

CCES: Coverage and Cluster-based Energy efficient Node Scheduling Scheme for Mobile Sensor Network

Mohammed Saeed Al-kahtani

Department of Computer Engineering
Salman bin Abdulaziz University, Saudi Arabia
alkahtani@sau.edu.sa

Abstract - Scheduling the sensors active and sleep period is significantly important for achieving energy efficiency in resource constrained Wireless Sensor Networks (WSNs). Most existing node scheduling schemes consider only the energy efficiency of sensor nodes and cannot be used for mobility-centric applications since they are designed for static network topology. Though a few node scheduling schemes are designed to support sensors mobility they cannot guarantee network coverage. Thus, this paper introduces Coverage and Cluster-based Energy efficient Node Scheduling (CCES) scheme for Mobile WSN, which achieves energy efficiency by selecting a minimum number of active nodes in each cluster and increases the probability of having no sensing hole in the network while supporting mobility of sensor nodes. Simulation results show that CCES scheduling scheme has lower network energy consumptions, and higher network lifetime in terms of the remaining network energy and the rounds when the first node fails as compared to an existing Cluster-based Coverage preserved Node Scheduling (CCNS) scheme.

Keywords. *Wireless Sensor Network; Node Scheduling; Network Coverage; Mobility.*

I. INTRODUCTION

Wireless Sensor Network (WSN) is one of the most emerging technologies that consist of a large number of small, cheap but resource constraint, i.e., low energy and memory sensor nodes. WSNs are infrastructure-less, and supports autonomous monitoring, self organization, and remote accessibility. Thus, WSNs have achieved widespread applicability in many application domains such as smart home, agriculture, battle field surveillance, wildfire detection, air and water pollution monitoring, animal habitat monitoring and health monitoring for elderly people. A large number of sensors are deployed either manually or randomly for most applications. For instance, they are thrown from the airplane in deep forest, battlefield, sea, and other areas where manual deployment is not possible. Once they are deployed they are expected to operate for a long period of time without

any human intervention. However, such dense sensor's deployment results multi-coverage or redundant data sensing where, several sensors sense the same data event. A large number of control messages are transmitted among sensors that results faster energy dissipation. Redundant data sensing also results channel congestion due to the large number of data collection by the member nodes and end-to-end data transmission delay. Sensors also dissipate energy for idle listening when the radios of sensors are kept on even if there is no data to sense or receive.

Among many solutions for reducing the energy consumptions, scheduling the active and sleep cycles of sensor nodes is very important for the energy efficiency of WSNs. This solution allows a small number of sensors to be in active mode that also guarantee the whole network coverage and the rest of the sensors in inactive or sleep mode by turning their radio off. Many scheduling schemes have been introduced in the literature [6-8, 11-17]. However, most of these scheduling schemes are designed for static sensor nodes and do not work for the mobility-centric WSN applications. For instance, the static node scheduling schemes do not work in health monitoring where sensors are attached to human body and mobile. Moreover, most existing approaches only consider achieving network energy efficiency and do not consider network coverage. Thus, this paper introduces a Coverage and Cluster-based Energy efficient Node Scheduling (CCES) scheme for Mobile WSNs, which has the following characteristics.

- The CCES node scheduling approach uses a Primary Cluster Head (PCH) and a number of Secondary Cluster Head (SCHs) in each cluster of the network. The PCH is responsible for selecting SCHs and active member nodes, transmitting control messages to the member nodes of the network, collecting and

aggregating data from the active member nodes and send to the BS. The SCHs are scheduled to wake-up to check the energy status of the PCH. If the remaining energy of the PCH goes below a threshold value an SCH will be selected as a PCH. Thus, CCES node scheduling approach has fault tolerance capability.

- The CCES node scheduling scheme is scalable and thus, can be used for a large scale WSN which monitors a large geographical area.
- The CCES node scheduling scheme reduces the number of active nodes at any sensing cycle. Thus, the network energy consumptions and end-to-end data transmission delay are also reduced.
- This CCES scheduling scheme can be reused in most WSN applications.
- In CCES scheme, alternative nodes to each active node are scheduled to wake-up at different timeslot and take over the responsibility of the active node if its residual energy goes below a threshold value. Thus, the proposed CCES scheme [6] is more energy efficient than the existing Cluster-based Coverage preserved Node Scheduling (CCNS) scheme since a subset of nodes which are alternative to the currently active subset of nodes wake-up at different timeslots and replace all nodes in the currently active subset if the any node in this subset fails due to energy shortage.

The remainder of this paper is organized as follows. Section II presents several existing nodes sleep scheduling schemes. Section III presents the working principle of the proposed CCES node scheduling scheme. In Section IV, we present the performance analysis and evaluation of CCES scheduling scheme. Section V concludes the paper with some future research directions.

II. RELATED WORK

Though most node scheduling algorithms in the literature consider energy efficiency of the networks, only a few of them considers scalability and mobility of sensors nodes. The work done by Jian-bo X. and Li P. [7] propose Intra-cluster Node Scheduling Algorithm where, base station (BS) selects a small number of active nodes in a cluster to provide full coverage and a large number of nodes in sleep/inactive mode in order to save energy. Initially, BS calculates the upper and lower bounds for the number of clusters and cluster heads (CHs) based on the network area. Then BS selects the number of active nodes, k based on the sensor's communication and sensing range and network coverage requirement. Once k is selected BS broadcasts this number to the network and CH chooses k most residual energy nodes as active nodes. When the member nodes receive a TIMESLOT message

from a CH they identify whether they belong to active nodes and accordingly calculate the starting time of their timeslots in TDMA scheme using the information of k , T , ID in the received TIMESLOT message.

