Mobility and Traffic Adapted Cluster Based Routing for Mobile Nodes (CBR-Mobile) Protocol in Wireless Sensor Networks

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Abstract. The technological advances in wireless communication, micro-electro-mechanical system (MEMS) technologies and digital electronics over the past few years have enabled the development of wireless sensor networks (WSN). In some applications, the WSN nodes are dedicated to be mobile rather than static. This requirement poses new and interesting challenges for both medium access control (MAC) and routing protocols design. In this paper, we propose mobility and traffic adapted cluster based routing for mobile nodes (CBR-Mobile) protocol in WSN to support mobility of sensor nodes in an energy-efficient manner, while maintaining maximum delivery ratio and minimum average delay. The mobility and traffic adapted scheduling based MAC design enables the cluster heads to reuse the free or unused timeslots to support the mobility of sensor nodes. Each cluster head maintains two simple database tables for mobility and traffic to achieve this adaptation. The designed CBR-Mobile protocol enables mobile sensor nodes that disconnected with their cluster heads to rejoin the network through other cluster heads within a short time. The proposed protocol can achieve around 43% improvement on packet delivery ratio while simultaneously offering lower delay and energy consumption compare to LEACH-Mobile protocol.

Keywords: WSN, cluster head, mobility, traffic, LEACH, LEACH-Mobile.

1 Introduction

Recent advances in wireless communication and micro-electro-mechanical system (MEMS) technologies led to emergence of low-power, small-scale, low-cost and multifunctional devices called sensors nodes. These devices are endowed with sensing, signal processing and wireless communication capabilities. Sensor nodes coupled with wireless networking to form powerful and collaborative information gathering system that is known as wireless sensor networks (WSN).

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The WSN consists of hundreds or thousands of wireless sensor nodes that are densely deployed, either inside the phenomenon or very close to it, to collect information about the events in the surrounding environment. It becomes the remote "eyes" and "ears" to monitor a variety of applications ranging from environmental monitoring applications, like habitat monitoring [1] - [3], to infrastructure monitoring [4], emergency health care and medical response [5] - [7], military and battlefield surveillance applications [8] - [10].

A general conception of sensor nodes is static and remains fixed in their position once they have been deployed for a long period of time [11] - [13]. As a consequence research interests are mainly focusing on energy consumption. However, some applications like habitat monitoring, wildlife (animal) tracking, search and rescue [14], RoboMote [15], Parasitic-Mobility [16], and medical care and disaster response applications [17], [18], have enabled mobility in WSN components [11] - [14].

In this paper, we proposed mobility and traffic adapted cluster based routing for mobile nodes (CBR-Mobile) protocol in WSN. The proposed CBR-Mobile protocol collaborates with mobility and traffic adapted medium access control (MAC) layer protocol to support sensor nodes mobility and improve packet delivery ratio. The cluster heads in CBR-Mobile support sensor nodes mobility by adaptively reassigning the timeslots according to mobility and traffic environments. The proposed protocol creates forward and backward schedules to adapt time scheduling according to mobility and traffic environments. It assigns two owners for each timeslot; original owner and alternative owner, such that it can work adaptively to mobility and traffic environments. The protocol keeps the new mobile sensor nodes in the simple database tables and serves these nodes whenever the unused timeslot is available. It can achieve around 43% improvement on packet delivery ratio while simultaneously offering lower delay and energy consumption compare to LEACH-Mobile protocol.

The rest of this paper is arranged as follows. Related work is presented in Section 2. The proposed mobility and traffic adapted scheduling in CBR-Mobile is discussed in Section 3. In Section 4, the mobility and traffic adapted techniques in CBR-Mobile are presented. Performance evaluation of proposed CBR-Mobile is discussed in Section 5. This paper is concluded in Section 6.

2 Related Work

Few protocols that handle mobility at MAC layer and routing have been proposed for WSN [13], [19]. Mobility-aware MAC (MS-MAC) protocol is a contention-based protocol designed to allow mobile sensor nodes to make quicker connections, while crossing the boundary of a virtual cluster [20]. A sensor node detects its neighbour’s mobility based on a change in its received signal level from the neighbour, or based on a loss of connection with this neighbour after a timeout period. The protocol maintains the connectivity by having the neighbours of a mobile sensor node stay awake for a longer time. When there is a mobile sensor node crossing cluster borders, the mobile sensor node and surrounding nodes form an active zone, and start working with a higher duty cycle. The MS-MAC protocol handles mobility in WSN by keeping the border sensor nodes between the clusters awake for a longer time, leading to very high energy consumption.

A scheduled-based protocol, called mobility adaptive collision free MAC (MMAC) protocol has been designed to support sensor nodes mobility by adapting the frame size, transmission slots, and random-access slots according to mobility environments [21]. The MMAC protocol uses mobility estimation algorithm to predict the position of the nodes in next frame if large number of nodes are expected to enter or leave. However, the MMAC protocol has the disadvantages of high complex scheduling algorithm and a synchronization problem as the two hop neighbours need to be synchronized simultaneously.

