

Research Article

Capacity-Preserved, Energy-Enhanced Hybrid Topology Management Scheme in Wireless Sensor Networks for Hazardous Applications

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A wireless sensor network is composed of large number of sensor nodes and they are densely deployed in the field to monitor the environment, collect the data and route it to a sink. The main constraint is that the nodes in such a network have a battery of limited stored energy the network lifetime gets reduced. There are various topology management schemes such as SPAN, STEM, GAF, BEES and so forth, for improving network parameters such as capacity, lifetime, coverage and latency. These schemes do not improve all the mentioned network parameters. Sustainable Physical Activity in Neighbourhood (SPAN) scheme, preserves network capacity, decreases latency but provides less energy savings. Sparse Topology and Energy Management (STEM) scheme does not preserve capacity resulting in great energy savings and high latency. In the proposed scheme, new coordinator rule is implemented in SPAN, and then integrated with STEM. It is observed that the energy conserved increases by about 3.18% to 4.17% without sacrificing network capacity. Due to definite path in the proposed scheme the latency is reduced by almost half the latency of STEM scheme.

1. Introduction

Sensor nodes consist of a processing unit, transceiver unit, sensing unit, and power unit. A wireless sensor network [1, 2] consists of large number of sensor nodes densely deployed in the field. These nodes will monitor the environment and detect if any event occurs and sends the corresponding information to the sink. In sensor networks, the nodes operate with battery of limited energy storage capacity. The transceiver unit consumes more power compared to other units and the sensor nodes can be used efficiently by putting their transceiver units in an off state. Various topology management schemes have already been proposed [3–5] to use the transceiver effectively and improve the network parameters such as lifetime at the cost of latency and capacity. Sustainable physical activity in neighbourhood (SPAN) [6] is a topology scheme in which a few nodes will be in active state called coordinator and form a backbone path, lowering the latency in SPAN. The drawback of SPAN is that

it has less system lifetime compared to sparse topology and energy management (STEM). STEM [7], is another topology scheme in which each and every node will have two radios, a data plane radio, and a wake-up plane radio. Usually, the data plane radio will be in off state, and if any event occurs, the wake-up plane radio will send wake-up message and activate the data plane radio of another node. The main advantage of STEM is that it has longer system lifetime. The drawback of STEM is high latency and less capacity. In this paper, 80, 90, 100, 110, 120 nodes are deployed in various field sizes such as 60 m * 60 m, 85 m * 85 m, 105 m * 105 m (15 scenarios), and the interaction of STEM and SPAN is analysed in all these scenarios.

Wireless sensor networks (WSNs) have wide applications [8, 9] such as health, military, and environment monitoring for detecting any hazards. This growth has led to widespread popularity in wireless communication, and hence numerous research works are being carried out in this field. In large-scale wireless sensor networks or in hazardous applications,

it is impossible to either recharge or replace the batteries. Hence energy has to be used efficiently in order to improve the lifetime of the network. This motivated us to propose a scheme to improve the important network parameters.

The rest of the paper is organised as follows. Different topology management schemes are discussed in Section 2. Section 3 deals with the proposed scheme; in Section 4, the performance analysis are discussed. Section 5 concludes the paper.

2. Related Work

The main aim of topology schemes [3, 10–12] in wireless sensor network is to reduce the energy consumption and maintain connectivity to efficiently forward data to sink. In STEM, [7, 13, 14] the wake-up radio is periodically on for monitoring the environment. Typically, the data radio in the next hop between a node and the sink will be in the off state. To overcome this problem, each node will periodically turn on their radio for a short time to check if any other nodes want to communicate with it. In principle, the communication capacity could be reduced to virtually zero, by turning off the radios of all nodes (i.e., putting them in the sleep mode). When a possible event is detected, the main processor is woken up to analyze the data in detail. The radio, which is normally turned off, is woken up if the processor decides that the data needs to be forwarded to sink. Now, the problem is the radio of the next hop to the data sink is still turned off, if it did not detect that same event. As a solution, each node periodically turns on its radio for a short time to listen if someone wants to communicate with it [7, 15].

In most of the applications, nodes are in the idle state and waiting for the event to happen. STEM reduces the energy consumption of the sensor node by switching its radio off when it is idle. STEM with wake-up interval of 600 ms, which reduces the energy consumption of the node by a factor of about 2.5. STEM conserves energy at the expense of network capacity and higher latency.

In sustainable physical activity in neighbourhood scheme (SPAN) [6], only few nodes will be elected as coordinators. If two neighbours of a node cannot reach each other directly, then that node becomes a coordinator. The coordinators are selected based on this coordinator-election rule such that equal chance is given for all the nodes to become coordinators. The coordinators will form a definite backbone path in the network through which data is forwarded from source to sink. Since there is a definite backbone path, the latency is less. SPAN preserves network capacity.

In geographic adaptive fidelity scheme (GAF) [16, 17], the network is divided into several grids, and in each and every grid, only one node will remain in “on” state. Thus, if there are “ n ” grids in the network, then there will be only “ n ” nodes in “on” state in the network. Here energy is conserved. The main drawback of GAF is that it typically uses GPS to determine node location. In many settings such as indoors or under trees, where GPS does not work properly, location information is not available. The dependency on global location information thus limits GAFs usefulness, and

also GPS is used for location information that is relatively costly. GAF sizes its grid based on radio range R . In order to reach the nodes in the neighbouring grid, the size of the square grid is fixed as $r \leq (R/\sqrt{5})$. With this definition nodes in a grid can reach all the nodes in the horizontally and vertically neighbouring grids. As a result, few nodes in the corner of the diagonal grid is not reachable.

In the adaptive self-configuring sensor network topology scheme (ASCENT) [18], nodes will be in active, passive, test and sleep states. Active nodes participate in the data transmission. The nodes in test and passive state are checked continuously to become active for successful transmission of data packets. The node that detects the loss of packets sends help message to neighbouring nodes to join the network. The nodes in passive state receive these messages and check to become active node if needed. Hence data loss is reduced and successful transmission takes place.

