An improved dual-sink architecture with a modified media access control protocol, energy-aware, and quality-of-service guaranteed routing algorithms for wireless body area network

Abdullahi Abdu Ibrahim

Abstract
To reduce frequent sensor recharging and replacement due to resource constraint, it becomes imperative to increase the management of energy and network’s quality of service. To this end, this article provides a new wireless body sensor network architecture with two sink nodes and multiple energy management and quality-of-service algorithms. The first algorithm is the normal data avoidance algorithm that is responsible for decreasing the energy usage by avoiding the transmission of normal data. Duplicate data avoidance algorithm avoid transmitting duplicate data thus saving the bandwidth and battery life. Past knowledge-based weighted routing algorithm oversees taking the ideal direction to transmit information, hence improving quality of service. Furthermore, sleep scheduling is integrated to further improve the battery life. In addition, in our proposed model, linear programming which is based on mathematical models was used to model the network lifetime maximization and continuous data transmission minimization. Through simulation in Castalia-based OMNeT++ demonstrates that our proposed work outperforms the works of quasi-sleep-preempt-supported with regard to network lifetime and delay with 50% and 30% improvement, respectively, moreover, it improves the work of critical data with respect to packet drop and throughput with 30% and 75% improvement, respectively.

Keywords
Body sensor network (BSN), quality of service, algorithms, media access control, normal data, emergency data, Castalia, wireless body area network

Date received: 20 September 2021; accepted: 6 March 2022
Handling Editor: Benny Lo

Introduction
Proportion of senior citizens is considerably growing in industrialized countries and poor countries also. The disturbing growth in population of senior citizens is resulting to overburdening of medical facilities and rise in cost of healthcare. The World Health Organization (WHO) forecasts that the people older 65 years will soon be larger than the number of kids less than 5 years old. However, every year millions of individuals pass on yearly diseases, for example, Parkinson’s diseases,

[Contact Information]

Creative Commons CC BY. This article is distributed under the terms of the Creative Commons Attribution 4.0 License (https://creativecommons.org/licenses/by/4.0/) which permits any use, reproduction and distribution of the work without further permission provided the original work is attributed as specified on the SAGE and Open Access pages (https://us.sagepub.com/en-us/nam/open-access-at-sage).
cardiovascular diseases, cancer, and diabetes. The most important challenge with these fatal ailments is that individuals realize the warning signs and have the illness diagnosed when it too late. However, scientists have showed that if these diseases are noticed in their initial stages, they can be prevented. A major solution to this problem is a sensor network consisting of wearable or in vivo sensors which are cheap and can detect diseases in their early stages, as a result leading to significant enhancements in life quality. This sensor network is referred to as wireless body sensor network (WBSN).\(^\text{3}\)

Nadeem et al.\(^\text{4}\) proposed a protocol called SIMPLE that decreases the energy expenditure and enhances the network throughput. However, quality of service (QoS) was not considered despite its significant importance in WBSN.

Paper published in Ahmad et al.,\(^\text{5}\) which is an enhancement on Javaid et al.,\(^\text{6}\) was developed to improve the energy management and throughput whereas reducing the drop of the packets. The nodes were positioned by considering the nodes energy degree. Mix communication approach is considered whereby direct communication is employed for urgent data whereas multi-hop is employed for non-urgent ones. The method to separate non-critical and critical data (CD) was not discussed. CD can be sensitive, but there was no information on the consequences of sensitive data. Ahmed et al.\(^\text{7}\) proposed an algorithm that evades interference among dissimilar wireless body area network (WBAN) in a hospital. On the contrary, routing data between the nodes were not giving due consideration. Moreover, energy consumption and QoS have been given little or no attention. Sagar et al.\(^\text{8}\) proposed a technique that transmits only CD and ignores normal data in order to save energy; however, reliability of the channel and packet dropped is not considered. A reliability guaranteed WBAN structure that monitors the physiological parameters of an individual continuously for an extensive duration. A modified media access control (MAC) protocol is employed; however, significant energy saving is not achieved because of frequent transmission of all kinds of data.

To this end, we design our research objectives to achieve the following contributions:

1. A new WBAN architecture made up of twin nodes which improve both QoS and network lifetime (NL) of the network. The nodes are termed as high normal sink (HNS) and emergency sink (ES) which are responsible for gathering high normal data (HND) and emergency data (ED), respectively.

