



CEPRAN-Cooperative Energy Efficient and Priority Based Reliable Routing Protocol with Network Coding for WBAN

M. Geetha¹ · R. Ganesan¹

Published online: 6 September 2020
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Abstract

The wireless body area network (WBAN) can effectively modify the health and lifestyle monitoring specifically where multiple body parameters are measured using biomedical sensor devices. However, power consumption and reliability are crucial issues in WBAN. Cooperative Communication usually prolongs the network lifetime of WBAN and allows reliable delivery of bio-medical packets. Hence, the main aim of this investigation is to propose a novel protocol Cooperative Energy efficient and Priority based Reliable routing protocol with Network coding (CEPRAN) to enhance the reliability and energy efficiency of WBAN using cooperative communication method. Firstly, to identify a relay node from the group of sensor nodes for data forwarding, an enhanced Cuckoo search optimization algorithm is proposed. Secondly, Cooperative Random Linear Network Coding approach is incorporated into the relay node to improve the packet transfer rate. CEPRAN is implemented in Ns-3 simulator and the experimental results prove that the proposed protocol outperforms the existing SIMPLE Protocol.

Keywords (WBAN · Cuckoo search optimization algorithm · Network coding · Random linear network coding)

1 Introduction

The wireless body area network (WBAN) can effectively modify the wellness and lifestyle of mankind, specifically in the health monitoring applications. In both, emergencies and the day-to-day scenarios, those monitored need bio-medical sensing devices that are operated by placing either outside or inside the individual. Here, the bio-information needs to be accurately transferred and collected at the destination nodes. The monitoring team keeps a check on the individual, based on the gathered medical inputs. In the field of health monitoring, the most sought after topic in recent times is the energy utilization of sensor nodes

✉ M. Geetha
geethaestherj@gmail.com

R. Ganesan
ganesan.r@vit.ac.in

¹ School of Computing Science and Engineering, Vellore Institute of Technology, Chennai Campus, Chennai, India

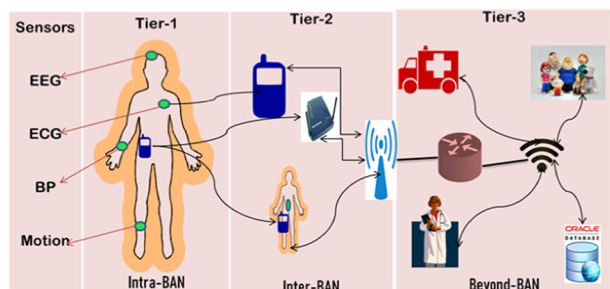
in WBANs to enable proper and long term functioning of health monitoring. A network (WBAN) comprises of many bio-sensor devices. A sink node placed near the human body, and in some applications one or more relay nodes placed around the human body. WBAN is marginally deviated from wireless sensor networks because of its unique properties [1–3]. The bandwidth is limited and mutable because it is more susceptible to interferences and noise. In WBAN, nodes are completely heterogeneous. Nodes are expected to consume less transmission power to avoid any harm to the human body.

The nodes in WBAN, senses the various important health parameters and transferred those signals to the sink. Figure 1 depicts the WBAN architecture and its three level communications.

Communication occurs in Tier-1, between bio-sensor nodes and coordinator/master-node/sink-node and among WBAN nodes, too. This level of communication occurs directly at the body of the patient. The communication is effected by using small-sized batteries, and is of short range (1–5 m), hence the energy is limited. Tier-1 sensor nodes transmit signals to the sink-coordinator node located within the same tier. Information processed in this Tier-1 is immediately forwarded to an access point that is located in Tier-2. Communication in Tier-2 enables amongst the coordinator nodes/sink/server and the gateway, or the access points. This tier links WBANs with different other networks that may be accessed by the Internet. Tier-3 finds use in urban area. Using a gateway as a bridge, tiers 3 and 2 are connected, followed by a link between the Internet and an application, e.g. emergency care, ambulance services, caretakers, etc. with ease.

WBANs need to function error-free for long durations using the same battery, specifically for nodes that are implants. Therefore, managing energy is a key issue in WBAN environment. Constant monitoring and transmittance of data, with large distances between these linked sensors utilize excessive energy. Sensors in 1-hop communicating models are spread widely away from the sink which, may deteriorate sooner owing to higher consumption of energy in spread out transmittals. In multi-hop communicating models, the energy used in the forwarding sensors that are closer to sink is higher. As in WSNs, WBANs have problems of reliable data transmission and energy management, too. Owing to their small size, these nodes have minimal power resources. The WBAN sensing nodes are few, and replacing them often is not feasible owing to energy dissipation. Communication consumes most energy, limiting the WBAN life-time, and hence, disturbing the WBAN operation. Also, the mobility of the body causes varying route loss because of shadowing. For minimizing fading within a wireless channel, cooperative communication approaches are being increasingly recognized as a capable method for creating spatial diversities. Typically, in a cooperative approach, the source nodes either use one hop link or relays to forward their data to sink. In schemes of this kind, spatial diversity is created. By employing cooperative

Fig. 1 Three tier architecture



communication, improved energy efficiency and reliability of the WBAN topology is possible.