The work done by Jiang et al. [8] propose a Random Scheduling algorithm where nodes randomly join in a disjoint set i where, $1 \leq i \leq k$ and nodes set work in a round robin fashion provided that only one node set works at any time. This approach does not require any priori localization of the sensor nodes and thus, is considered energy efficient. However, an uneven random distribution of nodes in k set may affect the performance of this method in terms of the lifetime of the network. To eliminate these problems of random and uneven node set Lim J. C. and Bleakley C.J. propose a Multiple Subset (MULS) of active node scheduling scheme [11]. In MULS, nodes in the network initially gather exploratory data to find relationship among data sensing at different nodes. Then BS creates clusters with nodes that have a stronger data relationship. A number of subsets of nodes are selected in each cluster which works as active nodes in that cluster in round robin fashion. Using these active nodes, the value at all other nodes in a cluster can be predicted. Hence, this method is based on scheduling and prediction. 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.

Hence, Liu et al. propose Energy-aware Coverage-based Node Scheduling scheme (ECNS) [12] that guarantees protection for sensors and network connectivity at a desired coverage level while nodes reduce energy consumptions though local information exchange with neighbors to decide when they are eligible to turn their radio off (sleep mode). A sensor is k -self protected if the location of each sensor has at least $k - 1$ coverage. This approach also ensures sensor's 2-self-protection and solves the 1-coverage problem successfully, which is not enough in applications that require k -coverage. ECNS solves this coverage problem. ECNS works in rounds that comprise of neighbor discovery phase and a node scheduling phase, followed by a sensing phase. In neighbor discovery phase each node with residual energy above a threshold value sends a HELLO message to inform its ID and residual energy and the receiver adds an entry in its neighbor list if the sender is in its communication range. These messages transmissions will be discarded by non-neighbor nodes. Newly deployed sensors will notice their existence through HELLO message whereas failed nodes will be deleted from the list if no HELLO messages are sent from them for a long time. After this phase, a back-off withdrawal timer is calculated based on a sensor's residual and initial energy. If a sensor x receives a "POWER-OFF" message from its neighbor before the back-off timer expires x re-evaluates its redundancy eligibility and turns off the power (to go to inactive mode) if it is still eligible to be turned off and broadcasts the "POWER-OFF" message to its neighbors.

The calculation of timer ensures that a sensor with a low residual energy will have a short timer and hence, a higher probability to be put into sleep mode (balances energy).

Most of node scheduling algorithms are designed for homogeneous sensor networks. The work done by Deng et al. [4] propose a Linear Distance-based (LDS) node scheduling scheme for cluster-based high density and heterogeneous networks, where a node x that is further away from the base station (BS) has a higher probability of sleeping since the node y that is close to BS receives a large number of data from x and other nodes in a multi-hop transmissions. However, LDS suffers from uneven drainage of sensors' energy that results the faster failure of y than those of x . Hence, Deng et al. further propose a Balanced-energy sleep scheduling scheme [4] where sleeping probability of a node not only depends on the distance between a node and its CH but also the residual node energy and free buffer space. This scheme is considered energy efficient and dynamic since it does not assume any prior distribution of a fraction of sleeping nodes in each round.

The work done by Cheng-zhi et al. proposes Sleep-scheduling Energy-efficient Algorithm (SEA) [13], which also considers the heterogeneousness and redundancy of nodes and calculates the sleeping probability of a node based on the minimum number of nodes that covers an area of the network. If a random number (between 0 and 1) generated by a nodes is less than the sleeping probability the node resides in sleep state and vice versa. This scheduling scheme achieves more energy efficiency as compared to existing heterogeneous node duty cycle scheduling algorithms.

Hwang et al. [6] introduces a network coverage-aware cluster-based node scheduling approach, which works by dividing the network into clusters and cluster heads (CHs) 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 the rest sponsor sets into sleep mode.

The work done by Ren et al. proposes a two phase sleep scheduling (TPSS) protocol [14] that is used in sensor networks for object tracking applications. TPSS exploits sensors redundancy for network coverage and uses different scheduling scheme in different phases and optimizes itself in terms of network coverage and node state prediction. Choosing an appropriate number of active nodes is significantly important to get better tracking quality. Thus, TPSS protocol balances the

number of active nodes and tracking quality by formalizing it as a network coverage problem. Connected- k neighborhood (CKN) [17] is a sleep scheduling algorithm of WSN for geographic routing where a portion of nodes are awoken at a particular time to achieve energy efficiency of the network while keeping the whole network connected. Each node selects a random rank that determines the sleep or awake state of itself and connectivity status of its currently awake neighbor nodes. Every node will have at least a certain number of awoken neighbors after running CKN which is directly proportional to the value of k . However, CKN uses static BS or sink and is not considered efficient as compared to an approach that uses mobile sink node.

