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Co-REERP: Cooperative Reliable and Energy Efficient Routing Protocol for Intra Body Sensor Network (Intra-WBSN)

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Abstract

Intra-WBSN are generally short range wireless health monitoring networks, consisting of strategically placed miniaturized, intelligent and low powered bio-sensors. They perform various applications in healthcare, fitness, military, sport and consumer electronics. The network stability and the network longevity of such networks have prime focus in current research. Routing schemes have a significant potential to make such network energy efficient by sending the sensing data properly and promptly. In this paper, we have proposed a relay based cooperative routing scheme to achieve high energy efficiency. Sensing data from the bio-sensor node have been delivered on the basis data priority. The sensing data with high priority has been directly transmitted to body network controller (BNC). The delivery of normal sensing data from bio-sensor to the BNC through relay nod or cooperative node. These nodes are deployed in clothes, they can be easily replaced or recharged, it provide effective, easy and comfortable health monitoring. Through simulation results, the proposed routing protocol achieved improved performance in terms of energy efficiency, network stability, network lifetime, path-loss and throughput in comparison to the existing routing schemes.

Keywords Intra wireless body sensor network (Intra-WBSN) · Body network coordinator (BNC) · Energy efficiency · Relay

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1 Introduction

Promising advancement in the miniaturisation of integrated circuit, sensing technologies and wireless communication, Intra-WBSNs have got an opportunity to provide a comfortable, affordable and reliable health monitoring [1, 2]. Strategically placed bio-sensor nodes can monitor different human biological information such as blood pressure, EEG, ECG signals, body temperature, glucose level, etc., [3, 4]. The three-tier hierarchical communication architecture is required to send the sensing information from bio-sensor nodes to the medical experts or any required medical centre. Intra-WBSN is the first tier star topology network. It is managed and regulated through implant and wearable bio-sensors. These bio-sensor nodes are sense the vital information, process and forward it to the central controller called body network coordinator (BNC). Normally a PDA or a smart phone is used as BNC [5, 6]. In the second tier, Inter-WBSN communication establishes a communication link between Intra-WBSN and beyond-WBSN [7]. Data is collected by different BNCs and forwarded to one or more access points called sinks. These are equipped with large storage capacity, high processing speed and excessive energy source. Sinks are considered as master node in health care monitoring infrastructure [1, 6]. Beyond-WBSN is the last stage, it provides the real time health monitoring. It is designed to communicate with the outer-world. Sinks forward their data to the medical expert or the required health-monitoring destination by using regular communicating infrastructure such as internet, Wi-Fi, etc., [8, 9].

Intra-WBSNs are usually a short range (about two meters) wireless sensor networks, which are composed of bio-sensor nodes. These nodes are characterized by small size, less storage, less processing capabilities and energy constraint resources. Since bio-sensor nodes have energy constraint battery power, the regularly replacement of its battery is a sophisticated medical procedure [10]. Intra-WBSN can be more energy efficient by the effective utilization of resources. So the efficient energy utilization of bio-sensor nodes have got the prime focus in current research. This associates the network stability and network lifetime of Intra-WBSN.

Due to limited transmission range of bio-sensor nodes, direct transmission of the sensing data is not feasible in most of the cases. Cooperative communication is better choice to reduce transmission distance. It is the most favorable solution to mitigate the effect of fading and increases robustness in wireless communication. In cooperative communication, source nodes transmit their sensing data through intermediate node or direct link. Recent research shows that there are significant improvements in intra-WBSN's performance by employing cooperative schemes.

Routing protocols play a major role to provide effective communication between the bio-sensor nodes and BNC. To increase the energy efficiency of Intra-WBSN, different routing schemes have been proposed. It consider two types of sensing data, normal and emergency data. Emergency data is directly transmitted to BNC while normal sensing data is forwarded to BNC through multi-hop [11]. In the case of multi-hop communication, a forwarder node or intermediate node is selected among the bio-sensor nodes. Forwarder nodes are selected on the basis of cost function [12, 13]. These nodes aggregate sensing data from its bio-sensor nodes and forward it to the BNC. It causes high energy dissipation of forwarder nodes. Through the deployment of the relay node, it minimize the energy dissipation of forwarder nodes.

In this paper, a relay based cooperative data routing schemes for Intra-WBSN has been proposed. It minimized the transmitting power of bio-sensor node by reducing the transmitting distance. It has two major advantages, (1) minimize the energy consumption of bio-sensor nodes during transmission of sensing data. (2) protects the human tissue from heating effect and radiation. The relay nodes have been deployed in the patient's cloth. They can be easily recharged or replaced, it assists in easy maintenance of Intra-WBSN. Through the MATLAB simulation results, it is verified that the proposed routing protocol achieved better performance in comparison to RE-ATTEMPT [11] and Co-LAEEBA [13] routing protocols.

The remaining parts paper has been organized as follow. Section 2 has summarized the related works. Cooperative communication model for Intra-WBSN has been discussed in Sect. 3. Section 4 has been described the analysis of energy consumption and outage probability. Working details of proposed data routing protocol are presented in Sect. 5. Simulation results and their analysis has been described in Sect. 6. Section 7 has conclude the work with future scope, finally references have been provided at the end of the paper.

2 Related Work

In last decade, many data routing algorithm have been proposed by considering some major aspects, such as efficient energy utilization, efficient bandwidth utilization quick and reliable delivery of sensing data etc.

Authors in [14], have discussed the packet size optimization for Intra-WBSN. Through different error control codes, this optimization has been analyzed for implant as well as wearable bio-sensor nodes. Authors have illustrated that the energy efficiency increases with the increase in packet size till optimal packet length. However, the energy efficiency has been found to decrease with further increase in packet size after optimal length.