Mobility adaptive hybrid MAC (MH-MAC) protocol has been proposed to handle sensor nodes mobility by adjusting the ratio of contention timeslots and scheduled timeslots as well as the frame time [19]. MH-MAC is a hybrid protocol that uses both contention and schedule-based channel access mechanism. The protocol uses contention timeslots for mobile sensor nodes while uses the schedule timeslots for static sensor nodes. MH-MAC uses mobility estimation algorithm to determine the mobility type of sensor nodes. When the sensor node estimates its mobility type, it broadcasts its mobility type to the neighbourhood, and hence they can estimate their mobility types and so on. The protocol responds to different levels of mobility; it dynamically adapts the ratio between static and mobile timeslots and the frame size according to the mobility types of sensor nodes. In addition, the protocol is traffic-adaptive; if the sensor node which owns the current timeslot do not has data to send, the timeslot can be assigned to another sensor node. However, the MH-MAC protocol has mobility information beacon message overhead at the beginning of each frame to exchange the mobility information. Each node is assumed to have mobility information about all sensor nodes in the network which is invalid assumption in the large WSNs. All the sensor nodes have to be synchronized when the frame time is changed, and the mobile timeslots are adjusted.

Similar to MAC layer protocols, a number of routing protocols have been designed to support mobility in mobile WSN [13]. Cluster based energy efficient scheme (CES) for mobile WSN [22] was designed based on low energy adaptive clustering hierarchy (LEACH) protocol [23]. The CES relies on weighing *k*-density, residual energy and mobility parameters for cluster head election. The protocol re-elects new cluster head when the cluster head moves to another cluster.

The LEACH-Mobile protocol [24] supports sensor nodes mobility in WSN by adding membership declaration to LEACH protocol. The LEACH-Mobile outperforms LEACH in terms of packet loss in mobility centric environment. Cluster head election in LEACH-Mobile has been improved by LEACH-Mobile enhanced (LEACH-ME) [13] whereby sensor node with minimum mobility factor is elected as cluster head. However, the LEACH-Mobile protocol has the following drawbacks:

- Packet loss in LEACH-Mobile is relatively high and increases rapidly when the number or speed of mobile sensor nodes is increased in the network.
- Mobile sensor nodes in LEACH-Mobile have to wait for two consecutive failures in receiving '*data request*' message from the cluster head before they attempt to join the new cluster.

- The LEACH-Mobile protocol is neither traffic-adaptive nor mobility-adaptive protocol. The assigned timeslots to the sensor nodes that do not have data to send or move out of the cluster are remained wastes.
- The wasted energy in idle listening and overhearing of LEACH-Mobile protocol is high. After mobile sensor nodes lose the connection with their cluster heads, they will keep their receivers ON to receive the cluster heads' announcement messages. Hence, they will receive any message sent in the vicinity even the messages are not destined to them.

3 Mobility and Traffic Adapted Scheduling in CBR-Mobile

In mobility environment WSN, scheduling has to be done while taking into account supporting mobility and maintaining the low duty cycle of sensor nodes through keeping sensor nodes in sleep mode as long as possible. In CBR-Mobile, scheduling should address the following characteristics:

- Mobility-adaptive: the scheduling algorithm should be adaptive to the mobility of sensor nodes. This enables avoidance of waste timeslots or bandwidth utilization in the old cluster and fast inclusion of mobile sensor nodes in the new cluster.
- Traffic-adaptive: the scheduling algorithm should be adaptive to the traffic in the sensor nodes. This enables sensor nodes to release their timeslots when there are no data to send. Hence, it increases the bandwidth utilization and decreases the latency in the network.
- The scheduling should maintain the low duty cycle of sensor nodes. This keeps the sleep schedule for the sensor nodes such that it can decrease the energy consumption of the small battery.

In order to enable time division multiple access (TDMA) scheduling to support mobility and traffic adaptation, the cluster head should update all sensor nodes members by all the changes in the schedule which require the sensor nodes to be in active mode most of the time or wake up periodically to receive the TDMA schedule updates. This increases sensor nodes duty cycle which depletes the energy of these sensor nodes. In our scheduling technique, the assigned timeslots to the mobile sensor nodes that moved out of the cluster or have not data to send will be reassigned to the mobile sensor nodes that join the cluster or to the sensor nodes that have data to send.

In CBR-Mobile, each cluster head maintains two simple database tables to enable mobility and traffic adapted scheduling while maintaining low duty cycle to conserve the energy in the small battery. These simple databases will be discussed in the following subsections.

3.1 New Membership Requesters (NEW_MEM_REQs) Database

New membership requesters (NEW_MEM_REQs) database is a simple database introduced to keep information about all mobile sensor nodes that joined the cluster.

When mobile sensor node loses the connection with its cluster, it will broadcast Join Message (JOIN_MSG) to all nearby cluster heads. The cluster heads that receive this JOIN_MSG will add the mobile sensor node to its database. The cluster head keeps and queues the mobile sensor nodes in NEW_MEM_REQs database as first-in first-out (FIFO) scheduling order. Figure 1 illustrates how the new mobile sensor node is added to the NEW_MEM_REQs database.

