RB-IEMRP: RELAY BASED IMPROVED THROUGHPUT ENERGY-EFFICIENT MULTI-HOP ROUTING PROTOCOL FOR INTRA BODY SENSOR NETWORK (INTRA-WBSN)

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ABSTRACT

In this paper, we have proposed a Relay based Improved Throughput and Energy-efficient Multi-hop Routing Protocol (Rb-IEMRP) for the Intra Wireless Body Sensor Network (Intra-WBSN). Moreover, mathematical analysis has been presented, to calculate the minimum number of relay nodes require to be deployed corresponding to the bio-sensor nodes in Intra-WBSN. Normal sensing data from bio-sensor nodes forwarded to BNC through relay nodes while emergency data is directly transmitted to BNC. Relays nodes are placed in the patients' cloth. It can be easily replaced or recharged that facilitates effective health monitoring. The proposed routing protocol has achieved better network stability, network lifetime, energy efficiency and throughput as compared to Stable Increased Throughput Multi-Hop Protocol for Link Efficiency in Wireless Body Area Networks (SIMPLE) and Reliable Energy Efficient Critical Data Routing in Wireless Body Area Networks (REEC) routing protocols. It has been validated through simulation results.

KEYWORDS

Intra wireless body sensor network (Intra-WBSN), Body node coordinator (BNC), Relay, Wireless body sensor network (WBSN), Energy efficiency.

1. INTRODUCTION

Advancement in wireless communication with sensing technology, conventional health care technology has achieved a significant improvement through the Wireless Body Sensor Network (WBSN). It performs the different types of operations including patient monitoring, the performance of athletes, military, consumer electronics and, others [1, 2]. WBSN is continual monitoring of the patient's different biological information such as ECG signals, blood pressure, body temperature, glucose level, EEG, etc. Generally, the communication architecture of WBSN is divided into three different tiers: Intra-WBSN, Inter-WBSN and, Beyond-WBSN [3, 4]. Intra-WBSN communication is managed and controlled through implant and wearable bio-sensors. These bio-sensors are capable of sensing and processing human vital information and forward these data to a central network controller called body node coordinator (BNC). Normally personal digital assistant (PDA) or smart-phone is used for BNC in Intra-WBSN [5]. Inter-WBSN has established a communication link between Intra-WBSN and Beyond-WBSN. It acts as a bridge between Intra-WBSN and Beyond-WBSN. BNCs forward their data to one or more access points called sink. The sink is considered as a master node of health care monitoring infrastructure [1, 6]. Beyond-WBSN communication is designed for various applications and facilitates real-time health monitoring. Sinks forward their information to the medical destination or share its information to any other health monitoring destination via regular communicating infrastructure such as the internet, Wi-Fi, etc.

Through the integration of sensing technology with communication technology (CT), Intra-WBSN got an opportunity to provide comfortable, affordable and reliable health monitoring. These networks are generally short range (about 2 meters). The deployed bio-sensor nodes are powered by energy constraint batteries. Frequent replacement of batteries is not an easy task because it requires sophisticated medical procedures [7].

Extending the operational duration of such networks has paramount importance. So, the current research focuses on the energy capabilities of bio-sensor nodes which are associated with the network stability and network lifetime of Intra-WBSN [8]. The effective utilization of resources enhances the network life of Intra-WBSN. The communication strategy consumes about 80% energy of bio-sensor nodes [9]. Besides this, the routing protocol can play a significant role in providing effective communication between bio-sensor nodes. In most of cases, direct transmission of sensing data is not feasible due to limited transmitting distance of bio-sensor nodes. In the current research, multi-hop communication is a better choice to improve energy efficiency. Different routing algorithms have already been proposed to enhance the energy efficiency of Intra-WBSN. Those routing schemes considered two types of data; normal sensing data and emergency data. Sensing information from bio-sensor nodes less than a threshold value has been treated as normal data while sensing information greater than the threshold value has been considered as an emergency data. In uses of such protocols, normal sensing data is forwarded to BNC through multi-hop while emergency data is directly delivered to BNC [10-12]. Furthermore, a cost function has been introduced to select the intermediate (forwarder) node for multi-hop communication [13-16]. The selected intermediate node aggregates sensed data from other corresponding bio-sensor nodes and forward these data to BNC, which causes high energy dissipation of the forwarder node. These problems of high energy dissipation of forwarder nodes have overcome through the deployment of relay nodes.