In [15], by the introducing relay nodes, authors proposed an energy-efficient and cost-effective design for Intra-WBSN. Energy aware Intra-WBSN design model is used for finding optimum number of relay nodes and their deployed position. Through integer linear programming model, the proposed scheme minimizes the energy consumption of bio-sensor nodes as well as that of network and also reduces their installation cost.

The authors in [16], have discussed that the placement of BNCs have significantly influence in the energy efficiency and the network lifetime of Intra-WBSN. To analyze the energy efficiency, bio-sensor residual energy and the transmitting distance are the significant metric. By selection of these metric, authors have placed the BNC at three different place around the body, proposed three routing scheme for Intra-WBSN and finally conclude that, the network life time can be enhance up to 47% through effective placement of BNC.

Authors proposed RE-ATTEMPT [11], an energy efficient routing protocol for Intra-WBSN. The placing of the bio-sensors nodes are according to its energy levels. The high energy bio-sensor nodes are deployed near the BNC while BNC is placed at center of human body. Emergency data is directly transmitted (single-hop) to BNC while normal data has delivered through multi-hop communication.

In [12], authors have proposed iM-SIMPLE routing scheme for Intra-WBSN. The proposed routing scheme have achieved high throughput, energy efficiency and support the body posture movement. To minimize the energy consumption, multi-hop communication has been utilized. On the basis of cost-function, the forwarder node or intermediate node has been selected. Normal sensing data from bio-sensor nodes is forwarded to BNC through the forwarder node while energy data is directly transmitted to BNC.

In [13], the authors have proposed Co-LAEEBA, a cooperative data routing mechanism. The cooperative scheme has significant affect in the increment of energy efficiency and the minimization path loss of Intra-WBSN. On the basis of data priority, single-hop and multi-hop routing has been utilized. It has introduced the cost function to select the most feasible route from bio-sensor nodes to BNC. By the application of cooperative scheme, the proposed mechanism has achieved higher network stability, throughput and network lifetime at the cost of increased delay.

Authors in [17] have proposed a relay based cooperative communication scheme for intra-WBSN. With different relay nodes, an analytical model for packet error rate (PER) and energy efficiency (EE) has been analyzed. A routing algorithm, enhance incremental cooperative critical data transmission in emergencies for static Intra-WBSN (EInCo-CESat) has been proposed for Intra-WBSN. The proposed algorithm achieved better network stability, less packet error rate (PER) and high throughput at cost of high energy consumption.

3 Cooperative Communication Model for Intra-WBSN

We have consider three types of nodes in Intra-WBSN (Fig. 1), i.e., bio-sensor nodes (S), cooperative node or relay nodes (R) and BNC. Bio-sensor nodes are responsible to sense, process the human vital information and forward it to either cooperative node or BNC. Relay nodes are intermediate nodes used to forward data to BNC while BNC receives, manipulate and send the data to the outer world. Two types of communication phases

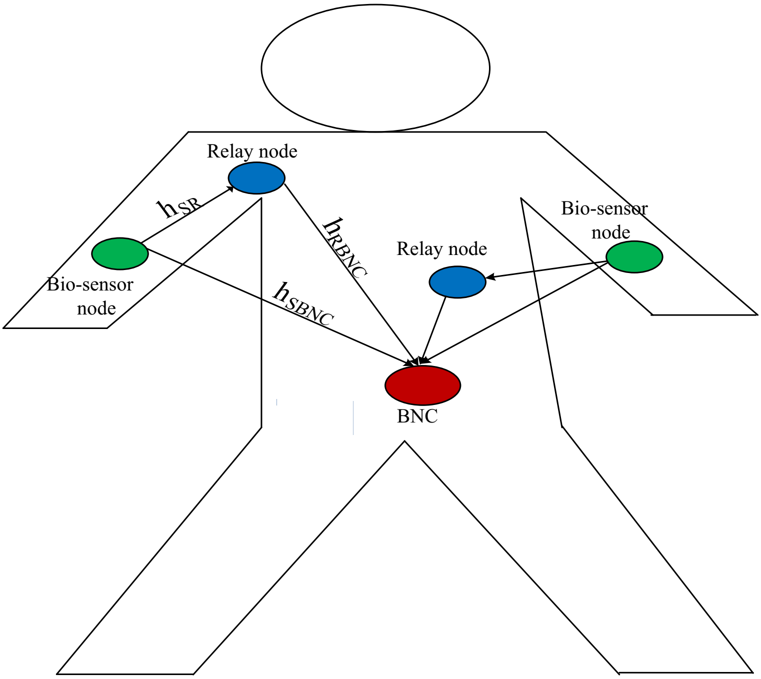


Fig. 1 Cooperative communication model for Intra-WBSN

are considered. In the first phase, normal sensing data of bio-sensor nodes are forwarded through relay nodes while critical data are directly delivered to BNC. In the second phase, relay nodes aggregate the received sensing data and forward them to BNC. In the first phase, information received at relay node and BNC can expressed as

$$Y_{SR} = H_{SR}X_s + N_{SR} \tag{1}$$

$$Y_{SBNC} = H_{SBNC}X_s + N_{SBNC} \tag{2}$$

where X_s is symbol transmitted from bio-sensor nodes (S). H_{SR} and H_{SBNC} are channel characteristic of wireless medium from bio-sensor nodes to relay and bio-sensor nodes to BNC respectively. Noise component of these channels are N_{SR} and N_{SBNC} respectively. These noise component are characterized with zero mean and variance σ^2 and denoted as $N \sim (0,\sigma^2)$. Information is transmitted from either bio-sensor node to relay node or bio-sensor node to BNC, encounter path-loss and fading which leads to link failure. Including fading and path-loss, Eqs. 1 and 2 can be expressed as

$$Y_{SR} = \left[S_{SR}\left(PL_{OSR} + 10.n.\frac{d_{SR}}{d_0}\right)\right]X_S + N_{SR} \tag{3}$$

$$Y_{SR} = \left[S_{SBNC}\cdot\left(PL_{OBNC} + 10.n.\frac{d_{SBNC}}{d_0}\right)\right]X_S + N_{SBNC} \tag{4}$$

