A Proposed Adaptive Mobility of MAC Protocol Using Sleep and Wake Cycling in Wireless Sensor Network

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Abstract: - In wireless sensor networks have imposed significant challenges for the medium access control (MAC) protocol design to provide reliable communication with good data rates and low energy consumption using Sleep wake cycle nodes. Most of the MAC protocols proposed for wireless sensor networks assume static sensor nodes but nodes know their locations, and they sleep-wake cycle, waking up periodically but not synchronously, which usually causes upgradation in network performance in scenarios involving mobile sensors. When a node has a packet to forward to the sink, there is a trade-off between how long this node waits for a suitable neighbor to wake up, and the progress the packet makes towards the sink once it is forwarded to this neighbor. In this paper, we introduce a mobility awareness and energy-efficient medium access control protocol with sleep and wake up cycle (shortly abbreviated as MMAC-SW) for mobile wireless sensor networks. Our MMAC-SW is based on a hybrid scheme of TDMA and CSMA that informs sensor nodes when to wake up or when to go to sleep to save energy. Through computer simulations, we evaluate the performance of the MMAC-SW and compare it against the MMAC protocol. Simulation results will show that MMAC-SW outperforms MMAC in terms of energy consumption, packet delivery ratio, and average packet delay. Keywords: energy efficient, MAC protocol, mobility handling, sleep and wake cycling.

1. INTRODUCTION

A wireless sensor network (WSN) is a network of self-organizing low powered devices having sensing and communication capabilities. These small and inexpensive devices are battery powered, thus sensor nodes must be energy efficient [4]. As developments of these micro-electromechanical systems, digital electronics, and wireless communications technologies have led to create low cost, low power, and multifunctional sensor devices [3]. In such WSNs, typically the nodes rely on batteries, or energy harvested from their surroundings, and, hence, need to be extremely parsimonious in their use of energy. In order to conserve energy, the nodes operate in sleep-wake cycles. In such WSNs, typically the nodes rely on batteries, or energy harvested from their surroundings, and, hence, need to be extremely parsimonious in their use of energy. In order to conserve energy, the nodes operate in sleep-wake cycles; when a node wakes up it performs sensing, and also can assist in forwarding any alarm packets towards the sink. There are numerous advantages of MMAC-SW using sleep and wake-up cycle over the static WSNs. In particular, it offers:

i) dynamic network coverage [11], by reaching areas that have not been adequately sampled.
ii) data routing repair, by replacing failed routing nodes with their adequate node in the network.
iii) data muling, by collecting and disseminating data/reading from stationary nodes out of range.
iv) staged data stream processing, by conducting in-network processing of continuous and ad hoc queries.
v) user access points, by enabling connection to handheld and other mobile devices that are out of range from the communication infrastructure.

Energy consumption has been considered as the single and important design key in sensor networks, hence, the most recent work on medium access control (MAC) protocol for sensor networks focused on energy efficiency, where MAC protocols play a crucial role in controlling the usage of the radio unit. The radio transceiver unit is the major power consumer unit in the sensor node. For most MAC protocols designed for WSNs [12], it is assumed that the sensor nodes are stationary, which causes performance degradation when these protocols are applied in mobile environments. In this paper, we present an adaptive mobility aware, and energy-efficient MAC (MMAC-SW) protocol using sleep and wake up cycles for wireless sensor networks. MMAC-SW is a hybrid based MAC protocols that combines the advantages of the protocols presented in [11][12][13] while offsetting their shortcomings. MEMAC utilizes a hybrid approach of both scheduled (TDMA) and contention
based (CSMA) medium access schemes. MMAC-SW differentiates between data and control messages; long data messages are assigned scheduled TDMA slots (only those nodes, which have data to send are assigned slots), whilst short control messages are assigned random access slots. This technique limits message collisions and reduces the total energy consumed by the radio transceiver [12]. Furthermore, MMAC-SW uses a dynamic frame size to enable the protocol to effectively adapt itself to changes in mobility conditions. Mobility prediction through the use of the first order auto aggressive moving average model [14] is used to dynamically adjust the frame size and control the channel access in an efficient way according to the mobility conditions. We have designed and implemented the MMAC-SW protocol in event network simulator, where many simulation experiments are carried out to evaluate the performance of MMAC-SW and compared it with MMAC [14]. The rest of the paper is organized as follows. We present and discuss some related works in section II. Describes the MMAC-SW protocol, In section III describe what will be the system model of the protocol. In section IV Describes the Data transfer phase performance is studied through intensive simulation experiments. Finally, we conclude the paper in section V.