In this paper, we have discussed the optimal number of relay nodes for deployed bio-sensor nodes and proposed a relay based data routing for the Intra-WBSN. Multi-hop topology is utilized to improve the energy efficiency of bio-sensor nodes. Normal sensing data is forwarded to BNC through deployed relay nodes while emergency data is directly communicated to BNC. The relay nodes reduce the transmitting distance of bio-sensor nodes which have two major advantages: (1) to protect the human tissues from heating effect and radiation, (2) to decrease the energy consumption of bio-sensor nodes during forwarding of the sensing data. The relay nodes are deployed in the patients' clothes. They can be easily replaced or recharged which permits easy maintenance of Intra-WBSN. Moreover, through simulation, it is verified that proposed routing protocol depicts better performance in comparison to Stable Increased Throughput Multi-Hop Protocol for Link Efficiency in Wireless Body Area Networks (SIMPLE) [13] and Reliable Energy Efficient Critical Data Routing in Wireless Body Area Networks (REEC) [16] routing protocols.

The remaining part of this paper is structured in different sections. Section 2 has summarized the related works. Optimal numbers of relay nodes for deployed bio-sensor nodes have been discussed in section 3. Section 4 has focused on terminologies and performance parameters. System model and details of the proposed data routing protocol have been described in section 5. Section 6 has discussed the simulation results and their comparative analysis. The conclusion of the work and future scope are discussed in section 7 and finally, references are provided at the end of the paper.

2. RELATED WORKS

Different data routing schemes have been proposed since the last decade by considering some major aspects, such as efficient energy utilization, quick and reliable delivery of sensing data, efficient bandwidth utilization, etc.

In [9], the authors exhibited that the placement of BNCs significantly influenced the energy efficiency and network lifetime of Intra-WBSN. Through proper metric selection, the authors proposed three different routing schemes for the placement of BNC. The authors show that the network lifetime can increase up to 47% through effective placement of BNC.

Authors in [17] proposed an energy-efficient RE-ATTEMPT routing protocol for patient monitoring through Intra-WBSN. The bio-sensor nodes are deployed according to their energy levels. The Body node coordinator (BNC) is placed at the centre of the human body. Emergency data is directly delivered (single-hop) to BNC while normal data is delivered through multi-hop communication. The operation of this routing protocol is completed in four different phases. Initially, all bio-sensor nodes and BNC broadcast a short message called Hello-message which contains bio-sensor node's ids, their deployment positions and available residual energy. The Selection of route is done on the basis of priority of data whether sensing data is normal or emergency. BNC allocates a time slot to all bio-sensor nodes to forward the sensing data. Finally, the sensed information is communicated within the assigned time slots.

In [18], the authors proposed the routing scheme (iM-SIMPLE) for Intra-WBSN. The proposed routing scheme achieved high throughput, energy efficiency and supported body posture movement. Multi-hop communication is utilized to enhance energy efficiency. Sensing data from bio-sensor nodes is forwarded to BNC through the intermediate node (forwarder node). The selection of forwarder nodes is based on the cost-function. The cost-function is the function of bio-sensor residual energy and distance between bio-sensor nodes and BNC.

Authors in [19] proposed a data cooperative routing mechanism (Co-LAEEBA) with minimum path-loss for the Intra-WBSN. Multi-hop and single-hop routing are utilized on the basis of data priority. The proposed routing algorithm introduced a cost function to select the most feasible route from bio-sensor nodes to BNC. Moreover, the cooperative routing scheme is facilitated to avoid redundant transmission. The proposed mechanism maximizes the network stability, network lifetime and throughput at the cost of increased delay.

In [20], the authors proposed a cost-effective and energy-efficient design for Intra-WBSN by introducing relay nodes. Energy-Aware WBAN Design Model (EAWD) is proposed for finding the optimum number of relay nodes and their deployed positions. Through the integer linear programming model, the proposed scheme minimizes nodes' energy consumption as well as network energy consumption and their installation cost. Authors in [22] proposed packet size optimization for intra-WBSN to increase energy efficiency. The authors discussed packet size optimization for the implant as well as wearable biosensor nodes through different error control codes. Authors illustrated that energy efficiency decreases when packet size increases after optimized the packet length.

3. ANALYSIS OF OPTIMAL NUMBER OF RELAY NODES

Let the area of Intra-WBSN $=M\times N$.
n= Number of bio- sensor nodes

K= Number of relays.

n/K= Number of bio-sensor nodes associated with relay.