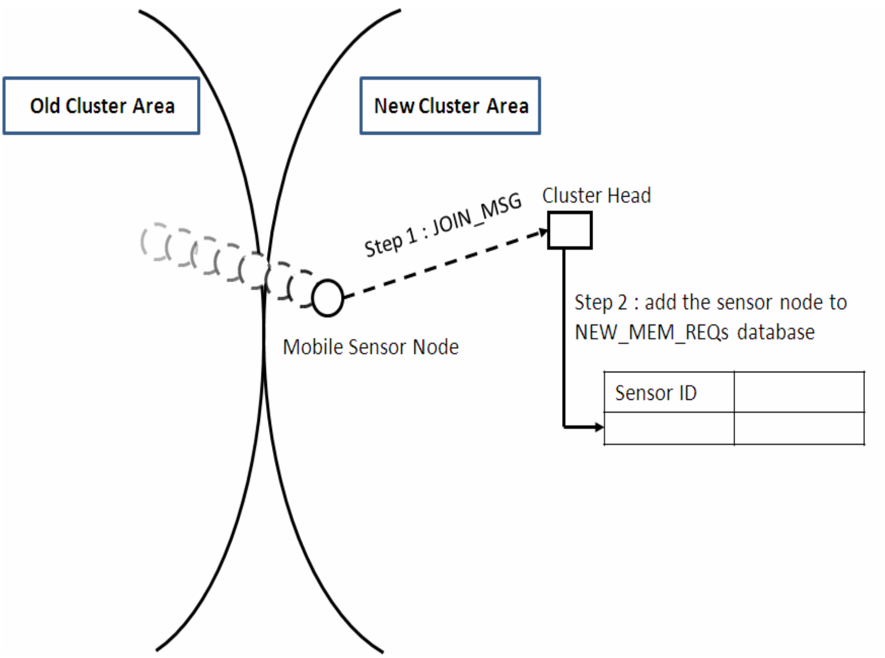


Fig. 1. Registration of mobile sensor node in the new cluster

3.2 Alternative Schedule Database (ALT_SCH)

Whenever the cluster head creates TDMA time schedule, it creates alternative schedule (ALT_SCH) database as well. This database determines which sensor nodes can replace the sensor nodes in the original schedule. The ALT_SCH is created as the reverse schedule to original TDMA. This will overcome the cumulative free timeslots problem which is necessary for waking up the sensor nodes to announce the schedule updates for the cluster members. The cluster head assigns two owners sensor nodes for each timeslot; the original owner from the original schedule and the alternative owner from the ALT_SCH. Figure 2 shows the frame timeslots and the scheduled original and alternative owners.

	T1	T2	T3	T4	T5	T6	T7	T8
Original time schedule	N1	N2	N3	N4	N5	N6	N7	N8
ALT_SCH	N8	N7	N6	N5	N4	N3	N2	N1

Fig. 2. Frame structure of the original and ALT_SCH time schedules

4 Mobility and Traffic Adapted Techniques in CBR-Mobile

The mobility and traffic adapted specifications, besides supporting sensor nodes mobility, have the added values of high bandwidth utilization by eliminating wasted timeslots. These specifications enable the cluster head to assign unused timeslots to other sensor nodes. When the cluster head assures that the original owner of the current timeslot does not want to use it (either move out of the cluster or has not data to send), the cluster head will reassign the timeslot to other sensor or mobile sensor nodes that enter the cluster border.

CBR-Mobile acts as query based protocol. At the beginning of the timeslot, both original and alternative owners are wakeup. The cluster head sends a data request message (DATA_REQ_MSG) to the original owner sensor node that owns the current timeslot. If the original owner has data, it switches on its radio transmitter and sends its data back to the cluster head as shown in Figure 3. At the end of the transmission, the node turns off its radio and goes back to sleep mode, thus minimizing energy dissipation.

The alternative owner will wait for timeout period called timeout second data request (TOUT2_DATA_REQ), then go back to sleep mode since the cluster head will never offer timeslot for replacement. This conserves energy consumption in the alternative owner. The TOUT2_DATA_REQ is calculated as

$$\text{TOUT2\_DATA\_REQ} > \text{MAX}\left(\begin{bmatrix}\text{Transmit time(DATA\_REQ\_MSG)}\\ +\\ \text{Transmit time(HASN'T DATA\_MSG)}\end{bmatrix}, \text{TOUT\_DATA}\right) \tag{1}$$

If the original owner did not receive the DATA_REQ_MSG within timeout called timeout data request (TOUT_DATA_REQ), it assumes that it has moved out of the cluster. Then, it broadcasts JOIN_MSG to nearby cluster heads to join the cluster. The TOUT_DATA_REQ is given by