2. Enhanced-media access control (E-MAC) algorithm is developed to split the data into normal data (ND), HND, and ED packet. The E-MAC does not add complexity or overhead because emergency level of data is represented in 0s and 1s.

3. Normal data avoidance (NDA) algorithm which decreases the energy consumption by ignoring the transmission of ND.

4. To further decrease the energy consumption by developing a duplicate data avoidance (DDA) algorithm that avoids transmitting duplicate data.

5. Past knowledge-based weighted (PKW) routing protocol is in charge of selecting the optimal route for data transmission, hence improving QoS.

6. Sleep scheduling is integrated to further improve the battery life.

7. Provided mathematical models based on linear optimization for NL maximization, permanent transmission of data, and end-to-end delay minimization.

### Related works

Some of the related studies proposed by researchers in the health monitoring area of WBAN are provided here. The focus will be on their contributions in terms of proposing different routing protocol to overcome different energy and QoS-constraints, for instance, throughput, delay, and packet drop. Data transmission technique for more than one WBSN fields was proposed with clustering method in Mu et al.\(^\text{9}\)

The main goal of the work was the enhancement of the QoS in the WBSN field. In order to achieve that, an individual organizing adaptive grouping method was presented with more than one WBSNs. The drawback of the technique is the cluster formation that takes into account more than one body sensor networks (BSNs) and a one body area network (BAN) sensor uses regular method which additionally rises the energy depletion. A new BSN architecture with two sinks that enhances the QoS and extends the NL was presented.\(^\text{10}\)

The proposed work comprises of four protocols among which are Improved Medium Access Control Protocol (I-MAC) and PKW. Because of its importance, intensity is decided by the two sensor nodes and the sin. Shimly et al.\(^\text{11}\) proposed a carrier sense multiple access with collision algorithm to remove the challenges in time division multiple access. In order to achieve that, the shortest path routing (SPR), which selects single path based on distance metric, and cooperative multi-path routing (CMR), which selects multiple paths based on back-off time, are utilized. However, this led to greater loss and depletion of energy. Also, the planning does not take into consideration the cruciality points of the data which is extremely needed in the wireless body area network environment. For optimum route choice, ant colony optimization (ACO) algorithm
was introduced in wireless body area network.\textsuperscript{12} The ACO locates an optimal route among the sender and the destination. It achieves energy improvement and weight stabilizing at the same time at every intermediary sensor. For the duration of route change, cluster head (CH) rotation was enabled to realize energy improvement. Nevertheless, the ACO has greater data communication lag. A routing protocol called Tripe-EEC chooses the ideal routes with great remaining energy, and the lowest possible temperature increase was proposed by Ullah et al.\textsuperscript{13}

The authors group the sick people’s information into four groups, namely, regular data, data on-demand, emergency information of small threshold result, and emergency information of great threshold result. Other algorithms were created for calculating cruciality of physiological parameters and sharing of dynamic and battery effective routes by eliminating dispute among them. They compared their work with advanced protocols in a realistic medical environment. However, in the route selection, they considered only one metric which is grossly insufficient and multiple hop increase delay in ED transmission. Crucial, urgency, and classified forwarding methods for effective communication of a patient’s important information to the sink were presented for mobility supported WBAN.\textsuperscript{14} The data transmitting was achieved by predecessor-successor-node (PSN) technique. Even though the work efficiently utilizes energy, it proves inefficient for a real-time environment.

ORACE-Net is presented for the multi-BAN setting.\textsuperscript{15} The technique calculates the value of the link between multiple BANs to opt for the ideal route for the sending of data. Although the link value metric enhances the data communication, it increases the delay due to multiple hops. Therefore, several factors must be considered in the multi-BAN setting. In addition, the measured metrics are inadequate to attain improved QoS and energy effectiveness.

QoS and energy management were the focus in these studies.\textsuperscript{16–19} The studies centered around lowering the power consumption, packet drop, and delay while improving the link quality and throughput. The downside for their achievement was the increase in complexity and cost of implementation. The literature\textsuperscript{20–32} proposed various protocols, techniques, and algorithms for energy utilization and QoS improvement; however, they fail to provide any mathematical models to this effect.

