

4TQS: Four Tiers OVER Quality of Sensing with Energy Improvement in Wireless Sensor Network

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Abstract

This paper presents four algorithms for QoSensing (4TQS) and routing on dynamics Wireless Sensor Networks. Since many types of researches held on QoSensing improvement in terms of coverage and connectivity enhancement. In a WSN with a density of 120 static and 30 mobile nodes, the major power-consuming activities are mobility and communication. Such power constraint has a great effect on the node activities and the same network. We analyzed the occurrence of coverage holes which is, regions inside the area of interest that are void of operational nodes for sensing and/or routing purposes. 4TQS method shows clustering phase through neuro-fuzzy based affinity propagation NFAP, sleep scheduling phase with ESLS algorithm and the assist of coverage enhancement phase in which HAHP is involved. Routing phase and connectivity metrics are improved with DTMR algorithm. Involvement of four efficient algorithms results in improved QoSensing in WSN. We analyzed our proposed method in both Star and Mesh topology in order to evaluate the QoSensing metrics in both topologies. Our method shows promising results in QoSensing metrics or performance in dynamics WSNs.

Keywords

QoSensing, 4Tiers, Metrics, Coverage, Connectivity

1. Introduction

When all nodes have the same hardware and capabilities, the network is homogeneous; otherwise, it is heterogeneous. Grouping of nodes within the network to facilitate or improve communication makes it hierarchical. In a flat network,

all of its nodes communicate on the same level with the sink. A static WSN has stationary nodes whereas in a dynamic network, the nodes are mobile. Conventional researches on target coverage in tradeoff between Sensing Quality and network lifetime mainly focus to increase the nodes lifetime. Increasing sensing quality is of the utmost importance to ensure comfort living in Smart Cities. These smart cities are envisioned to be heavily dependent on wireless sensor networks and internet of things [1]. According to E. Palacios *et al.* [2], coverage and connectivity are the major constraints in QoSensing. High coverage and connectivity require high delay and energy. Thus, energy and delay also play vital role in QoSensing. Here, authors consider throughput, delay, energy consumption, connectivity, jitter, packet delivery ratio, and coverage as major performance metrics.

To enhance QoSensing in terms of coverage factor, many research works such as Coverage Contribution Area (CCA) [3], Centralized Lloyd-Like Algorithm (CLLA) [4], and the method to calculate the maximum lifetime target coverage MLTC [5] are presented in WSN. CCA resolves k-coverage problem in which at least k-nodes are required to cover the particular target. In CCA, residual energy of sensor node is considered as major constraint. In CLLA, the centralized and distributed algorithms provide a flexible and explicit tradeoff between sensing uncertainty and network lifetime. MLTC is based on the target which is covered by a minimum number of sensor nodes that is defined as $target_{min}$. This scheme calculates the maximum lifetime target coverage MLTC which is equal to the sum of the lifetimes of the sensor nodes that cover $target_{min}$. Connectivity enhancement in relay node selection and deployment is achieved by utilizing Local search Approximation Algorithm (LSAA), and Relay Location Selection Algorithm (RLSA) [6]. Key idea behind this work is coverage enhancement and optimal relay node location results in high connectivity in the network. Joint Clustering and Routing (JCR) is introduced to improve connectivity between sensor nodes in the network [7]. The inter-cluster topology is formed by adapting backoff timer and gradient routing protocol with the consideration of transmission range. In [8], a heuristic algorithm is capable of adjusting its sensing range and location by itself to monitor more number of targets. The heuristic algorithm has better network lifetime than the existing algorithms in both simple and k-coverage scenarios.

Some research works are held on WSN to resolve both coverage and connectivity problems. In [9], author attempts to solve joint coverage and connectivity problem by enabling optimal sensor deployment strategy. This problem is formulated as minimum cost reliability constrained sensor node deployment problem and solution is determined by Ant Colony Optimization (ACO) algorithm. Mobile sensor node deployment problem is divided into two sub-problems, namely target coverage problem and network connectivity problem [10]. Former problem is solved by clique partition based heuristic algorithm and Voronoi partition-based TV-greedy algorithm. Whereas, Steiner minimum tree-based solu-

tion is presented to solve later problem. Energy efficiency which is an important and indirect QoSensing metric is improved with the help of efficient routing and clustering algorithms. Energy efficient routing protocol namely Prolong-Stable Election Protocol (P-SEP) is presented to minimize energy consumption in sensor network [11]. In cluster based WSN, energy aware routing algorithm selects optimal cluster head (CH) based on residual energy level, and intra-cluster distance [12]. By considering CHs as virtual backbone, route is constructed to sink. Regional Energy Aware Clustering with Isolated Nodes (REAC-IN) is an effective clustering algorithm incorporated in WSN in order to minimize energy consumption [13]. Here CH selection is carried-out based on residual energy of each sensor node and regional energy of nodes in that region. Adaptive Sleep Efficient Hybrid Medium Access Control (AEH-MAC) algorithm allows sensor nodes to adjust their sleeping time dynamically [14]. Sensor node adjusts the sleep time according to traffic load and coordinate wakeup time of neighbor nodes. This dynamic sleep scheduling improves energy efficiency of the network. In [15], [16] used k-out-of-n model to calculate the k-coverage probability, which determines the minimal number of nodes that are needed to be deployed in the monitored area. But on WSNs non deterministic in these two cases, mitigation techniques must be deployed to handle faults and QoSensing problems at run-time. Hence, coverage and connectivity issues represented the main concern to be considered in this paper.

The major contributions of this paper summarized as follows,

- A WSN architecture is designed for sensing or coverage of objectives formed in star topology, mesh with energy efficient cost.
- A method with four protocols of specific characteristics that act in four phases for dynamic WSNs with improvements in energy efficiency.
- All aforementioned QoSensing metrics are improved by 4TQS method and proposed method is implemented in two different network topologies such as star and mesh topology. Each QoSensing metric is analyzed in both topologies.

The rest of this paper is organized as follows: Section 2 analyzes the related works held on each QoSensing metric improvement. In Section 3, we highlight the problems existed in previous works. Section 4 explains the proposed 4TQS method with novel algorithms. In Section 5, performance of method is evaluated in two different topologies in terms of performance metrics. In Section 6, we conclude our contributions.

2. Related Works

Cover problem was resolved by K-coverage Enhancement Algorithm (KCEA) in which initial coverage stage was enhanced [17]. In KCEA, harmony search optimization algorithm was utilized to find value of k to attain k-coverage in WSN. This method increases complexity and latency due to involvement of multiple parameter initializations in harmony search algorithm. Coverage enhancement

was achieved Edge Based Centroid (EBC) algorithm in which convergence art was fast [18], and also evaluated effect of fading on the k-coverage of wireless sensor networks via techniques from stochastic geometry. In this scheme is affected by the significant level of the k-coverage degradation due to multipath fading compared to the case of no fading (fixed range). In [19] evaluated the impact of boundary and shadowing effects simultaneously in performance of a wireless multi-hop networks (WMNs). Here the influence of different network parameters on the network k-coverage performance and concludes that the detection range and location of sensor nodes have a positive effect on QoSensing.

In grid based WSN, coverage problem was solved by Enhanced Coverage Overlapping Sensing Ratio (ECOSR) [20]. Here behavior sensor node was approximated by random wave point sensor model. This method requires sensor nodes with maximum energy to achieve required coverage. Thus energy consumption is high in this method. A surface coverage algorithm was introduced to deal with coverage problem in sensor network for complex three-dimensional terrains [21]. In this surface coverage algorithm, grid division, simulated annealing, and local optimum algorithms were involved. Immersion of three different algorithms for one purpose increases complexity and time consumption.

Survivability aware connectivity restoration strategy was employed for WSN partition [22]. In this strategy load equilibrium mechanism was employed to connect partitioned segments while stopping points for mobile nodes were selected based on connectivity failure probability. In this strategy transmission is carried out through non-optimal path which increases transmission latency and packet loss. Received Signal Strength Indicator (RSSI) was utilized to enhance connectivity between nodes in ZigBee based WSN [23]. Accuracy improvement was achieved by Gaussian filtering with averaging method whereas computational overhead was minimized by median method based on RSSI samples. This method is not able to achieve high accuracy for nearly placed nodes and also increases energy consumption. Deployment strategy for sensor nodes in three-dimensional space was introduced to attain better connectivity and coverage in WSN [24]. In this strategy, problem of connectivity and coverage was resolved by four algorithms in different scenario. This method demands different algorithms for different types of targets which minimizes the efficiency.