$$0 < \text{TOUT\_DATA\_REQ} \le \text{Transmit time(DATA\_REQ\_MSG)} \tag{2}$$

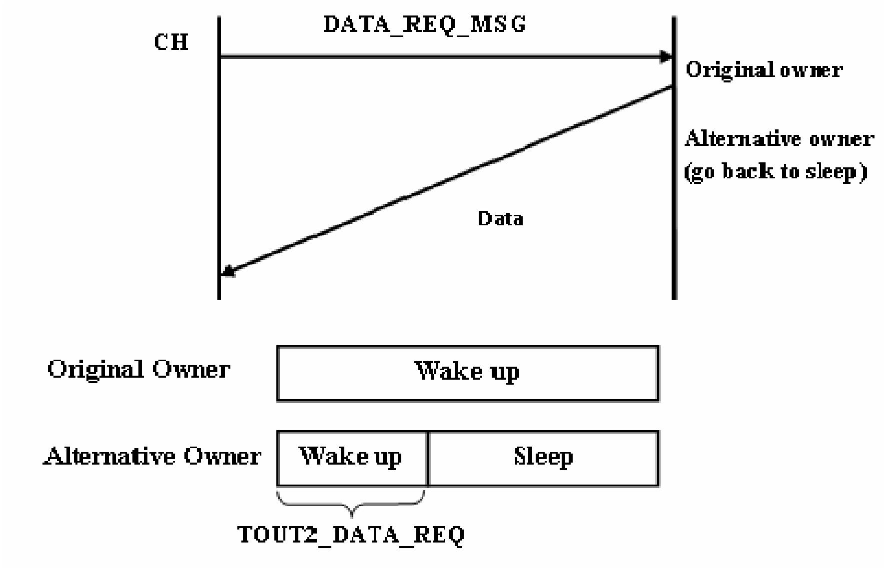


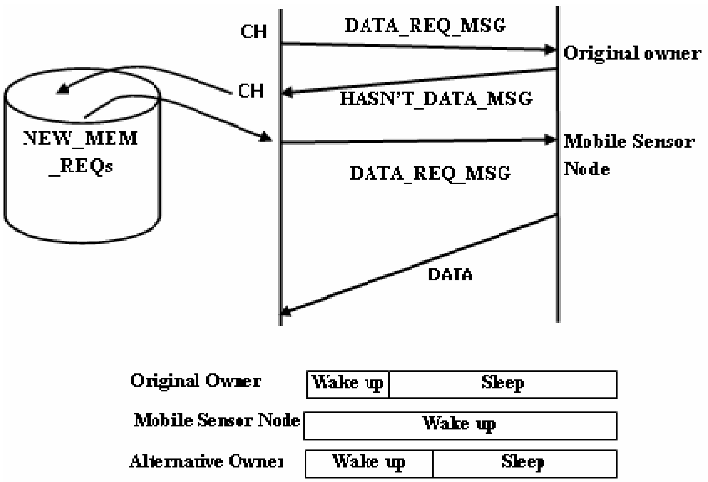
Fig. 3. Data transfer in the original and alternative owners' time schedule

CBR-Mobile works adaptively with the traffic. If the original owner sensor node has no data to send, the original owner will respond by sending hasn't data message (HASN'T_DATA_MSG) and go back to sleep. Then, the cluster head will query NEW_MEM_REQs database to retrieve the mobile sensor node that has the highest priority. If the NEW_MEM_REQs database has some mobile sensor nodes, the cluster head assigns the timeslot to the retrieved mobile sensor node and removes it from NEW_MEM_REQs database. The mobile sensor node stays awake during the timeslot to send the data to the cluster head. The alternative owner waits for TOUT2_DATA_REQ and goes back to sleep when it assures that the timeslot is assigned to mobile sensor node. If the NEW_MEM_REQs database is empty, the cluster head will assign the timeslot to the alternative owner in the ALT_SCH. However if the alternative owner has data, it stays awake and sends the data to the cluster head as shown in Figure 4. Besides that, the alternative owner will release its timeslot during this frame. As shown in Figure 4(a), the timeslot is reassigned to the mobile sensor node in NEW_MEM_REQs. In Figure 4(b), the timeslot is reassigned to the alternative owner sensor in ALT_SCH database.

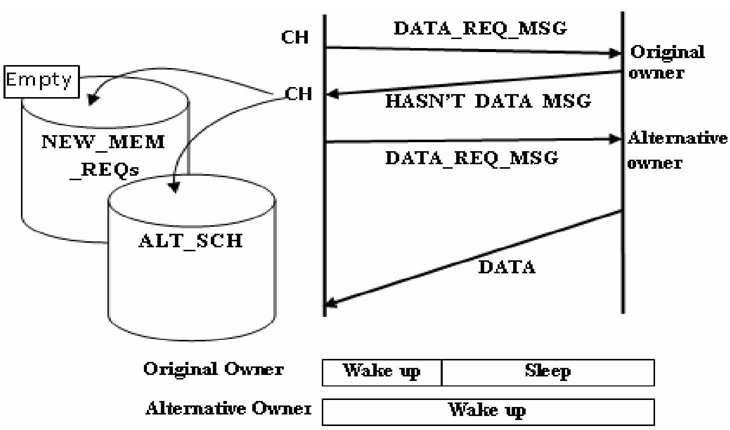
The CBR-Mobile works adaptively with the mobility of sensor nodes. If the original owner sensor node did not respond during the timeout period, called timeout data (TOUT_DATA), the cluster head assumes that the sensor node has been moved out of the cluster. The TOUT_DATA is derived as

$$\text{TOUT\_DATA} > \text{Transmit time(DATA\_REQ\_MSG)} \tag{3}$$

Hence, the cluster head can reuse this timeslot to another sensor node.



