Quality of Service-aware clustered triad layer architecture for critical data transmission in multi-body area network environment

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Abstract
Wireless Body Area Network (WBAN) is an important element of future smart healthcare services in smart cities. For this reason, many research works have been undergone in WBAN. The significant research issue in the WBAN environment is Quality of Service (QoS) provisioning. In literature, some of the works have been focused on QoS aspect of WBAN. However, they have only marginal impact due to ineffective network design and the usage of a single sink node. Also, most of the research works have been tested within a single BAN and present intra-BAN communication. In practical, an effective multi-BAN communication system is emerging due to the need of large-scale healthcare system. This paper addresses these issues and designs a novel QoS-aware Clustered Triad Layer (QC-TriL) architecture for multi-BAN environment. The novel QC-TriL uses dual sink nodes in each BAN and both sinks are deployed in the optimal positions. To determine the optimal position, Type-II Fuzzy Logic (T2FL) is proposed with different criteria. Next, we form clusters based on the positions of dual sink nodes. QC-TriL adopts criticality-aware routing by presenting Delay-aware One-Hop Transmission and Fused Rank Scheme (FuRank) for critical data and normal data routing respectively. The data transmission is organized by a novel 1D-Dragonfly topology-based Priority Dual TDMA (PD-TDMA) scheduling protocol. Finally, multi-BAN communication is enabled with an optimal route selected by QoS-aware Emperor Penguin Colony (QoS-EPC) algorithm. The QC-TriL multi-BAN environment is modeled in OMNeT++ simulator and evaluated in terms of energy consumption, packet delivery ratio, throughput, and delay. The experiments show promising results for the multi-BAN environment.

KEYWORDS
body-to-body communication, clustering, criticality-aware routing, smart cities, smart healthcare
INTRODUCTION

In this era of communication, Wireless Body Area Network (WBAN) is one of the most striking and also beneficial networks.\(^1,2\) A typical, WBAN consists of biomedical sensors or body sensors such as temperature, visual sensor, motion sensor, electrocardiogram (ECG), and so on with a sink node. The WBAN is responsible to acquire the physiological information of a person through sensory measurements. The applications of WBAN are wide including healthcare monitoring in smart and conventional cities, disease diagnosis, remote patient monitoring, and patient monitoring in hospitals.\(^3\) All in all, WBAN plays a pivotal role in this growing Internet of Things (IoT) environment.\(^4\) Though it has far-reaching advantages, it also involves some research issues.\(^5,6\) The first and foremost issue is the Quality of Service (QoS) degradation. In precise, energy efficiency and delay are the major QoS factors in WBAN. As the biomedical sensors are resource-constrained in nature and often generates critical physiological sign. This physiological must be transmitted without delay and loss to take immediate action on the patient’s health. Energy efficiency and delay can be improved by using clustering approach.\(^7,8\) Clustering is the process of grouping sensor nodes in the WBAN in order to minimize the transmission delay and energy consumption by enabling optimal data aggregation process. For achieving better QoS, routing has been considered as the best solution.\(^9\) The QoS-based approaches can be categorized based on the number of sink nodes deployed. The network routing with more than one sink node provides better reliability and minimizes the data transmission delay. But with multiple sink nodes, it is necessary to optimize the deployment process for achieving better efficiency. Besides, some routing algorithms solely concentrate on energy efficiency\(^10,11\) since energy is one of the significant constraints. In these algorithms, the energy metric is defined and it is considered as route selection criteria. In addition to the routing algorithms, scheduling methods have been focused to enhance the delay and delivery ratio.\(^12,13\) In WABN, the scheduling must consider the priority of the data. The priority value indicates the criticality level of the data.

All these research works have been presented upon single-BAN which is also known as intra-BAN communication. However, the current applications require multi-BAN or BAN-to-BAN or inter-BAN communication to manage the large-scale patient monitoring, hospital monitoring, and real-time race monitoring, and so on.\(^14\) But the existing research on multi-BAN communication is limited and the results are not fully analyzed.\(^15\)

An example scenario of multi-BAN communication is illustrated in Figure 1.\(^16-18\) In this case, the BAN sensors are deployed in each patient and the multiple patients form a multi-BAN environment. In single BAN approach, each BAN enabled in each patient must report the data to the base station (BS) which is deployed in the monitoring center. This long-distance communication needs large enough energy and congestion-less channel. On the other hand, the multi-BAN environment allows data transmission through multiple BANs which is useful in this scenario. Likewise, multi-BAN communication is helpful in many application scenarios but has a limited focus in literature. Overall, the following research issues still need attention in BAN communications,

- End-to-end QoS is achieved within single-BAN which is not sufficient and not suitable for real-time scenarios.
- Large delay is introduced in data transmission that has a high impact on critical data transmission.
- Energy efficiency is only focused on routing. In that, the poor metric design affects the energy as well as data transmission efficiency.

The above research problems are considered in this work. These problems are resolved with the novel BAN design.

1.1 Motivation and contributions

The core motivation behind this work is that the majority of the BAN-based research works focus on either route selection or scheduling with a single sink node. On the other hand, cluster formation has been proved to achieve better
There only limited works have focused on cluster-based WBAN and show better efficiency. In that works, the clear view on cluster formation is not discussed. Further, achieving delay and energy efficiency not only depends upon intra-BAN communication since it highly depends upon multi-BAN communication. Thus, it is needed to design a multi-BAN environment to achieve high-level QoS. Apart from this the critical data transmission also lacks due to higher energy consumption and delay. Therefore, we design our research objective to achieve better QoS by optimizing multi-BAN and critical data communication. This objective tends us to make the following prime contributions,

- We design a novel QoS-aware Clustered Triad Layer (QC-TriL) architecture to support multi-BAN as well as critical data communication. Besides, we optimize the communication within single-BAN and multi-BAN environment.
- The QC-TriL architecture presents a new concept of dual-sink deployment in the first layer, that is, BAN layer. The optimal positions for both sinks are determined by Type II Fuzzy (T2FL) that operates upon multiple criteria. Then, the clusters are formed with the sink nodes.
- We propose two different routing methods for critical and non-critical data. The critical data are transmitted through an optimal forwarder selected by Delay-aware One-Hop Transmission (D-OHT) while the non-critical data are transmitted through multiple forwarders selected by Fused Rank (FuRank) scheme. Both algorithms consider significant key factors for routing.
- Then, the data scheduling is carried by 1D-Dragonfly topology-based Priority Dual TDMA (PD-TDMA) protocol. The 1D-Dragonfly provides necessary information for scheduling.
- At last, BAN-to-BAN routing is established to ensure end-to-end QoS in the second layer, that is, multi-BAN layer. For optimal route selection, we present a QoS-aware Emperor Penguin Optimization (QoS-EPC) algorithm.