Energy consumption of bio-sensor due to transmission

$$E_{Node} = L \times E_{elec} + E_{amp}.(L, d_{SR})$$

Where E_{elec}= Energy consumption required (per bit) to run electronic circuit.
d_{SR}= Distance between bio-sensor node and relay.

$$E_{Node} = L.E_{elec} + E_{efs}.L.d_{SR}^2 \qquad \text{if } d_{SR} < d_o \tag{01}$$

$$E_{Node} = L.E_{elec} + E_{amp}.L.d_{SR}^4 \qquad \text{if } d_{SR} > d_o \tag{02}$$

E_{efs} and E_{amp} are energy consumption (per bit) required by the power amplifier. Its value depend on the reference distance d_o. The value of d_o is 10 cm.

L= Packet size length of bio-sensor node

Energy consumption on single relay

$$E_R = \frac{n}{K}(L.E_{\mathrm{DA}}+L.E_{elec}) + E_{amp}.L.d_{RBNC}^4 \tag{03}$$

E_{DA}= Data aggregation energy of relay node.
d_{RBNC}= Distance between relay node and BNC.
Let relays are uniformly distributed so area occupied by each relay $\frac{\mathrm{M}\times\mathrm{N}}{K}$
Now energy consumption of a relay node and its associated nodes

$$E_{Relay} = E_R + (\frac{n}{K}).E_{Node} \tag{04}$$

$$E_{Relay} = \frac{n}{K}(L.E_{DA}+L.E_{elec}) + E_{amp}.L.d_{RBNC}^4 + \frac{n}{k}(L.E_{elec}+n.E_{amp}.L.d_{SR}^4) \tag{05}$$

From equation (03)and (05) total energy consumption of network

$$E_{Total} = K.E_{Relay}$$

$$E_{Total} = (2.n.L.E_{elec}+n.L.E_{DA} + n.E_{amp}.L.d_{SR}^4 + K.E_{amp}.L.d_{RBNC}^4) \tag{06}$$

Assuming that node transmitting antenna is Omni directional. The expected distance bio-sensor node to relay

$$\mathrm{E}\,(d_{SR}^4) = \iint (x^2 + y^2)^2 .\rho(x, y)dx.dy \tag{07}$$

Where ρ is the node density equation (07) can be expressed as

$$\mathrm{E}\,(d_{SR}^4) = \int_0^{2\Pi} \int_0^{\frac{M\times N}{\Pi\times K}} r^4.\rho.r.dr.dQ \tag{08}$$

Here $\rho = \frac{K}{M\times N}$
Equation (08) can be expressed as

$$E\,(d_{SR}^4) = \frac{2.\Pi K}{M \times N} \int_0^{\sqrt{\frac{M \times N}{\Pi .K}}} r^5\, dr \tag{09}$$

$$E\,(d_{SR}^4) = \frac{1}{3} \frac{(M \times N)^2}{((\Pi .K)^2} \tag{10}$$

Now the expected distance relay to BNC

$$E\,(d_{RBNC}^4) = \iint (x^2 + y^2)^2\, \rho_1(x,y) dx.dy \tag{11}$$

Equation 11 can express as

$$E\,(d_{RBNC}^4) = \int_0^{2\Pi} \int_0^{\frac{M \times N}{\Pi}} r^4 .\rho_1 .r\ .dr.dQ \tag{12}$$

Here $\rho_1 = \frac{1}{M \times N}$

$$E\,(d_{RBNC}^4) = \frac{2.\Pi}{M \times N} \int_0^{\sqrt{\frac{M \times N}{\Pi .}}} r^5\, dr \tag{13}$$

$$E\,(d_{RBNC}^4) = \frac{(M \times N)^2}{(\Pi)^2} \tag{14}$$

From equation (09) and (14) equation (06) can express as

$$E_{Total} = (\ 2.n.L.E_{elec} + n.L.E_{DA} + \ + n.E_{amp}.L.\frac{1}{3}\frac{(M \times N)^2}{(\Pi .K)^2} + \ K.E_{amp}.L.\frac{(M \times N)^2}{(\Pi)^2}) \tag{15}$$

For finding optimal number of relay we put $\frac{dE_{Total}}{dk} = 0$ then equation 15 can be written as

$$\frac{1}{3}\frac{(M \times N)^2}{(\Pi)^2} - \frac{2}{3}\frac{(M \times N)^2}{(\Pi^2 \times K^3)} \times n = 0$$

Hence optimum number of relay nodes are $K = (2 \times n)^{\frac{1}{3}}$ (16)

4. Terminologies and Performance Parameters for Intra-WBSN

The performance parameters and terminologies are defined in the following subsection.

1) *Stability period*: It is defined as the network operation time when the first node dies. After the stability period, the network becomes unstable.

