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LLTP-QoS: Low Latency Traffic Prioritization and QoS-Aware Routing in Wireless Body Sensor Networks

FATIMA TUL ZUHRA[1], KAMALRULNIZAM BIN ABU BAKAR[1], ADNAN AHMED ARAIN[2], KHALED MOHAMAD ALMUSTAFA[3], TANZILA SABA[3], KHALID HASEEB[4], AND NAVEED ISLAM[4]
[1]Department of Computer Science, Faculty of Engineering, School of Computing, Universiti Teknologi Malaysia, Johor Bahru 81310, Malaysia
[2]Department of Telecommunication, Quaid-e-Awam University of Engineering, Science and Technology, Nawabshah 67450, Pakistan
[3]Department of Information Systems, College of Computer Science and Information Systems, Prince Sultan University, Riyadh 11586, Saudi Arabia
[4]Department of Computer Science, Islamia College University, Peshawar 25000, Pakistan

Corresponding author: Tanzila Saba (drstanzila@gmail.com)

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ABSTRACT Wireless Body Sensor Network (WBSN) is deployed in delay-sensitive application scenarios where providing Quality-of-Service (QoS) is utmost important. The QoS-aware routing protocol not only discovers a route from source to destination but also satisfies QoS requirements in heavily loaded wireless networks. Emergency / critical data packets must reach the intended destination without incurring significant delays and fulfill multiconstrained demands (reliability, delay, Packet Delivery Ratio (PDR)) of heterogeneous applications. Congestion occurs in heavy traffic situation when the incoming traffic load exceeds the capacity of transmission link, buffer overflows, packet collision, channel contention. Consequently, it impacts QoS in terms of packet loss, end-to-end delay and PDR. Moreover, the selection of poor links/routes may have detrimental impacts of the performance of WBSN and there can be significant variations in throughput, delay, network lifetime, route stability performance. Majority of the existing priority-aware routing protocols proposed for Medium Access Control (MAC) layer to solve the slot allocation problem by which data packets are classified into different categories. However, less attention has been given to traffic prioritization at network layer for data categorization. Furthermore, optimized traffic prioritization has been overlooked, thereby increases the data redundancy, queue/link delay, data loss and decreases the reliability of the network, and it does not satisfy the QoS requirements of WBSN and affects the critical data to be delivered in a less privileged manner. This work proposes the Low Latency Traffic Prioritization scheme for QoS-aware routing (LLTP-QoS). The LLTP-QoS is designed to enhance the transmission of critical data in a privileged manner (reliability) and avoids the end-to-end delay. The performance of proposed scheme is evaluated in terms of throughput, average end-to-end delay, PDR, normalized routing load, network lifetime through extensive simulations using Network Simulator-2 (NS2). The simulation results verified improved performance of proposed LLTP-QoS scheme as compared to existing routing protocols.

INDEX TERMS Wireless body sensor networks, physiological data, QoS, data traffic, priority queue, packet delivery ratio, latency.

I. INTRODUCTION

In healthcare applications of Wireless Body Sensor Network (WBSN), some heterogeneous biosensor nodes are attached or implanted inside the human body to monitor various aspects of human health (as shown in Figure 1). These biosensors sense the physiological data (blood pressure, temperature, Electrocardiogram (ECG), glucose, etc.) and transmit it to the master node [1]–[3]. Then the received data is broadcast to the base station for examination. Due to the heterogeneous nature, the physiological data requires a different kind of Quality-of-Service (QoS) to transmit without data loss/path loss and delay. To do so, various priority-aware routing schemes proposed to assign some priorities on the data packets when they are transmitted over the network, which is commonly known as data priority. Moreover,

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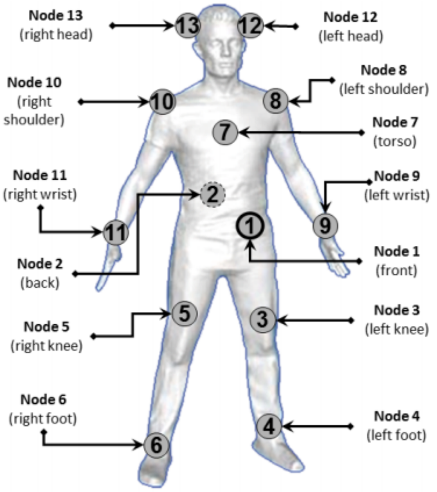


FIGURE 1. Nodes deployment in WBSN [14].

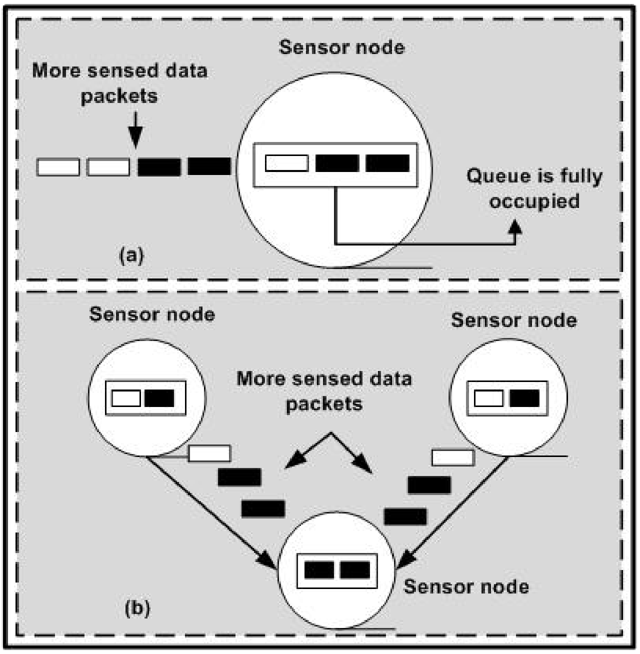


FIGURE 2. (a) Nodes and (b) link level congestion.

