Reliable Routing Algorithm for Wireless Body Area Sensor Networks

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Abstract
Wireless Body Area Networks (WBANs) are envisaged to play crucial role in psychological, medical and non-medical applications. A new communication method was proposed in this paper for the Wireless Body Area Networks (WBANs). We used the multi-hop algorithm and dynamic scheduling to develop the proposed method, which is known as WBAN-RDS. To this end, we used rounds with variant lengths instead of fixed lengths. On the other hand, if the relay selected for receiving and aggregating the data of other sensors is distanced from the sink, an intermediate relay can be used under special conditions to transmit information to the sink and to be able to transmit the data in a more energy-efficient way. In addition, it is highly important to control the sensor temperature due to the direct contact between the wireless sensors and the human body/tissue. This is because the excessive escalation of sensor temperature damages human tissues, which is one of the pitfalls of WBAN-based health care systems. The proposed design yields a long stability period. The livability of the nodes increased considerably and energy consumption decreased. WBAN-RDS is evaluated through extensive simulations in the NS-2 environment. The simulation results show that WBAN-RDS outperforms other existing solutions in terms of throughput, energy consumption and life time.

Keywords:
Wireless Body Area Networks (WBANs), WBAN-RDS, Reliable approach.

1. Introduction

Wireless Body Area Networks (WBANs) are getting growing interest because of their suitability for psychological, medical and non-medical applications. For example, in the former two, WBAN employ wearable or implantable tiny sensors in, on or around the human body to monitor physiological parameters such blood pressure, body temperature, heart rate and glucose level to determine the behavior or medical condition of a person. Employing WBAN for continuous pervasive healthcare monitoring can significantly reduce medical expenses. Similarly, these networks can be used to determine context-aware psychological classification (e.g., personality type, mood, psychological condition) in real-time based on physiological parameters, which can revolutionize human-interactions [1, 2]. in addition, WBANs include a collection of body sensor nodes that are low power, invasive or non-invasive, light-weight devices which are either worn on the body or implanted inside the body. The architecture of WBAN [1] can be considered as three different tiers, namely: Tier-1 as Intra-BAN, Tier-2 as Inter-BAN and Tier-3 as Extra-BAN as shown in Fig. 1. In Tier-1, the body sensor nodes collect the data and send to the coordinator. In Tier-2, the coordinator processes the received data and sends the information towards the sink node. From the sink node the packets are transmitted to the corresponding health-center through internet or other communication techniques. The health of individuals is an important prerequisite to the health of communities, making health care a necessity for society that should be provided somehow. The quality of medical service if the number of elderly people increases would be most likely to drop, making health care and medical costs increase dramatically [1]. On the other hand, cardiovascular disease is the leading cause of death in the world, accounting for 30 % of all deaths. According to figures, almost 17.5 million people in the world die of heart disease each year. In addition, about 246 million people worldwide suffer from diabetes, and the number will reach 380 million by 2025 in the absence of proper health care and necessary preventive measures. The incidence of other diseases such as kidney problems, Alzheimer's disease, Parkinson's disease, anxiety disorder, and infant syndrome can be reduced by providing health care [2]. One of the health care strategies is to utilize advanced technologies in the medical field. In this regard, the body area network is a recently introduced technology which allows monitoring a person's health.

Manuscript received October 5, 2026
Manuscript revised October 20, 2026
https://doi.org/10.22937/IJCSNS.2026.26.10.2

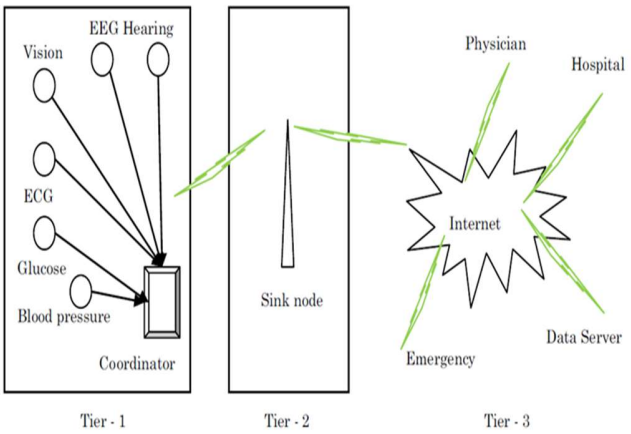


Figure. 1. Wireless body area network architecture.

