

ECSM: ENERGY EFFICIENT CLUSTERING SCHEME FOR MOBILE M2M COMMUNICATION NETWORKS

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ABSTRACT

Scheduling the active and idle period of machine type communication devices (MTC) such as RFID tags, sensors and smart meters are significantly important to achieve energy efficiency in the emerging machine to machine (M2M) communication networks, which comprises thousands of resource constrained MTC devices (i.e., low data rate, energy and bandwidth). However, only a few studies exist in the literature on node scheduling schemes of M2M communication networks. Most of these schemes consider only the energy efficiency of MTC devices and do not support mobility. Thus, we introduce an energy efficient, node scheduling scheme for mobile M2M (ECSM) communication networks. The ECSM scheduling scheme selects a minimum number of active MTC devices in each cluster and increases the probability of network coverage. Simulation results show that the ECSM scheduling scheme outperforms the existing cluster-based and well-known mobility centric LEACH-M and LEACH-ME schemes in terms of network energy consumption and lifetime.

KEYWORDS

Machine to Machine (M2M) communications, MTC devices, Node Scheduling, Network Coverage, Mobility.

1. INTRODUCTION

Machine to machine (M2M) communication networks are becoming popular in real-time monitoring, surveillance, and security applications since they are connected to a large number of machine type communication (MTC) devices. These devices have low energy, bandwidth and memory. They are integrated with sensors or RFID tags that result in multi-coverage or redundant data transmissions. Thus, these devices dissipate energy very fast and also create channel congestion and longer data transmission delay. Scheduling the active and sleep cycles of MTC devices is one of the most effective solutions to reduce energy consumption. This is because scheduling allows a small number of devices, which cover the network area to be in active mode and the rest of the MTC devices in inactive mode. Fig. 1 illustrates such an M2M communication framework that requires scheduling the sleep and wake-up time of MTC devices. However, only a

few studies exist in literature on coverage-aware node scheduling schemes, especially for sensor-based M2M communication networks. Most of these approaches do not support mobility. For instance, LEACH-M [4] and LEACH-ME [6, 7], CBR [3] are well known mobility-centric clustering protocols. However, these approaches either allow data redundancy or do not provide complete network coverage.

Thus, we introduce ECSM - an energy efficient cluster-based, node scheduling scheme for mobile M2M communication networks. This approach is scalable and application independent. The proposed ECSM approach uses a primary cluster head (PCH) [1, 2] and a number of secondary cluster heads (SCHs) in each cluster of the network. The PCH is responsible for selecting SCHs and active MTC devices, transmitting control messages to the member devices of the network, collecting and aggregating data from the active member devices and transmitting to the MTC gateway. The SCHs are scheduled to wake-up a predefined time interval to check the energy status of the PCH. If the PCH fails due to energy shortage an SCH with the most residual energy becomes the PCH. The ECSM scheme achieves energy efficiency by reducing the number of active MTC devices as compared to existing LEACH-M and LEACH-ME protocols.

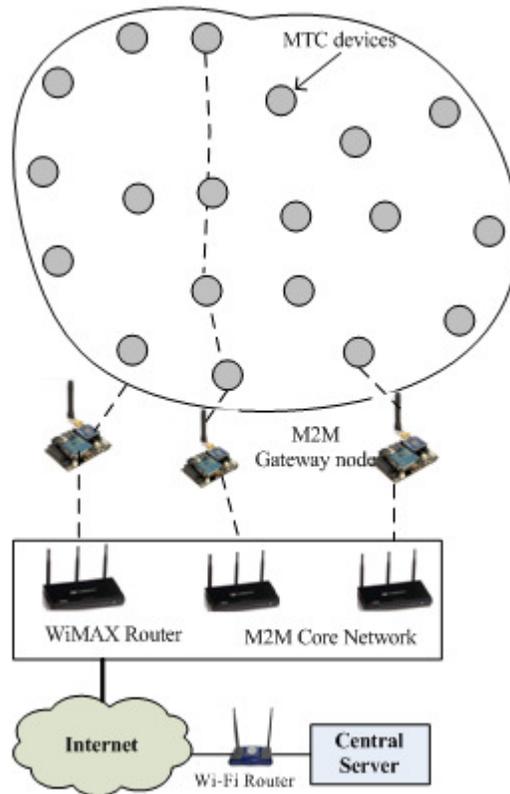


Figure 1. Sleep wake-up scheduling in M2M communication network

The remainder of this paper is organized as follows. Section 2 presents literature review on existing node scheduling schemes. Section 3 presents the working principle of ECSM node scheduling scheme along with some assumptions. Section 4 evaluates the performance of the ECSM scheduling scheme. Section 5 concludes the paper with some future research possibilities.