Graph based Coverage and Connectivity Technique (GCCT) was introduced to provide better connectivity and coverage in large-scale WSN [25]. This method also considered energy depletion and time consumption as performance metrics. In this method two different leader nodes namely core leader and super leader nodes are involved in which network lifetime is decreased.

In [26] evaluated some parameters of the QoS for performance of the WSN network under the AODV routing protocol in the NS-3 simulator. It analyzes 4 metrics (packet sent, received and lost, throughput, packet delivery rate and loss packets). The evaluation is made for a network in mesh topology. However, AODV generates uniform detection and it is not suitable for realistic environ-

ments. Therefore, show high energy cost, with a reduced life time in dynamics WSNs. In WSN assisted IoT, Energy Efficient Centroid based Routing Protocol (EECRP) was employed to minimize energy consumption [27]. In EECRP, clustering was performed by self-organizing of local nodes while centroid was selected based on residual energy of the node. Based on centroid position, CH rotation and CH selection were performed. Since BS location plays vital role in EECRP, this is method is not suitable for network in which BS is located outside from the network. In [28] proposes a PSO (Particle Swarm Optimization)-based uneven dynamic clustering multi-hop routing protocol (PUDCRP). In this proposed, time consumption is increased with respect to number of iterations. Hence route selection in this method involved with large time consumption.

In [29] presented a resource allocation scheme with delay optimization considering millimeter waves with QoS. However, in this scheme do not apply optimization methods to directly minimize system delay Delay constrained multi-hop routing and clustering mechanism was introduced with the aim of provided minimized energy consumption and end-to-end delay in WSN [30]. In this approach, CH selection, inter-cluster routing, and intra-clustering routing were performed based on a cost function which combine both energy and delay requirements. In multi-hop routing, distance is not considered which increases energy consumption in routing. In order to improve energy efficiency and delay efficiency in the network, QoS-aware Heterogeneously Clustered Routing (QHCR) protocol was developed [31]. Here communication between CH and long-distance node was enabled by multi hop communication based on path metric. Initial energy of sensor nodes, expected transmission counts, and minimum loss were involved in path metric. Since routing is performed in multi-hop, energy consumption of intermediate nodes is high. In [32] evaluated a data fusion protocol for WSN performance and data retrieval. By using data fusion, the protocol presents an effective way to monitor the global performance of the network. In this scheme, the necessary nodes to be moved is reduced which further reduced the overhead in the network.

3. Problem Definition

Energy-efficient Self-deployment Algorithm (ESA) was introduced [33]. Here sensor nodes in the network were move towards central node in order to improve connectivity. In each node neighbor node table was maintained in which locations of all sensor nodes were updated. Since sensor nodes are moved towards central node instead of target, this method is not effective to cover target and to improve sensing efficiency. Here space complexity also high due to maintaining of neighbor table. In [34] proposed protocol called multi-hop deterministic energy efficient routing (MDR). The protocol functionality can be described in two phases. Phase one comprises the selection of optimal CHs and phase two comprises how transmission is being done through node to CHs via automated selected SCHs and how the transmissions is done between the CHs to

base station via cluster routing. For homogeneous network based on multi-hop sub clustering and clustering routing to transmit the data to base station, mechanism show significant downgrade in performance, to adapt to different dynamics environments.

In coverage quality enhancement process, differential evolution process was employed to detect target position [35]. Here nodes were move towards targets according to distance with target. Thus, a target which has minimum distance with sensor nodes is covered with many sensor nodes while a target which is placed far away from the network is suffered from insufficient coverage. Therefore, this method is not able to cover all targets in the network. Maximizing coverage Quality with Minimum number of Sensor (MQMS) framework was introduced to improve coverage quality or network lifetime to enable trade-off between sensing quality and network lifetime [36]. In MQMS framework, same area is covered with multiple sensors due to poor deployment strategy and sensor nodes are statics. Thus, sensing quality is decreased in the network. Was presented a model to optimization of WSN deployment for sensing urban air pollution [37]. This scheme (ILP) based on integer linear programming modeling provides the relationship between resolution and number of sensing nodes. Thus, it is necessary to design an effectual approach to improve sensing quality in WSN with involvement of novel algorithms without computational as well as communication overhead.

4. Proposed Work

4.1. System Overview

In our proposed, WSN is intended with both static nodes (SNs) and Mobile Nodes (MNs). To improve QoSensing in designed WSN 4TQS method is comprised with following phases: 1) clustering phase, 2) sleep scheduling phase, 3) coverage enhancement phase, 4) routing phase. Proposed 4TQS architecture with N number of SNs a $SN = \{SN_1, SN_2, \dots, SN_N\}$ and M number of MNs as $MN = \{MN_1, MN_2, \dots, MN_M\}$ and Sink node (S) is depicted in **Figure 1**. Initially all sensor nodes are clustered with the assist of NFAP algorithm. In each cluster, ESLS algorithm is involved to manage sleep scheduling of sensor nodes. Coverage quality is enhanced through HAHP while connectivity is improved by DTMR routing algorithm. Thus, involvement of four effective algorithms in 4TQS method results in improved QoSensing metrics such as coverage, connectivity, energy efficiency, delay, and throughput. Each significant phase is detailed in following sections.

4.2. Clustering Phase

In this phase, a novel NFAP algorithm is presented in order to cluster the sensor nodes in the network. In NFAH algorithm, all sensor nodes are fed into neuro-fuzzy system to select exemplar node and based on exemplar node other nodes are clustered by affinity propagation algorithm. The key idea of affinity propagation

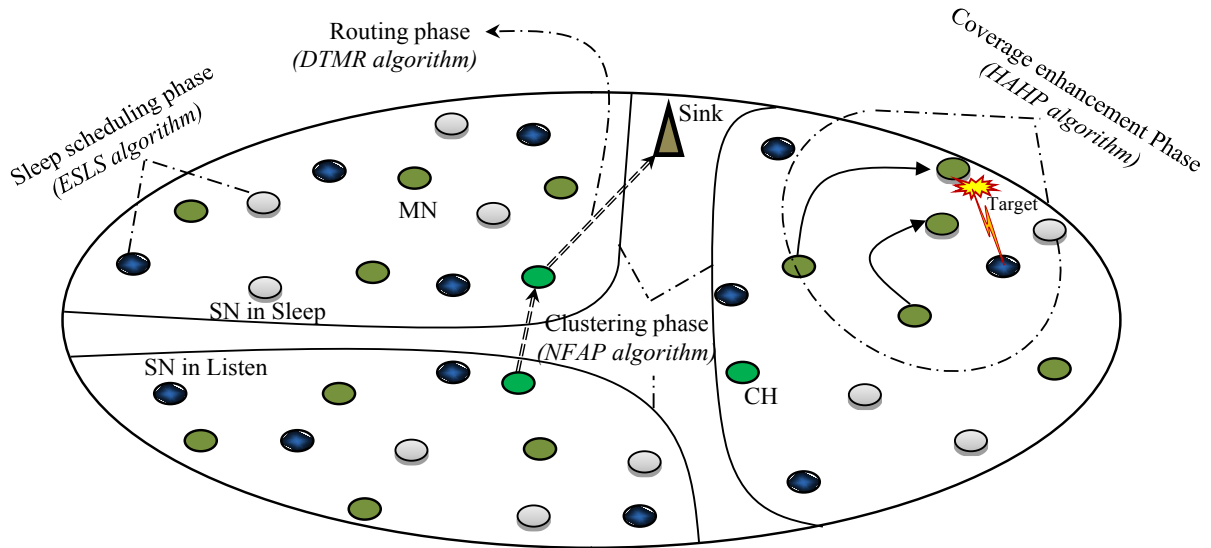


Figure 1. Architecture of 4TQS method with energy improvement in WSN.

method is based on message passing between data points (*i.e.*) similarity between data points. In affinity propagation, similarity between two data points is measured to check whether the given data point is capable of being exemplar for another one. If similarity is high, then the data points are assigned to same cluster. In 4TQS method, affinity propagation method is slightly modified to improve the performance. In NFAP algorithm, exemplar nodes are selected by neuro-fuzzy method based on significant metrics such as energy, distance with sink, centrality, and degree of node. Here neuro-fuzzy system is utilized for exemplar selection in order to support multiple nodes at the same time. A node which has high energy, minimum distance with sink, high centrality, and high degree is selected as exemplar node. If k number nodes are selected as exemplar, then k number of clusters formed in the network.