WBAN designs consider the diversity for improving the overall transmittal success by permitting duplicate messages at the sink. Diversity may be gained by making multiple sensors to cooperate with one other for upgrading the communication effectiveness. In contrast with a single sensor possessing an array of antennas, duplicate information is transmitted through a distributed antenna array consisting of multiple sensors for reaching the sink with a certain introduced delay. Cooperation may be defined as a group of units that work in unison for attaining a common purpose while sharing one another's resources. In such systems, the forwarding node sends a single data packet copy to a relay sensor node. This relay next amplifies/decodes every data packet in accordance with instructions and again transmits it to the final sink. The main goal of incorporating cooperative approach [4–6, 7] is for the enhancement of energy consumption in one hop and multi-hop networks. The relay node [8] plays an important role as a bridge between the nodes connected far from the sink. Special relays [9] only handle the traffic but it does not involve in sensing. Introducing additional nodes on human body may lead to discomfort. Node level cooperative approach is introduced to overcome the discomfort on the human body [9]. In this approach, any one of the nodes used in WBAN can act as the relay/forwarder node. This reduces the hardware cost. However, selection of relay node is the major challenge in this approach. The main objective of this work is to propose a protocol with dynamic selection of a relay node by using nature bio-inspired cuckoo search algorithm [10–13]. The proposed protocol combines one hop and multi hop approaches to forward the data to sink [14].

Cooperative Random Linear Network Coding (CRLNC) approach is incorporated on to the relay node [15–20]. Generally relay nodes can only forward the data. In the (CRLNC) additionally the relay nodes can perform coding operation on the independent bit streams at the network layer to send the multiple packets simultaneously thereby reducing the overall transmissions in the network [21]. The remaining portion of an article is arranged as follows: Sect. 2, explains the existing protocols. CEPRAN protocol design is discussed in Sect. 3. CRLNC method and its design part are given in Sect. 4. The analyses of results are produced in Sect. 5. Section 6, concludes with the extension of future work.

2 Related Work

Routing involves the selection of the optimal path for transmitting packets. There have been a number of routing protocols are addressed in the literature for Ad hoc and WSN networks. WBAN has a similar structure as MANETs when it comes to group mobility rather than node movement. However, surgery may be required to replace the implant nodes are the painful process, hence WBANs have higher transmission power limitations than conventional networks. It is therefore necessary for WBANs to have a better network life span so as to avoid the constant replacement and recharging of nodes and batteries. In addition, when compared to WSN, WBAN is influenced with frequent topological changes due to interference and mobility [22, 23]. The routing protocols used in WBANs are typically constructed from single-hop and multi-hop methods. In certain cases, sensors may send their collected data directly to sink, and they also use Multi-Hop system. Multi-hop protocols are further classified into relay based and cooperative protocols. Mostly these types of protocols use multi-hop topology in WBAN for energy optimization and to prolong the network

lifetime. Most WBAN RPs are conceived taking into account certain key objectives, e.g. energy consumption, rapid and dependable data delivery, bandwidth use, efficient utilization of resources present [24]. Javaid et al. [25] suggested a RP for heterogeneous WBSNs, i.e. Mobility-supporting Adaptive Threshold-based Thermal-aware Energy-efficient Multi-hop Protocol (M-ATTEMPT). In this scheme sensors with respect to the sink of their data rates were used in descending order. One hop and two hop approach was utilized for normal and emergency packets. It directly communicated for real-time data flow (crucial information) or data on requirement using multi-hop communication for regular data transmission. Owing to the aggregation of data in intermediate node, a delay can occur in multi-hop communication. Authors have suggested a mathematical method for solving this delay problem. It supports mobility. It achieves network lifetime and better stability period. The average age/maximum temperature increase analysis was not analysed properly.

The authors suggested Distance Aware Relaying Energy-efficient (DARE) [26] which has been designed to monitor patients who are stayed in the hospital wards. It is assumed that in each ward eight patients are located and are attached with seven sensors each. Several destinations have seen more than one sink in wards. Parametric information was sent to the nearest sink node in the wards of the sensors attached to the human body. Body relay nodes have been used to reduce the energy utilization. Such nodes aggregated the data and forwarded it to the nearest sink node available. Though it achieves better network life time, the method is tested for the multiple patients located in the single ward. The proposed protocol in this thesis has designed for the single WBAN. The DARE protocol can be used for the testing of multiple patients in the future. Researchers have introduced a protocol named as the Link Aware and Energy Efficient Scheme (LAEEBA) [24]. Forwarder node concept was introduced in this work. The selection process of forwarder node is achieved through the least distance and the higher residual energy. The primary goal is to find optimum path with a least path loss over a link. It maximizes throughput at the cost of increased delay, which can never be accepted in WBAN. Cost function calculation in every round added overhead.

Ahmed et al. [24] developed an RP with efficient energy draw while supporting mobility of the body. This configuration has temperature awareness, too, and can vary the route when hot-spots are detected. The RP has benefits of single and multi-hop communications. For regular and crucial data flow, a preference-based routing is conducted. Paths are chosen based on least-hop counts, thus reducing transmission delays. Energy management was not considered in the study. In a different study, Ahmed et al. [27], suggested a dependable ANYCAST RP in Zigbee-operated wireless monitoring where mobile sensing nodes choose the nearest sink for forwarding information in a WBAN. Here, control messages are minimized using rapid re-routing.

Nadeem et al. [14] proposed a WBAN RP called Stable Increased-throughput Multi-hop Protocol for Link Efficiency (SIMPLE). Cost function was derived to choose the forwarder node. The node which has most residual energy and least distance to the sink will elect as the forwarder. The former parameter provides a balance to the energy consumed between the sensing nodes, while the latter parameter sees to successful sinking of packet deliveries. SIMPLE protocol increases the network's stability time and its throughput. The study was conducted with eight nodes that are located on the body and has one sink node kept on the chest. Analysis of the results was based on network life, residual energy, and throughput. Energy enhancement and better stability period was achieved in this protocol. Forwarder selection in every round is the overhead. The node which is kept near the sink node may die sooner. This major drawback was addressed in the multi hop communication. iM-SIMPLE [28] which is the extension of SIMPLE protocol proposed by Nadeem et al.