### Mathematical modeling

Two linear programming mathematical models were discussed as follows: maximizing NL and minimizing continuous data transmission. The subsequent sections present more information.

### Maximizing the NL

Energy models that were provided in the literature\textsuperscript{7,33,34} were used. We select these models since they are in accordance with the assumptions of our technique. Energy expenditure in sending and receiving per bit is provided in equations (1)–(4). Since the proposed method is parent centered, consequently, the two distinct node types are parent and normal. Parent or forwarded node is any node that has at least the highest amount of remaining energy and the shortest duration to destination otherwise known as sink. They are considered the nodes with the least cost. The key objective is energy improvement and which is made as shown as follows. The objective function in equation (1) is the NL,\textsuperscript{T} maximization. Equation (2) defines NL prior to their energies were used. We select these models since they are in accordance with the assumptions of our technique. Energy models that were provided in the literature\textsuperscript{7,33,34} were used. We select these models since they are in accordance with the assumptions of our technique. Energy expenditure in sending and receiving per bit is provided in equations (1)–(4). Since the proposed method is parent centered, consequently, the two distinct node types are parent and normal. Parent or forwarded node is any node that has at least the highest amount of remaining energy and the shortest duration to destination otherwise known as sink. They are considered the nodes with the least cost. The key objective is energy improvement and which is made as shown as follows. The objective function in equation (1) is the NL,\textsuperscript{T} maximization. Equation (2) defines NL prior to their energies were used. We select these models since they are in accordance with the assumptions of our technique. Energy models that were provided in the literature\textsuperscript{7,33,34} were used. We select these models since they are in accordance with the assumptions of our technique.

\[\text{Maximize } T \quad (1)\]

\[\text{where } T = \sum_{r} t_r \forall r \in Z^+ \quad (2)\]

\[E_{RX}^p = (N - 1)E_{RX}^p(l) \quad (3)\]

\[E_{TOT}^p = N \otimes E_{TX}^p(l, d) + NL \otimes E_{ELEC}^p + E_{RX}^p \quad (4)\]

\[E_{TOT}^l = LE_S^l + LE_P^p + E_{TX}^p(l, d) \quad (5)\]

\[t_r = \frac{E_i}{\sum_p (LE_S^p + LE_P^p + E_{TX}^p(l, d))} \quad (6)\]

Subject to: \[E_i \leq E_0 \forall i \in N \quad (7.1)\]

\[E_p \leq E_0 \forall p \in N \quad (7.2)\]

\[\sum_i (LE_S^i + LE_P^p + E_{TX}^p(l, d)) \leq qE_i \forall i \in N \quad (7.3)\]

\[\sum_p (N \otimes E_{TX}^p(l, d) + NL \otimes E_{ELEC}^p + E_{RX}^p) \leq qE_p \forall i \in N \quad (7.4)\]

\[\sum_i E_{ip}^l \leq C_{ip} \forall i \in N \quad (7.5)\]

\[E_{ps}^l \leq C_{ip} \forall f \in N \quad (7.6)\]
Then, equation (6) gives details about the per round energy consumption expenditure of the network. In constraint (7.1 and 7.2), the initial energy $E_0$ must continually be larger than the current energies $E_i$ and $E_p$ because in every passage of time, the current energies decline. A node stops working when $E_i$ and $E_p \leq$ ETX. Constraints in equation (7.3) consider sensing, processing, and transmission of data by normal node and ensures that these events respect their initial energy level ($q = 1/T$). They are only present at the parent node leading to decreasing and stabilizing of the energy expenditure. Equation (7.4) in contrast does not take into account $E_s$ and $E_p$ which are only introduced in usual nodes. This also reduces and stabilizes the energy expenditure. Constraints in equations (7.5 and 7.6) guarantee flow conservation when data are routed from $i$ to $p$ and from $p$ to $s$ with their physical link abilities, $C_{ip}$ and $C_{ps}$, respectively. Violation of these two constraints results to increased congestion which triggers increased delay and eventually to data being dropped. In order to retransmit the dropped packets, further energy is expended that results in diminished NL. Constraint in equations (7.7 and 7.8) indicates that the routing algorithm should be able to minimize the communication gap $d_{ip}$ and $d_{ps}$ to its lowest possible value $d_{min}$.