In this paper, a new communication method was proposed for the Wireless Body Area Networks (WBANs). We used the multi-hop algorithm and dynamic scheduling to develop the proposed method, which is known as WBAN-RDS. To this end, we used rounds with variant lengths instead of fixed lengths. On the other hand, if the relay selected for receiving and aggregating the data of other sensors is distanced from the sink, an intermediate relay can be used under special conditions to transmit information to the sink and to be able to transmit the data in a more energy-efficient way. In addition, it is highly important to control the sensor temperature due to the direct contact between the wireless sensors and the human body/tissue. This is because the excessive escalation of sensor temperature damages human tissues, which is one of the pitfalls of WBAN-based health care systems. The proposed design yields a long stability period. The livability of the nodes increased considerably and energy consumption decreased. Fig. 2. Shows a typical WBAN layers.

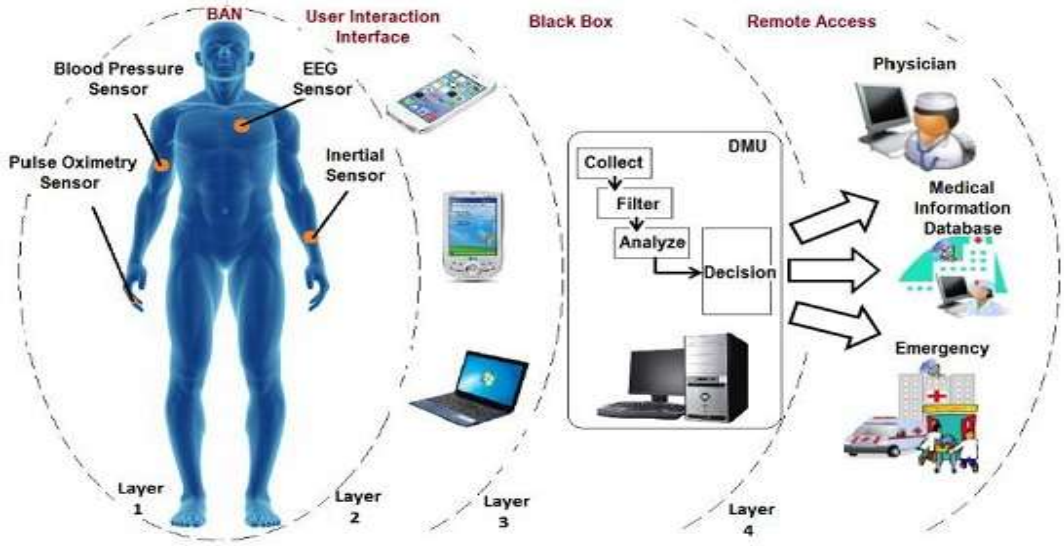


Figure. 2. A typical WBAN layers.

2. Related Works

In wireless body area sensor networks have attracted significant research interest. Some efforts are devoted to network topologies [3, 4]. Due to the typical behavior of radio links, the multi-hop topology is considered as a good solution for providing reliable and energy efficient communications in dynamic environments. In [5], the authors presented a thermal aware routing protocol in which each node selects a minimum hop route to the sink. When a parent node gets heated, the child nodes select another optimal route. Moreover, the authors take full advantage of both single hop and multi hop communication modes by choosing the former one in case of emergency data and the later one in case of normal data. In this way, the emergency data are sent to sink with the minimum possible delay. Latre et al. proposed a Secure Low-Delay Protocol for Multi-hop WBAN routing protocol (CICADA) which consists of a spanning tree structure [6]. CICADA uses Time Division Multiple Access (TDMA) protocol to schedule transmission of nodes. Nodes near the root act as forwarders or parents. These nodes collect data from their associated child nodes and relay it to sink. The load from child nodes on parent nodes causes parent nodes to deplete