[14], since SIMPLE protocol does not take into account; mobility and suitable numerical models for minimizing energy use and, in addition, extension of the throughput. Non cooperative protocols widely adopt multi hop transmission which may leads to early dead nodes, thus affecting the network lifetime in the long run. Therefore relay network approach and cooperative approaches have emerged.

A wide range of protocols using relay scheme has already been proposed in literature for WSN [25, 29–31]. In [25], the author advised an energy-aware routing algorithm that would use a minimal hop counts for data transfer. Zhang and Shen [29] introduced swarm intelligence approach in his protocol for relay selection. This [30] approach balances load equally between the nodes and is capable of achieving longer life. Another method suggested in [31] optimizes the total energy consumption based on path selection and bits allocation. Using the best intermediate hops, the optimum packet sizes are relayed to the destination.

An algorithm was proposed in [31] to optimize the relay selection process that reduces the network's total transmission capacity. However, it is difficult to port these approaches for WBANs owing to the various constraints of network and its infrastructure. Thousands of sensor-nodes are placed in WSNs, providing a substantial degree of redundancy, and requires multi-hop communication. WBANs, on the other hand, occupy a small area and have no redundancy, requiring just two hops. Reliable data delivery is the utmost important criteria for WBAN. In a nutshell, a development of relay selection algorithm is required for WBAN. The authors suggested some relay-assisted communication method for WBANs in the literature [32–38] to increase energy efficiency. However, these works often failed to discuss about the suitable relay selection mechanisms. In [4], Elias suggested an energy-aware model that optimizes the number and relays placed in WBAN. The model has been implemented using an integer linear programming method that reduces the overall energy costs of the network. In [39] a WBAN relay selection algorithm based on the UltraWide Band (UWB) was proposed. The proposed algorithm uses power-efficient technique for relay selection. As a result, overall power consumption has been reduced efficiently. In [40], UWB-based cooperative WBAN was proposed. Single relay concept was introduced in this method, which improves the life of the network. The problem of energy efficiency optimization is formulated in the paper for two distinct on body transmission.

In [41], a novel method for the lifetime extension of the network was designed. The objective function was formulated as a function using transmission node, cooperative node, transmission power and time slot. In [42], the authors suggested a game-theory method for the relay selection process. The proposed method addressed the challenges involve in the relay selection process and the model was tested in various scenarios. Author Zhang [43], introduced a relay selection technique to optimize the network life span. IEEE 802.15.6 standard has been used under the topology constrains. Given the range of sensor nodes in WBANs, energy consumption and remaining energy of each node was taken into account for formulating the objective function. Heuristic optimization algorithm was proposed for a relay node selection. References [4, 39–43], however, main focus is only on the average energy consumption without considering other important metrics of node such as distance, and path loss results in degradation of lifetime. Most authors used the concept of relaying without considering network coding (NC) scheme. Other researchers, on the other hand, incorporated Network Coding (NC) technique on the relay node. Additionally, a wide range of research has been carried out for the reliability concern using NC scheme into the relay node. In [44], the authors exploited RLNC's advantages in improving energy efficiency and throughput; they proposed a cloud-assisted RLNC-based MAC protocol called CLNC-MAC. There are also reports on NC scheme to boost WBAN's energy efficiency

[45] and some suggestion on a low-power encoding solution that achieves less error in WBSN communication [46]. XOR network coding operations have been used in their suggested scheme.

As far as RLNC is concerned, Movassaghi et al. proposed a new cooperative transmission scheme focused on demodulate-and-forward and WBSN network coding [47]. Though RLNC is widely used in literature, determinant problem in RLNC has not been addressed so far.

3 CEPRAN Protocol Design

3.1 Radio and Path Loss Model

First order radio model, proposed by Heinzelman and Balakrishnan [48] is used in this work for the energy calculation. It is mainly used due to its simplicity and flexibility in the implementation and degree of closeness to this work.

Energy consumption for a sensor node is calculated for four different states viz. data sensing and processing state, reception state, idle/sleeping and listening state. There are two formulae used in the radio model, one for each transmittal and reception as given in Eqs. (3) and (4). If a node sends a k -bit message across a distance d , and d^2 is the loss of energy due to transmission.

$E_{Tx}(k, d)$ is derived as given:

$$E_{Tx}(k, d) = E_{Tx-elec}(k) + E_{Tx-amp}(k, d) \quad (1)$$

$$E_{Tx}(k, d) = E_{Tx-elec} * k + E_{amp} * k * d^2 \quad (2)$$

Here, E_{Tx} is the transmitting node energy consumed per packet. Where, $E_{Tx-elec}$ is the essential energy for operating the electronic circuitry of transmitting nodes. E_{amp} denotes the amplifier energy and k denotes packet size. Wireless medium in WBAN is the human body that causes path loss and radio signal attenuation. The coefficient of path loss n is added to the first order radio model and the values of n ranges between 2 and 5.7 based on the LOS and NLOS. Hence, the Eq. (2) can be rewritten as mentioned below for the CEPRAN protocol design.

$$E_{Tx}(k, d) = E_{Tx-elec} * k + E_{amp} * n * k * d^n \quad (3)$$

$E_{Rx}(k)$ is derived as given below:

$$ERx(k) = E_{Rx-elec} * k \quad (4)$$

Nordic nRF 2401A is a low power transceiver is used in this work and 2.4 GHZ is the bandwidth used. The details of the radio transceiver are listed in Table 1 [28].