In enhanced SPAN (E-SPAN) [19], directional antennas are used. In this method, data is sent in directional mode and “hello” message is sent in omni mode. The receiver was in omni-directional mode, and transmitter was either in omni or directional mode. Here only one antenna can be enabled at a time. Reduction in energy should be of the order of 2.7 times of the energy gain at the best case. Hence E-SPAN is more efficient than SPAN.

2.1. System Model. The following assumptions and notations are used in the proposed model shown in Figure 1.

Assumptions made:

- (i) both uniform and random deployments of nodes;
- (ii) fixed transmission radius;
- (iii) sensing range is less than transmission range;
- (iv) dual radio;
- (v) homogeneous network;
- (vi) boundary effects are negligible.

2.2. Problem Description. Wireless sensor nodes have a battery of limited energy, and therefore the network lifetime depends on how wisely the energy is used. In critical applications such as chemical plants, forest fires, and nuclear reactors, it is often not possible to replace or recharge the battery. Our objective was to improve lifetime and reduce the latency without sacrificing the capacity. We achieve this by integrating the definite backbone of SPAN and dual radio approach of STEM to develop the network architecture with low power consumption and low latency.

3. Proposed Scheme

In the proposed technique, two different topology management schemes, namely, sparse topology and energy management (STEM) scheme and sustainable physical activity in neighbourhood (SPAN) scheme are integrated. Each and every node has two radios, namely, data plane and wake up plane. The coordinators are elected using the proposed coordinator eligibility algorithm. The noncoordinator nodes

will be put in sleep state and coordinator nodes will be turned on. These coordinators will form a definite backbone path through which data is forwarded to sink. When the sensor node detects an event, it will wake up its radio when it is needed to transmit data to the sink. Here the problem is that the radio of the next hop in the path to the data sink is still turned off. To overcome this problem, each node periodically turns on its radio at same time as shown in Figure 7, to check whether any of the other nodes wants to communicate with it. The wake-up plane will wake up the data plane radio, and thus a connection is established between two nodes and thereby data is sent. A node, which wants to communicate with other node, is initiator node and node, which is been communicated, is target node. The proposed scheme has been tested by deploying various numbers of node such as 80, 90, 100, 110, 120 in different field sizes such as 60 m * 60 m, 85 m * 85 m, 105 m * 105 m, and performance was analysed. Due to definite backbone path and dual radio, latency is reduced and more energy is conserved, preserving the capacity of the network. Capacity is the number of packets the network can successfully deliver per unit time. It is inversely proportional to the network's packet loss rate. The proposed hybrid scheme does not degrade the network capacity as that of SPAN. Hence, the capacity is preserved.

3.1. Uniform Deployment of Nodes. Nodes are deployed uniformly as shown in Figure 2. This uniform deployment of nodes will form segments of hexagon. Uniform deployment of nodes is used for many static applications such as precision agriculture, car parking, and chemical plants [20, 21]. Nodes are deployed uniformly with distance between two nodes in horizontal direction as “ r ” and the distance between two nodes in vertical direction as “ h .” Here radio range is “ R ” = 20 metres.

3.1.1. Derivation of Mathematical Model for Node Deployment. Let, $L * L$ be the size of the field,

“ N ” be the total number of nodes,

“ N_x ” be the number of nodes in the horizontal direction,

“ N_y ” be the number of nodes in the vertical direction,

“ D_x ,” and “ D_y ” be the distance between two nodes in horizontal and vertical directions, respectively;

“ r ” be the side of the hexagon;

“ h ” be the half the height of the hexagon in the vertical direction;

“ R ” be the radio range.

For uniform deployment, the distance between the nodes in the horizontal direction (r) and the distance between the nodes in the vertical direction (h) are predetermined and deployed accordingly.

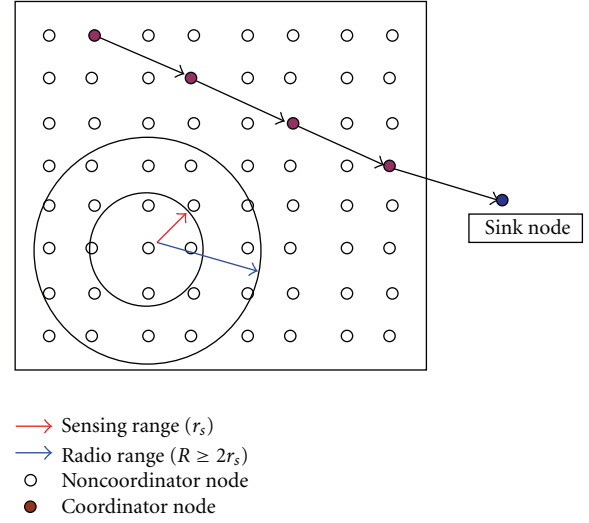


FIGURE 1: Proposed system model.

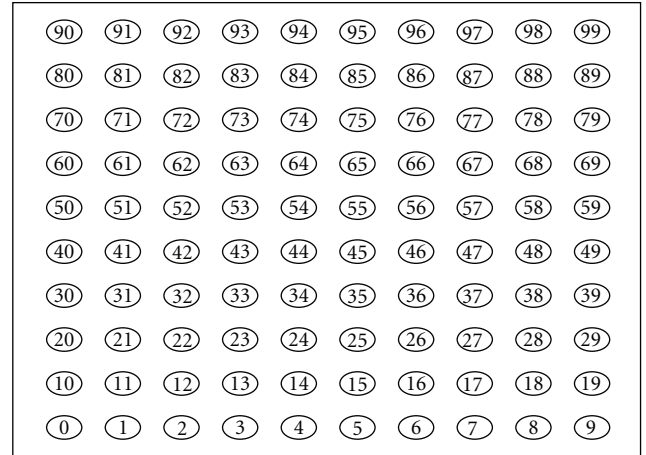


FIGURE 2: Uniform deployment of 100 nodes.

The relationship of the distance between the nodes in the vertical direction “ h ” and horizontal direction “ r ” is given by

$$h^2 = \left[r^2 - \left(\frac{r}{2} \right)^2 \right], \quad (1)$$

$$h = \frac{r\sqrt{3}}{2},$$

to ensure the connectivity $r \leq R$.

