Energy-efficient clustering and cooperative routing protocol for wireless body area networks (WBAN)

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Abstract.   Wireless Body Area Network (WBAN) may play an important role in real-time health monitoring in the near future. At the same time, WBAN based distant health monitoring is helpful in getting regular health updates and is cost-effective. In WBAN, tiny battery-operated sensors are placed on the human body, and some part of the battery's energy drains during each round of transmission. Therefore, conservation of battery power is an important feature in designing WBAN protocols. The main purpose this work to propose an energy-efficient clustering and cooperative routing protocol, that can be used in the real time health monitoring systems. In the proposed protocol, sensor nodes are divided into two parts, and each part has its own dedicated sink. Nodes within each part elect a cluster head (CH) based on the cost function, and the chosen CH, after aggregation of the data, sends it to the sink. Nodes within each cluster transfer their data to the sink either directly or via a forwarder node, depending on which path has the least energy dissipation. The forwarder node within the cluster will be elected using a forwarder function that depends on distance and residual energy. The solar energy harvesting mechanism is further considered which is helpful in restoring the battery's energy. The proposed mechanism can play an important role in real-time health monitoring in indoor and outdoor environments without the need for battery replacement for a long period of time. Finally, the proposed protocol is compared with recently proposed protocols, and significant improvements are observed in terms of performance metrics.

Keywords.   WBAN; energy efficient; stability period; network lifetime; delay and throughput.

1. Introduction

The most crucial factor to take into account in today's environment is each individual's health [1]. Many medical professionals are accessible to treat patients day and night. Unhygienic food and a polluted environment have led to a rise in the prevalence of diseases [2]. Patients with chronic conditions, such as diabetes, heart disease, high blood pressure, and others, now need to have their health status evaluated on a regular basis, which is expensive [3]. The number of doctors, hospitals, and other medical personnel required to care for the patients would probably increase along with the increase in patients [3]. In addition, patients need to be physically mobile, which could be challenging, and they no longer need to be in the hospital due to activities of daily life. Numerous healthcare organisations, such as the World Health Organization (WHO), encourage the use of WBAN because everyone's health is their top priority [4].

Telemedicine is the use of advanced information technology and communications to provide patients with a variety of healthcare services [5]. Telemedicine enables remote treatment and helps to overcome distance constraints, allowing for better medical access to remote rural regions. Recent developments in wireless communication and microprocessor technology have led to the development of small, sophisticated, wearable sensors for the human body [6]. In WBAN, sensors placed on the human body run on a small battery, and these battery-operated sensors require energy for data transmission and reception. These sensors continuously monitor the vital signs, and, in case of any change in data, updated information is sent to medical personnel for analysis and real-time diagnosis. However, in WBAN [7], ensuring the confidentiality and privacy of medical data is a challenging task. Throughout the last decade, a variety of studies have been done and healthcare systems based on WBAN have been developed. In WBAN, tiny sensors are placed on the human body to sense health-related data, e.g., electrocardiogram (ECG), electroencephalogram (EEG), blood sugar, temperature, etc. In WBAN, sensors have limited memory, computational capacity, and energy supply. One of the main issues in the design of WBAN is the conservation of the sensor's battery energy, which is depleted in each round of transmission and reception. In WBAN, the radio frequency (RF) at the physical layer of sensor nodes has a significant

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impact on energy usage. Furthermore, by adjusting the duty cycle of the RF component, the residual energy of the sensor nodes can be conserved with the help of MAC protocols. Although physical and MAC layer protocols increase network throughput, several additional criteria are not addressed, such as end-to-end packet delivery, addressing strategies, route selection techniques, etc. However, these issues can be resolved at the network layer by efficiently designing the network layer protocol [5–7]. WBAN's attributes and criteria differ from those of WSN, even though it is a subset of WSN. As a result, the WBAN routing protocol's structure is different from that of the WSN. In the design of WBAN routing protocols, a number of important factors, including the heterogeneous nature of the network, energy consumption, temperature, coverage area, mobility, and quality of service, must be taken into consideration.

In WBAN, sensor nodes (SNs) are used to collect data from the surrounding environment and, after processing, generate useful information and send it via wireless channel to other nodes. These nodes can also communicate with the base station (BS) by developing an ad-hoc communication protocol. The BS, also known as a sink, has more memory, computational capacity, and energy supply as compared to normal SNs. This BS further connects to the external world via a network where medical professionals can access the patient's data remotely. The fundamental disadvantage of these small SNs is that they have limited resources, such as battery capacity, which is quickly depleted due to various operations. Repetitive transmission of redundant sensed data in succeeding rounds, as well as re-transmission of data packets, contribute to the rapid depletion of battery energy. Data packets are retransmitted when they are unsuccessfully received at their destination, which is usually owing to path loss and the selection of inefficient paths among the SNs [6, 8]. The energy drain causes SNs to die prematurely, reducing the network's lifetime. The minimum energy consumption is an essential requirement for WBAN design. The objective of this paper is to design an energy-efficient WBAN protocol based on cluster heads and cooperative routing.

1.1 *Motivation and objectives*

The main aim of this research is to design an energy-efficient routing protocol for remote health monitoring using WBAN. The design of such a protocol is a difficult task as it depends on various attributes. In this work, attempts have been made to minimise energy dissipation by using cooperative routing, and for the conservation of battery energy, solar energy harvesting is considered. The main objectives of the proposed work are as follows:

1. Designing an energy-efficient protocol using cooperative routing

2. Inclusion of an energy harvesting scheme for the conservation of battery energy.

1.2 *Research contributions*

In the proposed protocol for energy minimization, various steps are considered. First, nodes that are near the sink transmit data directly to it. The remaining nodes are split into two groups, each of which has a separate sink node. Energy dissipation is reduced when a group of component nodes forms a cluster and elects a cluster head among them to transfer data to a sink. Even within the cluster, nodes either directly transmits to CH or forward via a forwarding mechanism (with the help of forwarding nodes) while selecting the minimum of either of the distances. Finally, in the proposed protocol, various mechanisms are used to minimise energy dissipation during each round of transmission. The novel contributions are as follows:

1. Direct transfer for nodes that are close to the sink
2. Both the cost forwarding function and path distances are considered in next hop selection.
3. Single-hop and multi-hop transmission are chosen based on energy dissipation and the path loss equation.
4. Inclusion of energy harvesting scheme for the conservation of the battery energy.

2. Literature survey

In this section, brief summary of classical and state-of-the-art methods is detailed.