Path loss model defines the distance variation between transmitter and receiver antennas and it is described in Eq. (5). The WBSN has two types of propagation model: sight line (LOS) and sight line (NLOS) [9].

$$PL(f, d) = P_{0db} + 10 \cdot n \cdot \log \left(\frac{d}{d_0} \right) + X\sigma \quad (5)$$

Table 1 Nordic nRF 2401A Radio Parameters [9, 28]

Metrics	Nordic nRF2401A transceiver
DC_ current (Transmission)	10.5 milliAmps
DC_ current (Reception)	18 milliAmps
Power Supply (min)	1.9 Volts
$E_{Tx-elec}$	16.7 nanoJ/bit
$E_{Rx-elec}$	36.1 nanoJ/bit
E_{amp}	1.97 nanoJ/bit/mn

PL defines the received power, where, d is the separation of transmitting and receiving antenna, d_0 indicates the reference separation, where, n , denote the path loss coefficient, and its value varies depending upon the propagation environment. The value of n varies between 3 and 4 for LOS, and 5 and 7.4 for NLOS. X indicates a Gaussian distribution random variable, where, σ denotes the standard deviation. P_0 , is expressed in Eq. (6).

$$P_0 = 10 \log_{10} (4\pi * d * f)^2 / c \quad (6)$$

where c denotes speed of light, d is the separation between the transmitting and receiving antenna, and f is frequency. $X\sigma$ is used for predicting the signal strength between the transmitter and receiver boundary.

3.2 WBAN System Model

In the CEPRAN protocol, WBAN network is organized with 10 sensor nodes placed in various parts of the body. A sink node placed on the waist is termed as Coordinator node. In the initial stage, the protocol assumes that the power and computing capabilities are equal in all the nodes. Nodes 1, 2, and 3 are assigned as ECG sensor, glucose sensor and EEG sensor node, respectively and are considered as high priority nodes. Hence, the data rates of these nodes are higher than other nodes. These three nodes are directly connected to the sink and the data transmission takes place using single hop communication. All the other 7 nodes cooperate with each other for transmission. Any one node among the 7 would timely act as relay node. Bio-inspired cuckoo search optimization algorithm is used for the relay node selection.

3.2.1 Initial Phase

- Sink node must transmit a short control packet containing the location of the sink.
- Upon receiving this control packet, all nodes must store the location of the sink.
- The bio sensor nodes will broadcast the control packet which contains the node ID, where it is located on the body and its current energy status.
- The location of the sink and its neighbors are updated to all the 10 nodes.

3.2.2 Relay node selection Using Enhanced Cuckoo Search Optimization algorithm

The authors (Xin-She Yang and Suash Deb) designed the Cuckoo Search Optimization Algorithm in the year 2009 [12]. The CSO uses three fundamental laws.

- Each cuckoo randomly selects the host nest and lays an egg.
- The nest with a best quality will be handed over to the next generation.
- The alien eggs are either wrecked by the host bird, or they construct a new nest in a new location.

The WBAN setup is simulated using NS-3 network simulator. In the simulator sensor nodes are deployed as static nodes and are connected to sink with the one hop and extended star topology. After the deployment of nodes, enhanced cuckoo search algorithm is applied for the selection of relay node. Each egg in a nest corresponds to a sensor node.

To start the search, the number of sensor nodes is selected. Objective function is calculated for the relay node selection. Objective function is a random walk modified and derived from the local search of cuckoo and is derived as follows:

$$F_x^t = k \cdot \frac{F_e^t(x)}{F_d^t(x)F_p^t(x)} \tag{7}$$

Let $F_e^t(x)$ denote the energy function then $F_e^t(x) = (P_e - \epsilon)$ where P_e is the total energy of each node and ϵ is the consumed energy. Let $F_d^t(x) = S_k - x$ where S_k is the sink node, x is the current node. $F_p^t(x)$ is a path loss function and is calculated using Eq. (5). The node which has the highest residual energy, minimum distance to sink, and less path loss will be considered as the relay node for that particular round. All the nodes are connected to the relay node and they will forward their data. Relay node forwards data to sink, Nodes 1, 2, and 3 are connected in the single hop and do not participate in relaying other nodes' data. The proposed algorithm is detailed in Table 2.

Table 2 Relay Node Selection Algorithm

Relay Node Selection Procedure
Step 1: Sink node broadcasts its location id to all sensor nodes (n);
Step 2: Each sensor node 'x' sends its location id, current energy status to sink;
Step 3: Repeat Step 4 for all values of 'x' where 'x' = {4, 5, 6...10}
Step 4: Sink node picks up a node randomly say (x), and evaluate its objective function using
$F_x^t = k \cdot \frac{F_e^t(x)}{F_d^t(x)F_p^t(x)}$
Step 5: Sink node chooses a relay node randomly among n nodes (say, x)
If ($F_x^t < F_j^t$),
substitute j as relay node (new solution)
End If
Step 6 : The final best solution 'j' will be the relay node in the next iteration;

3.2.3 Scheduling Phase

The sink allocates time slots for relays and nodes using Time Division Multiple Access (TDMA). In their scheduled time slots, the other nodes transmit the sensed information to the relay node and the aggregated packets are communicated to sink during its allotted slots. The node changes to idle state when there is no data to send. During transmissions, the node switches from idle to ready state.