The product of nodes arranged in horizontal and vertical directions gives the total number of nodes. So

$$N_x N_y = N, \quad (2)$$

$$D_x = \frac{L}{N_x - 1}, \quad (3)$$

$$D_y = \frac{L}{N_y - 1}. \quad (4)$$

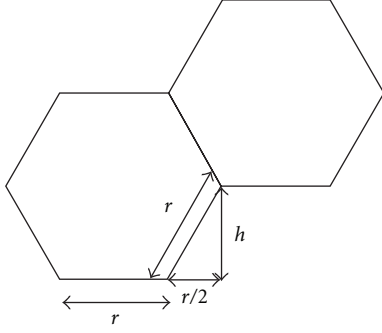


FIGURE 3: Calculation of location of nodes in uniform deployment.

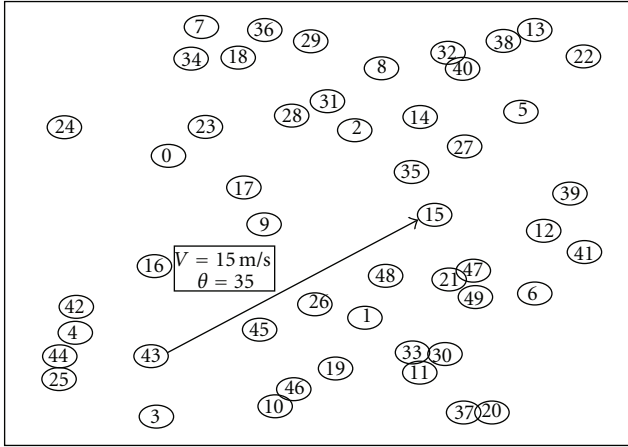


FIGURE 4: Random deployment of nodes (random waypoint model).

The distance between two nodes is arranged as shown in Figure 3, that is,

$$D_x : D_y = 1 : \frac{\sqrt{3}}{2}. \quad (5)$$

By using (2) to (5), we get,

$$1.155N_x^2 - 0.155N_x - N = 0. \quad (6)$$

By solving this we get the number of nodes in horizontal direction and by substituting this in (2) the number of nodes in vertical direction can be determined (see Algorithm 1).

3.2. Random Deployment of Nodes with Mobility. Here the nodes are deployed randomly in the field as shown in Figure 4 using random waypoint mobility model, which is the most widely used model [22]. Sensor nodes move randomly in the field and the destination, speed, and direction are all chosen randomly.

3.3. Coordinator Eligibility Rule. For more details (see Algorithms 2 and 3 or Figures 5 and 6).

3.4. Theoretical Analysis: Coordinator Calculation. In uniform deployment of nodes, the nodes will be at the vertex of hexagon [23]. Each hexagon has six vertices. Each node at the vertex is shared by three hexagons. Therefore, each hexagon has two coordinators. In order to find the number of coordinators, number of hexagons in the given area has to be known, which is given by

$$N_h = \frac{A_f}{A_h}. \quad (7)$$

Let the number of coordinator be “C” and non-coordinator be N_c :

$$C = 2 \left\lceil \frac{A_f}{A_h} \right\rceil, \quad (8)$$

$$C = 2 \left\lceil \frac{L^2}{6(\sqrt{3}/4)R^2} \right\rceil.$$

Thus, the number of coordinators is calculated.

The total number of nodes (N) is

$$N = C + N_c. \quad (9)$$

For N nodes, the coordinator node ratio is α and is given by

$$\alpha = \frac{C}{N}. \quad (10)$$

The noncoordinator node ratio is given by

$$\beta = 1 - \frac{C}{N}. \quad (11)$$

Thus,

$$C = N(1 - \beta). \quad (12)$$

Hence $N(1 - \beta)$ nodes will be in on state and $N\beta$ nodes will be in off state. For a field size of $L \times L$, the area is L^2 (m^2).

3.5. Theoretical Analysis: Latency Calculation. The initiator node will first start to send beacons to target node, and after receiving the beacons, the target node will respond to it. Once both of the nodes turned their data radio on, a link is established between them and data is transferred. If the transferred data is not intended for this node, then this becomes the initiator node and sends the packet to the node in the next hop towards destination, and this process is repeated. For simplicity, we did not use a location service in our simulations. A node obtains the location of the destination node from the general operations director (GOD) module in NS2 [24]. The location is required once per flow at the sender. Nevertheless, location services such as grids location service (GLS) [25] can be used with the hybrid scheme. To avoid the problem of interference between the wake-up beacon and the data transmission, transceiver uses dual radio and each radio operates at different frequency bands.

