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Performance analysis of multi-layered clustering network using fault tolerance multipath routing protocol (MRP-FT) in a wireless sensor network (WSN)

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Abstract

Wireless sensor networks (WSNs) are ad hoc and self-configuring networks having the possibility that any sensor node can connect or leave the network. With no central controller in WSN, wireless sensor nodes are considered responsible for data routing in the networks. The wireless sensor nodes are very small in size and have limited resources, therefore, it becomes difficult to recharge or replace the battery of the sensor nodes at far places. The present study focused on reducing the battery consumption of the sensor nodes by the deployment of the newly proposed Fault Tolerance Multipath Routing Protocol (MRP-FT) as compared with the existing Low Energy Adaptive Clustering Hierarchy (LEACH) protocol under particle swarm optimisation based fault tolerant routing (PSO-FT) technique. The proposed algorithm of MRP-FT-based on the dynamic clustering technique using Boltzmann learning of the neural network and the weights were adjusted according to the area of networks, number of nodes and rounds, the initial energy of nodes (E0), transmission energy of nodes (d<d0), data reviving energy (ERX), data aggregation energy (EDA), energy dissipation on free space (ϵfs), energy dissipation of multi-path delay (ϵ mp) and the packet size. The results of the present study revealed that the packet heads remains constant during the initial time period (up to 2500 seconds), and exhibited a sharp increase thereafter. The network energy consumption remains constant up to 2300 s and exhibited a sharp increase thereafter. High energy use after 2300 seconds describes the faulty occurrence in the network and leads to decreased reliability (%) of the existing protocol. The energy consumption was substantially reduced by 15 J (38.5%) due to the implementation of the newly proposed MRP-FT, compared with the existing PSO-FT protocol. The reduced delay of 22 packets was achieved with MRP-FT protocol, compared with the existing PSO-FT technique-based LEACH protocol. Nonetheless, the MRP-FT enhanced the packet overhead of 10.8% over the current protocol due to deploying more uniform clustering. Additionally, a 12% increase in reliability was achieved with the implementation of MRP-FT protocol emphasizing that network lifespan was prolonged efficiently with the proposed algorithm.

Keywords: *scalability, fault tolerance, neural networks, Boltzmann learning, wireless sensor network*

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1. Introduction

Wireless sensor networks (WSNs) are composed of thousands of cost-effective small devices called sensor nodes [7, 18, 23, 24, 32], which are connected through wireless networks for data gathering locally or relayed to the sink node through multi-hop wireless transmission [8, 22, 23]. Each wireless sensor node consists of sensors, processors, memory, radio frequency transceiver (radio), peripherals and the power supply unit, i.e., a non-rechargeable battery [3, 8, 22]. The sensor nodes are deployed on a geographical space for monitoring physical measures viz. temperature, humidity, vibrations etc. [7, 21, 22].

The WSNs are widely used in military services such as battlefield surveillance [44]; but now a day's these networks are extensively used in several industrial and commercial sectors, e.g., industry for monitoring and governance, machine health monitoring and so on [7, 22–24, 34, 35]. The sensing node contains a sensor unit to aggregate data from the surrounding environment, a measuring unit for data processing and storing, and a wireless communication unit for data transmission [23, 37]. The sensor network, therefore, must have enough lifetimes to fulfil the requirements of the applications [24, 32, 39]. The lack of energy during data aggregation and transfer enforces the sensor nodes to get die and ineffective and eventually causes the collapse of the whole network goals [8, 37].

Some design issues of clustering protocols must be addressed to design an efficient clustering/routing protocol [16, 30]. The important design issues are fault tolerance, operating environment, power consumption, data aggregation, service quality, data latency, overhead, and node deployment [22, 42, 47]. These issues are highly critical with important constraints like energy efficiency [23], stock limitation and a lifetime of networks [19, 25]. Several approaches have been applied to minimize the traffic into the network by clustering algorithms to make them highly capable of reducing energy consumption in WSNs [4, 6, 9, 21, 28]. The selection of cluster heads (CHs) and their interaction outperforms an algorithm's performance based on probabilistic regarding the energy scattering [15, 22, 43]. The low energy adaptive clustering hierarchy (LEACH) algorithm has played a key role in the development of several new algorithms [17, 23]. The LEACH algorithm involves the random selection of CHs with any nonclustered node choosing its CH depending upon its distances without considering the residual energy of CH [17]. The basic LEACH protocol can improve the network's life period, but these protocols still use probability-based with introducing deterministic components [28]. The conventional LEACH protocol undergoes the same issue of ungraded CH selection per round as with the other probability-based models [28]. Bani et al. [6] proposed an improved LEACH protocol as multi-hop LEACH (M-LEACH) which involves cluster members responding more as a leap from their corresponding CH and communicating in a multi-hop fashion. Their protocol has a condition that each sensor should aggregate data, which enhances the overhead for all sensors. To account for improved efficiency in data aggregation, Aslam et al. [4] applied two heterogeneous sensors viz. super (high capacity) and simple (low capacity). The super sensors possess capabilities of intensive communication and behave as CHs, while the low-capacity sensors with limited power stay close to the nearest neighbourhood and communicate directly in multi-hop [20, 46].