2.1 *Classification of routing protocols*

In WBAN, there are numerous issues that need to be addressed in order to design reliable protocols. Depending on these issues, protocols are classified as:

2.1.1 *QoS routing* In QoS-based routing, quality of service parameters is considered in the design of the protocol. The QoS routing protocol parameters are throughput and delay. The reliability-based protocol improves throughput while minimising delay, while the delay-tolerant protocol ensures packet delivery on time. The details of some of the notable QoS protocols are given in table 1. Ibrahim *et al* [9] considered link quality while considering the forwarding node. In this method, neighbouring links' weights are evaluated, and the link with the highest weight is chosen. However, the main limitation of the work is that it does not consider the energy of the nodes in the evaluation of weights. Ayatollahitafti *et al* [10] considered delay to be the main QoS parameter. In this method, a cost function is derived based on link

Table 1. Classification of WBAN routing protocol.

References	Main feature
QoS routing	
Ibrahim *et al* [9]	Consider link quality in forwarding packets
Ayatollahitafti *et al* [10]	Delay is main QoS parameter
Bangash *et al* [11]	Consider critical data routing
Ababneh *et al* [12]	Guaranteed data streaming
Khan *et al* [13]	Consider reliability of all the paths and choose best
Kaur *et al* [14]	Consider the cost function for next hop selection
Postural movement routing	
Sharma *et al* [15]	Effect of Posture Mobility
Goyal *et al* [16]	Deal with shadow effect due to postural mobility
Sangwan *et al* [17]	Efficient routing in posture movement
Energy-aware routing	
Qu *et al* [18]	Energy-aware Routing
Wang *et al* [19]	Fuzzy Controller Based Energy-aware Routing
Prasad *et al* [20]	Energy-aware Routing with very low power
Khan *et al* [21]	Cost function aware Energy-efficient Routing
Ullah *et al* [22]	Energy efficient reliable routing
Singla *et al* [23]	Energy aware path selection
Temperature-aware routing	
Jamil *et al* [24]	Diffusion of load based on temperature
Jalili *et al* [25]	Temperature-Aware Routing
Kathe *et al* [26]	Temperature-Aware Routing
Miscellaneous roting	
Ahmed *et al* [27]	Energy and Temperature aware routing
Ahmad *et al* [28]	Temperature and Posture Movement aware routing
Nadeem *et al* [29]	Temperature and Posture Movement aware routing
Geetha *et al* [30]	Energy efficient and priority based reliable routing
Ahmed *et al* [31]	Link aware and energy efficient scheme
Ahmed *et al* [32]	Co-operative Link aware and energy efficient scheme
I. Ha [33]	Forwarding function depends on energy and distance
Anwar *et al* [34]	Forwarding function depends on energy, distance and signal quality
Energy harvesting protocol	
Liu *et al* [35]	Throughput maximization using energy harvesting
Khan *et al* [36]	Energy harvested co-operative protocol
Boumaiz *et al* [37]	Energy harvested co-operative protocol
Roy *et al* [38]	Reinforcement learning based energy harvested protocol
Xu *et al* [39]	Reinforcement learning based energy harvested protocol

stability, initial and residual energy, and queue size. However, only one sink is considered, so losses are high and energy consumption falls sharply with number of rounds. Bangash *et al* [11] considered critical data routing as the main QoS parameter, however, link quality and energy are not considered in the calculation. Ababneh *et al* [12] proposed a protocol where data streaming was guaranteed. Khan *et al* [13] and Kaur *et al* [14] considered "best chosen path" and "best next hop selection" as QoS parameters.

2.1.2 *Postural movement routing* The human body's postural mobility has an impact on WBAN communication. Frequent body movement breaks the connectivity between nodes, and extra energy depletion occurs when sensors move away from the sink. Several studies have been conducted a few of them are highlighted in table 1. Sharma *et al* [15], discuss the effect of posture mobility on energy dissipation and various positions of sink node placement; however, the study is very limited. Goyal *et al* [16] deal with the shadow effect due to postural mobility; the K-means clustering algorithm is used for the classification of posture along-with an artificial neural network. However, no solution was proposed for the poor packet delivery ratio due to the movement of the body. Sangwan *et al* [17] discussed the effect of routing on posture movement and developed a cost function based on the residual and average energies of the nodes. However, as the

cost function is independent of distance and improvement in results are minimal.

2.1.3 *Energy-aware routing*

WBAN's battery is small and compact, and thus have limited lifetime. In WABN during transmission and reception, some energy gets consumed and depends on the circuitry, number of bits and distance. Therefore, many energy-aware routing techniques have been proposed to conserve battery power and prolong network lifetime using various mechanism as detailed in table 1. Qu *et al* [18] developed a maximum benefit function by considering, residual energy, transmission efficiency, bandwidth, and hop-count.but due to only having one sink node, energy depletes at a faster rate. Wang *et al* [19] proposed a cost function based on residual energy and link quality, and for the optimization of the cost function, fuzzy logic was used. In this protocol, direct transmission to a sink node is prohibited, so depletion of energy is fast. Prasad *et al* [20] also proposed an energy aware protocol where very low-power transmitters and receivers are used. Khan *et al* [21] proposed an energy aware protocol based on residual energy and distance among the nodes. Ullah *et al* [22] considered various parameters in designing the cost function. This protocol is based on two sinks along with clustering of the nodes. As direct transmission to the sink is not allowed, delay is more. The work presented by Singla *et al* [23] is also based on the energy efficiency of the nodes, with throughput maximisation and delay minimization.

2.1.4 *Temperature-aware routing*

The sensors implanted in or on the human body emit radiation and can impact the human body through WBAN. To avoid temperature rises and radiation that can have an adverse heating effect on the human body, many thermal-aware routing protocols have been developed, and a few of them are detailed in table 1. Jamil *et al* [24] proposed the concept of load distribution for the temperature control mechanism. However, some of the nodes are heavily loaded, and their energy falls rapidly. Jalili *et al* [25] and Kathe *et al* [26] also presented temperature aware routing protocols. Both of these protocols are based on the search for an alternate path if the temperature of the intermediate node is above threshold.

2.1.5 *Miscellaneous protocols*

Recently proposed protocols considered more than one parameter, thus being referred to in this work as "miscellaneous protocols." Ahmed *et al* [27] proposed a protocol based on the minimization of dissipated energy and the rise in temperature. Similarly, protocols based on energy conservation and posture movement were proposed by Ahmed *et al* [28] and Nadeem *et al* [29]. Geetha *et al* [30] considered the energy efficiency and priority of the data. Ahmed *et al* [31] proposed a protocol that considers link

state and energy efficiency. In Ahmed *et al* [32], co-operative linkage state and energy efficiency were considered. I. Ha [33] proposed a protocol based on the forwarding function, which depends on energy and distance. In Anwar *et al* [34] work, a forwarding function was proposed that depends on energy, distance, and signal quality.

Miscellaneous protocols are more efficient than conventional protocols based on one parameter.