S_{SR} and S_{SBNC} are fading coefficients which are multiplicative in nature.d_{SR} is distance between bio-sensor node and relay node.d_{SBNC} is distance between relay node and BNC. Equations 3 and 4 can be expressed as [18].

$$Y_{SR} = \left[a_o e^{j\phi_o}\left(PL_{OSR} + 10.n.\frac{d_{SR}}{d_0}\right)\right]X_S + N_{SR} \tag{5}$$

$$Y_{SR} = \left[a_1 e^{j\phi_1}\left(PL_{OBNC} + 10.n.\frac{d_{SBNC}}{d_0}\right)\right]X_S + N_{SBNC} \tag{6}$$

where a_o, a_1 and ϕ_o, ϕ_1 are amplitude and phase components due to fading between bio-sensor and relay and relay to BNC respectively. In second phase, relay nodes receive the sensing data from the corresponding bio-sensor nodes, aggregate, process and forward it to BNC. Information received at BNC is expressed as

$$Y_{RBNC} = \left[S_{RBNC}\left(PL_{ORBNC} + 10.n.\frac{d_{RBNC}}{d_0}\right)\right]X'_S + N_{RBNC} \tag{7}$$

where S_{RBNC} is fading coefficient between relay node and BNC. d_{RBNC} is distance between relay and BNC. N_{RBNC} is Gaussian noise between relay node and BNC, which is also characterized with zero mean and variance σ^2 and denoted as $N \sim (0, \sigma^2)$. X'_S is information transmitted symbols from relay node to BNC. Equation 7 can expressed as [18].

$$Y_{SR} = \left[a_2 e^{j\phi_2}.\left(PL_{ORBNC} + 10.n.\frac{d_{RBNC}}{d_0}\right)\right]X'_S + N_{RBNC} \tag{8}$$

where a_2 and ϕ_2 are amplitude and phase components due to fading between relay and BNC.

4 Analysis of Energy Consumption and Outage Probability

The energy consumption of bio-sensor nodes depends on power consumed in RF circuitry, distance between bio-sensor and destination node and bit rate. Energy consumption in the case of direct transmission [19] can be expressed as.

$$E_{SBNC} = \frac{P_{PA}^{SBNC} + P_{Trans} + P_{reciever}}{R_b} \tag{9}$$

where $P_{PA}^{SBNC} = \left(\frac{\beta}{Y}\right)P_{SBNC}$, is the consumption of power by the power amplifier for the transmission of packet.β is PAR: peak to average ratio, it depends on the modulation scheme. Y is drain efficiency of transmit amplifier. P_{SBNC} is the power required by bio-sensor nodes to transmit its sensing data to BNC. P_{Trans} and $P_{reciever}$ are the power consumptions due to internal circuitry of transmitting and receiving antenna. R_b is data rate in bit/s.

In fading channel, outage probability is the most widely used performance metric in cooperative communication. It provides a suitable condition for the data transmission over the channel. when signal to noise ratio (SNR) at receiver falls below outage threshold λ_{th}, outage occurs. It is expressed as $2^{\Delta} - 1$, where Δ is the spectral efficiency. For data transmission between bio-sensor nodes and BNC, Outage probability ($\mathcal{O}_{S-BNC}$) in Gamma distribution fading can express as [20].

$$\mathcal{O}_{S-BNC} = \mathcal{O}\left(SNR_{S-BNC} < \lambda_{th}\right) = \frac{\Psi\left(m, \beta^{v}\lambda_{th}^{v}N/(P_{PA}^{SBNC}SNR_{SBNC})^{v}\right)}{\Gamma(m)} \tag{10}$$

where $\beta = (\Gamma(m+1)/v)/\Gamma(m)$, m is fading coefficient, v is shape parameter. $\Psi(x,y) = \int_0^y z^{x-1}\exp(-z)dz$ is an incomplete gamma function. $\Psi(x) = \int_0^\infty z^{x-1}\exp(-z)dz$ is complete Gamma function. At high SNR, $\Psi(x,y) \sim \left(\frac{1}{x}\right).\ y^x$ [21]. N is the noise power spectral density. So outage probability between bio-sensor node and BNC can be expressed as

$$\mathcal{O}_{S-BNC} = \frac{1}{\Gamma(m+1)}(\beta^{v}\lambda_{th}^{v}N/P_{PA}^{SBNC}SNR_{SBNC})^{m} \tag{11}$$

The energy consumption in cooperative communication can be express as

$$E_{CC} = \mathrm{P}_{\mathrm{SR}}.\frac{P_{PA}^{SR} + P_{Trans} + P_{reciever}}{R_b} + \left(1 - \mathrm{P}_{\mathrm{SR}}\right).\frac{2P_{PA}^{SR} + 2P_{Trans} + 2P_{reciever}}{R_b} \tag{12}$$

where $P_{PA}^{SR} = \left(\frac{\beta}{Y}\right)P_{SR}$. In Eq. (12), the first term correspond to the energy consumption if relay node is not able to decode correctly. Second term corresponds to the energy consumption when relay node is able to decode successfully and forward data to BNC. For multi-hop communication, outage probability of individual link between bio-sensor node and relay can be expressed as

$$\begin{aligned} \mathcal{O}_{S-R} &= \mathcal{O}\left(SNR_{S-R} < \lambda_{th}\right) = \frac{\Psi\left(m, \beta^{v}\lambda_{th}^{v}N/(P_{PA}^{S-R}SNR_{S-R})^{v}\right)}{\Gamma(m)} \\ \mathcal{O}_{S-R} &= \frac{1}{\Gamma(m+1)}\left(\beta^{v}\lambda_{th}^{v}N\big/P_{PA}^{S-R}SNR_{S-R}\right)^{m} \end{aligned} \tag{13}$$

