



Energy Efficient Dynamic Cluster Head and Routing Path Selection Strategy for WBANs

Roopali¹ · Rakesh Kumar¹

Published online: 25 January 2020
© Springer Science+Business Media, LLC, part of Springer Nature 2020

Abstract

Wireless Body Area Networks, a new promising technology, have the competence to reform healthcare and contribute ubiquitous health monitoring services to patients both at homes and hospitals. WBAN comprises of low power sensor nodes that communicate based on radio frequency communicational technologies. Sensor nodes are either wearable or implantable (beneath the skin). However, it is difficult to recharge or replace the devices that are used to sense the body parameters. Thus, energy consumption and prolonged lifetime of the networks is a major concern and more energy efficient routing protocols for WBANs are required. We have proposed a routing protocol based on GA for WBANs which is efficient in terms of energy efficiency and network lifetime. Cost function is defined on the basis of residual energy and distance parameter so that the near by nodes are selected in a cluster which makes ideal cluster distribution and reduces energy consumption. The proposed algorithm focuses on Inter-BAN communication. The simulation results of the proposed protocol are compared with previously known schemes in terms of different parameters, such as energy efficiency, network lifetime, throughput, packet delivery ratio and average delay and have shown the enhanced performance. Also, the proposed scheme has enhanced energy optimization by 28–29% with respect to the existing schemes.

Keywords Energy efficiency · Clustering · Cluster head selection · Routing · Routing protocols · Routing path · Sensors · Ubiquitous healthcare · Wireless body area networks

1 Introduction

The chronic diseases are responsible for 71% of deaths globally and 53% of deaths in India as per the survey of World Health Organization (WHO) [1]. As the society is becoming more health conscious, most of the diseases can be fought with the amalgamation of health and information technology. This is actually useful for a society with traditional health

✉ Roopali
roopalipunj31@gmail.com

Rakesh Kumar
raakeshdhiman@gmail.com

¹ Department of Computer Science and Engineering, National Institute of Technical Teachers Training and Research, Chandigarh, India

practices and infrastructure. With the advancement of sensing devices and communicational technologies, WBANs are capable of early diagnosis of diseases and can improve the quality of life by providing health facilities to the patients without visiting the doctor. However, several challenges such as energy efficiency, QoS, fault tolerance, usage of low power communicational technologies due to SAR, interference, dynamic network topology, managing heterogeneous data etc. are hindrances in their reliable and trustworthy adoption [2–6]. Despite of the aforementioned challenges, it is expected that wearable health device users will reach 65mn by 2023 all over the world as both the developed and developing countries focus on digital health [7]. Wearables have both medical and non-medical applications and can help population of all age groups equally on account of independent living. Modern lifestyle, inclination of society towards health and fitness and revolutionary devices have enforced people to imbibe technological health practices.

WBANs manifest Sensor Analyst Systems (SAS) as shown in Fig. 1 and constitute of biomedical sensing devices that sense various physiological parameters and data can be transmitted to a remote server from where the data is easily accessible to medical fraternity, doctor, care taker, family members, health insurance companies etc. This can provide the patient with real-time feedback and prescription from the doctor. Also, the data can be analysed before disseminating it to the end users for prediction and early detection of abnormal conditions.

WBANs require longer network lifetime as sensor nodes are energy constrained and can not be easily recharged or replaced. WBANs have frequent topological changes and higher mobility due to low transmit power of sensing devices, so already existing protocols for Ad-hoc Networks and WSNs are not suitable for WBANs [8]. Energy consumption of sensors is negligible during data acquisition, minimum during data processing and maximum during communication [9]. Hence, energy management during communication is important for providing longer network lifetime. Sensor nodes deplete their energy soon if direct communication is utilized whereas indirect communication via intermediate nodes can save energy to some extent. Thus, the cluster based routing protocols play vital role for energy management by selecting the best path to transmit data from source to the sink node via cluster heads and the intermediate nodes.

In this paper, we have proposed a dynamic cluster head and routing path selection protocol using multi-objective genetic algorithm to forward data packets from source to sink

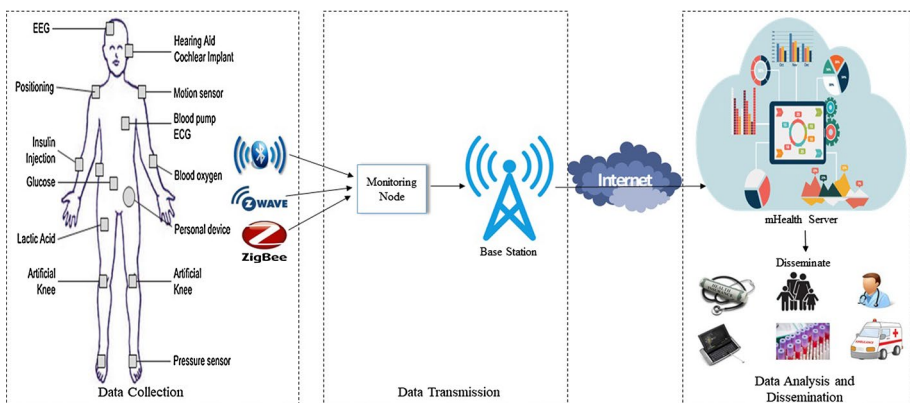


Fig. 1 General framework for sensor analyst systems [4]

node for in-door hospital scenario. The simulation results of the proposed protocol are evaluated and compared with the cluster based routing protocols like Anybody [10], HIT [11, 12], SECA-M [13], OCER [14], EERP [15]. The proposed routing protocol has been simulated using MatLAB simulator and its performance is evaluated in terms of total time taken to build clusters, overall energy consumption, network lifetime, packet delivery ratio, residual energy, throughput and average delay. The obtained results exhibit that the proposed scheme yields better results in terms of chosen parameters by using multi-objective GA to dynamically select cluster head.

The proposed algorithm is unique as it balances load both at the cluster head as well as at the cluster members so that the sensor nodes can retain their residual energy for a longer time period. The significance of proposed scheme is that it provides efficient and reliable communication with optimized energy utilization in the network. Relevance of the proposed scheme is to minimize energy consumption and maximize network lifetime accounting to adequate usage of residual energy, sense radius and load balancing for transmission of desired data from source to sink. Thus, it provides continuous data sensing by WBANs for longer time period and provides ubiquitous health monitoring.

Rest of the paper is organized as follows. Section 2 describe pros and cons of few cluster based routing protocols. Section 3 formulates the problem for designing the proposed protocol. Section 4 evaluates performance of the protocol and discusses the results obtained after simulation. Section 5 concludes the paper and presents the future direction.

2 Related Work

This section presents the concise overview of WBANs and different cluster based routing protocols proposed by various researchers.

Wireless Body Area Network (WBAN); the term first coined in 2001 by Van Dam et al. [16], is defined by IEEE 802.15 (Task group 6) as a real-time, wireless, short-range communication standard consisting of low power devices for communicating in and around human body for various medical and non-medical applications [3, 17, 18]. WBANs have applications in both medico and non-medico domains. With reference to medical applications, WBANs can allow the patients to be in their natural environment and follow routine activities while measuring physiological data. The patient need not visit the doctor in person and helps in reducing hospital cost and improving quality of life as well [2, 3, 5, 8, 19–21]. Also, WBANs have non-medical applications in entertainment, consumer electronics, virtual reality, gaming for skill, educational enhancements, smart homes and item tracking [22–24].

In [10], the authors proposed a self organizing routing protocol, namely Anybody, that starts by dividing the network into clusters and then it explores the most efficient routing path from each source node to remote sink node. It has high energy consumption. Random nodes are selected as cluster heads and the cluster building process is either periodic or event driven. In [11, 12], the authors proposed a Hybrid Indirect Transmission protocol that divides the network into clusters and utilizes cluster heads for indirect transmission so that number of transmissions to base station are reduced. Therefore, HIT greatly helps in reducing energy consumption and network delay.

In [25], the authors proposed an Adaptive Multihop tree-based Routing (AMR) protocol. Cluster heads are selected forming a tree like structure using fuzzy logic and improves network performance in terms of throughput and energy consumption. Also, this protocol is

able to extend network lifetime by balancing out energy consumption. In [13], the authors proposed an energy efficient routing protocol that uses uniform clustering and forms a hierarchical tree like structure to select cluster head amongst the nodes. This reduces the data transmission distances between nodes, and hence the energy consumption is reduced. It balances the network load amongst the cluster heads and enhances network lifetime.

In [26], the authors proposed a cluster based routing scheme for WBANs that constructs clusters on the basis of residual energy. They have considered both inter and intra-WBAN communication. However, they have not considered packet delivery ratio. In [27], the authors proposed a fuzzy based clustering routing protocol. It is energy efficient and uses direct transmission between source and sink node depending upon location of sensor node. The node near to the coordinator node is selected as the cluster head. It has high transmission overhead. It uses fuzzy logic to select the cluster heads.

In [28], the authors proposed an energy efficient routing scheme (EERS) which has a tree like structure that utilizes multi-hop transmissions in WBANs. It establishes an energy efficient end-to-end path from source to sink as well as adaptively choose transmission power for sensor nodes. It has high transmission overhead.

In [29], the authors proposed semiautonomous adaptive routing (SEA-BAN) protocol that evenly distributes the energy amongst the sensor nodes. It is a cluster-based routing protocol that utilizes features of both direct transmission as well as multi-hop transmission methods, depending on the remaining energy level of the nodes. In [30], the authors proposed a routing protocol that maximizes the throughput and minimizes energy consumption. The authors presented a multi-objective problem. Cluster heads are selected at random and it has trade-off between transmission overhead and end-to-end packet delay.