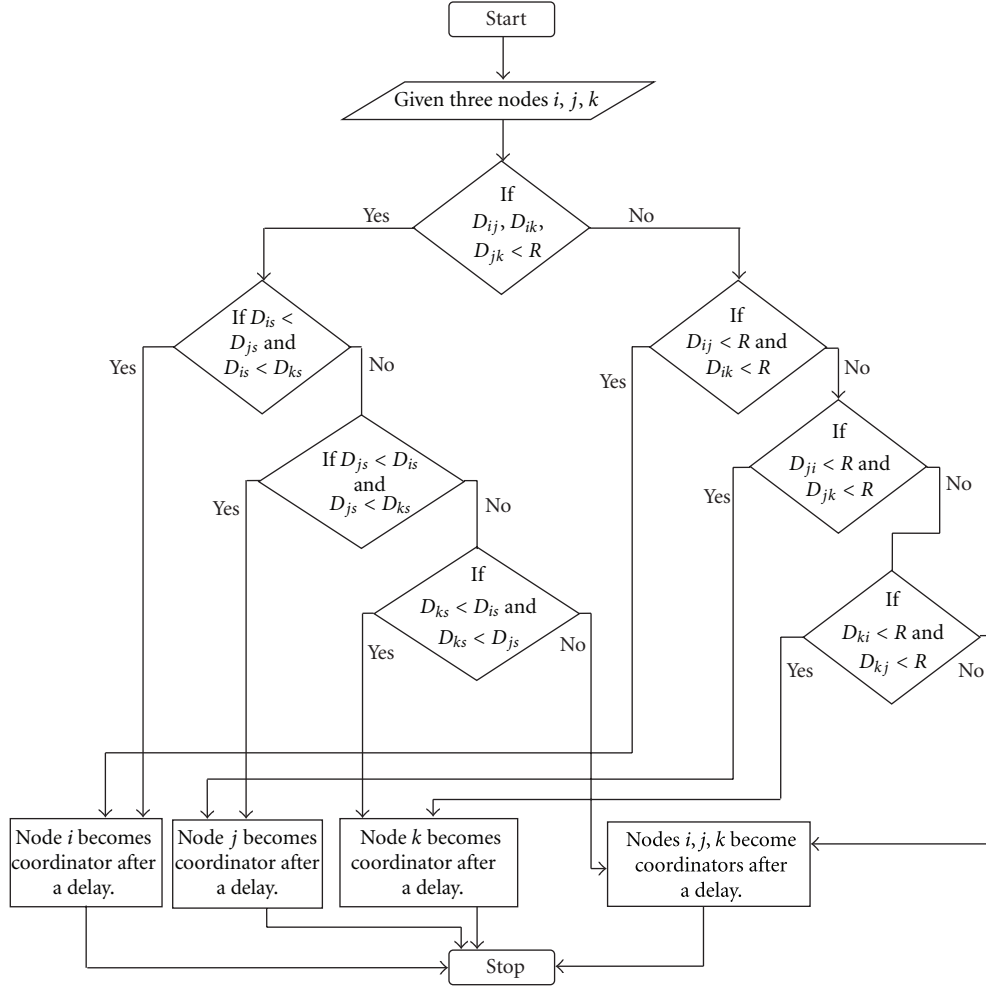


FIGURE 5: Flowchart for coordinator election.

The frequency band f_w (wake-up plane radio) is used to transmit the wake-up messages. Once the target node has received a wake-up message, both the nodes will turn on its radio operating at frequency band f_d . The data packets are transmitted in this frequency band, and they are called data plane (f_d). The time taken for this process is set up latency. The probability of the target node being turned on at the same time as the initiator node during the time interval “ T ” is given by

$$P(T_S = B_{XY}) = \frac{T_B - B_X}{T}. \quad (13)$$

If the total time period (T) is greater than “ON” time duration (T_b) of wake-up plane radio, then the average set up Latency per hop is given by

$$T_S = \frac{T + B_{XY}}{2}. \quad (14)$$

If the total time period (T) is equal to “ON” time duration (T_b) of wake-up plane radio, then the average set up latency per hop is given by

$$T_s = B_{xy}. \quad (15)$$

The total latency between source and sink is given by

$$T_l = T_s * (C - 1). \quad (16)$$

4. Performance Evaluation

The proposed hybrid topology management scheme is implemented and performance parameters like energy conservation, latency, and capacity are analysed and compared with SPAN and STEM topology management schemes. It is observed that the combined scheme has better performance and overcomes the limitations of both STEM and SPAN.

4.1. Simulation Environment. In this work, network simulator-2 (NS-2) tool is used, and both uniform and random deployments of nodes are considered separately over the sensor field. Here transmission range is fixed as $R = 20$ m, which has the radio characteristics as shown in Table 1. The power consumed by the node in transmit and receive mode is the power required for transmission and reception, respectively. Idle power is the power consumed when radio is on but no

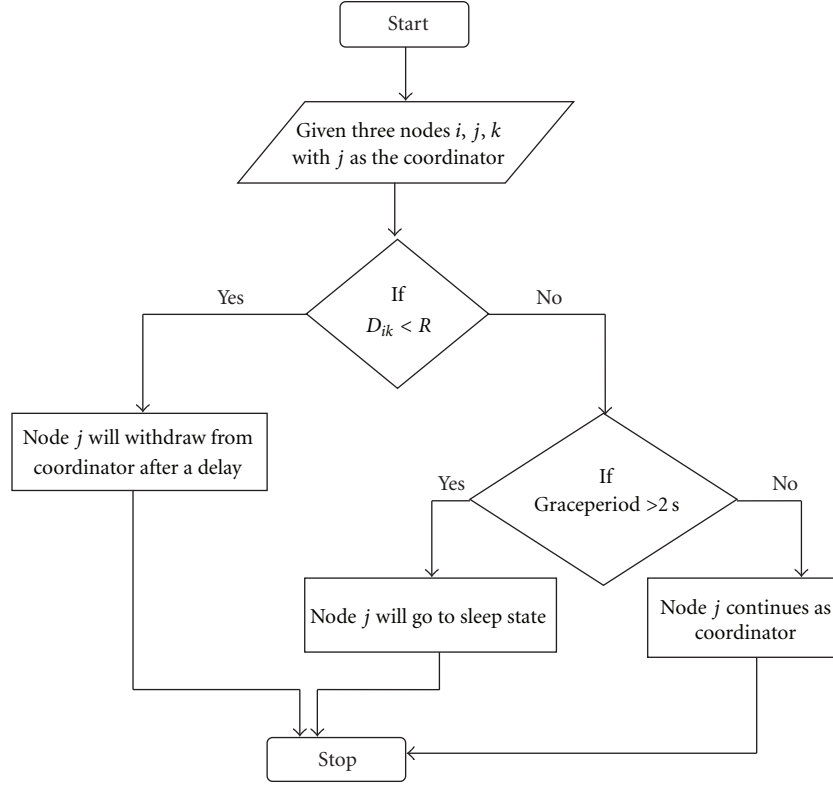
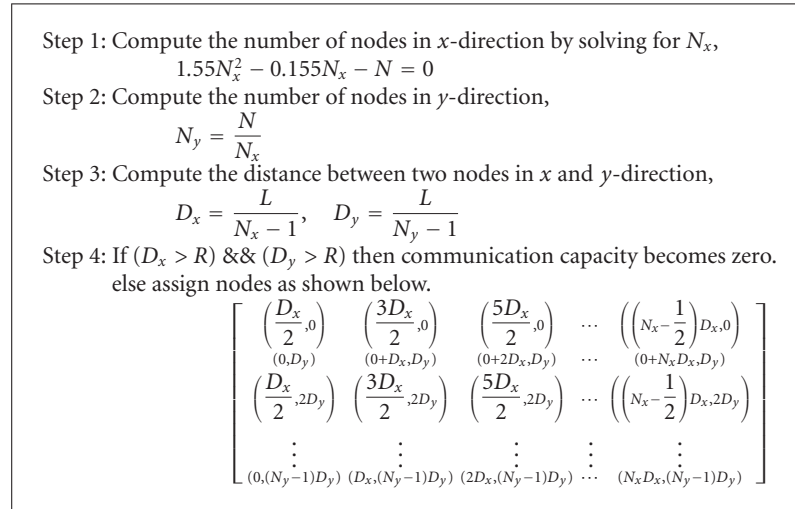


FIGURE 6: Flowchart for coordinator withdrawal.



