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RESEARCH ARTICLE

Enhanced QoS-Aware Routing Protocol for Delay Sensitive Data in Wireless Body Area Networks

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ABSTRACT The Wireless Body Area Network (WBAN) shows potential as a technology that can provide high-quality healthcare services to its users. However, the limited battery life of low-power devices attached to the body is a challenge. The data must be sent through a reliable connection with minimum delay to the healthcare centre since it directly influences user satisfaction. In case of potentially fatal situation, transmitting data at the right time is important. Therefore, more policies and methods for better end-to-end performance of a network are required. In this paper, the end-to-end delay of network over a wireless channel from sensor to healthcare centre has been analyzed. The proposed work presents an Enhanced Quality of Service Aware Routing Protocol for Delay Sensitive Data (EQRD). EQRD reduces the delay by proposing a Bandwidth Utilization Constant to maximize the utilization of channel capacity. It finds the best minimum number of slots that can be used for data transmission for the minimization of delay and maximization of throughput. By analyzing various parameters, the EQRD protocol's effectiveness was evaluated in relation to other delay-aware routing protocols. The findings indicate that the proposed protocol has superior performance with regards to throughput, energy efficiency, and delay.

INDEX TERMS Delay aware, throughput maximization, routing protocol, WBAN, energy efficient, QoS, delay minimization.

I. INTRODUCTION

Wireless Body Area Networks (WBANs) are intriguing growing interest because of their appropriateness for a wide range of applications which require compelling Quality of Service (QoS). One of the most popular WBAN application is the healthcare monitoring system which could have significant impact the medical domain in near future [1], [2], [3], [4], [5], [6], [7]. There are a number of intriguing problems that must be solved before this technology can become widespread [8], [9], [10], [11], [12], [13], [14], [15].

The WBANs are event driven networks in which sometimes delay may cause fatal consequences. Measuring the network delay is important for a number of reasons. The important information does reach the sink ultimately at the cost of bandwidth and power, but it is now obsolete. This reduces the network efficiency [16]. Delay minimization plays a vital role in averting the life endangering conditions. Apparently due to the constrained network capacity, delay is increased in the network.To this purpose, numerous routing strategies have been reported in the literature, each of which affects the network's end-to-end path delay and overall energy consumption.

The proposed approach in this paper is the Enhanced QoS Aware Routing Protocol for Delay Sensitive Data (EQRD),

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which is a new delay aware routing protocol. EQRD selects the forwarder node by utilizing the proposed method. The proposed technique minimizes the data transmission as well as the queuing delay, thereby enabling a high rate of successful delivery of messages by utilizing the proposed delay minimization and throughput maximization models. This study is an extension of the prior work namely Optimized Cost Effective and Energy Efficient Routing protocol (OCER) which is reliable, optimized as well as energy efficient routing scheme for ordinary data packets to consider the continuous network operation for sustaining the functionality of WBAN for the longest time [17]. However, OCER did not consider the delay sensitive packets which may provide life saving information in critical condition.

The research presents the Enhanced QoS-aware Routing Protocol for Delay Sensitive Data (EQRD) as a solution to the challenges faced in minimising data transmission and queuing delays, while simultaneously maximising throughput in Wireless Body Area Networks (WBANs). The current routing protocols, such as A Multi-Hop QoS-Aware, Predicting Link Quality Estimation (PLQE) Routing Protocol [18], MIQoS-RP: Multi-Constraint Intra-BAN [19], and QoS-Aware Routing Protocol, have made valuable contributions to Wireless Body Area Networks (WBANs). However, these protocols also have certain limitations that serve as a driving force for the development of the Enhanced Quality of Service Routing Protocol (EQRD). The PLQE Routing Protocol utilises link quality prediction and link delay estimation for its operation. However, it is important to note that the accuracy of its predictions may be constrained, which can lead to potential instances of data loss. Moreover, it exhibits difficulties in efficiently managing rapid topological alterations, resulting in delays and compromised data transmission. In contrast, the MIQoS-RP protocol prioritises route selection based on multiple constraints, although it possesses restricted evaluation criteria and scalability considerations. On the other hand, the Enhanced Quality of Service Routing and Data (EQRD) protocol presents innovative models that aim to reduce latency, increase data transfer rate, and optimise bandwidth usage specifically for managing time-sensitive information in Wireless Body Area Networks (WBANs). By conducting rigorous simulations and performing comparative analyses with established protocols such as Data-Centric Multiobjective QoS-Aware (DMQoS), QoS-aware Peering Routing protocol for Delay-sensitive data (QPRD), PLQE, and MIQoS-RP, the study has successfully demonstrated the superior performance of the Enhanced Quality of Service Routing protocol for Delay-sensitive data (EQRD). The EQRD algorithm efficiently reduces the time it takes for data to travel from one end of a network to another, decreases the amount of energy used, and improves various aspects of service quality in Wireless Body Area Networks (WBANs). This makes EQRD a cutting-edge and effective solution for enhancing the delivery of healthcare data in WBANs.The DMQoS protocol has a specific limitation where it only takes into account the delay information of adjacent nodes. This can lead to the discarding of packets if a suitable next-hop node that meets the required delay criteria cannot be identified. This methodology results in a higher volume of network traffic and does not provide a reliable assurance of meeting the desired end-to-end latency. However, while QPRD acknowledges the significance of energy efficiency in real-time patient monitoring, it does not provide detailed analysis or optimisation methods for energy consumption. This lack of attention to detail can impede the efficiency of the protocol in terms of energy consumption, particularly for devices with restricted battery life in Wireless Body Area Networks (WBANs). By solving these issues and making special additions, EQRD distinguishes itself as a reliable and efficient routing system for dealing with delay-sensitive data in WBANs. It guarantees consistent performance, energy efficiency, and reliable data transfer, all of which are crucial for real-time patient monitoring in hospital settings.

The main contributions of proposed work is as follow:

Firstly, the significance of delay minimization and throughput maximization problem is examined and use of parallelized transmissions for different sized packets to save time slots are advocated to achieve efficiency. Secondly, a novel Delay Minimization Model, Throughput Maximization Model and Bandwidth Utilization Constant (BUC) for heterogeneous sized data packets has been presented. The proposed protocol's performance is evaluated through extensive simulations, which involve a comparison with two other protocols, Data-Centric Multiobjective QoS-Aware (DMQoS) [20] and QoS-aware Peering Routing protocol for Delay-sensitive data (QPRD) [21]. The results indicate that EQRD effectively minimizes end-to-end delay and energy consumption while also enhancing other QoS parameters such as packet timeout, throughput, and the number of forwarded packets.

The paper is organized as follows: Section II provides an overview of the state-of-the-art protocol schemes. Section III presents the network model, delay minimization model, throughput maximization model, and the proposed routing protocol. Section IV covers the results and their discussion, while Section V concludes the paper.

II. RELATED WORK

In the WBAN literature, QoS aware routing protocols have not gained much consideration in the onset of research. However, over the last decade, researchers have investigated WBAN performance from the context of Energy and Delay aware routing protocols for WBAN and worked on throughput maximization techniques for evaluating performance metrics. In this section, related work reported in literature has been presented.