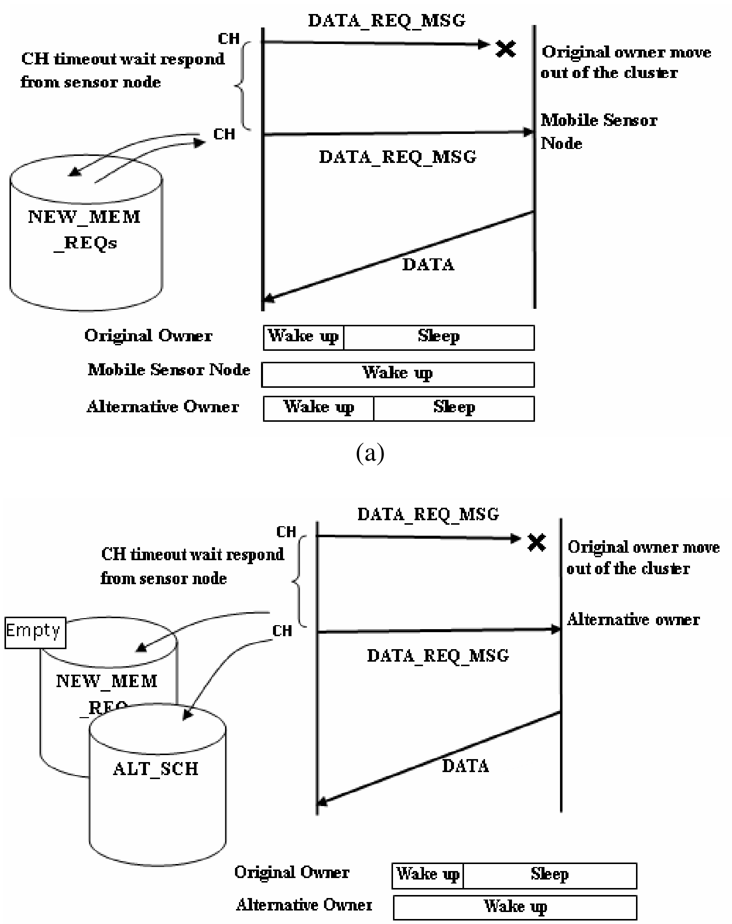
(a)



(b)

Fig. 4. Traffic-adaptive. (a) reassigned the timeslot to the mobile sensor node, and (b) reassigned timeslot to the alternative owner.

Then, the cluster head will query NEW_MEM_REQs database to retrieve the mobile sensor node that has the highest priority. If the NEW_MEM_REQs database has some mobile sensor nodes, the cluster head assigns the timeslot to the retrieved mobile sensor node. The alternative owner waits for TOUT2_DATA_REQ and goes back to sleep when it assures that the timeslot is assigned to mobile sensor node. If the NEW_MEM_REQs database is empty, the cluster head will assign the timeslot to the alternative owner in the ALT_SCH as shown in Figure 5. In Figure 5(a), the timeslot is reassigned to the mobile sensor node retrieved from the NEW_MEM_REQs database, while in Figure 5(b), the timeslot is reassigned to the alternative owner sensor node retrieved from the ALT_SCH database.



(b)

Fig. 5. Mobility-adaptive (a) reassigned the timeslot to the mobile sensor node, and (b) reassigned timeslot to the alternative owner.

At the end of the frame, the cluster head checks NEW_MEM_REQs database. If it contains some mobile sensor nodes, they will be allowed to join the cluster. The cluster head sends announcement message (ANN_MSG) to mobile sensor nodes. Upon receiving this message, the mobile sensor nodes will respond by sending JOIN_MSG. At this time, the frame time is finished and the cluster head prepares and goes for next round. The cluster head will remove non-responding sensor nodes, add the new mobile sensor nodes to the schedule and broadcast the new schedule to all members.

This mobility and traffic-adaptive technique enable the mobile sensor nodes to join the cluster within a short time and hence achieve high packet delivery ratio. It maintains low duty cycle and decrease overhearing so that it conserves the sensor nodes' energy. It decreases the latency of the protocol since the sensor nodes that have data will not suffer from the latency caused by unused timeslots. The integrated pattern of mobility and traffic-adaptive scheduling in CBR-Mobile gives the protocol special capability to support mobility and high traffic of sensor nodes. As a result, mobility and traffic adapted scheduling support one the other.

5 Performance Evaluation of Proposed CBR-Mobile

In order to evaluate the performance of the CBR-Mobile, a simulator is developed using MATLAB as compared with the LEACH-Mobile. The measured performance metrics in demonstrating the improvement and strength features of our design are packet delivery ratio, average energy consumption and average packet delay.

One hundred sensor nodes are deployed randomly in the 50 x 50 m^2 field. The network is divided into five clusters with one sensor node acting as cluster head. All cluster heads are assumed to be static. These sensor nodes are moving in the network according to the random waypoint model [25]. Each mobile node picks its random direction from $(0, 2\pi]$ and moves from its current position in that direction toward a new position for a distance d with a speed v between [$Vmin$, $Vmax$], where d is exponentially distributed. When mobile sensor node reaches the destination, it pauses for a period of time. When the node hits the boundary, it will be reflected at the boundary.