Khediri et al. [25] applied optimisation low energy adaptive clustering hierarchy (O-LEACH) for the improvement of existing conventional LEACH and LEACH-C topology to select clusters alternately for energy optimisation in WSNs. The O-LEACH protocol considers the selection of clusters according to the residual energy of nodes dynamically. The results revealed that the proposed algorithm (O-LEACH) achieved longer stability, compared with conventional LEACH and centralized LEACH (LEACH-C) protocols. However, according to Heinzelman et al. [17], the base station (BS) of LEACH-C guarantees more uniform distribution of energy among all the clusters, and the algorithm defines a threshold for energy and each node with more energy than the threshold is considered for the election of the CH. In addition, Hady et al. [15] applied a low-energy adaptive clustering hierarchy centralized sleeping (LEACH-CS) protocol for WSNs using an intelligent sleeping mechanism (ISM) algorithm for selecting the sensor nodes. While comparing the proposed LEACH-CS with the existing LEACH-C, Hady et al. [15] reported an extended lifetime of network by ca. 35%, and minimising the end-to-end delay of data by ca. 50%, compared with LEACH-C. In another study, Kannan and Raja [21] divided the network primary and Sary tiers based on the received signal strength indication of sensor nodes from the BS. The proposed distributed cluster head scheduling (DCHS) was used to support the divided tiers in WSN architecture to elect the CH nodes and the gateway nodes. The DCHS satisfactorily distributed the CHs among the sensor nodes while avoiding frequent CH selection through received signal strength indication (RSSI) and its residual [21]. Akhtar et al. [2] reported that RSSI approach has the limitation that it considers only the intra-cluster routing while lacking focus on inter-cluster routing. Nonetheless, the RSSI algorithm has enhanced the energy efficiency by ca. 17%, compared with TOSSIM simulator which did not involve real-time hardware to record the signal strength. The LEACH-C integrates a centralised protocol in the selection CHs, in the same steady state phase as for conventional LEACH [17]. In LEACH-C, the BS gathers the respective position and energy state of each sensor node with higher than the average energy for different nodes was used to elect the CHs during the initial set-up phase. The major limitation of LEACH-C topology was the consideration of only the energy level of sensor nodes for the election of the CHs, which results in high energy consumption while communicating between the BS and CHs [17]. The periodic selection of CHs based on their residual energy and deployment of hybrid energy-efficient distributed (HEED) clustering protocol support only the building of a two-level hierarchy and lack of multilevel hierarchies [45]. A novel energy-efficient dynamic clustering approach which considers each node to estimate the number of active nodes in real-time while estimating its optimal probability of becoming a CH and monitoring the received signal power from its neighbouring nodes was studied by Xu et al. [43]. Manjula et al. [29] applied LEACH-CE protocol with consideration of 5% of alive nodes in WSN as CHs, and the BS makes 10% of the nodes go to sleep mode, well before the selection of CHs. In sleep mode, the nodes do not sense any data and they did not receive CH information from the BS. The model chooses randomly the nodes switched to the sleeping mode which does not guarantee the quality of data even if it preserves the lifetime. Gautam et al. [12] reported that dynamic clustering and distance aware routing (DDAR) algorithm integrates two-stage hierarchical clustering viz. CH and super-cluster heads (SCHs) were the most energy efficient (ca. 15.5% energy saving) than the LEACH protocol. It involves the dynamic selection of CHs to substantially reduce the chances of unnecessary selection of CHs. Even when a large number of sensor nodes in WSN are dead, the network can pursue its job even with a low number of alive nodes [12]. Fan and Jin [10] used a multi-weight-based clustering algorithm (MWBCA) based on a weighting function for clustering and the linear combination of the power transmission, residual energy of node, the number of neighbours and duration that the node was CH. In MWBCA, each node broadcast its aggregated weight to neighbours and a node with minimum weight is selected as the CH. It can avoid nodes of premature death due to excessive energy costs, while the elected nodes behave alternately as CHs. A hybrid algorithm that integrates LEACH with virtual force data (LEACH-VF) involves the application of virtual force to each cluster node to move the sensor to maximize the coverage area while minimizing the energy expenditure [5].

The literature review revealed that the different algorithms proposed so far had several advantages and disadvantages as well. Dehghani et al. [8] reported that although the LEACH-VF had the advantage of non-overlap and non-hole in the coverage area, it has low energy efficiency due to the non-uniform distribution of energy on the sensor nodes. The HEED protocol has scalability for multi-hop communication and uniform distribution of energy during inter-clustering, but the non-uniform distribution of energy conception is due to high overhead [45]. The MWBCA algorithm ensures the uniform distribution of energy on nodes but has a problem of high control messages overhead responsible for the selection of suitable CHs [5]. To enhance the energy efficiency, packet overhead, reliability and network lifespan of the existing WSNs and to help solve the energy cost problem in data gathering WSNs, the present study deployed a new algorithm, i.e., fault tolerance multipath routing protocol (MRP-FT) to compare the energy efficiency with the existing low energy adaptive clustering hierarchy (LEACH) protocol under particle swarm optimisation based fault tolerant routing (PSO-FT) technique.

2. Characteristics of wireless sensor network

2.1. Fault tolerance, operating environment and power consumption

The sensors are dispersed in an environment known as a sensor node field (Figure 1), which showed that the sensing nodes are connected with a sink via multi-hop and communicate to users with the help of internet or satellite networks [33]. A few sensor nodes in WSNs may fail due to a lack of power or environmental interferences, which has not been desirable because the failure of sensor nodes affects the performance and functionality of networks [31].

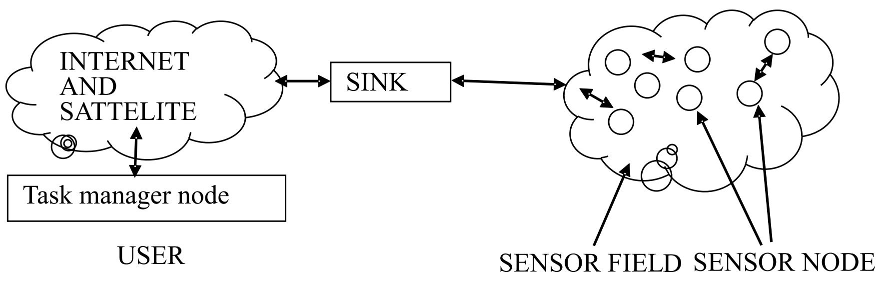

Figure 1. Basic architecture design of wireless sensor network (WSN)

The ability to sustain node failure without any interruption is called fault tolerance. Since WSNs are set in different operating environments like at bottom of the ocean, in a home or building attached to a fast-moving vehicle; therefore, the lifetime and stability were different for different environments. The transmission energy consumption required by multi-hop routing protocol should be less, and the lesser energy consumption gives more lifetimes to sensor nodes. The fault-tolerance is an important challenge to WSN [47, 48]. Therefore, to avoid data loss from the key sensor nodes, the fault tolerance of CHs is generally required. Additionally, regrouping has been the most instinctive strategy for recuperating from a disappointment of a bunch. However, it by and large messes up the ongoing activity. The rapid deployment, self-organisation and fault tolerance distinctiveness of sensor networks construct them as a very capable sensing method for different applications [31, 47].

2.2. Data aggregation, quality of service and connectivity

Data aggregation is the compilation of data from different sources by computation. In WSN, the sensor node generates a significant amount of data. Therefore, similar packets from multiple nodes could be aggregated so that number of transmissions is decreased, and energy efficiency is increased. The quality of service required by the applications could be the duration, energy efficiency, the data reliably collaborative processing and location awareness [15]. All these factors affect the choice of routing protocols for a particular application. Data aggregation/fusion is a technique for WSN to save energy. Clustering by data aggregation is an important method in which every CH aggregates collect information and transmits fused data to BS. Normally, CHs formed a tree-like structure for transmitting aggregated data through multi-hopping and other CHs that result in energy savings [26]. Sensor nodes for the most part were sending information to at least one BS through a single-hop or multi-hop steering. Therefore, sensor nodes which cannot connect with the other sensor nodes are isolated and furthermore, their information could not be communicated to the BS. The assurance of the network has been the fundamental objective for the bunching of steering conventions in WSNs. The significant model is that when some data that disturbing all these sensor nodes should have been gathered through an assigned combination of sensor nodes in bunching of directing conventions [39].