The routing decision in Multipath Multi-SPEED protocol (MMSPEED) given by has considered the delay bound packets and multiple reliability for QoS provisioning [22]. It probabilistically sent duplicate packets toward multiple paths. The energy parameter is not taken into account which makes it unsuitable for BAN applications. Multi-constrained QoS Multipath Routing (MCMP) A QoS aware routing framework introduced by [23] has exploited the cross-layer design to provide QoS support for biomedical sensor networks. It aimed to impart routing service on the basis of data packet priority. The routes are decided based on readiness of sensor node, packet priority level and wireless channel status. However, this protocol didn't clearly mention the operation of the routing protocol. Moreover, queuing delay is not considered during delay estimation. The transmission delay didn't take into account the size of data packet and data rate. Robust and Energy Efficient multipath Routing protocol (REER) is an energy-efficient and reliable routing protocol that exploited the geographic information for cooperative communication in order to find the routes [24]. Distributed Aggregate Routing Algorithm (DARA) has been proposed by creating short and long-range forwarding zones respectively for critical and non-critical data packets [25]. A weighted sum of energy, delay and geographic progress is taken as the routing metric. Both critical and non-critical data packets use the same routing metric that degrades the QoS performance.

The DMQoS contributed better results with regards to the path delay for delay-sensitive packets than many previously researched techniques [20], [22], [23], [24], [25], [26]. However, DMQoS utilized the hop-by-hop approach to choose the neighbor node. In this hop-by-hop approach, the neighbor sensor with lowest delay is chosen as the next hop which further determined the next hop node with minimum delay to reach the sink node. This method only considered the delay information of neighboring nodes. If the neighboring node is unable to locate an upstream next hop node with a delay that meets the necessary criteria, the packet is discarded. However, this approach increased the overall network traffic and didn't assure the required end-to-end latency. Thermal-aware multiconstrained intrabody QoS (TMQoS) is a proactive cross-layer routing protocol designed for in-vivo WBANs that takes into account multiple constraints including thermal considerations [27]. It is a thermal aware multi-constrained intra-body QoS routing protocol that utilized the hotspot avoidance mechanism to evade the packets for traversal through heated areas known as hotspots. TMQoS achieved the lower delay for delay constrained packets when the traffic load is less but it didn't perform well when traffic load is high because the convergence time gets prolonged due to increased contention resulting in stale information during high traffic load. An Efficient Next Hop Selection Algorithm for Multi-Hop Body Area Networks (ENSA-BAN) used link cost function for improving the overall QoS performance of the network [28]. Network performance was measured based on the energy consumption of nodes and QoS requirements. Average delay of less than 16 ms and approximately 96% PDR was obtained. However, the protocol did not consider body movements.QPRD aimed to overcome the limitations of DMQoS by selecting an intermediate node based on the minimum end-to-end path delay [21]. To minimize delay, QPRD formulates the problem as a linear programming one with multiple constraints.

Reference [29] gave a network management cost minimization framework to reduce the cost of network management and data dissemination delay. The authors performed optimization of QoS and throughput of the network. As a result of this, costs for data dissemination are minimized in addition to interference management and dynamic connectivity. Reference [30] presented traffic priority based delay-aware and energy efficient path allocation (Tripe-EEC) routing protocol for WBAN, which selected the optimal paths with minimum temperature rise and high residual energy of nodes. Reference [31] introduced a lightweight routing protocol known as LRPD, which operated in hop-by-hop fashion for optimizing the end-to-end latency. The protocol was evaluated for performance analysis against various existing protocols.

The lack of delay sensitive data motivated the authors for the development of delay aware WBAN routing solution. First and foremost, this paper investigates the delay-minimization problem. A delay model has been proposed to calculate the delay for heterogeneous sized data packets. A Bandwidth Utilization Constant for different packet sizes is formulated that finds the best minimum number of total time slots which are used to transmit the data packets by exploiting transmission parallelization technique in order to achieve maximum throughput and minimum delay. The solution of the throughput-maximization problem is used to propose an optimal solution to the delay-minimization problem for delay-sensitive packets.

The proposed work is based on QPRD that proposed a best bandwidth utilization approach for the selection of forwarder node. Delay-aware routing mechanisms choose the forwarder node based on the data with best performance metrics. For the performance evaluation of proposed technique, similar scenarios of QPRD have been taken.

III. MATERIALS AND METHODS

A. PROBLEM FORMULATION AND MODELING

This section presents an approach for throughput maximization and delay minimization on heterogeneous sized data packets. The proposed model (i) determines the optimal solution for various conditions, (ii) studies and evaluates the influence of network parameters on obtained solutions.

1) NETWORK MODEL AND ASSUMPTIONS

The hospital scenario considered a hierarchical WBAN with three communication tiers [32]. The first tier is focused on "intra-BAN communication," which involves wearable sensors on the patient's body forming a network for continuous monitoring.Point-to-point (P2P) linkages between body sensors can build a multi-hop path, and communication can also take place between the sensors and the BAN Coordinator (BANC). The sensors report information to the BANC, which coordinates everything in the cluster. Level two involves "inter-BAN communication" between the BANC and other PDDs. The **Patient Data Display** (PDD), which is the BANC's potential next hop, sends BAN data on to the Centralized Display Device (CDD), which is a third communication device. Tier three involves "beyond-BAN communication," which grants authorised access to patient data remotely via the Internet for healthcare providers.

We assume that the CDDs are connected directly to a power source, while the PDDs use consumable batteries and the BAN coordinators have limited energy availability. IEEE 802.15.4 is used for communication between the sensors and the BAN Coordinator (BANC). In contrast, IEEE 802.11 (Wi-Fi) is used for communication between the CDDs and authorized healthcare providers accessing patient data remotely. The present study is based on various assumptions where each node n_i communicates with its neighbours using a constant transmission power of -25 dBm. Data packets of varying sizes (64 bits, 32 bits, and 16 bits) are transmitted by the source nodes. For simplicity, we'll set B_max, the maximum allowed bandwidth, at 64 bits. It is presumed that all connections exist. If the distance between the sending node and the receiving node, denoted by (d_ij), is less than the size of the packet, the transmission is considered successful. It is ensured that the outgoing data flow is not more than the entering data flow plus any data created at time t.

The scenario in Figure 1 is represented as a connectivity graph $G = (S, E)$, where S is a set of vertices that represent the nodes in the network including BANC and E is the set of edges for the communication between two nodes. An edge $(s_i, s_j) \in$ E, iff s_i, s_j are within the communication range of each other. The neighbor set of s_i represented as $N(s_i)$ are the sensor nodes with which s_i has direct edges. All communication links are considered to be symmetric i.e., if $s_i \in N(s_j)$, then $s_j \in N(s_i)$.

Table 1 lists the basic notations used in this study. The main focus is on two issues: (i) to minimize end-to-end delay (ii) to maximize throughput.

TABLE 1. **Notation.**

Notation	Meaning
N	the number of sensors
n_s	node of origin s
n_k	adjacent node k
n_d	final node d
ID_d	Node ID of the final destination d
L_d	where the final node, d, is located
ID_k	Node ID of adjacent node K
$dist_{k,d}$	how far k is from d, the last node
E_k	k-node's energy-residual
$dist_{s,k}$	distance between nodes s and k that are neighbours
$dist_{s,d}$	the metric distance between nodes s and d
E_{max}	maximum energy at each node
NT	Neighbor Table
HP	Hello Packet
nh_k	next hop node k

2) PROPOSED DELAY MINIMIZATION MODEL

The end-to-end delay can be defined as the number of time slots that are required for delivering the set of packets from source to destination and the proposed work proposes a scheme for the minimization of end-to-end delay. This section addresses the delay minimization problem while routing the delay sensitive packets such that the least delay path gets selected. The key advantage of the proposed technique is that it allows better performance in terms of minimizing end-to-end delay and appropriate delivery of set of packets at the right time.