Each sensor node communicates with its cluster head directly. At the beginning of the simulation, 5% of the sensor nodes are randomly elected to be cluster head. These cluster heads broadcast advertisement messages (ADV_MSGs) to the rest of the sensor nodes in the network as in LEACH and LEACH-Mobile protocols. All cluster heads use the same transmit energy when they broadcast ADV_MSGs. Each sensor nodes may receive one or more ADV_MSGs from nearby cluster heads. After non-cluster head sensor nodes have received ADV_MSGs from one or more cluster heads, the sensor nodes will compare the received signal strength of these messages and decide to which cluster it belongs. By assuming symmetric propagation channels, the sensor node selects cluster head to which the minimum amount of transmitted energy is needed for communication. In the case when two cluster heads need the same minimum amount of transmitted energy, a random cluster head is chosen. After choosing the cluster head, sensor node sends registration message (REG_MSG) to inform the cluster head that it wants to be one of the cluster's members. After the cluster head receives REG_MSGs from sensor nodes that willing to join the cluster, the cluster head creates both original schedule and ALT_SCH to achieve traffic adaptive scheduling. The main simulation parameters are shown in Table 1.

Figure 6 depicts that the CBR-Mobile achieves a higher and more stable packet delivery ratios when the percentage of mobile nodes is increased. The mobility and traffic adapted techniques enable the mobile sensor nodes that lost connection with their cluster heads to join the new cluster within a short time. Hence, these mobile sensor nodes will not suffer from high packet loss. The CBR-Mobile achieves 43% higher packet delivery ratio compared to LEACH-Mobile when 90% of sensor nodes are mobile.

Table 1. Main Simulation Parameters

Parameters and Models	Value
Network (field) Size (L x W)	50 x 50 m^2
Number of Sensor Nodes (N)	100
Location of the Sink Node	(25,25)
Sensor Nodes Deployment	Random Deployment
Sensor ID	1-100
Maximum Transmission Range	19 m
Percentage of Cluster Head	5 %
Percentage of Mobile Sensor Nodes	0 – 90 %
Data Size	2000 bits
Mobility Model	Random Way Point Model
Speed	1-10 m/s
Radio Model	Two-Ray Ground model
NEW_MEM_REQs Database	Initially is empty
ALT_SCH	Reverse order of original schedule
Battery	Initial capacity is constant
Traffic Model	Constant Bit Rate and Poisson
Queuing Model	FIFO with Drop Tail Queue Mechanism
Idle Power	2.4 mW
Rx Power	67.2 mW
Tx Power	76.8 mW
Sleep Power	0.0048 mW

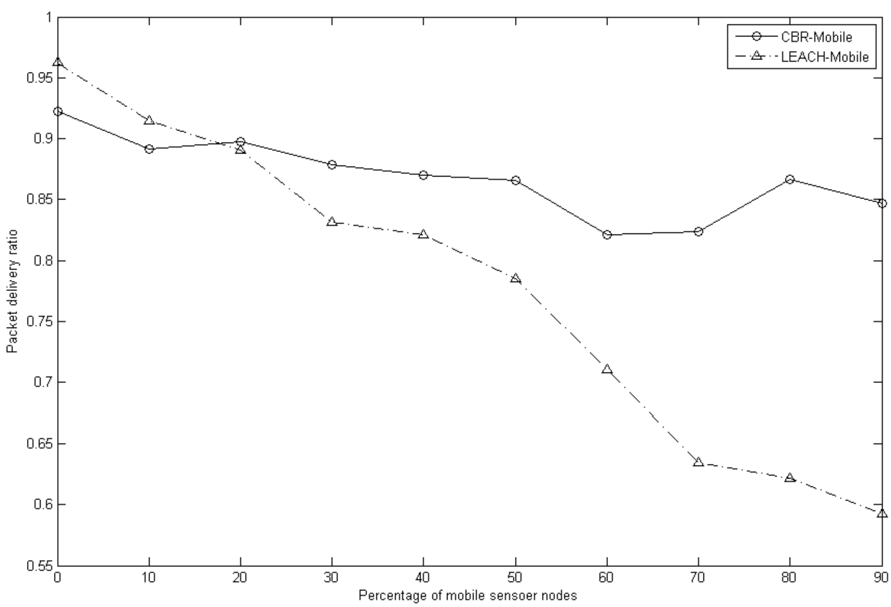


Fig. 6. Delivery ratio versus percentage of mobile sensor nodes

Figure 7 depicts that increasing the number of mobile sensor nodes in the network will increase the average energy consumption for both protocols. This is because when the number of mobile sensor nodes is increased, the mobile sensor nodes that leave their clusters will be increased as well. These mobile sensor nodes remain temporarily disconnected from the network for a period of time. During this period of disconnection, mobile sensor nodes keep their radio on to receive the registration messages. Hence, they will overhear any message sent in the vicinity and waste the energy. When the disconnection period is long, the mobile sensor node will overhear more messages and waste more energy. In addition, the figure indicates that when the percentage of mobile sensor nodes is increased, the CBR-Mobile protocol decreases the average energy consumption from 4 - 16% in high mobility environment compared with LEACH-Mobile. In CBR-Mobile, the disconnection periods for mobile sensor nodes are short. Hence, the mobile sensor nodes avoid overhearing many messages from the vicinity and this keeps their energy. On the contrary, the disconnection periods for mobile sensor nodes in LEACH-Mobile are long such that the mobile sensor nodes will overhear many data and control messages from the neighbourhoods. Hence, more energy is wasted.