the data traffic load issue arises when the heavy transmission takes place between various biosensor nodes. Usually, the data traffic is categorized into three categories such as on-demand, normal and emergency data traffic. In the on-demand data traffic circumstances, the data is demanded by the physician for diagnosis purpose and it can be continuous and non-continuous. In a normal data traffic situation, the data is transmitted at a regular interval of time and it can be high, medium and low traffic. Whereas, the emergency data traffic is unpredictable situation consists of critical data. However, the traffic heterogeneity in [4], is classified as ordinary (general) packets, emergency (high priority) packets, and delay sensitive (critical) packets. While the priority-based Medium Access Control (MAC) is categorized as a parametric method [5], [6], channelization based method [7], [8], and hybrid method [9], [10]. Besides, a single-hop transmission mode is applicable when there is no traffic overhead while the multi-hop mode is applicable when biosensors are out of the coverage area (away from master node) or consume more energy to transmit the data packets [11]–[13].

In past literature, a variety of priority-aware routing protocols have been proposed for WBSN, especially for the MAC layer. In the MAC standard, there is only one queue within a station and does not provide any service differentiation to the flows that might need some QoS. Moreover, the MAC priority-aware protocols are more focused on the priorities of the data frames (super-frames) and solve the slot allocation problems [4], [10], [15], [16]. However, the slot allocation strategy is not preferable for emergency data transmission, because it reduces the performance of MAC protocol in terms of minimum duration of super-frame and slots or insufficient slots, retransmission of collided data packets, delay, a frequent invocation of beacon interval and high energy consumption [17]. The high number of retransmission and collision degrade the performance, throughput, lifetime of the network and consumes a high amount of energy. Furthermore, some of the priority-aware protocols designed for the network layer [11], [18]–[20]. In the network layer, the priority queue algorithm is used for data categorization. In which all sensor nodes maintain two queues based on the priorities (high and low) of the data packets and consider a First In First Out (FIFO) technique in order to occupy the queues [21]. The high and low priorities are assigned based on the size and data rates of the data packets, but this is also not suitable for emergency data transmission, because it increases the data redundancy, queue delay, data loss and decreases the reliability of the network. Consequently, it affects the critical data to be delivered in a less privileged manner.

One of the most common issues (i.e. congestion) arises when the incoming traffic load exceeds the capacity of the transmission link, buffer overflows, packet collision and channel contention [22], [23]. There are two most common types of congestion, such as node level congestion and link level congestion (as shown in Figure 2). Referring to Figure 2, the black and white sensed data packets are critical and non-critical data packets respectively. In Figure 2(a), the node level congestion occurs when buffer/queue overflows, i.e. packet service rate is smaller than the packet arrival rate, while in Figure 2(b), the link level congestion occurs when many active sensor nodes use the same channel simultaneously, packet collision and channel contention/network interference. To enhance the Packet Delivery Ratio (PDR) and throughput of the network, it is very important to avoid both congestion types as much as possible by proposing an optimized routing protocol, which completely resolves the above-mentioned issues. Thus, this work investigates the existing traffic prioritization/priority-aware routing protocols and presents the LLTP-QoS routing protocol with the traffic prioritization (LLTP) and Optimized Route Discovery (ORD) scheme for intra-WBSN. The LLTP-QoS protocol is designed to enhance the critical data transmission (reliability), also avoids the node and link level congestion and end-to-end delay. The key contribution of this research work is as follows:

- We discuss the vulnerability of the existing priority-aware routing protocols for WBSN under heavy network traffic.
- We propose the LLTP-QoS routing protocol for WBSN which consists of two main phases such as (i) initialization and traffic prioritization phase and (ii) route discovery phase.
- The LLTP scheme uses priority queues with optimized scheduling mechanism to categorize the data traffic to avoid the node level congestion and queue delay.
- The ORD scheme uses the composite metric (M) to optimize route selection in pursuit of avoiding a congested link (link level congestion) and minimizing end-to-end delay, retransmissions and drop ratio.

The remaining paper is organized as follows: Section 2 briefly describes the related work (existing priority-aware routing protocols). Section 3 explains the overall network model, assumptions and proposed LLTP-QoS routing protocol. Section 4 presents the simulation results with the discussion. Finally, conclusion is presented in Section 5.

II. RELATED WORK

This section investigates the existing priority-aware routing protocols proposed for WBSN. Most of the researchers used priority concept to solve the MAC based slot allocation problem. The MAC super-frame structure is categorized into two classes such as IEEE 802.15.6 [14], [24], [25] and IEEE 802.15.4 [16], [26], [27]. The Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) and Time Division Multiple Access (TDMA) are the most common MAC schemes. In CSMA/CA, the biosensors compete for channel access prior to data transmission while in TDMA; the channel is categorized into time slots. The time slots can be fixed or variable. The time duration is assigned to each biosensor node to transmit the data packets within the defined time interval.

Moreover, in past literature, various MAC based priority-aware routing protocols have been proposed, which categorized the patient data packets into four different categories such critical, non-critical, delay and reliability sensitive data packets [4]. Critical (have low threshold values for instance, low heartbeat) and reliability sensitive (have high threshold values, for instance, high heartbeat) are emergency data packets. While non-critical and delay sensitive data packets (have normal data for instance, glucose and temperature reading) are non-emergency data packets [11], [18]. In MAC super-frame, different slots are allocated to all categories of the data packets. Different priority-based protocols are proposed to modify the structure of super-frame of IEEE 802.15.4 [16], [27], where works, the data traffic is categorized according to the data rates of different nodes and priorities are assigned by considering both data type and size.