1.2 Paper outline

The rest of this paper is organized as follows: Section 2 provides systematic review on related research works undergone in the BAN environment. In Section 3, we define the problem statement designed for this work. Section 4 explains the proposed QC-TriL in detail. In Section 5, the experimental results are discussed and comparative analysis is provided in detail. In the Section 6, we conclude our contributions and highlight the future research directions.

2 RELATED WORKS

In this section, we survey related research works presented on WBAN and multi-BAN environment. This section reviews the significant papers with its pros and cons.

2.1 Clustering and scheduling

In WBAN, body-to-body communication becomes emerging due to its need in real-time scenarios. A data transmission mechanism for the multiple-WBAN environment was presented with cluster formation method.21 The major objective of this work was to improve the QoS in the WBAN environment. For that, a self-organized dynamic clustering method was proposed with multiple WBANs. An inter-WBAN relaying protocol was proposed for data transmission. The clusters were formed within each cell based on the channel availability. However, the cluster formation considers the multiple BANs and the single-BAN sensors follows regular scheme which further increases the energy consumption. Cluster formation approach was initiated with a cost function computation in a single-BAN environment.22 Here clusters were formed by exchanging hello messages and one of the biosensors was selected as cluster head (CH). Then, the cost function was computed based on the link signal-to-noise ratio (SNR), transmission power, and distance. The selection of a normal sensor as CH increases energy consumption for those particular nodes which further results in inefficiency. Cluster-based WBAN was presented with dual sink nodes deployed in the left and right hips of the human.23 Cluster formation was initiated with the received signal strength indicator (RSSI) calculation. In the BAN, two clusters were formed and optimal CHs were selected. Here the data arranged in a TDMA manner. Here also the selection of normal nodes as CHs degrades
energy efficiency. Besides, TDMA scheduling is not suitable for emergency cases and degrades the data transmission efficiency.

An energy-efficient multi-hop routing protocol follows TDMA scheduling in WBAN networks. Routing path was established between the body sensor node and the sink node. For optimal parent node selection, Mamdani fuzzy logic was employed. In the rule base, five fuzzy rules were deployed based on the residual energy level. All data were transmitted by TDMA slots. However, considering a single metric for data transmission is not efficient and has higher data loss. Furthermore, TDMA scheduling is not suitable for emergency data transmission. Data scheduling was focused on Multi-BAN environment with optimal routing. An insistence aware medium access control (I-MAC) protocol was designed for achieving QoS and energy efficiency in WBAN. A prior knowledge-based weighted routing algorithm was proposed to select an optimal route. The route selection considers significant metrics like residual energy, link stability, distance, and delay. Further, sleep scheduling was followed based on the graph-based sleep scheduling algorithm. Here the criticality of the sensor node plays a major role. Further, the coordinator performs packet classification by split and map-based neural network. The priority level is determined by both sensor nodes and the coordinator which increases time consumption scheduling and data transmission. The multi-ban environment is tested but the data transmission among multiple BANs is not optimized. In multi-BAN, an adaptive CSMA/CA protocol was presented to eliminate the problems in TDMA scheduling. For routing, shortest path routing (SPR) and cooperative multipath routing (CMR) protocols are utilized. In SPR, the single path was selected upon distance metric and in CMR multiple paths were selected based on back-off time. Here, the route selection is not optimal which results in higher data loss and energy consumption. Similarly, the proposed scheduling does not consider the criticality level of the data which is highly demanded in the BAN environment. Thus, the cluster formation and scheduling approaches need to be optimized to achieve better QoS.

### 2.2 Routing in BAN environment

A directed diffusing routing protocol was introduced for WBANs. This work focuses on minimizing energy consumption in the network. The direction and rate of data transmission were indicated by the concept of gradient. The major criterion for optimal route selection was the hop count. The data were diffused directly through the route which has minimum hop count. For that, each node maintains the gradient information of its neighbor nodes with the shortest path. However, the authors have highlighted that this work is not suitable for emergency applications of WBAN since the algorithm has a large delay. For optimal route selection, Ant Colony Optimization (ACO) algorithm was proposed in WBAN. The ACO finds an optimum route between the source node and the sink node. The proposed ACO satisfies both energy efficiency and load balancing at each intermediate node. During route construction, CH rotation was enabled to achieve energy efficiency. Energy consumption and buffer space were considered for pheromone update. In general, the ACO algorithm has higher time consumption which increases the data transmission delay too. Simplified energy-balanced alternative aware routing algorithm (SEAR) was used in WBANs. The optimal route selection considers the residual energy level and current load level of the candidate node. Through optimal forwards, the data were transmitted to the sink node. For this purpose, an improved route request mechanism was proposed. The improved route request was forwarded at the route discovery time. Upon receiving a route reply, the algorithm computes the load and energy level. Then, optimal forwarder was selected from the candidate nodes. In this manner, the data were transmitted to the destination. This work is also not suitable for critical data transmission since it has a higher delay.

A traffic priority-based delay aware and energy-efficient path allocation routing protocol (Tripe-EEC) was presented to handle critical data. The Tripe-EEC selects a route with a higher residual energy level and minimum temperature rise. At first, the data were classified into normal, data on-demand, and emergency data based on low threshold readings to high threshold readings. Then, energy and delay-aware path was allocated for normal data. Further, the data on-demand algorithm was introduced for on-demand traffic transmission. For emergency data, the adaptive and energy-efficient path was selected. For three types of routes, a single metric is considered which is not sufficient. Also, a route with multiple hops relatively increases the delay for emergency data. A priority-aware routing scheme was proposed for mobility supported WBAN. The data routing was performed by Predecessor-Successor-Node (PSN) technique. The PSN technique was a hierarchical method and uses the priority level for optimal route selection. The overall PSN technique was working upon the energy metric. Although this work achieves better energy efficiency, this work is not suitable for a real-time environment where multiple-BANs are involved. An optimized routing approach for critical and emergency networks (ORACE-Net) was introduced for the multi-BAN environment. The ORACE-Net measures the link quality among multiple BANs to select the optimal route for data transmission. The link quality metric improves the data transmission but
also increases the delay due to a large number of hops. Thus, the multi-BAN environment must consider multiple factors for optimal routing. Although many research works have been presented on the WBAN routing, none of the works has focused on both single-BAN and multi-BAN communication which is a more practical scenario. Also, the considered metrics are not sufficient to achieve better QoS and energy efficiency.