ALGORITHM 1: Node deployment algorithm.

data is transferred. Sleeping power corresponds to the power consumed when the node is in sleep state.

In this simulation, traffic loads are generated by constant bit rate (CBR) flows. Different number of nodes such as 80, 90, 100, 110, and 120 is deployed both uniformly and randomly in $60 \text{ m} \times 60 \text{ m}$, $85 \times 85 \text{ m}$, $105 \text{ m} \times 105 \text{ m}$ field sizes separately. Here simulation time is set as 600 seconds.

4.2. Simulation Results. In uniform deployment of the nodes, the location of the nodes is predetermined and deployed.

For random deployment of nodes, nodes are deployed randomly, and random way point model is used as the mobility model. The proposed scheme is implemented by integrating STEM and SPAN topology management scheme, and coordinators are elected using proposed coordinator eligibility rule. The number of coordinators is observed in various field sizes ($60 \text{ m} \times 60 \text{ m}$, $85 \text{ m} \times 85 \text{ m}$, $105 \text{ m} \times 105 \text{ m}$) by deploying different number of nodes (80, 90, 100, 110, 120). Figure 8 shows the number of coordinators for all these scenarios and it is inferred that combined

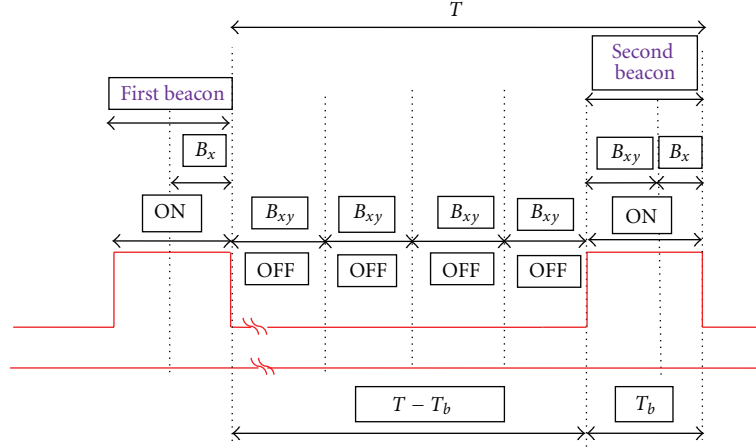


FIGURE 7: Latency analysis B_x : Transmit time of beacon; B_y : Inter beacon spacing; B_{xy} : Time taken for initiator node to send the beacon and receive response ($B_{xy} = B_x + B_y$); T_b : "ON" Time duration of target node ($T_b = B_{xy} + B_x$); and T : Total time period.

Step 1: Compute the number of neighbors for each node. Given nodes i and j in a wireless sensor network where all the nodes have the same radio range (R). D_{ij} denotes the Euclidean distance from i to j , and $D_{ij} \leq R$. Node j is node i 's neighbor.

Step 2: Nodes having maximum neighbors waits for the following delay and later announces as a coordinator.

$$\text{Delay} = \left[\left[\left(1 - \frac{E_y}{E_x} \right) + \left(1 - \frac{C}{0.5n(n-1)} \right) + R \right] * n * T \right]$$

Remaining nodes are put in sleep state.

Step 3: Let N_i, N_k are neighbors to N_j

If $N_{ik} > R$, then N_j become coordinator after the delay in Step 2.

Step 4: For all N_c , checks whether it is within the radio range of any coordinator node C .

Else that N_c become coordinator C .

Step 5: If two or more nodes satisfies Steps 1 to 4, then each node check its distance to the sink.

Step 6: if $(N_{is} < N_{js}) \&\& (N_{is} < N_{ks})$ then N_i becomes coordinator

else if $(N_{js} < N_{is}) \&\& (N_{js} < N_{ks})$ then N_j becomes coordinator

else N_k becomes coordinator

ALGORITHM 2: Coordinator election algorithm.

TABLE 1: Radio characteristics.

Radio mode	Power consumption (W)
Transmit	0.01488
Receive	0.01250
Idle	0.01236
Sleep	0.000016
Simulation Time	600 s

scheme has almost same number of coordinator as that of SPAN.

Also, it is inferred that as the number of nodes increases, the coordinator will almost remain constant because only a smaller fraction of nodes will become coordinator. As the field size increases, the distance between two nodes will increase, but the radio range remains constant. Since the distance between the nodes increases, the number of neighbours getting benefited will reduce. In order to cover

all the nodes in the field, number of coordinators elected increases for a constant radio range. Similarly, the number of coordinators in random deployment is also analysed.

Figure 9 shows the number of coordinators in random deployment for various scenarios as considered in uniform deployment. Unlike uniform deployment, the number of coordinators keeps varying to cover the entire field due to mobility.

Figure 10 shows the total energy conserved in the network for both combined scheme and SPAN scheme for different scenarios in uniform deployment. It is inferred that as the number of node increases, the total energy conserved in the network also increases. This is due to the fact that as the number of nodes increases, number of coordinators will remain constant, whereas the number of non-coordinator will increase. These non-coordinator nodes are put in sleep state and thereby more energy is conserved. It is also inferred that the combined scheme conserves more energy compared to SPAN scheme because

Step 1: Each coordinator checks periodically if it should withdraw as coordinator.
 Step 2: Let N_i, N_k are neighbors to N_j
 if $N_{ik} \leq R$, then N_j withdraws its coordinator after the delay
 Step 3: graceperiod = current time - last withdrawn
 if (graceperiod ≥ 2 s)
 sleep state

ALGORITHM 3: Coordinator withdrawal algorithm.