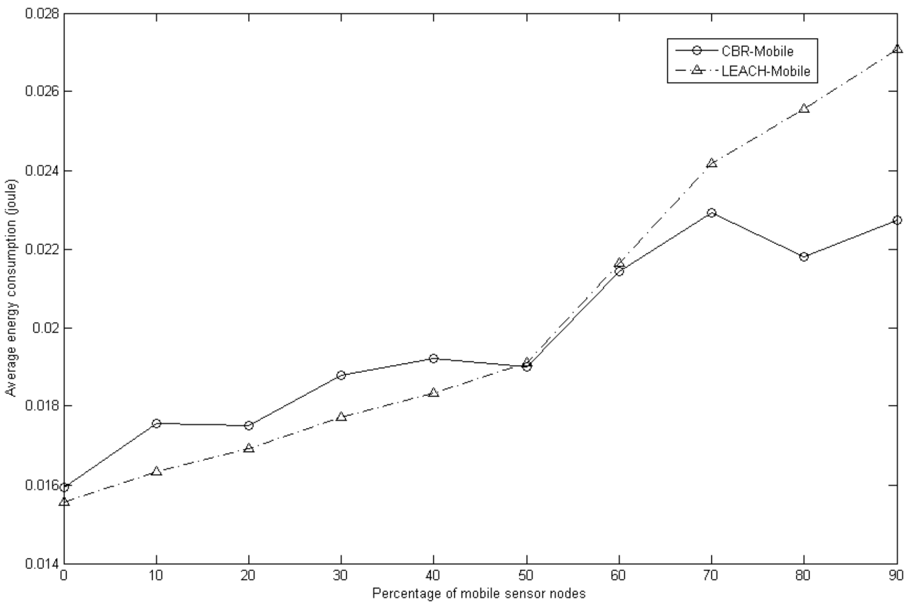


Fig. 7. Average energy consumption versus percentage of mobile sensor nodes

Figure 8 shows the packet delivery ratio as related to traffic generation rate for static and mobile networks. In mobility environment, the figure indicates that CBR-Mobile achieves high and stable packet delivery ratio when packet generation rate in sensor nodes is increased. It offers 9 - 25% higher delivery ratio than LEACH-Mobile. Mobility and traffic adapted techniques enable the protocol to achieve this ratio since the mobile sensor nodes can rejoin the new cluster within a short time.

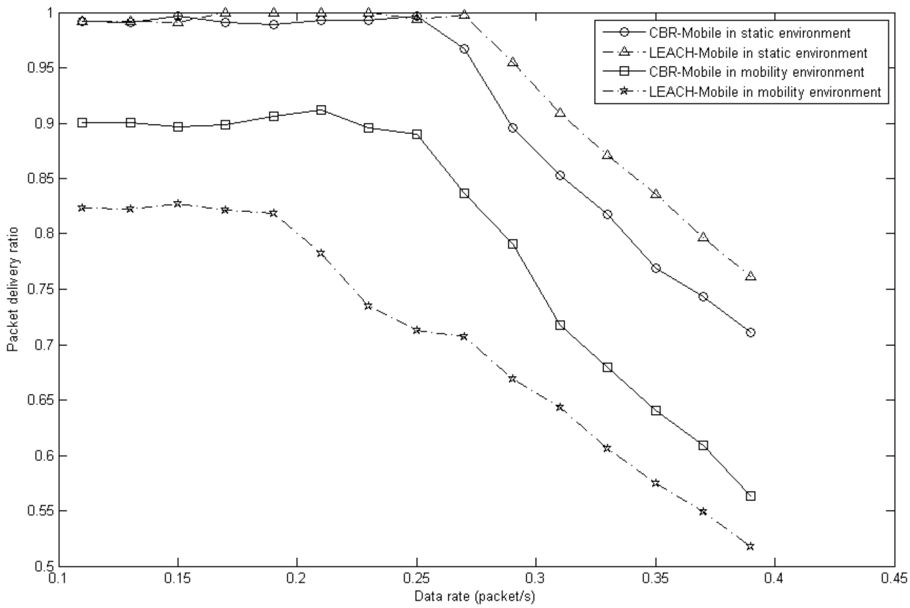
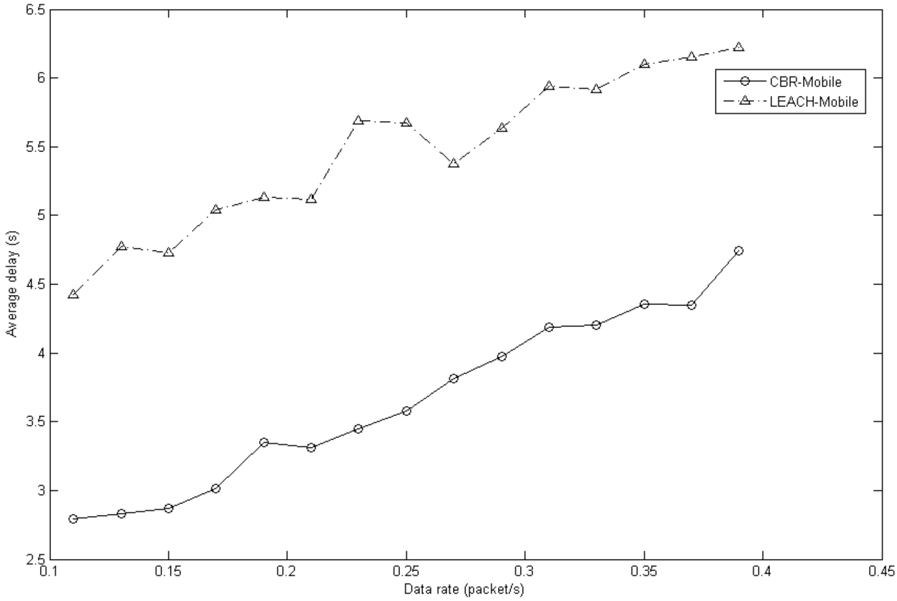