2. RELATED WORKS

Only a few studies exist in literature on the node scheduling schemes of machine to machine (M2M) communication networks. The work done by Elkheir et al. [5] proposes a co-operative sleep wakeup scheduling mechanism for M2M communications where a number of relay nodes are selected as active to cooperate source nodes for transmitting data to the destination based on their optimal residual energy. The rest of the nodes are kept in sleep mode for a fixed time interval. However, determining the optimal sleep time is a great challenge in M2M communication network because it comprises thousands of heterogeneous devices. Another work done in [11] proposes integrated hybrid MAC and network topology control scheme (i.e., cross layer concept of MAC and network layer with multi-channel TDMA scheme) for M2M communication networks. However, this approach does not consider the sleep scheduling of MTC devices.

We also present a number of sleep scheduling mechanisms of sensors since sensors are the main constituents of M2M communication networks. For instance, in intra-cluster node scheduling algorithm [9], the sink node selects a few active nodes in a cluster to provide full network coverage. All other nodes remain in sleep mode to reduce network energy consumption. A random scheduling scheme is introduced in [10], where nodes randomly join in a disjoint set of nodes. The set of nodes works in a round robin fashion. This scheme does not require any priori localization of the sensor nodes. However, an uneven random distribution of nodes in the node set affects the performance in terms of network lifetime. Thus, the work done by Lim and Bleakley propose a multiple subset (MULS) of active node scheduling scheme [12] to eliminate the problems of random scheduling scheme. This approach uses and gathers exploratory data to find relationship among data sensing at different nodes based on which clusters are formed with nodes having stronger data relationship. A number of subsets of nodes are selected as active in each cluster to work in round robin fashion. However, MULS is not effective for sensing the unwanted events that rarely occur in a cluster and cannot be easily predicted. MULS might also fail to ensure the full network connectivity. The work done by Hwang et al. [8] introduces a network coverage-aware cluster-based node scheduling approach. This approach works by dividing the network into clusters and group the member nodes into sponsor sets based on the nodes residual energy and neighborhood information. This approach allows only one sponsor set of a cluster to be active at each round and all other sponsor sets into sleep mode. However, most of these approaches do not support mobility. LEACH-M [4], LEACH-ME [6, 7], CBR [3], CBR-MWSN [3] are well-known mobility centric clustering protocols that can be used in M2M communication networks. These protocols also incorporate node scheduling using time division multiple access (TDMA) schemes which are not energy efficient.

3. ECSM NODE SCHEDULING SCHEME

We assume that MTC devices are homogeneous in terms of their initial energy and know their locations. The M2M area network is square shaped since network of any shape can be circumscribed into a square. Moreover, MTC devices are homogeneous in terms of mobility. M2M consists of a large number of MTC devices. Thus, it is expected that if an MTC device moves out of a cluster another device enters the cluster with a high probability. The ECSM scheme works into the following phases.

3.1 Network Setup phase

The MTC gateway or BS divides the network into a number of square-sized clusters since network area of any shape can be circumscribed into a square. The maximum distance between any two points in a cluster is less than or equal to the communication range of a wireless MTC device (e.g., sensor). The MTC gateway assigns ID to each cluster and determines its area through local mapping. MTC devices transmit their coordinates to the MTC BS through multi-hop communications. The BS assigns an ID to each node based on the cluster they belong to. For example, n_{ij} is the ID of j -th node in cluster i .

Cluster Head Selection - each cluster will have a primary cluster head (PCH) and a number of secondary cluster head (SCHs). The PCH is responsible for coordinating member MTC devices, collecting data from MTC devices nodes and sending the aggregate data to the MTC gateway. The SCHs are used as alternatives to the PCHs since they take over the responsibilities of PCHs whenever the PCH fails.