In **Figure 2**, the process of NFAP algorithm is depicted. Initially all sensor nodes including SNs and MNs are fed into neural network with membership function. Then the exemplar nodes are selected based on rule base in fuzzy system. Based on k exemplar nodes, all sensor nodes are clustered as in figure. In this algorithm two matrices are involved to update. Similarity between node i and exemplar E_k is computed in terms of Euclidian distance as follows,

$$Sim(E_k, i) = |E_k - Node_i|^2 \quad (1)$$

Then responsibility matrix and availability matrix are updated accordance to similarity. Responsibility (R) update is sent around as,

$$R(E_k, i) \leftarrow Sim(E_k, i) - \max_{i' \neq i} \{a(k, i') + s(k, i')\} \quad (2)$$

Then the availability is updated as,

$$a(k, i) \leftarrow \min \left(0, R(i, i) + \sum_{k' \neq \{k, i\}} \max(0, R(k', i)) \right) \quad (3)$$

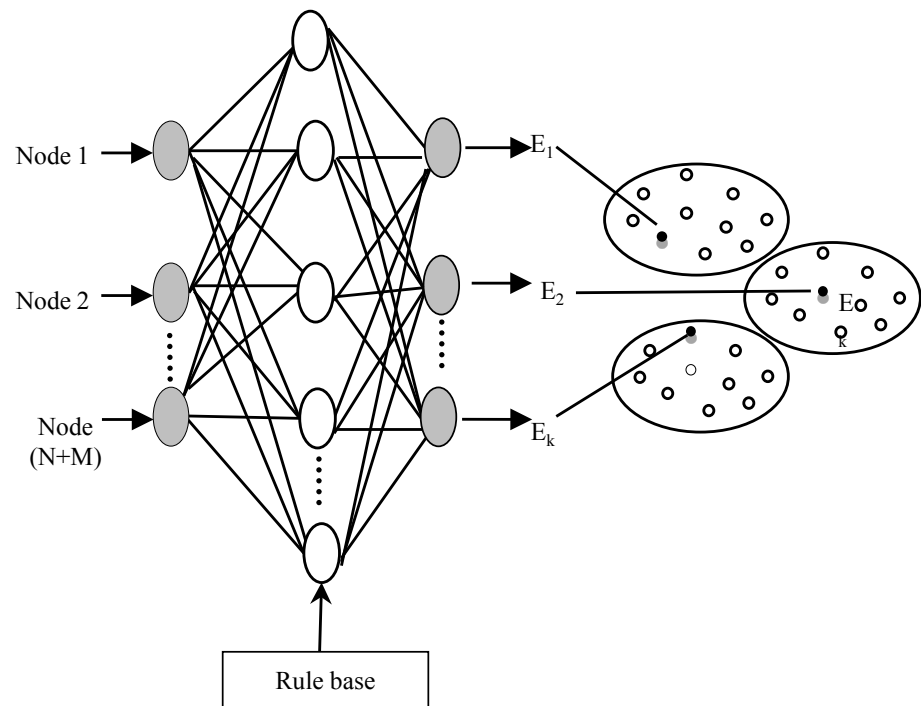


Figure 2. NFAP process.

Using above equations responsibility and availability are computed between each node and exemplar node. If exemplar k has positive responsibility and availability values for node i , then node i is assigned to k th cluster. This process is performed iteratively until all possible clusters are formed.

Algorithm 1 explains the overall process of NFAP algorithm-based clustering. Here exemplar nodes are assigned clusters heads (CHs) which are responsible for data gathering and routing. Thus, all sensor nodes in the network including SNs and MNs are clustered by NFAP algorithm efficiently. Major advantage of clustering is energy efficiency and minimized delay. Since NFAP algorithm selects CH based on residual energy, distance with sink node, centrality, and degree of node, clustering phase helps in QoSensing improvement. Here CH has high residual energy which increases network lifetime. Similarly, distance with sink node minimum for CH which results in minimized energy consumption and transmission delay. In each cluster, centrality and degree of the node are high which help to improve coverage and connectivity. Therefore, effectual clustering process based on NFAP results in improved QoSensing metrics.

4.3. Sleep Scheduling Phase

In WSN, it is assumed that all sensor nodes including SNs and MNs have same initial energy level. But energy dissipation in all nodes is not equal in all nodes. Since our proposed WSN involved with mobile nodes, it is obvious that mobile nodes consume more energy than static node. Major idea of involving mobile nodes is to enhance coverage in the network during event detection. Thus, the

Algorithm 1. NFAP based clustering.

```

Input:  $Ns = \{SNs, MNs\}$ 
Output:  $k$  clusters as  $C = \{C_1, C_2, \dots, C_k\}$ 
Begin
Initialize  $Ns$ 
Fed  $Ns$  into NFIS
For each  $SN, MN \in Ns$ 
    Find fizzy output upon rule base
    If (output=High)
        Select as exemplar  $E$ 
    Else
        Goto next node
    End if
End for
Find  $k$  exemplar as  $E_k$ 
For each  $SN, MN \in Ns$ 
    For each  $E \in E_k$ 
        Find  $Sim(E, Ns)$ 
        Update  $R, A$ 
        If  $R \& A == High$ 
            Assign  $Ns$  to  $c_k$ 
        Else
            Goto another cluster
        End if
    End for
Until
    Required clusters formed
End for
End

```

major purpose of mobile nodes is coverage enhancement. To minimize energy consumption in the network, ESLS algorithm is employed in WSN by 4TQS method. ESLS method allows MNs to sleep over sensing period and allows listen only after event detection in order to balance energy dissipation between SNs and MNs. Here ESLS algorithm schedules SNs based on energy level (El) and coverage (Cov). This algorithm is performed periodically by CH. In ESLS, SNs with low energy and low coverage area are provided with high sleep time whereas SNs with high energy level and coverage are provided with low sleep time. This is because SNs with low energy level are suffered by early node dead and SNs with low coverage dissipates higher energy to sense lower coverage. Initially SNs are sorted in ascending order based on energy level and coverage. Then node in first position is provided with high priority to sleep while node in last position is provided with low priority to sleep.

Consider set of nodes from SNs with high energy level and high coverage as $SN_H = \{SN_1, SN_2, \dots, SN_h\}$ and SNs with low energy level and low coverage as $SN_L = \{SN_1, SN_2, \dots, SN_l\}$ where $h+l = N$. Here SNH is follows scheduling in **Figure 3(a)** while SNL follows scheduling process in **Figure 3(b)**. Therefore, efficient sleep scheduling process results in high energy efficiency.

Steps in ESLS algorithm

Steps involved in ESLS

Step 1:	Initialize N_s
Step 2:	For all $MN \in N_s$
Step 3:	Assign (Sleep)
Step 4:	For all $SN \in N_s$
Step 5:	Find $EL&Cov$
Step 6:	If ($EL&Cov==High$)
Step 7:	Assign High priority
Step 8:	Schedule sleep time
Step 9:	Else
Step 10:	Assign low priority
Step 11:	Schedule sleep time
Step 12:	End if
Step 13:	End for
Step 14:	End

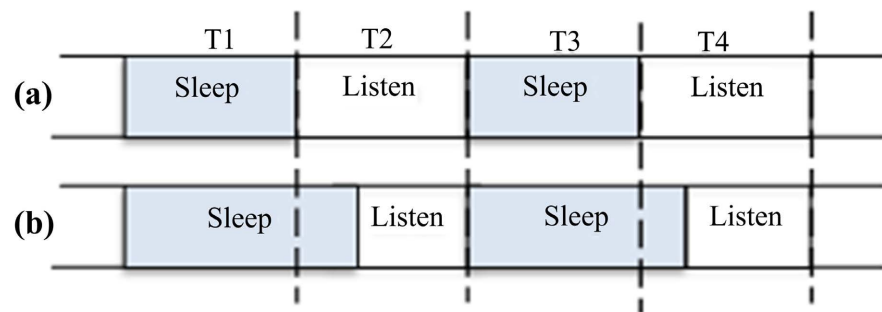


Figure 3. (a) Sleep scheduling for low priority SNs (b) Sleep scheduling for low priority SNs.