A Traffic priority-aware adaptive SLot allocation based MAC (TraySL-MAC) protocol is presented in [15]. In TraySL-MAC, there are three slot allocation algorithms have been developed, such as high threshold vital sign criticality-based, low threshold vital sign criticality-based and reduced contention adaptive slot allocation. The Contention over Reservation MAC (CoR-MAC) protocol considers contention-based reservation method, i.e. dual booking to minimize the delay and maximize channel usage [10]. In dual booking, other nodes can only access the reserved time slots when they are empty. In [28], a Priority-based Adaptive MAC (PA-MAC) protocol is proposed to allocates the time slots according to the traffic priority. In PA-MAC, the data traffic is prioritized by priority-guaranteed CSMA/CA procedure in the Contention Access Period (CAP). The Contention Free Period (CFP) is used to transfer significant numbers of consecutive data packets to the coordinator. If the contention is high in CAP period then it gives a high number of retransmissions and collision. The authors in [29] proposed a secure Priority based MAC (PMAC) to facilitate the critical and normal data traffic by using two CAP while the large data packets are facilitated by one CFP. Two adaptive MAC protocols were proposed in [30] to minimize the path loss ratio and average delay. One protocol minimizes the delay of emergency data by giving it a high priority, while the second protocol minimizes the path loss ratio of emergency and non-emergency data by applying utmost delay requirements to emergency data.

Recently, a MAC based Multiple Access with Reserve and Priority Control (MAR-PC) protocol is proposed in [21] and it defines the priority of each sensor node based on the size of FIFO and sampling rate. The proposed WBAN consists of nine sensor nodes, one central node and each sensor node consists of a FIFO memory. The central node maintains a priority vector, and the highest priority is assigned to the sensor node, which has the least priority vector. Another MAC based Energy Efficient and Load Balanced Priority Queue Algorithm (ELBPQA) is proposed for critical data transmission in [31]. In the proposed algorithm, the data packets are classified based on their location. If the data packets are received from the remote position, then it will be scheduled according to its deadline, else, if the data packets are received from the local position, then it will be scheduled according to data priority (high, medium, low and normal).

It is observed from the MAC based priority schemes that the majority of the MAC based priority schemes maintain the super-frames as per traffic load and traffic categorization,. Also, it pays more attention to high priority traffic and less attention to low priority traffic. Although Henna, et al. [32] proposed a Traffic Adaptive Priority Based MAC (TAP-MAC) protocol that considers low priority traffic based on traffic load and traffic categorization, in TAP-MAC, the data traffic is classified into three classes and various priorities are assigned to each class. Class one represents emergency data with the highest priority, class two signifies on-demand traffic with medium priority while the third class denotes normal traffic with the lowest priority. The CAP period is divided into CAP 1 and CAP 2 based on high and low priority traffic load to facilitate a fair chance to low priority traffic. In this way, low-priority traffic access to the CAP 2 period to transmit data. Furthermore, less amount of research has been done on the network layer which considers traffic classification along with routing. Few routing protocols (network layer based schemes) incorporataitng concept of prioritization is presented as follows.

The network layer based priority algorithms are presented in [11], [18], which distinguished the various traffic according to the type of the sensor nodes. Similarly, the Priority-Aware AODV (PA-AODV) protocol is presented in [19] and a Data Privacy based Pearson Correlation Coefficient (DP-PCC) is presented in [20]. Both of these schemes assign priorities according to the data rates. If the data rate is higher or equal to a predefined threshold, then it is treated as critical data otherwise it is considered as normal data. Some of the routing protocols [30], [33]–[38] make use of a data classification module which categorizes the patient's data into on-demand, normal and emergency data based on their low and high threshold values. In [35] the biosensor's data is categorized into normal, delay and reliability-sensitive data. The Thermal-aware Multiconstrained intrabody QoS-aware routing protocol (TMQoS) and Thermal-aware Localized QoS-aware routing protocol (TLQoS) are proposed respectively [36], [37]. In both TMQoS and TLQoS, a QoS-aware packet classifier is designed which classifies the data traffic into four different classes such as delay-constrained, reliability-constrained, non-delay-constrained and delay and reliability-constrained. The delay-sensitive data is the most critical data which needs to be delivered in the specified time period with high reliability. While the reliability-sensitive is also delivered with high reliability but can tolerate some delay. Moreover, a FIFO based queue mechanism is used to buffer the packets.

In the light of above mentioned related works, it can be observed that the majority of the priority-aware routing protocols are more focused on the structure of the super-frames and high priority data traffic. While very less amount of research has been done which consider the priority of data packets on the network layer, their transmission schemes are based on a FIFO priority queue algorithm. However, these protocols overlook the optimized traffic prioritization for emergency data transmission by using the following techniques: data redundancy, queue/link delay and data loss is increased while the reliability of the network is decreased. Furthermore, route selection is also not optimized, because they don't consider significant issues, such as network intra-interference, packet loss, retransmission and link breakage. Also, the sensor nodes can easily break the transmission link with its adjacent node, due to the heavy traffic, therefore, an efficient traffic prioritization and route discovery schemes should be incorporated in routing that addresses the aforementioned issues effectively.

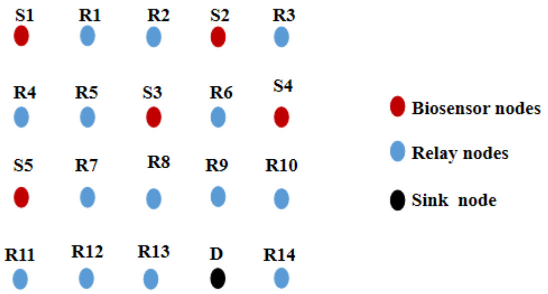


FIGURE 3. Network model of the proposed intra-WBAN.