their energy quickly. As energy efficient routing protocols are used to forward data from body sensors to external medical server(s). In [7], authors present an opportunistic protocol which supports mobility at the cost of low throughput and additional relay node(s). They deploy sink at the wrist. Whenever the link of sink node is disconnected from any sensor node, a relay node collects data from the sensor node(s). The probability of distant communication between mobile sink and sensor nodes increases due to frequent motion of the hands. As several sensor nodes are placed at different locations on human body. Depending on the pattern of mobility, the human body can be in several postures that lead to relative change in nodes' locations. For example, when hands of the patient move, the sink also moves which leads to high packet drop rate. MATTEMPT (thermal aware) routing protocol uses multi-hopping to route data from sensor nodes to sink [8]. This protocol selects a different route, whenever, the node acts like a hotspot, however, alternative route in such case leads to more energy consumption. Therefore, proper assumption should be made according to relative nodes' locations to make the network protocol robust against frequent topological changes. To minimize energy consumption and to avoid hot spots, we have previously proposed SIMPLE protocol [9]. In [10], Single-hop communication is used between sensor nodes and sink node. To overcome the problem of topological partitioning due to constant human body movement and ultra-short Radio Frequency (RF) transmission range. Sue *et al.* [2] used Multi-hop communication for communication between sink and root nods. However, in direct communication increase in temperature of sensor nodes may affect human body tissues. He also discussed that storage delay (due to topological disconnections) and congestion delay increase overall delay in Multi-hop communication that cannot be helpful for emergency services and makes. Multi-hop communication not a best choice. Ehyaie *et al*. [11] proposed a solution to minimize energy consumption. They deploy some non-sensing, dedicated nodes with additional energy source. This technique minimizes energy consumption of nodes and enhances the network lifetime, however, additional hardware required for relay nodes increase the cost of the network. A clustering based protocol A Self-Organization Protocol for Body Area Networks (ANYBODY) is proposed in [12]. The objective of this protocol is to restrict the sensor nodes to transmit data direct to sink. It improves the efficiency of network by changing the selection criteria of CHs. In [13] Nabi et al. proposed a protocol similar to store and forward mechanism. They integrate this store and forward scheme with Transmit Power Adaption (TPA). To control transmission power consumption, all nodes know their neighbors. Nodes transmit data with minimum power and with a stable link quality. A similar method was proposed by Guo et al. in [14]. They also used Transmission Power Control (TPC) scheme as Nabi et al. proposed. When link quality of a node decreased, an Automatic Repeat Request (ARR) is transmitted and retransmit the drop packet. Retransmission of lost packet increases the throughput of the network with the expense of energy consumption. In [13], proposed a multi hop protocol to monitor human body health conditions. This protocol is robust whenever subjected to frequent network topology changes due to variation in wireless link quality and postural changes. The proposed technique, similar to store and forward mechanism, integrates store and forward scheme with Transmit Power Adaption. To control transmission power consumption, all nodes are aware of their neighbors. Nodes transmit data with minimum power and stable link quality. Thus, the protocol avoids network disconnection to ensure reliable outgoing links. A similar method is proposed by [15]. They also use Transmission Power Control scheme as Nabi et al. proposed. When link quality of a node decreases, an Automatic Repeat Request (ARR) is sent. In response, the node retransmits the dropped packet. Retransmission of lost packet increases the throughput of the network at the expense of energy. In [16], the authors modify the CH selection approach of LEACH (LEACH-E) to improve the network lifetime by accounting for the available remaining energy level of each sensor node. In [17], the authors propose the HEED (Hybrid, Energy-Efficient, Distributed) clustering protocol to prolong the network lifetime and support scalable data aggregation. In this protocol, the CHs are probabilistically selected based on their residual energy, and the sensor nodes join the clusters according to their power level. A new clustering algorithm with cluster member (NCACM) bounds for energy dissipation avoidance in wireless sensor networks [18] is proposed to reduce the energy consumption and to extend the network lifetime. The authors determine a confidence value for any sensor node that might become a CH by using parameters such as the nodes' remaining energy, the distances between the nodes, and the distances between the CHs in each round. However, a random selection of a CH node could obtain a poor clustering setup in these previously developed schemes, and the CH nodes can be redundant for some rounds of operation. The distribution of CH nodes is not uniform; thus, a cluster can consist of a large number of sensor nodes, and some sensor nodes must transfer data through a longer distance. Additionally, a CH node consumes too much energy to receive and to aggregate data from its non-CH nodes and to transmit data to the BS. It is clear that the CH node will die quickly. Thus, a reasonable energy consumption is not obtaining d in the wireless sensor networks. LEACH-centralized (LEACH-C) is proposed as an improvement of LEACH that uses a centralized approach to create the clusters [19]. In [21, 22] authors try to optimize the energy and load balancing in their method that can improve the reliability and load balancing, also in [23] one robust efficiency measurement method proposed by the authors

that we can use it in WBAN. The Table 1 shows an comparative analysis of routing protocols.