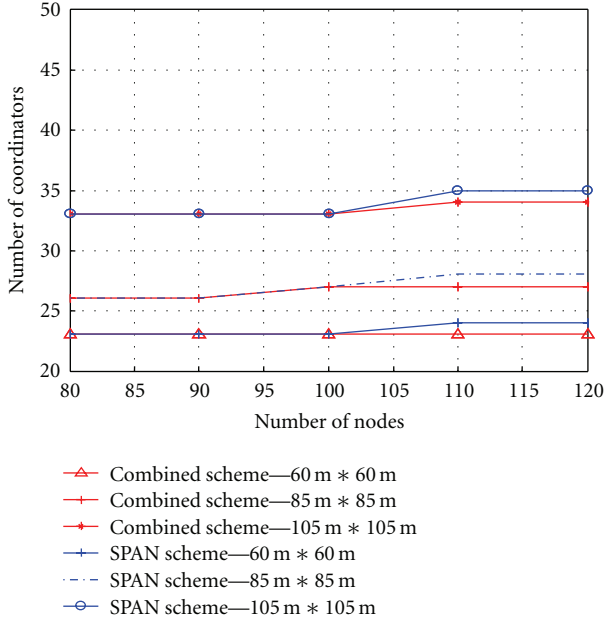


FIGURE 8: Number of coordinators in uniform deployment.

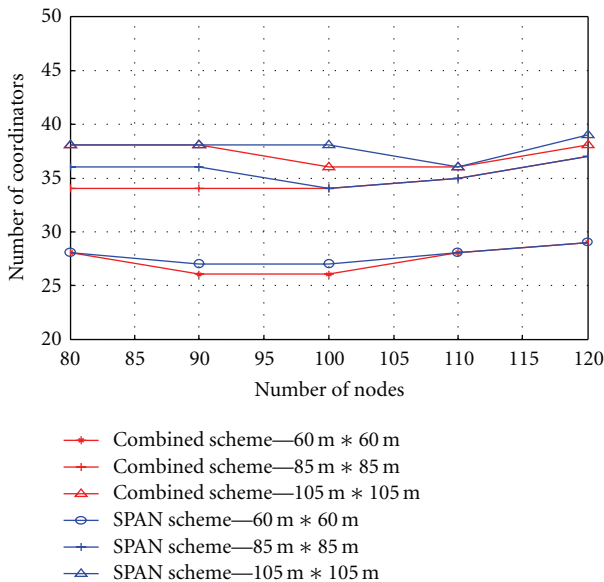


FIGURE 9: Number of coordinators in random deployment.

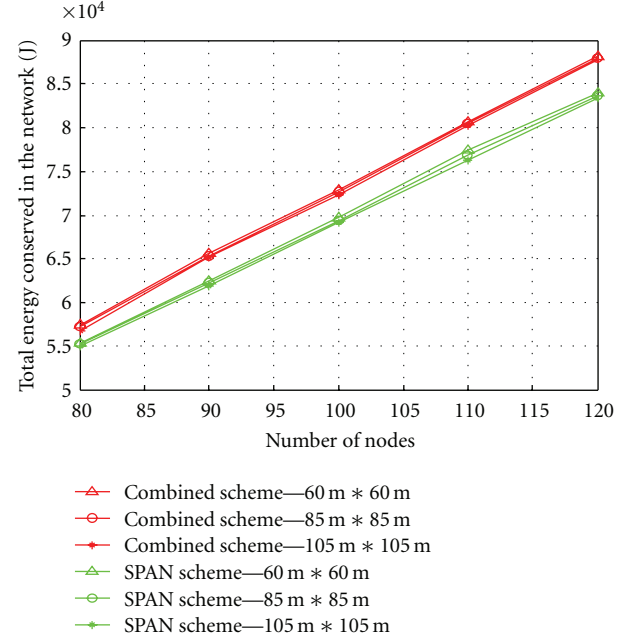


FIGURE 10: Energy conserved in the network (uniform deployment of nodes).

of low duty cycle radio concept and proposed coordinator eligibility rule. Here each and every node has initial energy as 1000 J. Hence, total energy conserved in the network is given as

$$E_{\text{conserved}} = E_{\text{total}} - E_{\text{consumed}}. \quad (17)$$

Similarly, total energy conserved in the network in random deployment for both SPAN and combined scheme for different scenarios is shown in Figure 11. It is inferred that the energy conserved in random deployment is less compared to uniform deployment. In random deployment, the combined scheme conserves more energy compared to SPAN scheme as the number of nodes increases and when field size is reduced.

Figure 12 shows the lifetime improvement factor of the combined scheme and SPAN scheme in uniform deployment. It is observed that combined scheme extends the network lifetime compared to SPAN. As the number of nodes increases, the lifetime improvement factor of the network increases for all the field size for both the schemes. SPAN improves the lifetime by about 3.3 times when the

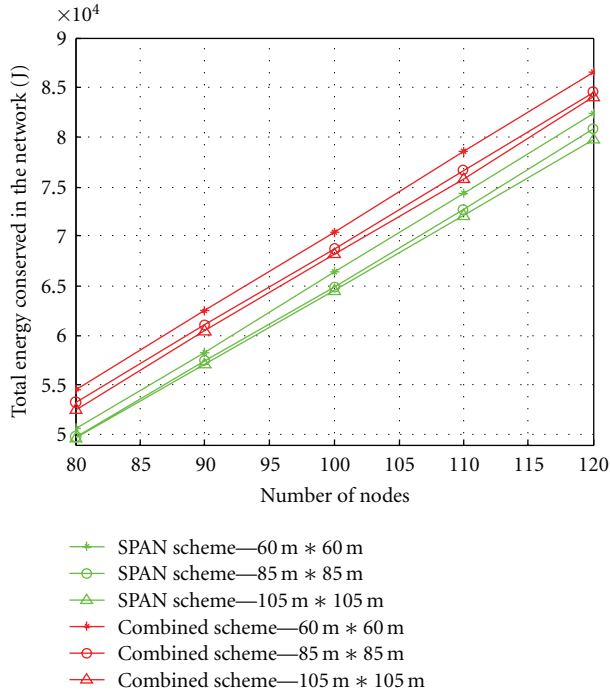


FIGURE 11: Energy conserved in the network (random deployment of nodes).