2.3. Data latency, overhead and node deployment

The data latency caused by data aggregation and multi-hop relays by some routing protocols creates excessive overheads to implement their algorithms, which is not suitable for some applications. The node deployment affects the performance of the routing protocol and the dependent applications. In deterministic distribution, the sensors are settled manually, and data is routed by predetermined paths. In self-organizing systems, the sensor nodes are scattered randomly and the position of the sink or the CH becomes an issue for the energy efficiency of the network [48].

The routing protocols in WSN are divided into three categories viz. (i) a flat network (location), and (ii) hierarchic routings. The flat routing consists of all sensing devices having similar activities and also the data sending occurs through multiple hops. The clustering hierarchical protocols are the best solution that can resolve most of the problems that nodes have different tasks such as CH considered above [15]. In each cluster, there is a CH that communicates with BS and other node called member nodes collects and transmits data to the CH (Figure 2). The cluster routing protocols have several advantages such as more salable, data aggregation/fusion, less energy consumption, more robustness, collision avoidance, latency reduction, load balancing, fault tolerance, and guaranteed connectivity. The CHs are responsible for data aggregation, data dissemination and network management. Clustering topology can make the routing in the cluster and therefore reduce the size of the routing table which is stored at every sensor node [39]. The WSNs are partitioned into the cluster, the lone CHs performed the assignment of the information transmission out of the groups. The method of the information transmission just that of the cluster helps in evading crashes in the middle of the nodes. From that point forward, information transmissions are performed by trusting that utilizing the kind of flooding that in level steering procedure, however just CHs performing information transmission in routing plan, that can diminish the bounces from wellsprings of information to the BS, that decline idleness.

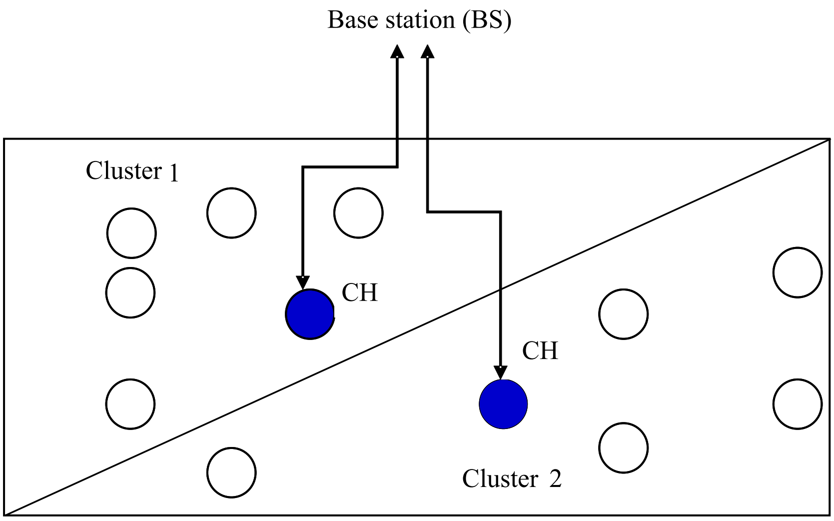

Figure 2. Clustering in the wireless signal network (WSN) (CH – cluster head, BS – base station)

2.4. Less energy consumption and more robustness

Information accumulation in the bunch assists with diminishing the transmission of information and saving energy. In addition, the clustering with intra-group as between bunch correspondences lessens the quantities of sensor hubs that play out quite a while ago and removed inter-changes [47]. The solitary CHs play out the information transmissions in the group steering plan, and therefore save energy consumption [15]. Clustering routing protocol controls the organisation changes containing node mobility and unusual disappointments. The clustering routing scheme needs to cope with all these changes in individual clusters so that the entire network becomes more robust and convenient for management. Therefore, to share the CH responsibility, the CHs are generally rotated among all the sensor nodes to avoid the single point that fails in cluster routing algorithms [23, 47, 48].

2.5. Collision avoidance and load balancing

In the multi-hop clustering model, WSN is partitioned in the grouping [24]. The information communication in the middle of sensor nodes involves two modes which are intra-clustering and inter-clustering separately for the information assortment and the information transmission. The assets are distributed symmetrically to every one of the clusters to make lessen impacts between the clusters and can be reused by grouping. It is a fundamental contemplation planning to build the network's lifetime of WSN [23, 24]. The appropriation of the sensor nodes in the clusters is for the most part considered for the cluster developments where CHs' are performing the information preparation and furthermore intra-cluster the board. For the most part, building same-sized clusters are embraced for expanding the organisation's lifetime as it forestalls untimely energy fatigue for CHs [22].

3. Classification of wireless sensor networks (WSNs)

The classification is based on the characteristics and functionality of the sensor nodes in WSNs. There are two types of WSNs viz. heterogeneous sensor networks and homogeneous sensor networks, which are explained below.

There are by and large two kinds of sensors. The sensors characterised by higher handling abilities and complex equipment are utilized to make a type of spine inside the WSN being preset as the CH nodes and fill in as information authorities and handling habitats for the information assembled by other sensor nodes [11]. However, the sensor with lower abilities is used to detect the ideal credits in the field. In homogeneous networks, all nodes had similar characteristics, equipment and handling capacities [40]. In this situation, each sensor can turn into a CH [4]. Besides, the head cluster can intermittently turn among the nodes to accomplish better burden adjusting and more uniform energy utilisation [11].

To gain more flexibility, fast execution, and convergence of the number of nodes in WSNs, the homogeneous sensor networks are used to provide distributed CH election and formation process of the cluster [11]. There are several approaches (centralized or hybrid), where one or more coordinator nodes or the BSs are responsible to partition the whole network offline and control the cluster membership [1]. These are naturally not suitable for practical general-purpose large-scale WSNs applications.

These are generally suitable for special-purpose, limited-scale applications where high-quality connectivity and network partitioning are needed [41]. In deterministic energy-efficient clustering (DEC) protocol which is similar to low energy adaptive clustering hierarchy (LEACH) protocol, the join request message contains cluster member identity (CM-ID), cluster head identity (CH-ID) and cluster member-residual energy (CM-RE) and the header which indicates the request. This way the residual energy (RE) information of cluster members (CMs) is familiar to their corresponding CHs, therefore, is localized and utilized for CH rotation in the subsequent rounds. The establishment of a heterogeneous WSN is done by using DEC routing protocol to increase the network lifetime and reduce energy consumption.