Similarly, outage probability of link between relay node and BNC can be expressed as

$$\mathcal{O}_{R-BNC} = \mathcal{O}\left(SNR_{R-BNC} < \lambda_{th}\right) = \frac{\Psi\left(m, \beta^{v}\lambda_{th}^{v}N/(P_{PA}^{R-BNC}SNR_{R-BNC})^{v}\right)}{\Gamma(m)} \tag{14}$$

$$\mathcal{O}_{R-BNC} = \frac{1}{\Gamma(m+1)}(\beta^{v}\lambda_{th}^{v}N/P_{PA}^{R-BNC}SNR_{R-BNC})^{m} \tag{15}$$

The overall outage probability for cooperative communication is express as the combination of each outage link.

$$\begin{aligned} \mathcal{O} = {} & \frac{1}{\Gamma(m+1)}\left(\beta^{v}\lambda_{th}^{v}N\big/P_{PA}^{S-R}SNR_{SBNC}\right)^{m} + \left(1 - \frac{1}{\Gamma(m+1)}\left(\beta^{v}\lambda_{th}^{v}N\big/P_{PA}^{S-R}SNR_{SBNC}\right)^{m}\right) \\ & \times \frac{1}{\Gamma(m+1)}(\beta^{v}\lambda_{th}^{v}N/P_{PA}^{R-BNC}SNR_{R-BNC})^{m} \end{aligned} \tag{16}$$

5 Co-REERP: The Proposed Protocol

In Co-REERP, relay based cooperative data routing protocol is proposed for Intra-WBSN. Cooperative scheme is utilized for the delivery of normal sensing data while the critical data is directly transmitted to BNC. To validate the improvement of Co-REERP, we compared its performance with existing routing protocols RE-ATTEMPT [11] and Co-LAEEBA [13]. The detail of Co-REERP has been discussed in the following sub-sections.

5.1 Network Model

In the proposed scheme, it is supposed that the human body is in standing phase. Ten bio-sensor nodes are deployed as shown in Fig. 2. The placement of BNC at the centroid of placed bio-sensor nodes. The Intra-WBSN consists of three types of nodes relay, implant and wearable nodes. CHIPCON CC240 and NORDIC nRF2401A transceivers are generally used for Intra-WBSN. NORDIC nRF2401A consume less energy and it is deployed on a single chip in comparison of CHIPCON CC240. The transmission range of NORDIC nRF2401A is less than 40 cm [21]. To reduce the transmitting distance of bio-sensor nodes we deploy three relay nodes. A brief summary about wearable as well as implant bio-sensor nodes are described in Table 1. Location of wearable and implant node are discussed in Table 2. Positions of relay nodes are discussed in Table 3. To improve the energy efficiency, the packet size has been varied on the characteristic of bio-sensor, whether it is wearable or implantable [15]. For simple calculation, it is assumed that all placed bio-sensor nodes have same energy about 0.5 J while relay node has energy about 1 J.

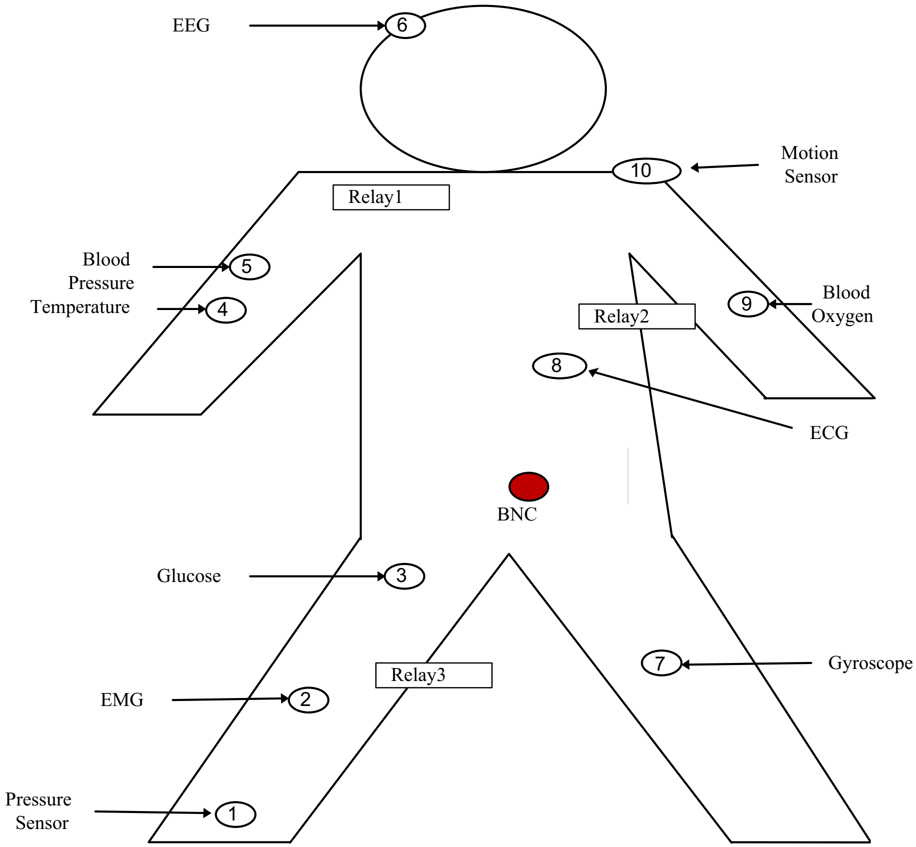


Fig. 2 Deployment of body sensor nodes [3–5]

