Efficient Cluster Based Routing Protocol for Collaborative Body Sensor Networks

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Abstract: Collaborative Body Sensor Networks (CBSNs) are collection of Body Sensor Networks that move in a given area and collaborate, interact and exchange data between each other to identify group activity, perceive events detected by group of individuals, and monitor the status of single and multiple persons. Even though some routing algorithms were proposed for Wireless Sensor Networks (WSNs) and Body Sensor Networks (BSNs), very few studies were found to cover routing in CBSNs. In this paper, we propose a robust cluster based scheme that increases the routing efficiency through the three steps of the routing process: cluster formation, cluster head election, and routing operation of data to the Base Station (BS). MATLAB simulations are performed to compare the performance of the proposed algorithm to other existing routing schemes. Results show that the proposed scheme outperforms others in terms of delay, energy consumption, and packet drop percentage, and therefore succeeds in addressing CBSN challenges.

1 INTRODUCTION

Collaborative Body Sensor Network (CBSN) is a network formed of multiple Body Sensor Networks (BSNs) (Boudargham et al., 2016) moving in the same area and able to collaborate and synchronize among each other to reach a common objective. This intercommunication between BSNs allows the development of collaborative applications like interactive games, social interactions between multiple persons, as well as group status monitoring such as supervising rescue teams condition, sports team performance, and employees status in industries etc., where instead of single individual monitoring, exchanging data and cooperative processing between many BSNs is a must to detect the activity of a group, identify the events perceived by many persons, and monitor the health of many individuals at the same time.

Cluster based routing is known to be efficient in extending WSN and BSN lifetime through spreading the energy consumption among sensor nodes (Ul Huque et al., 2013). In cluster based routing, nodes are assembled into clusters (Farhat et al., 2016), and every cluster has one Cluster Head (CH) that is elected among the corresponding nodes. Nodes within the cluster transmit their data to the CH, and only the CH can forward this data to the sink. The number of active nodes is therefore reduced, which decreases the delay and energy consumption of the network.

Even though many cluster based routing algorithms were proposed for WSNs and BSNs, very few studies were found to cover routing in CBSNs. For instance, authors in (Tauqir et al., 2013; Watteyne et al., 2007; Verma and Rai, 2015) propose schemes to route data between many patients in a hospital, however these articles do not account for mobility as they consider sensor nodes to be fixed either on the bedside, or in specific locations of the hospital. On the other hand, Aminian et al. propose in (Aminian and Naji, 2013) a system capable of monitoring several patients moving in a hospital; however, authors suggest using relay nodes placed in predetermined places to route data sent by the coordinator node of every patient to the Base Station (BS), which may not be feasible in all mediums.

In this paper, we study and propose an efficient cluster based routing scheme that is able to send data reliably from many BSNs in motion to the BS, without the need to add additional nodes to the network.

The following scenario is considered. The CBSN is formed of several BSNs moving in a 400 m^2 indoor area. Every BSN is a person who can be a patient in a hospital, employee in an industry or a rescue team in a building, equipped with medical sensors and a coordinator node. The medical sensors capture physiological data from the person's body and send it to the corresponding coordinator node who will transmit it in return to the BS. Every BSN is considered to be one node in the CBSN; and therefore, in this paper, a new cluster based routing algorithm of data from the different nodes in motion to the BS will be proposed and compared to other existing schemes.

The remainder of the article is organized as follows: Related work and research contribution are discussed in Section 2. A new efficient cluster based routing algorithm is then proposed in Section 3. Simulation of the suggested scheme is presented in Section 4, to end up with the conclusion and future work in Section 5.

2 Related Work and Research Contribution

Many cluster based routing schemes for WSNs and BSNs are presented in literature. They differ from each other by the way clusters are formed, the criteria used to elect the CH of each cluster, and the routing process for data to reach the BS.

For instance, LEACH protocol (Heinzelman et al., 2000) elects CHs by random rotation to distribute the energy consumption among all nodes in the network. Non- CH nodes then join the nearest CH. However, since CHs are randomly elected, non-CH nodes might be located out of the communication range of the elected CHs, and cannot therefore join a cluster; also, the number of nodes joining a cluster can be large, which would quickly exhaust the energy of the corresponding CH. In addition, direct transmission of data from nodes to the CH and from the CH to the sink is used, which might not be efficient if the distance between the nodes and the CH or between the CH and the sink is large (Boudargham et al., 2018).