A flock detection-based duty cycle scheduling scheme is proposed [15] for mobile sensor network based on the observation that the movement of animals (attached to sensors) follow the patterns of forming a flock. During the flocking period, the number of the neighboring nodes is stable and can be easily estimated. Thus, mobile nodes (attached to animals or human being) can detect the occurrences of flocks and modify its duty cycle accordingly. Table I presents comparison among several existing node scheduling schemes on some important features.

III. PROPOSED SCHEDULING SCHEME

This section presents the working principle of Coverage and Cluster-based Energy efficient Node Scheduling (CCES) scheme for Mobile Wireless Sensor Networks along with the general assumptions and important terminologies that are used throughout the paper to design the CCES scheme.

A. Assumptions

We make the following assumptions to design the CCES scheduling scheme.

- All sensors have the same initial energy, communication range, R_c and sensing range, R_s .
- Sensors know their position or coordinates.
- The network is assumed to be square shaped since network of any shape can be circumscribed into a square (is illustrated in Figure 1).
- Sensors are attached to objects such as human or animal body that make them mobile.
- Sensors are homogeneous in terms of mobility, i.e., if a node moves out of a cluster there is a high probability of another node entering into the cluster.

Table I. Comparison of several existing node scheduling schemes based on some features

Features	Intra-cluster[7]	Random [8]	MULS [11]	ECNS [12]	LDS[4]	SEA [13]	CCNS [6]	TPSS [14]	Flock-based[15]
Coverage-aware	√	X	X	√	√	√	√	√	X
BS selects active nodes	√	X	X	X	√		X (CH)	√	X (mobile)
A number of active node set, one set works at a time, others sleep	X	√	√	X	X	X	√	X	X
Heterogeneous	X	X	X	X	√	√	X	X	X
Duty cycle adjusted based on no. of neighbors of a node	X	X	X	√	X	X	X	√	
Supports mobility	X	X	X	X	X	X	X	√	√

- Each cluster is divided into a number of small squares that eases computing a number of Secondary Cluster Heads (SCHs) and active member nodes to provide the network coverage (Figure 2).

B. Working Principle

The base station (BS) divides the network into a number of square sized clusters in such a way that the maximum distance between any two points in a cluster is less than or equal to the communication range, R_c of a sensor. The BS assigns ID to each cluster and determines its area through local mapping. Sensors transmit their coordinates to the BS through multi-hop communications whenever they are deployed into the network. The BS assigns an ID to each node based on the cluster they belong to. For instance, n_{1i} represents i -th node of cluster 1. Fig. 1 illustrates that a network of irregular shape can be circumscribed into a square and Fig. 2 illustrates that the square network can be divided into a number of square clusters.

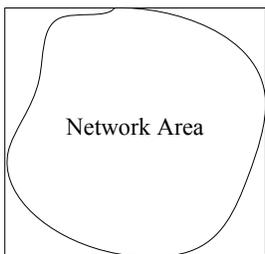


Figure 1. Network is circumscribed into a square.

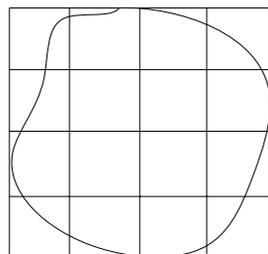


Figure 2. Network is divided into a number of square clusters.

1. 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 nodes, collecting data from member nodes and sending the aggregate data to the BS. The SCH is used as a backup of the PCH, which takes over the responsibility of the PCH whenever the PCH fails.

Since all nodes have the same initial energy the BS randomly selects a node C in each cluster as a PCH and notifies all member nodes about the PCH [1, 2]. Fig. 3 illustrates that node 6 is randomly selected as a PCH. Then, the PCH selects a number of nodes as Secondary Cluster Heads (SCHs), which are the neighbors and within the sensing range of the PCH. These SCHs normally remain in sleep mode and are scheduled to wake-up at a certain time interval (or timeslots) to check the energy status of the PCH. A SCH transmits a “HELLO” message to the PCH whenever it wakes-up. If the remaining energy of the PCH goes below a threshold value (THV) it replies the SCH with an “ACK-LOW-ENERGY” message and goes to the sleep mode. Then the SCH becomes a PCH and informs all other nodes of the cluster. Otherwise, the PCH replies the SCH with an “ACK-OK” message. Similarly, the neighboring nodes of an active member node in a cluster wake up at the predefined timeslot and transmit “HELLO” messages to

the active node. The active node replies with either “ACK-LOW-ENERGY” or “ACK-OK” messages, as is mentioned above. The threshold energy of a node is dynamically adjusted to balance the network energy consumptions. Initially, a certain percentage (e.g., 50%) of the node energy is considered as THV. If the remaining energy of the PCH goes below this initial THV and an SCH is found with the residual energy more than the THV, the threshold value will not change and the SCH will become PCH. If no SCH is found the THV is set to the residual energy of a node among PCH and all SCHs, which has the lowest residual energy. However, THV cannot be reduced after a certain energy level (e.g., 5%), which we call the failed energy level (FEL). A node is considered as died if its residual energy falls below the FEL.