4. Methodology proposed

4.1. Procedure for selection of cluster heads (CHs)

The fundamental point for all protocols is to build the WSN life period by utilizing the organisation's worldwide data without utilizing the neighbourhood data [44]. The disadvantage of most of the protocols is that there has not been an assurance that involves the selection of the ideal count of CHs and the selected CH has adequate energy [8, 41]. The deterministic CH selection and interaction outperform an algorithm dependent on probabilistic regarding the energy scattering [43]. The basic LEACH protocol can improve the network's life period, but these protocols still use probability-based with introducing deterministic components [28]. The conventional LEACH protocol undergoes the same issue of ungraded CH selection per round as with the other probability-based models [28]. Although, LEACH protocol expected the greatest setting that can assure the best work using the theoretical model, mostly time as output has been sub-optimal because of uncertainties in the CH selection process. As per these protocols, the procedure of the clustering process starts with a setup phase, once all the nodes help the indicator function for the selection of CHs. The selected CHs send advertising messages by using the non-persistent carrier sense multiple access-medium access control (CSMA-MAC) protocols. The informative message consists of the identity of CHs and the header file known as the announcement message. The nodes which are not chosen are called CMs to find their cluster by selecting the CH with the less communication price, which depends on the received signal energy of the advertisement message. By using CSMA-MAC protocol, CMs deliver the join request message to the elected CH.

Table 1. Advantages and disadvantages of protocols used in wireless sensor networks (WSNs)

Algorithm	Advantages	Disadvantages	References
Support vector machine	Not biased by outliers, insensitive to overfit, used as a linear classifier, learns from support vector unlike others that learn from correct and incorrect data	Inappropriate for non-linear problems, requires a large amount of time o process larger data sets does not perform well in case of overlapped classes, selection of an appropriate kernel function can be tricky	[13, 14, 46]
Naïve Bayes	Based on assumptions that all features are independent of one another, contribute equally to the outcome; it is a probabilistic classifier model whose crux is Bayes' theorem	The assumption that all features are equal is not always valid in real life (disadvantage of naive Bayes)	[46]
LEACH	Based on hierarchical clustering, very low scalability and transmission delays, low control message overhead, much less uniformity in the distribution of energy, very low algorithm complexity and 1-hop inter-cluster structure	Non-uniform distribution of cluster heads, selects the cluster head without considering the remaining energy, send data in 1-hop	[8, 32]
LEACH-C	Optimal number of clusters, uniform distribution of cluster heads, select the cluster head based on the residual energy	Send data in 1-hop	[8, 17]
LEACH-VF	Non-overlap in the Coverage 2; non-holes in the coverage,	Low energy efficiency 2; non-uniform distribution of energy	[8]
HEED	Scalability for multi-hop communication 2. Uniform distribution of energy inter-clustering	Non-uniform distribution of energy conception 2; high overhead	[8, 32] [41, 45]

The message consists of the header file, CM-ID and CH-ID and shows the message like a demand. The CHs set up a time division multiple access (TDMA) for its intra-clustering communications that end the set-up phase. After sensed data send from CM to CH and CHs to BS, the steady-state phase starts. By using direct sequencing spread spectrum (DSSS), we achieved inter-cluster communication. Considering the lack of information in the literature, a distributed-based model, i.e., fault tolerance multipath routing (MRP-FT) protocol was proposed which can yield a better life period and insures that the node with the largest RE will be elected as the CH. The proposed technique involved the following phases viz. CH selection (phase 1) and sensor node selection (phase 2). We hypothesized that the newly proposed MRP-FT protocol would help enhance energy efficiency with reduced delay and reliability as compared with the existing LEACH protocol under the particle swarm optimisation-based fault-tolerant routing (PSO-FT) technique. Table reftab1 illustrates the pros and cons of earlier proposed protocols in machine learning.

4.1.1. Phase 1. Cluster head selection

The CH selection is the first phase of the network. The network is deployed with a finite number of sensor nodes (Figure 3). The BS was deployed at the centre of the network, to flood the message in the network. The BS calculates the signal strength and nodes which have signal strength above the threshold value were considered eligible to be selected as the CH.

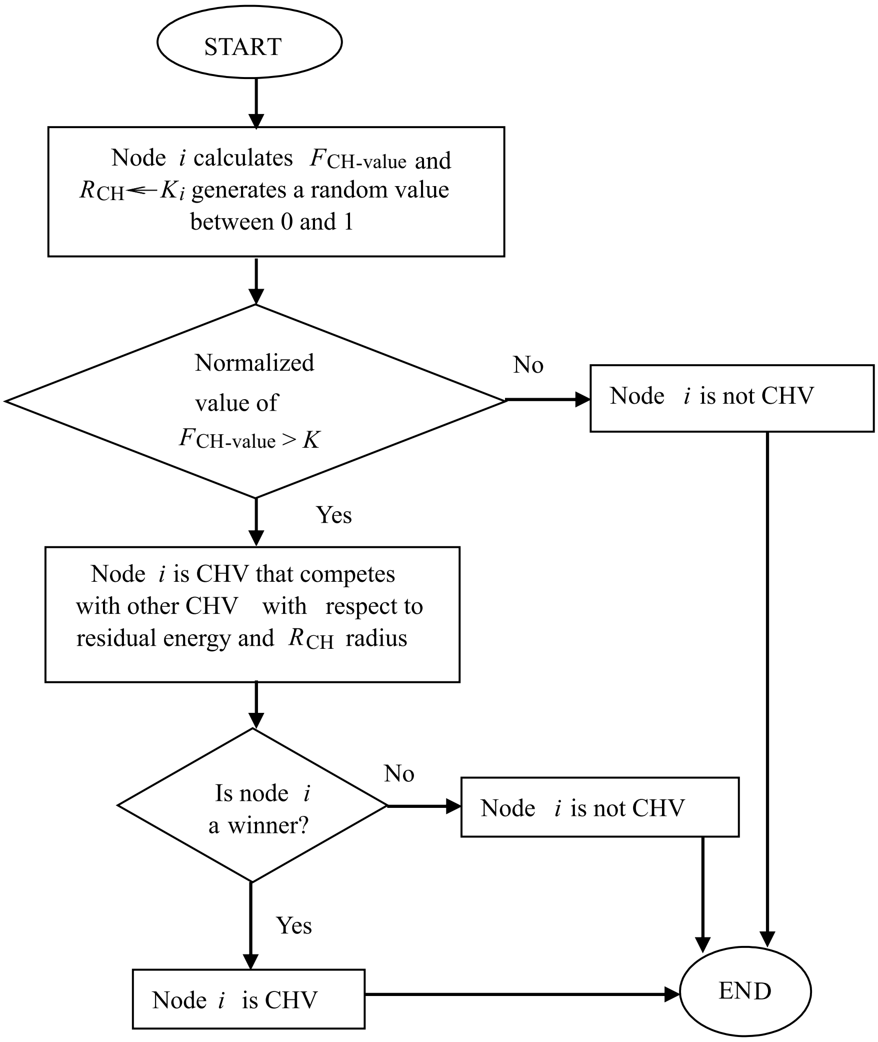

Figure 3. Proposed flowchart depicting the procedure for node selection

The threshold value was defined using the equation:

$$R_{CH} = R_{\min}\left[1 + \left(\frac{d_{BS} - d_{BS\,\min}}{d_{BS\,\max} - d_{BS\ \min}}\right)\right] \tag{1}$$

In equation (1), $R_{\min}$ is the radius of the cluster, d_{BS} is the node distance from the BS, $d_{BS\,\min}$ is the minimum distance from the BS.

$$F_{CH-\text{value}} = \alpha N_{\text{deg}} + \frac{\beta}{MSD_{\text{deg}}} + \frac{\gamma}{d_{BS}} \tag{2}$$

where N_{deg} is the number of neighbour nodes of the particular node, MSD_{deg} is the mean distance of all nodes in the network, α, β, and γ are three threshold values whose total is 1. The sensor node in the network generates a random value which lies between 0 and 1. The sensor node was selected as a cluster when it satisfies the condition given in the equation

$$K(I) > F_{CH-\text{value}} \tag{3}$$

where $K(i)$ is the random value generated by the sensor node individually.