Initially, the MTC gateway randomly selects an MTC device in each cluster as a PCH and informs all member MTC devices the ID of PCH [1, 2]. Fig. 4 illustrates that the MTC device with ID 6 is randomly selected as a PCH. Then, the PCH selects a number of devices as SCHs, which are within the sensing range of the PCH. The SCHs are kept in sleep mode and scheduled to wake-up at a pre-defined timeslot to check the energy status of the PCH. The SCH transmits a “Hello” message to the PCH whenever it wakes-up. If the residual energy of the PCH goes beyond a threshold (E_{th}) value the PCH replies with “ACK-LOW” message. Once the SCH replies with a message that it has taken over the responsibility of PCH the PCH goes to the sleep mode. The new PCH informs all member MTC devices. If the residual energy of the PCH is much more than the E_{th} , the PCH replies SCH with an “ACK-OK” message. Similarly, the alternatives (or neighboring) MTC devices of the active MTC devices of a cluster wake up at the predefined timeslot and transmit “Hello” messages to the active devices. The active MTC devices reply with either “ACK-LOW” or “ACK-OK” messages based on their energy status, as we already discussed.

The threshold energy, E_{th} of an MTC device is dynamically adjusted to balance the network energy consumptions. Initially, a certain percentage (e.g., 40%) of the node remaining energy is set to E_{th} . If the remaining energy of the PCH goes below E_{th} and an SCH is found with higher than the E_{th} the SCH becomes PCH. If no SCH is found, E_{th} is set to the residual energy of a node, which has the lowest energy among all MTC devices including PCH and SCHs. However, E_{th} cannot be reduced after a certain energy level, E_{fail} (e.g., 5%), which we call the failed energy level. A node is considered as dead/failed if its residual energy goes below E_{fail} .

Active MTC Device Selection - the PCH selects a number of MTC devices in each cluster, which provide network coverage and remain in active state. The work done in [15] is used to select the active MTC devices. The rest of the MTC devices of the cluster remain in inactive sleep state. However, at least one alternative device is selected for each active MTC device, a_1 . Alternative devices are also scheduled to wake up at predefined timeslots to check the energy status of a_1 . If the residual energy of a_1 goes below E_{th} , a_1 goes into the sleep state and the

alternative device for a_1 works as an active MTC node. The selection of active MTC devices is reinitiated if no alternative device exists due to nodes failure or mobility. Figs. 2 – 5 demonstrate the active node selection process of the ECSM scheduling scheme.

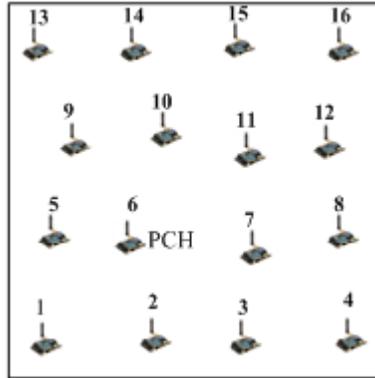


Figure 2. Primary Cluster Head (PCH) selection

Fig. 2 shows that the MTC device 6 of the cluster is randomly selected as a PCH by the MTC gateway. Fig. 3 shows the two furthest points A , and B of the cluster, which has distance equal to the communication range, R_c . Hence, if the PCH is located at the point A , the MTC device at the point B can still communicate with the PCH. We also assume that the cluster is divided into a number of small squares, where l is the length of a side of the square (Fig. 5) and has the following relationship with R_s .