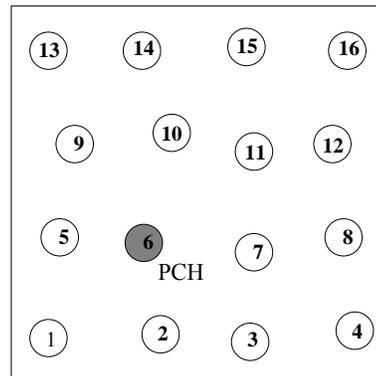


Figure 3. Primary Cluster Head (PCH) selection

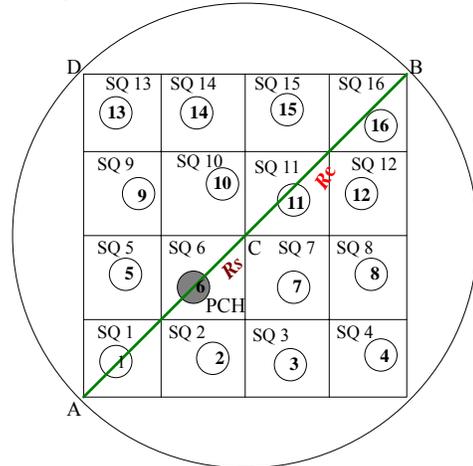


Figure 4. Divide a cluster into a number of small squares

2. Active and Alternative Nodes Selection Mechanisms

The PCH selects a subset of the member nodes in each cluster as active nodes, which provide sensing coverage in the area of cluster and remain in active state. We follow the active node selection process that is presented in [10]. All other nodes of the cluster will remain in sleep mode. However, for each of the active node a_1 at least one alternative node is selected that also covers the area of a_1 . Alternative nodes are also scheduled to wake up at different timeslot to check the energy status of the active node a_1 . If the residual energy of a_1 goes below a threshold value a_1 goes into the sleep

mode, the alternative node works as an active node and all other alternative nodes are rescheduled by the PCH to check the energy status of the new active node. The active and alternative nodes selection process will be redone if the number of alternative nodes reduces (e.g., a node fails if its energy reduces below a certain level).

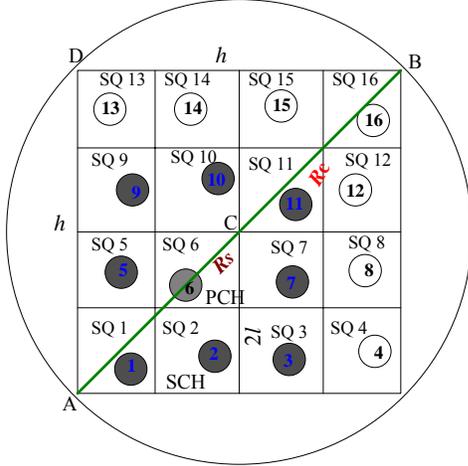


Figure 5. Secondary Cluster Head (SCH) selection

Figs 3 – 6 illustrate the working principle of this scheduling algorithm. Fig. 3 shows that the node 6 of the cluster is randomly selected as a PCH by the BS. Figure 4 shows that two furthest points A, and B of the cluster, which has the Euclidean distance equal to the communication range, R_c so that if the PCH is located at the point A, the member node at the point B can still communicate with the PCH. For the ease of computation we assume that the cluster is divided into a number of small squares where l is the length of a side of the square.

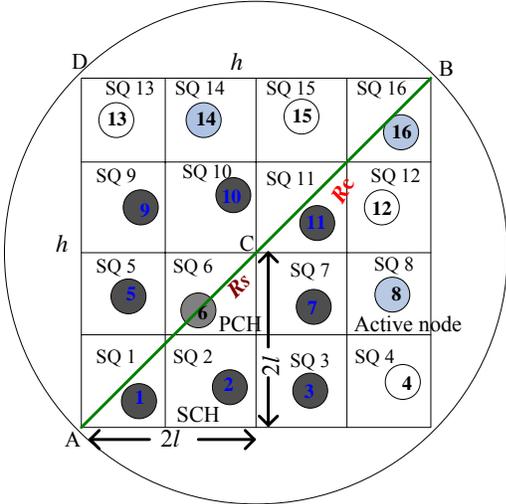


Figure 6. Active nodes selection for cluster and network coverage

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

Thus, if a node is at the bottom left corner of a square it can still cover (sense) the area of all neighboring squares.

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

Thus, the approximate area Δ_c of a square cluster (square) as is illustrated in Figure 5 is

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

Fig. 5 shows that the SCHs (black colored nodes with blue numbers 1, 2, 3, 5, 7, 9, 10, 11) are the nodes which are within the sensing range, R_s (i.e., Euclidian Distance CD) of CH (node 6) and reside in the neighboring squares of the PCH. Once SCHs are selected the PCH notifies the IDs of SCHs to all other members of the cluster. Similarly, other members of the cluster identify the number of nodes in their neighboring squares. The nodes, which are not neighbors of each other and have the higher neighboring nodes (node degree) are selected as the active member nodes of the cluster. For instance, light blue colored nodes, 8, 14, 16 are active member nodes. 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 nodes.