4.1.2. Phase 2. Leader node selection

The second phase of the technique is the selection of leader nodes in the network. The nodes which are not the CHs were selected as the leader node. The leader nodes are responsible to collect the data from the sensor nodes and pass the sensed data to the CHs (Figure 4).

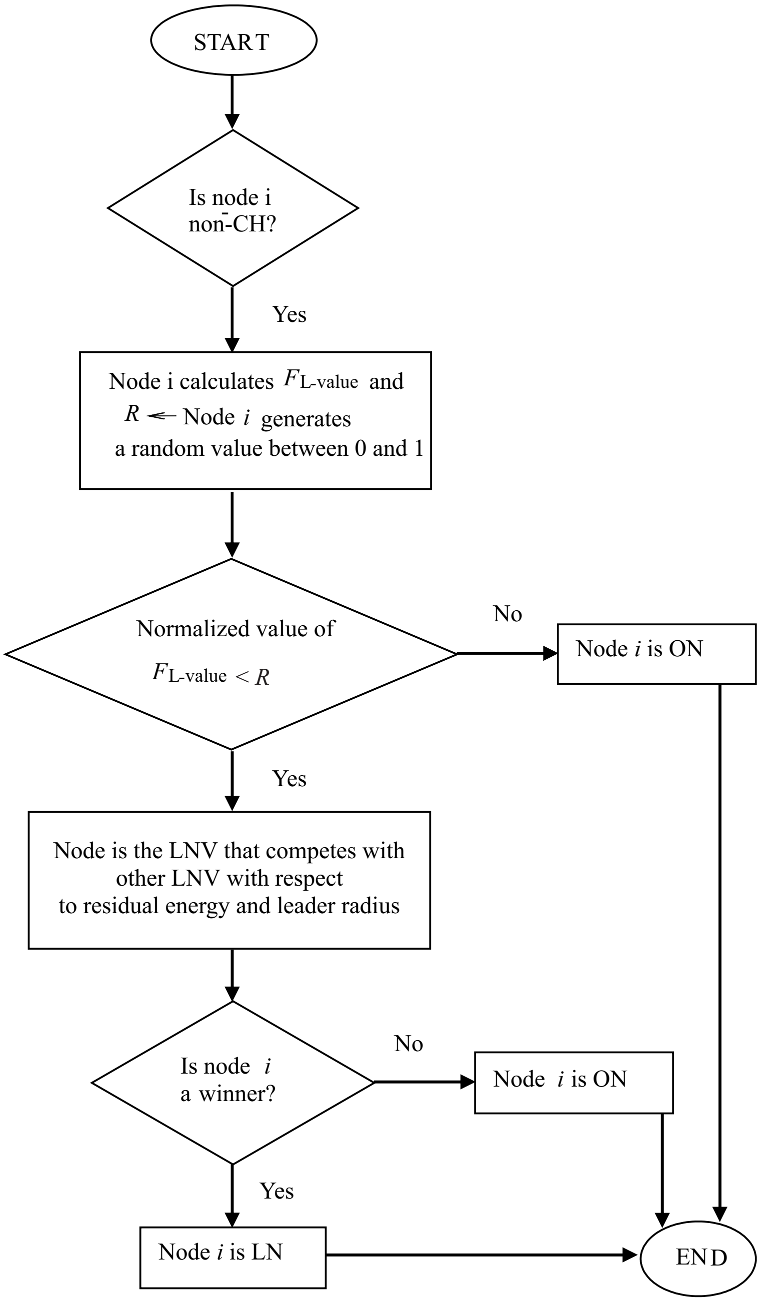

Figure 4. Flowchart depicting a step-wise procedure for the selection leader node in wireless sensor networks

The volunteer leader node was selected by using

$$F_{LN-\text{value}} = \eta M_{\text{deg}} + \frac{\lambda}{K_{LM}} \tag{4}$$

where M_{deg} is the number of leader nodes which are volunteers to select as a leader node. K_{LN} is the number of nodes which comes under the defined radius. In equation (4), η and λ are the two constants, whose total will be 1. The nodes which are the volunteers to be selected as leader nodes will generate a random number from 0 to 1 and nodes which satisfy the condition were selected as a leader node

$$K(I) > F_{LN-\text{value}} \tag{5}$$

4.1.3. Selection of suitable cluster heads (CHs)

In the present study, K means clustering which is based on an unsupervised learning algorithm was used to group the unlabeled data set into different clusters [46]. In this work, our main concern was re-clustering the grids using neural networks. Earlier research considers the clustering of grids as static, but we consider the clustering of grids as dynamic. It was adjustable and changeable according to the situation. In this node data set, data were easily adjustable according to the situation and calculations were made since battery consumption. The main concern was to avoid battery wastage and to enhance energy efficiency while reducing delay and reliability citeSN15. The CHs were also chosen according to the minimum battery consumption by applying an election algorithm. In the network in which numbers of batteries are placed, each battery has the data send capacity in mill ampere (mA). We considered that we have a number of batteries available and each battery forwards data from source to destination based on an ad hoc on-demand distance vector (AODV) algorithm. We included three clusters in which there were three CHs. The CHs were chosen according to the maximum sending capacity and minimum battery consumption. The battery which satisfies both conditions was considered the head of that cluster. The three batteries had the data sending capacities of 8 mA, 10 mA and 12 mA, respectively in a cluster. Thereafter, the CHs were chosen which send full data when they become dead.