Another cluster based scheme is the Improved LEACH protocol for BSN presented in (Zhang et al., 2015). Improved LEACH is an enhancement over the LEACH protocol since CHs are not only elected based on a certain probability, but also based on the residual energy of the nodes and the nodes type; i.e., less important nodes with the highest residual energy are chosen to be the CHs in a round. The problem with Improved LEACH is that even though it elects CHs based on significant parameters, it ignores other important criteria such as the nodes' distance to the sink, their mobility, and their communication range. Also, like in LEACH, the number of cluster members might be high, and direct transmission of data is adopted which decreases the routing efficiency (Boudargham et al., 2018).

In LEACH-TLCH (Fu et al., 2013), a secondary CH is elected and used in case the energy of the primary CH decreases below the average energy of all nodes in the network, or the distance between the primary CH and the BS increases above the average distance between the nodes and the BS. Non-CH nodes send their data to the primary CH either directly, or through the secondary CH that is the node with the highest residual energy in the cluster. This algorithm takes into account the energy of nodes in the election of the secondary CH, but other important parameters are disregarded. for instance if the distance between the secondary CH and primary CH is large, or if the connectivity between them is limited, the energy of the secondary CH will drain very quickly and data transmission will not be reliable.

Authors in (Arioua et al., 2016) propose a Multi-hop Cluster Routing approach for WSN. This scheme combines both LEACH and Minimum Transmission Energy (MTE) protocols. In this scheme, CHs are elected by random rotation, however unlike LEACH where cluster members send their data via direct transmission to the elected CH, data is sent indirectly via multi-hop route from the nodes to the CH based on the shortest path, in order to further minimize the energy consumption of nodes. Even though this algorithm succeeds in prolonging the network lifetime through multi-hop routing, CHs are elected via random rotation; inappropriate CHs might therefore be selected, which would decrease the routing efficiency.

Authors in (Watteyne et al., 2007) propose the Anybody protocol, in which nodes with the highest density are elected as CHs, where the density is computed as the ratio of the number of links to the number of nodes within two-hop neighborhood. The data is then sent from the cluster members to the elected CH via a multi-hop intra-cluster path, and from the CH to the sink through a multi-hop inter-cluster route. Since the CH election is based on highest density, this algorithm may not be efficient when the number of cluster members is high, specially that other important criteria such as energy of nodes, distance to the sink, etc. are not considered in the CH election process.

The above discussion shows that none of the cluster based schemes implemented for WSNs and BSNs present a complete solution that addresses CBSNs requirements. They either present shortcomings in the CH election criteria, or in the cluster formation, or in the routing operation.

Therefore in this paper, a robust cluster based routing scheme is proposed for CBSN to provide better QoS and reliable transmission of data. The main aim of this algorithm is to increase the routing efficiency in CBSN by decreasing the energy consumption and delay through every step of the routing process: the clusters formation, the CHs election, and the routing operation of data to the sink.

3 Proposed Routing Algorithm

As stated earlier, the CBSN is formed of many BSNs, and in the proposed algorithm, every BSN (one person) is represented by one node. Therefore in the following, a routing scheme of data from the coordinator node of every BSN to the BS is suggested.

The proposed algorithm consists of three steps:

1. Clusters formation
2. Cluster head election
3. Routing operation: Intra and Inter cluster routing.

3.1 Energy Model

The first order energy model, was used in the simulations. This model is widely adopted in many WSN and BSN studies (Tauqir et al., 2013; Verma and Rai, 2015; Nadeem et al., 2013; Javaid et al., 2013; Sahndhu et al., 2015; Tümer and Gündüz, 2010; Liaqat et al., 2016). The corresponding transmitter and receiver energy are as follows:

$$E_{TX}(L,d) = E_{Tx-elec} \cdot L + \varepsilon_{mp} \cdot L \cdot d^n \qquad (1)$$

$$E_{RX}(L) = E_{Rx-elec} \cdot L \qquad (2)$$

$E_{Tx-elec}$ and $E_{Rx-elec}$ represent the transmitter and the receiver electronic circuits' energy consumption respectively, and ε_{amp} represents the the transmit amplifier's energy consumption (Sahndhu et al., 2015). These values depend on the type of the transceiver used. We consider using Nordic nRF24L01 2.4 GHz transceivers that are frequently used in BSNs (Nadeem et al., 2013; Javaid et al., 2015). L indicates the packet size, and n represents the average Path Loss (PL) exponent of the network. Since the value of the Path Loss (PL) exponent in indoor locations ranges between 1.4 and 6 depending on the present obstructions (Perez-Vega et al., 1997), it is set to an average of 3.5 to emulate an indoor environment with obstacles causing diffraction and scattering of the signal.