II. MMAC-SW PROTOCOL

In sensor networks, nodes may fail (e.g., power drained) or new nodes may be added (e.g., additional sensors deployed), or sensor nodes may physically move from their locations, either because of the motion of the medium (e.g., water, air) or by means of a special motion hardware in the mobile sensor nodes. To accommodate these topology dynamics, our MMAC-SW protocol uses a hybrid approach of contention-based and scheduled-based schemes as in our previous MAC protocol (SEHM protocol) presented in [11]. MMAC-SW differs from SEHM protocol in terms of mobility handling of sensor nodes. MMAC-SW adapts the frame length according to mobility conditions by incorporating a mobility prediction model. In the following section we discuss some mobility issues.

A. Mobility Handling

Mobility in sensor networks brings some challenges in designing MAC protocols, which are mainly responsible for packet scheduling, transmission, collision avoidance, and resolution. Handling mobility at MAC layer involves careful trade-off in energy efficiency, throughput, and robustness under mobility. In this section, we discuss some mobility issues relevant to the MAC protocol design [19].

- The mobility of nodes causes synchronization and frame errors in the network. A mobility aware MAC protocol needs to cope with these errors by adjusting the frame time to reduce errors and allow nodes to make faster connections on joining or leaving the network.

- In contention based MAC protocols, as mobility increase the probability of collision increases accordingly, and hence retransmissions are required which leads to high energy consumption. A mobility aware MAC protocol should use the mobility information to wake-up and switch-off nodes accordingly in order to avoid collisions and decrease energy consumption.

- In scheduled based MAC protocols, a neighborhood inconsistency of two-hop neighbor information can occur, when mobile nodes join or leave the neighborhood. This leads to schedule inconsistencies. The MAC protocol should adapt the schedule according to mobility conditions in the network and determine which and when nodes are allowed to join or leave the neighborhood to eliminate these inconsistencies.

- Generally, mobility information needed by the MAC protocols includes node positions and the mobility information of their neighbors for better mobility detection and handling. Therefore, the mobility information has to be periodically disseminated to neighboring nodes which increases the overhead in the form of control messages in the MAC protocol. Instead of adding the mobility information into control packets of each layer, the mobility information may be made common to different layers through a common control message.

- An important limitation in designing mobility adaptive MAC protocols for sensor network is the choice of the mobility models considered in the design. It is important to choose a mobility model that applies to real life settings.

III. SYSTEM MODEL

A. Node Deployment

N identical sensor nodes are uniformly deployed in the region $R$. We take $N$ to be a Poisson random variable of rate $\beta$ where is the node density. Let $x_i, i = 1, 2, ..., N$, be the locations of the nodes. Additional source and sink nodes are placed at fixed locations $X_0 = (0, 0)$ and $X_{N+1} = (L, L)$ respectively. Thus including the source and sink nodes, there are a total of $N+2$ nodes in the disk. $rc$ is the communication range of each node. Two nodes $i$ and $j$ are called neighbors if and only if $|x_i - x_j| < rc$. The distance between node $i$ and sink $(N + 1)$ is $Li |XN+1 - Xi|$.
B. The Sleep-Wake Process