2.1.6 *Energy harvesting*

Recently, the WBAN protocol was proposed with energy harvesting, where sensor nodes charge their batteries using sunlight or human warmth [8]. However, the amount of charging depends on the exposure to sun light, just as human warmth also varies depending on whether a person is sitting, walking, running, etc. In recent work, such analysis has not been considered, and energy harvested is evaluated using

$$E^i_{Harvested}(\tau) = \int_t^{t+\tau} \Gamma_i(t)dt \qquad (1)$$

where $\Gamma_i(t)$ denotes the charging rate. This simple model is also considered in this work.

Liu *et al* [35] suggested a protocol based on energy harvesting with the aim of throughput maximization. Khan *et al* [36] and Boumaiz *et al* [37] proposed an energy harvesting cooperative protocol for better stability period and throughput maximization. Roy *et al* [38] and Xu *et al* [39] proposed a reinforcement learning based energy harvesting protocol. Reinforcement learning is used for better resource allocation and to maximise throughput while also minimising delay.

2.2 *Notable energy-aware routing protocols*

In this section, notable energy aware routing protocols are discussed.

M-ATTEMPT [28]: This protocol is developed for heterogeneous sensors placed on the human body. In this protocol, direct hop communication is used for critical data, while multi-hop communication is used for normal data. The sink node is placed on the wrist; therefore, in case of hand movements, the sink position alters, and also the distances of the nodes from the sink node also vary, decreasing network stability period.

SIMPLE [29]: This protocol is an advance version of the M-ATTEMPT protocol; the sink node is placed at the waist to minimise the sink position alteration when the person moves. Moreover, in multi-hop communication, the sink computes the cost function for each node, and this information is shared with all the nodes; based on the cost function, a node decides whether to become a forwarder or not. The cost function for a node '*i*' is evaluated as

$$CF(i) = \frac{d(i)}{E_{\text{Res}}(i)} \quad (2)$$

where, $d(i)$ is the distance of node 'i' from the sink and $E_{Res}(i)$ is the residual energy. The node with the lowest CF will be declared a forwarder. In SIMPLE, a node that is close to the sink is elected as a forwarder more frequently and it will die sooner.

CPRAN [30]: In this protocol, 10 nodes were considered, and a sink was placed on the waist. Three nodes that monitor EEG, blood sugar, and ECG are high priority nodes, and they directly transmit data to the sink. The seven rest nodes cooperate in data transmission, and any one of these nodes acts as a relay node. The selection of relay nodes is done using the cuckoo search algorithm. In this work, only the performance of the seven nodes is considered, while the three other high-priority nodes that directly send data to sink are left; moreover, the initial energy is higher than in the previously compared work, so an improvement in results is obvious.

LAEEBA [31]: This protocol is a hybrid of SIMPLE and CPRAN, and a sink was placed on the waist. Two nodes that monitor EEG, blood sugar are high priority nodes, and they directly transmit data to the sink. The six rest nodes cooperate in data transmission, and any one of these nodes acts as a relay node. The relay node is elected using a cost function:

$$CF(i) = \frac{\sqrt{d(i)}}{E_{\text{Res}}(i)} \quad (3)$$

The performance of the LAEEBA is better as compared to SIMPLE due to its cooperative nature. Still, due to more frequent transmissions, the forwarding node will have a higher probability of dying soon.

Co-LAEEBA [32]: This protocol is an advanced version of the LAEEBA protocol. In this protocol, the forwarding node is elected using the same cost function as in the LAEEBA protocol. In the Co-LAEEBA protocol, to minimise energy dissipation, both direct transfer and data transfer via relay nodes are proposed, so for these two paths, two different models are considered.

EECBSR [33]: In this protocol, sensor nodes are placed on both the front and back parts of the body to cater to the sensor node disconnection problem due to body posture movement. A total of 15 nodes are considered, with 10 on the front and 5 on the back of the body. Moreover, while selecting a forwarder node, the standard deviation of residual energy is considered for path selection. Let there are N number of sensor nodes with energies $\{E_1, E_2, ..., E_N\}$ with mean energy value as 'm', the standard deviation function (SD) is given by

$$SD(i) = \sqrt{\frac{(E_i - m)^2}{N}} \quad (4)$$

Finally path is selected using: Select path [min[SD(i)]]

ELR-W [34]:In this protocol, a path cost function is derived which depends on link efficiency (LE), residual energy (E_{Res}), hop count (HC) and distance (d) and defined as

$$PCF(i) = \sum_{\forall i \in N} \left[u \times \frac{1}{E_{\text{Res}}} + v \times \frac{1}{LE} + w \times HC + x \times d \right] \quad (5)$$

u, v, w and x are weighing parameters. The values of u, v, w and x are chosen based on the priority given to various measures.

Khan *et al* [21]: This protocol is modified version of ATTEMPT protocol. This protocol also consider the cost function for a node 'i' is evaluated as

$$CF(i) = \frac{d(i)}{E_{\text{Res}}(i)} \quad (6)$$

The sink node is placed at the center of the body. Total number of sensor nodes is considered to be eight. This protocol is very much similar to SIMPLE protocol.

Ullah *et al* [22]: work is similar to the work presented in this paper, where link quality, clustering mechanisms, and two sinks are considered in the selection of the best available path. However, as direct transmission is not allowed and cluster nodes always transmit to the cluster head, even though the distance is smaller compared to the indirect path, there is still room for improvement.

3. Path loss and energy consumption model

In this section path loss and energy consumption model is detailed.

3.1 *Path loss model*

The human body's shadowing and fading factors affect wireless signal propagation in WBANs. Several more advanced path-loss prediction models, such as [40–42], are available in the literature. These models were proposed for various environmental variables, and each has its own set of advantages and disadvantages.In this work, we have adopted the Kitiyama *et al* path loss model, which is also used in our benchmark protocols and other recent WBAN research [42]. This model considers two path loss models that depend on the distances between various nodes. Let the distance between transmitting node and cluster head is d_1 and distance between node and forwarding node is d_2. The path loss model can be expressed as

If $d_1 \geq d_2$

$$P_{Loss}^1 (dB) = \alpha \log_{10}(d_1) + \beta \log_{10}(f) + N_{df} \quad (7)$$

The values of α, β and N_{df} are 27.6, - 46.5 and 157, respectively.

If $d_2 \geq d_1$

$$P_{Loss}^2(dB) = 10\log_{10}\left(\frac{4\pi d_0 f}{c}\right)^2 + 10n\log_{10}\left(\frac{d_2}{d_0}\right) + \sigma \quad (8)$$

'f' is frequency, d_0 is 10 cm, c is the speed of light and σ is the standard deviation. In the above equation 'n' is path loss co-efficient and for line of sight (LoS) communication it's value lies in the range 0.2 to 1.4 and for non line of sight (NLOS) it's value isin the range 1.7 to 2.7.

3.2 *Energy consumption model*

In the literature, many radio communication models have been developed. However, because of its simplicity and relevance to our proposed work, the first order radio model is considered [43].