3.2 Clusters Formation

To form clusters, we consider that the BS is located at the center of MxM sensing area where persons forming the CBSN are distributed. This sensing area will be divided into a fixed number of clusters based on the optimal number of clusters formula presented in Equation (3). This formula is chosen since it evaluates the best number of clusters that leads to minimum total energy consumption in the network which is our target (Amini et al., 2012).

$$k_{optimal} = \sqrt{\frac{N_s \cdot \varepsilon_{fs} \cdot A}{2\pi(\varepsilon_{mp} \cdot d^n_{toBS} - E_{Rx-elec})}} \qquad (3)$$

where:

$k_{optimal}$: Optimal number of cluster.

N_s : Number of nodes distributed in the sensing area.

ε_{fs} : Energy of amplifier in free space computed for n=2.

A : MxM sensing area.

ε_{mp} : Energy of amplifier in multi-path fading.

d_{toBS} : Average distance between nodes and BS.

n : Average PL exponent of the network.

Since CBSNs are sizeable networks and nodes in CBSN are randomly distributed, nodes' density can be high in some parts of the sensing area. In this case, the number of nodes joining a cluster can be very large, which would quickly drain the CH energy. Therefore to reduce the energy consumption in the network, the BS distributes nodes evenly among the K_{opt} clusters. It limits the number of nodes in every cluster to N_c obtained through dividing the total number of nodes (N_s) by the optimal number of clusters

(K_{opt}). Every N_c nodes will be therefore grouped in one cluster having one CH.

Also, in order to reduce the computation overhead, re-cluster formation only occurs when nodes move outside their assigned cluster. Re-clustering computation is therefore avoided as long as the nodes remain in their assigned clusters even when they are in motion.

3.3 Cluster Head Election

To guarantee routing efficiency, it is essential to elect the appropriate CH of every cluster. In the proposed scheme, the CH is elected based on the following parameters:

- Distance between the nodes and the BS;
- Energy of nodes;
- Mobility of nodes;
- Transmission Scope (TS);

where TS of every node is defined as:

$$TS_{nodex} = \frac{1}{\text{PL exponent of node x}}. \tag{4}$$

TS reflects the connectivity and coverage strength of a node. It is computed as the reverse of the PL exponent of every node since the PL parameter encloses all the types of losses in the network: free-space loss, reflection, absorption, refraction, and diffraction losses. It also depends on the environment type (indoor or outdoor, urban or rural, etc.) and the medium of propagation (dry or humid air), along with the distance from the node to the BS.

Since nodes are mobile, the TS value of nodes is not fix. It is dynamic and changes depending on the current location of every node. Equation (4) suggests that higher TS value is achieved for lower PL exponent based on the node's location.

For every node, the Selection Score (SS) of becoming CH is computed using the following formula:

$$SS_x = \frac{E_x \cdot TS_x}{d_{toBS} \cdot M_x}, \tag{5}$$

where:

SS_x : Selection Score of node x to become a CH.

E_x : Residual energy of node x.

TS_x : Transmission Scope of node x as per Equation (4).

d_{toBS} : Distance from the transmitting node to the BS.

M_x : Mobility factor of node x.

The mobility factor of a node is computed based on the relative direction of node mobility. In general, mobility is either considered positive or negative. Positive mobility implies that nodes are moving closer to each other, which decreases the total energy consumption of the network, whereas negative mobility indicates that nodes are moving away from each other, which increases the total energy consumption. In every round, node i in a cluster evaluates the distance to every node in the same cluster. If the difference of distance between the current round and the previous round is negative, then nodes are moving away from each other, otherwise they are either moving closer or are stationary relative to each other. The mobility factor of node i will be then computed as (Kumar et al., 2010):

$$M_i(t) = \frac{\textit{Nb. of nodes moving away from i}}{N_c} \tag{6}$$

Where N_c represents the number of nodes in a cluster.

Equation (6) is therefore a measurement of negative mobility. For instance, if a node moves away for the rest of the nodes in the cluster, the corresponding mobility factor increases, and if it moves closer or remains stationary with respect to the other nodes, then its mobility factor decreases. Nodes with low mobility factor should therefore be selected as CHs since they lead to low energy consumption.