To conserve energy, each node performs periodic sleep-wake cycling. The sleep-wake times of the nodes are not synchronized. Since we are interested in studying the delay incurred in routing due to sleep-wake cycling alone, we neglect the transmission delay, propagation delay and other overhead delays. This means that if node i has a packet to transmit to its neighboring node j, then i can transmit immediately at the instant j wakes up. We model this by taking the time for which a node stays awake to be zero. More formally, let $T_i$, $i = 1, 2, ... N + 1$ be i.id. Random variables which are uniform on $[0, T]$, where T is the period of the sleep wake cycle. Then node i wakes up at the periodic instants $KT_i$, $K > 0$. We define the waiting time for i to wake up at time t as,

$$W_i(t) = \inf \{KT_i + T_i > t \cap k > 0\} - t.$$  

C. Forwarding Rules and Assumptions

Forwarding rules dictate the actions a node can take when it has to transmit. We are interested in decentralized policies where a node can take decisions only by observing the activities in its neighborhood (i.e., the disk of radius $r_c$ centered around the node of interest). In this regard we impose some restrictions on the network.

Traffic Model: There is a single packet in the network which is to be routed from the source to sink. At time 0, the packet is given to the source and the routing process begins. The nodes which get the packet for forwarding are called relay nodes. The packet traverses a sequence of relay nodes to eventually reach the sink, at which time the routing ends. Thus there is a single flow and further the flow consists of only one packet. This set up is reasonable, because in sensor networks we can assume that the events are sufficiently separated in time and/or location so that the flows due to two events do not intersect. To avoid multiple packet transmission by different nodes detecting the same event, the nodes can resolve among themselves to select one node (say the one closest to the sink), which can then transmit. Further, the information about an event comprises its location, and possibly target classification data, which along with some control bits can be easily incorporated in a single packet. This justifies the idea to study the performance of a single packet alone.

Forwarding Set: Each node knows its location and the location of the sink. The forwarding set of a node is the set of its neighbors that are closer to the sink then itself. A relay node considers forwarding the packet only to a node in its forwarding set. Each node knows the number of neighbors in its forwarding set, but is not aware of their locations and wake times. While in this paper we assume that each node knows the number of nodes in its forwarding set, it would be desirable to develop forwarding algorithms that do not require even this knowledge.

Data Transfer Phase

After the compilation of the clustering phase and the CHs are advertised, the data transfer phase begins. Data transfer in MMAC-SW is based on frames and the CHs control the frames. The CH is responsible for controlling the channel access between sensor nodes within the cluster and collects data from them. The frames are handled during multiple phases using a hybrid scheme of CSMA and TDMA. Each frame is composed of two slots (see Fig. 1): mini slot and a dynamic normal slot. The Mini-slot is used to transmit and receive control signals, and consists of three parts: Frame Synchronization (SYNC), Random Access, and Receive Scheduling. The Normal slot is used by sensor nodes to report their data to the CH. The frame length is made dynamic to make the protocol sensitive to mobility and traffic conditions (i.e. the number of time slots is increased or decreased according to the number of nodes that have data to send).

MMAC-SW protocol handles the channel access through the following four phases:

Schedule Calculation and Distribution, and Data Transfer. Nodes that have data to send should content for the channel during the Request/Update/Join phase and send their requests to the CH. As well those nodes which want to join or leave to/from the cluster should send requests during this phase. Then, sensor nodes use the TDMA slots calculated and distributed by the CH to send their data during the data transfer phase to CHs. Sensor nodes that have no data to transmit go to sleep directly after the end of the mini-slot. More details are given below about the operation of the MEMAC protocol in different phases:

Synchronization phase: At the beginning of each frame, the head node broadcasts a SYNC message to all sensor nodes all sensor nodes should be in receive mode during this phase to be able to capture the SYNC message. The SYNC message contains synchronization information for the packet Transmission.
Request/Leave/Join phase: During this phase, sensor nodes that have data to transmit content for the channel in order to acquire the access to send its request to the CH. The contention period should be long enough to enable all nodes that have data to send to pass their requests to the CH. As well, those nodes which are expected to leave or join the cluster should inform the CH by sending a leave or join message.