III. PROPOSED SCHEME

This section describes the proposed network model, assumptions and LLTP-QoS routing protocol. The LLTP-QoS includes two phases: (i) initialization and traffic prioritization phase and (ii) route discovery phase. The detail of each phase is given in the consequent sections. A detailed flowchart of the LLTP-QoS routing protocol is shown in Figure 6.

A. NETWORK MODEL AND ASSUMPTIONS

It is assumed that the proposed network model consists of five heterogeneous biosensors (implanted and wearable such as glucose, EMG, ECG, temperature and blood pressure), fourteen relay nodes and one sink node (as shown in Figure 3). All are interconnected through multihop mesh topology. The biosensor nodes operate as sender nodes while the relay nodes operate as forwarder nodes to forward the data packets to the sink node. The data packets are transmitted at a different transmission rate. Extra-BAN, inter-BAN communications, mobility and network interference are not included in this research work.

The deployment scenario is modeled as a Connectivity Graph such as $CG = (K, L, M)$, where K is the set of biosensor and relay nodes represented as $K = \{B_n\} \cup \{R_n\}$. Here, B_n is a group of all biosensor nodes $b_1, b_2, b_3, \ldots b_n$ and R_n is a group of all relay nodes $\{r_1, r_2, r_3, \ldots r_n\}.L$ is a set of all communication links between various biosensor nodes, relay nodes and sink node (S) $\left\{l_{1,} l_{2,} l_3, \ldots\ldots l_n\right\}$. M indicates the composite metric used for optimized route selection. The data packets from various sensor nodes are represented as $DP = \{CDP\} \cup \{NDP\}$. Each packet type (P.type) is represented by the least significant bit (0 or 1) of the header in Internet Protocol (IP) data packet. Here, CDP represents the critical data packets (P.type = 1) whereas NDP represents the non-critical data packets (P.type = 0) (as shown in Figure 4). It is also assumed that the glucose, EMG and ECG biosensor nodes generate CDP, while the temperature and blood pressure nodes generate NDP.

B. PROPOSED LLTP-QOS ROUTING PROTOCOL

1) INITIALIZATION AND LOW LATENCY TRAFFIC PRIORITIZATION PHASE

At first, the sensor nodes are deployed accordingly (as described in the previous subsection). Before data transmission, the sense data packets are classified as P_{low} and P_{high}.

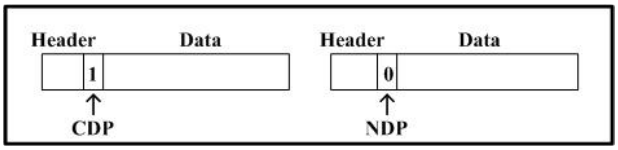


FIGURE 4. IP data packet structure.

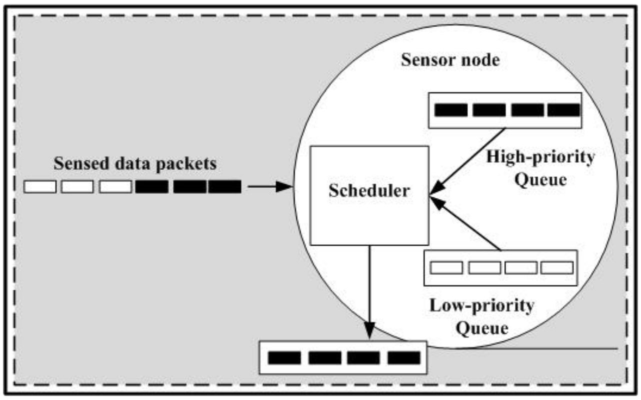


FIGURE 5. Working mechanism of LLTP phase.

TABLE 1. Packet prioritization based on the average length of a queue.

Average Length	Packet Allocation Type
0	Low (non-critical)
≤0.5	Low (non-critical)
>0.5<1	Low to high (critical)
1	High (most critical)

TABLE 2. Queue allocation rules based on the proposed strict en-queuing mechanism.

Case No.	Queue Allocation mechanism
1	If P_{low}& avg_length =0 or ≤0.5 then en-queue in PQ_{low}.
2	If P_{low}& avg_length =1(PQ_{low} overflows) then wait until timeout period expires. If timeout period is expired and PQ_{low} is still full, then en-queue in PQ_{high} (if it has available space)
3	If P_{high}& avg_length =0 or ≤0.5 then en-queue in PQ_{high} .
4	If If P_{high}& avg_length =1(PQ_{high} overflows) then wait until timeout period expires. If timeout period is expired and PQ_{high} is still full, then en-queue in PQ_{low}(if it has available space).

The P_{high} have the highest priority whereas the P_{low} have low priority. All sensor nodes maintain two separate queues i.e. high (PQ_{high}) and low (PQ_{low}) priority queues. These queues are occupied according to the packet type of each data packet either P_{high} or P_{low} (as shown in Figure 5). To avoid the node level congestion or minimized the queue latency, before en-queuing the data packets, an average length (avg_length) of each queue is measured. Usually, queue length/queue size is defined as the total number of data packets in a queue. By using this parameter, the packet delay status can be evaluated. The minimum and maximum threshold value is defined by the Queue Factor (QF) and evaluated by Equation 1.

$$QF = \frac{Remaining\ queue\ (Total\ queue - consumed\ queue)}{Total\ queue} \tag{1}$$