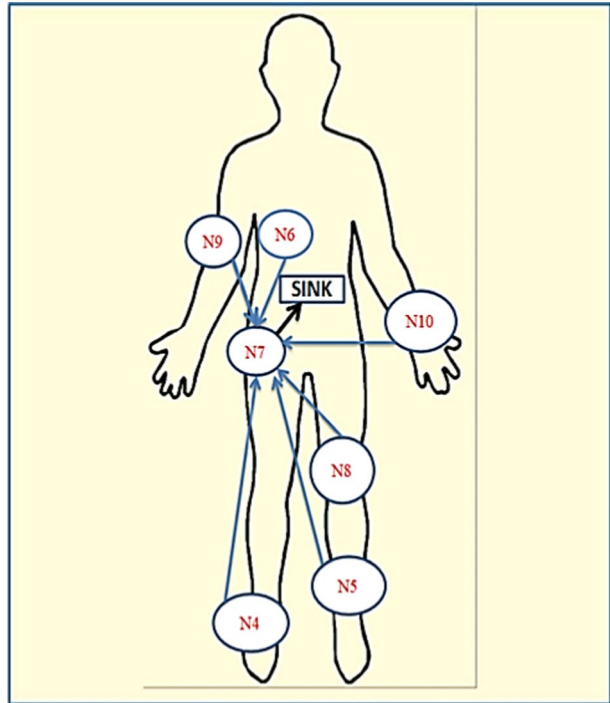
4 Cooperative Random Linear Network Coding

Network coding (Movassaghi et al. [47]) is a technique using mathematical operations to encode multiple packets from single source or from various sources at relay nodes, which reduces the number of transmissions in a network. In this study, Cooperative Random Linear Network Coding (CRLNC) is used to construct a Network Code relay node that can increase the likelihood of positive reception at the sink node. After the relay node selection using relay node selection algorithm, the relay performs network coding operation by combining multiple packets from different sources. This research work integrates cooperative communication and network coding for enhancing the data reliability. In CRLNC, it is assumed that all nodes have equal priorities when comes to data transmission. Initially, the priorities are not considered but in WBAN all nodes are set with different priorities in most of the cases. In order to consider priority nodes, CRLNC method is further modified as Reliable Prioritized based Random Linear Network Coding (RP-RLNC).

5 CRLNC Design Model

The system design model consists of biosensor nodes, relay node which performs network coding operation and the sink node. There are totally 7 biosensors nodes that are placed on the various parts of the human body and are numbered between N4-N10. The role of these sensor nodes is to sense and collect the vital parameters of the body and then forward those values to the relay node. This model adopts node level cooperative transmission in which the nodes cooperate with each other for the data transmission to occur. Any one among the sensor nodes will act as the relay node at a given time. Generally, the relay node only forwards the data to the destination whereas in this model the selected relay node will also perform the coding operations using RLNC method. The relay node acts as the bridge between the biosensor nodes and the sink node thus improving the energy efficiency. The relay node selection is carried out by the Enhanced Cuckoo Search algorithm. The algorithm decides the relay node for that time considering various parameters. The system model is shown in Fig. 2. Initially the biosensor node (N7) is elected as the relay node. The sink node announces N7 as the relay and sends the current location of the relay to the remaining nodes in the network. The biosensor nodes start transmitting the biomedical packets to N7 during the allotted time slot. The sink node schedules the time slot for relay to sink communication and nodes to relay communication using TDMA. The relay node is dynamically selected by the algorithm. In every round there is a possibility to have a new relay node in the selection process. The relay node N7 collects the packets from various sensor nodes and stores it in the ready queue. Once the packets arrived at the relay N7, it

Fig. 2 CRLNC system model



performs the coding operation. Algorithms for CRLNC encoding and decoding procedure are shown in Tables 3 and 4.

6 Simulation Results and Analysis

This section produces the simulation results and its analysis. Here, the Ns-3 simulator is used. The simulation settings are shown in Table 5. The sample calculation of objective function using the energy, distance, and path loss parameters are shown in Tables 6 and 7.

The Relay Node is selected based on the values of the objective function. Maxima value is taken for the selection. Initial energy is set as 1 J for all the nodes. Distance (in meters) is taken from each node to sink node, e.g. N4 is kept at 1.5 meters from sink node. Path loss is measured in decibels. In Table 6, free space path loss is considered. In free space, value n is taken as 2 in most of the cases. N1, N2, and N3 are directly connected to sink node and will not participate in the relaying process. The algorithm is implemented in all the remaining nodes, and the objective function is calculated based on the derived formula. In the initial stage, all the nodes have same energy. Energy consumption for transmission and reception of k bits is calculated using first order radio model. Path loss value increases with the increasing distance. According to the Table 6, N6 has minimum distance to sink, when compared to other nodes, and path loss value is lesser than other nodes. So for Round-1, N6 is selected as the RN. For the second round, energy value is decreased from 1 to 0.999 J. But N6 consumes more energy since it has been acting as the RN in the previous round. N6 had performed data collection from the other nodes and data forwarding to sink