Table 1 Bio-sensors deployment and their functions [3, 7, 8]

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

Table 2 Bio-sensors deployment [3, 7, 8]

S. no.	x coordinate (m)	y coordinate (m)
1	0.15	0.12
2	0.20	0.40
3	0.30	0.70
4	0.15	1.20
5	0.40	0.50
6	0.20	1.6
7	0.55	0.45
8	0.80	1.25
9	0.90	1.21
10	0.85	1.60

Table 3 Position of relay node

Position of relay	*x* coordinate (m)	y coordinate (m)
1	0.23	1.43
2	0.85	1.15
3	0.30	0.41

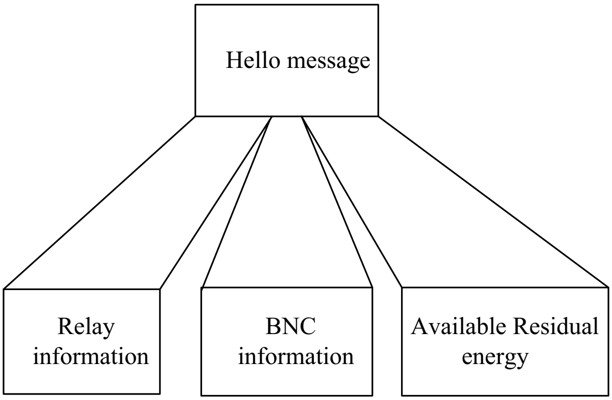


Fig. 3 Containt of HELLO message

5.2 Network Setup Phase

In the network set up phase, BNC broadcasts the HELLO message to its bio-sensor nodes, it contains the location of BNC in the body. Each bio-sensor node receives this message and stores the position of BNC. Then each bio-sensor nodes transmit a short message which contains its deployed position, its identification number and available residual energy in every round. In this way, all bio-sensor nodes update the position of BNC, available residual energy, relays information and optimum route to BNC. The content of hello message has been illustrated in Fig. 3.

5.3 Data Routing and Communication flow

To increase energy efficiency, Co-REERP introduced a relay based routing scheme. Bio-sensor nodes 4, 5 and 6 are attached with relay 1, bio-sensor nodes 8, 9 and 10 are assigned to relay 2 and bio-sensor nodes 1, 2, 3 and 7 are assigned with relay 3. Relay nodes receives the normal sensing data from its corresponding bio-sensor node, aggregate it and forward them to the BNC. In the case of critical sensing data, bio-sensor nodes directly transmit to BNC. Furthermore, for the normal sensing data of, if the distance between bio-sensor node and BNC is less than that of distance between bio-sensor node and relay, then bio-sensor nodes directly transmit data to BNC, else data is forwarded through relay. The communication flow diagram of the proposed routing scheme has been depicted in Fig. 4.

5.4 Path-Loss Selection Phase

Basically, the path-loss is the difference between transmitted power and received power. It is measure in decibels (dB). In Intra-WBSN, it is experienced due to the conductive behavior of human body, dielectric constant of different body parts and communication standards. The communication standards being MICS band, Bluetooth (IEEE802.15.1), ZigBee (802.15.4) and UWB (802.15.6). Path loss comprises of all the consequences linked with propagation path and physical object between transmitter and receiver. Therefore, the path loss depends on the distance been nodes and its operating frequency.

In this paper, we have introduced two types of existing path loss models. Bio-sensor nodes transmits their data to either relay or BNC. The transmitting distance between bio-sensor node and relay denoted as D_1 and transmitting distance between bio-sensor node and the BNC is denoted as D_2.

If $D_1 \leq D_2$, the bio-sensor node will follow the path loss mode-1, it is given by [22]

$$\mathrm{PL\ (d,f)[dB]} = \mathrm{a} \times \log_{10}^{\mathrm{D1}} + \mathrm{b} \times \log_{10}^{\mathrm{f}} + \mathrm{N}_{(\mathrm{D,f})} \tag{16}$$

LMS algorithm has been used to find the value of the co-efficient are as a, b and $N_{(D,f)}$. Values of these coefficients are $a=(-)\ 27.6$, $b=(-46.5)$ and $N_{(D,f)}=157$.

If $D_1 \geq_1 D_2$, the bio-sensor node will follow the path loss model-2, it is given by

$$\mathrm{PL}(\mathrm{d}_{\mathrm{i,j}}) = \mathrm{PL}_0 + 10\mathrm{n}\log_{10}^{\mathrm{D2}} + \mathrm{X}_\sigma \tag{17}$$

$$\mathrm{PL}_0 = 10\log_{10}^{\frac{(4\Pi \mathrm{f})^2}{\mathrm{c}}} \tag{18}$$

The value of reference distance is 10 cm, *n* is a path loss exponent and its value depends on the nature of environment. The value is 2 for free space, for line of sight communication (LOS) its value varies from 3 to 4 and for non-line sight communication, its value varies between 5 and 7. σ is standard deviation, c is the speed of light and f operating frequency.