2) Network residual energy: In every round, the average of remaining energy of all bio-sensor nodes is defined as network residual energy.

3) *Network lifetime*: The overall network operational time from the network establishment to the death of the last node is defined as network lifetime.

4) *Throughput:* The Total number of packets received successfully at BNC is called throughput.

5*) Data aggregation:* In Intra-WBSN, intermediate nodes gather the sensing information from bio-sensor nodes. They aggregate and forward information to BNC.

6) *Alive node:* The bio-sensor node which still has the remaining energy to forward the sensing data.
7) *Dead node:* The bio-sensor node which has residual energy less than required the transmission energy.
8) *Relay node*: This node has more energy than that of normal bio-sensors. Relay nodes aggregate sensing data from its corresponding bio-sensor nodes and forward them to BNC.

5. RB-IEMRP: THE PROPOSED PROTOCOL

In Rb-IEMRP, a relay-based data routing scheme has been proposed for Intra-WBSN to achieved efficient energy utilization of the bio-sensor node so that the network can operate for the longer duration of time. Multi-hop topology is utilized for normal data while emergency data is directly forwarded to BNC. To validate the improvement of Rb-IEMRP, we have compared its performance with existing routing protocols SIMPLE [13] and REEC [16]. Protocol details are described in the following sub-sections.

5.1 Network Model

In our proposed scheme, it is assumed that the human body is in the standing position. The placement of BNC is the centroid of deployed bio-sensor nodes. We deployed ten bio-sensor nodes as shown in Figure 1. The network consists of three types of nodes, wearable, implant and relay nodes. According to the mathematical model discussed in section III, the optimal number of relay nodes for the average height of the human body is 2.71. It is concluded that either two or three relay nodes can be placed. CHIPCON CC240 and NORDIC nRF2401A transceivers are commonly used for Intra-WBSN. NORDIC nRF2401A is deployed in a single chip and it consumes less energy in comparison to CHIPCON CC240. The transmission coverage of NORDIC nRF2401A is less than 40 cm [21]. So, to minimize the transmitting coverage of bio-sensor nodes, we placed three relay nodes. A brief summary of implant and wearable nodes are discussed in Table 1. The location of the wearable and implant node is described in Table 2. The Positions of relay nodes are discussed in Table 3. To improve energy efficiency, we vary the packet size depending on whether the bio-sensor nodes wearable or implantable [22]. Furthermore, for simplicity in calculation, deployed bio-sensor nodes have the same energy of about 0.5 Joule each while each relay node has the energy of about 1Joule.

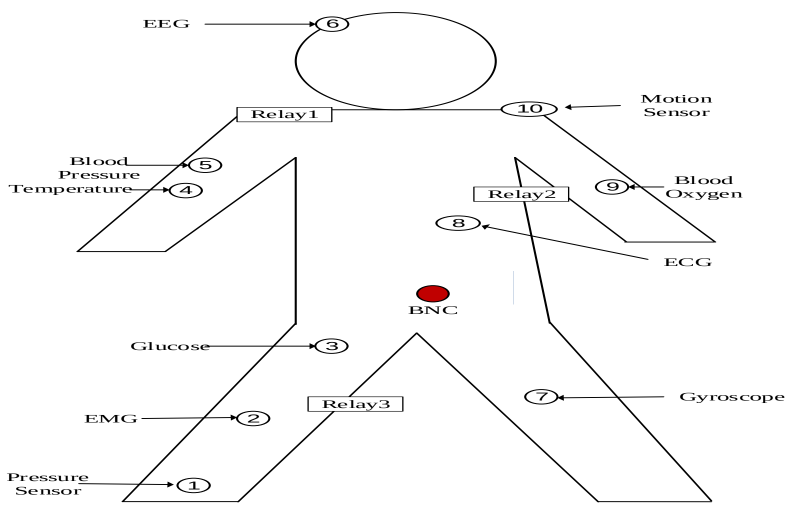

Figure 1: Deployment of bio- sensor nodes

Table 1: Bio-sensor function and their deployment [3, 7 and 8]

Bio-Sensor	Function	Deployment
Pressure	Measuring pressure distribution of human body.	Wearable
EMG	Nerve conducting electrical information are measured which is produced by human muscles	Wearable
Glucose	Measure the quantity of glucose which is circulating in the blood.	Implantable
Temperature	Monitoring the human body temperature	Wearable
Blood Pressure	Measure the peak pressure of systolic and minimum pressure of diastolic	Wearable
Motion	Monitor the physical movement of human body.	Wearable
EEG	Monitor electrical activities of human's scalp.	Wearable
Accelerometer/ Gyroscope	Monitor and recognize the posture movement of human body	Wearable
ECG	Monitoring human cardiac activity.	Wearable
Blood Oxygen	Measure the oxygen saturation for human blood	Wearable