From the related works, it is clear that there is a huge research gap in achieving QoS in the BAN environment. The major issues identified are the design of BAN environment, routing for critical and non-critical data. Research on the multi-BAN environment also needs in-depth analysis.

3 | PROBLEM DEFINITION

The prime objective of this research work is to achieve better QoS in the multi-BAN environment. The objective function is formulated as follows,

\[ \text{Obj} : \rightarrow \max \{E_E, PDR\} \& \min\{D_T\} \]  

The specific objective is formulated as maximizing energy efficiency \((E_E)\) and packet delivery ratio \((PDR)\) while minimizing transmission delay \((D_T)\) for both normal and critical data. Here, we considered three objectives for critical and normal data. All these objectives are highly related to the data criticality since the critical data transmission is one of the main aspects of WBAN environment. Achieving these objectives without considering data criticality results in improper QoS provisioning. Similarly, considering delay or PDR alone increases the energy consumption which needs to be avoided in the WBAN environment. Thus, we have formulated the objective of this work based on all three aspects with the consideration of data criticality. To main research problem statement that restricts this objective is that “single-BAN environment with single sink node with non-optimal position fails to achieve end-to-end QoS due to the additional factor like inefficient metric formulation and algorithm design”. This statement is derived from the multiple problem definitions explained below.

A dual sink approach using clustering BAN (DSCB) relies upon line-of-sight (LoS) and non-LoS (NLoS) communications.\(^3^6\) Although this work has dual sink nodes it has multiple pitfalls as follows: (i) clusters are formed randomly, thus the node located far away from the CH suffers from a large amount of energy consumption, (ii) although emergency data are transmitted in single-hop, it has to wait for its TDMA slot which increases delay, and (iii) the considered parameters for forwarder selection are insufficient to achieve better QoS since the data transmission is affected many other parameters. Genetic Algorithm (GA)-based adaptive objective function was designed for optimal route selection.\(^3^7\) Here using a single sink node with NLoS communication increases the data loss and time consumption. The emergency data also need to wait until the objective function changed by GA. But GA has a relatively large time consumption which is not suitable for the real-time environment. Link quality was considered as the weighting score for route selection.\(^3^8\) Here consideration of limited metric increases packet loss and delay. In particular, the emergency data are not able to be transmitted within the required time. Energy budget-based multiple attributes decision making (EB-MADM) was proposed with dynamic CH selection and route selection.\(^3^9\) Here ECG and respiratory sensors are considered as high priority sensors which are not sure that both sensors always provide emergency data. Thus, both sensors have higher energy consumption due to single-hop communication. Involvement of TDMA-based scheduling is not effective for critical data transmission and multi-hop routing with non-optimal nodes affects the data delivery. In precise, the majority of the works are not suitable for a practical scenario.

4 | PROPOSED QC-TRIL

This section explains the proposed QC-TriL network in detail. In this section, each and every process involved in the QC-TriL is explained with novel algorithms.

4.1 | QC-TriL model

The proposed QC-TriL model is a new architecture that is designed for multi-BAN environment. The proposed QC-TriL architecture consists of \(n\) number of BANs as \(\{\text{BAN}[] = [B_1, B_2, .., B_n]\}\). Each BAN represents a patient with multiple
biomedical sensor nodes. A BAN consists of \( m \) number of sensors as \( B_i[] = [N_1, N_2, ..., N_m] \). Each sensor node is dedicated to sense specific physiological parameter like ECG, respiratory, motion, and so on. The proposed QC-TriL architecture is illustrated in Figure 2. As shown in the figure, the clusters are formed within each BAN with dual sink nodes. Before that, the sink nodes are deployed in the optimal positions which improve the data transmission efficacy. Routing is customized based on the priority level of the data. For critical data single-hop, the optimal transmission is performed and for non-critical data multi-hop, optimal forwarders are selected. Further, end-to-end QoS is achieved by QoS-EPC algorithm-based BAN-to-BAN routing. In the proposed architecture, the data are transmitted in an adaptive and advanced scheduling manner.

The additional components used to build the QC-TriL architecture are,

- **Dual Sinks (\( S_1, S_2 \))**: Each BAN \( B_i \) consists of two sink nodes as \( S_1(i), S_2(i) \). The sink nodes are responsible to collect the sensed medical data from the body sensors. These sink nodes are deployed in the human body.
- **Hub**: The hub is the interface between two BANs. The hub of the \( i \)th BAN \( (H(i)) \) is responsible to collect the data from \( S_1(i) \) and \( S_2(i) \).
- **Base Station (BS)**: It is the termination point of the BAN communication. BS is responsible to aggregate medical data from all BANs and transmits the data to the responders via Internet.

The abovementioned components are arranged in three layers. The first layer comprises a single BAN with multiple medical sensors (from here the medical sensors, body sensors and biomedical sensors represent the same). The second layer comprises multiple BANs and the third layer has the BS. The end-to-end BAN communication starts with the first layer and ends in the last layer.