6 Simulation Results and Their Discussion

6.1 Performance Parameters

The performance parameters for existing protocol are defined as

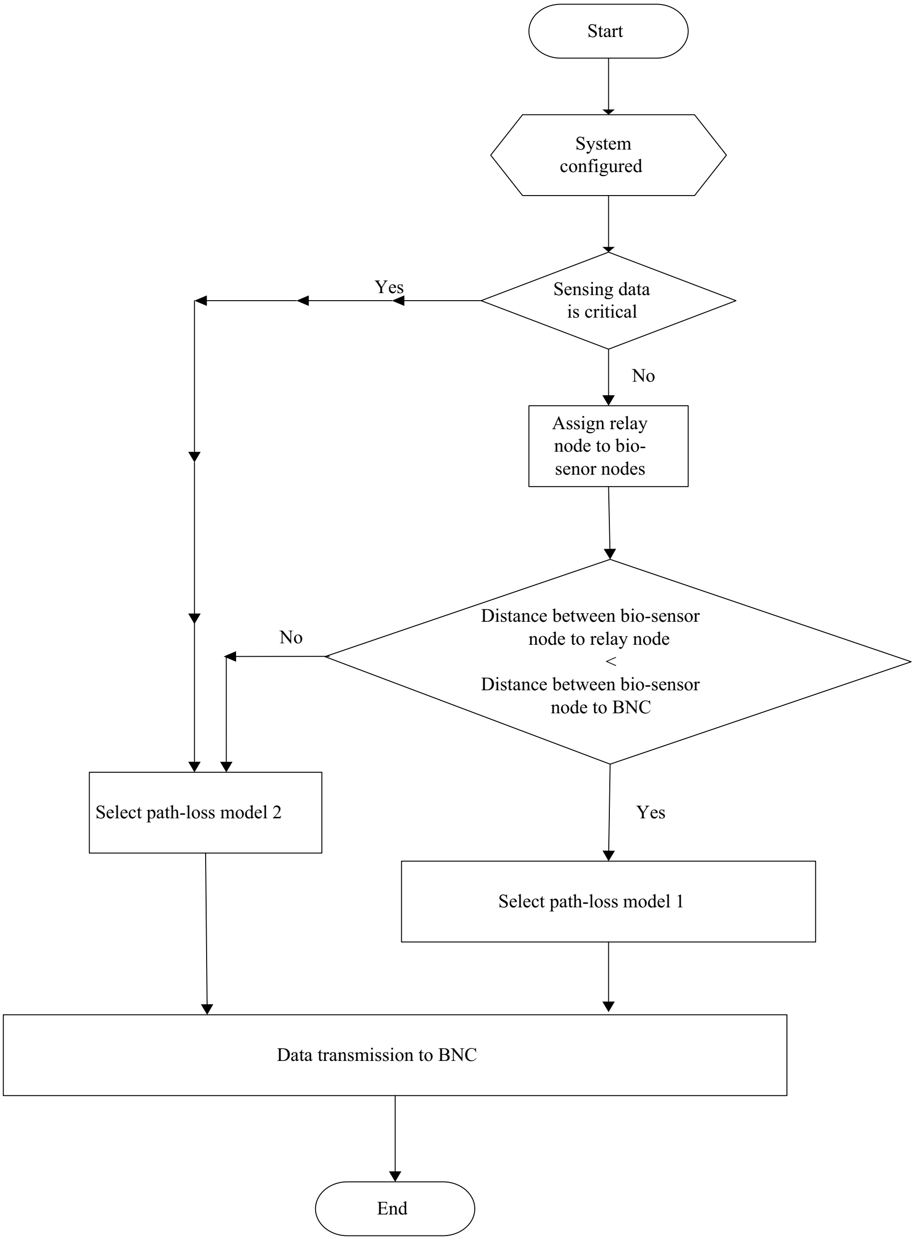


Fig. 4 Flowchart of Co-REERP

1. *Stability Period* It is defined as the network functional duration when the first node dies. After the stability period, the network becomes unstable.
2. *Network residual energy* It is the average of remaining energy of all bio-sensor nodes in the execution every round.

3. *Network lifetime* It is defined as, the total network functioning time from the network initialization to death of last node.
4. *Throughput* In execution of each round, the total number of packets success-fully received at BNC is defined as throughput.
5. *Path-loss*- It is the power attenuation, when the sensing data is routed from the transmitting end to receiving end.

6.2 Simulation Results and Their Analysis

Co-REERP have been analyzed through MATLAB simulation. To validate the performance of the proposed routing schemes, simulations are successfully executed the number of times and accordingly averages of results are plotted. Each simulation is executed over 16,000 rounds. The values of simulation parameters are described in Table 4. We compared its performance with the existing routing schemes RE-ATTEMPT [11] and Co-LAEEBA [13].

6.3 Stability Period and Network Lifetime

Figure 5 and Table 5 illustrates comparison of number of node dead after equal number of rounds. Figure 6 shows the comparison network stability and network life time of RE-ATTEMPT, Co-LAEEBA and Co-REERP routing protocols. Placement of relay nodes in proper place play a significant role to balance the energy in Co-REERP. The proposed routing scheme achieves 27.5% and 79.5% improvement in network stability in

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 (E_0)	0.5 J
Initial energy of relay nodes (.)	1.0 J

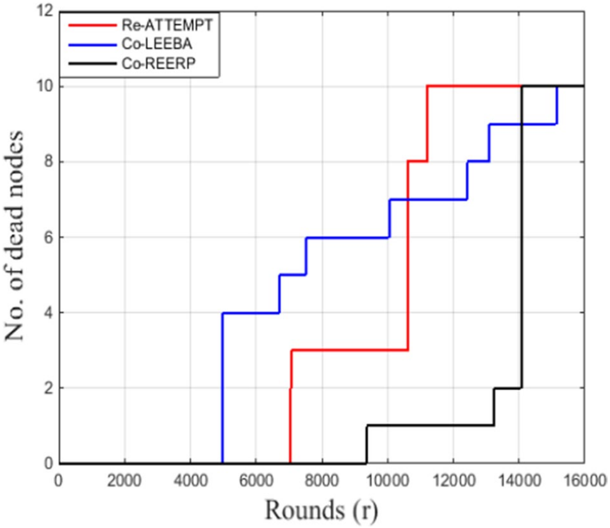


Fig. 5 Number of nodes dead versus round

comparison of RE-ATTEMPT and Co-LAEEBA respectively. Proposed routing schemes achieved 19.99% increment and 12.6% decrement of network lifetime in comparison to RE-ATTEMPT and Co-LAEEBA routing protocol respectively. Figure 7 shows comparison of rounds when each node is completely dead. When the remaining of the bio-sensor nodes becomes less than 0.003 J, then can be considered as dead node. Figure 7 shows Co-REERP has better results in comparison to existing routing protocols.