The active nodes at the border of each cluster also cover some area of neighboring clusters since the neighboring squares of the nodes at the border of a cluster reside in the neighboring cluster. For instance, node 14 will have neighboring squares that reside in its neighboring cluster and will cover the area of those squares in neighboring cluster. Let us assume that node P is an active node of the neighboring cluster of node 14 and resides in the neighboring square of node 14. Neither node P nor node 14 covers the area of all neighboring squares of each other. Thus, the proposed node scheduling algorithm cannot completely eliminate redundant data sensing. However, by reducing the number of active nodes this protocol achieves energy efficiency.

3. Mobility Management

The nodes are attached to objects such as human body, car, animal that make them mobile. We present how the mobility of different types of nodes is incorporated in the proposed CCES scheduling scheme.

In this protocol, each PCH has a number of SCHs and each active node has several alternative nodes. SCHs and alternative nodes remain in sleep mode. The PCH allocates timeslot for each active node to work using TDMA scheme. The proposed CCES scheduling scheme supports the mobility of sensor nodes as follows.

(i) SCH moves – In this protocol, each PCH has a number of SCHs. Thus, if a SCH x moves to another location of this cluster which is still within the sensing range of the PCH there will not be any change to the network setup of the protocol. If x moves inside the cluster but out the sensing range of the PCH the SCH x

will be deleted from the neighbor list of PCH and also the scheduled timeslot when x wakes-up and checks the energy status of the PCH. However, the PCH has still a number of SCHs that provides the fault tolerance of the protocol. The SCH x becomes a regular cluster member, neighbor of an active node and remain in sleep state.

(ii) Active and alternative nodes moves – if an active node x moves from its current location to another location of the cluster, x notifies its PCH. Then, the PCH will select the alternative node y to x that wakes up first as an active node and x will be kept in sleep mode if the new location of x is already covered (most likely). Otherwise, x will be selected as an active node. If x moves out of the cluster alternative node y to x which wakes up first becomes an active node. If the selection of y as an active node still keeps some area Δ uncovered, another sleeping node z that covers Δ will be selected as an active node, whenever z wakes up.

(iii) PCH moves - when the PCH moves inside or outside of the cluster, a SCH that wakes up first will be selected as a PCH and notifies all member nodes of the cluster. If the PCH is inside the cluster it becomes either a SCH (if it is within the sensing range of the new PCH) or a regular cluster member. If the PCH moves out the cluster it joins the new cluster by sending a “JOIN-REQUEST” message to the PCH.

IV. PERFORMANCE EVALUATION

In this section, we present the simulation model, performance analysis on the network energy consumptions and performance evaluation of the proposed Coverage and Cluster-based Energy efficient Node Scheduling (CCES) scheme of Mobile Wireless Sensor Network (WSN).

A. Energy Model

We assume that the topology of the proposed CCES scheme follows wireless communication model [3,5,9], where the radio energy consumptions for transmitting a data packet of size n bits over a distance d is represented by

$$E_{TX}(n, d) = E_{elec}(n) + E_{amp}(n, d) = n\varepsilon_{elec} + n\varepsilon_{fs}d^\alpha \quad (4)$$

Where, ε_{elec} denotes per bit energy consumptions to run the transmitter or receiver circuit, ε_{fs} denotes the energy consumptions of RF amplifiers for propagation loss, and α is a constant for propagation loss. $\alpha = 2$ for the straight line of sight or free space data propagation.

B. Performance Analysis

From Equation 1 the area of small squares in a cluster can be denoted as

$$\Delta_s = l \times l = \frac{R_s^2}{8} \quad (5)$$

Equation 3 estimates the area of a cluster as

$$\Delta_c = h \times h = \frac{R_c^2}{2} \quad (6)$$

Using the double range property [15], the communication range, R_c and sensing range, R_s is related as

$$R_c = a \times R_s \text{ Where } a \geq 2 \quad (7)$$

In the proposed CCES scheduling scheme, we assume the constant $a = 2$ though this is not true in real world scenario due to the irregular radio pattern.

$$R_c = 2 \times R_s \quad (8)$$

Thus, the number of small squares, n_s in each cluster can be estimated as

$$n_s = \frac{\Delta_c}{\Delta_s} = \frac{4 \times R_c^2}{R_s^2} = \frac{4 \times 4 \times R_s^2}{R_s^2} = 16 \times \beta \quad (9)$$

The cluster is not actually square shaped but can be circumscribed into a square. Thus, $n_s \leq 16$, which is adjusted by the constant β in Equation 9, $0 < \beta \leq 1$.

The cluster is not actually square shaped but can be circumscribed into a square. Thus, though Equation 9 estimates $n_s = 16$ actually, $n_s \leq 16$. Thus, we use the constant β in Equation 9 to adjust the value of n_s .

Figure 6 demonstrates that if a PCH is located in a square the upper and lower bound of the number of neighboring squares that it can cover is 8 and 3, respectively. The lower bound occurs if the PCH is placed at a corner small square in the cluster. Again, 3 active nodes can be selected in other corner squares which will cover 3 neighboring and non-overlapping squares. In such case, the maximum number of active nodes including PCH in a cluster will be only. If each neighboring square has at least one member node the number of backup PCH (SCH) and alternative nodes to the active nodes other than PCH will be 3 and 9, respectively. Similarly, we can estimate the number of PCH, SCH, active and alternative nodes for other network configurations including the upper bound of the number of neighboring squares to PCH.