Therefore, and as per Equation (5), in every cluster, the node with the highest energy and the TS, along with the lowest mobility factor and the shortest distance to the BS, will have the highest Selection Score (SS), will be therefore elected as CH.

3.4 Routing Operation

The routing operation encloses both intra- and inter-cluster routing. Intra-cluster routing refers to the process of transmitting data inside every cluster, i.e., the way to transmit data from the nodes belonging to a cluster to the elected CH. And inter-cluster routing is the process of delivering data to the final destination (the BS) from the different CHs in the network.

In the proposed algorithm, multi-hop flat model is used for both intra- and inter-cluster routing since it increases energy efficiency compared to direct routing models (Boudargham et al., 2018). In intra-cluster routing, a Cost Function (CF) of every node inside a cluster is computed as:

$$CF_x = \frac{d_{toCH}}{E_x \cdot TS_x} \tag{7}$$

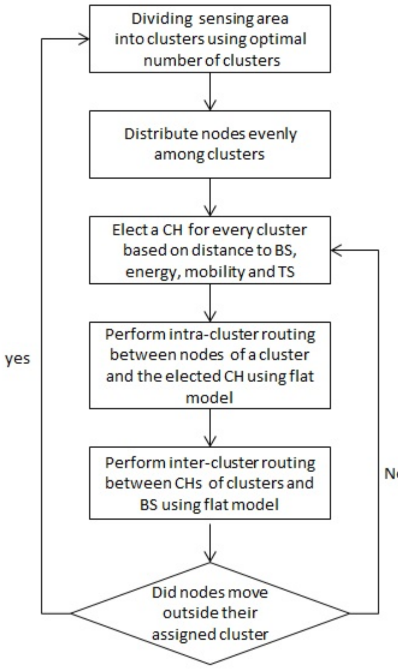

Figure 1: Proposed Algorithm Flow Chart

where:

d_{toCH} : Distance from node x, member of a cluster, to the elected CH of that cluster.

E_x : Residual energy of node x.

TS_x : Transmission Scope of node x based on its location.

Equation (7) implies that the node that is closest to the cluster elected CH, and possessing the highest residual energy and TS, is selected as a forwarder, and neighboring nodes send their data to this elected node. The CF computation aims therefore to optimize the routing operation by considering the dynamic environment and restricted resources in CBSN in the section of the forwarder.

Likewise, for inter-cluster routing, the CF of every CH is evaluated, and the CH with the lowest CF is chosen as the forwarder of data to the BS:

$$CF_{CH} = \frac{d_{toBS}}{E_{CH} \cdot TS_{CH}} \tag{8}$$

The flow chart and the illustration of the proposed algorithm are presented in Fig. 1 and Fig. 2 respectively.

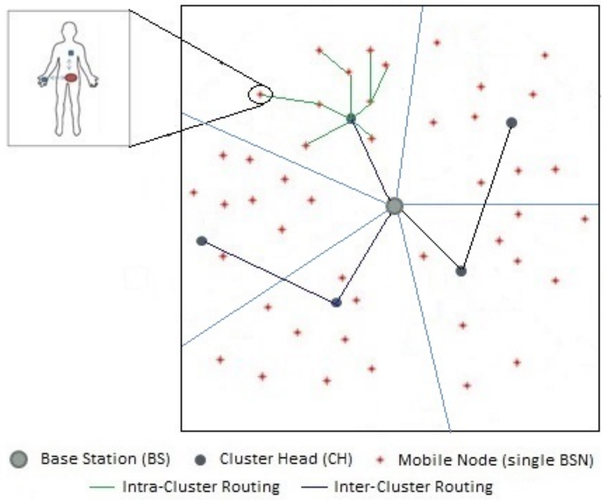

Figure 2: Proposed Algorithm Illustration

4 Simulation of the Proposed Scheme

4.1 Simulation Parameters

To assess the performance of the proposed algorithm, simulations of the delay, the energy consumption, and the percentage of dropped packets were performed using MATLAB R2014b. The suggested scheme is compared to four algorithms:

1. The LEACH protocol (Heinzelman et al., 2000). LEACH is chosen since it is one of the most famous cluster based routing schemes, and was implemented for many types of networks like BSN, WSN, and mobile networks.
2. The Improved LEACH (Zhang et al., 2015). This algorithm is chosen since it is a recent scheme used in BSN.
3. LEACH-TLCH (Fu et al., 2013). This algorithm is chosen for being recent and widely used in mobile networks.
4. Multi-hop Cluster Routing (Arioua et al., 2016). This algorithm is chosen since it is a recent algorithm using multi-hop intra-cluster routing.