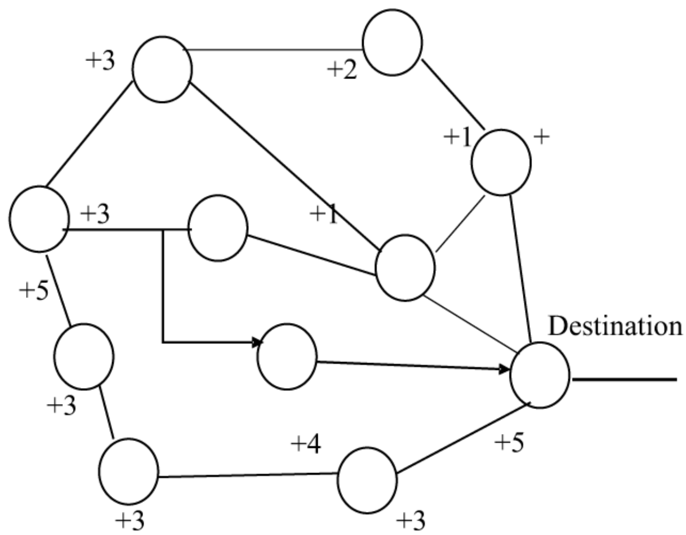

Figure 5. Higher battery nodes used in wireless sensor networks (WSNs)

The selection of 12 mA batteries as a CH sends data successfully but was not sufficient for another data packet transmission after that, therefore, energy wastage was there. However, if 10 mA was chosen, then there was a wastage of 2 mA battery. This battery cannot be used in the transmission of another data packet. Therefore, we choose a battery of 8 mA capacity as a CH so that the complete data transmission was successful, without any wastage. Again to choose the best path for those batteries which waste minimum battery storage and minimum hop count was also taken under consideration to choose the best route or path. After the transmission of the data, the battery died and then the re-clustering of grids again starts (Figure 5).

4.2. Tool for computational programming

The MATLAB editor was used for writing the code to implement the proposed and existing algorithm. The results were shown in the command window of MATLAB. MATLAB is a high-level language and interactive environment that enables one to perform computationally intensive tasks faster than with traditional programming languages such as C, C++, and FORTRAN. MATLAB helps in algorithm development, data visualisation and analysis, and numeric computation.

5. Results and performance analysis

5.1. Implementation of LEACH and improved protocol

The description of the first parameter and their respective values used to implement LEACH and improved fault tolerance multipath routing protocol (MRP-FT) included a 100 × 100 m area of network with 100 nodes and 200 rounds and node energy of 0.5 J (Table 2).

Table 2. Selected simulation parameters and their values used in the implementation of MRP-FT LEACH protocol

Parameter	Description	Value
$X_m \times Y_m$	area of the network	$100 \times 100\,\mathrm{m}^2$
N	number of nodes	100
$R_{\max}$	number of rounds	200
P	probability selected as CH	0.1
E_0	initial energy of a node	0.5 J
E_{TX} $(d < d_0)$	transmission energy of a node	50 nJ$\cdot$bit^{-1}
E_{RX}	receiving energy of a node	50 nJ$\cdot$bit^{-1}
E_{DA}	data aggregation energy	5 nJ$\cdot$bit^{-1} message
ϵ_{fs}	energy dissipation on free space	10 pJ$\cdot$bit^{-1} $\cdot$ m^{-2}
ϵ_{mp}	energy dissipation of multi-path delay	0.0013 pJ $\cdot$bit^{-1} $\cdot$ m^{-4}
Packets	packet size	1000 bits
α, β, and γ	threshold values	0.3333

The probability selected as CH was 0.1 and the transmission and receiving the energy of nodes was 50 nJ$\cdot$bit^{-1}, and the energy dissipated in free space was 10 pJ $\cdot$ bit^{-1} $\cdot$ m^{-1}. The implementation plan for the improved fault tolerance multipath routing (MRP-FT) protocol showed the number of sensor nodes in the network (Figure 6).

The dark blue nodes donate data that was currently communicated with other nodes, while the dead nodes were the maximum and degrade the performance of the network due to the wrong choice of CHs'.

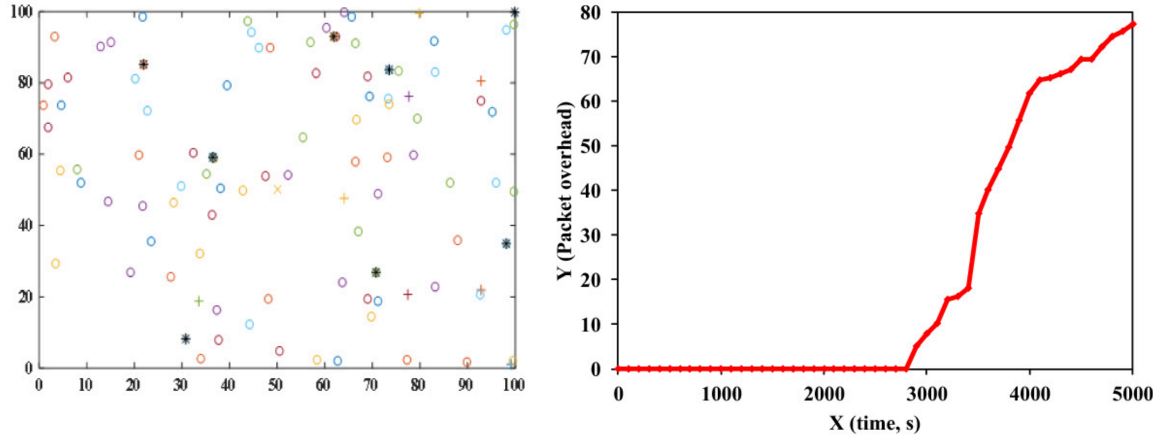

Figure 6. Deployment of the proposed network without modulation technique (left) and the time dependence of the packet overhead with the existing PSO-FT (right)

Figure 6 illustrates that packet overhead is the number of extra packets which are transmitted in the network. The bi-plots for routing overhead showed several rounds on the X-axis, while several packets are extra forwarded in the network on the Y-axis. The number of packets which get delayed in the network describes the delay in Figure 7.

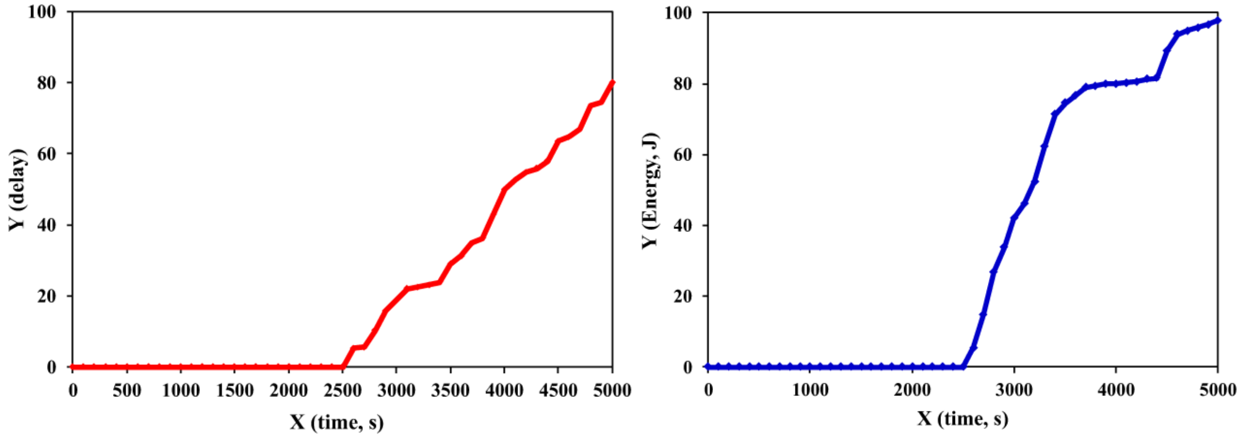

Figure 7. Time dependencies of the delay and time with the existing PSO-FT (left), and energy consumption (right) with the existing PSO-based fault-tolerant routing protocol