Table 1 Comparative analysis of routing protocols

Routing protocol	Type of protocol	Average delay	Energy consumption	PDR	Throughput
Multi-hop base [5]	Thermal-aware	low	*	*	*
CICADA [6]	spanning tree	Very-low	*	*	*
opportunistic routing[7]	opportunistic-aware	low	*	high	high
MATTEMPT [8]	thermal aware	low	low	low	low
SIMPLE [9]	Location-based	*	low	*	*
Single-hop [10]	ultra-short Radio Frequency	low	*	high	high
BASN [11]	Energy-based	*	Very-low	*	*
MEPF [14]	Transmission Power Control	*	low	*	high
HEED [17]	Clustering-based	low	Very-low	*	high
NCACM [18]	Clustering-based	*	Very-low	*	*

3. Proposed Approach (WBAN-RDS)

In this section, we design a WBAN-RDS approach by jointly employing the multi-hop and dynamic scheduling algorithm.

3.1 Radio model

Many radio models are proposed in the literature. We use the first order radio model [20], mainly due to two reasons; simplicity in implementation and the degree of closeness to our work. The energy costs for transmission, reception, aggregation and amplification of data are calculated as per the following equations.

$$E_{T_x}(k.d) = E_{T_{x-elec}}(k) + E_{T_{x-amp}}(k.d) \quad (1)$$

$$E_{T_x}(k.d) = E_{T_{x-elec}} \times k + E_{amp} \times k \times d^2 \quad (2)$$

$$E_{R_x}(k) = E_{R_{x-elec}}(k) E_{R_x}(k) = E_{R_{x-elec}} \times k \quad (3)$$

$$E_{R_x}(k) = E_{R_{x-elec}} \times k \quad (4)$$

where d is the distance between transmitter and receiver. E_{T_x} and E_{R_x} are the per packet energy consumption costs by the transmitter and receiver, respectively. Similarly, E_{T_x} -elec and are the per bit energy consumption values for the transmitter and receiver electronics circuitries, E_{R_x} -elec respectively. E_{amp} is the radio amplifier type and k is the packet length.

3.2 The Proposed WBAN-RDS Method

A new method for WBANs is proposed in this section. The proposed method selects the best routes using the cost function and temperature data and it employs the dynamic scheduling method in the scheduling phase. More details of the proposed WBAN-RDS method are proposed in the following.

3.2.1 The system model

In our proposed WBAN-RDS method, eight sensor nodes are placed in a human body. All of the nodes have high computational potential. The sink node is also placed on the person's waist. Node 1 is the ECG sensor and node 2 is the glucose sensor node. These two nodes transmit the data directly to the sink. Fig. 3, depicts the position of the nodes and the sink in the human body.

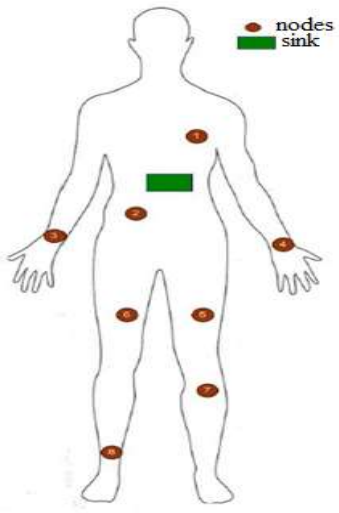


Figure. 3. The placement of the nodes in human body

3.2.2 Phase I

In this phase, the sink node sends a small information packet through flooding. After receiving the control packet all of the nodes store the position of the sink node, and the sensor nodes send a packet containing the node ID, the node position in the body, energy status of the nodes, and their current temperature. In this method, all of the sensor nodes update the data on the neighbors and the sink node.