**4.2 Dual sink deployment and cluster formation**

The foremost process in the proposed QC-TriL is that dual sink deployment and cluster formation. This process is carried at the first layer, that is, in each BAN. In the proposed work, all body sensors are organized in a new 1D-Dragonfly topology which is the fully-connected topology. At first, the body sensors are deployed in their dedicated positions (for example, ECG sensor is deployed nearer to the heart). Then, dual sink nodes \( S_1 \) and \( S_2 \) are deployed in the optimal positions. The optimal positions are determined by T2FL algorithm. To the best of our knowledge, this is the first work that deploys dual sink nodes in optimal positions in the multi-BAN environment. Optimal deployment of dual sink nodes assists in data transmission efficacy and energy efficiency. The positions of body sensors and the sink nodes are shown in Figure 3.
As shown in the figure, the sink deployment process operates upon three significant criteria such as average distance with the body sensors ($d_{avg}$), connectivity degree ($C_{deg}$), and centrality factor ($F_{cen}$). The T2FL algorithm considers multiple positions ($P = (x, y)$) coordinates as candidates and gives the best position ($x_{best}, y_{best}$) as the output. The criteria can be defined as follows,

**Definition 1.** ($d_{avg}$) This metric measures the average distance with the nearest neighbors. The distance is measured as the Euclidean distance between two points as follows,

$$d_{avg} = \frac{1}{k} \sum_{i=1}^{k} \sqrt{(x_i - x_j)^2 + (y_i - y_j)^2}$$

The above equation measures the distance between $i$th candidate position ($P_i = x_i, y_i$) and $j$th body sensor position ($x_j, y_j$) and $k$ denotes the number of neighbor nodes. This metric is important since the distance measure has a major impact on data transmission and energy efficiency. As the sink node is responsible to collect the data, the sink nodes must be deployed with lower distance with the body sensors.

**Definition 2.** ($C_{deg}$) The connectivity degree measures the number of body sensors connected to that $P_i$ directly. This metric measures the ability of that position to collect data from multiple body sensors.

**Definition 3.** ($F_{cen}$) This metric measures the distance between $P_i$ and the centroid point of the BAN. This metric decreases the distance between $S_1$ and $S_2$ which is useful when anyone of the sink node is unable to receive the data. In precise, consideration of $F_{cen}$ reduces the distance between all body sensors and the sink nodes while $d_{avg}$ minimizes the distance between the sink node and its neighboring body sensors. This metric is also computed as the Euclidean distance between $P_i$ and the centroid point.

### 4.2.1 Process in fuzzy engine

All defined criteria are computed for each candidate position and the optimal position $P_{best}$ is determined by applying the fuzzy rules. We use type II fuzzy sets instead of using the conventional fuzzy sets. The type II fuzzy sets are efficient and handle the uncertainty which is not possible in type I fuzzy sets. In T2FL, the three factors are computed for each $P_i$ and given to the fuzzifier. The fuzzifier maps all input values into the interval of [0,1]. Then, IF-THEN fuzzy rules are applied as follows,
IF \((d_{\text{Avg}}(P_i)) \&\& F_{\text{Cent}}(P_i)\) is low\&\& \((C_{\text{deg}}(P_i))\) is high, THEN \(P_t = P_{\text{best}}\)

The above rule represents the fuzzy rule for \(P_{\text{best}}\) candidate position. Similarly, 27 rules are deployed in the rule base for optimal position determination. The \(P_t\) which satisfies the rule is selected by the rule verification. The verification process is executed with the help of the rule base. Then the output is fed into the output block in which type-reducer and defuzzifier are included. The type-reducer is responsible to reduce the type-II set into the type-I set. Then the defuzzifier produces the crisp output which is used to make decision on the sink deployment. At the end of the T2FL algorithm, the optimal positions for \(S_t\) and \(S_2\) are identified.

4.2.2 | Cluster formation

In next, the clusters are formed by considering the \(S_1\) and \(S_2\) as the CH. In general, the sink node is responsible to aggregate the data from all body sensors. Thus, selecting sink nodes as CHs increases the efficiency. Let \(S_1(i)\) and \(S_2(i)\) are deployed in the \(B_t\) which has \(m\) body sensors. After optimal deployment, both sink nodes send request message (Join_Req) to all \(m\) sensors, that is, each \(N_j\) receives Join_Req from both \(S_1(i)\) and \(S_2(i)\). Then, the \(N_j\) computes the distance with both sink nodes. The sink node which has lower distance is considered to send a response (Join_Res) message. Upon receiving Join_Res, the sink node updates its member list with \(N_j\). In this manner, the nodes are clustered. The clustering process is performed at once since all nodes and the sinks are static. The sink nodes deployment and cluster formation processes are performed in each \(B_t \in \text{BAN}[]\). At the end of this stage, all body sensors are clustered and the sinks are deployed in the optimal positions.

4.3 | Criticality-aware multi-hop routing

As stated earlier, the proposed QC-TriL focuses on both single-BAN communication and multi-BAN communication to achieve end-to-end QoS. In single-BAN communication, both one-hop communication and multi-hop communication are performed based on the criticality level of the data. The criticality level of the data is determined by each body sensor based on the threshold value \((\tau)\). This threshold value is set upon the type of the body sensor. For example, the non-critical data of temperature sensor ranges from 97 to 98 degree, otherwise, the data are critical. In this manner, the criticality level of the data is identified. Then, the body sensor appends the criticality level (0 for non-critical and 1 for critical) with the data. Based on this criticality level, the data are transmitted to the CH, that is, sink node. In most of the existing works, critical data are transmitted directly to the sink node. However, this consumes large energy for the body sensors which generates critical data frequently. To overcome this issue, we introduce the concept of one-hop communication for critical data and multi-hop communication for non-critical data.

4.3.1 | D-OHT-based critical data transmission

We propose D-OHT scheme for critical data transmission. If a body sensor \(N_i\) has critical data, then it executes D-OHT scheme to select optimal one-hop forwarder (1HF_{\text{opt}}) between that node and the sink node. Let \(N_i\) is presented in the first cluster with the CH of \(S_1\). Now the \(N_i\) needs to transmit the critical data to the sink. For that, the \(N_i\) selects 1HF_{\text{opt}} based on expected delay \((D_{\text{ex}})\) and residual energy level \((RE)\), The \(D_{\text{ex}}\) of the neighboring node \(N_j\) is computed as follows,

\[
D_{\text{ex}} = wT_0 \frac{R_i - d(N_i,N_j)}{R_i}
\]

The expected delay is computed based on the waiting time \((wT_0)\), the transmission range of \(N_i\) \((R_i)\), and the distance between \(N_i\) and \(N_j\). The node which has lower \(D_{\text{ex}}\) and higher \(RE\) is selected as 1HF_{\text{opt}} for critical data transmission. In most of the research works, the critical data have been transmitted to the sink directly. In direct communication, there is high possibility to have NLoS communication. Since the sink node is deployed away from the body sensor and the motion of the human greatly affect the LoS communication. As a result, many critical data have transmitted through NLoS communication. However, NLoS communication leads to high data loss which may degrade the reliability of critical data. Here we present one-hop forwarder-based data transmission which ensures LoS communication for critical data also.
Therefore, we achieve high reliability for critical data. As the critical data are transmitted through one-hop forwarder, the delay is low and the energy efficiency is high. The $1HF_{\text{opt}}$ first verifies the criticality level. If the data are critical, then it transmits the data to the sink immediately. Otherwise, it seeks for optimal next-hop node. Thus, the critical data are transmitted to the corresponding CH without delay.