**Continuous data transmission minimization**

Constant data communication results to constant energy reduction. Constant transmission is tackled here and presented as follows

Minimizing $CT_{sp} \forall s, p \in N$ \hspace{1cm} (8)

where $CT_{sp} = \begin{cases} E_i - E_{TX}, & \text{if } D_s \neq D_S \\ E_i - 0, & \text{if } D_s = D_S \end{cases}$ \hspace{1cm} (9)

Subject to: $n_{sp}^{s-p} \rightarrow 0 \forall n \in Z^+$ \hspace{1cm} (10)

The objective function in equation (8) intends to reduce the constant transmission (CT) of data from sending node $s$ to parent node $p$. CT means the constant reduction in the node’s energy $E_i$ when each data is sensed. Equation (9) gives information; in the initial part of equation (9), currently sensed data $D_s$ are dissimilar from the formerly sensed data $D_S$, and consequence $E_i$ is reduced by $E_{TX}$. In the second part of equation (8), however, presently sensed data are the identical as the formerly sensed data; therefore, no transmission arises resulting to rise in network lifespan. Given that the sensed data are randomly produced, the type of data that is generated cannot be determined. Whenever the second portion of equation (9) takes place, no data are transferred which prevent communication of equal data and improve network lifespan. This is implemented in constraint (7.1). Violation of equation (7.1) will result to retransmission of the same data which will lead to rise in NL.

**Proposed Dual-sink Energy-efficient and QoS architecture for BSN**

The entire architecture of the proposed Dual-sink Energy-efficient and QoS architecture for BSN (DEQ-BSN) is depicted in Figure 1 and its components are described as follows:

1. BASN: the body area sensor nodes (BASNs) are positioned around the body to monitor the vitals, route the sensed data, and send the data to the appropriate destination sensor node.
2. E-MAC protocol: it is created to divide the data into ND, HND, and ED packet. The E-MAC does not add complexity or overhead because emergency level of data is represented in 0s and 1s.

3. HNS: it oversees receiving HND from BASN.

4. ES: it oversees receiving ED from BASN.

5. NDA algorithm: it decreases the energy consumption by ignoring the transmission of ND, which is provided in Algorithm 1.

6. DDA algorithm: it is responsible for avoiding the transmission of duplicate data, which is shown in Algorithm 2.

7. sPKW algorithm: its role is for selecting the best possible path for data communication in case of HND, hence improving QoS and battery life. However, in the case of ED, the data are communicated promptly to the ES without delay. In a nutshell, PKW employs both single-hop and multi-hop communication. Single hop is enabled if the data are an ED such as shown in Table 1 while multi-hop communication is employed if the data are a HND as seen in Table 1.

In PKW-multi-hop communication, the optimal next hop is chosen on the basis of weight value that is defined by considering some metrics and past knowledge of neighboring nodes. The past knowledge of neighboring nodes is the amount of packets successfully sent through the BASN. The weight value is computed as follows

\[ W_i = (RE_i + LS_i) - (D_i + DS_i) + PK \]  

where \( W_i \) is the weight value of node \( i \), \( PK \) is the past knowledge of neighboring nodes, \( RE_i \) is the residual energy, \( LS_i \) is the link stability, \( D_i \) is the delay in transmission to sink, and \( DS_i \) is the distance to sink. Equation (11) shows how the weight value is computed. Table 2 shows the notations and meaning.

The sensor node with the greatest weight value is deemed as the optimal next hop for data transmission. By computing the weight value, throughput is maximized while delay, reliability, and energy consumption are minimized. The overall PKW algorithm can be seen in Algorithm 3.

The link stability can be computed as given in equation (12). For example, to find the link stability between \( BASN_j \) and \( BASN_i \), the coverage range of \( BASN_j \) is

### Table 1. Data type filed binary form.

| Data type | Binary form | Diabetic example (fasting blood sugar) | Communication |
|-----------|-------------|---------------------------------------|--------------|
| ND        | 0 0         | 70–100 mg/dL                         | Ignored      |
| HN        | 0 1         | 101–125 mg/dL                        | PKW-multi-hop|
| ED        | 1 1         | 125 and mg/dL                        | Single-hop   |

