Power Saving Method for Target Tracking Sensor Networks to Improve the Lifetime

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Abstract

Target tracking sensor networks monitor and track the movement of a target object. Power management in these sensor networks is crucial to prolong the network lifetime. We propose a new protocol PMM (Power Management Method for tracking sensor networks) that provides a dynamic sleep schedule for the radios such that maximum power is saved without affecting the sensors' activities. When there is no target, the communication modules of sensor nodes are put into sleep using a static schedule, except the outline nodes. Inside nodes do not perform the sensing activity in the surveillance state. If a target arrives, the sleep schedule for the radios is changed dynamically in order to send the arrival message to neighboring sensors. Whenever receiving the arrival message, the sleeping neighbor nodes start sensing. The objectives of our protocol are to (1) balance the lifetime of all the sensor nodes in the network to increase the network lifetime (2) reduce the power consumption by activating the sensors only when the target arrives in that region. Simulation results show that PMM provides a significant amount of Power savings and potentially increases the network lifetime by 25% more than S-MAC at very less load.

Keywords: Target tracking sensor networks, MAC protocols, Power management, Sleep methods

1. INTRODUCTION

Wireless sensor networks (WSN) can be used for a number of strategic applications such as coordinated target detection, surveillance, and localization [1]-[4]. In target tracking applications, interesting events like movement of an intruder, movement of wild life in forest or reservoirs, or movement of enemy tanks in battle-field can be monitored. The monitoring sensor network should remain at certain level of vigilance, as well as work in an unattended manner as long as possible. The user is only interested in the occurrence of a certain event or a set of events. The interesting events happen infrequently with long intervals of inactivity.

The sensor nodes can stay in sleeping mode during the long intervals of inactivity and be awake in the tracking state. The network operations have two states. In the surveillance state, when there are no events of interest in the field, the sensors should be ready to detect any possible occurrences. In the tracking state, the network should react in response to any moving target and the sensors collaborate in measuring the target's path and speed.

A given area can be monitored perfectly with a set of sensor nodes to detect targets. However, since the sensor nodes have limited power, the quality of monitoring becomes inversely proportional to the lifetime of the network. Power saving operations at each node plays a critical role in extending the network lifetime. The more time the nodes are active, the more power they drain out and hence new nodes should be redeployed to monitor the network area. This implies increase of cost of maintenance of the network. On the other hand, the less time the nodes are active, the more power they conserve and hence longer will be the time for redeployment. However existing target tracking protocols are not specifically designed to track targets with minimum power consumption.

In our paper, we propose a novel sleep schedule PMM (Power Management Method for Target tracking sensor networks) for the radios that save maximum power without affecting the sensors' activities. In the surveillance state, the inside nodes are allowed to sleep more. When the target enters the network, the sleep schedule of the interior nodes is varied dynamically based on the movement of the target. This helps to track the target with minimum power consumption. In addition, our schedule improves lifetime by balancing the lifetime of the inside and outer nodes.

The rest of the paper is organized as follows. In Section II, the related work that discusses thevarious types of sleep planning is presented. The proposed power management method and the theoretical analysis are explained in Section III. The simulation results for evaluating the performance of our protocol are presented in Section IV. Finally, the conclusion is given in Section V.

II. RELATED WORK

In target tracking sensor networks, nodes are in idle state for most time, when no event happens. It would be a significant waste of power if all nodes always keep their radios on, since the radio is a major power consumer. An ideal power conservation policy would switch radios off when a node is not required to act either as a data source or relay in multi-hop routing. Various contention-based and TDMA-based MAC protocols proposed to reduce power consumption have been discussed in [7].

TRAMA [8] is a scheduling protocol that allows nodes to switch to the low power idle state whenever they are not transmitting and receiving. It determines which node can transmit at a particular slot based on the traffic information at each node. In [9], event scheduling is used which allows each node to power down its radio during the portion of the schedule that does not match its particular event subscription. However, TDMA-based protocols are complex to maintain in a multi-hop sensor network due to their timing synchronization.