In [31], the authors proposed a stable dynamic forward-connected routing protocol (SDFR protocol) which is completely self-organized. In this protocol, energy, forward-connected range and stability are considered. However, cluster head selection is static. In [14], the authors proposed two algorithms, viz., an optimized cost effective routing protocol (OCER) and an Extended OCER that uses Genetic Algorithm for transmitting data from source to sink via most optimal route selection. It also considers inter-BAN communication. The proposed protocol is energy efficient however does not consider cross layer interactions.

In [15], the authors proposed routing protocol for WBANs which is energy efficient. It supports mobility and sets priority for data while transmitting. The cost function of the proposed scheme finds variations in distance between source and sink using random walk mobility model. Also, it processes only critical data at sensor level. Data is categorised on the basis of priorities which depends on the condition of a patient. Thus, only critical data is forwarded for reduced energy consumption.

In [32], authors proposed a reliable, stable and efficient network for WBASN which is energy efficient. Two parameters are used in objective function to select the forwarder node. Multi-hopping reduces the distance of data communication and saves energy consumption.

In [33], the authors have proposed a task offloading scheme for WBANs with an aim to handle the mobility-aware resource intensive applications. This helps to transfer resource extensive computations and energy consumption from the user devices to mobile computing servers.

In [34], the authors proposed Self-organized Dynamic Clustering (SDC) scheme for a scenario where multiple WBANs communicate that lessens interference and improves the QoS. It gives focus to spectrum allocation for multiple WBANs. It transfers data packets from source to sink via cluster head that have low privacy and high reliability.

In [35], the authors have proposed cluster based security schemes for secure routing of data from source to sink using metaheuristic techniques such as PSO and Fuzzy logic to select the trusted node to transmit data. In [36], the authors have proposed a scheme using firefly algorithm to detect the trusted nodes to transfer data from source to sink via cluster head and encryption is performed at the sink node from where the data is transferred to the hospital database.

In [37], the authors have built a cloud-WBAN framework over open source cloud simulator CloudSim. The authors have integrated cloud computing and WBANs. It gives an optimal scheme for providing resources efficiently to fluctuating demands of WBANs to deliver real-time health services to the users.

3 Problem Formulation

This section elaborates the proposed algorithm of dynamic cluster head and routing path selection for energy efficient routing in WBANs. Also, the network model, energy model, pathloss model are explained in the subsequent subsections that are used to illustrate the performance of the proposed scheme. The proposed model optimizes the performance in terms of overall energy consumption, residual energy, network lifetime, average delay, packet delivery ratio and throughput. The existing routing protocols have not focused on load balancing at cluster head which leads to early depletion of residual energy and ultimately decreases the network lifetime for both direct and multi-hop communication between the source nodes and remote base station.

The proposed scheme utilizes GA to select cluster head. As GA is an NP-Hard problem [38], it randomly selects from the initial population and optimizes the results globally. GA is evolutionary algorithm that converges and provides with global optimal solutions so it can make an optimal choice for the purpose of selecting cluster head. GA uses random search procedure to search the optimal solutions in the parameter space [39]. GA requires an objective function for optimization of parameters and reach an optimal point [40]. In the proposed scheme, the goal is to cluster the nodes around the selected cluster heads so that the physical size of clusters are not widely dispersed. Objective function, based on two parameters, viz., residual energy and sense radius, is optimized to achieve the aforementioned objectives. To select the next population, application specific genetic operators are used.

3.1 WBAN Model

This section explicates the network model, energy model and pathloss model for the proposed protocol.

3.1.1 Network Topology and Model

In this paper, we have considered an indoor hospital environment for tier-1 WBAN communication and data collection procedure as shown in Fig. 1. The hospital building may consist of n number of floors with m number of patients on each floor. We assume here that each patient has only one body sensor placed on it. Therefore, the communication can be amongst the sensors attached on different patients. We have considered n patients each with one sensor on the body, set $S = S1, S2, S3...Sn$ denoting the total population. As each

sensor node has same power and communicational abilities, the communication can be point to point (P2P) for establishing multihop paths so that the data can be transferred from source to sink via intermediate nodes instead of the direct data transfer from source to sink. The latter method consumes more energy. Thus, the sensor nodes are divided into clusters and a node with optimal value of cost function is elected as a cluster head.

3.1.2 Energy Model

It is observed from the related literature that energy consumption of sensor nodes is negligible during data acquisition, minimum during data processing but maximum during data communication. Thus, more focus is given by the researchers on energy consumption during communication. Maximum of the energy of sensor nodes is consumed during data transmission, reception, processing and cluster formation [41]. This is represented as First Order Radio model [42, 43]. Energy consumption is calculated with the help of the following equations, energy consumed by transmitter and amplifier is shown in Eq. 1 at the transmitter end whereas energy consumed by the receiver is shown in Eq. 2 during reception at the receiving end. Values used by energy parameters in energy model are given in Table 1.

$$\begin{aligned} E_{Tx}(p, r) &= E_{Telec}(r) + E_{Amp}(p, r) \\ E_{Tx}(p, r) &= E_{elec} * r + \epsilon_{Amp} * r * p^2 \end{aligned} \quad (1)$$

where E_{Tx} is total energy consumption at the transmitter end, E_{Telec} is energy consumed by the transmitter, E_{Amp} is energy consumed by the amplifier for transmitting r -bit long message at p distance.

$$\begin{aligned} E_{Rx}(r) &= E_{Relec}(r) \\ E_{Rx}(r) &= E_{elec} * r \end{aligned} \quad (2)$$

where E_{Rx} is total energy consumption at the receiver end, E_{Relec} is energy consumed by the receiver, for receiving r -bit long message at p distance.

Table 1 Values of parameters used in energy model

Symbols	Description	Values
N_{cyc}	No. of clock cycles	0.97×10^6
C_{avg}	Average capacitance	22 pF
V_{sup}	Supply voltage to sensor	2.7 V
f	Frequency	191.42 MHz
x	Transmit packet size	2 kb
I_0	Leakage current	1.196 mA
E_{amp}	Energy dissipation: power	100 pJ/bit/m ²
E_{Txelec}	Energy dissipation	50 nJ/bit/m ²
I	Current	8 mA
T	Active time	1 ms
T_{tr}	Time between two consecutive packets	300 ms
V_t	Thermal voltage	0.2 V
T_{sens}	Sensing time duration	0.5 ms
I_{sens}	Current during sensing	25 mA

Another form of energy consumption during data processing in WBANs is during switching (E_s) of the modes, i.e., from sleep mode to wake mode or vice versa and due to current leakage (E_l). Total energy consumption for processing packet of size x bits by each sensor node, E_{proc_x} , per round is given by Eq. 3.

$$E_{proc_x}(x, N_{cyc}) = xN_{cyc}C_{avg}V_{sup}^2 + xV_{sup}\left(I_0e^{k_p\frac{V_{sup}}{V_t}}\right)\left(\frac{N_{cyc}}{f}\right) \quad (3)$$

where I_0 is the leakage current, f is sensor frequency, N_{cyc} is the number of clock cycles per task, C_{avg} is the average capacitance, V_t is the thermal voltage, and k_p is a constant. Total energy consumption by the cluster head (CH), $E_{proc_{CH}}$, per round is given by Eq. 4.

$$E_{proc_{CH}}(h_1, x, N_{cyc}) = h_1E_{proc_N}(x, N_{cyc}) \quad (4)$$

where N_{cyc} is the number of clock cycles per task, C_{avg} is the average capacitance switched per cycle.

3.1.3 Path Loss Model

If the power of Electromagnetic waves decreases gradually due to absorption, propagation, diffraction, reflection through a medium, it is termed as pathloss. In the case of WBANs, sensor nodes are placed on human body so the waves are either absorbed by the body, propagate through the body, reflect or refract around the body. Pathloss is mainly dependant on distance through which the EM waves have to travel and the frequency at which they travel. The pathloss PL_d , at distance d between nodes and the frequency is given in Eq. 5.

$$PL(d) = PL(d_0) + 10n\log\left(\frac{d}{d_0}\right) \quad (5)$$

where $PL(d_0)$ is the path loss in dB at a reference distance d_0 . Reference distance is calculated using Eq. 6 and n is the path loss exponent which varies for free space and placement of sensor on human body. The average pathloss model of the human body has parameters $d_0 = 10$ cm and $PL(d_0) = 35.2$ dB.

$$PL(d_0) = 10 * \log(4\pi * d_0f) * c \quad (6)$$

Here, f represents frequency of operation, and c represents the speed of light. Pathloss is affected by the body movements due to change in distance between sensor nodes. If the value of pathloss deviates from its mean value, then it is known as shadowing effect. The total pathloss considering shadowing factor may be given by Eq. 7.

$$PL = PL(d) + X\sigma \quad (7)$$

Here, $X\sigma$ is a shadowing factor in dB. It follows gaussian distribution of random variables. It has zero mean and standard deviation.