Let us assume that the number of nodes in the network is N and the average number of active node sets with minimum overlapping or non-overlapping area coverage is p . Thus, the average number of active node set is $m = \left\lfloor \frac{N}{p} \right\rfloor$

If one node set, S_1 is active, $m - 1$ set of nodes remain in sleep mode and each of the $m - 1$ sets wake-up at a particular time interval (in round robin fashion) to check the energy status of nodes in the active node set S_1 in CCNS scheduling scheme. If one or more nodes in S_1 are drained out, one of the active nodes of S_1 broadcasts a beacon message to the nodes of set S_2 to become active. Thus, if the energy of a node of an active node set is drained out the total number of transmitted message = $|S_2| \approx p$.

Since the number of node set is m , the average number of message transmitted $\approx m \times p$

Moreover, each node of a wake-up set dissipates energy for idle listening. If the energy dissipation of a node for idle state is E_{idle} the total energy consumptions over t_n timeslots can be represented as

$$E_{CCNS-idle} \geq t_n \times p \times E_{idle} \quad (10)$$

We assume that the energy dissipation of active nodes in the proposed CCES scheduling scheme is homogeneous (i.e., almost equal though it depends on the distance from a node to PCH). Initially, the PCH schedules alternative nodes to the active nodes to wake-up in round robin fashion until the residual energy of a node goes below the threshold energy EN-TH1 (i.e., the residual energy of all other active nodes will go below EN-TH1 soon). Then, alternative node to an active node wakes-up at a predefined time interval to check the energy status.

If the energy dissipation of a node for idle state is E_{idle} the total energy consumptions over t_n timeslots can be represented as

$$E_{CCES-idle} \geq t_n \times E_{idle} \quad (11)$$

In Equation 11, $t_n \leq t_{th}$ and t_{th} is the number of timeslots after when the residual energy of the first node goes below EN-TH1.

If $t_n > t_{th}$ and $t_n = t_{th} + t_x$ the total energy dissipation is represent as

$$E_{CCES-idle} \geq t_{th} \times E_{idle} + t_x \times p \times E_{idle} \quad (12)$$

In such case Equation 12 can be represented as

$$E_{CCES-idle} \geq t_{th} \times p \times E_{idle} + t_x \times p \times E_{idle} \quad (13)$$

From Equations 10 and 11 we can infer that

$$E_{CCES-idle} < E_{CCNS-idle} \quad (14)$$

Thus, the energy consumptions of the sensors nodes using proposed CCES scheduling scheme in idle state will be lower than that in the existing CCNS [6] scheduling scheme.

C. Simulation Setup and Results

We perform simulation to measure the performance of the proposed CCES scheduling scheme in terms of energy consumptions, network lifetime, number of data transmission and round number the first node fails and compare with the existing CCNS algorithm. This is because there is a similarity between the CCES and CCNS algorithms where both algorithms work by scheduling a number of active nodes. The network energy consumptions are defined as the energy consumptions of all sensor nodes for transmitting, receiving, and aggregating data for a

certain number of rounds. Network lifetime is defined as the remaining energy of the network after a certain number of rounds and it reflects the time duration the network works. Number of data transmission is the total number of message transmissions among the nodes over a certain number of rounds defined as the total time that is required by all active member nodes of clusters to BS through PCHs.

TABLE II. SIMULATION PARAMETERS AND THEIR VALUES

Parameter	Value
Network area	100 meter x 100 meter
Number of nodes	Maximum 200
Number of clusters	4 – 8
Coordinate of base station	100 x105 meter
Transmission energy consumptions	50 nJoule/bit
Energy consumption in free space	0.01 nJoule/bit/m ²
Energy consumptions in idle state	.00185 nJoule/sec
Initial energy of each node	3 Joule (2 AA batteries of 1.5 volt each)
Data transmission rate	250 Kbps

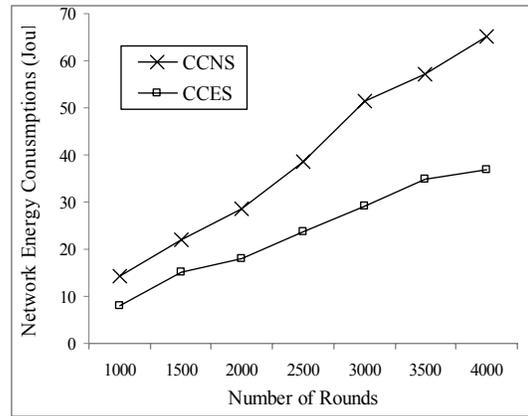


Figure 7. Comparison of network energy consumptions

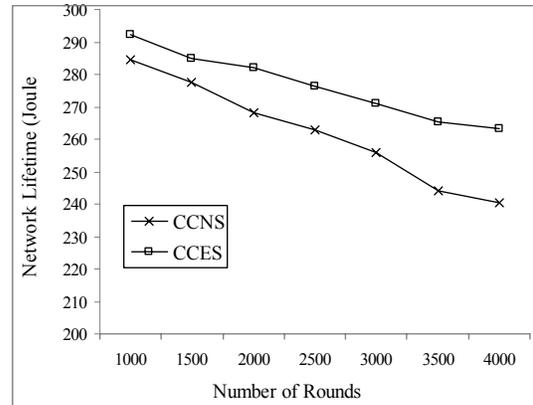


Figure 8. Comparison of network lifetime

We consider an area of size 100 meters x 100 meters as a network model. We randomly deploy sensors into the network. Table II presents all other simulation parameters and their respective values. We run the simulation for a fixed number of clusters, and nodes by varying the number of rounds, where a round comprises network setup phase (PCH selection, active and alternative node selection) and steady phase (e.g.,

routing). Each round has a number of frames, where each node a timeslot in each frame. We set the number of clusters, and nodes to 4 and 100, respectively, and place the BS outside all clusters at the coordinate (55, 105).