The delay minimization module tracks the time required for acquiring the channel ($DL_{channel(s)}$), transmission time ($DL_{trans(s)}$), and MAC layer queuing delay ($DL_{MACqueue(s)}$) of a packet. This information is then sent to the network layer for calculating the node delay ($DL_{node(s)}$) as given in Equation 1.

$$DL_{node(s)} = DL_{trans(s)} + DL_{queue+channel} \tag{1}$$

The Hello packets of the node are updated periodically. QPRD takes 4 seconds as time interval for simulations, as the delay module sends the delays after every 4 seconds for MAC queue and channel capture. The average transmission delay (DL_{trans}) is determined by using Equation 2.

$$DL_{trans} = \frac{1}{R_{bit}} \frac{\sum_{z=1}^{n} N_{bit}(z)}{n} \tag{2}$$

In this analysis, we employ a data rate of 250 Kbps (represented by R_bit) and a packet size of N_bit. In this context, n stands for the total number of packets sent in a 4-second window.By employing a window size of 4 seconds, the protocol guarantees the timely transmission and periodic updating of Hello packets, which carry crucial control information.This time interval facilitates the capture of delays occurring over a substantial duration, thereby enabling more precise measurement and analysis of the delays encountered within the network.

a. Proposed Transmission Delay
Let $N_{basebit} = 64$

$$\begin{aligned} DL_{trans(i)} = w_1 * \{\frac{1}{R_{bit}} &\frac{\underset{x=-2}{\sum_{z_{16}=1}^{n_{16}} N_{basebit}(z) \times 2^x}}{n_{16}}\} \\ + w_2 * \{&\frac{1}{R_{bit}} \frac{\underset{x=-1}{\sum_{z_{32}=1}^{n_{32}} N_{basebit}(z) \times 2^x}}{n_{32}}\} \\ + w_3 * \{&\frac{1}{R_{bit}} \frac{\underset{x=0}{\sum_{z_{64}=1}^{n_{64}} N_{basebit}(z) \times 2^x}}{n_{64}}\} \end{aligned} \tag{3}$$

Subject to:

$$w_1 + w_2 + w_3 = 1 \tag{4}$$

$$n_{16} + n_{32} + n_{64} = n \tag{5}$$

where

$$w_1 = 0.1428 \tag{6}$$

$$w_2 = 0.2857 \tag{7}$$

$$w_3 = 0.5715 \tag{8}$$

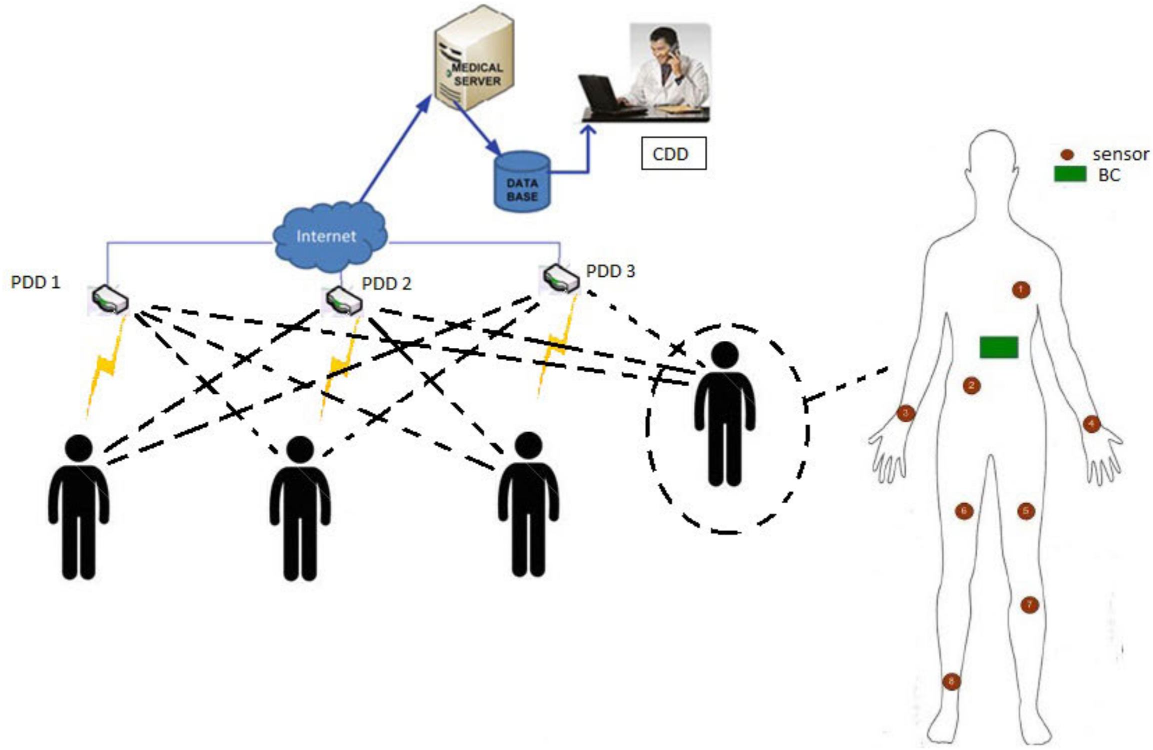

FIGURE 1. WBAN communication system.

Here, n is the total number of packets transmitted in a single cycle, and w_1, w_2, and w_3 are the delay constants for the three packet sizes of 16 bits, 32 bits, and 64 bits, respectively. Choosing a packet size of 16 bits enables the depiction of situations where the data being transmitted is relatively small or where minimal overhead is preferred. This decision demonstrates its benefits in scenarios where there is limited network capacity, as reducing the size of packets aids in preserving bandwidth. In a similar manner, a 32-bit packet size is selected to accurately represent the typical data sizes that are frequently encountered in the analysed application or network. This particular size achieves a harmonious equilibrium between the amount of data being transmitted and the additional information required for transmission, thereby offering a pragmatic depiction of data transmission scenarios encountered in real-world situations. Alternatively, a 64-bit packet size is chosen to replicate situations where there is a requirement to transmit larger volumes of data within each packet. This is especially pertinent when handling substantial data payloads or when there is a need for high data rates.Through the examination of various packet sizes, the analysis provides valuable information regarding the performance of the system under different data loads. This analysis assists in identifying the most suitable packet size for specific requirements. The values of x (-2, -1, and 0) are commonly used to introduce variability in the computation of transmission delays for various packet sizes. The values mentioned are specific factors or parameters that are included in the transmission delay formula. They allow for the analysis of delay characteristics related to each packet size.The inclusion of packet sizes (16 bit, 32 bit, and 64 bit) and the values of x (-2, -1, and 0) in the analysis enables the representation of a wide range of scenarios, encompassing varying data sizes, including small, moderate, and large. This enables a thorough evaluation of system performance and assists in determining the optimal packet size for specific needs.

The following formulas calculate the values of w_1, w_2, and w_3 for 16-bit, 32-bit, and 64-bit packets, respectively.

Total number of bits = 16 + 32 + 64 = 112 bits.