The transmission energy for 'v' number of bits is give by

$$E_{TX}(v,d) = E_{TX-elec}(v) + E_{amp}(v,d) \quad (9)$$

After expanding the amplifier energy term we get

$$E_{TX}(v,d) = E_{TX-elec} \times v + E_{amp} \times v \times n \times d^2 \quad (10)$$

The receiver energy is given by

$$E_{RX}(v) = E_{RX-elec}(v), \quad (11)$$

or

$$E_{RX}(v) = E_{RX-elec} \times v \quad (12)$$

The data aggregation energy is give by

$$E_{DA}(v) = E_{DA}(v) \quad (13)$$

or

$$E_{DA}(v) = E_{DA} \times v \quad (14)$$

Because the loss co-efficient n for terrestrial wireless networks differs from that of the human body, Equation (11) can be re-written as

$$E_{TX}(v,d,l) = E_{TX-elec} \times v + E_{amp} \times v \times n \times d^l \quad (15)$$

3.3 *Energy analysis*

Sensor nodes in WBANs use either single-hop (direct) or multi-hop communication, depending on the distances among the nodes. When the distance between the sensor node and the sink is smaller, single-hop transmission consumes less energy and is thus preferred. In multi-hop communication, the distance between sensor nodes and sink is larger, so sensor nodes send data to sink via intermediate
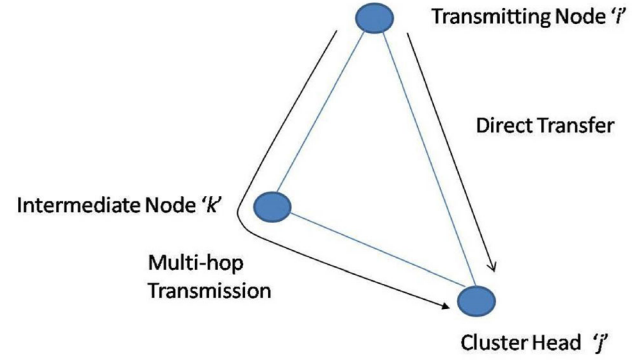

Figure 1. Schematic of direct and multi-hop transmission.

nodes. The overall energy of the entire system may be higher in multihop than in direct communication transmission to the sink node. For a better understanding, consider figure 1. Let 'i' is the transmitting node, and the node 'j' is cluster head (CH) and 'k' is the intermediate node. Referring figure 1, node 'i' transmit directly to cluster head (CH) then the transmission energy is

$$E_{TX}^{i,j}(v,d) = E_{TX-elec} \times v + E_{amp} \times v \times n \times d_{ij}^l \quad (16)$$

The transmission energy between node 'i' and intermediate node 'k' is

$$E_{TX}^{i,k}(v,d) = E_{TX-elec} \times v + E_{amp} \times v \times n \times d_{ik}^l \quad (17)$$

The receiver energy for node 'k' is

$$E_{RX}^{k}(v,d) = E_{RX} \times v \quad (18)$$

The transmission energy between node 'k' and intermediate node 'j' is

$$E_{TX}^{k,j}(v,d) = E_{TX-elec} \times v + E_{amp} \times v \times n \times d_{jk}^l \quad (19)$$

The transmission energy from node 'i' to sink node 'j' via intermediate node 'k' is

$$E_{TX}^{i,k,j}(v,d) = E_{TX}^{i,k}(v,d) + E_{RX}^{k}(v,d) + E_{TX}^{k,j}(v,d) \quad (20)$$

or

$$E_{TX}^{i,k,j}(v,d) = E_{TX-elec} \times v + E_{amp} \times v \times n \times d_{jk}^l + E_{RX} \times v \\ + E_{TX-elec} \times v + E_{amp} \times v \times n \times d_{jk}^l$$

$$(21)$$

From Equations 16 and 21, we get

$$d_{ij}^l = d_{jk}^l + d_{jk}^l + \frac{E_{RX} + E_{TX-elec}}{E_{amp} \times n}, \quad (22)$$

Multi-hop transmission is beneficial when

$$d_{ij}^l > d_{jk}^l + d_{jk}^l + \frac{E_{RX} + E_{TX-elec}}{E_{amp} \times n} \qquad (23)$$

4. Proposed protocol

The block diagram for the important steps of the proposed protocol is shown in figure 2. In the initial step, nodes are deployed on the body. Thereafter, a cluster is formed. Next, distance calculation is done, the required amount of power is evaluated and cost and forward functions are derived. Finally, data transmission is done. The detailed description of each process is elaborated in sub-section 4.2.

The fourteen node deployment is shown in figure 3. Two sink nodes are placed on both hips (marked green). The position and location of nodes are detailed in table 2. The 14 nodes are normal nodes with equal initial energies. The sink nodes (S_1, S_2) are advanced, high-energy nodes. The whole body is divided into two parts, i.e., the upper and lower abdomen. The nodes from the upper and lower abdomen form two clusters, and the cluster head is elected from the nodes in the respective clusters. The cluster head further transmits data to sink nodes. The nodes that carry sensitive data or are closer to the sink node can transmit data directly to the sink node. Thus, both single-hop and multi-hop transmission are done. The sensor nodes send data to corresponding cluster heads, and these clusters further send data to the appropriate sink node.

4.1 *Initialization phase*

The hello messages are sent from the two predetermined sink nodes to start this phase. Then all other sensor nodes in the network send back reply messages. These messages achieve four primary goals: each node in the network is fully informed about its (1) neighbours, (2) all possible routes going to the sink node, (3) sink node position, and (4) information about its specific CH. The structure of the packet is shown in figure 4. The packet contains information about the source node (ID_s), destination node (ID_j), node location (x,y), distance between the source and destination nodes (s,j) and residual energy (E_{Res}).

Every node maintains a neighbour table, which is filled with information obtained during Hello and Reply packet exchanges. The information in the neighbour table is used to determine which forwarder node should be used. After receiving the hello packet, each node adds its own information to it and broadcasts it to its neighbours. If the reply message is not received within the specified time period, the link between neighbouring nodes is considered broken. The routing table is changed in this situation, and all associated entries for this neighbour are erased.