5.2 Network Configuration Phase

BNC broadcasts a short message (HELLO message) to all nodes which contain the position of BNC in the body. Every bio-sensor and relay node receives this HELLO message and stores the deployed position of BNC. Then all bio-sensor nodes and relay nodes transmit a short message, which contains their ID, deployment position and available residual energy in every round. In this way, all bio-sensor nodes relay nodes, and BNC update their positions, available residual Energy and the optimum route to BNC. The Content of a hello message is illustrated in Figure 2.

Table 2: Deployment of bio-sensor nodes [1, 2]

Sl. No	Bio sensor name	*x* coordinate(m)	y coordinate(m)
1	Pressure	0.15	0.12
2	EMG	0.20	0.40
3	Glucose	0.30	0.70
4	Temperature	0.15	1.20
5	Blood Pressure	0.40	0.50
6	EEG	0.20	1.35
7	Gyroscope	0.55	0.45
8	ECG	0.80	1.25
9	Blood Oxygen	0.90	1.21
10	Motion Sensor	0.85	1.60

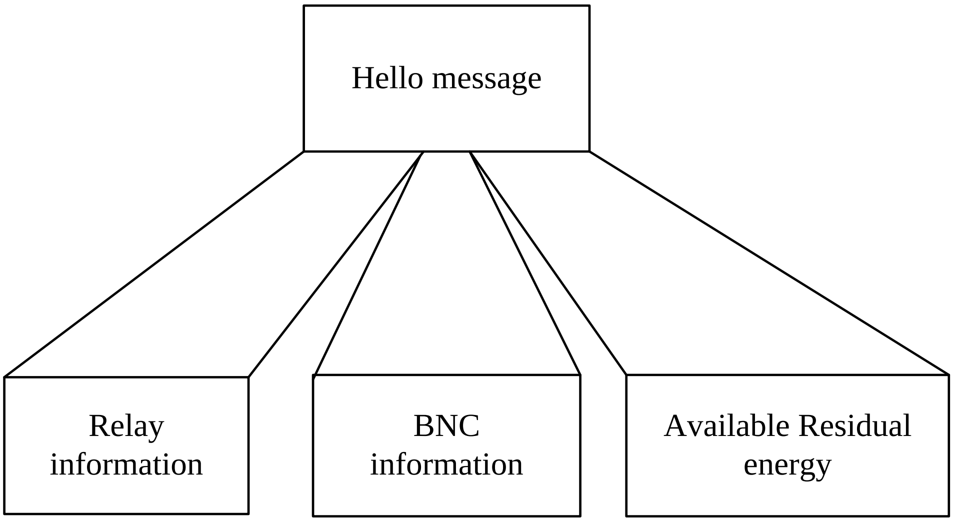

Figure 2: Format of HELLO message

Table 3: Position of relay nodes

x coordinate(m)	y coordinate(m)
0.23	1.43
0.85	1.38
0.30	0.41

5.3 Data Routing and Communication Flow

To enhance efficient utilization of energy conservation, Rb-IEMRP introduced a relay based routing scheme. Bio-sensor nodes 4, 5, 6 are assigned to relay 1, bio-sensor nodes 8, 9, 10 are assigned to relay 2 and bio-sensor nodes 1, 2, 3, 7 are assigned to relay 3. Relay nodes aggregate normal sensing data and forward these data to BNC. In the case of emergency, data from bio-sensor nodes is directly forwarded to BNC. Moreover, if distance between the bio-sensor and BNC is less than that of distance between bio-sensor node and relay, the bio-sensor node directly forwards data to BNC. The communication flow diagram of the proposed routing scheme is shown in Figure 3.