ND: normal data; HN: high normal data; ED: emergency data; PKW: past knowledge-based weighted.
divided by distance between sensor node $j$ to sensor node $i$

$$LS_i = \frac{(R)BSN_j}{(Dist)BSN_j - (Dist)BSN_i}$$  \hspace{1cm} (12)

8. Sleep–wake duty cycle: it is responsible for reducing the idle listening and overhearing while increasing the NL and throughput. The sleep and wake up schedule are assigned according to the kind of information that is sensed by the sensor node. The flow chat of the whole operation is shown in Figure 2. First, $S_{ND}$ represent the sensor node with $n$ number of ND packets. $S_{HND}$ represent the sensor nodes with $n$ number of HND packets, and $S_{ED}$ represent the sensor nodes with $n$ number of ED packets. On the condition that the sum of the number of ED packets and high normal packets is higher than the number of packets ND packets for a particular BSN, then that BSN is deemed as an emergency BSN and allotted with T/2 time slot. Subsequently, the BSN ID is broadcasted to all other nodes to stop it from becoming forwarder.

**Simulation evaluation**

This section analysis and evaluates the implementation of the proposed DEQ-BSN architecture pertaining to NL, throughput, delay, and packet drop performance metrics. The comparison is made with similar techniques such as Simple, iM-Simple, Energy-aware QoS-guaranteed WBAN (EQ-WBAN), Link aware and energy efficiency protocol for wireless body sensor network and cooperative (Co-LLEEBA), quasi-sleep-preempt-supported (QS-PS), and CD.

**Algorithm 3.** Past knowledge-based weighted (PKW) routing algorithm.

```
1 Start
2 For all Data Packets
3    If (Data Type == 00)
4        Ignore
5    If (Data Type == 11)
6        Transmit to ES node
7    If (previous data! = current data)
8        Transmit to sink
9 For all neighbor nodes
10    Find W
11    If ($W_i$ == highest)
12        Select BSN
13        Transmit data packet to BSN
14        If (Residual Energy < Transmission Energy)
15        End if
16        End if
17 End for
18 End if
19 End if
20 End
```

![Figure 2. Sleep–wake duty cycle operations.](image)

**Simulation tool**

The simulation environment used in this work is Castalia-based OMNET ++ frameworks. The choice for OMNET ++ was as a result of the analysis performs by Elias and Mehaoua that shows OMNET ++ is better than all similar simulators especially with respect to implementation of routing protocols. Table 3 shows simulation parameters.

**Energy consumption.** It is described as the sum of the energy expended by nodes during different activities like sensing ($E_S$), transmitting ($E_T$), and receiving ($E_R$) of data packets (Table 4).

In Figure 3, the energy consumption of the proposed DEQ-BSN was compared with No Algorithm, QS-PS, and EQ-WBAN. It can be seen that our proposed DEQ-BSN significantly outperforms No-Algo, QS-PS,
and EQ-WBAN by 60%, 50%, and 10%, respectively. The reason is that in No-Algo, whenever the data are sensed, it is transmitted without considering any algorithms. In the case of QS-PS, a complex tree topology is used which lead to an increase in energy consumption and finally, for EQ-WBAN, non-CD were transmitted, duplicate data were not considered, and coordinator was used which added complexity, delay, and increase in energy consumption. However, our proposed technique outperforms all the others due to the algorithms that were used.

**Network Lifetime (NL)**. This is the time period in which all the nodes in the network are active. Hence, it is the time taken for the first node to die. It can be computed as shown in equation (13)

\[ NL = \frac{\varepsilon_0 - E[W]}{P_C + \lambda E[r]} \]  

where \( P_C \) is the constant power continuous power consumption, \( E[W] \) is the exempted waste, \( \lambda \) is the average reporting rate of sensor, and \( \varepsilon_0 \) is the network initial energy and expected reporting energy \( (E[r]) \).

In Figure 4, the NL of the proposed DEQ-BSN was compared with similar state-of-art algorithms. In No-Algo algorithm, its NL is only 8 s, this is because nodes are transmitting without following any algorithm. In iM-Simple, it achieved a lifetime of 60 s because of the inefficient selection of intermediate node. While in the case of EQ-WBAN, a better NL of 96 s was realized although lower than our algorithm. This is because complexity of CR and transmission of duplicate and non-CD. The proposed work achieves a much longer NL due to the implementation of NDA, DDA, PKW, and sleep–wake duty cycle algorithms.