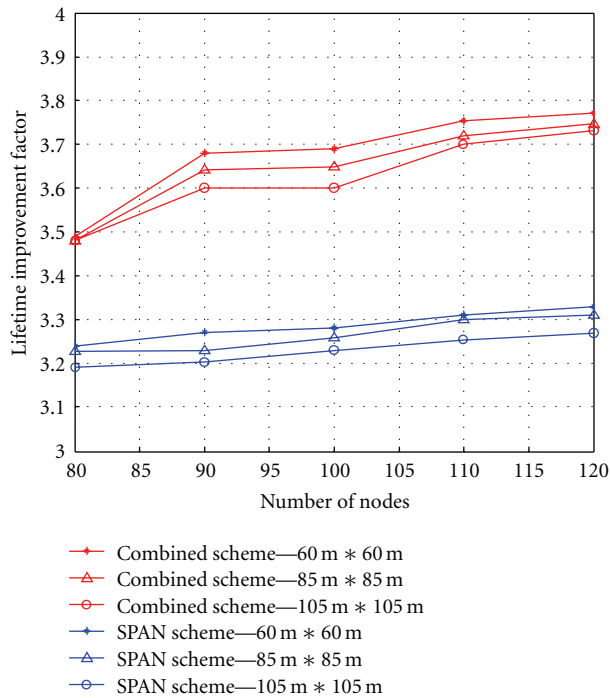


FIGURE 12: Lifetime improvement factor for uniform deployment of nodes.

number of nodes is 120 in 60 m * 60 m field size. Compared to SPAN, combined scheme improves lifetime further to approximately 3.8 when the number of nodes is 120 in 60 m * 60 m field size. It is inferred that as the number of nodes increases for a given field size, lifetime increases. Also

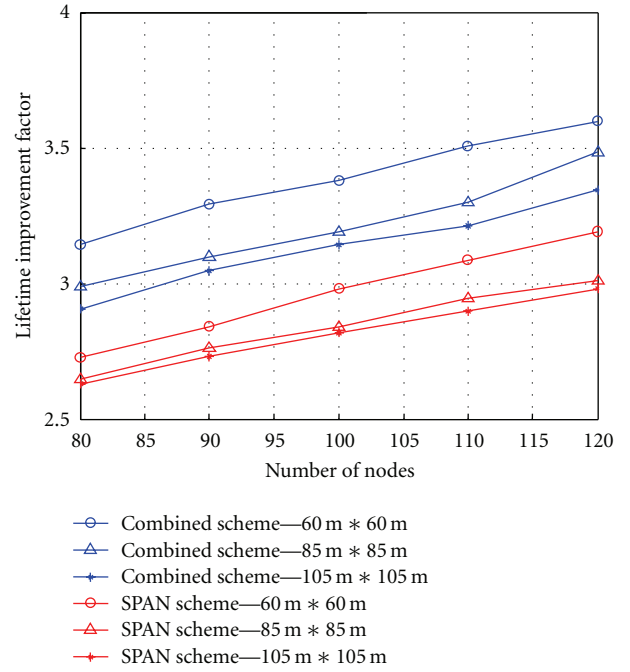


FIGURE 13: Lifetime improvement factor for random deployment with mobility.

as the field size is reduced for a given number of nodes, lifetime increases.

Figure 13 shows the lifetime improvement factor of combined scheme and SPAN scheme in random deployment. As the number of nodes increases, the lifetime improvement factor of the network increases for all the field size for both the schemes. SPAN improves the lifetime by about 3.2 times when the number of nodes is 120 in 60 m * 60 m field size. Compared to SPAN, combined scheme improves lifetime further to approximately 3.6 when the number of nodes is 120 in 60 m * 60 m field size. It is observed that as the number of nodes increases for a given field size, lifetime increases. Also as the field size is reduced for given number of nodes, lifetime increases. SPAN preserves capacity to a great extent thereby exploiting the energy factor. STEM conserves energy whereas it does not preserve capacity. Thus by combining STEM and SPAN, capacity is preserved and also energy is conserved. Capacity is the total number of packets delivered successfully per unit time. Here, graph is plotted between number of nodes and capacity by varying the field size as shown in Figure 14. The combined scheme preserves capacity without sacrificing energy and latency. It is observed that as the number of nodes increases, the capacity is reduced. Figure 15 shows the capacity in the network where random deployment is employed for eight different scenarios. The combined scheme preserves the capacity as that of the SPAN in all the scenarios. Figure 16 shows the latency for STEM and combined scheme by deploying nodes uniformly in the field. It is observed that STEM has more latency due to indefinite backbone path. This increase goes further as the number of nodes increases in

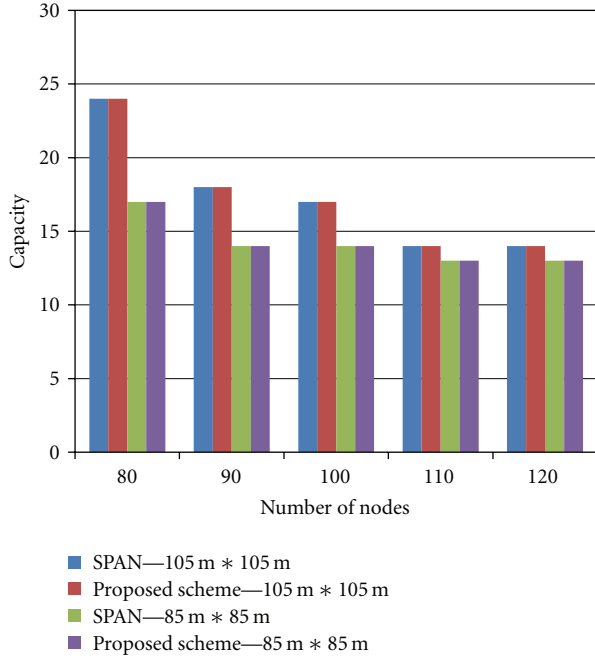


FIGURE 14: Capacity in uniform deployment network.