3.2.3 Phase II: selecting a relay with dynamic scheduling in WBANS-RDS

In wireless networks and WBAN, the network lifetime is divided into time periods and a relay is selected at the beginning of each round to receive the data on other sensors, aggregate the data, and send the results to the sink node. Afterwards, the network accomplishes its primary task. Although the selection of the relay balances energy consumption in the nodes and prevents the early death of the relayed nodes, the overload resulting from selecting the relay at the beginning of each round and transmission of control packets, leads to the loss of energy in the nodes. In fact, as the interval between the rounds increases the resulting overload decreases. On the other hand, an increase in this interval reduces the load balance among the nodes, hence the need for a compromise between the nodes. To this end, we used the dynamic scheduling method in the proposed WBAN-RDS method. In other words, instead of using fixed-length rounds used in most protocols, rounds with varying lengths are used. Therefore, when the WBAN is first started the energy level of all of the nodes is high, and thus the rounds are longer. Over time, the length of the rounds decreases as the energy of the sensors declines and the new relay is selected more quickly to increase the load balance and the network lifetime. One of the best solutions for reducing the consumption of and dissipation of energy is to use a relay and multiple hops in routing the data packets. In the proposed WBAN-RDS method, a relay is used to collect the data on other sensors. According to the cost function (CF) formula (relation 5) the node with the maximum remaining energy and the shortest distance from the sink is selected in each round.

$$CF\ (i) = \frac{d\ (i)}{RE\ (i)} \quad (5)$$

If i is the node ID and d_i is the distance between node i and the sink, $RE_{(i)}$ shows the remaining energy of node i, which is obtained by subtracting the current node energy consumption from the previous total energy consumption. The remaining energy of a farther sensor may be much higher, which leads to its selection in a round. Therefore, if the sensor aims to send the data directly to the sink, it must use a higher energy level which results in the loss of its energy. As a result, if the farther sensors are selected as the relay in a round, another layer is selected using formula (5) as the second hop to transmit the aggregated data on the previous relay to the sink and use less energy to transmit the data. The latter result leads to an increase in the overall lifetime of the network. In addition, to improve the conformity of the proposed WBAN-RDS method under the existing condition, the current sensor temperature is added to the cost function calculation parameters to select a route and a relay for transmission of data to the sink. Consequently, with an increase in the sensor temperature to the threshold temperature, that given node is considered a hot node with a decreased probability of being selected as the relay. In other words, a node with the highest remaining energy, the lowest number of hops to the sink, and the lowest current temperature (or a temperature below the threshold temperature and the hotspot) is selected. As stated, after receiving a control packet from the sink (which contains the sink position in the body) each node broadcasts its ID, energy status, and the current temperature through flooding. The sink uses this information and the new cost function to calculate the cost function for all of the nodes. It selects the node with the smallest cost function as the relay node and broadcasts its ID. Moreover, if the temperature of a node exceeds the threshold temperature it cuts the link for several rounds to reach the normal temperature and then reestablishes the link. In addition, if the packet node receives data and its temperature reaches the threshold level, it sends the data packet back to the previous node, which marks the link as a hot link. Hence, the selected relay node collects the information and transmits it to the sink. The remaining energy of the relay node is high and it has the shortest distance from the sink. It also does not have a high current temperature, and thus it consumes less energy to transmit the data to the sink. The glucose and ECG (heart status) sensor nodes directly connect to the sink and do not take part in the data transmission process.

3.2.4 Transmission Scheduling of Sensor Nodes

In this phase, the relay node uses the time-division multiple access (TDMA) method and time slots to allocate access to other sensor nodes. All of the sensor nodes, except for the glucose and ECG sensor nodes, transmit all of the sensed data in their time slots to the relay node. When a node lacks data for transmission, it switches to the standby mode. The nodes wake up at their corresponding times. The scheduling for transmission of data reduces energy dissipation in the sensor nodes.

4 Performance Evaluation

In this part, we evaluate the performance of the proposed approach (WBAN-RDS) in the problem of reliability in wireless body area sensor networks.

We conduct extensive simulations to evaluate the effectiveness and performance of our WBAN-RDS and compare it with TARA approach. We evaluate the throughput, energy consumption and life time.

Throughput is the number of packets successfully received at sink. In WBANs, routing protocols are needed which give high network throughput for reliable monitoring of the patients, elderly people, etc. The throughput is calculated in Equation (6) follows:

$$\left(\frac{\sum_{j=1}^{n} Packets\ successfully\ recieved}{\sum_{j=1}^{n} Packets\ originated}\right) \quad (6)$$

Energy consumption is defined as the total amount of energy consumed by the network to transmit a data packet from a sensor node to the sink. The energy consumption is calculated in Equation (7) follows:

$$E_{transmit} + E_{received} \quad (7)$$

Life time is the total number of nodes which are alive at end of all cycles of the algorithm.