### 4.3.2 FuRank-based non-critical data transmission

For non-critical data, we present FuRank scheme which fuses significant criteria for optimal multiple forwarders selection. The FuRank scheme computes five important parameters for each candidate node. The considered significant parameters are described in Table 1.

Here the $LQ$ of $N_j$ is computed as follows,

$$LQ (N_i, N_j) = \frac{\text{Signal Power}}{\text{Noise Power}}$$  \hspace{1cm} (4)

Similarly, $EC_{\text{ex}}$ is computed as follows,

$$EC_{\text{ex}} = E_{\text{elec}} \times \rho \times \varepsilon_F \times d^2$$  \hspace{1cm} (5)

Here $\rho$ denotes the number of bits needs to be transmitted, $\varepsilon_F$ represents free-space constant and $d$ denotes the distance between $N_i$ and $N_j$. For every neighboring node $N_j$ the source node $N_i$ computes all five parameters. Then, it fuses these parameters to rank the neighboring nodes. The fused parameter for $i$th node ($FuP_j$) is computed as follows,

$$FuP_j = \frac{\sum RE, LQ, \varphi}{\sum EC_{\text{ex}}, d}$$  \hspace{1cm} (6)

For each neighboring node, the $FuP_j$ value is computed. Then, the nodes are arranged in the descending order, that is, the node with high $FuP_j$ value will have the first rank. In this manner, the data are forwarded to the optimal forwarder ($For_{\text{opt}}$) node. Then, that forwarder node executes the FuRank procedure to select next-hop optimal forwarder. In this manner, the non-critical data are transmitted to the sink node through optimal forwarder nodes.

In Figure 4, the process of D-OHT and FuRank scheme is illustrated. At first, the source node checks the criticality level of the data to select one-hop or multi-hop communication. Then, it follows optimal forwarder selection as per the algorithm. At last, the data are transmitted to the sink node through optimal forwarders.

### 4.4 Topology and priority-based scheduling

After optimal forwarder selection, the body sensor request for a time slot to transmit the data. In the BAN, there is a high possibility for a node $N_j$ to be an optimal forwarder for more than one source nodes. In this case, all nodes transmit the data

| TABLE 1 | Fusing parameters with description |
|-----------------|-----------------------------------|
| **Parameter**   | **Description**                   | **Importance**                          |
| Residual energy (RE) | Measures the current energy level of the body sensor | When this metric is low, then the sensor will be subjected to more energy consumption |
| Link quality (LQ) | Measures the quality of communication link as the measure of SNR | It decides the efficiency of data transmission. If $LQ$ is low, then the data loss will be high |
| Expected energy consumption (EC_{ex}) | Calculates the expected energy consumed at $N_i$ to transmit the data to $N_j$ | If $EC_{ex}$ is high, then the source node most likely to have huge energy loss |
| Distance (d) | This parameter measures the Euclidean distance between $N_i$ and $N_j$ | The distance plays pivotal role in delay, energy consumption and data loss |
| Throughput ($\varphi$) | Measures the throughput can be achieved by the candidate node | This metric is important to achieve better transmission efficiency |
at the same time which leads to high congestion. Thus, we propose a novel topology and priority-aware scheduling namely PD-TDMA protocol to abridge the issue of congestion. The PD-TDMA protocol works with dual scheduling process, that is, for critical data and non-critical data. After optimal forwarder selection, each node sends a slot request (Slot_Req) to the corresponding CH. Upon receiving a request from $L$ number of member nodes, the CH organizes the requests based on priority level. The priority level is high for critical data and low for non-critical data. The time period $T$ is split into $L$ number of time slots as $t_1, t_2, \ldots, t_L$. At first, the required time slots are assigned to all body sensors which have critical data. In that slots, the critical data are transmitted to the $1HF_{opt}$ and then the $1HF_{opt}$ transmits the data to CH without any delay. This mitigates the excess delay due to scheduling process for critical data. For non-critical data scheduling, the CH extracts the current topology which is constructed with the 1D-Dragonfly topology of the cluster to obtain the connectivity information. Based on this connectivity information, the CH further schedules the data for transmission.

Let $N_1$ and $N_2$ be the source nodes and $N_3$ be the optimal forwarder for both nodes. Now, the CH needs to assign time slots to transmit the data to $N_3$. In this case, the CH extracts the topology of the cluster and finds the connectivity between those nodes in terms of distance measure, that is, $d(N_1, N_3)$ and $d(N_2, N_3)$. The node which has lower distance will get scheduled at first with the minimum time slots and the node with large distance will get scheduled at next with maximum time slots. That is if $d(N_1, N_3)$ is low, then the first slot $t_1$ is assigned to $N_1 \rightarrow N_3$ communication so that the $N_1$ will transmit the data with minimum slot. This assures lower waiting time for $N_2 \rightarrow N_3$ communication. The next time slots $t_2$ and $t_3$ are assigned for $N_2 \rightarrow N_3$ communication since the distance is large, that is, the data transmission will need more slots. Thus, unlike in TDMA, we assign time slots based on the topology and priority level in an adaptive manner.

In Figure 5, the procedure for data scheduling by proposed PD-TDMA is illustrated. As shown in the figure, the CH first schedules the critical data to the optimal forwarder. If any conflict occurs, then it assigns the time slots based on the deadline. In the next schedule, the CH assigns time slots for the body sensors based on the topology. Without PD-TDMA scheduling, critical data will have a large time delay. Overall, the waiting time is also increased. By using the proposed PD-TDMA, the proposed work achieves a lower delay for the data. In addition, the number of time slots needs for communication is assigned based on the distance value in a novel manner which minimizes frequent data retransmissions. In precise, the proposed PD-TDMA protocol works better than prior scheduling algorithms in all aspects.