Since mobile nodes are assigned to sleep and SNs are scheduled with optimal scheduling strategy, ESLS method helps to improve energy efficiency without loss in coverage.

4.4. Coverage Enhancement Phase

In all possible paths which provide minimum cost function is selected as optimal path and selected for routing. In 4TQS method, network is designed with both static nodes and mobile nodes. In the network, mobile nodes are scheduled to sleep in all time by ESLS algorithm and static nodes are dynamically scheduled to sleep and listen. SNs which are in listen period sense the environment for event detection. If any target is detected, then the node informs the event detection to CH. Since major objective of this phase is to enhance the coverage of target, CH computes the coverage intensity in target region. This is because, the MNs are in sleep and some SNs also in sleep. So, it is not fair to cover the target region with small number of active nodes. Hence coverage intensity computation plays vital role in 4TQS method. If coverage intensity is largely enough, then CH doesn't made decision on mobile node reposition. Otherwise, CH takes decision on mobile node reposition and selects optimal mobile node for reposition by HAHF algorithm. The selected mobile node is scheduled to listen mode until the event is completed. As stated earlier, consider N_s with N number of

SNs and M number of MNs. If a node SN_i in cluster C_k senses a target T at time t . Immediately SN_i reports to CH_k about event detection. Then CH_k computes coverage intensity (CI) for region T as follows,

$$CI = 1 - (1 - q)^x \quad (4)$$

CI is calculated in terms of probability of coverage (q) and number of active nodes (x). Probability of coverage (q) is computed in terms of sensing range (R), size of deployment region (D), as

$$q = \frac{\pi R^2}{D} \quad (5)$$

If CI is high, then the mobile node reposition is not necessary. Otherwise CH_k selects optimal MN in C_k for reposition. Optimal MN is selected by HAHP algorithm. In HAHP algorithm, optimal MN is selected based on multiple criteria such as energy level (El), moving distance (MD), and distance with CH (CD). Optimal mobile node selection through HAHP is detailed in following steps,

Step 1: Initially the problem is decomposed into hierarchy of goal, criterion, and alternatives. In 4TQS method, goal is to select optimal mobile node for reposition based on criterions such as El, MD, and CD. The alternatives are v mobile nodes present in C_k .

Step 2: In next step, priorities for each criterion is derived by Bayesian optimization model. This step illustrates the importance of each criterion in decision making. In Bayesian optimization, improvement level plays vital role in priority provision. Probability of improvement is expressed as,

$$\text{Improvement} = \phi(\gamma(x)) \quad (6)$$

Here $\gamma(x)$ is obtained as follows,

$$\gamma(x) = \frac{f(x_{best}) - \mu_x}{\sigma(x)} \quad (7)$$

Hence predictive mean function (μ_x) of problem $f(x)$, predictive marginal function ($\sigma(x)$) are involved in improvement prediction. Based on probability of improvement, each criterion is provided with priority value. If probability of improvement for a criterion is high, then that criterion is provided with high weight value (or) priority value. This priority value indicates the importance level of that criterion in decision making. After weight value provision, pairwise comparison matrix is generated as follows,

$$PM = \begin{pmatrix} 1 & w_1 & w_2 \\ \frac{1}{w_1} & 1 & w_3 \\ \frac{1}{w_2} & \frac{1}{w_3} & 1 \\ \text{Sum 1} & \text{Sum 2} & \text{Sum 3} \end{pmatrix} \quad (8)$$

Based on sum values, the pairwise matrix is normalized. In normalized matrix, each row wise average value is computed in order to predict priority value for each criterion.

Step 3: In this step Consistency Index (CIx) is computed. From pairwise matrix (PM) and normalized matrix, weighted matrix is generated. A random matrix is generated in this step. The maximum eigenvalue λ_{\max} is determined from both random matrix and weighted matrix. Then the CIx is calculated as,

$$CIx = \frac{\lambda_{\max} - S}{S - 1} \quad (9)$$

Here S is the size of weighted matrix.

Step 4: Finally, rating value for each alternative is determined based on CI and the ratings are multiplied with criterion weight value to obtain global ratings. In this manner, HAHP selects optimal mobile node for (MN_{op}) for reposition. The selected (MN_{op}) is repositioned to target region in order to improve coverage.

Algorithm 2 explains the overall process involved in coverage enhancement phase. Since MN for reposition is selected based on multiple criteria, energy consumption and delay for repositioning is small. Therefore, proposed coverage enhancement algorithm in 4TQS method not only improves coverage and also results in better energy efficiency, and delay. In 4TQS method target is covered by required sensor nodes which improves sensing quality in the network. The next process is to improve connectivity in the network through routing algorithm.

Algorithm 2. Coverage Enhancement algorithm.

```

Input:  $T, MNs, SNs, CH_k$ 
Output: Coverage enhancement
1: Begin
2: For  $SN \in C_k$ 
3: Sense the target
4:   If ( $T$  detected)
5:     Report  $\rightarrow CH_k$ 
6:   Else
7:     Follows sleep scheduling
8:   End If
9: End for
10: In  $CH_k$ 
11: Compute CI
12: If (CI==high)
13:   Don't move MN
14: Else
15:   Select MN from HAHP
16:   Initialize  $MNs \in C_k$ 
17:   For all  $MNs$ 
18:     Find CIx
19:     Find rating
20:     Select  $MN_{op}$ 
21:     Move  $MN_{op} \rightarrow T$ 
22:   End for
23: End If
24: End

```

4.5. Routing Phase

In this phase an optimal route selection algorithm is presented with the aim of minimizing delay and improving connectivity. Since data transmission is carried out between CH and sink node, the connectivity between CHs and sink node is major concern in WSN. CH selection in clustering phase also considers distance as major constraint. Thus, the connectivity between selected CH and sink is already strengthened. In order to improve the connectivity, 4TQS method presents an efficient DTMR algorithm for routing. In DTMR algorithm initially all possible paths are detected. And cost function for each path is computed based on path latency, and hop count. The path which provides minimum cost function is selected for routing. Through this path data transmission between sink node and CH is carried out.

Consider CH_k wants to transmit data to sink (S). Initially all possible paths are detected as $P = \{P_1, P_2, \dots, P_p\}$. Then cost function for p^{th} path is computed as,

$$CF_p = \sum Delay_p, HC_p \quad (10)$$

where $Delay_p$ is computed as,

$$Delay_p = \sum_{q=1}^N D_q \quad (11)$$

Here D_q refers to the delay of q^{th} SN present in Ck. The path selection condition is formulated as,

$$Path_{optimal} = \min(CF_p) \quad (12)$$

In all possible paths which provide minimum cost function is selected as optimal path and selected for routing.

Steps involved in DTMR

Steps involved in DTMR algorithm

Step 1:	Initialize DTMR
Step 2:	Find all possible paths $P \in P_p$
Step 3:	For each $P \in P_p$
Step 4:	Find $Delay_p$
Step 5:	Fid HC
Step 6:	Compute CF_p
Step 7:	If ($CF_p == Small$)
Step 8:	Select as optimal path
Step 9:	Else
Step 10:	Goto step3
Step 11:	End if
Step 12:	End for
Step 13:	End

Since $Path_{optimal}$ is selected with the consideration of delay and hop count (HC) of the path, data transmission is efficient in the network. The path selected by DTMR has active SNs only which ensures reliable connectivity between sink and CHs. Therefore, proposed 4TQS method achieves better QoSensing metrics such

as coverage, connectivity, delay, energy efficiency, and throughput.

5. Experimental Evaluation

In this section we analyze foremost QoSensing metrics in two different topologies (star and mesh) through our proposed method. This section is comprised with following subsections such as simulation environment, performance metrics, and analysis of performance metrics. Each subsection is detailed as follows.

5.1. Simulation Environment

To implement our proposed 4TQS method, NS-3.26 network simulator is utilized. Significant simulation parameters considered in our work are depicted in **Table 1**.

In star topology nodes are organized around a central hub. Here communication is held in centralized manner. Simulation environment of our proposed work in star topology is depicted in **Figure 4**. Whereas mesh topology is a distributed, adaptive, and self-organized network topology. Simulation environment of 4TQS method in mesh topology is illustrated in **Figure 5**.