3.2 Routing Scheme

This section describes the phases of the proposed protocol which optimizes the energy consumption and network lifetime of WBANs. The proposed routing protocol is explained below in the subsequent sections and a block diagram which depicts the series of steps

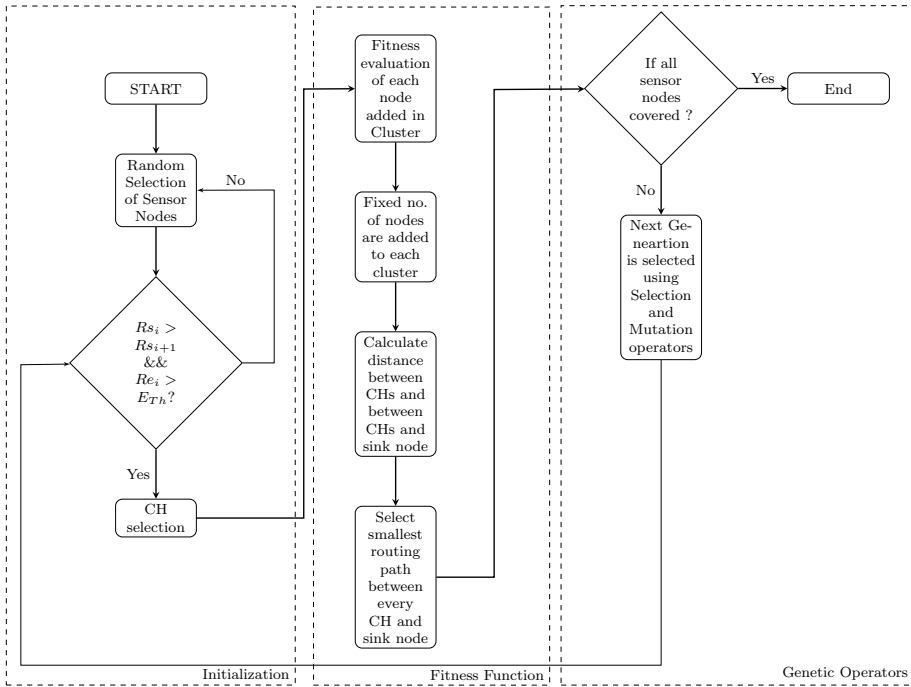


Fig. 2 Block diagram of proposed scheme

that are followed by the proposed protocol is shown in Fig. 2 [39]. Figure 5 also shows the working of one round of the proposed scheme. After one round of the proposed routing protocol, there are two possibilities. First, some nodes may not be considered as we have an upper limit on the number of cluster members. Second, new nodes may enter the network. The process repeats for the left out and new nodes forming the second round of the proposed scheme.

3.2.1 Cluster Setup Phase

The initial population describes the total number of sensor nodes in the network initialized with fields as ID, residual energy, location coordinates and sensing range. Residual energy of a sensor node defines the communicational abilities of the nodes. The nodes are then added to the clusters to avoid direct communication from source to sink as it consumes more energy. As all the nodes have same power and communicational abilities, we add equal number of nodes to every cluster to achieve load balancing at the cluster head. Thus, the number of clusters is known beforehand. If N is the total population and n defines the cluster members as specified by the users, then, the optimal number of clusters required to cover the whole network is given by N/n . The constraints for inclusion of the nodes in any

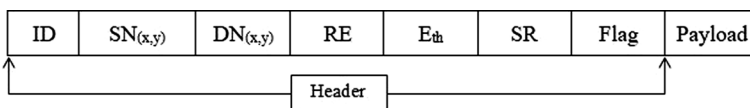


Fig. 3 Hello packet

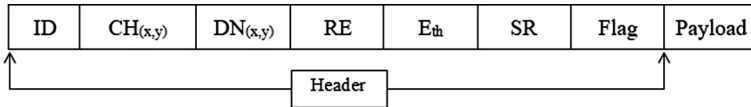


Fig. 4 Cluster head hello packet

cluster is checked at global level. Thus, there is no need to check conditions at each level which reduces the overhead. The optimal value of n accounts to load balancing at cluster head and managing the physical size of clusters. CH maintains a routing table on the reception of hello packets from other members of the cluster.

The Figs. 3 and 4 show the hello packets of the sensor nodes and the cluster heads respectively. The hello packet contains the information regarding node id (ID), location coordinates ($SN_{x,y}$, $DN_{x,y}$, $CH_{x,y}$), residual energy (RE), threshold value (E_{th}), sense radius (SR), flag bit and the payload. If flag bit is set then the node is a cluster head otherwise a cluster member. Whenever the CH receives a packet it stores information as ID_{s_i} , RE_{s_i} , SR_{s_i} , X_{s_i} , Y_{s_i} in routing table. The routing tables are updated either when a node is at its dead point, i.e., about to shred its residual energy below a particular threshold or a new node is to be added in the network. The initialization of the network is explained in Algorithm 1 (Fig. 5).

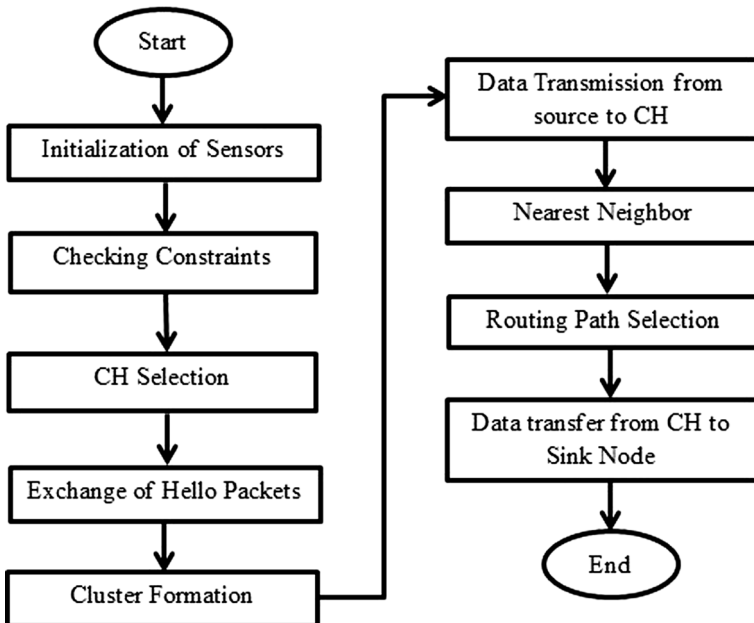


Fig. 5 Workflow chart of round 1 of the proposed algorithm

Algorithm 1 Initializing Network

```

1: Select a set of initial population  $N$ 
2: Maintain the information of each node  $i$  in  $N$  as
3:  $ID \leftarrow ID_i$ 
4:  $RE \leftarrow RE_i$ 
5:  $SR \leftarrow SR_i$ 
6:  $Xloc \leftarrow Xloc_i$ 
7:  $Yloc \leftarrow Yloc_i$ 
8: for ( $i = 1; i \leq N; i++$ ) do
9:   if ( $Re_i \geq E_{Th}$ ) then
10:     $ValidNodes \leftarrow i$ 
11:   end if
12: end for
13: define  $n$ 
14: no. of clusters =  $N/n$ 
15: for ( $i = 1; i \leq ValidNodes; i++$ ) do
16:   Arrange  $i$  in descending order of  $RE$ 
17:   Select top  $n$  nodes as  $CH$ 
18: end for

```

3.2.2 Fitness Evaluation

Multi-objective fitness function is applied to determine the quality of all the valid nodes that are capable of communicating with other nodes as well as the sink node. Fitness function is defined by two parameters, i.e., residual energy R_e and sensing range R_s of the nodes and is represented in terms of knapsack problem as given by Eq. 8.

$$f = \sum_{i=1}^n R_s_i R_e_i$$

subject to (8)

$$R_s_i \leq R_{s_{i+1}}$$

$$R_e_i \geq E_{Th}$$

The proposed scheme first selects the best nodes as the head of clusters in the network and then finds the best route to transmit data to the sink node while considering the optimization of energy consumption and network lifetime. The cost function assigns weights, w_1 and w_2 to two parameters residual energy RE and sense radius S_r respectively to provide relative importance to the parameters as given by Eq. 9. The various values of weights give different cluster heads and routing path. However, the optimal solution is given by node with least value of cost function.

$$Cost = w_1 \left| \frac{RE_{max} - RE_x}{RE_{max}} \right| + w_2 \left| \frac{Sr_{max} - Sr_x}{Sr_{max}} \right|$$

(9)

subject to

$$w_1 + w_2 = 1$$

where $0 \leq w_1 \leq 1, 0.5 \leq w_2 \leq 1$.