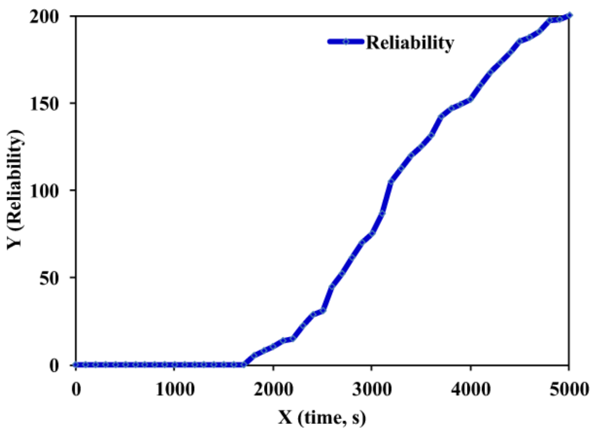

Figure 8. Time dependencies of the reliability by the use of existing PSO-FT (left) and the deployment of the proposed network with an adaptive modulation technique (right)

These relationships illustrate the packet overhead (Y-axis) and time (X-axis) with the existing particle swarm optimisation-based fault-tolerant routing protocol (PSO-FT). The packet heads remain constant during the initial time up to 2500 s and exhibited a sharp increase after that. The delay in the network was high due to the implementation of a simple LEACH protocol. The relationship between energy consumption (Y-axis) and time (X-axis) clearly revealed that the network energy consumption remained constant up to 2300 s, and exhibited a sharp increase thereafter (Figure 7). High energy use after 2300 s has been ascribed to faulty occurrence in the network. The relationship between the reliability (Y-axis, in %) of the existing technique and time (X-axis) showed that the reliability of the existing Boltzmann learning technique was less with increasing time due to fault occurrence (Figure 8).

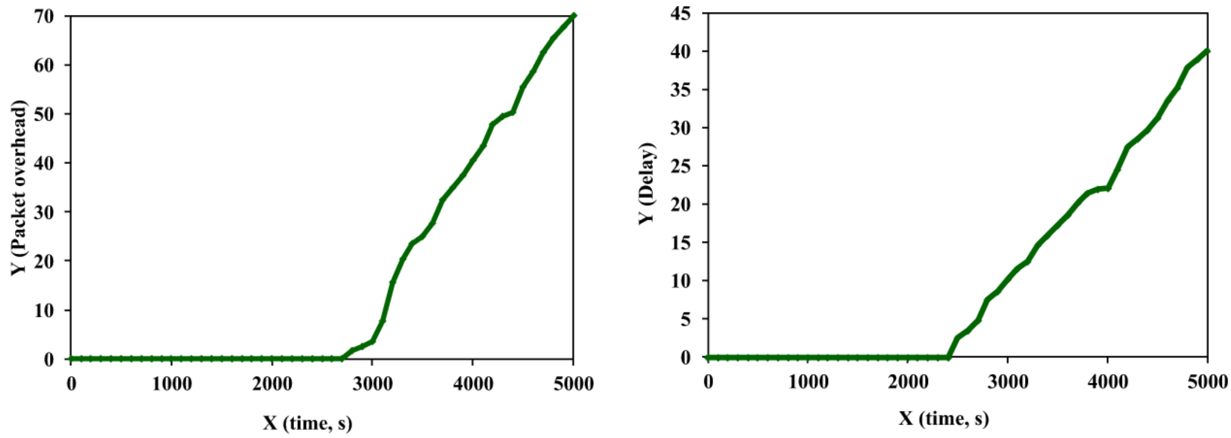

Figure 9. Time dependencies of the packet overhead using a new pack overhead with a proposed MRP-FT (left) and the delay with a proposed MRP-FT (right)

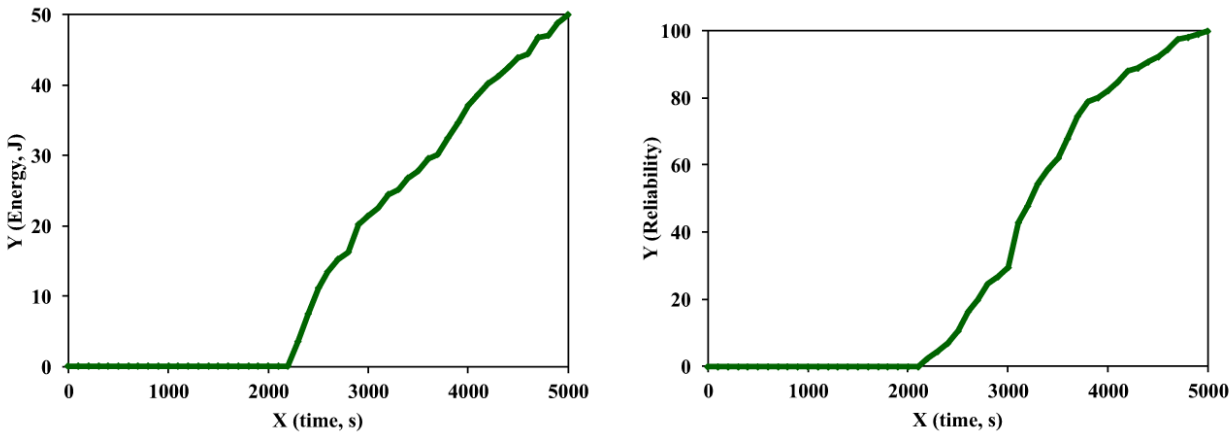

Figure 10. Time dependencies of the energy consumption with a proposed MRP-FT (left) and the relationship between reliability by the use of proposed MRP-FT (right)

5.2. Deployment of the network with an adaptive modulation technique

The implementation plan for the improved fault tolerance multipath routing protocol (MRP-FT) showed that sensor nodes were deployed in the network and the dead nodes were reduced as compared with the low energy adaptive clustering hierarchy (LEACH) protocol (Figure 8). The MRP-FT-based selection of CHs significantly reduced the bit error rate (BER) which helps increase the network lifetime. Results revealed that the packet overhead increased with an increase in the time using the proposed adaptive modulation technique for CH selection (Figure 9). The delay of the adaptive modulation technique