Weightage of 16-bits packet in 112 bits = $\frac{16}{112} = 0.1428$

Weightage of 32-bits packet in 112 bits = $\frac{32}{112} = 0.2857$

Weightage of 64-bits packet in 112 bits = $\frac{64}{112} = 0.5715$

Therefore, the probabilities of packet delays for 16-bits, 32-bits, and 64-bits are 0.1428, 0.2857, and 0.5715, respectively.

Furthermore, 2^x is the Bandwidth Utilization Efficiency Factor which gives the slot occupation of a single packet. When the value of x is 0, full slot is occupied, which is the case of 64-bits packet. When the value of x is -1, one-half slot is occupied, which is the case of 32-bits packet. When the value of x is −2, one-fourth of the slot is occupied, which is the case of 16-bits packet. To increase the bandwidth utilization, this paper proposes the Throughput Maximization model presented in Section 3.1.3.

b. Queuing Delay

Queuing delay occurs when there is a limited network capacity, leading to congestion when the traffic load in the network exceeds the network capacity, and the packets are transmitted sequentially. This lengthens the waiting time in the queue, which in turn lengthens the total transit time. The time a packet spends in queues during its journey through the network is known as its queuing delay. In the proposed work, since the network capacity is taken equal to the maximum packet size and the transmissions are parallelized; congestion does not take place, reducing the queuing delay. Also, the number of time slots used for data transmission are reduced due to parallelized transmissions, therefore maximum bandwidth utilization takes place. Since there is less waiting time that packets spend in queues, queuing delay will also be reduced. The Exponentially Weighted Moving Average (EWMA) formula is utilized to determine the delay (network layers' queues, MAC and capturing the channel) and is given in [21].

$$DL_{queue+channel} = (1-\rho) \times DL_{queue+channel} + \rho \times DL_{queue+channel} \tag{9}$$

The delay value received by the node when sending the first packet is used as the initial value for $DL_{q}ueue + channel$. In this case, $0 rholeq 1$ specifies an average value for the weighting factor. Values for *rho* were arbitrarily chosen to mirror those suggested in [21], where such values are said to be $0.2. \leq \rho \leq 0.3$. In this paper, the optimal value of ρ is taken to be 0.2 [21].

The path delay $DL_{path(s,d)}$ is the delay between sensor node s and destination sensor node d and is determined by using Equation 10.

$$DL_{path(s,d)} = DL_{node(s)} + DL_{path(k,d)} \tag{10}$$

where, initial value of $DL_{path(s,d)}$ is zero when k=d.

$\mathrm{DL}_{node(s)}$ is calculated using Equation 1.

The heterogeneous packets of packet size 64-bits, 32-bits and 16-bits are randomly generated.

3) PROPOSED THROUGHPUT MAXIMIZATION MODEL

During the transmission of a delay-sensitive data packet over a channel, the packet slot gets wasted if the slot for larger packet size data is assigned to a smaller packet size data. This results in lowering of throughput. To avoid delay getting infinite under heavy traffic load, it is imperative to maintain a high throughput value. The proposed Bandwidth Utilization model provides a technique for increasing bandwidth utilization so that the throughput is maximized.

The present work proposes a Bandwidth Utilization Constant (BUC)

$$BUC_p = \frac{N_p}{CC} \tag{11}$$

$$MNP_p = \frac{BUC_{max}}{BUC_p} \tag{12}$$

where N_p denotes the packet size, CC denotes the Channel Capacity and MNP denotes the Maximum Number of Packets that can be sent in one cycle.

Therefore, optimal number of time slots utilized in one round is given by Equation 13.

$$TotalSlots/BandwidthUtilized(S) = \sum_{p} (BUC) N_p \tag{13}$$

In the multihop wireless networks, communication may involve multiple transmissions on the links along a path from source to destination and for delivering a packet, transmissions occur in sequence. In the proposed technique, transmissions are parallelized on the same communication channel. Focus is mainly on obtaining maximum efficiency in transmission parallelization for heterogeneous sized data packets. This provides the smallest number of time slots for performing different sets of compatible transmissions. Basically, given a total set of packet transmissions to be performed, these are allocated to a minimum number of time slots so as to maximize parallelization and resource reuse [33].

The minimization of number of time slots by transmission parallelization helps in reducing the end-to-end delay as well as energy consumption [33]. For mathematical analysis for the total time taken when n bits are transmitted with and without the proposed approach is presented in Appendix.

B. ENHANCED QoS-AWARE ROUTING (EQRD) PROTOCOL FOR DELAY-SENSITIVE DATA

The objective of this study is to explore the paths taken by nodes to transmit delay-sensitive data from the source node to the sink while meeting the specific requirements of minimizing delay in the network. The network model is designed to take advantage of maximum bandwidth utilization by transmitting data packets in parallel. Overall network throughput, packet timeouts, forwarded packet counts, and power consumption are the metrics against which performance is measured. The findings show that the network achieves the best possible throughput with the minimum end-to-end delay. For the purpose of executing the proposed method and attaining the required results, the delay minimization and throughput maximisation models are formulated in Section III.

The proposed protocol EQRD presented in this section works on an indoor hospital environment application similar to QPRD [21]. It offers a system for 1) determining the node delay and path delay of heterogeneous sized data packets 2) finding the most appropriate route, and 3) choosing the best neighbor node with due consideration to the packet delay requirements.

Figure 2 shows the framework of the proposed protocol EQRD comprising of six modules: MAC receiver, Delay Estimator Module (DEM), Hello Module (HM), Routing Module (RM) and Queuing Delay Control Module (QDM).

EQRD protocol architecture is installed in BANC as it can effectively handle the routing of data packets, optimize the transmission paths, and ensure that the QoS requirements, such as minimizing data transmission and queuing delays while maximizing throughput are met. The BANC acts as a decision-making entity that determines the most suitable routes for data transmission based on the information received from the sensors and other devices in the network.

Data or hello packets received by a node's MAC receiver from other nodes are only transmitted to the network layer if their destination address is the node's broadcast address or MAC address. The Delay Estimator Module (DEM) tracks the packet's queueing and transmission times as well as the channel capture and MAC queuing delays ($DL_c hannel(s)$, $DL_M ACqueue(s)$, and $DL_t rans(s)$, respectively). In order to calculate the time it takes for a delay-sensitive packet to go via a channel, the Bandwidth Utilisation Constant has been proposed. The Hello protocol module of the network layer is responsible for sending out hello packets. The data is utilised by the Hello protocol module's neighbour table constructor mechanism to determine the node delay ($DL_n ode(s)$).

Priority is provided to 64-bit data by the Queuing delay control module, while 16-bit data is given the lowest priority.

a. Hello Packet and Routing Table

To prevent unnecessary overhead and populate the routing table, EQRD periodically performs a Hello exchange between nodes in the network. Node k will include the values ID_d, L_d, ID_k, d, L_k, D_k, d, and $DL_p ath(k, d)$ in its Hello packet. In order to update and send a Hello packet received from a neighbouring node, node n_s first calculates $DL_p ath(s, d)$ using the neighbour table construction. There are fields for hop-by-hop delay $DL_n ode(s)$ and end-to-end path delay $DL_p ath(k, d)$ in node $s' sneighbourtablestructure$ (ID$_d$, L_d, ID_k, L_k, D_k, d, D_s, d, and $DL_n ode(s)$, DL$_k$)). When a new Hello packet is received, the neighbour table is updated by the constructor module. Fields for ID_d, L_d, nh_d, and $DL_p ath(s), d)$ can be found in the routing table of sensor node n_s. The routing module builds the routing table and decides which path to take for time-critical data.

b. Routing Algorithm

Algorithm 1 presents the optimal route selection based on the minimum path delay. Table 1 presents the notation used in Algorithm 1.