As an output of the fitness function, n best nodes are selected as the cluster heads (CH). The nodes which lie in the sensing range of the cluster head, i.e. near to CHs, are added to the respective clusters so that the cluster is not widely dispersed. If the cluster is widely dispersed, the nodes at the far end of the cluster are likely to shred their energy soon as compared to the other nodes. The distance between the nodes is calculated using Eq. 10. Cluster members transmit data to CH as soon as the clusters are formed after the transmission and reception of hello packets. Routing table is updated dynamically. The cluster head node has the maximum residual energy so there is less probability of its failure and being declared as a dead node. As all the nodes are homogeneous and have same power, cluster head has to keep track of the second best node in terms of residual energy with the help of routing table. Before it completely shreds its energy, it sends the location coordinates of the second best node to the cluster members. Cluster member then sends the hello packet to the new CH so that there is no interruption in the communication. Also, it sends a control message consisting of its residual energy to the second best node and informs the node to act as cluster head. This process is explicated in Algorithm 2.

$$d = \sqrt{(CH_x - n_x)^2 + (CH_y - n_y)^2} \quad (10)$$

Algorithm 2 Cluster Formation

Input: Cluster Member (CM), Cluster Head (CH), Hello packet received by CH from CM

- 1: Repeat \forall ValidNodes i
 - 2: **for** ($i = 1; i \leq n; i++$) **do**
 - 3: Calculate d_{min} which defines the minimum distance of every node i to every CH
 - 4: **end for**
 - 5: Add i to Cluster with minimum d_{min} till Cluster has n CM
 - 6: **if** i is not added in any cluster then calc 2nd min distance **then**
 - 7: Add i to Cluster with minimum d_{min} till Cluster has n CM
 - 8: **end if**
 - 9: CH maintains the information of each CM after it receives hello packets as
 - 10: $ID \leftarrow ID_i$
 - 11: $RE \leftarrow RE_i$
 - 12: $SR \leftarrow SR_i$
 - 13: $Xloc \leftarrow Xloc_i$
 - 14: $Yloc \leftarrow Yloc_i$
 - 15: **if** $RE_{ch} \leq E_{th}$ **then**
 - 16: Find the node second to CH in terms of RE from the routing table and it becomes the new CH
 - 17: CH sends the $(Xloc, Yloc)$ of new CH to the cluster members
 - 18: Cluster members send hello packets to new CH and the communication starts
 - 19: **end if**
-

3.2.3 Routing Path Selection

After the cluster formation, all the cluster members transmit data to their respective cluster heads. Each cluster head serves equal number of sensor nodes so they equally shred their

energy (ignoring the data processing cost). However, if each cluster head sends data to the sink node on its own, it is likely to shed its energy soon. We have proposed a routing path selection scheme as explained in Algorithm 3 that selects a routing path amongst the cluster heads for transmitting the data to the sink. Each cluster head will share their location coordinates, residual energy with the rest of the cluster heads thus forming a graph of $n + 1$ vertices where n is the total no. of cluster heads in the network and 1 for the sink node. Now, there are two possible path costs, firstly the direct path cost between the cluster head and the sink node and secondly the indirect path cost between the cluster head and the sink node via intermediate nodes as given in Eqs. 11 and 12. The routing path is selected in such a way that the cluster head which is far from the sink node will send the data to cluster head nearer to it and it will in turn forward the data to the cluster head or the sink node whichever is nearer.

$$d_{iS} = \begin{cases} C_{iS} & \text{if } k = 0 \\ \min(C_{iS}, C_{ik} + C_{kS}) & \text{if } k \geq 1 \end{cases} \quad (11)$$

$$(12)$$

By this method the cluster heads are not over burdened to transmit data to the remotely located sink node as multi-hop communication is used to transmit data to the sink node. The paths are selected based upon the minimum distance between the nodes of the graph formed. This helps in reduction of energy consumption of the cluster heads as well as increases the network lifetime.

Algorithm 3 Routing Path Selection

Input: Location coordinates of CH (x,y)

Output: Shortest routing path from every CH to sink

Variables: CH is a set containing all cluster heads, k is the intermediate vertex between the respective CH and the sink, d_{iS} is the cost of the distance between the cluster head and the sink.

```

1: Repeat  $\forall$  CH  $i$ 
2: Set CH contains all the cluster heads in the network,
    $CH = 1, 2, 3, \dots, n$ 
3: For any pair of vertices  $(i, S) \in CH$ , consider all paths
   from  $i$  to  $j$  whose intermediate vertices,  $k$ , are all drawn
   from  $1, 2, \dots, n$ .
4: for  $(i = 1; i \leq n; i++)$  do
5:   if  $k == 0$  then
6:      $d_{iS} = C_{iS}$ 
7:   else
8:      $d_{iS} = \min(d_{iS}, d_{ik} + d_{kS})$ 
9:   end if
10: end for

```

4 Results and Discussions

In this section, we validate the performance of our proposed protocol by simulation as well as by analytical proof in the subsequent subsections.

4.1 Simulation Results

The proposed protocol is simulated using a simulation model in Matlab and we have compared our proposed protocol with Anybody [10], HIT [11, 12], SECA-M [13], OCER [14], EERP [15]. We assume that the same sensor nodes are employed on the patients. We have considered the indoor hospital environment. The proposed algorithm has two different phases, namely, cluster setup and routing path selection. To illustrate the effectiveness of the proposed protocol various parameters such as total time taken to build clusters, overall energy consumption, network lifetime, throughput, residual energy, packet delivery ratio and average delay are considered.

As we want to measure the effective performance of the proposed scheme, we want to free ourselves from lower layer considerations. Sensor nodes communicate using CSMA/CD with power-level that is selected apriori. We have used the IEEE 802.11 MAC protocol, nevertheless, it has little or no impact on the simulation results as we dont count specific IEEE 802.11 layer 2 messages and we only log the activity of our proposed protocol. We have considered two different scenarios. Scenario 1 sends static number of packets and scenario 2 sends variable number of packets from source to sink. The description of simulation platform and simulation parameters are listed in Tables 2 and 3 respectively. The description of parameters for Genetic Algorithm are shown in Table 4. The assumptions for simulating the proposed scheme are as follows:

- Sink node is fixed and located far from the sensor nodes.
- Sensor nodes are randomly distributed in the sensing area.
- All sensor nodes are in capacity to send data to the sink node.
- All sensor nodes are homogeneous in behaviour and energy restrained.
- Only CH nodes can communicate with sink node.
- CM nodes can monitor data and directly send data to the CH node, or through the non-CH hop nodes.
- Sensor nodes cannot be recharged. A node continues to sense and transfer data until its energy is depleted and is considered as an outlier (dead node).

In cluster setup phase, first phase of the proposed protocol, as given in Algorithm 2 is used to create clusters and find the cluster head of each cluster for indirect communication with the sink. Direct communication from source to sink will lead to early depletion of residual energy of sensor nodes. Thus, the proposed protocol uses indirect communication from source to sink via cluster head. The Fig. 6 shows the total time taken to construct the clusters and elect cluster head by Anybody, HIT, SECA-M, EERP and the proposed scheme. The proposed protocol takes less time as compared to other protocols because the cluster formation begins as soon as the node detects another node in its sensing range and hello messages are sent later to start the communication and maintain the routing table.

The Fig. 7 depicts energy consumption by each protocol for scenario 1 and Fig. 8 depicts energy consumption by each protocol for scenario 2. In the proposed scheme, residual energy based cost function is used to optimize the energy consumption. After applying GA to all nodes and the nodes with maximum value of residual energy is chosen as the cluster head in order to cover the whole network. Equal number of nodes within the sense radius of each cluster head are chosen as cluster members so that the

Table 2 Description of simulation platform

Items	Specifications
Operating system	Windows 10 Professional 64 bits
Processor	Intel(R) i5 CPU @ 2.20 GHz
Memory	6 GB RAM
Design tool	MatLab 2016a

Table 3 Simulation parameters

Parameters	Values
Electronics energy (Eelec)	50 nJ/bit
Communication energy (fs)	15 pJ/bit/m ²
Communication energy (mp)	0.0015 pJ/bit/m ⁴
Minimum threshold value of energy	3 J
Packet size	2000 bits
Sensing area (M M)	500 m 500 m
Position of sink node (x, y)	(500, 500)
Number of sensor nodes (N)	100, 200, 500, and 1000

physical size of cluster is not widely dispersed. This way cluster heads are alive for longer period of time as it balances load on each cluster. It is seen from the the graphs that the proposed scheme consumes less energy than the other schemes. Figure 9 shows the overall energy comparison of the protocols.

Figure 10 shows the energy consumption for the transmit powers of 25 dBm, – 20dBm, 15 dBm, 10 dBm and – 5 dBm respectively. The graph shows the same trend as the proposed scheme consumes lesser energy. Due to high transmit powers less packets are forwarded through the intermediate nodes which is responsible for more energy consumption. However, the proposed scheme uses multihop communication and more packets are forwarded through the intermediate nodes. Thus, enhancing network lifetime and reducing energy consumption.

Network lifetime is defined as the time till which the first node dies. It is also given as no. of iterations per round which defines the number of living nodes. Comparison of the total no. of nodes in the network and the no. of rounds till the first node dies is shown in Fig. 11. The proposed scheme has longer network lifetime as compared to the other schemes due to multihop communication and selecting optimized routing path for data transmission to the sink. Figure 12 shows the comparison of total time taken and the

Table 4 Genetic algorithm parameters

Parameter	Value
Maximum iterations	10
Population size	20
Selection strategy	Roulette wheel scheme
Crossover operator	Uniform
Mutation operator	Binary transpose

number of intermediate nodes till the first node dies. We have observed that using the proposed scheme the sensor nodes live for a longer time period.

Figure 13 compares the throughput of various protocols. Throughput is defined as the total number of packets successfully received at the sink node. The proposed scheme achieves higher throughput than the other schemes as the proposed scheme as higher network lifetime so more number of packets can be sent. The more sensor nodes are alive for larger no. of iterations, the more packets can be transmitted to the sink node. Increased stable conditions result in the maximum packets sent to sink node with response to the whole network. Figure 14 compares the throughput of various schemes at power levels of 25 dBm, -20dBm, 15 dBm, 10 dBm and -5 dBm respectively. The proposed scheme achieves consistent throughput at various levels due to selection procedure of the next node in the routing path.