$$R_s^2 = (2l)^2 + (2l)^2 \Rightarrow l = \frac{R_s}{2\sqrt{2}} \quad (1)$$

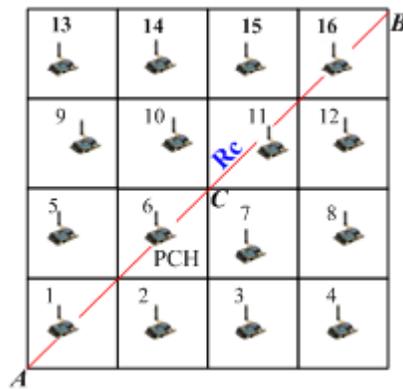


Figure 3. Divide a cluster into a number of small squares

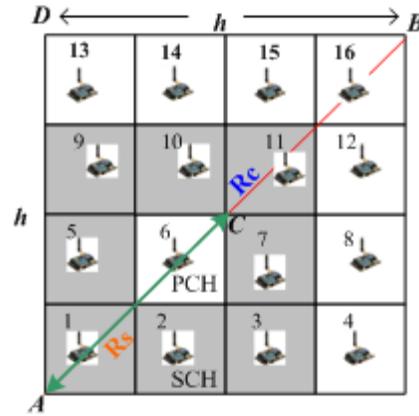


Figure 4. Secondary Cluster Head (SCH) selection

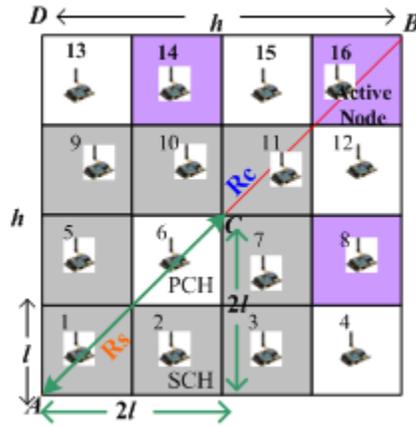


Figure 5. Active nodes selection for cluster and network coverage

This will ease the selection process of active MTC devices because an MTC sensing device that is located in a square can cover (sense) the area of all neighboring squares. Thus, once a device in a square is selected as active, nodes in all neighboring can be kept in sleep mode (inactive). From Fig. 5 we also find that

$$R_c^2 = h^2 + h^2 \Rightarrow h = \frac{R_c}{\sqrt{2}} \quad (2)$$

Thus, the area, A_c of a cluster (square) is approximated as

$$A_c = h \times h = \frac{R_c}{\sqrt{2}} \times \frac{R_c}{\sqrt{2}} = \frac{R_c^2}{2} \quad (3)$$

Fig. 4 illustrates that the SCHs (i.e., the devices that reside in ash colored squares having ID 1, 2, 3, 5, 7, 9, 10, 11) are within the sensing range, R_s (i.e., distance, AC) of the PCH or device 6.

Once SCHs are selected the PCH notifies the IDs of SCHs to all member MTC devices. All member devices can also calculate the number of devices in their neighboring squares, which is used as a node degree. The device with the highest node degree is selected as an active member device. Other active members are selected from the rest of members, which are not the neighbor

of an active member and has the highest node degree among the rest of member nodes. Fig. 5 illustrates this active member selection process. The nodes that reside in the violet colored squares, 8, 14, 16 are active MTC devices. Other member nodes 4, 12, 15, 13 remain in sleep mode and are scheduled by the PCH to wake-up at the predefined time period to check the energy status of neighboring active MTC devices.

The active MTC sensing devices at the border area of each cluster also provide network cover over some area of neighboring clusters since the neighboring squares of the borderline MTC devices are located in the neighboring cluster. For instance, the neighboring squares of the MTC device 14 are located in its neighboring cluster. Thus, the MTC device 14 covers the area of those squares in neighboring cluster. Let us assume that P is an active MTC device that resides in the neighboring square of node 14 in the adjacent cluster. Neither P nor node 14 covers the area of all neighboring squares of each other. Thus, the ECSM scheduling algorithm cannot completely eliminate redundant data sensing. However, by reducing the number of active MTC devices the ECSM scheme achieves energy efficiency.

3.2 Mobility Management

The MTC devices can be mobile since they are attached to objects such as human body, car, animal that make them mobile. This section presents how mobility of MTC devices is incorporated in the ECSM scheduling, especially when PCHs, SCHs, active and alternative MTC devices move.

Mobility of PCHs – whenever a PCH moves inside or outside of the cluster, an SCH that wakes-up at the next timeslot becomes PCH only if its residual energy is more than E_{th} and notifies the member MTC devices of the cluster. If the PCH (that moved) still resides inside the cluster it becomes either an SCH if it is within the sensing range of the new PCH or a regular cluster member. If the PCH moves outside of the cluster it joins a new cluster, C_i by sending a “JOIN-REQUEST” message to the PCH of C_i .

Mobility of SCHs – each PCH has a number of SCHs. Thus, if an SCH moves into another location of the cluster, which is still within the sensing range of the PCH the role of SCH does not change. Only the PCH updates the location information of the SCH. If the SCH moves inside the cluster but outside the sensing range of the PCH, the PCH deletes the SCH from its neighbor list and also the scheduled timeslot of the SCH. However, the PCH still has a number of SCHs. The SCH (that moved) becomes a regular cluster member, neighbor of an active MTC device and remains in sleep mode.