Simulation parameters are summarized in Table 1.

ε_{fs} represents the energy consumption of the transmit amplifier in free space. It is obtained by computing ε_{mp} in Equation (1) for n=2 and by using the actual power consumption of the Nordic transceiver as found in the datasheet (Semiconductor, 2007).

As explained earlier, the number of nodes inside every cluster is obtained by finding the ratio of the total

Simulation Parameter	Value
Area	Indoor 400 m^2
Number of Nodes (N_s)	50
Nodes Status	Mobile
$E_{Tx-elec}$	16.7 nJ/bit
$E_{Rx-elec}$	36.1 nJ/bit
ε_{amp}	1.97 nJ/bit
ε_{fs}	10.9 nJ/bit
PL Exponent	1.4 - 6
Average PL Exponent (n)	3.5
Packet Size	4000 bits
Clusters Density N_c	N_s / K_{opt}
Mobility Model	Random Way Point

Table 1: Simulation Parameters

number of nodes (N_s) to the optimal number of clusters (K_{opt}). For instance, if K_{opt} is found to be 5, then every cluster will be formed of 10 nodes for 50 total number of nodes.

In order to make simulations closest to reality, the value of the PL exponent used to compute the TS of every node is variable, depending of the node's location. It ranges between 1.4 and 6 for indoor sites as per Table 2 (Perez-Vega et al., 1997).

PL Exponent	Propagation Medium
1.4-1.9	Wave Guidance
2	Free Space Loss (FSL)
3	FSL+multipath
4	Non-LOS, diffraction, scattering
4-6	Shadowing and complete obstruction (Obstacles and walls)

Table 2: PL Exponent Values

4.2 Results and Discussion

To assess the performance of the proposed scheme, the total delay induced by the proposed algorithm, LEACH, Improved LEACH, LEACH-TLCH and Multi-hop clustering is presented in Fig. 3. Results show that LEACH induces the highest delay among the other protocols, since it elects CHs randomly without accounting for important parameters that guarantee correct CH election. Also LEACH use direct intra- and inter-cluster transmission of data which would induce higher delays due to transmission of packets over longer distances and through many obstacles. Improved LEACH performs better than LEACH since it considers the residual energy of nodes to elect CHs. However, but it underperforms other protocols since it doesn't consider other important criteria and follows direct intra- and inter-cluster routing operation. Multi-hop Clustering protocol induces lower delays than LEACH and Improved LEACH since it adopts intra-cluster multi-hop routing; however it underperforms LEACH-TLCH and the proposed scheme since it elects CHs by random rotation which might lead to incorrect CHs selection. LEACH-TLCH outperforms the other protocols since it considers both the distance to the BS and the residual energy of nodes in the routing process and follows two-hop intra-cluster routing operation; however, this protocol induces higher delay than the proposed scheme since it doesn't account for the medium condition surrounding the nodes, nor their mobility in the CH election. Also, the algorithm chooses the secondary CH based on its residual energy only, ignoring other important parameters like distance to CH and transmission scope, which increases the transmission delay. The proposed algorithm outperforms all the other schemes since it works on minimizing the network delay throughout the three steps of the routing process: It divides the the network into optimal number of clusters which would decrease communication overheads, leading to less delay. It also ensures the election of appropriate CHs through taking into account the mobility and the transmission scope of the nodes, in addition to the node's energy and the distance to the BS. This is in addition to adopting multi-hop intra- and inter-cluster routing and choosing the appropriate forwarder based on nodes distance, residual energy and transmission scope. This guarantees reliable transmission of data and therefore reduces the delay induced by re-transmission of packets or transmission of data through long paths.