IEEE 802.11 distributed coordination function (DCF) [10] is a CSMA type protocol in which power consumption is very high due to idle listening of nodes. S-MAC [11] is a contention-based protocol with integrated low-duty-cycle operation that supports multi-hop operation. The basic scheme of S-MAC is to put all nodes into periodic listen and sleep. Nodes exchange and coordinate on their sleep schedules rather than randomly sleep on their own. The overall gain on power savings is much higher. However, periodic sleeping increases latency and reduces throughput, since a sender must wait for the receiver to wake up before it can send out data. T-MAC [12] reduces idle listening by transmitting all messages in bursts of variable length and sleeping between bursts. However latency in T-MAC increases because data arrived during sleep is queued until the next active cycle. D-MAC [13] follows a periodic sleep schedule with an offset that depends upon its depth on the data-gathering tree but does not use collision avoidance methods.

However, the above mentioned protocols are not meant for target tracking applications and do not focus on balancing the lifetime of the sensor nodes which are deployed at different parts of the network. Whereas our protocol uses an adaptive sleep schedule to reduce the latency and increase the power savings.

For a target tracking sensor network, though intensive coverage is needed at the time and location of the target event, partial coverage is enough during the surveillance state. An algorithm to alert nodes along the projected path of the target is discussed in [5]. Chao Gui, et al [6] presented an power saving mechanism for target tracking sensor networks. For the surveillance state, they developed a sleep plan for each sensor node for when to turn them off. From a spatial perspective, the sleep plan governs the distribution as well as the number of active sensors at any given time. But this protocol reduces power consumption by scheduling only the sensing activity and does not provide the sleep schedule for the radios of the nodes like our protocol.

A. **Our Work**

In the tracking environment, nodes that are far away from sink have to forward fewer packets and hence their lifetime is longer. The nodes that are nearer to sink suffer due to high load, as they have to forward the packets of all the other outer nodes. This leads to reduction in lifetime of the nearby nodes. Existing sleep planning protocols are not specifically designed to balance the lifetime of all the nodes in target tracking application.

We propose a new protocol (PMM) that provides an adaptive sleep schedule for the radios such that the target tracking can be done with minimum power consumption. The objective of our protocol is to balance the lifetime of both the nearby and far away sensor nodes to prolong the network lifetime. Whenever there is no target, radios of the inside nodes are put into sleep and activated during the presence of the target. Though the sleep schedule saves power, it may lead to missing of event detection as the nodes are put into sleep mode. Hence the sleep schedule of interior nodes is changed dynamically during the arrival of a target.

III. PMM PROTOCOL

In target tracking applications, the target enters in the outer region and moves randomly in the environment. Hence, the sensing information has to be communicated to the data sink only during the target's arrival. We exploit the above feature to design an effective sleep schedule for target tracking sensor networks that minimizes energy consumption. Our sleep schedule is designed to suit the surveillance and tracking state. It conserves energy by allowing more nodes to sleep in the surveillance state and tracks the target by dynamically changing the schedule in the tracking state.

Our PMM protocol is designed to have two types of sleep planning to suit the above condition. It follows a *(1) static sleep schedule* when there is no target (surveillance state) and (2) *dynamic sleep schedule* when there is target (tracking state). In PMM, the radio of border layer nodes is always 'on' to communicate with the interior layers if a target is detected. The interior nodes' radios are not on unless otherwise they have been informed by their neighbors that a target is found. Interior nodes that are nearer to the sink are given the chance to sleep more when compared to the border nodes. This kind of sleep schedule enables us to balance the lifetime of all the nodes. However, there may be some control packet overhead to implement the dynamic schedule.

Assumptions: All the nodes are considered to be homogeneous and static. The base station is located in the center of the network. The ratio of communication radius to sensing radius is considered as two. Single or multiple targets can be tracked in a 2-dimensional terrain space. Nodes in the network are GPS equipped or use localization algorithms, so that information about the node's position is used to find the exact trajectory of the target.