The specifications provided in **Table 1** are applicable for both star and mesh topologies.

By considering significant parameters highlighted in **Table 1**, we analyze proposed method in both star and mesh topologies.

Table 1. Simulation parameters.

Parameter		Value
Number of nodes	Static nodes	120
	Mobile nodes	30
Number of sink node		1
Number of Target		1
Mobility model of SNs		Constant mobility model
Mobility model of MNs		Random way point model
Speed of MNs	In Star	30 mbps
	In Mesh	100 mbps
Topology		Star and Mesh
Initial energy		0.5 Joules
Simulation area		1000 × 1000 m
Packet interval		0.5 sec
Simulation time		15 seconds
Sensing range		25 m
Data acquired bytes		1 KB
Number of bits transmitted		400 bits

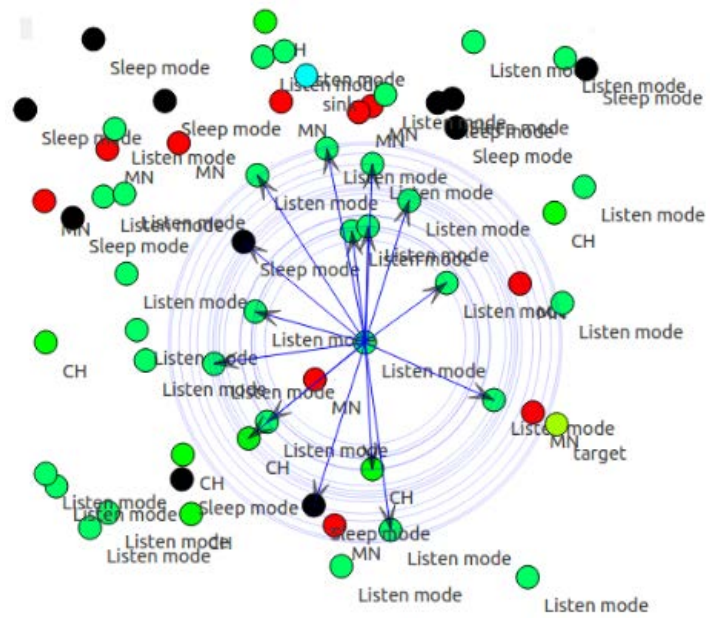


Figure 4. Star topology.

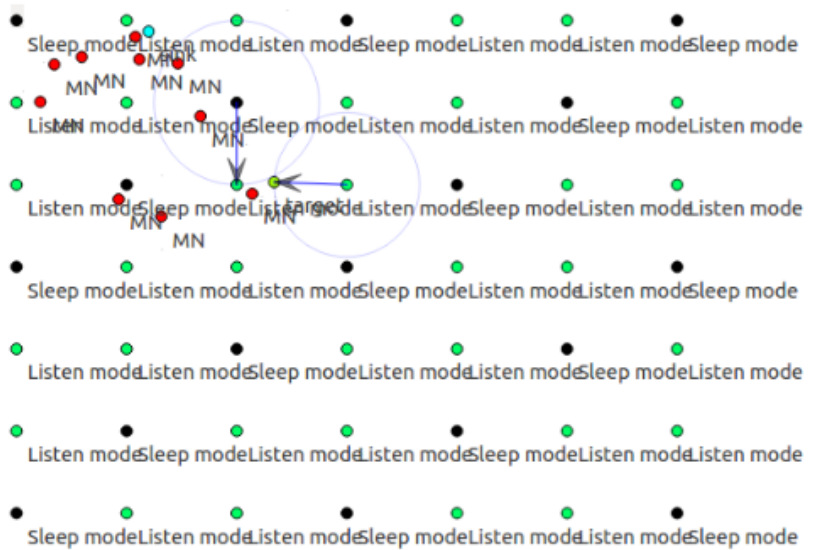


Figure 5. Mesh topology.

5.2. Performance Metrics

To evaluate QoSensing in WSN through our proposed method, we consider performance metrics which play vital role in quality of sensing. In order to evaluate the QoSensing following performance metrics are considered: coverage rate, connectivity ratio, energy consumption, end-to-end delay, and throughput. Each significant metric is described in below subsections.

5.2.1. Coverage Rate (C. Rate)

Coverage rate is defined as the ratio between area of network covered by sensor nodes to the total area of network. This metric is directly depends upon coverage

intensity. It can be expressed as,

$$\text{Coverage rate} = \frac{\text{area covered by sensor nodes}}{\text{Total area}} \quad (13)$$

This metric is considered as major QoSensing metric (*i.e.*) coverage rate is high in the network indicates the improvement in sensing quality in the network. Thus we consider coverage rate as important metric for our analysis.

5.2.2. Connectivity Ratio (C. Ratio)

Connectivity ratio is defined as the ratio between number for nodes connected with sink and total number of nodes in the network. It is given as,

$$\text{Connectivity ratio} = \frac{\text{No of nodes connected to sink}}{\text{Total number of nodes}} \quad (14)$$

Connectivity in the network ensures that there is at least one path is available between sink node and sensor nodes. High connectivity in the network increases coverage rate which results in better quality of sensing.

5.2.3. Energy Consumption (EC)

Energy consumption in the network is defined as the amount of energy consumed to perform processes such as sensing, transmitting, and receiving. It is computed as,

$$\text{Energy consumption} = \sum_{i \in N} E_{Tx}^i, E_{Rx}^i E_{sensing}^i \quad (15)$$

Here energy consumed by a sensor node i during transmission, receiving, and sensing are denoted $E_{Tx}^i, E_{Rx}^i, E_{sensing}^i$ respectively. If sensing quality of in the network is high, and then the energy consumption in the network is low (*i.e.*) an efficient QoSensing improvement method achieves high sensing quality even with small number of sensor nodes.

5.2.4. End-to-End Delay (E2E Delay)

End-to-end delay is defined as the average time taken by a data packet to reach destination from sources. This metric includes all possible delays during transmission such as queuing delay, processing delay, propagation delay, and transmission delay.

$$\text{Delay} = \frac{\text{Sum of time spent to deliver data}}{\text{Amount of data received by sink node}} \quad (16)$$

E2E delay represents the connectivity in the network indirectly (*i.e.*) if the connectivity in the network is high then E2E delay is small. Hence E2E delay impact on sensing quality of the network.

5.2.5. Throughput (Thr)

Throughput is defined as the total number of packets transmitted to the specified destination in given time. This metric is high when connectivity and coverage are high in the network. Also, this metric evaluates the performance of routing algorithm.

5.3. Analysis of QoSensing

In this section, we analyze the quality of sensing in WSN through proposed method in terms of performance metrics in two different topologies.

5.3.1. Analysis of Coverage Rate

In proposed 4TQS method coverage is improved in coverage enhancement phase. Here we evaluate the effectiveness of coverage enhancement phase in both topologies.

Figure 6 provides the graphical representation of coverage rate analysis in both topologies. It is clear that reasonable coverage rate is achieved in both topologies. In 4TQS method both static and mobile nodes are presented in the network. Involvement of mobile node repositioning in 4TQS method helps in achieving highest coverage rate. Since coverage is enhanced based on coverage intensity, 4TQS method is able to solve coverage problem in WSN. Proposed work provides coverage rate about 0.157 averagely in star topology and 0.138 in mesh topology. It is worth to note that proposed method provides nearly 0.15 as coverage rate in both topologies even with small number of sensor nodes present in the network. The result is obtained for a network with 30 sensor nodes. But coverage rate is directly proportional to number of sensor nodes. Therefore, proposed method is well performed in both topologies in terms of coverage rate.

5.3.2. Analysis of Connectivity Ratio

This metric evaluates the performance of clustering algorithm and routing algorithm in both topologies. This metric is directly proportional to number of sensor nodes in the network.