### 4.5 QoS-aware BAN-to-BAN routing

At the end of the scheduling process, all body sensors transmit their data to the CH through optimal forwarders in their assigned time slots. The CHs transmit the aggregated data to the hub. Both CHs transmit the critical data without any
time delay and aggregates the non-critical data in order to minimize energy consumption. In the multi-BAN environment, the BS is deployed typically at far away from the network (for example for patient monitoring in hospitals). In this scenario, the $H_i$ is unable to transmit the data BS with assured QoS. To ensure end-to-end QoS, we present QoS-EPC algorithm for BAN-to-BAN communication. As discussed in the literature, the majority of the existing research works have been presented QoS provisioning within a single BAN which is not able to assure end-to-end QoS. For this purpose, we present BAN-to-BAN communication with optimal route selection. The BAN-to-BAN routing is enabled through the hubs of each BAN. After gathering the data from dual sinks, the hub selects an optimal route for data transmission by considering other BANs as intermediates. The optimal route selection follows QoS-EPC algorithm which considers multiple significant metrics. The EPC algorithm is a new bio-inspired algorithm that works upon the nature of penguins. At first, the available routes ($Ar_1, Ar_2, ... , Ar_g$) are assigned as the initial population of emperor penguins ($EPs$). Each $EP$, that is, $Ar$ is initialized in its position and the cost function ($fn(c)$) is computed in terms of fitness value. For each $EP$, the fitness value ($Fv$) is computed as follows,

$$Fv(EP_i) = \frac{1}{\sum HC_i D_{Avg_i} ETX_{Avg_i}}$$ (7)

Here $HC$ represents the hop count and $D_{Avg}$ represents the average delay and $ETX_{Avg}$ defines the average expected transmission count. The average values of a route $EP_i$ are computed as follows,

$$D_{Avg} = \frac{\sum_{j=1}^{v} D_{ex}(j)}{v}$$ (8)

$$ETX_{Avg} = \frac{\sum_{j=1}^{v} ETX(j)}{v}$$ (9)

where $ETX(j) = 1/1 - \text{error probability}$ that measures the link quality of the route and $v$ represents the number of nodes in that route. Then, all $EPs$ adjust their positions toward the fittest $EP$, that is, the $EP$ which has high $Fv$. The heat radiation of the $EP$ is computed as,

$$Q_{EP} = B \sigma \omega^4$$ (10)

Here $Q_{EP}$ is the heat transfer per unit time, $B$ is the total surface area, $\sigma$ is the Stefan-Boltzmann constant, and $\omega$ is the absolute temperature. Then, the attractiveness ($\gamma_{EP}$) of each penguin is computed as,

$$\gamma_{EP} = Q_{EP} e^{-\beta x}$$ (11)
where $\beta$ is the attenuation coefficient and $\alpha$ is the distance between the two EPs. After evaluation of $Fv$ and $\gamma$, all EPs are moved toward the fittest EP. The coordinated movement is determined by the following equation,

$$x_{fit} = a_1 \cos \theta_{fit} e^{\alpha \gamma_{fit}}$$  \hspace{1cm} (12)$$

$$y_{fit} = a_1 \sin \theta_{fit} e^{\alpha \gamma_{fit}}$$  \hspace{1cm} (13)$$

Over iteration, the optimal solution, that is, EP which has higher $Fv$ is selected as the optimal route.

**Pseudocode 1. QoS-EPC algorithm**

| Start |
|-------|
| Initialize $AR \rightarrow EPs$ |
| While iteration<Maximum Iteration |
| Do |
| For each $EP_i \in AR$ |
| Generate position |
| Find $f_n(c_i)$ |
| Assign $f_n(c_i) \rightarrow Fv(EP_i)$ |
| Find Fittest EP |
| Compute $Q_{EP}$ |
| Compute $y_{EP}$ |
| Compute $x_{fit}, y_{fit}$ |
| Move all EPs towards best EP |
| End for |
| Sort and find $EP_{best}$ |
| Update $Q_{EP}$ |
| Update $y_{EP}$ |
| End While |
| End |

The procedure of the proposed QoS-EPC algorithm is presented in pseudocode 1 for optimal route selection. In this optimal route, the data are transmitted to the BS where further processes are carried. Here data transmission through optimal route assures high reliability for both critical and non-critical data. In addition, consideration delay and hop count metrics also minimizes delay for data transmission. Thus, the data are transmitted within minimum time consumption. It can be seen that the sink nodes always send the critical data at first to the hub which also sends the critical data to the BS firstly. This minimizes the delay for critical data. The overall proposed QC-TriL model assures end-to-end QoS through dual sink deployment, optimal multi-hop transmission, priority-based scheduling and QoSBAN-to-BAN routing. In precise, the proposed QC-TriL is suitable for real-time BAN communications.

### 4.6 Complexity analysis

The main issue in the WBAN is usage of complex algorithms which consume more time. Increase in time complexity increases the energy consumption and transmission delay. Mainly, critical data transmission takes large time to reach the destination which is not suitable for WBAN environment. However, the proposed work minimizes the complexity since the work presents a clustered WBAN environment. In the clustered environment, the complexity for route selection and scheduling is minimized gradually. The overall complexity achieved by the proposed work is expressed as,

$$\text{Complexity} = NT_{2FL} + O \left( \frac{N_{D-OHT}}{m} \right) \left( \frac{N_{PuRank}}{m} \right) + O (N_{EPC})$$  \hspace{1cm} (14)$$

From above equation, it is clear that proposed work has minimum complexity which makes it usable for multi-BAN environment.
5 | EXPERIMENTAL EVALUATION

This section analyzes the proposed QC-TriL model in terms of performance metrics. This section first provides detailed simulation settings and then compares the obtained results accordingly.

5.1 | Simulation settings

The proposed QC-TriL architecture is modeled in OMNeT++-4.6 simulator. The algorithms are written in C++ language. At first, the OMNeT++ is installed on the PC which operates with Windows-7 operating system. Then, the required model libraries are imported and the simulation parameters are settled up. The detailed simulation parameters are provided in the Table 2. After simulation settings, the simulations are performed by varying the simulation parameters. From the simulations, the observations are made. The simulation testbed created in OMNeT++ is shown in the Figure 6. As shown in the figure, the simulation parameters are initialized firstly. Then, single BAN is configured to create a multi-BAN environment.

In simulation we generate both critical and non-critical packets. For this we set the threshold value for each type of body sensor as shown in the Figure 7.