Routing path is selected between the cluster heads and sink which acts as a backbone to send the data from cluster head to the sink. Direct communication from cluster head to sink can shred the energy of cluster heads very early which can lead to untimely selection of second cluster head in a cluster. Thus, a routing path is selected. Figure 15 shows the overall time taken to select the routing path and Fig. 16 shows the time taken to select routing path with varied intermediate nodes. It is seen that the proposed scheme takes less time to select routing path with different intermediate nodes.

Information packets are discarded whenever the capacity of the communication link is not suitable for transmission and reception of data during the communication process. The communicating links have varying quality due to the mobile nature of the networks. This problem effects the energy consumption parameter significantly. Thus, the no. of packets sent by the sensor nodes are not equal to the no. of packets received by sink. Figure 17 shows average packet drop which is less as compared to existing routing protocol techniques.

Propagation delay is the time taken by the data to move from source to sink, i.e., the distance between the source and the sink divided by the speed of the signal expressed in milliseconds (ms). As in the proposed scheme the clusters are not widely dispersed so the successful data transmission from the sensor nodes is to be done for the nearest

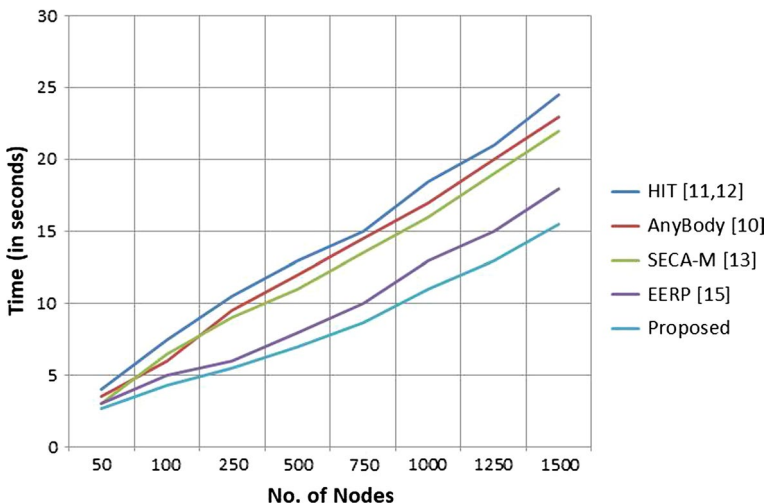


Fig. 6 Total time taken to construct the clusters

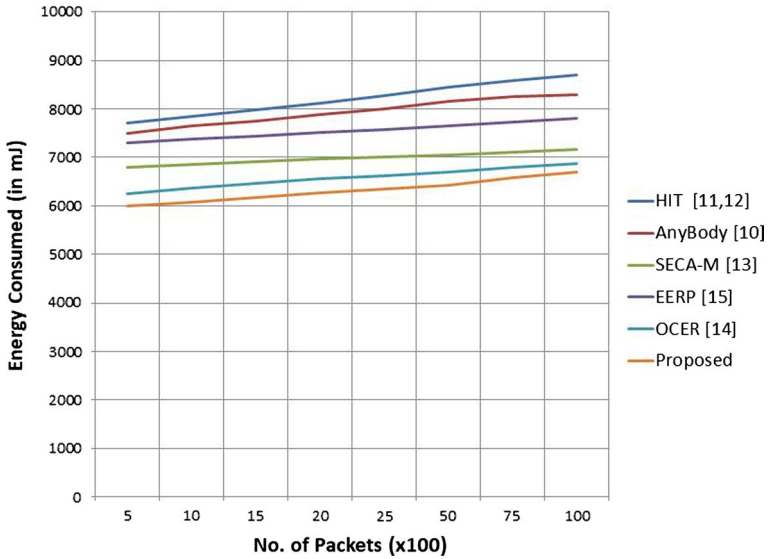


Fig. 7 Energy consumption for variable no. of packets

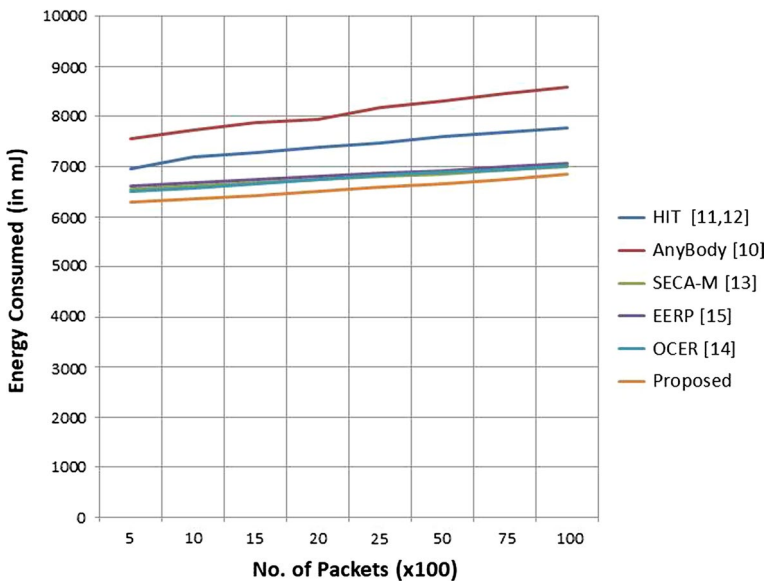


Fig. 8 Energy consumption for fixed no. of packets

node. Thus, there is a decrease in the delay. Figure 18 shows the comparison of average propagation delay between the proposed scheme and the existing schemes.

Residual energy is the remaining energy in the sensor node. After each round the overall energy expenditure (in joules (J)) is measured. The proposed protocol dissipates low energy so the sensor nodes have extra power at the end of the execution. The

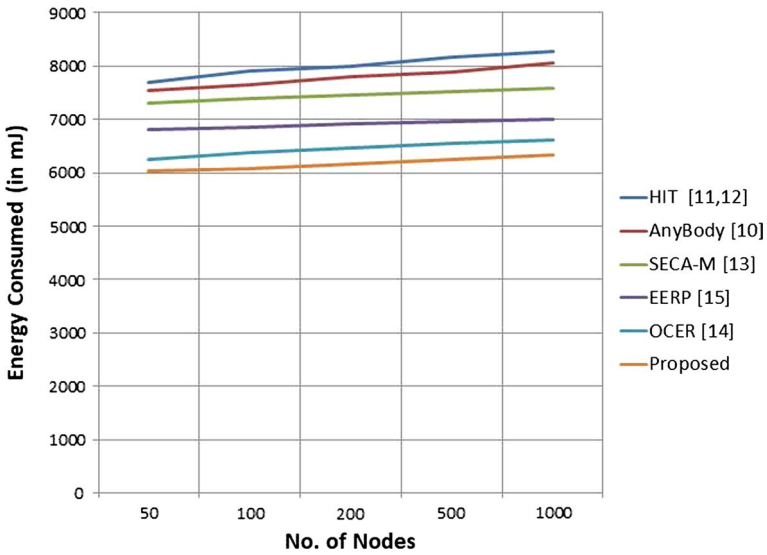


Fig. 9 Overall energy consumption

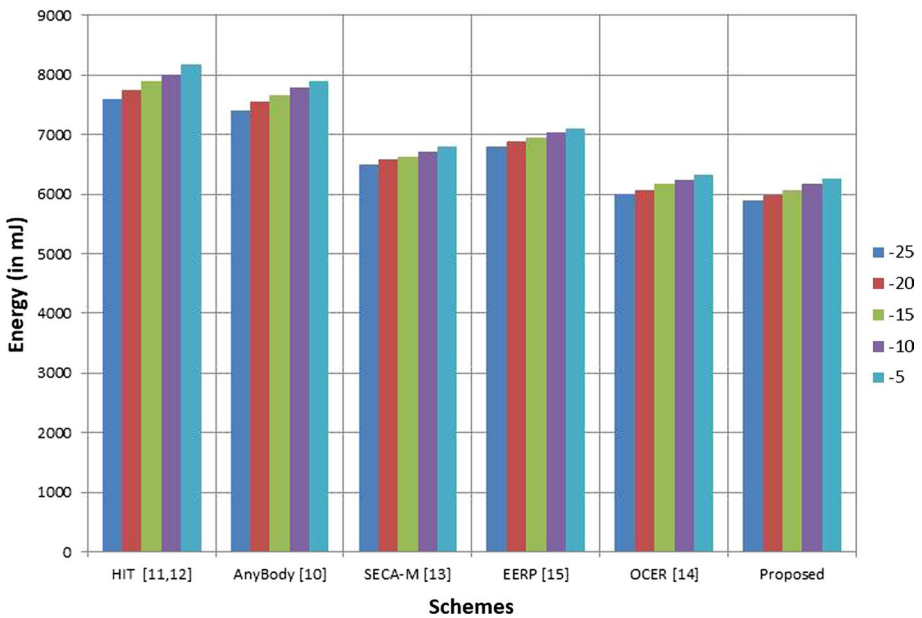


Fig. 10 Energy consumption at various power levels

average residual energy with the increasing number of iterations is as shown in Fig. 19. The minimum value of cost function identifies the node that can be used for transmission of data successfully.