We have implemented proposed approach in the NS-2 on Fedora 11. The simulation parameters are given in Table 2.

Figure. 4, compares the performance of WBAN-RDS with that of TARA approach. The objective is to increase successful packet reception at the sink because every information is critical in WBANs. In our WBAN-RDS, the forwarder node collects data from its member nodes and forwards it to sink. WBAN-RDS protocol achieves high throughput than TARA, as shown in fig 6. number of packets send to sink depends on the number of alive nodes. More alive nodes send more packets to sink which increases the throughput of network. The stability period of TARA is shorter than WBAN-RDS approach which means number of packets sent to sink decreased. Hence, throughput of TARA decreased. On the hand, WBAN-RDS schema achieves high throughput due to longer stability period.

Table 2. Simulation Parameters

Parameters	Value		
Network size	6m X 6m		
Parameters	CC2420	nRF-2401A	*Unit*
DC Current (Tx)	17.4	10.5	*mA*
DC Current (Rx)	19.7	18	*mA*
Supply Voltage (min)	2.1	1.9	*mA*
$E_{Tx-elec}$	96.9	16.7	*nJ /bit*
$E_{Rx-elec}$	172.8	36.1	*nJ /bit*
E_{amp}	2.71e-7	1.97e-9	*J/b*
Number of rounds	5000		
Number of nodes	10		
Radio range	10m		
Initial energy of nodes	0.5 Jules		
Simulation time	200 sec		

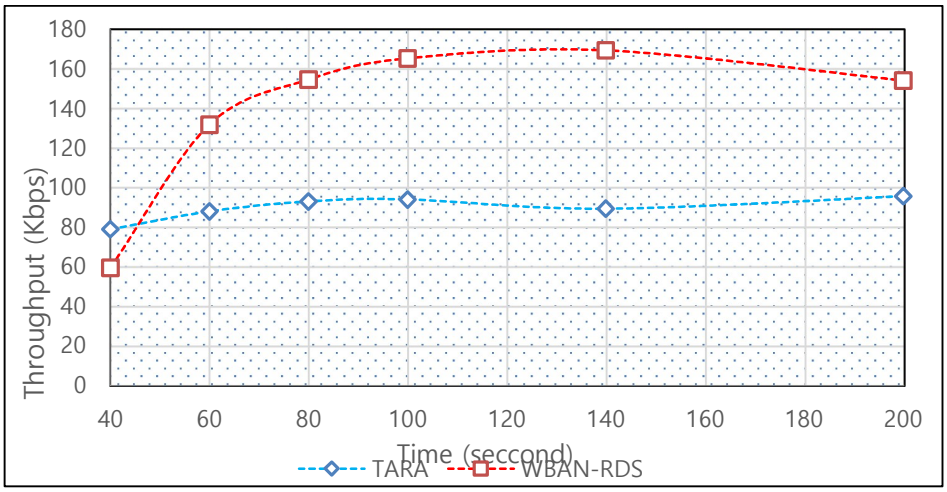


Figure. 4. Network throughput of WBAN-RDS versus simulation times.

Figure. 5, compares the performance of WBAN-RDS with that of TARA approach. The WBAN-RDS model use multi hop topology, in which each farthest node transmits its data to sink through a forwarder node. Forwarder node is elected using aforementioned cost function. Selection of appropriate forwarder in each round contributes to save energy. To transfer packets to sink, our multi hop topology use different forwarder node in each round, this restricts over loading of particular node. Simulation results show that WBAN-RDS protocol consumes minimum energy till 40% of simulation time. It means, in stability period, more nodes have enough energy and they transmit more data packet to sink. It also improves the throughput of the network.