4.2 *Cluster formation and head selection*

In order to disperse load on a single sink node and make the network convergence process easier, wireless sensor networks are frequently partitioned into discrete regions called clusters, each with its own Cluster Head (CH). In the similar context two clusters are considered, each with its own CH. By default, both sinks S_1 and S_2 are connected to pre-assigns CH. To avoid collisions in the common medium, both CHs send advertisement messages to all other sensor nodes using the CSMA/CA access mechanism. The below given algorithm 1, describe the cluster head selection and forwarding node selection.
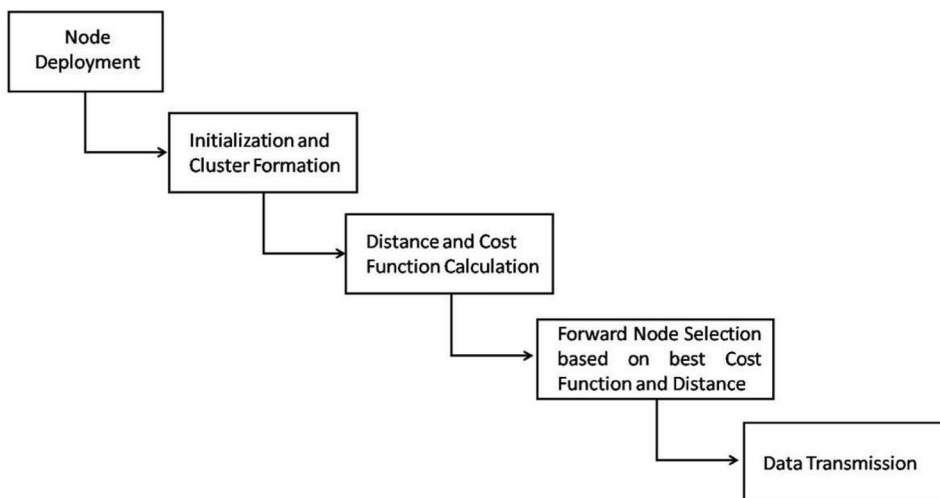

Figure 2. Block diagram of proposed WBAN protocol steps.

Algorithm 1 : Cluster head selection and forwarding node selection

Ω : Set of all sensor nodes

$P_r(j)$: Received signal power from node 'j'

P_t : Transmitted power (dBm)

E_0 : Initial energy of the sensor nodes

$E_{res}(i)$ Residual Energy of node 'i'

N: Number of nodes in a cluster

d_{ij} and d^{ij} : Distance between node i and j

$d(i, \sin k)$: distance between node i and sink

Initialization Phase:

for $i = 1 : \Omega$ **do**

node i'estimate the distance from all the nodes using RSSI and broadcast BEACON message

for $j = 1 : \Omega$ **do**

node 'j'receives beacon from node 'i'

node 'j'evaluate distance from node 'i'and evaluate path loss using

$P_{Loss}^{i,j}(dB) = P_t(dBm) - P_r^{i,j}(dBm)$

evaluate

$$d_1^{ij} = 10^{\left(\frac{P_{Loss}^{1(i,j)}(dB) - \beta \log_{10}(f) - N_{eff}}{\alpha}\right)} \quad \text{and} \quad d_2^{ij} = d_0 10^{\left(\frac{P_{Loss}^{2(i,j)}(dB) - 10\log_{10}\left(\frac{4\pi d_0 f}{c}\right)^2 - \sigma}{10n}\right)}$$

save distances at node j from all other nodes

end for

end for

CH selection phase

for $i = 1 : \Omega$ **do**

$E_{TX-NonCH}(v,d) = E_{TX-elec} \times v + E_{amp} \times v \times n \times \left(d^{ij}\right)^l$

Total energy loss of node 'i'

$E_{Loss}(i) = \left(E_{TX} + E_{DA}\right)v + E_{amp} \times v \times n \times \left(d^{ij}\right)^l (i, Sink) + (N-1)vE_{RX}$

Compute transmit power $P_{RT} = \dfrac{SNR}{\alpha}$

Each node send $E_{TX-NonCH}$, $E_{Loss}(i)$, $E_{res}(i)$ and P_{RT} to sink

compute $CF(i) = \dfrac{E_{Loss}(i)}{E_{Res}(i)} \times P_{RT}$

end for

for $i = 1 : \Omega$ **do**

if $CF(i)$ is minimum for node 'i'

node 'i' will be declared as CH by sink

end if

end for

for $i = 1 : \Omega$ **do**

each node maintain routing table,

evaluates distances and

if

$d_{ij}^l > d_{jk}^l + d_{jk}^l + \dfrac{E_{RX} + E_{TX-elec}}{E_{amp} \times n}$ (refer equation 23)

Evaluate

$FF(i) = \dfrac{\sqrt[l]{(d_{ij})}}{E_{Res}(i)}$

for $i = 1 : \Omega$ **do**

if $FF(i)$ is minimum for node 'i'

node 'i' will be forwarding node

end if

end for

$$d_1^{ij} = 10^{\left(\frac{P_{Loss}^{1(i,j)}(dB) - \beta \log_{10}(f) - N_{eff}}{\alpha}\right)} \text{ and}$$

$$d_2^{ij} = d_0 10^{\left(\frac{P_{Loss}^{2(i,j)}(dB) - 10\log_{10}\left(\frac{4\pi d_0 f}{c}\right)^2 - \sigma}{10n}\right)} \quad (24)$$

Required transmitted power calculations The SNR of the communication link must be estimated first in order to estimate the total needed transmission power, which is stated in Equation (13)

$$P_{RT} = \frac{SNR}{\alpha}, \quad (25)$$

α is path-loss exponent. SNR is signal to noise ratio and expressed as

$$SNR(dB) = 10\log_{10}\frac{P_{Sig}}{P_{Noise}} \quad (26)$$

Cost function (CF) The cost function is evaluated for each node within the cluster, and it is recorded after the neighbour CF computation, and then it is verified to see if this node is the last node in the neighbour database. If not, another node from the neighbour table is chosen, and the procedure is repeated; otherwise, the neighbour with the highest CF is chosen as the cluster head. In CF evaluation, energy loss between the nodes, residual energy and P_{RT} is considered:

$$CF(i) = \frac{E_{Loss}(i)}{E_{Res}(i)} \times P_{RT}, \quad (27)$$

The cluster head will receive data from (N-1) nodes will aggregate and will transfer to sink node, therefore total energy loss will be

$$E_{Loss}(i) = (E_{TX} + E_{DA})v + E_{amp} \times v \times n \times (d^{ij})^l (i, Sink) + (N-1)vE_{RX} \quad (28)$$

and the residual energy for cluster head is given by

$$E_{Res}(i) = E_o(i) - E_{Loss}(i) \quad (29)$$

For the other transmitting nodes, the residual energy will be

$$E_{Res}(i) = E_o(i) - E_{TX}(i) \quad (30)$$

Finally, if for a node $E_{Res}(i) \leq E_{TX}(i)$, then node is considered dead.