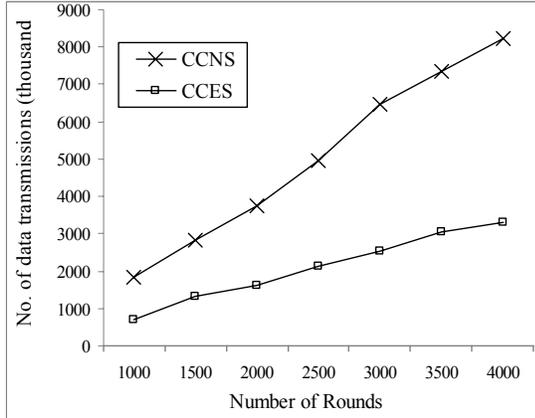


Figure 9. Comparison of number of data communications

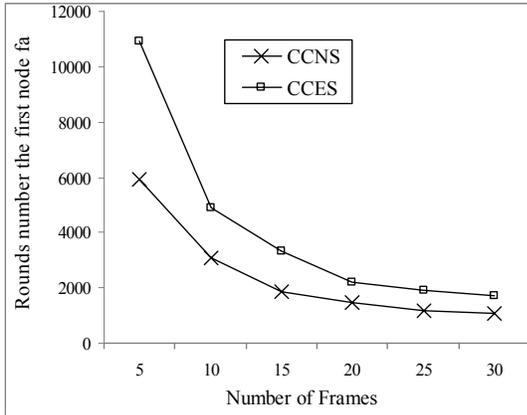


Figure 10. Rounds at which the first node fails varying number of frames in each rounds

Fig. 7 shows that the network energy consumptions of the proposed CCES scheduling scheme is much lower than that of the existing CCNS algorithm. This is because CCES scheduling scheme selects a minimum number of active nodes which provides network coverage and remain active mode until the energy of an active node goes below a threshold value. One or more alternative nodes are assigned to each active node which are also scheduled to wake-up at their predefined timeslot, whereas a subset of nodes which are alternatives to a subset of active nodes wakeup in the existing CCNS algorithm at each timeslot to check the energy status of the subset of active nodes. This also results less network lifetime of the CCNS scheduling scheme (as is illustrated in Fig. 8). Fig. 9 demonstrates that the number of data transmissions is much more in the CCNS scheduling scheme than the proposed CCES since the subset of nodes that wake-up at timeslots transmit beacon messages to the set of active nodes to know their energy status. Similarly, Fig. 10 demonstrates that the first node fails much faster in the CCNS algorithm than the proposed CCES scheduling scheme. This is because each node consumes more energy in

CCNS algorithm than that in the CCES algorithm.

D. Discussion

In the existing CCNS node scheduling scheme if the residual energy of a node x in an active node set S_1 goes below the threshold value, another node set S_2 that was in the sleep mode wakes-up and becomes active. This is not energy efficient because due to the energy status of a single node in S_1 all other nodes in S_1 , which have higher residual energy, go to the sleep mode. In the existing CCES node scheduling scheme, two energy thresholds are used to balance the energy consumptions. An active node a_1 will be replaced by its substitute or alternative node whenever its energy goes below the energy threshold1 (EN-TH1) and remain into the sleep mode until the residual energy of all alternative nodes covering the area of a_1 goes below EN-TH1. Thus, CCES achieves energy efficiency. Table III presents comparison among the proposed CCES and existing CCNS scheduling schemes on some important features.

TABLE III. COMARISON OF THE PROPOSED CCES AND EXISTING CCNS SCHEDULING SCHEME

Features	CCNS	CCES
Coverage-aware	√	√
BS selects active nodes	X (CH)	√
A number of active node set, one set works at a time, others sleep	√	X
Uses a primary cluster head and a number of secondary cluster heads	X	√
Duty cycle adjusted based on no. of neighbors of a node	X	√
Support fault tolerance for primary cluster head	X	√
Supports mobility	X	√

V. CONCLUSION AND FUTURE WORK

This paper introduces Coverage and Cluster-based Energy efficient Node Scheduling scheme (CCES) for Mobile Wireless Sensor Networks. This protocol provides fault tolerance by selecting a number of Secondary Cluster Heads (SCHs) and alternative nodes to each active node. We estimate the maximum number of active nodes in each cluster for a particular sensing and communication range of sensor nodes. Mathematical analysis and simulation results show that the CCES scheduling scheme has less network energy consumptions as compared to the existing CCNS scheduling scheme. Moreover, the CCES scheme supports mobility of sensor nodes. Though we compare the proposed CCES algorithm with the static CCNS algorithm since the CCNS algorithm also works by scheduling a set of active nodes, which is similar to the proposed CCES algorithm we plan to compare the performance of CCES algorithm with existing mobility centric scheduling schemes. Furthermore, we plan to compare the performance of CCES scheduling scheme in terms of end-to-end delay and packet loss ratio and also with more existing scheduling schemes.