The variable nh_k stores the identifiers of all the nodes that are neighbours to node n_s. If there is only one entry in nh_k, then that is the one and only path that will be recorded in nh_d. In every other case, nh_k is ordered by delay, with the lowest delay path being recorded in nh_d. Next hop candidate nh_d has its path delay value $DL_p ath(s, d)$ saved in the routing table.

The suggested routing method seeks to filter the neighbour table and pick, from several candidate entries, the one with the lowest path delay for a given destination.

Algorithm 1 Routing Table Constructor Algorithm for Delay-Sensitive Packets

```
Require: Neighbor table $NH_{s,d} \forall d \in$ (sensor nodes, BANC, MDC, NSC)
Initialize:
    - Hello Module (HM): Periodically updates the neighbor table
    - MAC Receiver: Receives packets from neighboring nodes
    - Delay Estimation Module (DEM): Estimates the transmission delay for each path
    - Routing Module (RM): Constructs the routing table for delay-sensitive packets
    - Queuing Delay Control Module (QDM): Controls queuing delay and packet forwarding
Procedure:
for each $d \in (sensor\ nodes, BANC, MDC, NSC)$ do
    $nh_k = \texttt{all neighbor nodes}\ k \in nh_{(s,d)}$
    Add all neighbor nodes $n_k$ to the neighbor table entry of $n_s$
    if $(nh_k == 1)$ then
        $nh_d \leftarrow nh_k$        // Assign the only neighbor to the destination $nh_d$
    else
        if $nh_k > 1$ then
            Sort $nh_k$ in ascending order of $DL_{path(s,d)}$        // Sort neighbors based on their path delay
            for each neighbor node $n_k \in nh_k$ do
                if $(DL_{path(s,d)} < DL_{req})$ then
                        // Check if path delay is within the required delay
                    Send the packet to $nh_d$        // Forward the packet to the next-hop node
                else
                    Drop the packet immediately        // Discard the packet due to excessive delay
                end if
            end for
        end if
    end if
end for
```

1) PARAMETER SETTING AND CONFIGURATION

Table 2 enumerates the different network parameters employed during the simulations:

IV. RESULTS AND DISCUSSION

End-to-end delay and throughput for three different scenarios have been compared between the EQRD, QDPR, and DMQoS protocols using Matlab simulator. In the first scenario, all of the nodes are assumed to be immobile.In the

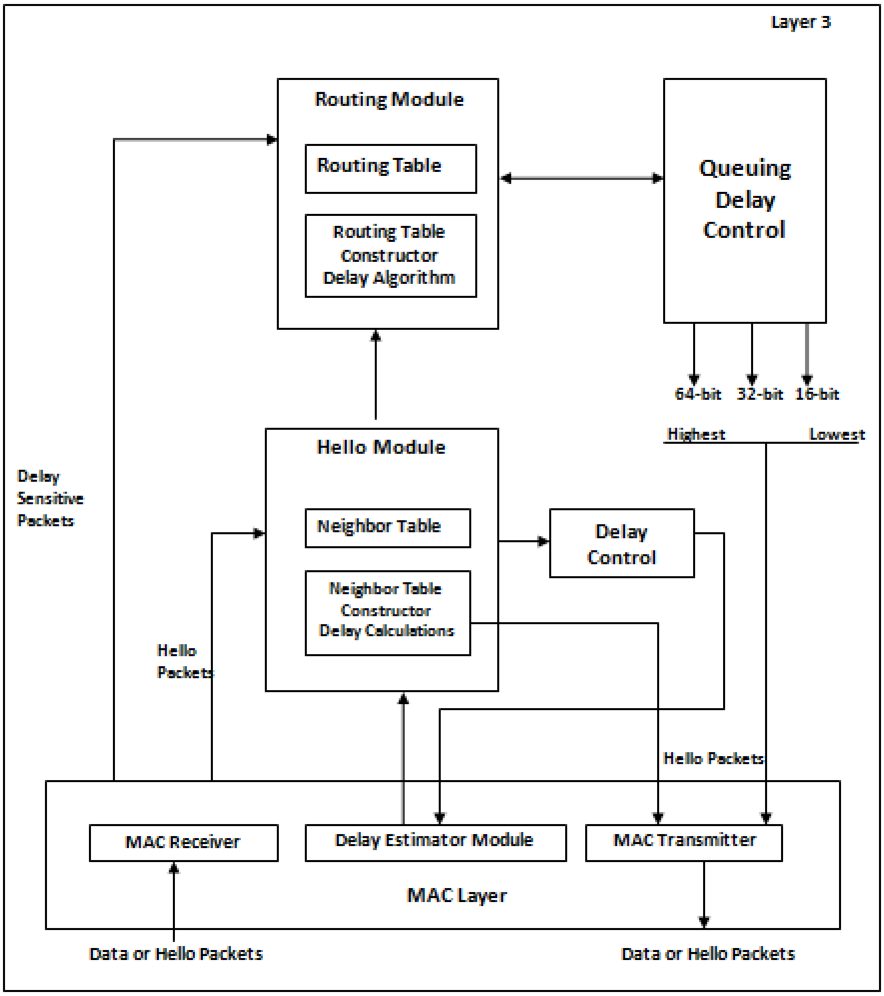

FIGURE 2. EQRD protocol architecture.

TABLE 2. Network parameters.

Information of Parameters	Value
Scenario 1 and 2	Area : 9m × 9m Scenario 3: 21m × 16m
Type of Deployment	Scenario 1: Each node is fixed Scenario 2: Source node $B4$ is mobile Scenario 3: Context of a Hospital
Total nodes	Scenario 1 and 2: Total nodes 8 (4 BANs, 3 MDCs, 1 NSC) Scenario 3: 49 nodes (24 BANs, 24 MDCs, 1 NSC)
Initial Node Positions	Scenario 1 and 2: NSC$(0,3)$, MDC1$(2,5)$, MDC2$(2,1)$, MDC3$(3,3)$, BANC1$(5,5)$, BANC2$(5,1)$, BANC3$(6,3)$, BANC4$(9,3)$ Scenario 3: As shown in Figure 11.
Initial Node Energy (E_i)	normal Node: 18700(mJ) BAN Coordinator: 20570 (mJ)
Transmission power	−25 dBm
Application Type	Event Driven

second scenario, where the source node, B_4, is in motion, the scalability of the protocol is put to the test. In the third scenario, we tested the scalability of the protocol by changing the amount of packets sent. The performance analysis of EQRD included the calculation of throughput, intermediate node throughput, overall energy usage, and packet timeouts. The simulation results showed that EQRD's proposed end-to-end path delay mechanisms were effective in achieving higher throughput, reducing the packets forwarded by intermediate nodes, and reducing packet timeouts. The outcomes obtained from the scenarios are discussed in detail below.

A. COMPARISON OF EQRD WITH OTHER METHODS

Each coordinator has been located in 63.3m × 63.3m = 4000 m^2 area inside the total area of 2000m × 2000m = 4,000,000 m^2. Such dimensions are not feasible for an indoor-hospital environment that has been considered for the proposed work. The parameters of network employed in simulation are same as that of QPRD and are listed in Table 2. The Network Switching Center (NSC),Medical Data Collector(MDCs) and BANC have been placed within the specified area of 9m × 9m = 81 m^2 in the proposed work.