Referring to Table 1 and 2, the maximum and minimum threshold values are defined in between the 0-1 range. At first, the average length of each queue is determined, which is more or less or equal to the mediate threshold value (which is 0.5) then the priority based data packets are inserted accordingly. If the average length of each queue is equal to the maximum threshold value (which is 1), then the queue overflow strategy is applied as described in Algorithm 1. However, a strict priority mechanism is implemented by which the PQ_{high} packets are transmitted before PQ_{low} data packets. For instance, the ECG data packets should be transmitted before temperature data packets. In case, if a sensor node recieves multiple high priority packets, P_{high}, then the packets with smaller size will be transmitted first. However, in the case of PQ_{high} overflows, if the average length of PQ_{high} reached to the maximum limit, whereas PQ_{low} is either empty or half occupied then the P_{high} are assigned to the PQ_{low}. Moreover, a timeout policy is also applied on PQ_{high} and PQ_{low} by which P_{high} and P_{low} are discarded respectively. The timeout policy applied to those data packets which have exceeds defined time period limit. In this way old data packets residing in queues are discarded. Furthermore, the Traffic Prioritization Factor TPF is evaluated by Equation 2.

$$TPF = \frac{Total\ number\ of\ P_{high}}{Total\ number\ of\ data\_pkt} \tag{2}$$

To avoid the link level congestion throughout the initialization phase, each biosensor broadcasts the "HELLO" packet to all adjacent nodes and evaluates the values of each parameter of M. The M is the integrated sum of TPF, Link Delay (LD) and Link Delivery Ratio (LDR). The value of LD is determined by the time difference between sent hello packets and received acknowledged packets and is evaluated by Equation 2.While the value of LDR is defined by the ratio of received hello packets to the sent hello packets on a particular link, as shown in Equation 3 and Equation 4.

$$LD = \frac{HelloPacket_{Ack} - HelloPacket_{sent}}{2} \tag{3}$$

$$LDR = \frac{Number\ of\ HelloPacket_{Ack}}{Number\ of\ HelloPacket_{sent}} \tag{4}$$

Equation 5 is the formation of composite Metric (M) which is the integrated sum of TPF, LD, and LDR.

$$M = \sum\nolimits_{link \in r} (max\ (TPF) + max\ (LDR) + min\ (LD)) \tag{5}$$

Algorithm 1 Low Latency Traffic Prioritization Scheme

```
Begin
Set $data\_pkt \leftarrow$ data packet
Set $\delta \leftarrow$ defined threshold value
Set $P_{high} \leftarrow$ critical data packets
Set $P_{low} \leftarrow$ normal data packets
Set $PQ_{high} \leftarrow$ high priority queue
Set $PQ_{low} \leftarrow$ low priority queue
Set $avg\_length \leftarrow$ average queue length
Set $max\_thresh \leftarrow$ maximum threshold value
Set $min\_thresh \leftarrow$ minimum threshold value
Set $max\_time \leftarrow$ maximum time to which a data packet keep inline in a specific queue
Set $control\_pkt \leftarrow$ control packet
Set $pkt_{deadline} \leftarrow$ deadline of a sensed data packet
Set $trans_{time} \leftarrow$ transmission deadline
Set $pkt_{type} \leftarrow$ data packet type
procedure data prioritization
Set the $data\_pkt$ priority
For each sensed $data\_pkt$
If ($pkt_{type} == 1$) then
    Declared as critical $data\_pkt(P_{high})$
    Call sub procedure data packet queuing
    En-queue to $PQ_{high}$
Else if ($pkt_{type} == 0$) then
    Declared as normal $data\_pkt(P_{low})$
    Call sub procedure data packet queuing
    En-queue to $PQ_{low}$
End if
End procedure
sub procedure data packet queuing
Set the priority queues $\left(PQ_{high} and PQ_{low}\right)$
Measure the average queue length ($avg\_length$) of $PQ_{high}$ and $PQ_{low}$
Set the $max\_thresh$ and $min\_thresh$ by queue factor ($QF$)
$QF = \frac{Remaining\ queue}{Total queue}$; $threshold\ range$:0-1
If ($pkt_{type}$ is $P_{high}$) && ($avg\_length_{PQ_{high}} < max\_thresh_{PQ_{high}}$) && ($avg\_length_{PQ_{high}} == min\_thresh_{PQ_{high}}$) then
   Add the $data\_pkt(P_{high})$ to $PQ_{high}$
Else if ($avg\_length_{PQ_{high}} == max\_thresh_{PQ_{high}}$) then
    Call sub procedure queue overflow
Else if ($pkt_{type}$ is $P_{low}$) && ($avg\_thresh_{PQ_{low}} < max\_thresh_{PQ_{low}}$) && ($avg\_length_{PQ_{low}} == min\_thresh_{PQ_{low}}$) then
Add the $data\_pkt(P_{low})$ to $PQ_{low}$
Else if ($avg\_length_{PQ_{low}} == max\_thresh_{PQ_{low}}$) then
    Call sub procedure queue overflow
End if
End sub procedure
sub procedure queue overflow
Set the queue time limit ($max\_time$)
Implement strict queue strategy
If ($avg\_length_{PQ_{high}} == max\_thresh_{PQ_{high}}$) && ($avg\_length_{PQ_{low}} == min\_thresh_{PQ_{low}}$) && ($pkt_{deadline} < trans_{time}$) then
    Add the $data\_pkt(P_{high})$ to $PQ_{low}$
Else if ($avg\_length_{PQ_{low}} == max\_thresh_{PQ_{low}}$) && ($pkt_{deadline} < trans_{time}$) && (queued $data\_pkt$ in $PQ_{low} == max\_time$) then
    Delete the oldest $data\_pkt$ from $PQ_{low}$
    Add the $data\_pkt(P_{low})$ to $PQ_{low}$
Else if ($avg\_length_{PQ_{high}} == max\_thresh_{PQ_{high}}$) && ($avg\_length_{PQ_{low}} == max\_thresh_{PQ_{low}}$) && ($pkt_{deadline} < trans_{time}$) && (queued $data\_pkt$ in $PQ_{low} == max\_time$) then
    Delete the oldest $data\_pkt$ from $PQ_{low}$
    Add new $data\_pkt(P_{high})$ to $PQ_{low}$
Else
    Delete the oldest $data\_pkt$ from $PQ_{high}$
    Add new $data\_pkt(P_{high})$ to $PQ_{high}$
End if
End sub procedure
End
```