REFERENCES

- [1] M.S. Al-kahtani, H.T. Mouftah, "A stable clustering formation infrastructure protocol in mobile ad hoc networks" *IEEE International Conference on Wireless and Mobile Computing, Networking and Communications (WiMob'05)*, pp. 406-413, Aug 22-24, 2005, Canada.
- [2] M. S. Al-kahtani, H.T. Mouftah, "Enhancements for clustering stability in mobile ad hoc networks", *Q2SWinet'05 - Proceedings of the First ACM Workshop on Q2S and Security for Wireless and Mobile Networks*, pp. 112-121, October 13, 2005, Montreal, Canada.
- [3] F. Bajaber and I. Awan, "Dynamic/Static Clustering Protocol for Wireless Sensor Network," *Computer Modeling and Simulation, 2008. EMS '08. Second UKSIM European Symposium on*, pp. 524-529, 2008.
- [4] J. Deng, S. H. Yunghsiang, W.B. Heinzelman, P.K. Varshney, "Balanced-energy sleep scheduling scheme for high density cluster-based sensor networks", *Applications and Services in Wireless Networks. ASWN 2004. 4th Workshop on*, pp. 99- 108, 9-11 Aug. 2004.
- [5] W.B. Heinzelman, A.P. Chandrakasan, and H. Balakrishnan. An application specific protocol architecture for wireless microsensor networks. *Wireless Communications, IEEE Transactions on*, 1(4):660 - 670, Oct 2002.
- [6] S.F. Hwang, Y.Y. Su, Y.Y. Lin, C.-R. Dow, "A Cluster-Based Coverage-Preserved Node Scheduling Scheme in Wireless Sensor Networks," *Mobile and Ubiquitous Systems: Networking & Services, 2006 Third Annual International Conference on*, pp.1-7, July 2006.
- [7] X. Jian-bo, P. Li, "A New Intra-cluster Node Scheduling Algorithm of Clustering Data Collection Protocol in WSNs," *Electronic Computer Technology, International Conference on*, pp.582-586, 20-22 Feb. 2009.
- [8] J. Jiang, L. Fang, J. Wen, G. Wu, H. Zhang, "Random Scheduling for Wireless Sensor Networks", *Parallel and Distributed Processing with Applications, 2009 IEEE International Symposium on*, pp.324-332, 10-12 Aug. 2009.
- [9] L. Karim, N. Nasser, and T. Sheltami. A fault tolerant dynamic clustering protocol of wireless sensor networks. In *Global Telecommunications Conference, 2009. GLOBECOM 2009. IEEE*, pages 1- 6, 30 Nov - Dec 4 2009.
- [10] L. Karim, N. Nasser and T.E. Salti, "Routing on Mini-Gabriel Graphs in Wireless Sensor Networks", *the IEEE International Conference on Wireless and Mobile Computing, Networking and Communications (WiMob)*, pp. 105-110, China, October 2011.
- [11] J.C. Lim, C.J. Bleakley, "Extending the lifetime of sensor networks using prediction and scheduling", *Intelligent Sensors, Sensor Networks and Information Processing, ISSNIP 2008. International Conference on*, pp.563-568, 15-18 Dec, 2008.
- [12] J. Liu, N. Gu, S. He, "An Energy-Aware Coverage Based Node Scheduling Scheme for Wireless Sensor Networks", *Young Computer Scientists, 2008. ICYCS 2008. The 9th International Conference for*, pp.462-468, 18-21 Nov. 2008.
- [13] C.-Z. Long, H. Chen, W.-L. Wu, L.-H. Li, M.-T. Xiang, "A Topology Algorithm Based on Sleep-Scheduling in Heterogeneous Wireless Sensor Networks," *Wireless Communications, Networking and Mobile Computing, 2008. WiCOM '08. 4th International Conference on*, pp.1-5, 12-14 Oct. 2008.
- [14] Q. Ren, J. Li, H. Gao, "TPSS: A two-phase sleep scheduling protocol for object tracking in sensor networks," *Mobile Adhoc and Sensor Systems, 2009. MASS '09. IEEE 6th International Conference on*, pp.458-465, 12-15 Oct. 2009.
- [15] X. Zhang, Z. D. Wu, "Flock detection based duty cycle scheduling in mobile wireless sensor networks", *Local Computer Networks (LCN), IEEE 36th Conference on*, pp.777-784, 4-7 Oct. 2011.
- [16] G. Zhou, T. He, S. Krishnamurthy, and John A. Stankovic. Impact of radio irregularity on wireless sensor networks. In *MobiSys*, 2004.
- [17] C. Zhu, L.T. Yang, L. Shu, L.Wang, T. Hara, "Sleep scheduling towards geographic routing in duty-cycled sensor networks with a mobile sink," *Sensor, Mesh and Ad Hoc Communications and Networks (SECON), 2011 8th Annual IEEE Communications Society Conference on*, pp.158-160, 27-30 June 2011.