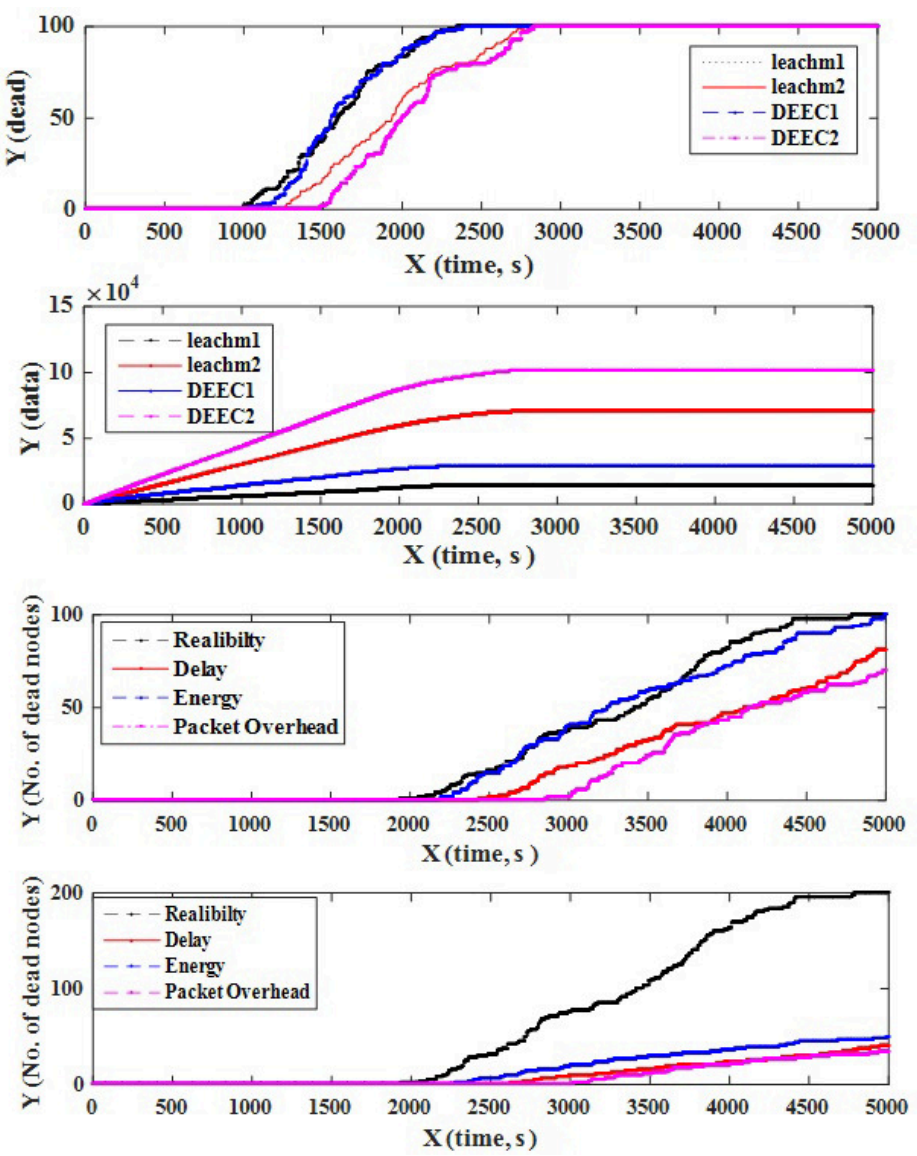

Figure 11. Comparative assessment of reliability, energy consumption and packet overhead with the existing PSO-based routing algorithm and newly proposed MRP-FT

(MPR-FT) with adaptive modulations (on the Y-axis) and a number of rounds (on the X-axis) showed that the delay was considerably decreased by 22 packets, compared with the existing PSO-FT.

Figure 10 illustrates the energy consumption (on Y-axis, in J) with a proposed adaptive modulation technique (MRP-FT) in relation to time (on X-axis). These results indicate that the energy consumption was substantially reduced by 15 J (ca. 38.5%) due to the implementation of the proposed MRP-FT, compared with the existing protocol PSO-FT. These results are highly encouraging as compared with the results of Akhtar et al. [2], who reported that RSSI algorithm is capable of enhancing energy efficiency by only ca. 17% more than the TOSSIM simulator. While comparing the proposed LEACH-CS with the existing LEACH-C, Hady et al. [15] reported an extended network lifetime by ca. 35% and minimizing the end-to-end delay of data by ca. 50%, compared with LEACH-C. The comparison of conventional LEACH and the improved dynamic clustering and distance aware routing (DDAR) algorithm which uses two-stage hierarchical clustering viz. CHs and SCHs offer ca. 15.5% energy saving compared with the LEACH protocol [35]. The results of the present investigation, therefore, highlight the superiority of the proposed MRP-FT algorithm over a dynamic DDAR protocol in terms of the energy efficiency of WSN.

Table 3. Selected simulation parameters used in MRP-FT and LEACH protocols

Parameter	Description	Value
$X_m \times Y_m$	area of the network	$100 \times 100\ \mathrm{m}^2$
N	number of nodes	100
$R_{\max}$	number of rounds	200
P	probability selected as CH	0.1
E_0	initial energy of the node	0.5 J
$E_{TX}(d < d_0)$	transmission energy of a node	$50\ \mathrm{nJ} \cdot \mathrm{bit}^{-1}$

The reliability of the proposed MRP-FT was considerably higher by ca. 12% as compared to PSO-FT-based routing algorithm (Figure 10 and Table 3). Figure 11 showed the comparative assessment of the existing Boltzmann learning and newly proposed adaptive modulation technique (MRP-FT) using reliability, delay, energy consumption and packet overhead [36]. These results show the better performance of the newly proposed MRP-FT compared with the existing PSO-FT (Table 3). Results show that a newly proposed algorithm deployed only 65 packet overheads, 7 packets less compared with the existing algorithm (72 packets). These results revealed that the newly MRP-FT proposed increased the lifetime of WSN, compared with the existing Boltzmann learning algorithm.

6. Conclusions

These results revealed the overwhelming significance of the newly proposed Fault tolerance multipath routing (MRP-FT) protocol for increased energy efficiency by ca. 15 J (ca. 38.5%) over the existing low energy adaptive clustering hierarchy (LEACH) protocol. The proposed algorithm deployed a uniform clustering approach to enhance the packet overhead of 7 packets (ca. 10.8%) than the existing protocol. Nonetheless, the ca. 12% increase in reliability was achieved with the implementation of MRP-FT protocol with a considerable delay of 18 packets emphasizing that network lifespan was prolonged efficiently with the proposed algorithm. The study outcomes would be of high significance in enhancing the energy efficiency of wireless networks and helping solve the energy cost problem in data gathering WSNs.

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