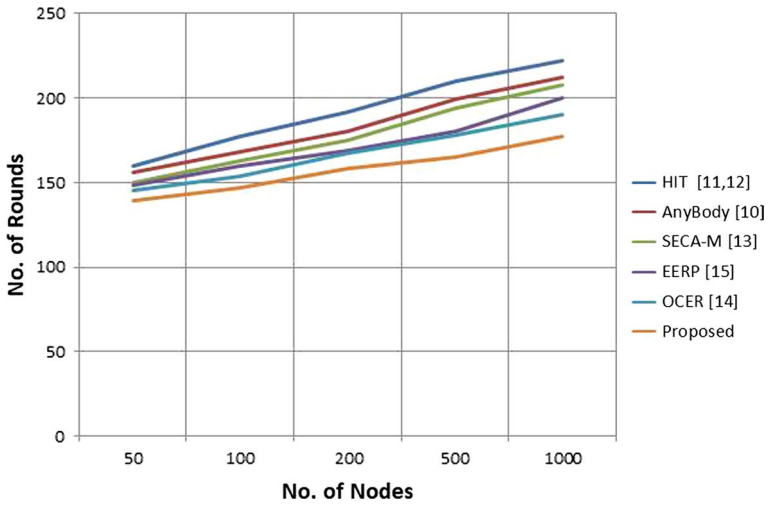


Fig. 11 Network lifetime

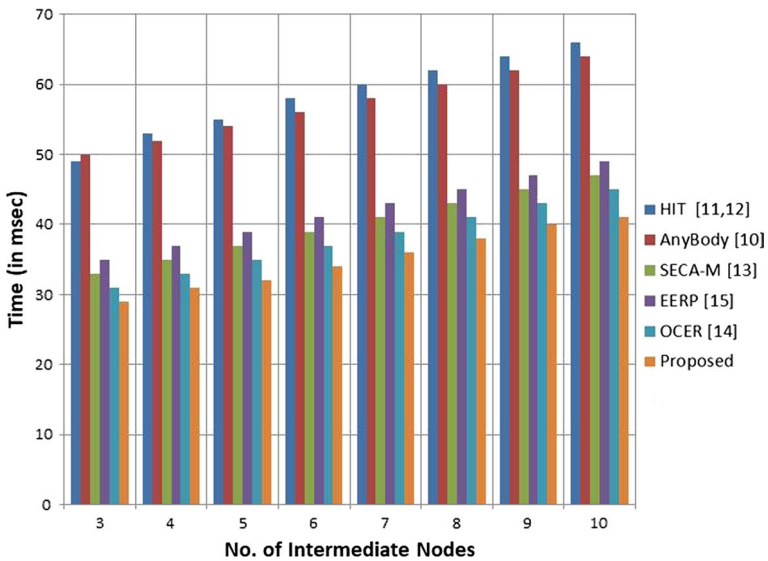


Fig. 12 Network lifetime with varied intermediate nodes

4.2 Analytical Results

In this section, we discuss the analytical results of the proposed algorithm with respect to performance parameters such as load balancing, communicational overhead, energy optimization and fault tolerance.