Forwarding function (FF) Each node also evaluates distance from cluster head and neighbouring nodes and check if

$d_{ij}^l > d_{jk}^l + d_{jk}^l + \frac{E_{RX} + E_{TX-elec}}{E_{amp} \times n}$, then node '$i$' forward its data to neighbouring nodes using the forwarding function
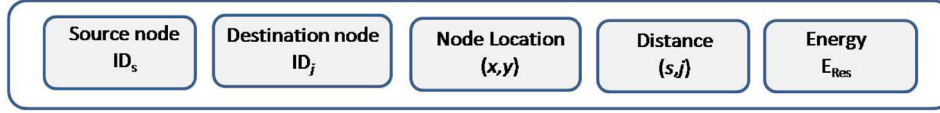

Figure 3. Position of sensor nodes.

Table 2. Sensors node location and body position.

Sn Number	Sensor type	Location (x,y) cm	Body position
1	EEG	(32, 177)	Head
2	ECG	(35,137)	Chest
3	ECG	(22,135)	Chest
4	Glucose	(36, 101)	Stomach
5	Glucose	(35, 21)	Stomach
6	Motion	(8,145)	Shoulder
7	EMG	(6,98)	Hand wrist
8	BP	(37,127)	Hand triceps
9	Pulse Oximeter	(40,101)	Hand wrist
10	Lactic Acid	(22,91)	Thigh
11	Accelerometer	(45,45)	Knee
12	Respiration	(15,50)	Thigh
13	Pressure	(15,45)	Leg
14	Pressure	(25,17)	Leg
S$_1$	–	(30,103)	Hip
S$_2$	–	(9105)	Hip

Distance calculation using path loss model First of all, distance between all the nodes are evaluated using path loss model equations 7 and 8. The calculated distances can be represented as

Figure 4. Structure of packet format.

$$FF(i) = \frac{\sqrt[l]{(d_{ij})}}{E_{\text{Res}}(i)} \qquad (31)$$

and a node with min FF will be selected as forwarder. And for the forwarder node the residual energy will be

$$E_{\text{Res}}(i) = E_o(i) - E_{TX}(i) - E_{RX}(i) \qquad (32)$$

4.3 *Data transmission phase*

The data transmission phase is described in algorithm 2. The data transmission phase consists of three situations. The first situation is whether data is sensed or not, the second situation checks for normal and critical data, and the third situation checks for direct or forwarder node transfer. If the sense data is critical, then it is directly transferred to the sink. If situations 1 and 3 are true, then data is transferred to the intermediate node; if situation 1 is true and situation 3 is false, then the distance of the transmitting node from CH and sink is evaluated, and if the distance between the transmitting node and cluster head is less than the distance between the transmitting node and sink, i.e., then data is transmitted to the cluster head (CH) else it will be transmitted to sink. Three nodes that are close to the sink (figure 2) directly transmit data to the sink (shown with a red arrow). Finally, if the data does not satisfy the above three situations, it will be discarded.

Algorithm 2 : Data Transmission

CH : Cluster head
Situation 1: New data is sensed
Situation 2: Data is critical

Situation 3: $d_{ij}^l > d_{jk}^l + d_{jk}^l + \dfrac{E_{RX} + E_{TX-elec}}{E_{amp} \times n}$

for $j= 1: \Omega$ **do**
If Situation 2==True
Node 'i' directly transmit to sink
else
If (Situation 1==True, Situation 3==False) **then**
If $d(i, CH) < d(i, \sin k)$ **then**
Node i transmit to CH
If (Situation 1==True, Situation 3==True) **then**
Node i transmit to data to forwarding node
end if
end if
end if
else
discard data
end for
Data Aggregation at CH
Receive data from cluster member node
Add CRC and forward to sink

In the data transmission phase, we consider that each link has enough capacity to prevent any data loss. Moreover, links between the nodes are stable, and they never fail during the complete simulation process. The transmitting node has more outgoing data, the sink node has more incoming data, and for the rest of the nodes, incoming and outgoing data are equal.

5. Performance evaluation

The key important performance measures are detailed in next sub-section.

5.1 *Performance metrics*

(1) Network Lifetime**:** The complete functioning period of any network is referred to as the "network life time." The time begins with the deployment of all nodes and ends with their demise. It is one of the most important
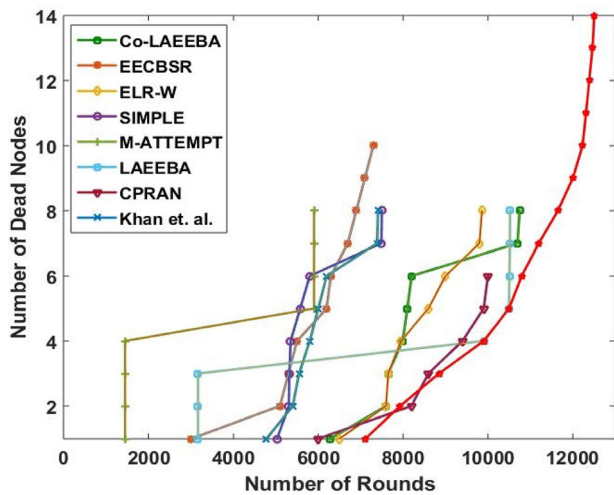
Table 3. Simulation parameters.

Parameter	Value
Total number of Sensor nodes	14
Sink nodes	2
Initial energy (E_0)	0.5 *J*
Transmitter Energy ($E_{TX-elec}$)	16.7*nj/bit*
Receiver Energy(E_{RX})	36.1 *nj/bit*
Amplifier Energy (E_{amp})	1.98 *nj/bit*
Packet size (v)	3000 bits
Value of 'l'	3.5
Frequency (f)	2.4 GHz
Wavelength (λ)	0.138 m
Standard deviation (σ)	4.1

Figure 5. Number of dead nodes vs. number of rounds.

Table 4. Number of dead nodes in different rounds.

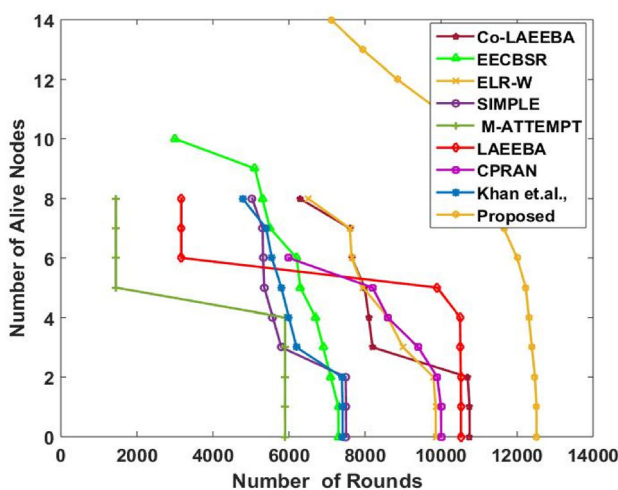| Protocol	First node dies	Number of dead nodes (Rounds)					
		2000	4000	6000	8000	10000	12000
Co-LAEEBA	6283	0	0	0	4	6	8
EECBSR	3000	0	1	4	10	–	–
ELR-W	6500	0	0	0	4	8	
SIMPLE	5030	0	0	6	8		
LAEEBA	3168	0	3	3	3	4	8
CPRAN	5990	0	0	1	1	6	
M-ATTEMPT	1447	1	3	3	8	–	–
Khan et.al	4780	0	0	5	8	–	–
Proposed	7109	0	0	0	1	4	8

Figure 6. Number of alive nodes vs. number of rounds.

performance features of networks with a large number of mobile and battery-operated nodes, such as all sensor networks. Increased network life-time contributes to a network's optimal performance.