2) ROUTE DISCOVERY PHASE

The LLTP-QoS routing is initiated with a route discovery phase where each biosensor node broadcasts the data packets to its destination node. The route discovery process modernizes the routing mechanism of the traditional AODV routing protocol by replacing the single hop count metric with a new composite routing metric. The route discovery process discovers the optimized routes by using M as shown in Equation 5. In this phase, the source node broadcast a Route Request (*RREQ*) packets to its adjacent nodes. The nodes receive the *RREQ* packet and check for the valid route to the destination in their routing table. If there is a route to the destination, the node responds with route reply, otherwise, the route request is forwarded to subsequent neighbor until it reaches the node having a valid route to the destination, or the destination itself. The Route Reply (*RREP*) packets are unicasted to upstream nodes via the reverse route. The TPF, LD and LDR values, evaluated during the initialization phase are appended to *RREP* packet and forwarded to the source node. The source node might receive multiple *RREPs* via various routes and computes the cost for M metric (for each one of the notified route). The AODV routing protocol discovers a shortest hop count route for the data transmission ((as shown in Figure 7(a)). However, the proposed routing protocol optimizes the route selection by keeping in view TPF, LDR and LD, which are most crucial factors for WBAN. The route that satisfies the QoS requirements in Equation 5, is selected as an active route (as shown in Figure 7(b)), thereby leading to improved network performance.

Referring to Figure 7(a), the source node (S1) initiates the route discovery process by sending the RREQ packet (blue arrow) towards all the adjacent nodes and this process continues until it reaches to the destination node. After