Mobility of active and alternative MTC devices – if an active MTC device x moves from its current location to another location of the cluster, the alternative device y that wakes-up first becomes active and notifies its PCH. Then, x is kept in sleep mode if the new location of x is already covered (most likely) by turning its radio-off. Otherwise, x is again selected as an active device. If x moves out of the cluster the alternative node y that wakes up first becomes active. If the selection of y as an active node still leaves some area of the network uncovered, another sleeping MTC device z that covers those areas becomes active whenever z wakes up.

4. PERFORMANCE EVALUATION

This section presents the energy model, simulation model and results.

4.1 Energy Model

The proposed ECSM scheduling scheme follows the energy model used in [3, 6, 10]. In this model, the energy consumption for transmitting a data packet of size k bits over a distance d is represented by

$$E_{TX}(k, d) = k \times \epsilon_{elec} + k \times \epsilon_{fs} \times d^\alpha \quad (4)$$

where ϵ_{elec} and ϵ_{fs} represent energy consumption of the transmitter/receiver circuitry for each bit data, and RF amplifiers for propagation loss, respectively. The constant α is used to represent propagation loss such as $\alpha = 2$ for the straight line of sight or free space data propagation.

4.2 Simulation Setup and Results

A simulation model is designed to measure the performance of the proposed ECSM scheduling scheme in terms of network energy consumptions, network lifetime, and number of data transmissions. The network energy consumption is defined as the energy consumption of MTC devices for transmitting, receiving, and aggregating data for a certain number of rounds where a round comprises a network setup phase and a number of steady phases. Network lifetime is defined as the remaining energy of the network after a certain number of rounds. We compare the proposed ECSM scheduling scheme with existing mobility centric LEACH-M and LEACH-ME schemes.

Table 1. Simulation parameters and their values

Parameter	Value
Network area	100m x 100m
Number of nodes	Maximum 200
Number of clusters	4 – 8
Coordinate of base station	(100 x105)
Transmission energy consumptions	50 nJoule/bit
Energy consumption in free space	0.01 nJoule/bit/m ²
Energy consumptions in idle state	0.00185 nJoule/sec
Initial energy of each node	3 Joule (2 AA batteries of 1.5 volt each)
Data transmission rate	250 Kbps
Velocity	2 – 6 meters/second

A network of size 100m x 100m is used in the simulation model where MTC devices or sensors are randomly deployed. Table I presents simulation parameters and their respective values. The simulation is run for a fixed number of clusters, and nodes by varying the number of rounds. We set the number of clusters, and nodes to 4 and 100, respectively, and place the MTC gateway outside all clusters at the coordinate (55, 105). Node moves at the speed of 2 – 6 meters/second. Figs. 6 – 8 illustrate the performance of the proposed ECSM node scheduling scheme and compare it with the existing LEACH-M and LEACH-ME scheduling schemes in terms of network energy consumption and network lifetime.