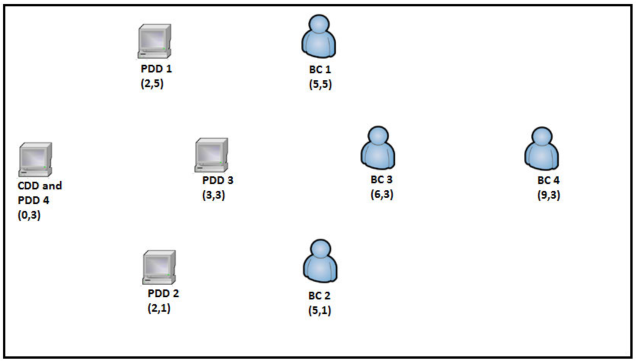

FIGURE 3. Nodes deployment for Scenario 1.

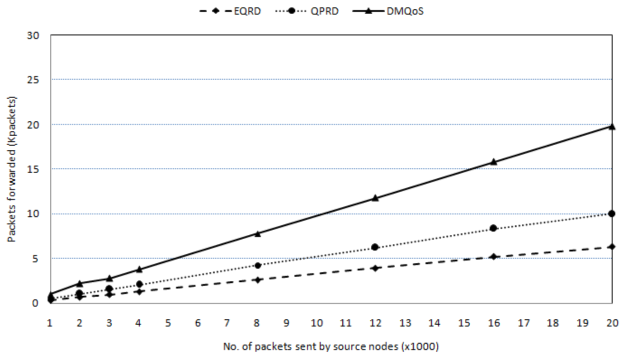

FIGURE 5. Forwarded data packets by intermediate nodes.

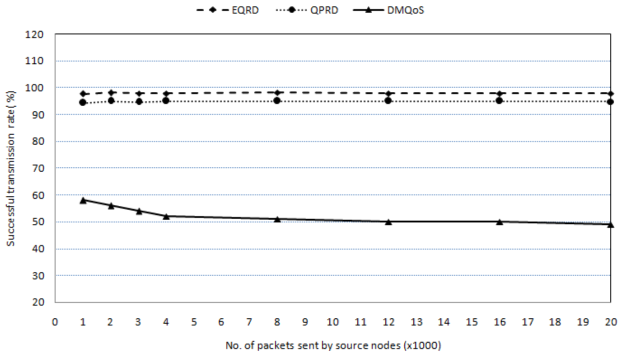

FIGURE 4. Throughput.

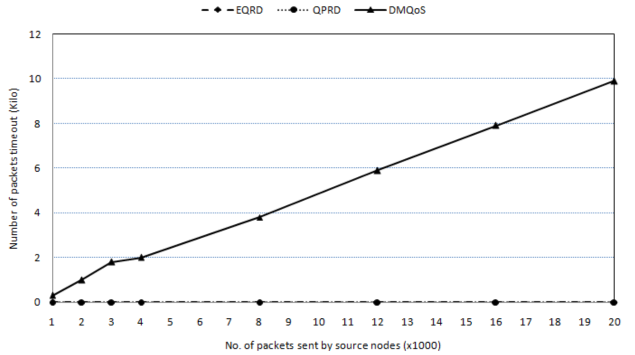

FIGURE 6. Packets timeout.

1) SCENARIO 1: STATIC NODES (ALL)

Figure 3 illustrates the deployment of the nodes in Scenario 1, where all nodes are stationary. Figure 4 shows that EQRD consistently achieves a throughput of 98% or higher, while QPRD achieves a throughput of 94%. DMQoS exhibits a throughput ranging from 49% to 57%. The throughput continuously decreases from 57% for a higher offer load of 20K to 49% for a lower offered data traffic of 1K. The use of a Geographic Forwarding strategy for choosing the next hop has resulted in this drop in performance. Because DMQoS selects the optimum next hop based on the energy parameter rather than latency, packets may time out if the protocol is used. This causes an increase in network congestion and packet loss. QPRD uses end-to-end path delay to solve these problems. By delaying data transmissions from beginning to finish and making full use of the available bandwidth through parallelized transmissions, EQRD is able to boost throughput significantly.

According to Figure 3, in the current network setup, $BANC_2$ is the node most central to the MDCs and NSCs. When data packets originating at source nodes are routed through $BANC_2$ on their way to MDCs or NSCs, congestion is caused. The amount of packets forwarded by intermediate nodes is decreased in EQRD and QPRD since BAN Coordinators only forward data to each other when absolutely necessary. It has been shown that fewer data packets are forwarded by intermediate nodes in EQRD than in DMQoS or QPRD, as depicted in Figure 5.

Packets are transmitted in a sequential order on the channel for both QPRD and DMQoS. In contrast to EQRD, in which data packets of varying sizes are pooled together to the maximum channel capacity and delivered as a single slot, each individual packet counts towards the total. Therefore, to make the most of the available bandwidth, we count as one (in a single time slot) the transmission of four 16-bit packets and two 32-bit packets. This improves transmission efficiency because the intermediate nodes can now send and receive up to 64 bits of data at once (if that's what the channel can handle).

Figure 6 shows that neither QPRD nor EQRD experienced any timed-out data packets under varying traffic loads (i.e., the number of packets delivered by the source node ranging from 0K to 20K). This is because these protocols have a clear establishment of end-to-end path delay, which ensures that packets are delivered to the destination while considering the minimum delay requirement. Moreover, due to the utilization of simultaneous transmissions, the number of time slots required to send the same number of packets is reduced, which leads to a decrease in network traffic and prevents packet timeouts. As a result, EQRD and QPRD outperform DMQoS by reducing the amount of traffic and the number of timed-out packets.

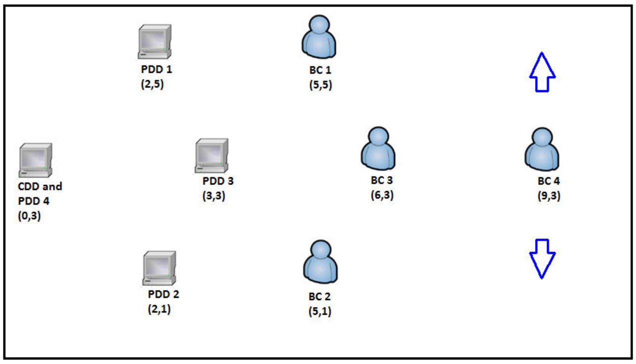

FIGURE 7. Nodes deployment for Scenario 2.

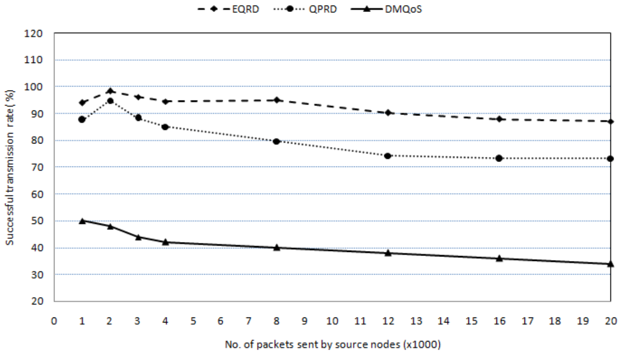

FIGURE 8. Throughput.