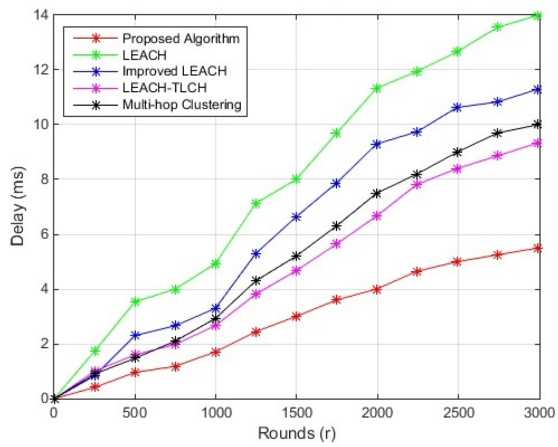

Figure 3: Delay Performance of Different Routing Schemes

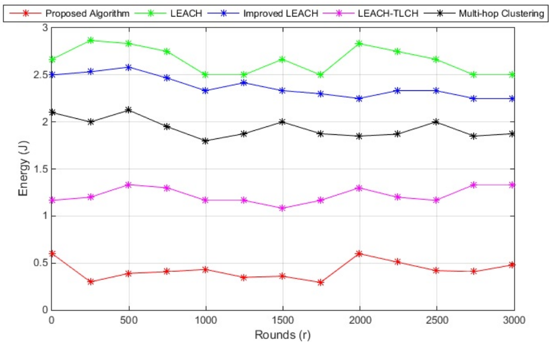

Figure 4: Energy Performance of Different Routing Schemes

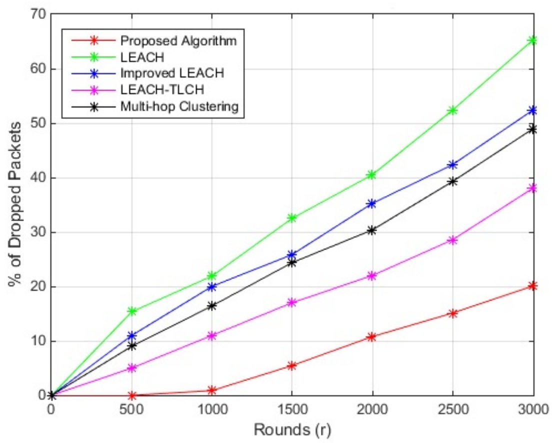

Figure 5: Percentage of Dropped Packets

Fig. 4 and Fig. 5 illustrate the energy consumed by the nodes in different rounds and the total percentage of dropped packets for the five compared schemes. Both figures show that the proposed scheme performs better than the other algorithms. For instance, the LEACH protocol consumes the highest energy since CHs are elected randomly, thus much more energy is needed to transmit data to the BS. Also, large size clusters can be formed in LEACH, which will quickly drain the energy of the CH and increase the total energy consumption of the network, and will lead to high dropped packets percentage as shown in Fig. 5. Improved LEACH performs better than LEACH protocol, since it accounts for the energy of nodes in the CH election, which would better distribute the energy consumption between nodes and lead to lower packet drop percentage. As for Multi-hop Clustering scheme, it consumes less energy than LEACH and Improved LEACH due to its multi-hop inta-cluster routing operation that will guarantee transmission of data through shorter paths. LEACH-TLCH performs better than the above protocols since it considers both the energy of nodes and the distance to the base station in the selection of the CHs, and adopts two-hop intra-cluster routing, which decreases the network overall energy consumption leading to less percentage of dropped packets. The proposed scheme outperforms all the compared scheme in terms of energy and packet drop rate since it works on saving energy throughout the cluster formation, CH election, and routing operation. Dividing the network into optimal number of clusters leads to minimum energy consumption, and limiting the number of nodes within clusters avoids the formation of large clusters that will quickly drain the energy of CHs; electing appropriate CHs fairly distribute the energy between nodes, and following muti-hop routing operation within every cluster and between clusters ensures reliable transmission of data to the BS, minimizing therefore the re-transmission of packets which will further decrease the network's energy consumption and packets' drop rate.

The obtained results prove therefore that the proposed algorithm succeeds in providing efficient routing and reliable transmission in CBSN.

5 Conclusion and Future Work

In this paper, a new robust and efficient cluster based routing algorithm is proposed to guarantee fast transmission of data while maintaining high energy efficiency. The proposed scheme works on increasing the delay and energy efficiency through the three routing phases: cluster formation, CH election and routing operation. The suggested protocol was compared to many other existing schemes. Results showed that it induces less delay and energy consumption than the other algorithms and leads to fewer packets drop, and thus succeeds in helping CBSNs to face many challenges such as mobility, limited resources, and coverage range. Future work includes testing the performance of multi-level cluster based scheme rather than flat model in inter-cluster routing for large number of nodes, as well as testing the proposed scheme under different scenarios such as underwater and hostile environments.

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