Table 3 CRLNC Encoding Process

CRLNC Encoding Process	
Step 1:	At time t, if node N_i ($i=4, \dots, 10$) acts as a relay node
Step 2:	Pick the packet C_k from RQ
Step 3:	If packet C_k is forward packet set exit
Step 4:	If Node N acts as R Then
Step 5:	R forward packet C_k to sink
Step 6:	Insert packet C_k to forward packet set
Step 7:	Else
Step 8:	If Node N acts as R_c
Step 9:	R_c collects packets from $N_i \in RQ$
Step 10:	R_c generates random coefficient T_n^k
Step 11:	R_c checks for determinant of $T_n^{(k)}$
Step 12 :	If determinant of $T_n^{(k)} \neq 0 \Rightarrow$ then encode $E_n = product C_k \cdot T_n^{(k)}$
Step 13:	Else Change $T_n^{(k)}$
Step 14:	R_c transmits $E_n, T_n^{(k)}$ to sink node
Step 15:	Endif
Step 16:	Endif
Step 17:	Endif
Step 18:	If RQ $\neq 0$ Go to Step 2
Step 19:	Else Exit
Step 20:	Endif

Table 4 CRLNC Decoding Process

CRLNC Decoding Algorithm	
Step 1:	If Sink receive packets from R_c Then
Step 2:	The sink receive random coefficient $T_n^{(k)}$ and E_n the encoded packet
Step 3:	Sink Apply Gaussian Elimination Algorithm
Step 4:	$C_k = product E_n \cdot (T_n^{(k)})^{-1}$
Step 5:	Store C_k in the Sink memory
Step 6:	Else
Step 7:	Sink receive packets from R
Step 8:	Store Packet in the sink memory
Step 9:	Endif

nodes, thus consuming more energy. In the next round, since N7 shows the highest value, it has been selected as the RN.

In Table 7, the RN is selected based on the objective function value. Again, maxima value is taken for the selection. Initial energy and distance is maintained as stated earlier. In this table, LOS and NLOS path losses are considered. In free space, n value is taken as 2 in most of the cases, while in LOS, n value is taken as 2, 3.38 and 5.1. N1, N2, and N3

Table 5 Simulator Settings

Simulation parameter	Value
NS-3 version	NS-allinone-3.17
Nodes	10 sensor nodes, 1 sink
Terrain dimensions	50 * 50 m
Mac layer	802.15.4
Simulation time	30 Mins
Mobility model	Random way point
Node speed	Random from 3 to 7 m/s
Routing protocol	CEPRAN
Propagation model	Two ray ground
Channel bandwidth	256 Kbps

Table 6 Objective function calculation sample

Node-ID	N4	N5	N6	N7	N8	N9	N10
Dist (m)	1.5	1.2	0.5	0.5	0.6	0.8	0.9
Energy (J)	1.0	1.0	1.0	1.0	1.0	1.0	1.0
PL (db), FS-2	43.5	41.63	34.02	34.02	38.11	38.11	39.13
Round-1 Fitness Value (MAX)	24.2	31.6	92.9	92.9	74.0	51.8	44.91
Energy(J)	0.999	0.999	0.999	0.979	0.999	0.999	0.999
Round-2 Fitness Value (MAX)	24.8	32.4	94.2	95.3	75.9	53.2	46.0

The highlighted value is the maximum value calculated from the objective function. The node which has highest value has been elected as the relay node

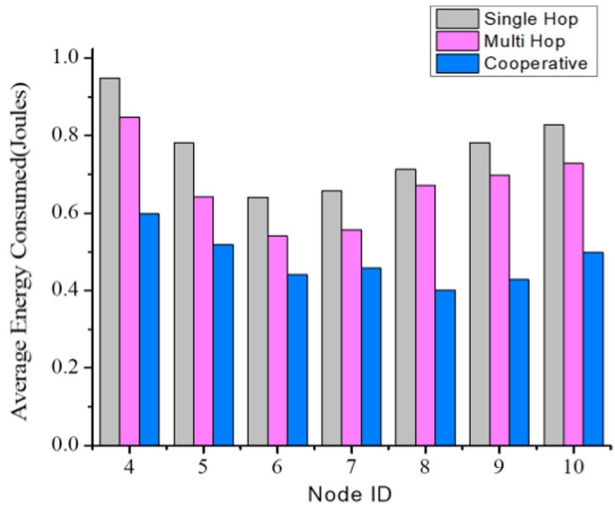
Table 7 Objective function calculation sample

Node-ID	N4	N5	N6	N7	N8	N9	N10
Dist (m)	1.5	1.2	0.5	0.5	0.6	0.8	0.9
Energy (J)	1.0	1.0	1.0	1.0	1.0	1.0	1.0
PL (db), FS, LOS	29.59	26.2	60.1	29.5	41.63	47.02	34.02
Round-1 Fitness Value (MAX)	24.0	31.6	92.9	127.3	74.0	51.8	44.6
Energy (J)	0.999	0.999	0.999	0.979	0.999	0.999	0.999
Round-2 Fitness Value (MAX)	24.0	43.4	92.2	125.0	101.6	71.2	44.7

The highlighted value indicates the changes in pathloss. The node 7 has less path loss value and it has been elected as a relay node

are directly connected to sink node and will not participate in the relaying process. The algorithm is implemented in all the remaining nodes, and objective function is calculated based on the derived formula. In the initial stage all the nodes have same energy. Energy consumption for transmission and reception of k bits is calculated using first order radio model. Path loss increases with the increasing distances. According to the Table 7, N6 and

Fig. 3 Node level energy comparison



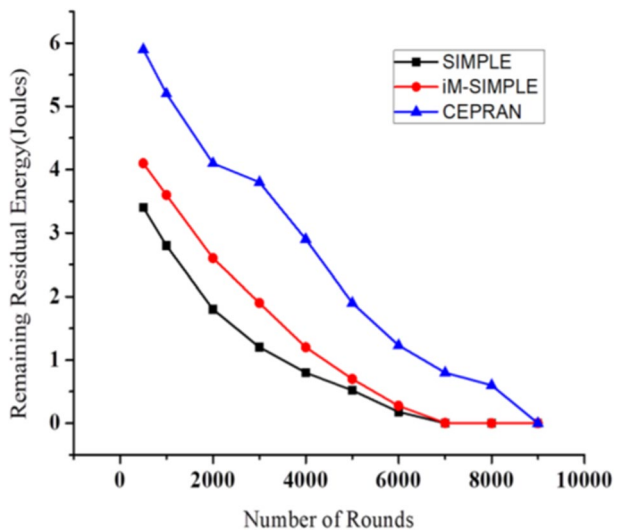
N7 have the minimum distances to sink, as compared to other nodes and the path loss value is lesser in N7 than N6. So, for Round-1, N7 is selected as the RN.

