it can communicate without being interfered by other nodes. [2].

a. Occupied slots:

It is a bit vector with number of bits equal to number of time slots (as shown in Figure 2). In this bit vector, nodes keep track of controlled time slots around them and share this information with neighbours. Each position in the occupied slots bit vector represents a time slot. When a node receives a Control Message (CM) / beacon message successfully, it updates the vector by setting a logical '1' at the position of the time slot, otherwise a '0' will be inserted. A node inserts a '1' at the time slot it controls [2].

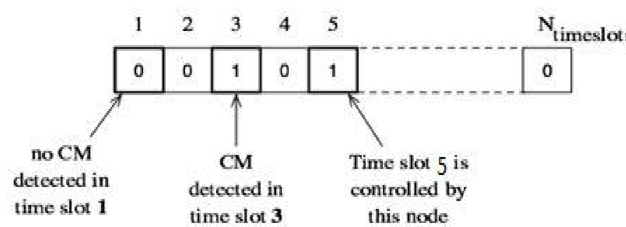

Figure 2: Example of the bit vector occupied slots [2]

b. Finding "Free" Time Slots:

When a node joins the wireless network, it needs to find out which time slot to control, before it can start sending data and participate in networking. Each node already present in the network, broadcasts a Control Message (CM) or beacon in its time slot. By listening to an entire frame, the new node in the network is aware of all its first order neighbours. Every node in the network gathers this local time slot usage information and transmits it in its occupied slots field in the CM. This allows a new node in the network to obtain a two-hop view of the network, providing information to create a list of free time slots from which the node can choose any. Assume that a node chooses a random time slot for the list of free ones [2].

When a node finds a neighbour transmitting in a certain time slot, it inserts a '1' in the occupied slots bit vector at the respective position for the timeslot, otherwise a zero is inserted at the position. To obtain a list of free time slots, a node needs to perform logical 'OR' operation on all the received occupied slots bit vectors that were transmitted in the frame. A '0' in the resulting vector means that the time slot is considered free in a two hop region and a '1' that a time slot is already taken by a first or second order neighbour. This ensures a spatial time slot re-usage after no less than three hops. The algorithm is illustrated in figure 3. In figure 3 the gray shaded node is new in the network. It listens for a complete frame and discovers that time slots 1, 2 and 7 are not used. It can safely choose one of those three slots. When there are no more free slots the node remains in initialization state, periodically monitoring frames to find an empty time slot. And data size. If the destination IDs match then the node remains in listen state till the packet is received. If the packet is not destined to that node, it checks the data size. If the data size is less than the threshold value then the node goes to light sleep state. Else the node goes to deep sleep state.

As radio energy consumption is a major component contributing to the overall energy consumption at each node, current MAC protocols put the radio in deep sleep mode while there is no data to send or receive, in order to reduce energy consumption. Putting the nodes to light sleep state in case of small data packets helps avoiding energy wastage due to frequent switching between deep sleep and active state.

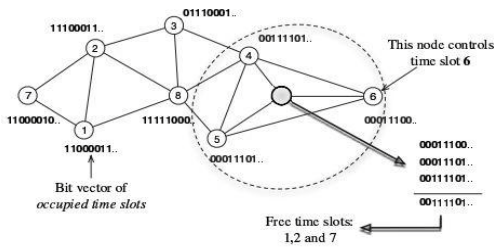

Figure 3: Method for finding free slots [2]

E. *Energy management in sensing unit:*

Hierarchical sensing [13] is an efficient strategy to reduce energy consumption of sensing unit. According to this strategy multiple sensors are installed on the sensor nodes to observe the same phenomenon with a different resolution and power consumption. The idea behind hierarchical sensing technique is to dynamically select which of the available sensors must be activated, by trading off accuracy for energy conservation. The final measurement is inferred by processing data coming from all sensors. In most cases, simple sensors are energy efficient but provide a very limited resolution. On the other hand, advanced/complex sensors can give a more accurate characterization of the sensed phenomenon at the cost of higher energy consumption. At first, low-power sensors are considered to provide a coarse-grained characterization of the sensing field. Then accurate but power hungry- sensors can be activated to collect detailed data and to improve the coarser description.

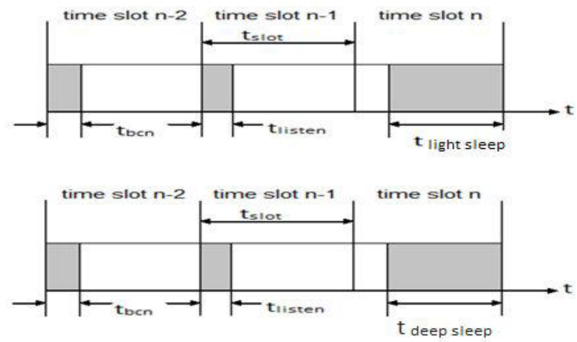

Figure 4: Frame structure for OLMAC protocol

a. *Protocol scenario:*

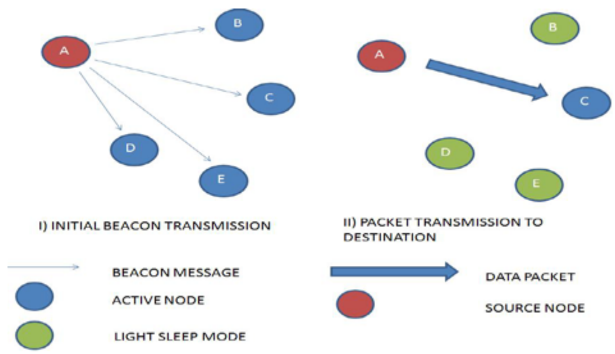

Figure 5: Scenario with light sleep mode

III. PROPOSED WORK- OLMAC

In this paper we propose an optimized TDMA based MAC layer protocol-OLMAC. This protocol is based on LMAC and ELMAC protocols. A new light sleep mode is introduced OLMAC protocol. This conserves the radio power consumed while switching from deep sleep state to active state during small data packet transmission. A node uses a timeslot allocation mechanism to occupy a timeslot as described in section II. At the start of the time slot, a beacon message is sent. The contents of beacon message are shown in table I.