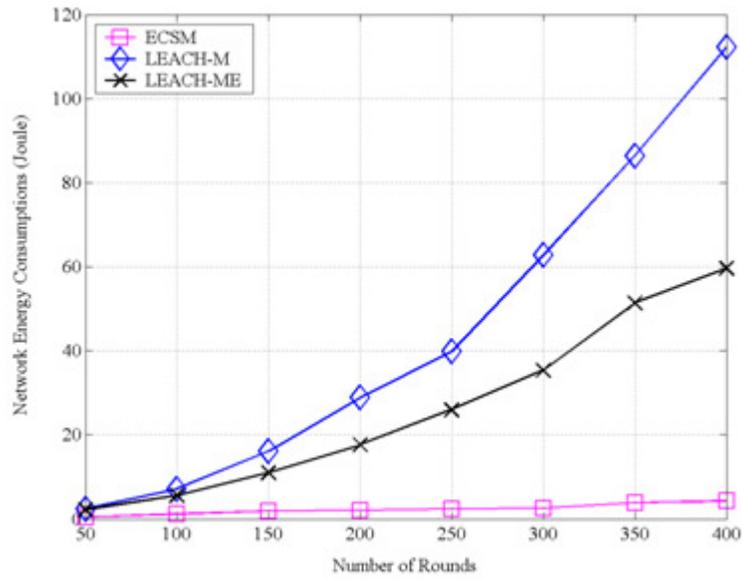


Figure 6. Network energy consumptions over a number of rounds

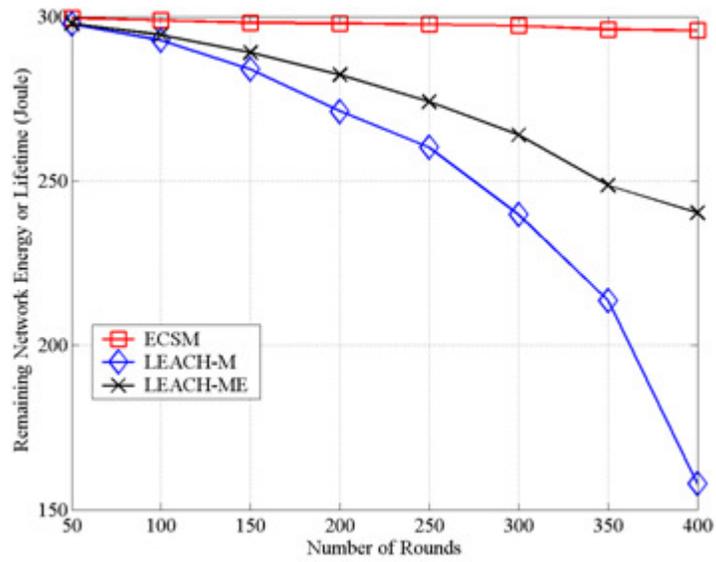


Figure 7. Network lifetime in terms of remaining network energy over a number of rounds

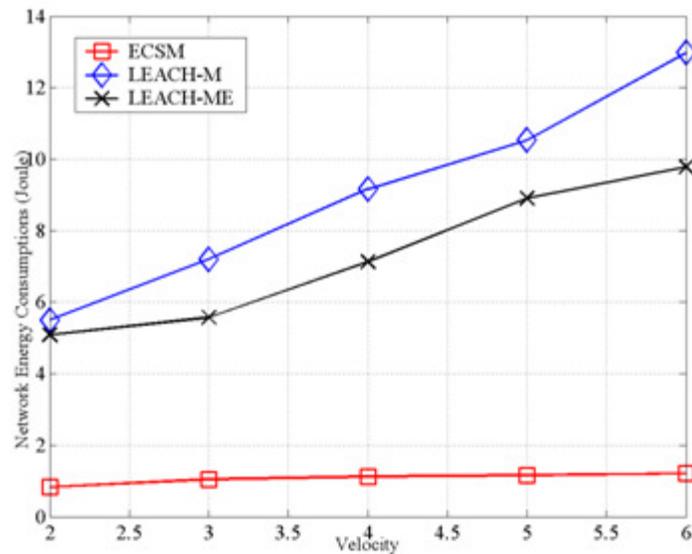


Figure 8. Network energy consumptions varying the velocity.

Fig. 6 demonstrates that the ECSM scheduling scheme consumes much less energy as compared to the existing LEACH-M and LEACH-ME protocols because the number of active member devices are more than that in ECSM scheme. Moreover, LEACH-M and LEACH-ME protocols require a large number of message transmissions in network setup phase and a large number of packets are lost if the CH keeps moving before selecting a new CH for the next round. Fig. 7 shows that the lifetime of ECSM scheduling scheme is much more than those of LEACH-M and LEACH-ME protocols. Fig. 8 demonstrates that network energy consumption of ECSM, LEACH-M and LEACH-ME increase a little bit for increasing the velocity of MTC devices since the MTC devices travel a long distance at higher velocity and are expected to reside far away from the CH that consumes more energy. However, there is also the possibility that MTC devices come closer to the CH from a distant place.

5. CONCLUSION

This paper introduces Energy efficient, Cluster-based Scheduling scheme for Mobile M2M communication networks (ECSM). The ECSM scheme selects a number of active machine type communication (MTC) devices that provides network coverage and alternative devices for each active device to support fault tolerance. Moreover, a number of secondary cluster heads (SCHs) are also selected for each primary CH (PCH). Performance analysis and simulation results show that the ECSM scheduling scheme has longer network lifetime as compared to existing LEACH-M and LEACH-ME protocols. Moreover, the ECSM scheme supports mobility of sensor nodes. In future, we plan to compare the performance of ECSM scheduling scheme in terms of end-to-end delay and packet loss ratio and also with more existing scheduling schemes.

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