(2) **Stability Period:** It's the period of time leading up to the death of the first sensor node (SN). It can alternatively be described as the time until all SNs survive. It is one of the most important performance criteria for evaluating any sensor network approach. The SNs in networks with a greater stability period live for a longer time.

(3) **Throughput:** The term "throughput" refers to the amount of data successfully transmitted from the SN to the sink. It is one of the most critical network performance metrics. One of the primary goals of any protocol (particularly a routing protocol) is to maximise the number of data packets delivered successfully. In terms of performance, the network with the highest throughput is regarded as the best.

(4) **End to End Delay:** It is defined as the time consumed from packet transmission to its reception. This time includes processing time at the transmitter and receiver, propagation time, and buffering time. The processing time is heavily dependent on the number of operations in the used algorithm, and more complex algorithms have relatively more processing time. In real time WBAN applications, this delay should be as minimal as possible.

6. Results and discussion

The simulation is performed in MATLAB. The performance and comparison of the proposed protocol with recently proposed WBAN protocols are detailed. The results are compared with LAEEBA, Co-LAEEBA, ELR-W, EECBSR, SIMPLE, M-ATTEMPT, and Khan *et al* [44], protocols. The simulation parameters are detailed in table 3.

6.1 *Stability period*

In figure 5, the number of dead nodes vs. the number of rounds is shown. The performance of M-ATTEMPT is the poorest among the compared protocols. In this protocol, the stability period is only 1447 rounds, and all of a sudden, 4 nodes become dead, leading to greater instability. The stability period of the EECBSR protocol is 3000 rounds, and nodes die at regular intervals. The stability period in the LAEEBA protocol is 3168 rounds, but after a large number of rounds, no more nodes die. In Khan *et al*, the work stability period is 4780 rounds, which is very similar to SIMPLE protocol 5030 rounds. In LAEEBA, SIMPLE, and Khan *et al*, the stability period is improved due to the

Table 5. Number of alive nodes in different rounds.

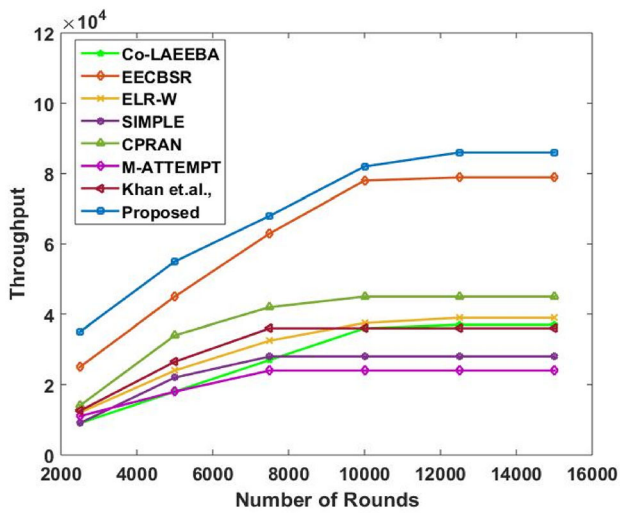| Protocol	Last node dies (Rounds)	Number of Alive nodes (Rounds)					
		2000	4000	6000	8000	10000	12000
Co-LAEEBA	10751	8	8	8	4	2	0
EECBSR	7300	8	9	6	0	–	–
ELR-W	9860	8	8	8	4	0	
SIMPLE	7501	8	8	2	0	–	–
LAEEBA	10525	8	5	5	5	4	0
CPRAN	10004	8	8	6	6	1	0
M-ATTEMPT	5923	7	5	5	0	–	–
Khan et.al.	7410	8	8	3	0	–	–
Proposed	12510	14	14	14	13	10	6

Figure 7. Throughput vs. number of rounds.

forwarding node mechanism. In CPRAN, the stability period is 5990 rounds, but it should be kept in mind that in CPRAN the initial energy of the nodes is considered to be 1 J, thus the comparison is not fair, but we have included it in the results as this protocol was recently reported. In Co-LAEEBA protocol, the stability period is 6283 rounds. In the ELR-W protocol, the stability period is 6500; the prolonged stability period is due to better forwarding function. In the proposed protocol, the stability period is 7109 rounds.

In table 4, the number of dead nodes vs. the number of rounds is shown. For the first 2000 rounds, the number of dead nodes is zero for all the protocols considered except for M-ATTEMPT, where one node dies. After the completion of 6000 rounds, more than 60 percent of nodes die for Khan *et al*, and for the SIMPLE protocol, 75 percent of nodes die, while for the rest of the protocols, the percentage of die nodes is less than or equal to 50 percent. In the protocols EECBSR, SIMPLE, M-ATTEMPT, and Khan *et al*, all the nodes die before the completion of 8000

Table 6. Throughput in different rounds.

| Protocol	Number of dead nodes (Rounds)					
	2500	5000	7500	10000	12500	15000
Co-LAEEBA	0.9×10^4	1.8×10^4	2.7×10^4	3.6×10^4	3.7×10^4	3.7×10^4
EECBSR	2.5×10^4	4.5×10^4	6.3×10^4	7.89×10^4	7.89×10^4	7.89×10^4
ELR-W	1.2×10^4	2.4×10^4	3.25×10^4	3.75×10^4	3.9×10^4	3.9×10^4
SIMPLE	0.9×10^4	2.2×10^4	2.8×10^4	2.8×10^4	2.8×10^4	2.8×10^4
LAEEBA	DNA	DNA	DNA	DNA	2.2×10^4	2.2×10^4
CPRAN	1.4×10^4	3.4×10^4	4.2×10^4	4.5×10^4	4.5×10^4	4.5×10^4
M-ATTEMPT	1.1×10^4	1.8×10^4	2.4×10^4	2.4×10^4	2.4×10^4	2.4×10^4
Khan et.al.	1.25×10^4	2.65×10^4	3.6×10^4	3.6×10^4	3.6×10^4	3.6×10^4
Proposed	3.5×10^4	5.5×10^4	6.8×10^4	8.2×10^4	8.6×10^4	8.6×10^4

DNA: Data not available
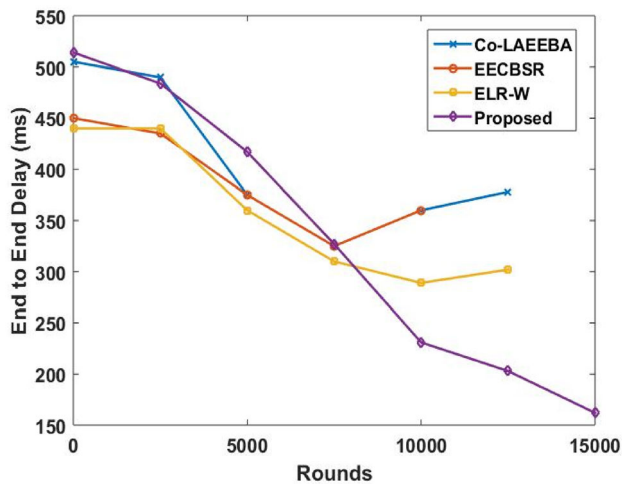
Figure 8. End to end delay vs. number of rounds.