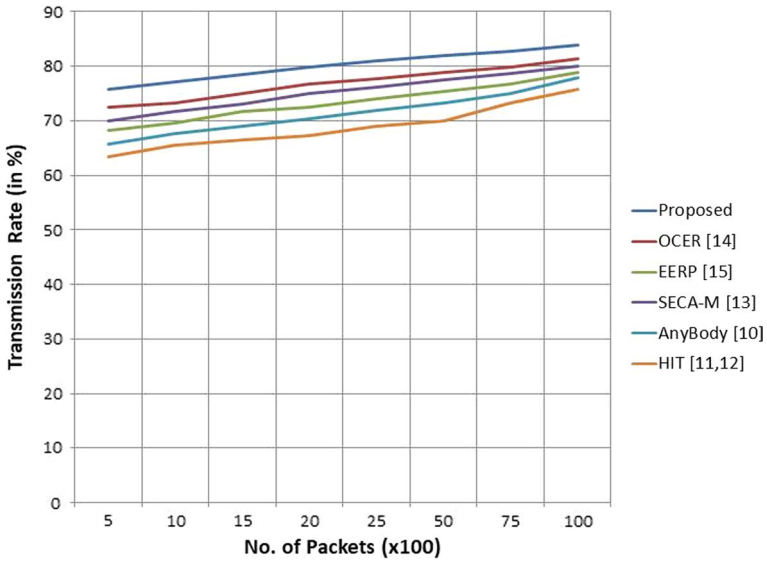


Fig. 13 Throughput

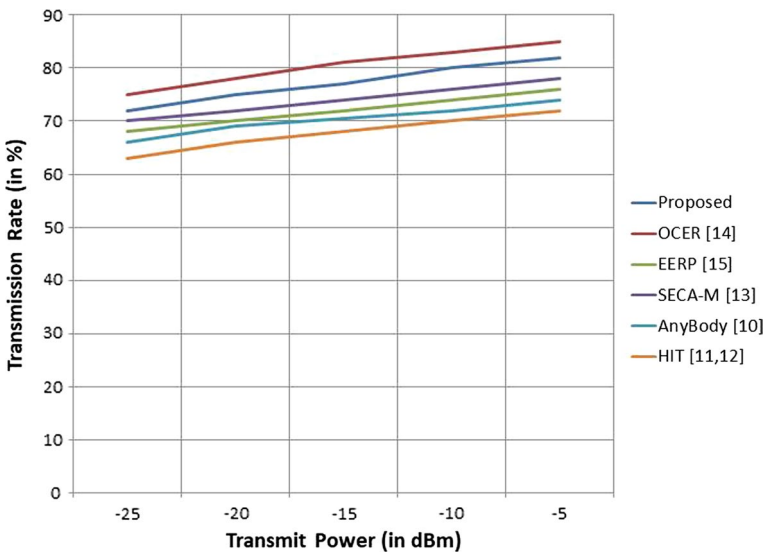


Fig. 14 Throughput at varied power levels

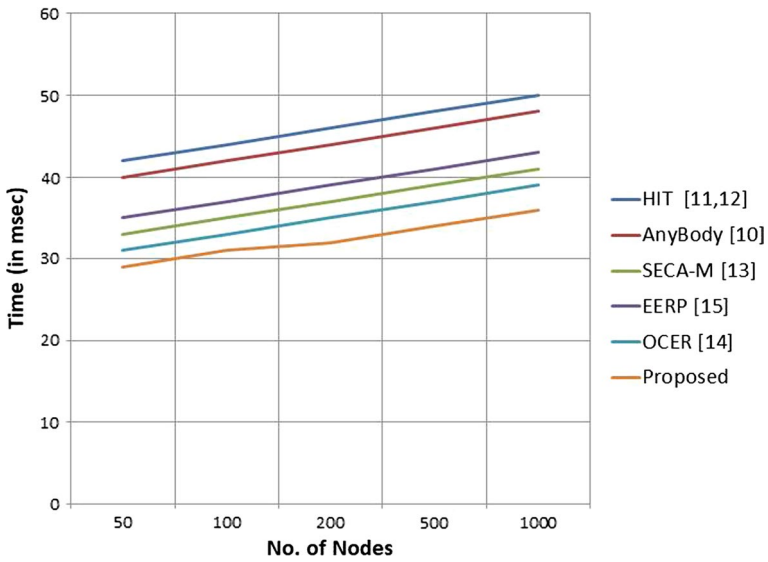


Fig. 15 Overall time taken to select routing path

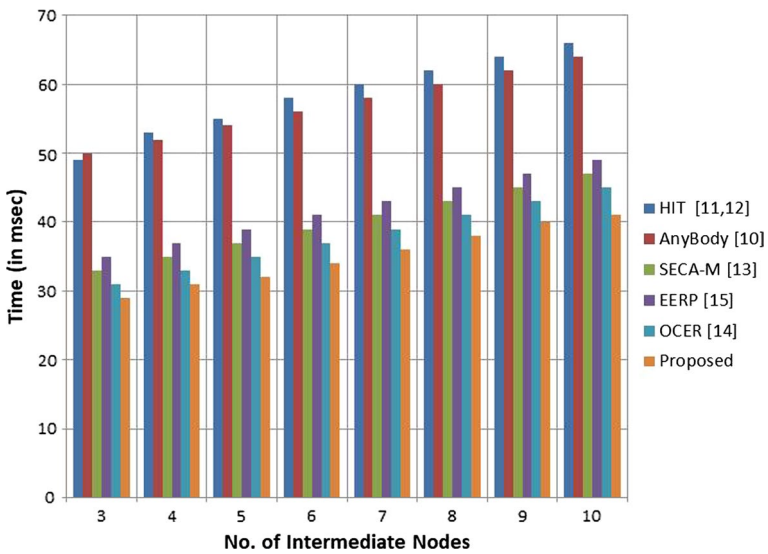


Fig. 16 Time taken to select routing path with varied intermediate nodes

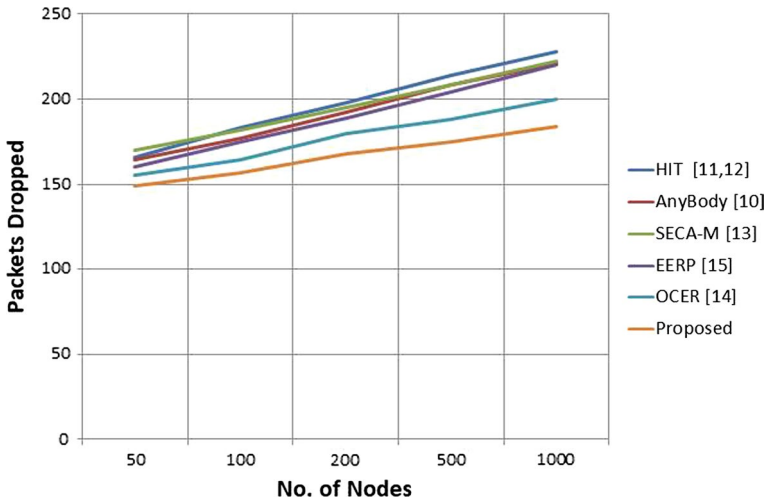


Fig. 17 Average packet delivery ratio

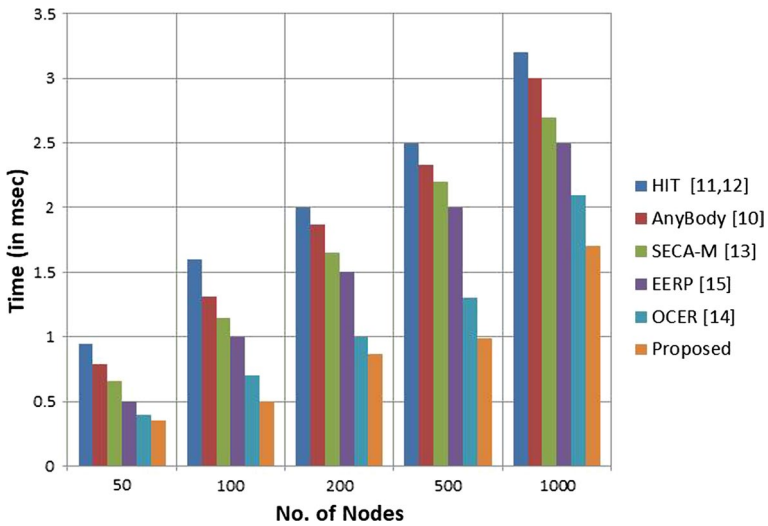


Fig. 18 Propagation delay

Lemma 1 The optimal number of cluster heads N_{ch} in the whole network depends on the total number of nodes N in the network and the number of cluster members n as $N_{ch} = N/n$.

Proof The proposed protocol considers equal number of cluster members in each cluster, so the optimal number of cluster heads required depends on total number of nodes in the network N and the number of cluster members n to cover the entire network. These values are pre-defined so the number of cluster head required to cover the whole network is known beforehand as shown in Eqs. 13 and 14.

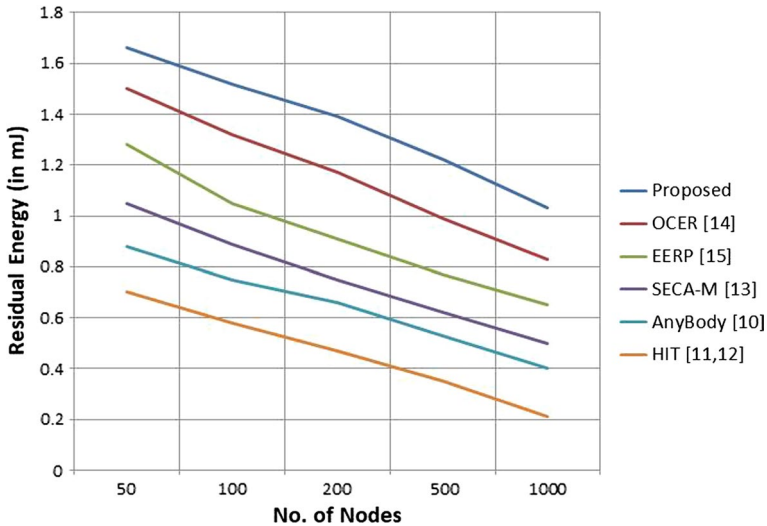


Fig. 19 Residual energy

$$n_{ch} = \begin{cases} N/n & \text{if } n \bmod N == 0 \\ \lceil N/n \rceil & \text{otherwise} \end{cases} \quad (13)$$

$$(14)$$

The average case occurs when n is sufficiently large with respect to the total number of nodes and less number of clusters are built whereas the worst case occurs when n is small and large number of clusters are required to cover the whole network. Also, large clusters will increase the physical size of the cluster. After the election of cluster heads, routing path amongst the cluster heads is selected to transmit data from source to sink. Routing path allows to have multi-hop transmissions from cluster head to sink so that cluster head which is far from sink need not send the data via direct transmissions. This helps the proposed protocol to attain load balancing at each cluster head by maintaining equal number of cluster members and physical size of cluster. Ultimately it helps to optimize energy consumption. The existing schemes are not focused on achieving load balancing at the cluster head which drains off the energy early as compared to the proposed scheme. Also, each cluster head in the existing schemes serves different number of cluster members which leads to more number of transmissions. Thus, more energy is consumed in the case of existing schemes and network lifetime decreases. \square

Lemma 2 *Let be the communicational overhead in the network which depends upon the number of control messages and re-transmissions of the packets.*

Proof It depends upon the number of control messages and re-transmissions. The proposed protocol has reduced communicational overhead as all the conditions for the nodes are checked at global level and not at each phase of the proposed scheme. The communication starts after the transmission and reception of control messages which are sent only once. This reduces the overhead as well as saves energy of the respective nodes. There are lesser

number of re-transmissions as the packets are successfully received at the sink node due to multi-hop transmission scheme. Also, reduced packet drop ratio helps in reducing the number of re-transmissions. \square

Lemma 3 Let E be the energy consumption of the network which is proportional to distance between source and sink, transmission rate and network lifetime as $E \propto dt_r/l$.

Proof The energy consumption E of the network is directly proportional to distance between source and sink d . The data sensed by the source nodes is to be successfully transmitted to the remote sink node. The distance is calculated as the euclidean distance using the location coordinates of the nodes. Also, the energy consumption is directly proportional to transmission rate t_r which includes the communicational overhead as well as the re-transmissions if the packets are dropped. It is indirectly proportional to network lifetime l because if the energy consumption increases nodes will die soon which decreases the network lifetime as shown in Eq. 15.

$$E = \frac{a \left| \sqrt{(CH_x - n_x)^2 + (CH_y - n_y)^2} \right| + b|t_r|}{c|l|} \quad (15)$$

subject to

$$a + b - c = 1$$

where $0 \leq a \leq 1, 0 \leq b \leq 1, 0.5 \leq c \leq 1$.

The proposed scheme is energy efficient as it uses multi-hop transmissions from source node to cluster head and cluster head to sink node. Thus, reducing the distance to be covered in a single transmission. Also, helps in reducing the rate of re-transmissions as the proposed scheme has less communicational overhead and less number of packets are dropped due to longer network lifetime and throughput. \square

Lemma 4 The proposed protocol is fault tolerant and reliable.

Proof The proposed protocol is fault tolerant and reliable as cluster head maintains a routing table which is updated dynamically. It stores the information regarding node identity ID , residual energy RE , sense radius SR , location coordinates (X_{loc}, Y_{loc}) of each cluster member. When the residual energy of the cluster head is less than or equal to the prescribed threshold (below which nodes are considered dead), it selects the second best node in terms of residual energy from routing table. Cluster head sends the location coordinates of the selected node to the cluster members. Cluster members send hello packets to the new node for initiating the communication process without hindrance. Thus, increasing network lifetime. Also, the proposed protocol is reliable as the communication does not hinder even if the cluster head drains off its energy. \square

5 Conclusion and Future Scope

In this paper, we propose an energy efficient cluster head and routing path selection protocol for WBANs. As WBANs are designed to continually sense the biomedical data, preserving the energy of each node can help increase the lifetime of the network. The

proposed protocol uses a cost function based on residual energy and sense radius to determine the cluster head. The node with maximum value of residual energy is selected as the cluster head and the cluster members are within the sense radius of the cluster head so that the cluster is not widely dispersed. Thus, it balances load at the cluster head which further optimizes the energy consumption and network lifetime. The proposed protocol is based on GA for global optimization of the cost function. The performance of the proposed protocol is compared with anybody, HIT, SECA-M, OCER and EERP in terms of energy consumption, network lifetime, residual energy, packet delivery ration, average delay and throughput. The simulation results illustrate that the proposed scheme could achieve upto 28–29% energy savings which enhances its network lifetime as well. Thus, the proposed scheme increases the effectiveness of WBANs used for ubiquitous health monitoring.

In the future, the proposed scheme can be extended for considering node mobility, body movements and cross layer interactions for complex network scenarios.