Figure 3 presents the average energy consumed after 3000 rounds at each node using single-hop, multi-hop, and multi hop using cooperative approaches. It is seen that the cooperative approach consumes the least energy at all nodes. Remaining energy at all nodes after 3000 rounds are more in the cooperative transmission. This clearly shows that the proposed approach prolongs the network life time.

In Fig. 4, the residual energy is plotted against the number of rounds. Here, the residual energy curve for SIMPLE and iM-SIMPLE reach to 0 at 6000, respectively. However the CEPRAN protocol saves better energy due to lesser number of dead nodes.

Figure 5 presents the life time of the network by comparing the number of dead nodes versus the number of rounds. In SIMPLE protocol, all of a sudden 3 nodes became dead at

Fig. 4 Remaining residual energy versus Rounds



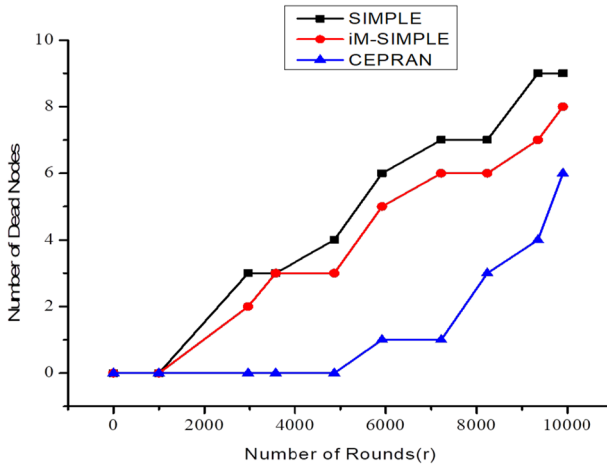


Fig. 5 Number of dead nodes versus rounds

round 3000. In the proposed CEPRAN protocol till 4997 rounds the number of dead node is zero. The first dead node appears at 6000 rounds in the proposed CEPRAN protocol and is still maintained at 7897 rounds. By this time, the SIMPLE and iM-SIMPLE protocol already shows to 4–6 dead nodes.

Figure 6 depicts the packet received at sink vs the number of rounds. The result shows that the performance of the CEPRAN protocols is greater than the SIMPLE and iM-SIMPLE protocol. A significant difference can be found in the number of packets obtained at the sink after 6000 rounds.

In Fig. 7, Packet delivery ratio of SIMPLE, CEPRAN and CEPRAN-CRLNC is plotted. SIMPLE is the existing protocol that uses single and multi-hop communication. CEPRAN is the proposed protocol that uses multi hop cooperative approach for the transmission. In this, relay node only performs forwarding and does not include network coding operations. Here in CEPRAN, the CRLNC network coding method is incorporated based on RLNC. So the packet delivery reaches to 92% for 100 packets, 90% for 500 packets, and 89% for 1000 packets which are much higher than those obtained in the SIMPLE and CEPRAN. So