In **Figure 7**, we analyze connectivity ration in star and mesh topologies. From

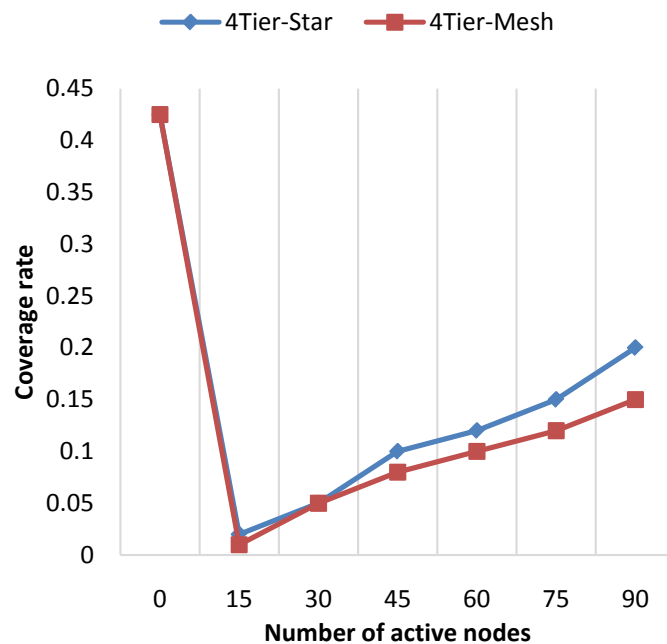


Figure 6. Analysis of coverage rate.

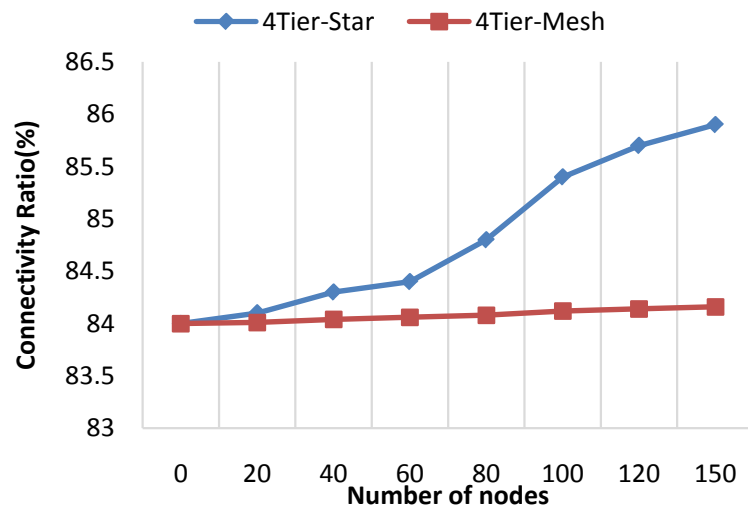


Figure 7. Analysis of connectivity ratio.

the graph, it is clear that connectivity in star topology is better than mesh topology. This is because, in star topology each node is connected with the centralized hub which may be CH or sink node. In our proposed 4TQS method, network is clustered by using NFAP algorithm in which each CH is selected optimally. Thus each node in the cluster is connected with CH in order to transmit sensing information. So the connectivity between each node and CH is ensured. Similarly effective routing algorithm namely DTMR is responsible to maintain connectivity between CH and sink node. So connectivity in star topology is slightly better than mesh topology. But in mesh topology, connectivity inside the cluster is not assured while connectivity with sink is preserved by DTMR algorithm. Therefore connectivity in mesh topology is slightly lesser than star topology. The average connectivity ratio in star topology is 84.7% while average connectivity in mesh topology is 84.06%.

5.3.3. Analysis of Energy Consumption

Efficient clustering algorithm and routing algorithm minimize energy consumption. In this subsection, we analyze the impact of topology in energy consumption with respect to sensing quality.

Graphical representation of energy consumption analysis is depicted in Figure 8. From the figure, it is clear that energy consumption is better in star topology compared with mesh topology. The major sources of energy consumption are transmission, receiving, and sensing. Since connectivity is high in star topology, energy consumption during transmission is negligible. Thus star topology achieves minimized energy consumption than mesh topology.

Even with minimum connectivity, energy consumption in mesh topology is marginally lower than star topology. This is due to involvement of efficient routing algorithm in 4TQS method. Since the transmission path is selected based on cost function, transmission is fast and requires minimum energy. Therefore proposed method provides minimized energy consumption in both star and

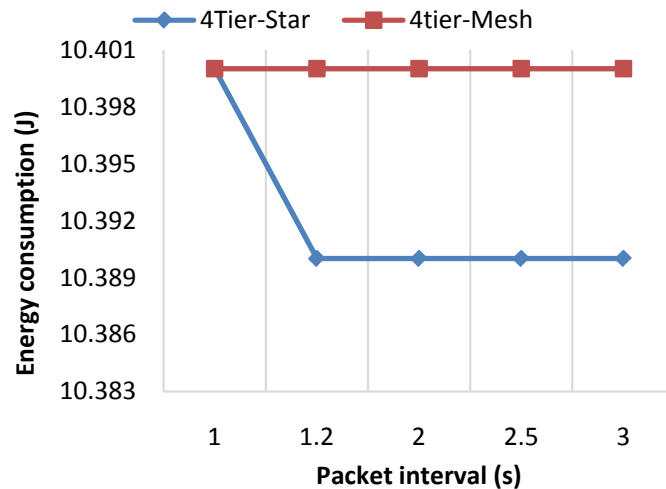


Figure 8. Analysis of energy consumption.

mesh topologies. In star topology, energy consumption is 10.39 Joules while in mesh topology average energy consumption is 10.4 Joules. In both topologies, energy consumption is maintained as constant. In proposed method, energy consumption is minimized due to involvement of both static and mobile nodes. Energy consumption in static node is held in the form of sensing energy while energy is consumed due to movement in mobile nodes.

5.3.4. Analysis of E2E Delay

This metric evaluates the performance of routing algorithm in the network.

In **Figure 9**, we analyze end-to-end delay in proposed method in two different topologies. For a network with high connectivity, this metric is low. Thus lower E2E delay represents the connectivity in the network. Since connectivity is high in star topology, E2E delay also minimized in star topology. Proposed method provides small E2E delay in both topologies with the help of effectual delay tolerance routing algorithm. Here the transmission path is preferred as optimal path, if it provides minimum delay. Through this optimal path, data transmission is carried out. Therefore delay introduced during data transmission is small in the network. The difference between these topologies occurs due to connectivity ratio. Since connectivity ratio in star topology is high, delay is minimized slightly compared with mesh topology. Our proposed method introduces average delay of 0.3994 seconds in star topology while this measurement is about 0.39995 seconds in mesh topology.

5.3.5. Analysis of Throughput

This metric evaluates the routing algorithm involved in the network in terms of numbers of bits transmitted per second in the network. Analysis of throughput in two topologies is depicted in **Figure 10**. Here throughput efficiency is marginally high in mesh topology

This result shows the efficiency of DTMR algorithm presented in 4TQS method. Since DTMR selects optimal path for transmission, high throughput efficiency is

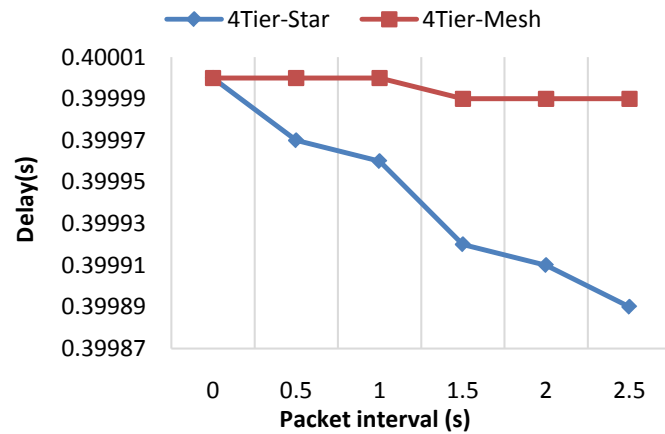


Figure 9. Analysis of E2E delay.