Schedule Calculation and Distribution phase: In this phase the CH calculates the schedule and broadcasts it to the other nodes within the cluster. The schedule contains those nodes which have data to send only. Nodes that want to leave or join the cluster are not considered in the current schedule. Thus, the frame length is adjusted according to the number of request, leave, and join messages. If the number of request messages are greater than the number of join/leave messages, then the frame length is increased otherwise the frame length is reduced. The frame adjustment algorithm of the MEMAC protocol is an improved version of the mobility adaptive algorithm presented in [13], the algorithm is as follow:
1. For all nodes within the cluster, calculate the predicted states using the AR-I model.
2. For all nodes in the cluster, calculate the average estimated location.
3. Using the above information construct the set of joining 'J' and leaving 'L' nodes.
4. Count the request messages and construct a set of nodes which have a data to send 'R'.
5. If a node n is a member of the set of joining or leaving nodes, do not consider n in the schedule.
6. If the number of members in set 'R' are greater than the number of members in both sets of 'J' and 'L', then increase the frame length, otherwise reduce the frame length.
7. Adjust the frame normal slot and the random access period in the frame structure according to the new frame time.

Finally, the CH broadcasts the schedule packet to all sensor nodes that contains the TDMA slots for the subsequent phase “data transfer phase”. In this phase all sensor nodes should be in receive mode.

Data Transfer phase: In this phase, sensor nodes use the TDMA slots to transmit their data to the CH or to communicate with their neighbors. All sensor nodes that have no traffic to transmit or receive should turn their radios transceivers off and enter sleep mode. Once data are reported to CHs, the BS collects data from CHs. A dynamic TDMA scheme is used to allow CHs to access the channel and report their data to the BS. The BS is responsible of calculating and distributing time slots to CHs. We assume that all CHs have data to report to the BS. As a result, the random access period is removed, and the frame becomes as shown in Fig. 2.

IV. PERFORMANCE ANALYSIS

To study and evaluate the performance of the MMAC-SW protocol and compare it with MMAC protocol, we will use Sensor Simulator framework [24]. The simulator contains a model of the EYES wireless sensor node [26]. Furthermore, the simulator has the same limits as the EYES nodes have. Additionally, the simulator has modules for all layers of the WSN protocol stack. The Energy consumption in the EYES model is based on the amount of energy the radio consumes. The consumed energy by the CPU as a result of the protocol execution is not taken into account. The motivation behind using Sensor Simulator is that it enables users to easily modify the sensor network and to implement large scale networks. Furthermore, it executes at least an order of magnitude faster than NS-2 and makes more efficient use of the available memory [24]. In this section we investigate the performance of the proposed protocol MMAC-SW in a clustered network topology, and compare it against MMAC protocol. The performance metrics used in the evaluation of MMAC-SW will be the average energy consumption, average packet delivery ratio and average delay.

V. CONCLUSION and FUTURE WORK

The evolution of stationary WSNs in conjunction with the advances made by the distributed robotics and low power embedded systems communities have led to a new class of Mobile Wireless Sensor Networks (MSNs). In addition to the energy constraints and processing power limitations, mobility in MSN adds a new design dimension. Most of the proposed MAC protocols for WSN networks are designed assuming that sensor nodes are stationary. This assumption no longer valid for MSNs. Therefore designing a mobility aware MAC protocols becomes more and more important. In this paper, we presented MMAC-SW protocol - an adaptive mobility aware and energy efficient MAC protocol for MSNs using sleep and wake up cycles. MMAC-SW combines the benefits of contention based and scheduled based protocols to achieve a significant amount of energy
savings. MMAC-SW adjusts the frame length according to mobility information of the sensor nodes and the number of nodes that have data to send, this avoids wasting slots by excluding the nodes which are expected to leave or join the cluster and those nodes which have no data to transmit from the TDMA schedule, and to switch nodes to sleep mode when they are not included in the communication process. Through extensive simulation experiments, we are proposed our protocol and compared it against MMAC protocol. Simulation results will demonstrate that our MMAC-SW protocol performs the energy efficient in terms of average energy consumption, average delivery ratio, and average packet delay.

REFERENCES