**Packet dropped**. A sensor node drops packet whenever it residual energy is less than the required threshold to transmit a data packet. Figure 5 illustrates the number of packets dropped based on the implemented algorithm. Our proposed algorithm drops the fewest number of packets due to the several techniques that make up our

| Operation     | Energy consumption |
|---------------|--------------------|
| Sleep         | 0.02 mA            |
| Transmission  | 17 mA              |
| Reception     | 16.4 mA            |

**Table 4. Sensor node energy expended.**

| Parameter                                         | Value                      |
|---------------------------------------------------|----------------------------|
| Field                                             | 1000 × 1000                |
| WBSN standard                                     | IEEE 802.15.6              |
| Humans                                            | 1                          |
| BSNs                                              | 5–7                        |
| Coordinators                                      | 1                          |
| Sink nodes                                        | 2                          |
| End users                                         | 2                          |
| MAC header length                                 | 32                         |
| Packet size                                       | 2 kb                       |
| Pay load                                          | Max 2000 byte              |
| Bandwidth                                         | 20 MHz                     |
| Transmission rate                                 | Five packets/s             |
| Number of super frame slots                       | 16                         |
| Slot duration                                     | 1 s                        |
| Data rate                                         | 1024                       |
| Transmission energy consumption                   | 3.1 mW                     |
| Buffer capacity                                   | 32                         |
| Packet interval                                   | 4 s                        |
| Transmission power                                | 10 mW                      |
| Simulation time                                   | 150 s                      |

WBSN: wireless body sensor network; BSN: body sensor network; MAC: media access control.

**Table 3. Simulation values.**
proposed Dual-sink Energy-efficient and QoS architecture for BSN (DEQ-BSN) especially the employment of dual-sink node. In CD algorithm, about 40% of packets are dropped. In addition, for Energy-aware QoS-guaranteed WBAN (EQ-WBAN), more packets are dropped than our algorithm because of their inefficient techniques that makes up their algorithm.

Transmission delay. It is the total time taken by the data packet to get to the sink node from the source. Delay is expressed in equation (14)

$$\text{Delay} = \sum P_{lept} + \sum P_{t} eP_t[10]$$

(14)

where $t_r$ is the time taken by a node to receive a data packet, and $t_s$ is the time taken to send number of packets to the next node.

Figure 6 shows the delay experienced by the proposed algorithm and similar ones. QS-PS incurred about 80 ms delay as a result of the complex tree topology used in the algorithm. In the case of CD, a delay of about 62 ms was obtained regardless of the criticality of data packet. While EQ-BAN achieved less delay compared to the other two, it failed to match the delay is DEQ-WBAN because of the use of CR which coordinates all of the EQ-BAN techniques, hence causing delay. The proposed DEQ-BAN outperforms all the similar algorithms because of its dual architecture, multiple algorithms, and lack of CR.

Network throughput. It is the total amount of packets sent to actual target in specific time duration. It is additionally described as packet size divided by transmission times as shown in equation (15)

$$\text{Throughput} = \frac{\text{Packet size}}{\text{Transmission time}}$$

(15)

Figure 7 shows the throughput comparison of DEQ-BSN and similar works. It is evident from the figure that our algorithm achieves higher throughput. No-Algo has the lowest throughput because it depletes its energy fast; hence, it is unable to transmit any data to the sink node. CD achieves better network throughput compared to No-Algo; it throughput is significantly lower than the rest because of the large number of packet losses. Even though EQ-WBAN attained a throughput of around 75 kbps, our proposed technique outperforms it due to its limited packet drop.

The above findings demonstrate that the proposed DEQ-BSN substantially surpasses similar algorithms in delay, NL, energy consumption, packet drop, and...
throughput. Hence, it can be concluded that our dual-sink architecture with E-MAC protocol, NDA, DDA, PKW, and sleep–wake up duty cycle is efficient enough to increase the total performance of the network. This proves that if our work is applied in real-time scenario, it will attain similar results.