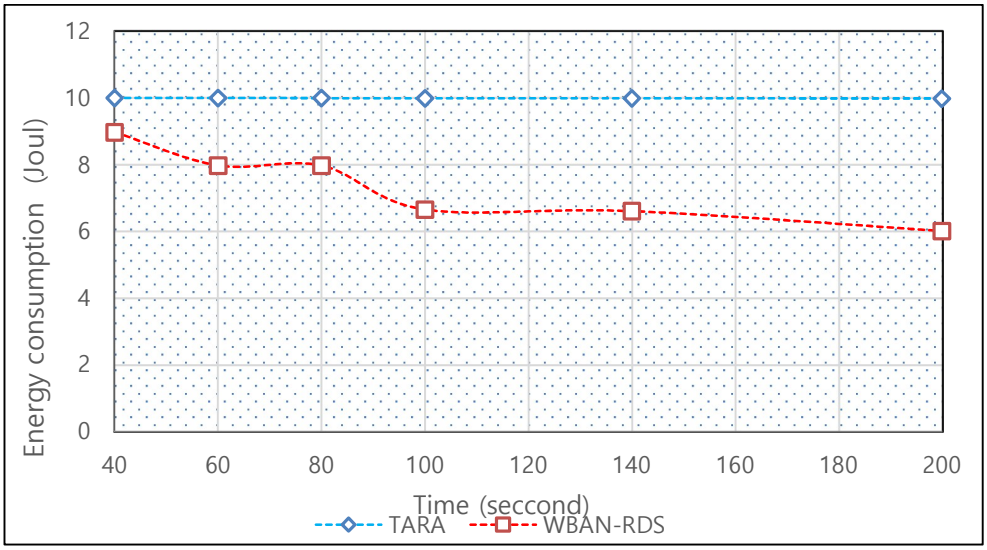


Figure. 5. Energy consumption of WBAN-RDS versus simulation times.

Figure. 6 compares the performance of WBAN-RDS with that of TARA approach. Network lifetime increases as the simulation times increase because of the increment in overall energy consumption in the network. More nodes staying in reception and idle listening radio states increase the energy consumption. Network lifetime for WBAN-RDS is higher than TARA. The reason behind this is that WBAN-RDS selects relay nodes having high residual energy which improves the power consumption load division. Thus, network lifetime is higher in our proposed approach in comparison to TARA.

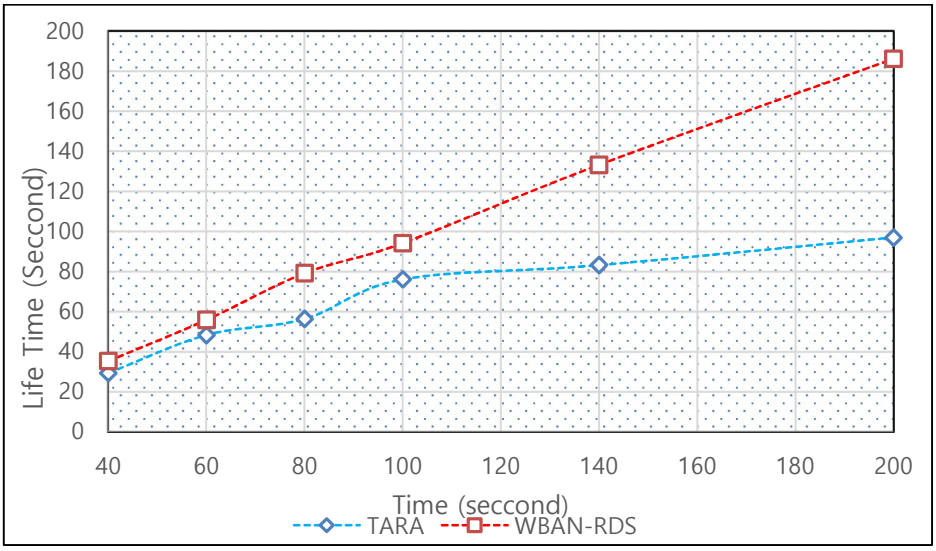


Figure. 6. Network life time of WBAN-RDS versus simulation times.

5 Conclusion

Energy saving is a challenging issue in wireless body sensor networks. To reduce the energy consumption and prolong the lifetime of the sensor nodes, new and efficient energy saving schemes must be developed. The WBAN-RDS method uses the multi-hop algorithm and dynamic scheduling. To this end, a node is selected as the relay node in each round. The selected node has a high level of energy and has a short distance from the sink. The temperature of this node should not also reach the threshold temperature. Consequently, the best node is selected in each round. In our proposed WBAN-RDS method there is no need for the sensor nodes to be awake and in the standby mode all the time; rather, each node transmits the data at a certain time using the scheduling technique. The result is a decrease in energy consumption of the sensor nodes. The proposed WBAN-RDS method yielded a long stability period. The nodes live long and consume less energy. The long stability period and low consumption of energy result in a considerable throughput. Simulation results showed that, in average, the overall performance of WBAN-RDS is around 30% better than TARA in terms of throughput, energy consumption and life time.

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