A. **Static Sleep Schedule**

In our paper, sensor nodes are categorized as border nodes and interior nodes and are operated in layers. The top two layers are considered as border layers and the rest are interior layers. The borders nodes (radio) are kept alert all the time in order to detect the target. But the border nodes may die out quickly if they are active (sensing + communicating) all the time. So we keep two border layers to sense at alternate time intervals such that one layer is always ready to detect any target. The radios of border layer nodes are either always 'on' or periodically 'on' (based on the application and target speed) to communicate with the interior layers if a target is detected. The radio of all the interior nodes is not 'on' unless otherwise they have been informed by their neighbors that a target is found. Also interior nodes do not perform the sensing activity until a target's arrival message is received. Interior nodes follow a sleep schedule that is different from that of the border nodes to conserve power. Figure 1 shows the proposed sleep schedule during the surveillance state. A unit time T is divided into two slots Ton and Toff. The nodes in border layers will be active during Ton and sleep during Toff. We assume there are n-1 interior layers. The nodes in layer (n-1) will wakeup once in every two units of time. The nodes in layer (n-3) will wakeup once in every four units of time. The nodes in (n-5) layer will wakeup once in every eight units of time and so on. Layers (n-2), (n-4)... are used for synchronization. The effectiveness of this sleep schedule is interior nodes that are nearer to the sink are given the chance to sleep more when compared to the border nodes. The key idea is though the interior nodes have longer sleep time, they can receive the target's arrival message in time as the target takes some time to reach the interior nodes.

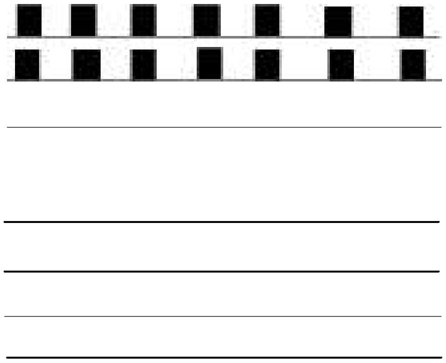

Fig. 1 Sleep schedule for radios of nodes when there is no target

Balancing the lifetime of the nodes:

In target tracking, interior nodes that are nearer to the sink will be forwarding a lot of data packets from the exterior layers. If a target arrives, the interior nodes handle more traffic when compared with that of the exterior nodes because of their data-forwarding task. This leads to decrease in the lifetime of the interior nodes. On the other hand, the exterior nodes will have higher lifetime, because of less forwarding overhead. Hence there is a need to balance the lifetime of border nodes and interior nodes so that the overall network lifetime increases.

Each sensor node consists of sensing, computing, storing and communicating modules. In order to conserve power, the energy saving by the communication can be reduced by periodically making the radio off using appropriate sleep schedule. Let E_pkt and E_radio denote the energy consumption for packet transmission and periodic radio 'on' respectively. The interior nodes have higher E_pkt value and lower E_radio value; where as the border nodes have lower E_pkt value and higher E_radio value. Hence, Interior (E_pkt + E_radio) is almost equal to border (E_pkt + E_radio). Since our sleep schedule saves more power at the interior nodes by allowing them to sleep whenever no target is found in the network, the lifetime of the nodes is balanced. This leads PMM to achieve maximum lifetime in target tracking networks.

B. Dynamic Sleep Schedule

In the tracking state, the static schedule is dynamically changed to track the target with spatial and temporal precision. Since the interior nodes have longer sleep time, there are possibilities that they may not be alert when a target arrives. Hence, whenever a target enters the network area, the radio schedule is changed dynamically for the nearby nodes. As the target moves, the neighboring nodes are informed to be alert, i.e. the nodes should be able to sense before the target reaches that position. Whenever a target is identified, the one-hop neighbors are made alert immediately. Then the 2nd , 3rd.. 'n'th hop neighbors are informed to change their sleep schedule. The nodes reduce the sleep interval by adding additional 'on' time slots. As the number of hops increases, the number of additional 'on' slots required decreases. The desired value of n depends on the application and target speed.