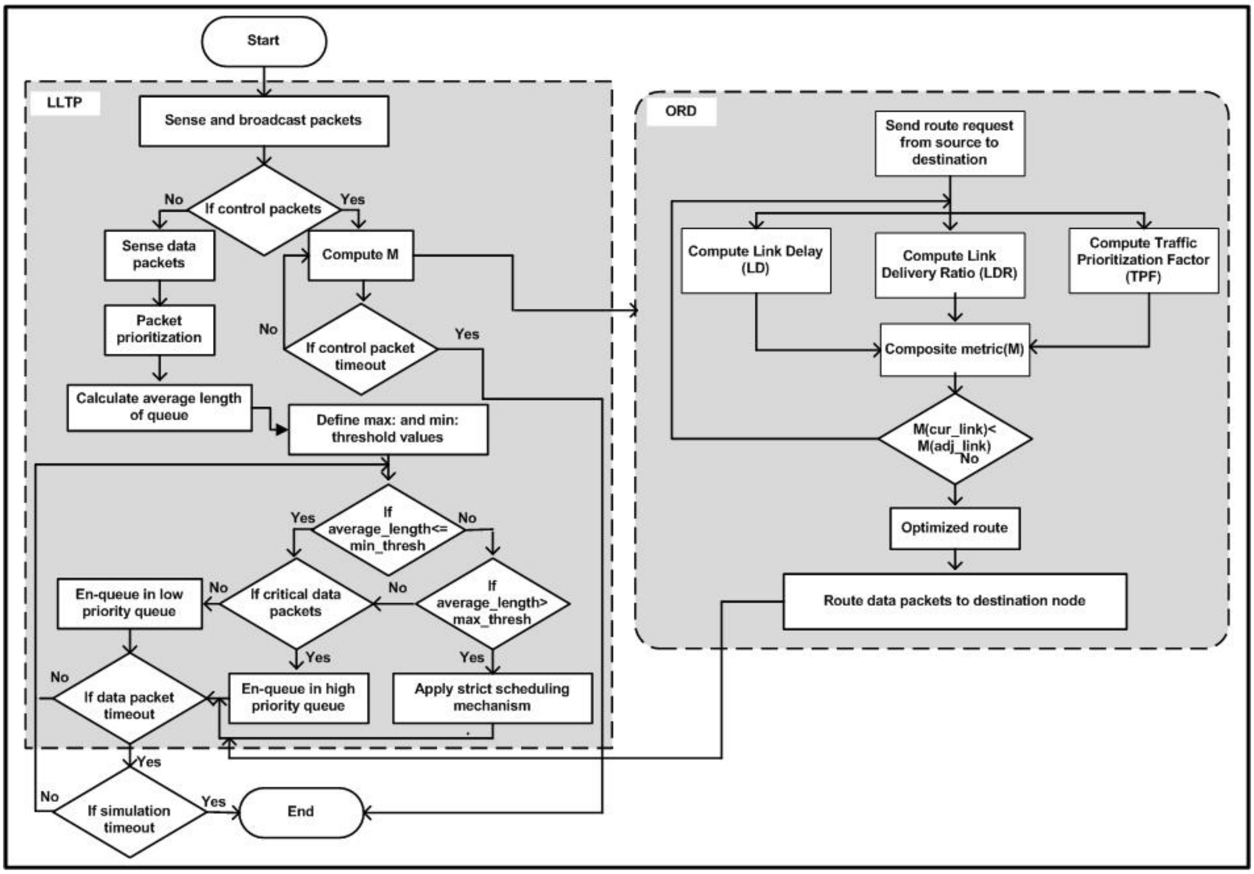


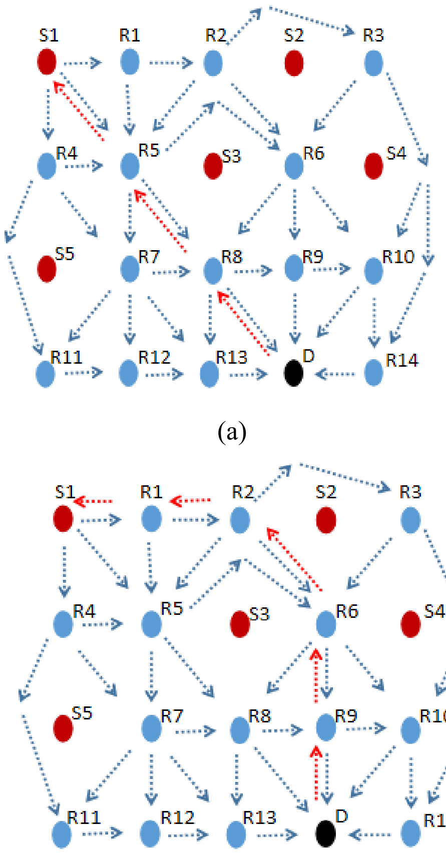
FIGURE 6. Flowchart of the proposed LLTP-QoS routing protocol.

receiving the RREQ packet, the adjacent nodes generate a RREP packet towards the sender node. When the RREQ packet is received by a destination node, it constructs a reverse minimum hop count route towards the sender node by a RREP packet (red arrow) (D→R8→R5→S1). While in Figure 7(b), the source S1 node initiates the route discovery process by sending the RREQ packet (blue arrow) towards all the adjacent nodes and this process continues until it reaches to the destination node. After receiving the RREQ packet, the adjacent nodes generate a RREP packet towards the sender node. The RREP packets contain the composite metric entrires such as TPF, LDR and LD values. The source node receives multiple RREP packets from different routes. The source node computes the route cost based on M (composite metric) and select the most optimized route satisfying the QoS requirements. When the RREQ packet is received by a destination node, it constructs a reverse M cost route towards the sender node by a RREP packet (red arrow) (D→R9→R6→R2→R1→S1).

IV. SIMULATION RESULTS AND DISCUSSIONS

This section describes the simulation setup and results of the proposed LLTP-QoS routing protocol. The LLTP-QoS protocol is simulated and evaluated by using Network Simulator-2 (NS2). Table 3 illustrates the different parameters used in the simulation. The QoS performance of the LLTP-QoS protocol is analyzed with the simulation in terms of throughput, average end-to-end delay, PDR, normalized routing load and network lifetime. The implementation is based on AODV routing protocol.

To demonstrate the accurate estimation of the LLTP-QoS protocol, at first, the simulation is performed according to the proposed network model 2m x 2m along with the 20 randomly deployed sensor nodes of 50 cm transmission range. All sensor nodes have different traffic load (50-250 kbps) while each sensor node maintains two different priority queues for traffic prioritization along with the average queue length of 100 data packets. Finally, the simulation is stopped after 1000 seconds. Figure 8, 9, 10, 11 and 12 present the performance comparison of the LLTP-QoS routing protocol and existing priority-aware routing protocols. The simulation results illustrate that the LLTP-QoS protocol shows improved performance as compared to PA-AODV and standard AODV. The traffic prioritization in PA-AODV is based on the data rates and the highest priority is assigned to the data packet which has high data rate value. Moreover, their route selection mechanism is based on QoS, which considers the hop count for route selection. Similarly, the standard AODV uses FIFO for packet scheduling and hops count for route selection. Reliable critical data transmission and congestion issues have



(a)

(b)

FIGURE 7. **Route discovery mechanism of (a) AODV and (b) LLTP-QoS routing protocol.**

TABLE 3. **Simulation parameters.**

Parameters	Values
Deployment Area	2m x 2m
Sensor nodes	5
Sink node	1
Relay nodes	14
Transmission range of nodes	50 cm
Propagation model	TwoRayGround
Network interface type	WirelessPhy
Traffic type	CBR
IEEE 802.15.4 standard	Default values
Transport layer protocol	UDP
Simulation Time	1000 seconds
Packet Size	100 bytes
Queue Limit	100
Traffic Load	50,100,150,200,250 kbps
Routing Protocols	LLTP-QoS, PA-AODV and standard AODV

been overlooked. However, the LLTP-QoS protocol has presented an optimized traffic prioritization mechanism due to which the critical data packets are transmitted efficiently. Figure 8 shows that LLTP-QoS achieves better average end-to-end delay performance, as compared to the PA-AODV and standard AODV. Both PA-AODV and standard AODV show increased number of packets insertions (en-queue) and route selections under heavy traffic, therefore, lead to high communication delay. Figure 9 shows that LLTP-QoS achieves high PDR performance as per the high data rate as compared to the PA-AODV and standard AODV. The LLTP-QoS selects the link with high prioritization factor, delivery ratio and low link delay.