Table 3 demonstrates that the utilization of the end-to-end path delay mechanism in QPRD does not impact the overall energy consumption compared to DMQoS. However, EQRD reduces energy consumption by enabling multiple packet transmissions in a single cycle due to parallelized transmissions, thereby decreasing individual packet transmissions. This reduction in energy consumption, along with reduced delay and increased throughput, is advantageous.

TABLE 3. Overall energy consumption.

Source Node Packet Transmission Rate	EQRD(mJ)	QPRD(mJ)	DMQoS(mJ)
1K	7.66	18.14	18.14
2K	15.32	36.27	36.27
3K	21.70	49.77	49.77
4K	33.54	63.22	63.22
8K	68.89	110	110
12K	112.56	170	170
16K	175.27	220	220
20K	187.61	275.7	275.7

Overall, EQRD outperforms both QPRD and DMQoS in the case of a stationary source node.

2) SCENARIO 2: SOURCE NODE IS MOBILE

Scenario 2 in Figure 7 shows that EQRD performs better than QPRD and DMQoS when node B4 is believed to be moving vertically at a speed of 1 metre per second, which is thought to be the speed of a fast walking patient.

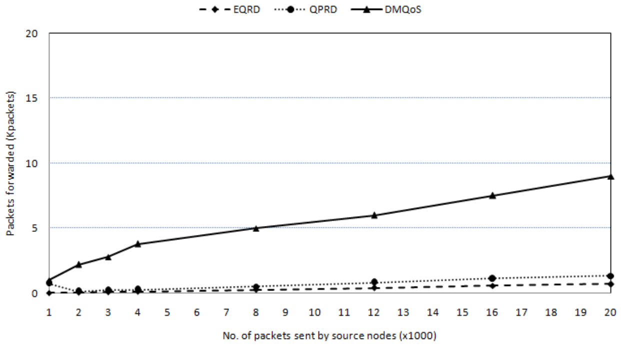

FIGURE 9. Packets forwarded by intermediate nodes.

As can be shown in Figure 8, EQRD offers throughput more than 90% at data packet rates less than 12K. After 12K, the throughput starts to drop off significantly, whereas with QPRD, it grows from 80% to 94% up to 2K packets, and then gradually drops to 71%. Throughput for DMQoS is much lower, dropping from $50to32$ per cent as load increases. When there is node mobility, packets are lost because the sending node is now out of range.

Figure 9 shows that compared to QPRD and DMQoS protocols in Scenario 2, the total number of data packets transmitted by intermediate nodes is smaller when using EQRD. It is as likely that the mobile node will move in the direction of the proper next hop node, with a probability of 50%, as it is that it will move in the opposite direction, with a probability of 50%. Moving towards the intermediate node increases the likelihood that the data will be transmitted to the next correct node, while moving away from the intermediate node increases the likelihood that the data will be transmitted directly to the destination node rather than being forwarded through the intermediate node. Because of this, fewer packets are forwarded by intermediate nodes than in the no-mobile situation and the static scenario combined. With parallelized transmissions, more data can be sent in less time, reducing the number of packets that must be transmitted to intermediate nodes. The QPRD protocol uses a routing method to ensure that data packets are transmitted directly to the intended recipient and bypass any intermediate nodes when the recipient is locally accessible.

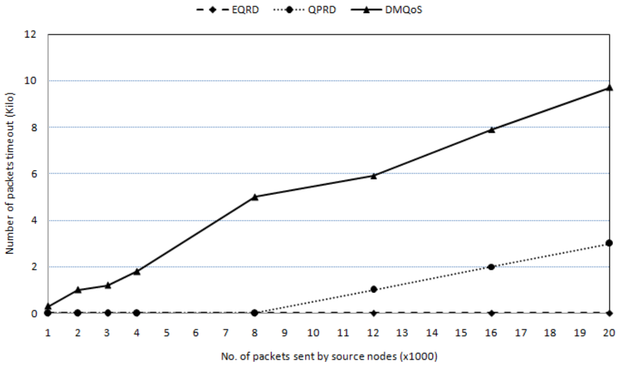

FIGURE 10. Packets timeout.

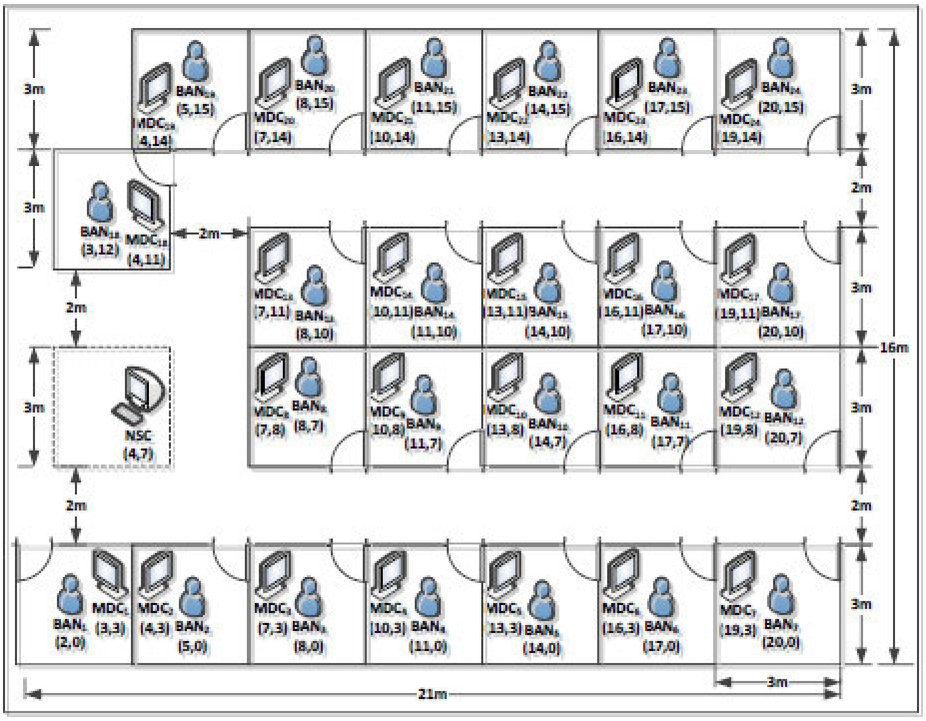

FIGURE 11. Nodes deployment for Scenario 3.

Figure 10 demonstrates that as the bandwidth is fully utilised and the time slots are decreased, the transmission time for each packet is also decreased in EQRD. Hence, the packets reach the destination before the timeout. For QPRD, no packets timed out until the transmission of $8K$ packets or less. However, when the number of data packets exceeded $8K$, more packets timed out as the source node moved out of the transmission range of neighboring nodes. In comparison to QPRD, DMQoS had more packet timeouts. For data transmission rates of less than $4K$, 40% of the data packets timed out. But, for packet transmission rates above $4K$, the packet timeout value increased to approximately 50% due to the hop-by-hop approach followed by DMQoS for routing of data packets. Moreover, the mobility of the source node worsened the packet timeout issue compared to the static node scenario (*Scenario* 1 in Figure 6).

Table 3 shows that the energy consumption of EQRD ranges from 7.66 Joules to 187.61 Joules for transmitting $1K$ to $20K$ packets from the source nodes, while QPRD and DMQoS have energy consumption ranging from 18.9 Joules to 275.7 Joules in the same scenario. The reduced energy consumption in EQRD is attributed to the fact that parallelized transmissions of packets occur in a single cycle, using fewer time slots, and no bandwidth is wasted. This reduces the number of packet transmissions required, which ultimately lowers the energy consumption.