From the created testbed, the observations are made to prove the efficacy of proposed QC-TriL. The observations are made based on the performance metrics for comparison. In next section, the detailed comparative analysis is provided.

| Parameter                          | Value                                      |
|------------------------------------|--------------------------------------------|
| Simulation Area                    | 750*750 m                                  |
| BAN Configuration                  |                                            |
| Number of BANs                     | 10                                         |
| Number of sensors in a BAN         | 10                                         |
| Number of sinks                    | 20 (2 For Each BAN)                       |
| Number of hubs                     | 10 (1 For Each BAN)                       |
| Body sensor types                  | ECG, EEG, Visual, Temperature, Pressure, Accelerometer, Glucose, BP, Respiration, EMG |
| Channel configuration              |                                            |
| PHY model                          | IEEE 802.15.6                              |
| Bandwidth                          | 1 MHz                                      |
| Number of channels                 | 79                                         |
| Frequency range                    | 2400–2483.5 MHz                            |
| Data rate                          | 1024 bps                                   |
| Energy configuration               |                                            |
| Initial energy level of a node     | 100 J                                      |
| Transmission energy                | 17 mJ                                      |
| Receiving energy                   | 8.2 mJ                                     |
| Traffic configuration              |                                            |
| Traffic types                      | Critical, non-critical                     |
| Number of packets                  | 10,000 (Approx.)                           |
| Packet interval                    | 10 ms                                      |
| Packet size                        | 1024 bits                                  |
| Header size                        | 32bits                                     |
| Number of retransmissions          | 2                                          |
| Number of slots                    | 12                                         |
| Slot duration                      | 1S                                         |
| Simulation time                    | 150 s                                      |
Comparative analysis

This section compares the proposed work with the previous research works such as DSCB\textsuperscript{31} method, GA\textsuperscript{35} based routing, and EB-MADM method.\textsuperscript{38} For performance evaluation, energy consumption, PDR, throughput and delay metrics are considered.

In Table 3, the previous research works are compared and the demerits are discussed. We can see that each work has some drawbacks that affect the overall performance. These demerits play pivotal role in performance which can be proved by comparisons.

5.2.1 Comparison on energy consumption

Energy consumption measures the total amount of energy consumed in each node. We measure the energy consumption as average value as follows,
| Criteria                        | DSCB                        | GA                        | EB-MADM                   | QC-TriL                    |
|--------------------------------|-----------------------------|---------------------------|---------------------------|---------------------------|
| Contribution                   | Dual Sinks Cluster in WBAN  | GA-based adaptive objective function for routing | Energy-based routing       | QC-TriL model              |
|                                |                             |                           |                           | Multi-BAN routing          |
|                                |                             |                           |                           | Critical-BAN routing       |
| Multi-BAN environment          | No                          | No                        | No                        | Yes                       |
| Sink deployment                | Front and back body of human| Random                    | Random                    | Optimal position by T2FL   |
| Critical data transmission     | Direct hop                  | Direct hop but wait for objective function | Direct hop                | D-OFT scheme              |
| Non-critical data transmission | Through optimal forwarder   | GA-based routing          | EB-MADM                   | FuRank scheme              |
| BAN-to-BAN routing             | No                          | No                        | No                        | QoS-EPC algorithm          |
| Scheduling                     | TDMA                        | TDMA                      | TDMA                      | PD-TDMA                    |
| QoS Achieved                   | ↓                           | ↓                         | ↓                         | ↑                          |

Note: ↓-Low; ↑-High.

\[ \text{EC}_{\text{Avg}} = \frac{\sum_{i=1}^{n} \sum_{j=1}^{m} \text{EC}(N_j(i))}{n \times m} \]  

Here the average energy consumption (\(\text{EC}_{\text{Avg}}\)) is computed from the energy consumption of each \(j\)th node in \(i\)th BAN (\(N_j(i)\)).

In Figure 8, the average energy consumption obtained for proposed and existing works have been analyzed. The comparison shows that the proposed QC-TriL has lower energy consumption when compared to other research works. The energy consumption rises with the increase in simulation time. In proposed QC-TriL, the energy consumption at the simulation time of 150 s is 0.25 J which is 2 J lower than EB-MADM method and GA-based routing method and also 1.75 J lower than DSCB method. From this data, it is clear that the proposed QC-TriL architecture is more energy-efficient than other works. Although the DSCB method uses dual sink nodes, the non-optimal deployment leads to the large energy consumption among body sensors. In GA method and EB-MADM methods use a single sink node which increases the energy consumption drastically. Involvement of dual sink nodes at the optimal positions and cluster formation improves the energy efficiency of the proposed work. Further, the data are transmitted through optimal forwarders which mitigate energy consumption due to retransmissions. We also minimize the energy consumption by utilizing cluster-based WBAN design. In general, cluster-based network consumes lower energy than the non-clustered environment since the data are aggregated by the sink nodes. It minimizes the energy consumption in each sensor node by minimizing the transmission distance. Thus, the proposed QC-TriL achieves better energy efficiency than other research works.

![Figure 8](image-url)
5.2.2 Comparison on PDR

PDR is defined as the ratio between number of packets generated by the source node and the amount of packets received at the destination. Here the source is body sensor and the destination is BS. This metric measures the how many packets are transmitted to the BS by a body sensor successfully. This metric is computed as follows,

$$PDR_{Avg} = \frac{\sum_{i=1}^{n} PDR(i)}{n}$$  \hspace{1cm} (16)

The average PDR of the proposed multi-BAN environment is computed from the individual PDR achieved by each $i$th BAN ($PDR(i)$).

In Figure 9, the PDR is compared with respect to the number of nodes. The PDR is improved with the increase in the number of body sensors. In proposed work, 97% of packets are received by the BS successfully. The PDR will be improved if and if only the end-to-end QoS is achieved. In EB-MADM method, only 76% of packets are transmitted to the BS, that is, 24% of packets are lost due to inefficient route selection. In EB-MADM and GA methods, the routing considers only energy metric which leads to huge data loss. In the DSCB method, 80% of packets are transmitted successfully. But 20% of packets are lost. In addition, all existing research works have only focused on data transmission between sensors and the hub.

The data transmission between sensors and BS, that is, BAN-to-BAN routing is not focused. Thus, the prior research works have high packet loss compared to proposed QC-TriL. Also, we consider link quality as the major metric in FuRank and QoS-EPC algorithm which further leads to better PDR. This analysis shows that the proposed QC-TriL architecture has the ability to improve data transmission in the BAN environments.