6.4 Network Residual Energy

The average residual energy of Intra-WBSN in each round has been depicted in Fig. 8 and Table 6. Initial energy of each bio-sensor nodes is 0.5 J and thus the total initial energy of the Intra-WBSN is 5.0 J. The proposed scheme uses multi-hop communication through relay nodes. Bio-sensor nodes forward the sensing data to its assigned relay nodes. Relay nodes reduce the transmitting range of bio-sensor node, they minimize the energy consumption of bio-sensor nodes. Hence Co-REERP has better residual energy in compare to the existing routing scheme.

6.5 Throughput

The patient monitoring system required the routing protocols should have maximum throughput. It depends on the better network life of Intra-WBSN. The network life

Table 5 Number of nodes dead after equal number of rounds

S. no.	Name of routing protocol	Node died at rounds (r)									
		6000	7000	8000	9000	10,000	11,000	12,000	13,000	14,000	15,000
1	RE-ATTEMPT	NIL	NIL	3	3	3	8	10	10	10	10
2	Co-LAEEBA	4	5	6	6	6	7	7	8	9	9
3	Co-REERP	NIL	NIL	NIL	1	1	1	1	2	10	10

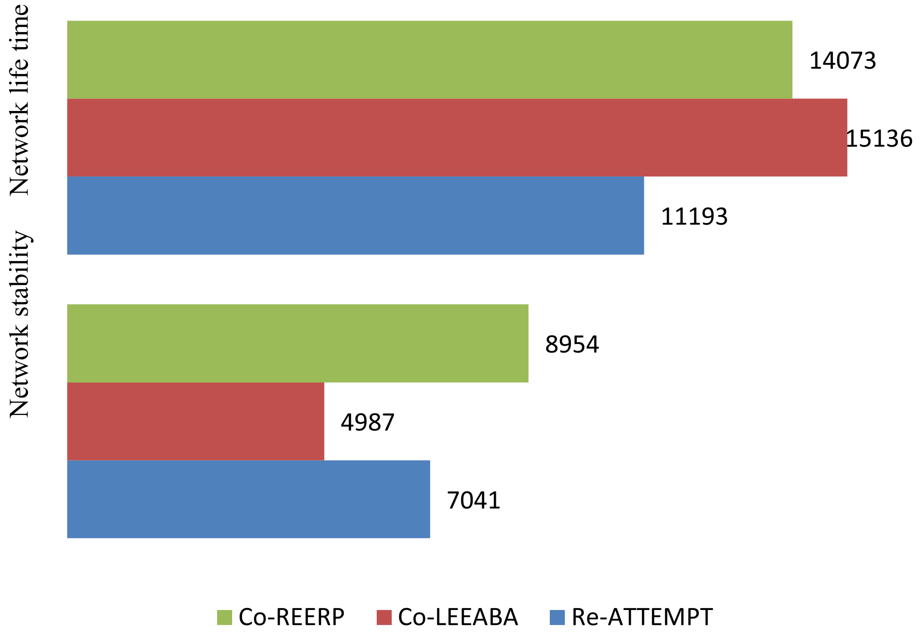
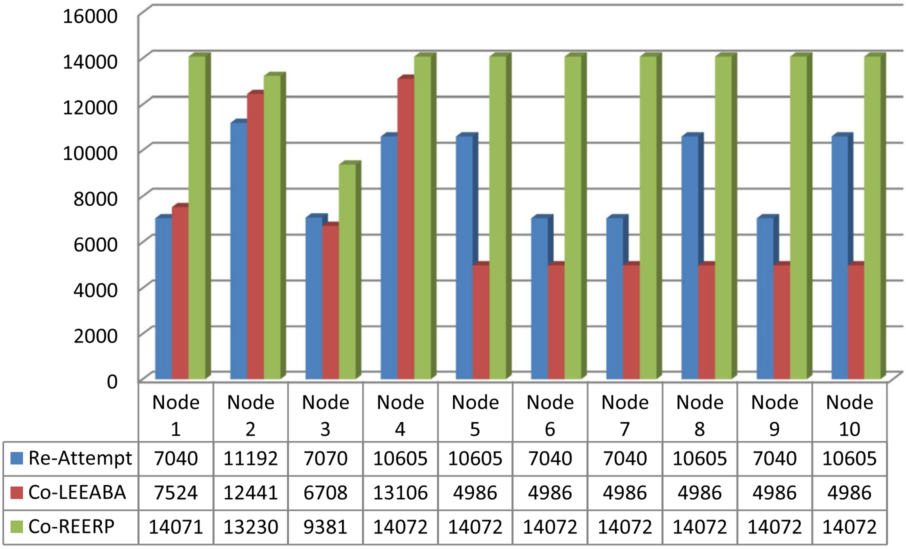


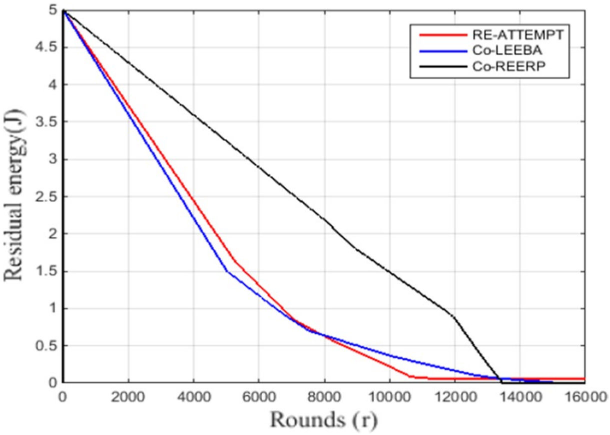
Fig. 6 Comparison of network stability and network lifetime in rounds (r)