When the source node is mobile, EQRD has shown better overall performance compared to QPRD and DMQoS.

3) SCENARIO 3: TEST OF SCALABILITY IN A REAL HOSPITAL CONTEXT USING 24BED (49NODE)

Previous research in [21] examined the scalability of EQRD in a simulated hospital setting with 24 beds and 49 nodes. This experiment utilised a space about 16 million by 21 million in size.

In a hospital environment, the recommended transmission range for BAN communication is such that two beds are separated by a distance of 3m. For the scalability test, a total of 49 nodes were utilized in the deployment area, which includes 24 MDCs, 24 BANs, and 1 NSC as depicted in Figure 11. All BANs have sent packets to their corresponding MDCs, and all MDCs and BANs have communicated with one another and the NSC using the Hello protocol. While BANs are free to roam the area at will, MDCs are typically only allowed to move within the confines of the room in which they have been placed. The MDC in one room is considered to communicate with the MDC in the room next door.

As the number of nodes in the simulations increased to 49, EQRD's performance was found to be superior to that of QPRD and DMQoS. Figure 12 displays that EQRD has a throughput of 92%, QPRD has a throughput of 88%, and DMQoS has a throughput of 58%.

Figure 13 depicts that there are no instances of packet timeouts in EQRD and QPRD, whereas in DMQoS, around 25K packets are timed out. These results demonstrate that EQRD is an efficient and effective protocol even in a larger deployment area.

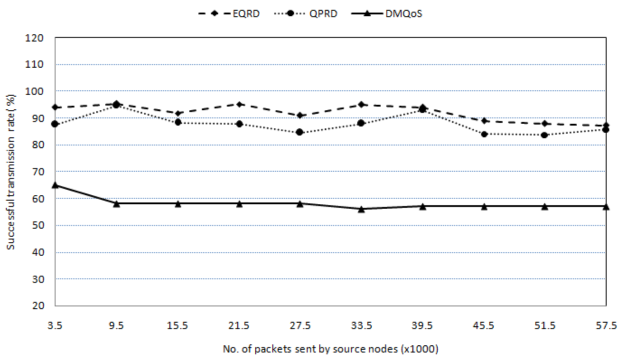

FIGURE 12. Throughput.

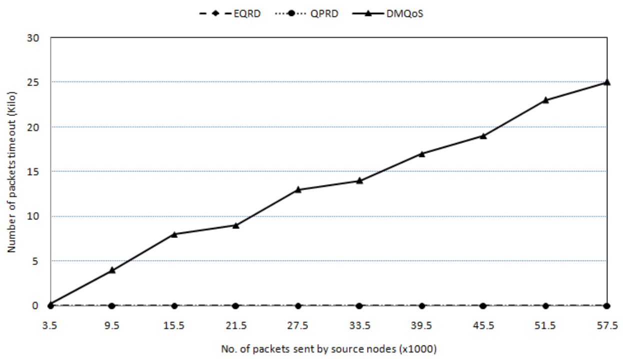

FIGURE 13. Timeout.

V. CONCLUSION AND FUTURE WORK

In this paper, the EQRD protocol is presented as a solution to timely reception of information and avoidance of life-threatening situations for delay-sensitive data. The protocol utilizes parallelized transmission to minimize end-to-end delay, packet timeouts, and re-transmissions, leading to increased efficiency and reduced energy consumption. The paper also introduces a novel bandwidth utilization constant and a node selection method based on path delay value. The proposed EQRD protocol was evaluated through simulations in both stationary and mobile scenarios. The results showed that in the stationary scenario, EQRD outperformed QPRD with a throughput of more than 97% for delay-sensitive packets. In the mobile scenario, EQRD achieved an average increase of 13% in successful transmission rate compared to QPRD. Numerical measurements also showed that EQRD might save energy compared to QPRD and DMQoS while sending 1K-20K packets from the source nodes by as much as 50.7% and as little as 20.3%. Despite having a larger number of nodes in the BAN, the EQRD protocol still performs better than QPRD and DMQoS, as shown by the scalability tests. In future research, different scheduling techniques can be explored to allocate time slots to packets of different sizes in the queue so that 100% throughput can be achieved and the channel capacity can be fully utilized. Additionally, deep learning can be applied to analyze patient data with potentially positive outcomes. The study also suggests that WBANs will evolve with cognitive networks that share the crowded radio spectrum fairly among new technologies and techniques.

APPENDIX

MATHEMATICAL ANALYSIS

In this section, analytical expressions for the total time taken when n bits are transmitted with and without the proposed approach are presented. The used notations are described below:

N_{16}, N_{32} and N_{64} are the number of 16-bits, 32-bits and 64-bits packets respectively. N is the total number of 16-bits, 32-bits and 64-bits packets such that

$$N = N_{16} + N_{32} + N_{64} \tag{14}$$

The size of the base packet is assumed to be of 64-bits i.e. $N_{basebit} = 64$

The reason for it is that the base packet is a critical packet. Therefore, it should be transmitted in the least possible time. So, it must not take more than one cycle which is possible only if channel bandwidth and packet size is equal. Since total bandwidth is taken as 64-bits, to utilize this bandwidth to its full capacity, 64-bits data has to be transmitted.

Total time required to transmit N packets = Time required to transmit N_{64} packets + Time required to transmit N_{32} packets + Time required to transmit N_{16} packets

i. General Scenario

Total number of bits to be transmitted
$= (N_{64} \times 64 + N_{32} \times 32 + N_{16} \times 16)$
Let x = time required to transmit 1-bit data
Total time required(TTR) = Total bits × per bit time = Total bits × x

$$= (N_{64} \times 64 + N_{32} \times 32 + N_{16} \times 16) \times x$$
$$= 16 \times (N_{64} \times 4 + N_{32} \times 2 + N_{16} \times 1) \times x \tag{15}$$

If b is the baud rate and x is the time to transmit 1-bit data, then

$$x = \frac{1}{b} \tag{16}$$

In terms of baud rate,

$$TTR_G = 16 \times (4N_{64} + 2N_{32} + N_{16})/b \tag{17}$$

Since the data is taken in terms of bits, Equation $A5$ gives the least required time to transmit the data. If, in any case, the time taken is less than the time given by Equation $A5$, it implies that the number of bits to be transmitted are also less.

ii. Using Proposed Approach

The proposed approach claims the minimum time taken in terms of slots. Lesser the number of slots used, lesser is the time taken.

Here, one slot is equal to the time taken to transmit 64 units or the base packet.

If b is the baud rate, time taken by 1 bit = $\frac{1}{b}$
Therefore, time taken by 1 slot = $\frac{1}{b} \times 64 = \frac{64}{b}$
Total time in slots = $\sum_{p}(BUC)_{p}N_{p}$
where p varies from 1 to N and N = $N_{16} + N_{32} + N_{64}$
Total time in seconds = $\frac{64}{b} \times N_{64} \times 1 + \frac{64}{b} \times N_{32} \times \frac{1}{2} + \frac{64}{b} \times N_{16} \times \frac{1}{4}$

$$TTR_{P} = 16 \times (4N_{64} + 2N_{32} + N_{16})/b \tag{18}$$

The total time taken to transmit the packets to the destination as depicted by Equation $A5$ in the proposed approach is same as the least amount of time required to transmit the data bits in the general scenario as shown in Equation $A4$. Therefore, the proposed approach gives the minimum best number of slots for data transmission.

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