References

1. World Health Statistics. (2018). <http://apps.who.int/iris/bitstream/handle/10665/272596/9789241565585-eng.pdf>. Retrieved December 14, 2018.
2. Movassaghi, S., Abolhasan, M., Lipman, J., Smith, D., & Jamalipour, A. (2014). Wireless body area networks: A survey. *IEEE Communications Surveys & Tutorials*, *16*(3), 1658–1686.
3. Latré, B., Braem, B., Moerman, I., Blondia, C., & Demeester, P. (2011). A survey on wireless body area networks. *Wireless Networks*, *17*(1), 1–18.
4. Punj, R., & Kumar, R. (2019). Technological aspects of WBANs for health monitoring: A comprehensive review. *Wireless Networks*, *25*(3), 1125–1157.
5. Ullah, S., Higgins, H., Braem, B., Latre, B., Blondia, C., Moerman, I., et al. (2012). A comprehensive survey of wireless body area networks. *Journal of Medical Systems*, *36*(3), 1065–1094.
6. Touati, F., & Tabish, R. (2013). U-healthcare system: State-of-the-art review and challenges. *Journal of Medical Systems*, *37*(3), 9949.
7. Iot Medical Devices Market. <https://www.marketsandmarkets.com/PressReleases/iot-medical-device.asp>. Retrieved November 24, 2018.
8. Movassaghi, S., Abolhasan, M., & Lipman, J. (2013). A review of routing protocols in wireless body area networks. *Journal of Networks*, *8*(3), 559–575.
9. Effatparvar, M., Dehghan, M., & Rahmani, A. M. (2016). A comprehensive survey of energy-aware routing protocols in wireless body area sensor networks. *Journal of Medical Systems*, *40*(9), 201–228.
10. Watteyne, T., Augé-Blum, I., Dohler, M., & Barthel, D. (2007). Anybody: A self-organization protocol for body area networks. In *Proceedings of the ICST 2nd international conference on body area networks* (pp. 1–6).
11. Culpepper, J., Dung, L., & Moh, M. (2003). Hybrid indirect transmissions (HIT) for data gathering in wireless micro sensor networks with biomedical applications. In *Proceedings of 18th IEEE annual workshop on computer communications (CCW 2003)* (pp. 124–133).
12. Culpepper, B. J., Dung, L., & Moh, M. (2004). Design and analysis of hybrid indirect transmissions (HIT) for data gathering in wireless micro sensor networks. *ACM SIGMOBILE Mobile Computing and Communications Review*, *8*(1), 61–83.
13. Chang, J.-Y., & Ju, P.-H. (2014). An energy-saving routing architecture with a uniform clustering algorithm for wireless body sensor networks. *Future Generation Computer Systems*, *35*, 128–140.
14. Kaur, N., & Singh, S. (2017). Optimized cost effective and energy efficient routing protocol for wireless body area networks. *Ad Hoc Networks*, *61*, 65–84.
15. Navya, V., & Deepalakshmi, P. (2018). Energy efficient routing for critical physiological parameters in wireless body area networks under mobile emergency scenarios. *Computers & Electrical Engineering*, *72*, 512–525.
16. Van Daele, P., Moerman, I., & Demeester, P. (2014). Wireless body area networks: Status and opportunities. In *Proceedings of XXXIth IEEE general assembly and scientific symposium (URSI GASS)* (pp. 1–4).

17. Hanson, M. A., Powell, H. C., Jr., Barth, A. T., Ringgenberg, K., Calhoun, B. H., Aylor, J. H., et al. (2009). Body area sensor networks: Challenges and opportunities. *Computer*, 42(1), 58.
18. Chen, M., Gonzalez, S., Vasilakos, A., Cao, H., & Leung, V. C. (2011). Body area networks: A survey. *Mobile Networks and Applications*, 16(2), 171–193.
19. Zhang, Y., Sun, L., Song, H., & Cao, X. (2014). Ubiquitous WSN for healthcare: Recent advances and future prospects. *IEEE Internet of Things Journal*, 1(4), 311–318.
20. Abidi, B., Jilbab, A., & Haziti, M. E. (2017). Wireless sensor networks in biomedical: Wireless body area networks. In *Europe and MENA cooperation advances in information and communication technologies* (pp. 321–329). Cham: Springer.
21. Cavallari, R., Martelli, F., Rosini, R., Buratti, C., & Verdone, R. (2014). A survey on wireless body area networks: Technologies and design challenges. *IEEE Communications Surveys & Tutorials*, 16(3), 1635–1657.
22. Tobón, D. P., Falk, T. H., & Maier, M. (2013). Context awareness in WBANs: A survey on medical and non-medical applications. *IEEE Wireless Communications*, 20(4), 30–37.
23. Castillejo, P., Martinez, J.-F., Rodriguez-Molina, J., & Cuerva, A. (2013). Integration of wearable devices in a wireless sensor network for an e-health application. *IEEE Wireless Communications*, 20(4), 38–49.
24. Cao, H., Leung, V., Chow, C., & Chan, H. (2009). Enabling technologies for wireless body area networks: A survey and outlook. *IEEE Communications Magazine*, 47(12), 84–93.
25. Ortiz, A. M., Ababneh, N., Timmons, N., & Morrison, J. (2012). Adaptive routing for multihop IEEE 802.15. 6 wireless body area networks. In *Proceedings of 20th international conference on software, telecommunications and computer networks (SoftCOM)* (pp. 1–5).
26. Afsana, F., Jahan, N., & Kaiser, M. (2015). An energy efficient cluster based forwarding scheme for body area network using nano-scale electromagnetic communication. In *Proceedings of IEEE international WIE conference on electrical and computer engineering (WIECON-ECE)* (pp. 491–494).
27. Singh, K., & Singh, R. K. (2015). An energy efficient fuzzy based adaptive routing protocol for wireless body area network. In *Proceedings of IEEE UP section conference on electrical computer and electronics (UPCON)* (pp. 1–6).
28. Liang, L., Ge, Y., Feng, G., Ni, W., & Wai, A. A. P. (2014). A low overhead tree-based energy-efficient routing scheme for multi-hop wireless body area networks. *Computer Networks*, 70, 45–58.
29. ul Huque, M. T. I., Munasinghe, K. S., Abolhasan, M., & Jamalipour, A. (2013). Sea-ban: Semi-autonomous adaptive routing in wireless body area networks. In *Proceedings of 7th international conference on signal processing and communication systems (ICSPCS)* (pp. 1–7).
30. Rajagopalan, R. (2016). Energy efficient routing algorithm for patient monitoring in body sensor networks. In *Proceedings of IEEE 13th international conference on wearable and implantable body sensor networks (BSN)* (pp. 141–146).
31. Li, C., Zhang, Z., Xiong, F., & Liu, Q. (2015). An efficient and stable route protocol in wearable body networks. In *Proceedings of first international conference on computational intelligence theory, systems and applications (CCITSA)* (pp. 104–109).
32. Khan, R. A., Mohammadani, K. H., Soomro, A. A., Hussain, J., Khan, S., Arain, T. H., et al. (2018). An energy efficient routing protocol for wireless body area sensor networks. *Wireless Personal Communications*, 99(4), 1443–1454.
33. Liao, Y., Han, Y., Yu, Q., Ai, Q., Liu, Q., & Leeson, M. S. (2018). Wireless body area network mobility-aware task offloading scheme. *IEEE Access*, 6, 61366–61376.
34. Mu, J., Stewart, R., Han, L., & Crawford, D. (2018). A self-organized dynamic clustering method and its multiple access mechanism for multiple WBANs. *IEEE Internet of Things Journal*, 6(4), 6042–6051.
35. Isabel, R., & Baburaj, E. (2018). An optimal trust aware cluster based routing protocol using fuzzy based trust inference model and improved evolutionary particle swarm optimization in WBANs. *Wireless Personal Communications*, 101(1), 201–222.
36. Anguraj, D. K., & Smys, S. (2018). Trust-based intrusion detection and clustering approach for wireless body area networks. *Wireless Personal Communications*, 104, 1–20.
37. Bhardwaj, T., & Sharma, S. C. (2018). Cloud-WBAN: An experimental framework for cloud-enabled wireless body area network with efficient virtual resource utilization. *Sustainable Computing: Informatics and Systems*, 20, 14–33.
38. Chatterjee, M., Das, S. K., & Turgut, D. (2002). WCA: A weighted clustering algorithm for mobile Ad Hoc networks. *Cluster Computing*, 5(2), 193–204.
39. Punj, R., & Kumar, R. (2018). CHS-GA: An approach for cluster head selection using genetic algorithm for WBANs. In M. Auer & D. Zutin (Eds.), *Online Engineering & Internet of Things. Lecture Notes in Networks and Systems* (Vol 22, pp. 28–35). Cham: Springer.

40. Goldberg, D. E. (1989). *Genetic algorithms in search, optimization & machine learning*, 8th edn. London: Pearson Education.
41. Halgamuge, M. N., Zukerman, M., Ramamohanarao, K., & Vu, H. L. (2009). An estimation of sensor energy consumption. *Progress in Electromagnetics Research*, 12, 259–295.
42. Heinzelman, W. R., Chandrakasan, A., & Balakrishnan, H. (2000). Energy-efficient communication protocol for wireless microsensor networks. In *Proceedings of the 33rd IEEE annual Hawaii international conference on system sciences* (pp. 1–10).
43. Datta, N. (2014). Study and design of energy efficient block cipher for wireless body area networks (WBANs).

Publisher's Note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.



Roopali received her B.Tech. in Computer Science and Engineering from GuruNanak Dev University, Amritsar, India and M.E. in Information Technology from Panjab University, Chandigarh, India. At present she is pursuing Ph.D. at National Institute of Technical Teacher Training and Research, Chandigarh, India.



Rakesh Kumar received his B.Tech. in Computer Science and Engineering from Punjab Technical University, Jalandhar, India, M.Tech. in Information Technology from Guru Gobind Singh Indraprastha University, New Delhia, India and Ph.D. in Computer Engineering from N.I.T. Kurukshetra, India in 2004, 2008 and 2015 respectively. At present, he is working as an Assistant Professor in the department of Computer Science and Engineering at NITTTR Chandigarh. He has number of International/National conference/journal publications to his credit. He is also a reviewer of many international journals/conferences. He has guiding/guided many Ph.D. and M.Tech. candidates. His key area of interest includes MANET, VANET, Sensor Networks, Discrete Mathematics Structure.