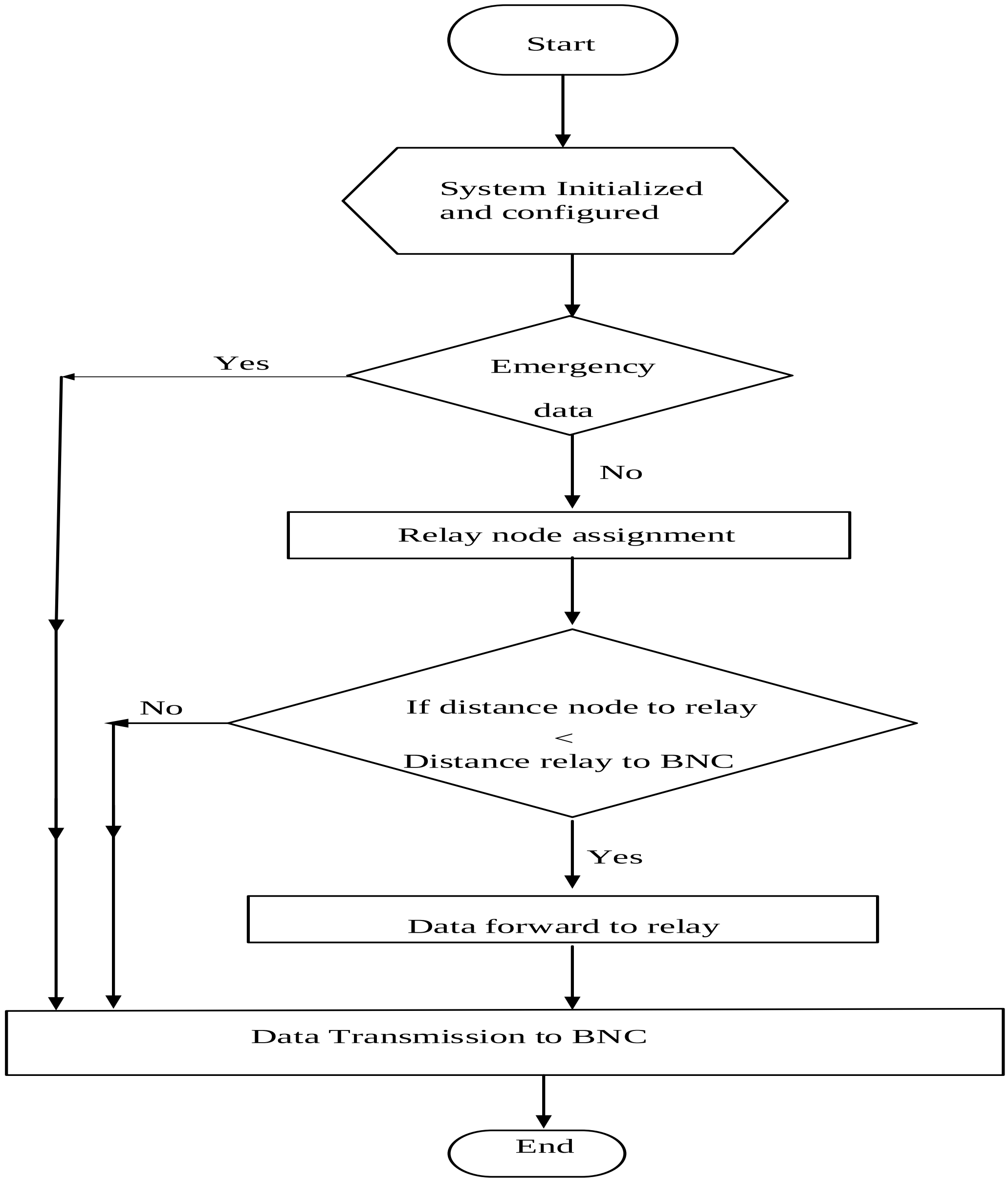

Figure 3. Flowchart of Rb-IEMRP

6. Simulation Results and Discussion

The performance of the Rb-IEMRP routing scheme has been analyzed through simulation. To validate the performance, simulations are executed five times and the average of results is plotted. Each simulation executes over 18000 rounds. The value of simulation parameters is given in Table 4. To evaluate the performance of the proposed Rb-IEMRP protocol, we compared its performance with the existing routing scheme SIMPLE [13] and REEC [16]. Different performance parameters like network stability, network lifetime, residual energy and throughput have been evaluated in the next section.

Table 4: Simulations Parameters

Parameters	value
Number of nodes	10
$E_{trans-elect}$	16.7 nJ/bit
$E_{rec-elect}$	36.1 nJ/bit
ϵ_{amp}	1.97 nJ/bit/mn
DC current(Tx)	10.5 mA
DC current(Rx)	18 mA
Supply voltage(min)	1.9 V
Packet size(Implant Sensor)	3000
Packet size(Wearable Sensor)	2000
Initial energy of bio-sensor node (E_o)	0.5J
Initial energy of relay node(E_{1_o})	1.0J

6.1 Stability Period and Network Lifetime

Figure 4 and Table 5 have described the comparison of a number of the dead node after the equal number of rounds. Figure 5 shows the comparison of network stability and network lifetime of SIMPLE, REEC ,and Rb-IEMRP. Relay-based scheme showed a significant role to balance the energy consumption of bio-sensor nodes. The proposed routing scheme Rb-IEMRP got better results in comparison to existing routing protocols. In the case of network stability and network lifetime discussed in Figure 5, Rb-IEMRP and SIMPLE have almost the same network stability and 52% more stable in comparison to REEC. In the proposed routing schemes, the average network lifetime has achieved the increment of 37% and 16% respectively in comparison to REEC and SIMPLE routing protocols.