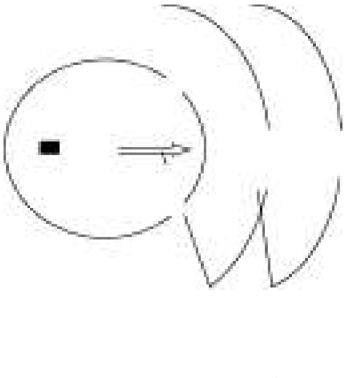

Fig. 2. Target movement from region A and the next hop neighbors

Assume the target is currently moving in region A as shown in Figure 2. From the velocity of the target, we predict the future location of the target. Let the predicted path of target movement is B, C, D...N. The one- hop neighbors (region B), two hop neighbors (region C), three hop neighbors (region D) change their schedule dynamically. This change is applied till 'n' th hop neighbors. As the target moves, the path should be activated dynamically. Figure 3 shows the old and new sleep schedule of the neighboring nodes as the target moves from region A towards region D.

C. Theoretical Analysis

In this section, we analyze our protocol's static and dynamic schedules and mathematically show how the lifetime increases. Let S be the maximum speed of target and R be the coverage radius of sensor node. Let Tmax be the maximum sleep time of an interior node. In *Static sleep schedule* ie when there is no target, we find the maximum sleep time for the sensor nodes as per the details in Table 1. *In Dynamic sleep schedule,* the sleeping interior nodes should be activated before the target enters in that region because tracking should not fail due to late alert message. Let H be the number of hops to be activated prior before the target enters into that region. The maximum sleep time is given as follows:

$$Tmax < R/S * H \qquad (1)$$

Hence, we derive the number of hops to be initiated prior as,

$$H > Tmax * S/ R \qquad (2)$$

TABLE 1 Maximum Sleep time

Node description	**Max sleep time between two consecutive 'on' slots**
Node is 1-hop away from border nodes	**R/S**
Node is 2-hops away from border nodes	2R/S
Node is n-hops away from border nodes	**(n-1)R/S**

Balancing Lifetime:

We find the energy consumption of the border and interior nodes as follows. The notations used are listed in Table 2. For S-MAC protocol, all the nodes in the border layer and interior layer will be sleeping for the same time. Hence, energy consumption of the border and interior nodes in S-MAC is given by equations 3 and 4.

$$Eborder = [Ttotal/(Tsleep +Ton) * Elisten] + [K * Etx] \qquad (3)$$

$$Einterior = [Ttotal/(Tsleep +Ton) * Elisten] + [Nodes * K * Etx] \qquad (4)$$

Here, Eborder < Einterior, which leads to lesser lifetime of the network. In EST protocol, the sleep time is based on Tmax and the interior nodes are allowed to sleep more. So, energy consumption of the border and interior nodes in EST is given by equations 5and 6.

$$Eborder = [Ttotal/(Tsleep +Ton) * Elisten] + [K * Etx] \qquad (5)$$

$$Einterior = [Ttotal/((n-1)*R/S +Ton) * Elisten] + [Nodes * K * Etx] \qquad (6)$$

Though Eborder and Einterior are not exactly equal, there exists a balance in energy consumption of border nodes and interior nodes, which leads to increase in the network lifetime. Hence PMM increases the network lifetime compared to S-MAC.

IV. SIMULATION RESULTS

The performance for PMM is evaluated using the GloMoSim [14] discrete event simulator. The parameters used in our simulation are listed in Table 3. The terrain area is 1000m x 1000m with a uniform random distribution of 1000 nodes. The target enters the field at a random location and moves at a constant speed. The simulation setup is run when there is no target and when there is target with different amounts of network traffic. To compare the performance of PMM with other schedules, we evaluate the 3 protocols, namely (1) 802.11 DCF (nodes are always on) (2) S-MAC (all the nodes are on for every 4 sec period) (3) PMM (the border nodes at 11th hop are always on and the sleep time increases as the hop length decreases). Table 4 shows the periodicity of the active time period in PMM schedule.