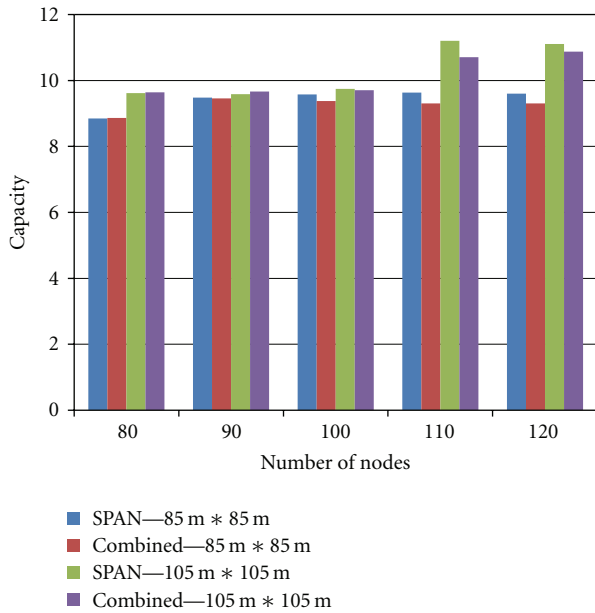


FIGURE 15: Capacity in random deployment network.

the different fields. Also the latency increases as the field size increases. The latency decreases for all the scenarios in combined scheme due to definite backbone path formed by the coordinators. The data is forwarded from source to sink through this path.

Figure 17 shows the latency of combined scheme and STEM scheme by deploying nodes randomly in the field. It is observed that the combined scheme has less latency compared to STEM scheme.

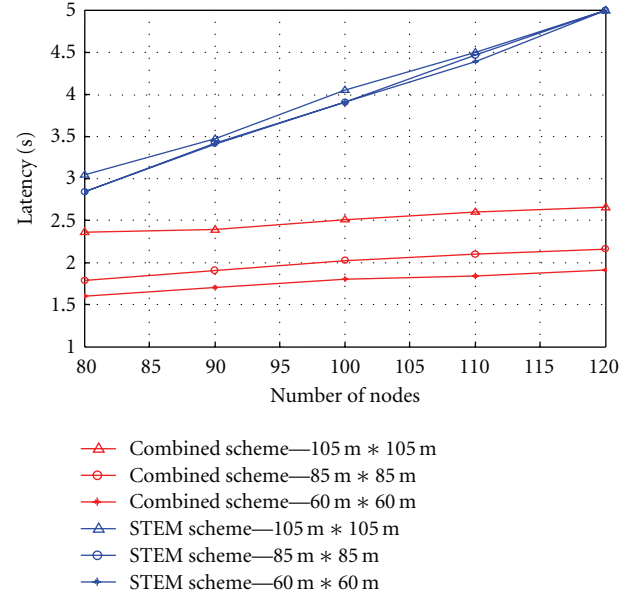


FIGURE 16: Latency in the network (uniform deployment).

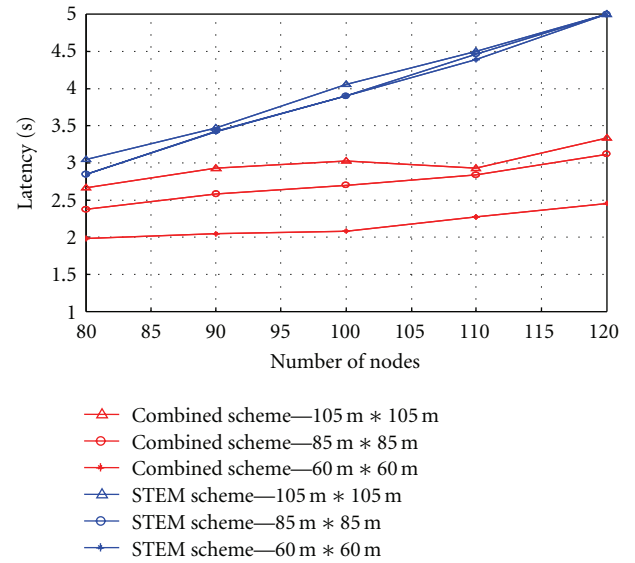


FIGURE 17: Latency in the network (random deployment).

5. Conclusion

In this paper, hybrid topology management scheme is proposed by integrating STEM and SPAN and coordinators are elected using new coordinator eligibility rule. Here various parameters such as energy conservation, lifetime, capacity, and latency are analysed by deploying 80, 90, 100, 110, and 120 nodes in various field sizes such as 60 m * 60 m, 85 m * 85 m, and 105 m * 105 m using uniform and random deployments of nodes. It is inferred that in both cases, as number of nodes increases, the total energy conserved in the network increases by keeping field size constant. Similarly, as the field size is reduced, the total energy conserved in

the network is increased for fixed number of nodes. Thus, it can be concluded that deploying more nodes (120 nodes) in small field size (60 m * 60 m) conserves more energy.

It is also inferred that the combined scheme results in more energy conservation compared to SPAN, which reflects in further improvement in lifetime factor of about 3.8 compared to SPAN. The combined scheme has less latency compared to STEM due to definite backbone path through which the data is forwarded to sink. These improvements in the network parameters such as energy conservation, lifetime, and latency are achieved without sacrificing capacity. The critical application requires the data to be forwarded quickly to the sink by conserving more energy without any loss of data. Since the proposed scheme meets all these requirements, it will be well suited for hazardous applications.

Notations and Definition

R :	Radio range
r :	Distance between two nodes in horizontal direction
h :	Distance between two nodes in vertical direction
f_d :	Data plane radio
f_w :	Wake up plane radio
B_x :	Transmit time of beacon
B_y :	Inter beacon spacing
B_{xy} :	Time taken for initiator node to send the beacon and receive response
T_b :	"ON" Time duration of target node
T_s :	Set up latency
C :	Number of coordinators
N :	Total number of nodes
N_c :	Number of non-coordinators
α :	Coordinator node ratio
β :	Non-coordinator ratio
$E_{\text{conserved}}$:	Energy conserved in the network
E_x :	Maximum amount of energy
E_y :	Remaining amount of energy
N_h :	Number of hexagons
A_f :	Area of the field
A_h :	Area of the hexagon.

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