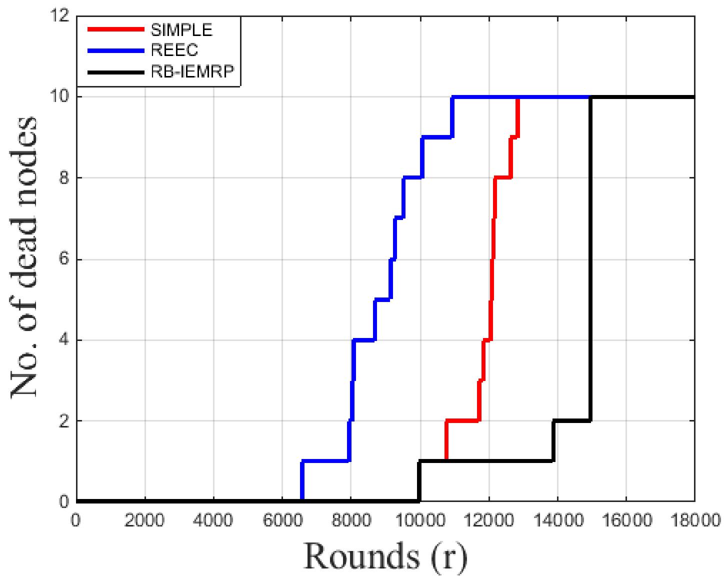

Figure 4. Number of dead nodes Vs. rounds(r)

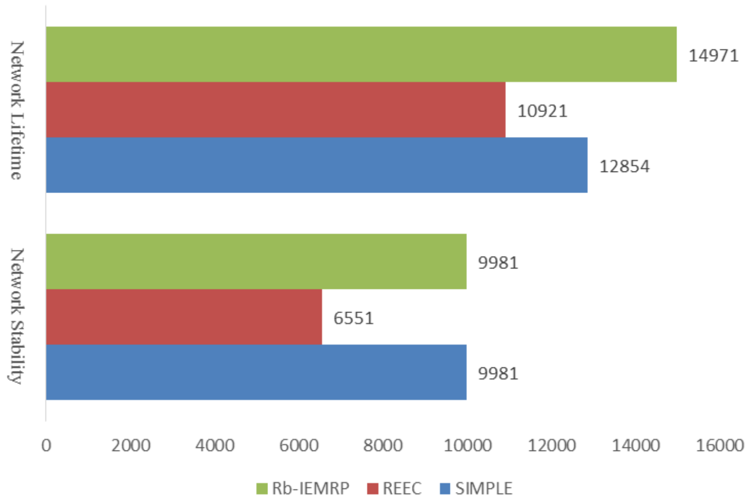

Figure 5. Comparison of network stability and network life time in rounds(r)

Table.5: Number of nodes dead after equal no of rounds (r)

Sl. No	Name of routing Protocol	Node died after equal number Vs rounds (r)								
		7000	8000	9000	10000	11000	12000	13000	14000	15000
1	SIMPLE	NIL	NIL	NIL	NIL	1	4	10	10	10
2	REEC	1	2	5	8	10	10	10	10	10
3	RB-IEMRP	NIL	NIL	NIL	NIL	1	1	1	2	10

6.2 Residual Energy

The energy consumption of the network in each round is described in Figure 6 and Table 6. The initial energy of each bio-sensor node is 0.5J. Thus, the total energy of the network is 5.0J. Our proposed protocol used a multi-hop mode of communication through relay nodes. The Bio-sensor node forwards the sensing data to its assigned relay node. Since the relay nodes minimize the transmitting range of bio-sensor nodes, the energy consumption of bio-sensor nodes is reduced. Rb-IEMRP has better residual energy in comparison to existing protocols.