Conclusion

This article has presented a dual-sink WBAN architecture with energy-efficient and QoS routing protocols. The aim of the dual-sink node is to ensure that each type of node reach its appropriate sink without delay in separating the data packets. Five different algorithms were presented which increase the network lifetime and the QoS of the network. The first algorithm is the NDA that ignores the transmission of ND. Next is the DDA that avoids the transmission of duplicate data. Then, PKW algorithm is used for selecting the optimal route for data transmission, hence improving QoS. Sleep scheduling is incorporated to help improve the battery life. Next, linear programming–based mathematical model was designed to model the network lifetime maximization and continuous data transmission minimization. Exhaustive simulation in OMNeT++ tool demonstrates that the proposed work surpasses similar state-of-the-art research with regard to network lifetime, throughput, energy consumption, delay, and dropped packets. As a future work, we intend to add energy harvesting and security to further increase the overall performance and defend the network against major attacks.

Declaration of conflicting interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Funding

The author(s) received no financial support for the research, authorship, and/or publication of this article.

ORCID iD

Abdullahi Ibrahim  
https://orcid.org/0000-0001-9145-1939

References

1. Javaid N, Nadeem Q, Imran M, et al. IM-SIMPLE: iMproved stable increased throughput multi-hop link efficient routing protocol for Wireless Body Area Networks. *Comput Human Behav* 2015; 51: 1003–1011.
2. Shirazi G and Lampe L. Lifetime maximization in UWB sensor networks for event detection. *IEEE Trans Signal Pr* 2011; 59(9): 4411–4423.
3. Movassaghi S, Abolhasan M, Lipman J, et al. Wireless body area networks: a survey. *IEEE Commun Survey Tutor* 2014; 16(3): 1658–1686.
4. Nadeem Q, Javaid N, Mohammad S, et al. Simple: stable increased throughput multi-hop protocol for link efficiency in wireless body area networks. In: *The 8th international conference broadband and wireless computing, communication and applications (BWCCA)*, Compiegne, 28–30 October 2013. New York: IEEE.
5. Ahmad A, Javaid NN, Qasim U, et al. RE-ATTEMPT: a new energy-efficient routing protocol for wireless body area sensor networks. *Int J Distrib Sens Netw* 2014; 10: 464010.
6. Javaid N, Abbas Z, Fareed MS, et al. M-ATTEMPT: a new energy-efficient routing protocol for wireless body area sensor networks. In: *The 4th international conference on ambient systems, networks and technologies (ANT)*, Elsevier, Halifax, NS, Canada, 25–28 June 2013.
7. Ahmed S, Javaid N and Yousaf S. Co-LAEEBA: cooperative link aware and energy efficient protocol for wireless body area networks. *Comput Human Behav* 2015; 51: 1205–1215.
8. Sagar AK, Singh S and Kumar A. Energy-aware WBAN for health monitoring using critical data routing (CDR). *Wireless Pers Commun* 2020; 112: 273–302.
9. Mu J, Stewart RW, Han L, et al. A self organized dynamic clustering method and its multiple access mechanism for multiple WBANs. *IEEE Intern Things J* 2019; 6: 6042–6051.
10. Abdu AI, Bayat O and Ugan ON. Designing insensitivity-aware medium access control protocol and energy conscious routing in quality-of-service-guaranteed wireless body area network. *Int J Distrib Sens Netw* 2019; 15: 1–15.
11. Shimal SM, Smith DB and Movassaghi S. Cross-layer designs for body-to-body networks: adaptive CSMA/CA with distributed routing. In: *2018 IEEE international conference on communications (ICC)*, Kansas City, MO, 20–24 May 2018, pp. 1–6. New York: IEEE.
12. Rakhee and Srinivas MB. Energy efficiency in load balancing of nodes using soft computing approach in WBAN. In: Yadav N, Yadav A, Bansal JC, et al. (eds) *Harmony search and nature inspired optimization algorithms*. New York: Springer, 2019, pp. 423–440.
13. Ullah F, Ullah Z, Ahmad S, et al. Traffic priority based delay-aware and energy efficient path allocation routing protocol for wireless body area network. *J Ambient Intel Human Comput* 2019; 10: 3775–3794.
14. Navya V and Deepalakshmi P. Energy efficient routing for critical physiological parameters in wireless body area networks under mobile emergency scenarios. *Comput Electr Eng* 2018; 72: 512–525.
15. Arbia DB, Alam MM, Atitia R, et al. ORACLENet: A novel multi-hop body-to-body routing protocol for public safety networks. *Peer Peer Netw Appl* 2017; 10: 726–749.
16. Manirabona A and Forauri LC. A 4-tiers architecture for mobile WBAN based health remote monitoring system. *Wireless Netw* 2018; 24: 2179–2190.
17. Abiodun AS, Anist MH, Ali I, et al. Reducing power consumption in wireless body area networks: a novel data
segregation and classification technique. IEEE Consum Electron Mag 2017; 6(4): 38–47.