5.2.3 Comparison on throughput

Throughput is defined as the total amount of data packets transmitted to the destination in given period of time. This metric is also measured as the average value for multi-BAN environment.

In Figure 10, the throughput obtained by the proposed QC-TriL is compared with existing works. Averagely, 1289 packets are successfully transmitted per second in the proposed QC-TriL model. The throughput highly depends upon the congestion level and optimal data routing. In the proposed work, congestion is mitigated by the PD-TDMA method while optimal data transmission is enabled by D-OHT, FuRank scheme and QoS-EPC algorithm. At first, we deployed the sink nodes in the optimal positions with the optimum dragonfly topology. This enables the data transmission effectual. Next, the data transmission is optimized by avoiding congestion using PD-TDMA scheduling. Then, optimal routing supports to achieve higher throughput. Thus, throughput achieved by the proposed work is better than previous works.

In particular, GA-based routing has 554 packets/s as throughput which is more than twice time lower than the proposed QC-TriL model. As the GA consumes more time for route selection, it fails to transmit the data within a given period. In next, the EB-MADM method has 582 packets/s since it only focuses on energy consumption. In the DSCB method, 774...
5.2.4 Comparison on delay

Delay is defined as the time taken by a data packet to reach the BS from the body sensor. The delay metric includes the waiting time and propagation time.

In Figure 12, the delay obtained by proposed and existing research works has been compared with respect to simulation time. The increase in delay with the increase in simulation time shows the increase in the congestion level over time. As
the delay is greatly affected by route selection time and scheduling, the GA-based method has a higher delay up to 47 ms. Similarly, the EB-MADM method has delay up to 41 ms. In both works, a single sink node is used. Thus, the congestion level is increased in the sink node which increases the delay. Although DSCB uses dual sink nodes, it has delay up to 25 ms due to TDMA-based scheduling. In the proposed work, PD-TDMA is presented which decreases the delay and the optimal routing also helps in minimizing the delay. In the proposed work, the delay is 8 ms at the simulation time of 150 s. This is relatively lower than the existing research works. In addition, the 8 ms of delay is introduced for non-critical data only. The critical data have delay much lower than 8 ms. In the proposed work, the delay attained for critical data is 0.8 ms since the critical data are transmitted through one-hop forwarder and also it is scheduled first. Thus, the proposed work is suitable for achieving a better delay.

5.2.5 Comparison on complexity

Complexity of the proposed work is compared in terms of number of computations taken by the proposed algorithm to achieve the best results. We have compared the complexity of the proposed work in Figure 13.

The analysis shows that the proposed work has minimum complexity, that is, takes only 100 computations for scheduling and routing while all existing works have higher complexity. In EB-MADM, the 200 computations are required to grab optimum results since the MADM methods generally have higher complexity to run the algorithm. In the same way, GA has higher complexity since it takes large iterations to achieve best result. Thus, GA has higher computational complexity than other works. Over, the analysis confirms that the proposed work has minimum computational complexity than other works.

5.2.6 Summarization of obtained results

This subsection analyzes the overall obtained results in the proposed and existing works. The summarization is provided in Table 4.

The analysis shows that the proposed QC-TriL work has obtained better results for each evaluated metric. The proposed work minimizes energy consumption and delay while maximizing PDR and throughput. That is the proposed work better in overall QoS. In QoS analysis, these metrics measure the energy efficiency, delay and data transmission efficiency. The proposed QC-TriL achieves better results for each metric which relatively increases the QoS. The proposed QC-TriL achieves better QoS by using dual sinks-based cluster formation and optimal routing. For optimal data transmission, we

![Complexity](image)

**FIGURE 13** Analysis on complexity

**TABLE 4** Overall analysis on numerical observations

| QoS Metric          | DSCB | GA  | EB-MADM | QC-TriL |
|---------------------|------|-----|---------|---------|
| Energy consumption (J) | 1.6  | 1.8 | 1.8     | 0.18    |
| PDR (%)             | 76.1 | 72  | 72.8    | 95.1    |
| Throughput (packets/s) | 774  | 554 | 582     | 1289    |
| Delay (ms)          | 23.6 | 38.4| 33.4    | 8.9     |
use D-OHT scheme, FuRank scheme and QoS-EPC algorithm. By using these schemes, we assure end-to-end QoS service for the multi-BAN environment. In addition, we also present priority-based scheduling to minimize the data transmission delay. From the obtained results, it is clear that the proposed work achieves better performance and suitable for the real-time multi-BAN scenario.

6 | CONCLUSION AND FUTURE WORK

In this paper, we presented a novel QC-TriL architecture for achieving better QoS in the multi-BAN environment. The proposed multi-BAN network is organized into three layers. At first, each BAN is deployed with dual sink nodes in optimal positions. For optimal sink deployment process, T2FL algorithm is presented with three major criteria. Then, the clusters are formed by considering sink nodes as CHs. In the clustered BAN, critical data are transmitted by D-OHT scheme and the non-critical data are transmitted by a new FuRank scheme-based multi-hop communication. Before that, the optimal time slots are allotted for data transmission by CHs, that is, dual sink nodes. For data scheduling, we propose PD-TDMA protocol that operates upon the 1D-Dragonfly topology information. The BAN-to-BAN communication is optimized by using QoS-EPC algorithm which considers QoS parameters for route selection. Involvement of optimal sink node deployment, clustering, and routing improves the overall efficiency of the proposed work. The experiments executed in OMNeT++ simulation tool shows that the proposed QC-TriL achieves better results in terms of energy consumption (decreased to 0.18 J), PDR (increased up to 95.1%), throughput (increased up to 1289 packets/s), and delay (decreased to 8.9 ms). In future, we have planned to integrate the proposed multi-BAN environment with the 5G communications to make it suitable for growing IoT applications. We also intend to use a different level of priority values (along with critical and non-critical levels) to achieve QoS satisfaction rather than QoS maximization as discussed in Reference 40. Besides, security is also the interesting and important aspect of the multi-BAN environment. As the scope of this research is to achieve better QoS, we planned to consider security aspects in the future.

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DATA AVAILABILITY STATEMENT

Data sharing not applicable to this article as no datasets were generated or analysed during the current study.

CONFLICT OF INTEREST

The author declares no conflict of interest relevant to this article.

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