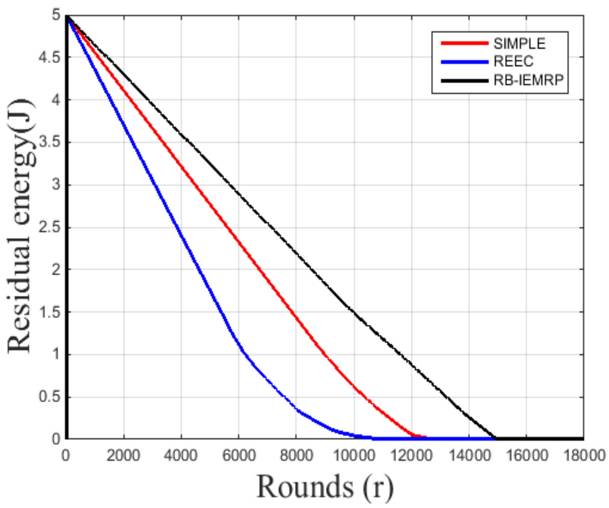

Figure 6. Comparison of network residual energy

Table 6. Network residual energy after equal no of rounds (r)

Sl. No	Name of routing Protocol	Residual energy after equal number Vs. rounds (r)								
		7000	8000	9000	10000	11000	12000	14000	15000	16000
1	SIMPLE	1.879	1.4333	0.996	0.619	0.316	0.064	0	0	0
2	REEC	0.701	0.355	0.355	0.155	0.044	0	0	0	0
3	RB-IEMRP	2.540	2.189	1.837	1.487	1.186	0.881	0.567	0.259	0

6.3 Throughput

The total number of packets received successfully at BNC is defined as throughput. For a health care monitoring system, a routing scheme should have maximized throughput. A number of the packet received at BNC depends on the average network life of Intra-WBSN. The Average network life corresponds to the number of bio-sensor nodes alive. More the number of bio-sensor nodes alive, greater is the probability of packet received at BNC. Figure 7and Table 7 described that the Rb-IEMRP protocol achieved higher throughput in comparison of the existing protocol.

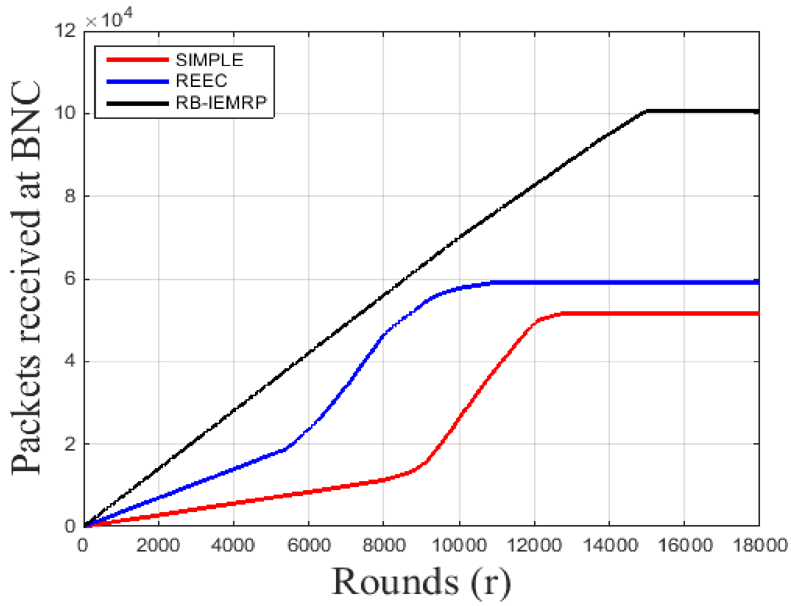

Figure 7. Comparison of throughput

Table 7: Through Put after equal no of rounds (r)

Sl. No	Name of routing Protocol	Throughput after equal number of rounds (r)						
		4000	6000	8000	10000	12000	14000	16000
1	SIMPLE	5626	8418	11236	26201	49006	51708	51708
2	REEC	14036	23693	46533	57877	59263	59263	59263
3	RB-IEMRP	28044	42003	55990	69967	82609	95134	100530

7. CONCLUSION

A relay based Rb-IEMRP routing protocol has been proposed to enhance throughput and energy-efficiency for Intra-WBSN. Bio-sensor nodes are strategically placed on the human body to monitor normal data as well as emergency data. The Optimal number of relay nodes for deployed bio-sensors has been analyzed. Relay nodes have been placed at appropriate places to enhance the performance of Rb-IEMRP. With the help of linear programming, it is validated that the proposed scheme depicted better performance in comparison to the existing routing protocols in terms of performance parameters like stability period, network lifetime, residual-energy and throughput with a marginal increase in the cost for deployment of relay nodes.

Our future works are focused on energy efficient routing schemes for body posture movement.

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