18. Qureshi KN, Din S, Jeon G, et al. Link quality and energy utilization based preferable next hop selection routing for wireless body area networks. Comput Comm 2020; 149: 382–392.

19. Choudhary A, Nizamuddin M, Singh MK, et al. Energy budget based multiple attribute decision making (EB-MADM) algorithm for cooperative clustering in wireless body area networks. J Electr Eng Tech 2019; 14: 421–433.

20. Khan RA, Xin Q and Roshan N. RK-energy efficient routing protocol for wireless body area sensor networks. Wireless Pers Commun 2020; 116: 709–721.

21. Yang G, Wu X, Li Y, et al. Energy efficient protocol for routing and scheduling in wireless body area networks. Wireless Netw 2020; 26: 1265–1273.

22. Goyal R, Patel RB, Bhaduria HS, et al. An energy efficient QoS supported optimized transmission rate technique in WBANs. Wireless Pers Commun 2021; 117: 235–260.

23. Sunny S and Devendra P. Wireless body area network (WBAN): a review of schemes and protocols. Mater Today 2021; 49: 3488–3496.

24. Rasool SMR and Gafoor SAA. Energy efficiency and QoS concession technique utilizing OMAC protocol for WBAN. Physcol Educ J 2021; 58(4): 1420–1411.

25. Ibrahim AA, Bayat O, Ucan ON, et al. Weighted energy and QoS based multi-hop transmission routing algorithm for WBAN. In: 6th international engineering conference “Sustainable Technology and Development” (IEC), Erbil, Iraq, 26–27 February 2020, pp. 191–195. New York: IEEE.

26. Ibrahim AA, Tijani Salawudeen A, UÇAN ON, et al. A novel energy-conscious threshold-based dAta Transmission routing protocol for wireless body area network (NEAT). In: International congress on human-computer interaction, optimization and robotic applications (HORA), Ankara, 26–28 June 2020, pp. 1–5. New York: IEEE.

27. Ibrahim AA. Quality of service-aware clustered triad layer architecture for critical data transmission in multi-body area network environment. Eng Report 2021; 3: e12356.

28. Dawood Al-obaidi MA and Abd Ibrahaim A. R-SIMPLE: reliable stable increased-throughput multi-hop protocol for link efficiency in wireless body area networks. In: International congress on human-computer interaction, optimization and robotic applications (HORA), Ankara, 26–28 June 2020, pp. 1–5. New York: IEEE.

29. Ibrahim AA, Bayat O, Ucan ON, et al. EN-NEAT: enhanced energy efficient threshold-based emergency data transmission routing protocol for wireless body area network. In: Yang XS, Sherratt S, Dey N, et al. (eds) Third international congress on information and communication technology. Advances in intelligent systems and computing, vol. 797. Singapore: Springer, 2019, pp. 325–334.

30. ur Rehman Khana A, Bilalb SM and Othmana M. A performance comparison of network simulators for wireless networks, 2013, https://arxiv.org/abs/1307.4129

31. Liu J, Li M, Yuan B, et al. A novel energy efficient MAC protocol for wireless body area network. China Commun 2015; 12(2): 11–20.

32. Raja KS and Kiruthika U. An energy efficient method for secure and reliable data transmission in wireless body area networks using RelAODV. Wireless Pers Commun 2015; 83(4): 2975–2997.

33. Elias J and Mehaoua A. Energy-aware topology design for wireless body area networks. In: IEEE international conference on communications (ICC), Ottawa, ON, Canada, 10–15 June 2012. New York: IEEE.

34. Naddafzadeh-Shirazi G, Shenouda MB and Lampe L. Second order cone programming for sensor network localization with anchor position uncertainty. IEEE Trans Wirel Commun 2013; 13(2): 749–763.