Table 7. End to end delay (milli-second) in different rounds.

Protocol	End to end delay (milli-second) (Rounds)						
	0	2500	5000	7500	10000	12500	15000
Co-LAEEBA	505	490	375	325	360	378	
EECBSR	450	435	375	325	360	–	
ELR-W	440	440	360	310	289	302	
Proposed	514	484	387	327	231	203	162

Table 8. Throughput in different rounds.

Protocol	Stability Period	Network lifetime	Throughput	Delay (ms)
Co-LAEEBA	6283	10751	3.7×10^4	505
EECBSR	3000	7300	7.89×10^4	450
RK et.al	4810	7502	2.8×10^4	DNA
Proposed	7109	12510	8.6×10^4	514

rounds. In protocols LAEEBA, Co-LAEEBA, and CPRAN, all nodes die after about 10,000 rounds. In the proposed protocol, all the nodes die after 12,000 rounds.

6.2 Network lifetime

In figure 6, the relationship between the number of alive nodes and the number of rounds is shown. Again, the performance of the M-ATTEMPT protocol is poor, and the last four nodes die all of a sudden. The network lifetime is 5923 rounds. The stability periods of the EECBSR, SIMPLE, and Khan *et al*, protocols are around 7500 rounds. In the ELR-W protocol, the stability period is 9860 rounds. In the LAEEBA protocol, the stability period is 10525 rounds. In the COLEBA stability period, this number improved

further to 10751 rounds. In our proposed protocol, the stability period is 12510 rounds.

In table 5, the relationship between the number of alive nodes and the number of rounds is shown. For the first 2000 rounds of the M-ATTEMPT protocol, 7 nodes remain alive. In the protocols EECBSR, SIMPLE, M-ATTEMPT, and Khan *et al*, no nodes remain alive at the completion of 8000 rounds. After the completion of 10000 rounds, in protocols LAEEBA, Co-LAEEBA, and CPRAN, no node remains alive. In the proposed protocol, 8 nodes are still alive after 12000 rounds.

6.3 Throughput

In figure 7, throughput vs. number of rounds is shown. In terms of throughput, the performance of the M-ATTEMPY protocol is the poorest, with a maximum throughput of 2.4×10^4 packets. The throughput of the SIMPLE protocol is 2.8×10^4 packets. In the case of Khan *et al* work at a maximum throughput of 3.6×10^4 packets. In the case, of the ELR-W protocol, the maximum throughput of 3.9×10^4 packets. In the case of Co-LAEEBA the maximum throughput is of 3.7×10^4 packets. The throughput under the CPRAN protocol is 4.5×10^4. Maximum throughput under the EECBSR protocol is 7.89×10^4 rounds. The throughput under the proposed protocol is 8.6×10^4 packets.

In table 6, the throughput for different numbers of rounds is shown. The maximum throughput of most of the protocols ranges from 2.2×10^4 to 3.7×10^4 packets. In the case of the EECBSR protocol throughput is of 7.89×10^4 packets, which are delivered within 10000 rounds. In the proposed protocol, throughput is of 8.6×10^4 packets, which is achieved in 12500 rounds.

In figure 8, end-to-end delay vs. number of rounds is shown. In the case of the ELR-W protocol, the initial delay is smaller in comparison to other considered protocols. EECBSR protocol delay is 450 ms, while for Co-LAEEBA delay is 505 ms. In the case of the proposed protocol, the end to end delay is 514 ms. In Co-LAEEBA and ELR-W protocols, the delay first falls and then increases. In table 7, the end-to-end delay for different numbers of rounds is shown. Here, four protocols are compared. The end to end delay decreases with the number of rounds and is the minimum in the proposed protocol. The initial delay in the proposed protocol is the highest at 514 milliseconds. In the early stage of the proposed protocol, intensive calculations are done to find the optimal cluster head as well as distance calculations, which are not required later on. Thus, the delay starts to decrease. The end to end delay is also reduced due to the use of dual sink nodes; thus, the distance between the sink node and sensor nodes reduces. The clustering mechanism also reduces the delay, and finally, the direct transfer of the data to sink nodes by closer nodes also further reduces the delay.

Finally, in table 8, three protocols Co-LAEEBA, EECBSR, and Proposed are described. In Co-LAEEBA

stability period and network lifetime are good, but the throughput is poor. In the case of the EECBSR protocol, stability is poor, network lifetime is moderate, but throughput is good. In the proposed protocol, all the performance metrics, i.e., stability period, network lifetime, and throughput, show superior results. In the initial stage, the delay is greater, but it stabilises with the number of rounds and is finally very small in the proposed protocol. In Co-LAEEBA out of two paths, each node can select one of the paths with a lesser dissipation of energy. Thus, results improve as compared to traditional protocols. In EECBSR, for the minimization of energy dissipation, nodes are placed on the front and back of the body. Recently, the RK protocol [45] was proposed, which is very similar to Khan *et al*, work and whose results are also equivalent.

7. Conclusions

In this paper, an energy-efficient protocol based on clustering and cooperative routing is proposed. For the cluster head selection, a cost function is proposed, which itself depends on energy loss during transmission, residual energy, and the signal-to-noise ratio. The nodes within the cluster check their distances with CH and neighbouring nodes, which act as forwarders, and select the path with the least energy dissipation. The forwarder nodes themselves are selected on the basis of residual energy and distance from the transmitted node. The nodes that are close to the sink node directly transfer data to the sink. Thus, in the proposed protocol, various mechanisms are chosen to minimise energy dissipation. The performance measurement is done using computer simulation, and the results are compared with recently published works. In comparison to the Co-LAEEBA protocol, the stability period is improved by more than 13% and the network lifetime by more than 16%, while the throughput is improved by 11% as compared to the EECBSR protocol. The end-to-end delay in the proposed protocol is also less in comparison to state-of-the-art protocols.

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Declarations

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Consent for publication Yes.

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