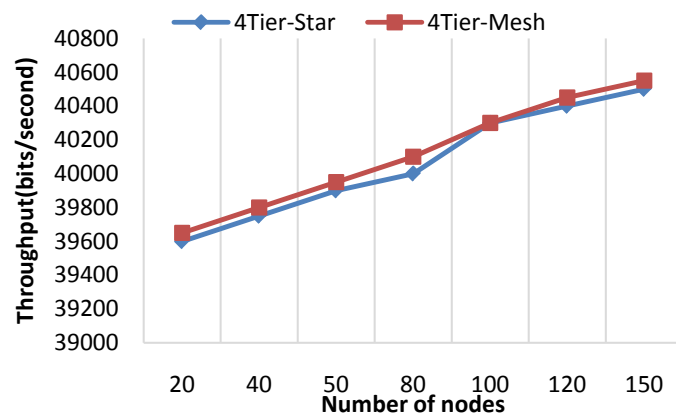


Figure 10. Analysis of throughput.

achieved. Even in the presence of 10 nodes in the network, DTMR algorithm helps to transmit 39,600 bits per second in the network. Thus proposed method provides reasonable results in throughput efficiency in both topologies. Average throughput in star topology is 40,008.3 bits per second whereas in mesh topology is 40,050 bits per second.

Thus, QoSensing metrics in proposed method are analyzed in both star and mesh topology. In order to show the efficiency of our proposed method, we compare our proposed method with existing works QoS with AODV [26], multi-hop routing [30], Data fusion method [32], and MDR method [34] held on WSN QoSensing improvement.

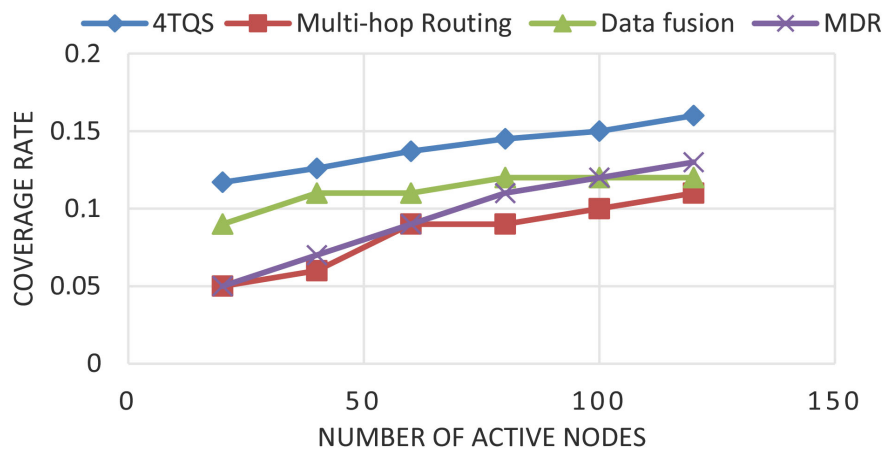
In Figure 11, the coverage rate for the proposed mechanism with respect to the number active nodes compared other schemes.

4TQS respect to other schemes has high coverage rate and performance in both topology. Compared our method with experimental results that used approximate parameters; Star and mesh topology, network with proportion of static and mobile nodes up to 300 nodes. Initial energy in nodes is up to 500 joules, interval intervals up to 10 seconds, coverage area 1000×1000 meters.

In Table 2, comparative analysis of QoSensing improvement in proposed

Table 2. Comparative analysis.

Work/metric	[26]	[30]	[32]	[34]	4TQS	
					Star	Mesh
C.Rate	-	0.07	0.12	0.04	0.157	0.138
C.ratio	80.6	75.7	62.75	85,3	84.7	84.06
EC	12.74	18.33	13.62	13.71	10.39	10.4
Delay	0.8	0.7	0.8	0.5	0.3994	0.3999
Thr	28,000	-	25,000	41,000	40,008	40,050

**Figure 11.** Coverage rate 4TQS versus other schemes.

method with other previous works is depicted. From the table it is clear that each QoS metric is improved in our proposed 4Tire method in both topologies. Here connectivity ratio of 4TQS method is lower than MDR method. It is worth noting that in MDR method, connectivity ratio is obtained with minimum 300 nodes which is relatively higher than our proposed work. Since connectivity increases with respect to number of nodes, the result is obtained. Even with small number of nodes, 4TQS method achieves considerable connectivity ratio. Thus, significant QoS metrics are analyzed in two different WSN topologies comparative analysis shows that proposed 4TQS method provides better QoS in WSN.

6. Conclusion

4TQS method is proposed to reduce the energy consumed by communication in dynamic WSNs. The method with algorithms for clustering clusters with distributed fault tolerance was presented, avoiding coverage holes efficiently. Here, the CH was optimally selected based on residual energy and the runtime discovery was made in the event of a CH failure, increasing connectivity. Enhanced delay tolerant routing improves WSN metrics as well as improves energy efficiency. 4TQS metrics were compared with similar trials. Thus, we propose the usage 4TQS method to solve the problem of detecting and bypassing holes in

WSNs. In future, our proposed method evaluates cluster and tree topologies in order to analyze QoSensing in those hierarchical topologies.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

- [1] Khalil, M., Khalid, A., Khan, F.U. and Shabbir, A. (2018) A Review of Routing Protocol Selection for Wireless Sensor Networks in Smart Cities. 2018 *24th Asia-Pacific Conference on Communications (APCC)*, Ningbo, 12-14 November 2018, 610-615. <https://doi.org/10.1109/APCC.2018.8633456>
- [2] Palacios, E., Philco, O., Cordova, L. and Bastidas, G. (2019) Analyzing and Improving Quality of Sensing in Wireless Sensor Network. 2019 *IEEE CHILEAN Conference on Electrical, Electronics Engineering, Information and Communication Technologies (CHILECON)*, Valparaiso, 13-27 November 2019, 1-7. <https://doi.org/10.1109/CHILECON47746.2019.8987604>
- [3] Yu, J., Wan, S., Cheng, X. and Yu, D. (2017) Coverage Contribution Area Based K-Coverage for Wireless Sensor Networks. *IEEE Transactions on Vehicular Technology*, **66**, 8510-8523. <https://doi.org/10.1109/TVT.2017.2681692>
- [4] Guo, J. and Jafarkhani, H. (2019) Movement-Efficient Sensor Deployment in Wireless Sensor Networks with Limited Communication Range. *IEEE Transactions on Wireless Communications*, **18**, 3469-3484. <https://doi.org/10.1109/TWC.2019.2914199>
- [5] Saadi, N., Bounceur, A., Euler, R., Lounis, M., Bezoui, M., Kerkar, M., *et al.* (2020) Maximum Lifetime Target Coverage in Wireless Sensor Networks. *Wireless Personal Communications*, **111**, 1525-1543. <https://doi.org/10.1007/s11277-019-06935-5>
- [6] Ma, C., Liang, W., Zheng, M. and Sharif, H. (2016) A Connectivity-Aware Approximation Algorithm for Relay Node Placement in Wireless Sensor Networks. *IEEE Sensors Journal*, **16**, 515-528. <https://doi.org/10.1109/JSEN.2015.2456931>
- [7] Xu, Z., Chen, L., Chen, C. and Guan, X. (2016) Joint Clustering and Routing Design for Reliable and Efficient Data Collection in Large-Scale Wireless Sensor Networks. *IEEE Internet of Things Journal*, **3**, 520-532. <https://doi.org/10.1109/JIOT.2015.2482363>
- [8] Krishnan, M., Rajagopal, V. and Rathinasamy, S. (2018) Performance Evaluation of Sensor Deployment Using Optimization Techniques and Scheduling Approach for K-Coverage in WSNs. *Wireless Networks*, **24**, 683-693. <https://doi.org/10.1007/s11276-016-1361-5>
- [9] Deif, D.S. and Gadallah, Y. (2017) An Ant Colony Optimization Approach for the Deployment of Reliable Wireless Sensor Networks. *IEEE Access*, **5**, 10744-10756. <https://doi.org/10.1109/ACCESS.2017.2711484>
- [10] Liao, Z., Wang, J., Zhang, S., Cao, J. and Min, G. (2015) Minimizing Movement for Target Coverage and Network Connectivity in Mobile Sensor Networks. *IEEE Transactions on Parallel and Distributed Systems*, **26**, 1971-1983. <https://doi.org/10.1109/TPDS.2014.2333011>
- [11] Vinueza Naranjo, P.G., Shojafar, M., Mostafaei, H., Pooranian, Z. and Baccarelli, E. (2017) P-SEP: A Prolong Stable Election Routing Algorithm for Energy-Limited