	Node 1	Node 2	Node 3	Node 4	Node 5	Node 6	Node 7	Node 8	Node 9	Node 10
🟦 Re-Attempt	7040	11192	7070	10605	10605	7040	7040	10605	7040	10605
🟥 Co-LEEABA	7524	12441	6708	13106	4986	4986	4986	4986	4986	4986
🟩 Co-REERP	14071	13230	9381	14072	14072	14072	14072	14072	14072	14072

Fig. 7 Comparison of nodes dead in rounds

Fig. 8 Comparison of network residual energy



corresponds to number of bio-sensor nodes alive. More the number of bio-sensor nodes alive, there is a better the probability of packets being received at BNC. Figure 9 shows that Co-REERP protocol gives 56.53% and 68.14% higher throughput in comparison to existing protocols RE-ATTEMPT and Co-LAEEBA respectively.

6.6 Path-Loss

Figure 10 and Table 7 have described the path-loss analysis of Co-REERP, Re-ATTEMPT and Co-LEEBA protocols. We have used constant frequency 2.4 GHz, path loss coefficient n of 3.38 and standard deviation Ϭ of 4.1. The proposed Co-REERP protocol shows reduced path-loss of 280.3 dB which is significant improvement in comparison to the existing Intra-WBSN protocols.

7 Conclusion

In this paper, for monitoring of biological parameters of human body, bio-sensor nodes are strategically placed (either implanted or deployed). We have proposed relay based cooperative data routing schemes to enhance the efficient energy utilization of bio-sensor nodes. The energy consumption of bio-sensor nodes are directly linked with the transmitting distance, therefore, the placement of relay nodes at appropriate place reduces the transmitting distance. Normal sensing data is forwarded to BNC through

Table 6 Residual energy after equal number of rounds

S. no.	Name of routing protocol	Residual energy after rounds (r)									
		6000	7000	8000	9000	10,000	11,000	12,000	13,000	14,000	15,000
1	Re-ATTEMPT	1.509	0.926	0.669	0.435	0.200	0.108	0.029	0.029	0.029	0.029
2	Co-LAEEBA	1.187	0.867	0.656	0.522	0.388	0.286	0.186	0.104	0.678	0.034
3	CO-REERP	2.892	2.540	2.188	1.788	1.485	1.186	0.866	0.253	0	0

Fig. 9 Comparison of throughput

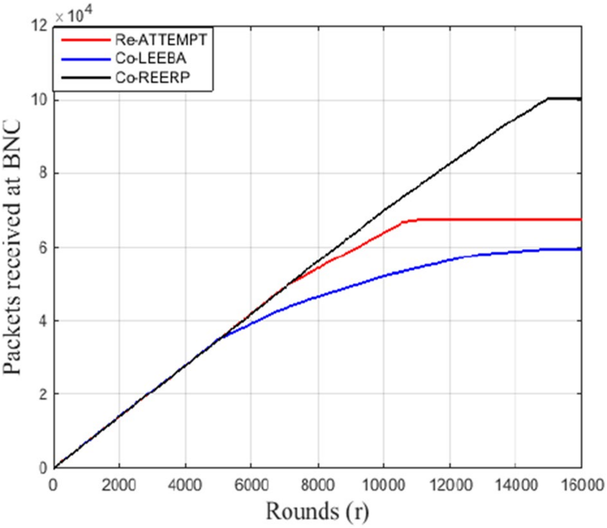
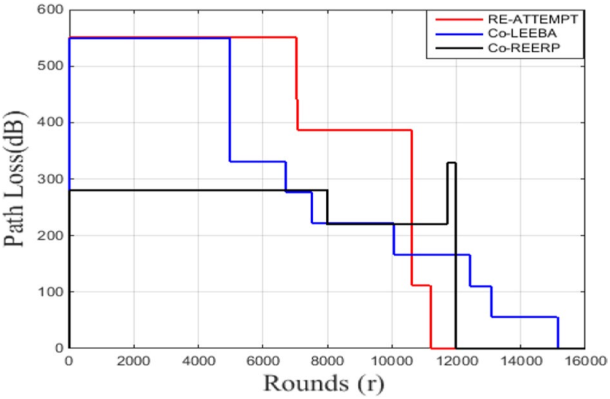


Fig. 10 Comparison of path-loss



relay nodes while the emergency data is directly delivered to BNC. Relay nodes are deployed in the patient's clothes. They are easily replaceable and rechargeable, it allows the easy maintenance of Intra-WBSN. With the help of linear programming, it is validated that the proposed scheme have better performance in comparison with the existing protocols in terms of performance metrics stability period, residual-energy, network lifetime, throughput, path-loss at the increased cost of deployment of relay nodes.

Our future works are focused on to develop energy efficient routing protocol due to body posture movement.

Table 7 Path-loss analysis after equal number of interval

S. no	Name of routing protocol	Path-loss rounds (r)									
		6000	7000	8000	9000	10,000	11,000	12,000	13,000	14,000	15,000
1	RE-ATTEMPT	469	496	386	330.6	330.6	55.9	0	0	0	0
2	Co-LAEEBA	330.6	276.4	222.7	222.7	222.7	166	166	110.1	55.9	55.9
3	Co-REERP	280.3	280.3	280.3	220.9	220.9	220.9	220.9	328.8	0	0

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