A. **Energy Consumption:**

Energy consumption of the nodes is analyzed for SMAC and PMM protocols in the surveillance and tracking state. Here, energy consumption refers to average energy consumption of a node at a particular hop length. We vary the hop length between the sensors (near the target) and sink from 1 to 10 and compare the results. The

TABLE 2 Notations

Description	**Notation**
Radio listen time at periodic on slot	Ton
Sleep time in between 2 active slots	Tsleep
Lifetime of the network	Ttotal
Energy consumed by border nodes	Eborder
Energy consumed by interior nodes	Einterior
No of nodes that forward the packets	Nodes
Energy consumed in listen mode of radio	Elisten
Energy consumed in transfer mode of radio	Etx
No of packets sent by each node	K

performance of PMM in the tracking state is analyzed by varying the data traffic from 50 to 500 packets throughout the lifetime.

(a) In Surveillance state:

Figure 4 shows the energy consumption when there is no target. SMAC consumes more energy due to the fixed periodic sleep of the radio. However, our PMM protocol consumes minimum energy because of its static sleep schedule where the interior nodes are allowed to sleep longer. PMM saves nearly 85% more energy compared to SMAC protocol when hop length is less.

Parameters	**Values**	**Parameters**	**Values**
Transmitting power	14 mw	Bandwidth	2.4 Kbps
Receiving power	13 mw	Packet size	512 bytes
Power consumption in idle mode	12 mw	Speed of the vehicle	15 m/s
Power consumption in sleep mode	0.0016 mw	Sensing range	60 meters
Terrain area	1000 x 1000 m	Transmission range (radio)	120 meters
Nodes	1000	Simulation time	1 hour

TABLE 3 Simulation Parameters

TABLE 4 Radio schedule

Hop length from sink	**Active time for**	**Hop length from sink**	**Active time for** every
1	**40** sec	**7**	16 sec
2	**36** sec	**8**	12 sec
3	**32** sec	**9**	8 sec
4	**28** sec	**10**	4 sec
5	**24** sec	**11**	Always on

(b) In Tracking State:

The energy consumption for different amounts of data traffic is obtained in the tracking state. Figure 5 shows the energy consumption of the node at different hop lengths when 50 packets are transmitted by different sensor nodes. Figure 6 shows the results when the data traffic is 200 packets. Figure 7 shows the results when 500 packets are generated at different sensor nodes and transmitted. In SMAC, energy consumption of nodes at larger hop length is less as the energy required for forwarding the packets is less compared to the nodes at one- hop length as they have to forward more packets. SMAC consumes more energy when the data traffic is increased because the sleep time for all the nodes is periodic. PMM protocol follows a dynamic sleep schedule by allowing the interior nodes to sleep more and activating the neighbor nodes only during the presence of the target. Hence, PMM achieves minimum energy consumption with respect to SMAC. As hop length increases, nodes in that interior region sleep for more time and the number packets to be forwarded will be less, hence energy consumption decreases as E(total)=E(active)+E(forward). When compared to SMAC, PMM saves approximately 75% more energy when the data traffic is 50 packets, saves nearly 60 % of energy when the traffic is 200

V. CONCLUSIONS

In this paper, we proposed a novel rgy saving sleep Schedule for Target tracking sensor network (PMM) to increase the network lifetime. We introduced a dynamic sleep schedule, which activates the neighboring nodes along the target trajectory if a target is found. This enables the next hop neighbors to start the sensing task before the target reaches that region. This kind of power saving does not affect the tracking job and energy savings is increased as the nodes in a particular spatial domain are activated, only in the tracking state. We showed using the theoretical analysis that our protocol balances the lifetime of both the interior nodes and border nodes to maximize the network lifetime. Simulation results proved that our PMM schedule for target tracking networks performs better than SMAC and IEEE 802.11 DCF protocols with respect to network lifetime. When compared to SMAC, PMM protocol reduces the energy consumption and increases the network lifetime by 25% at low data traffic.

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