Table I: Byte distribution of beacon message

Description	**Size (Bytes)**
Time Slot	1
Time Synchronization	1
Occupied Slots	4
Destination ID	2
Data Size	1
TOTAL	9

Consider a topology of five nodes (A, B, C, D, E) as

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shown in figure 5. Let node A be given the first slot. Node A sends a beacon signal which has its destination as node C and data size less than threshold. The beacon signal will be broadcasted by A and will be received by all other nodes. After receiving the packet, the nodes check for destination ID and data size. Nodes B, D and E go to the low power state since the data size is less than threshold. If the nodes are put to deep sleep state, they will have to wake up after a short duration and listen to next slot beacon message. Since switching from deep sleep to active state consumes energy, going into sleeping for a short duration and then waking up soon for listening to next beacon message will waste considerable amount of energy. Putting the nodes to light sleep state saves the energy wasted in frequent switching. Node C will remain in active state and listen to the data unit.

If there is a data to be transmitted, the sender node informs the destination node in the beacon packet. After receiving.

If the data size is greater than the threshold, the nodes B, D and E will go to the deep sleep state. Nodes are not put to light sleep state since the data packet is of a long duration and putting the node to light sleep state will consume more power than putting the node to deep sleep. The scenario is depicted in figure 6.

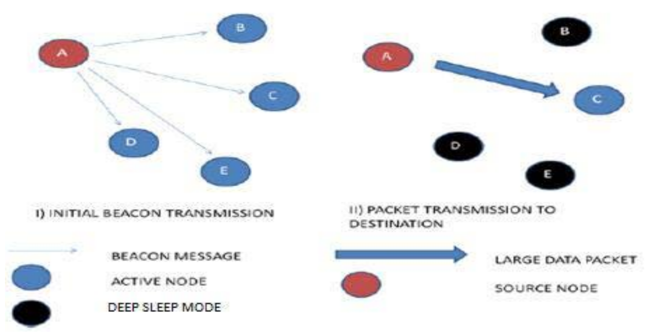

Figure 6: Scenario with deep sleep mode beacon packet, the receiving nodes check for destination ID

A. Characteristics of OLMAC

a. OLMAC is TDMA based protocol. Since only one node transmits in a given time slot there would be no collision of packets. Hence energy wastage due to *collision and retransmission* of packets is eliminated.

b. During its time slot, a node will transmit a message which consists of two parts: control message/beacon and a data unit. The beacon consists of fields like destination ID. When a beacon is received, the node will compare its ID with the destination ID present in beacon. If the IDs match then the node will remain active and listen to the data unit of the message. But if the IDs do not match, the node will go to sleep mode. This will reduce the energy consumption due to *idle listening and over hearing.*

c. OLMAC contains a new state of node called the light sleep state. In case of small message (less than threshold) a node enters light sleep state instead of deep sleep state. This reduces the *switching energy* consumed by the node while switching from deep sleep state to active state.

The OLMAC technique described in section III deals with energy management at communication level. To reduce energy consumed by sensing unit, we can use the hierarchical sensing strategy [13]. Combination of the two strategies would reduce considerable amount of energy consumption and in turn increase the network lifetime.

IV. IMPLEMENTATION AND PERFORMANCE EVALUATION

We plan to evaluate performance of the proposed protocol (OLMAC) by simulation using OMNeT++ simulator. We would then compare the proposed protocol (OLMAC) with the existing protocol- ELMAC.

To compare ELMAC and OLMAC we would simulate different scenarios for each protocol. In case of ELMAC, deep sleep mode would be used. In case of OLMAC deep sleep mode and light sleep mode would be used. Graphs could be plotted for the scenarios to evaluate the energy consumption of nodes as time progresses. We could then perform relative network life time comparison, to check which of the two protocols performs better.

V. CONCLUSION

Energy management is a crucial factor in the design of a wireless sensor network (WSN) because sensor nodes in WSN have low energy capacity. Energy wastage has to be reduced in order to increase network lifetime. In this paper we have proposed an optimized TDMA based MAC layer protocol-OLMAC in order to prolong network lifetime. OLMAC inherits good features from LMAC and ELMAC protocols and would avoid the main sources of energy wastage. A light sleep mode is introduced in OLMAC in order to reduce the switching energy consumption of nodes. Transition from light sleep mode to active mode would be quick and energy inexpensive compared to deep sleep mode. Nodes will be put in light sleep state instead of deep sleep state when the data packet to be sent is small. If the data packet is large, then the nodes will be put to deep sleep state. This process would decrease the energy wastage which takes place due to switching from deep sleep state to active state in case of small data packets transmissions. Also hierarchical sensing strategy would reduce energy consumption in WSN to quite an extent. Thus OLMAC and hierarchical sensing would increase the network lifetime.

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