Fig. 6 Packet Received at the Sink versus Rounds

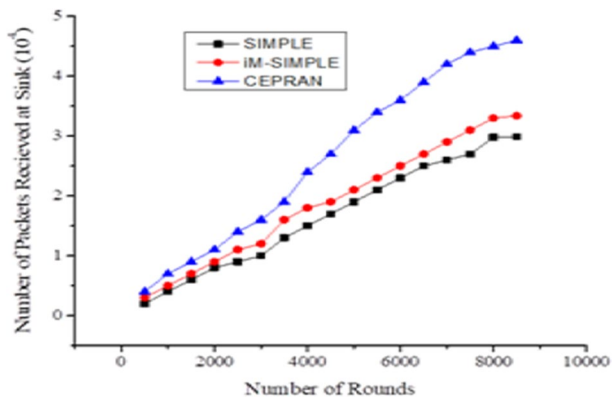


Fig. 7 Packet delivery ratio analysis

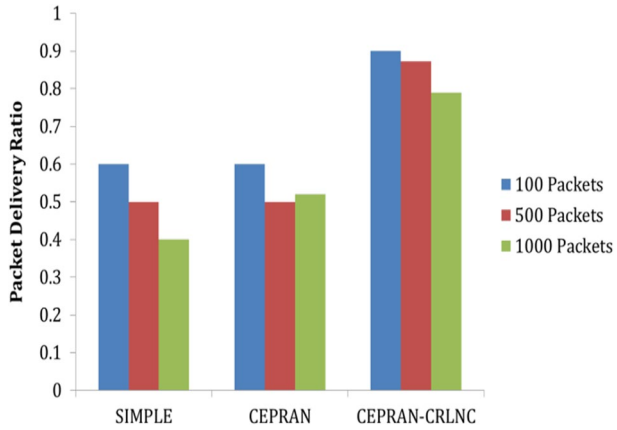
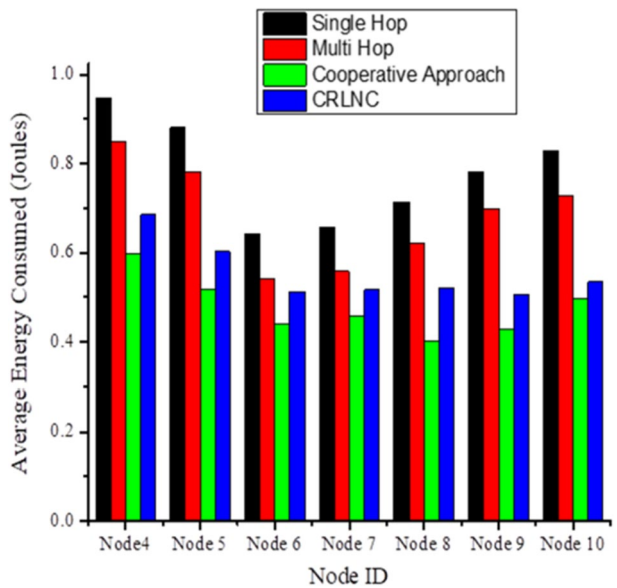


Fig. 8 Node level energy comparison

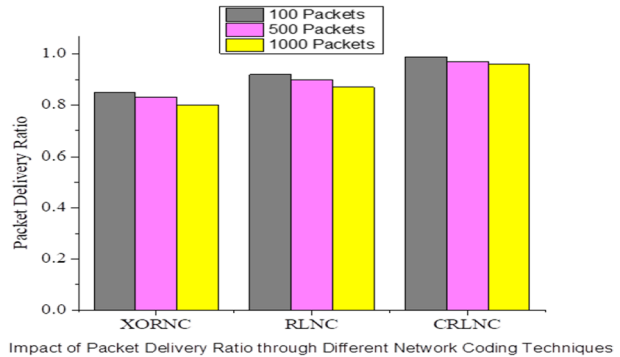


the CRLNC method increases the overall packet delivery ratio which in turn increases the reliability of the network which is the main goal of this work.

Figure 8 presents the average energy consumed after 3000 rounds at each node using single-hop, multi-hop and multi hop using cooperative approach and CRLNC. It is seen that the cooperative approach consumes least energy at all nodes. Remaining energy at all nodes after 3000 rounds are more in the cooperative transmission. CRLNC consumes more energy due to network coding operation but better results are obtained when compared with single and multi-hop approaches. Therefore, with that remaining energy the network can still exist for few more rounds and in turn the network life time in CRLNC is prolonged.

Figure 9 depicts the impact of packet delivery ratio on various NC techniques. XORNC, RLNC are the existing techniques widely used. CRLNC, the proposed method

Fig. 9 Impact of Packet Delivery Ratio through different NC techniques



is the enhanced version of RLNC. Here, XORNC, RLNC, CRLNC methods are compared and simulated. Results are compared for 100, 500 and 1000 packets. XORNC produces 80% results. RLNC produces 90% throughput. Due to the determinant problem, 10% of packets get dropped using RLNC while CRLNC overcomes the existing problem thus achieving 90 to 95% of reliable packet delivery.

7 Conclusion and Future Work

This work proposes a protocol based on cooperative communication that focusses on energy consumption of nodes and reliability of data packets. For this purpose, an integrated reliability model is adapted and the proposed hybrid technique is an incorporation of CEPRAN and CRLNC. A novel optimization algorithm is described for the relay node selection by enhancing the bio-inspired cuckoo search algorithm. The algorithm considers distance, energy, and path loss as the major parameters to decide which among the existing nodes can function as the relay node. It is found that the proposed protocol CEPRAN works well in comparison to earlier proposed protocol SIMPLE and iM-SIMPLE. The throughput of the proposed CRLNC protocol nearly reaches 93%. Such reliable delivery of biomedical packets can be used in many lifesaving applications. Incorporation of RLNC in the relay node has increased packet delivery ratio and reduces the retransmission. It is also found that the remaining residual energy at node level is greatly enhanced thus extending the life time of the network. Further work can be extended with mobility scenarios. Other Quality of Service delay metrics need to be analysed and the protocol testing in a real time hospital environment can be a further study.

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M. Geetha is an Assistant Professor in School of Computing Science and Engineering at Vellore Institute of Technology Chennai Campus since Jan 2012. She completed her Masters in Anna University, and now pursuing Ph.D. in the field of Wireless Body Area networks. She has published several research papers in the National and International journals. Her areas of research include WSN and IoT.



Dr. Ganesan Ramachandran is an Associate Professor in School of Computing Science and Engineering at Vellore Institute of Technology Chennai Campus since July 2012. Also, he is acting as an Assistant Director for the Office of International Relations and Outreach Programs from 2018 onwards. He was a program chair for B.Tech. Computer Science and Engineering during the year 2013–2017. He is one of the active members of the Board of Studies (BoS) for School of Computing Science and Engineering, VIT Chennai and other educational institutions and University. Earlier, he was an Associate Professor and Head of the Department at Computer Science Department, PSG College of Arts and Science, Coimbatore from 1998 to 2012. He is having more than 20 years of teaching experience. He obtained his Doctor of Philosophy in Computer Science from Bharathiar University, Coimbatore in the year 2011. His area of research work is Information Security and Network Security. Under his supervision, 3 of them have successfully completed their PhD in Computer Science and 4 of them are pursuing their PhD. He has published several research papers in the National and International Level Journals.