Fig. 8. Packet delivery ratio versus traffic generation rate for static and mobile networks

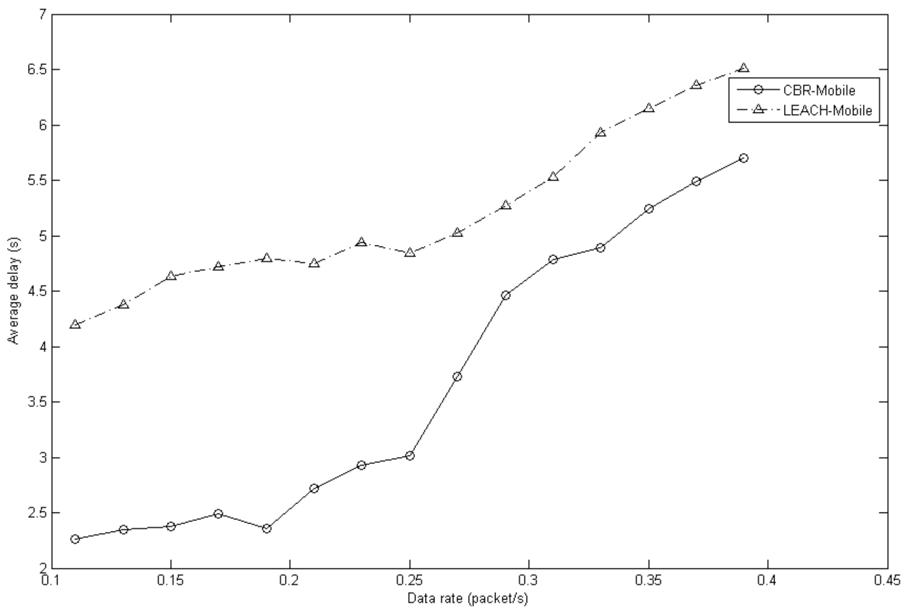
In static environment, the LEACH-Mobile maintains the steady state situation until 0.27 packets per second while CBR-Mobile maintains it until 0.25 packets per second. In comparison, the figure shows that, in mobility environment, the LEACH-Mobile maintains the steady state situation until 0.19 packets per second, while CBR-Mobile maintains it until 0.25 packets per second. LEACH-Mobile shortens the life of steady state situation by 30% in mobility as compared with static environment. Packet delivery ratio for LEACH-Mobile in mobility environment drops by 30% relative to the static environment, while the packet delivery ratio for CBR-Mobile in mobility environment drops by 13% relative to the static environment.

In the WSN, the generated traffic load heavily depends on the application. This generated traffic can be classified into two categories; event-driven reporting and periodic data collection. In event-driven reporting, sensor nodes are responsible for detecting and reporting events after the occurrence. This type of traffic is modelled by Poisson traffic [26]. While in periodic data collection, sensor nodes report their samples in specific time intervals. This type of traffic is modelled by constant bit rate traffic [27].

To investigate the effect of different generated traffic on the average delay of CBR-Mobile, the average delay between CBR-Mobile and LEACH-Mobile are compared under constant bit rate and Poisson traffic. Figure 9 shows that CBR-Mobile achieves less average delay for both Poisson and constant bit rate traffics. It has the advantage of 30 - 39% less average delay for constant bit rate traffic and 13 - 47% for the Poisson traffic as shown in Figures 9(a) and 9(b), respectively. This figure shows that the presented CBR-Mobile protocol is adaptive to any type of traffics and can achieve lower average delay compared to the LEACH-Mobile protocol.



(a)



(b)

Fig. 9. Average delay versus traffic generation rate, (a) constant bit rate and (b) Poisson

6 Conclusions

Supporting mobility in sensor nodes becomes increasingly useful in various applications. Mobility and traffic adapted specifications result in substantial support for mobility of sensor nodes. They enable disconnected mobile sensor nodes to rejoin the network within a short time and avoid the accumulative data loss. The timeslots originally assigned to the outgoing mobile sensor nodes and those assigned to sensor nodes that do not have traffic to send can be reassigned to the new mobile sensor nodes when they enter into any of these clusters. The simulation results demonstrate that our proposed CBR-Mobile protocol has significantly increased the packet delivery ratio compared to the LEACH-Mobile protocol. It also decreases the energy consumption and the average delay at the same time.

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