- Heterogeneous Fog-Supported Wireless Sensor Networks. *The Journal of Supercomputing*, **73**, 733-755. <https://doi.org/10.1007/s11227-016-1785-9>
- [12] Amgoth, T. and Jana, P.K. (2015) Energy-Aware Routing Algorithm for Wireless Sensor Networks. *Computers and Electrical Engineering*, **41**, 357-367. <https://doi.org/10.1016/j.compeleceng.2014.07.010>
- [13] Leu, J.-S., Chiang, T.-H., Yu, M.-C. and Su, K.-W. (2015) Energy Efficient Clustering Scheme for Prolonging the Lifetime of Wireless Sensor Network with Isolated Nodes. *IEEE Communications Letters*, **19**, 259-262. <https://doi.org/10.1109/LCOMM.2014.2379715>
- [14] Bakhsh, S.T., Al Ghamdi, R., Alalhi, A.H., Tahir, S. and Aman Sheikh, M. (2017) Adaptive Sleep Efficient Hybrid Medium Access Control Algorithm for Next Generation Wireless Sensor Networks. *EURASIP Journal on Wireless Communications and Networking*, **2017**, Article No. 84. <https://doi.org/10.1186/s13638-017-0870-y>
- [15] Lin, C., Cui, L., Coit, D.W. and Lv, M. (2017) Performance Analysis for a Wireless Sensor Network of Star Topology with Random Nodes Deployment. *Wireless Personal Communications*, **97**, 3993-4013. <https://doi.org/10.1007/s11277-017-4711-4>
- [16] Ali Moridi, M., Kawamura, Y., Sharifzadeh, M., Knox Chanda, E., Wagner, M. and Okawa, H. (2018) Performance Analysis of ZigBee Network Topologies for Underground Space Monitoring and Communication Systems. *Tunnelling and Underground Space Technology*, **71**, 201-209. <https://doi.org/10.1016/j.tust.2017.08.018>
- [17] Mohamed, S.M., Hamza, H.S. and Saroit, I.A. (2015) Harmony Search-Based K-Coverage Enhancement in Wireless Sensor Networks. *International Journal of Electronics and Communication Engineering*, **9**, 178-186.
- [18] Sirajo Aliyu, M., Hanan Abdullah, A., Chizari, H., Sabbah, T. and Altameem, A. (2016) Coverage Enhancement Algorithms for Distributed Mobile Sensors Deployment in Wireless Sensor Networks. *International Journal of Distributed Sensor Networks*, **12**, No. 3. <https://doi.org/10.1155/2016/9169236>
- [19] Nagar, J., Kumar Chaturvedi, S. and Soh, S. (2021) Wireless Multi-Hop Network Coverage Incorporating Boundary and Shadowing Effects. *IETE Technical Review*, 1-16. <https://doi.org/10.1080/02564602.2021.1968963>
- [20] Elisha George, A., Paulus, R. and Jaiswal, A.K. (2015) Enhancement of Data Aggregation Grid based Coverage Ratio Using Overlap Sensing Ratio with Awgn Channel in Heterogeneous WSNs. *International Journal of Computer Applications*, **128**, 1-5. <https://doi.org/10.5120/ijca2015906739>
- [21] Xiao, F., Yang, X., Yang, M., Sun, L., Wang, R. and Yang, P. (2016) Surface Coverage Algorithm in Directional Sensor Networks for Three-Dimensional Complex Terrains. *Tsinghua Science and Technology*, **21**, 397-406. <https://doi.org/10.1109/TST.2016.7536717>
- [22] Liu, X. (2017) Survivability-Aware Connectivity Restoration for Partitioned Wireless Sensor Networks. *IEEE Communications Letters*, **21**, 2444-2447. <https://doi.org/10.1109/LCOMM.2017.2699174>
- [23] Chung, S.M., Kim, K.T., Song, J. and Youn, H.Y. (2016) Enhancing Node Connectivity by Utilizing RSSI for ZigBee-Based WSN. *IEEE International Conference on Information and Communication Technology*, Jeju, 19-21 October 2016, 555-560. <https://doi.org/10.1109/ICTC.2016.7763532>
- [24] Wu, C.Q. and Wang, L. (2017) On Efficient Deployment of Wireless Sensors for Coverage and Connectivity in Constrained 3D Space. *Sensors*, **17**, Article No. 2304. <https://doi.org/10.3390/s17102304>

- [25] Sakkari, D.S. and Basavaraju, T.G. (2015) GCCT: A Graph-Based Coverage and Connectivity Technique for Enhanced Quality of Service in WSN. *Wireless Personal Communications*, **85**, 1295-1315. <https://doi.org/10.1007/s11277-015-2841-0>
- [26] Cedeño, N.Z., Asqui, O.P. and Chaw, E.E. (2019) The Performance of QoS in Wireless Sensor Networks. 2019 *14th Iberian Conference on Information Systems and Technologies (CISTI)*, Coimbra, 19-22 June 2019, 1-5. <https://doi.org/10.23919/CISTI.2019.8760756>
- [27] Shen, J., Wang, A., Wang, C., Hung Patrick, C.K. and Lai, C.-F. (2017) An Efficient Centroid-Based Routing Protocol for Energy Management in WSN-Assisted IoT. *IEEE Access*, **5**, 18469-18479. <https://doi.org/10.1109/ACCESS.2017.2749606>
- [28] Ruan, D. and Huang, J. (2019) A PSO-Based Uneven Dynamic Clustering Multi-Hop Routing Protocol for Wireless Sensor Networks. *Sensors*, **19**, Article No. 1835. <https://doi.org/10.3390/s19081835>
- [29] Ferreira, M.V.G., Vieira, F.H.T. and Carvalho, M.N.L. (2020) A Resource Allocation Scheme with Delay Optimization Considering mmWave Wireless Networks. *International Journal of Communications, Network and System Sciences*, **13**, 105-119. <https://doi.org/10.4236/ijcns.2020.137007>
- [30] Huynh, T.-T., Dinh-Duc, A.-V. and Tran, C.-H. (2016) Delay-Constrained Energy-Efficient Cluster-Based Multi-Hop Routing in Wireless Sensor Networks. *Journal of Communications and Networks*, **18**, 580-588. <https://doi.org/10.1109/JCN.2016.000081>
- [31] Amjad, M., Khalil Afzal, M., Umer, T. and Kim, B.-S. (2017) QoS-Aware and Heterogeneously Clustered Routing Protocol for Wireless Sensor Networks. *IEEE Access*, **5**, 10250-10262. <https://doi.org/10.1109/ACCESS.2017.2712662>
- [32] Pereira, V., Monteiro, E. and Sá Silva, J. (2016) A Data Fusion Protocol for WSN Performance and Data Retrieval. *NOMS 2016: 2016 IEEE/IFIP Network Operations and Management Symposium*, Istanbul, 25-29 April 2016, 834-837. <https://doi.org/10.1109/NOMS.2016.7502910>
- [33] Khelil, A. and Beghdad, R. (2016) ESA: An Efficient Self-Deployment Algorithm for Coverage in Wireless Sensor Networks. *Procedia Computer Science*, **98**, 40-47. <https://doi.org/10.1016/j.procs.2016.09.009>
- [34] Philco, O., Marrone, L. and Estupinan, E. (2021) Multihop Deterministic Energy Efficient Routing Protocol for Wireless Sensor Networks MDR. *International Journal of Communications, Network and System Sciences*, **14**, 31-45. <https://doi.org/10.4236/ijcns.2021.143003>
- [35] Zhang Q. and Fok, M.P. (2017) A Two-Phase Coverage-Enhancing Algorithm for Hybrid Wireless Sensor Networks. *Sensors*, **17**, Article No. 117. <https://doi.org/10.3390/s17010117>
- [36] Sharmin, S., Narin Nur, F., Razzaque, A., Rahman, M., Almogren, A. and Mehedi Hassan, M. (2017) Tradeoff between Sensing Quality and Network Lifetime for Heterogeneous Target Coverage Using Directional Sensor Nodes. *IEEE Access*, **5**, 15490-15504. <https://doi.org/10.1109/ACCESS.2017.2718548>
- [37] Boubrima, A., Bechkit, W. and Rivano, H. (2019) On the Optimization of WSN Deployment for Sensing Physical Phenomena: Applications to Urban Air Pollution Monitoring. In: Ammari, H., Eds., *Mission-Oriented Sensor Networks and Systems: Art and Science*, Vol. 163. Springer, Cham, 99-145. https://doi.org/10.1007/978-3-319-91146-5_4