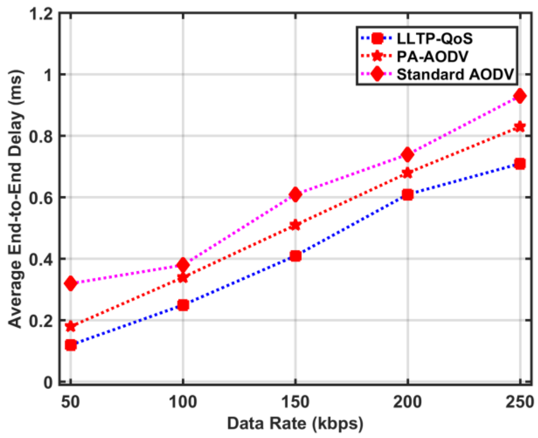


FIGURE 8. **Average end-to-end delay at different data rates.**

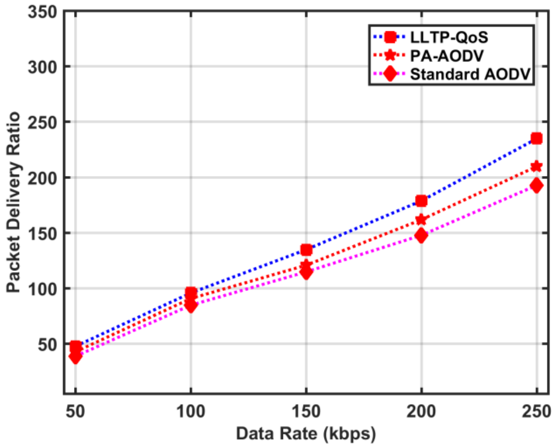


FIGURE 9. **Packet delivery Ratio at different data rates.**

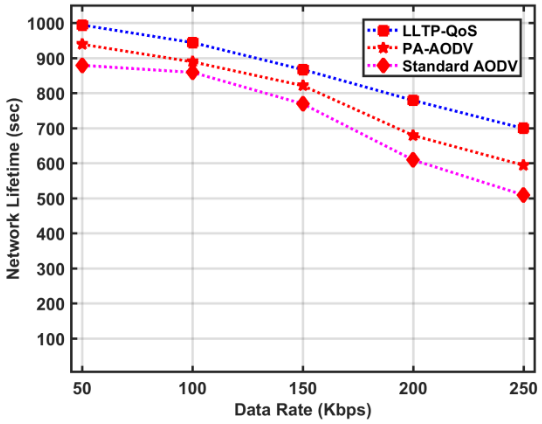


FIGURE 10. **Network lifetime at different data rates.**

Figure 10 shows the network lifetime of the proposed network model. The LLTP-QoS achieves high network life-

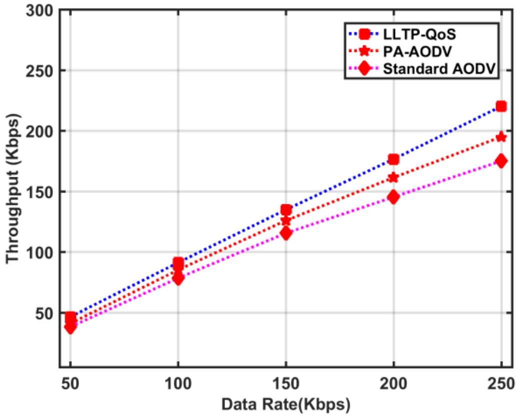


FIGURE 11. **Throughput at different data rates.**

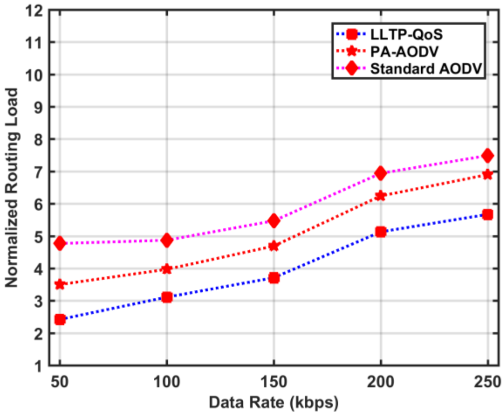


FIGURE 12. **Normalized routing load at different data rates.**

time at high data rates as compared to the PA-AODV and standard AODV. Figure 11 shows that LLTP-QoS achieves higher throughput compared to the PA-AODV and AODV routing protocols. As the network load increases, LLTP-QoS, PA-AODV and AODV show increased throughput. Figure 12 shows the normalized routing load of the LLTP-QoS, PA-AODV and AODV. The existing routing schemes PA-AODV and AODV show increased routing load, due to the increased number of route selections. The LLTP-QoS has less routing load as compared to the PA-AODV and AODV routing protocols.

The simulation results demonstrate the proposed LLTP-QoS routing protocol performance with optimized traffic prioritization and route selection. As a result of the adopted methodology, the reliability of critical data transmission is enhanced.

V. CONCLUSION

This paper has presented the LLTP-QoS routing protocol for intra-WBSN, which addresses the problems faced by the existing priority-aware routing protocols for WBSNs. Moreover, the LLTP-QoS is designed to enhance critical data transmission and avoids node and link level congestion. Furthermore, the LLTP-QoS consists of two main schemes such as traffic prioritization and route discovery schemes. The LLTP scheme has effectively prioritized the data packets using a strict queue allocation mechanism and also avoids the node level congestion. While M is proposed for route selection, which consists of three different parameters i.e. TPF, LD and LDR. The optimized route satisfying an integrated set of requirements is selected thereby leading to improved network performance in terms of throughput, average end-to-end delay, PDR, normalized routing load and network lifetime. The simulation results verified the improved performance of LLTP-QoS protocol as compared to the existing routing protocols. We aim to investigate the efficiency of proposed LLTP-QoS in terms of mobile and network interference scenarios as an extended future work to the presented propsed shcemes.

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FATIMA TUL ZUHRA received the B. Sc. degree in computer science from the Quaid-e-Awam University of Engineering, Science and Technology, Pakistan, in 2009, and the M.C.S. degree from the University of Malaya, Malaysia, in 2016. She is currently pursuing the Ph.D. degree with the Department of Computer Science, Faculty of Engineering, School of Computing, Universiti Teknologi Malaysia, Johor Bahru, Malaysia. Her research interests include wireless sensor networks (WSNs), wireless body sensor networks (WBSNs), and routing algorithms.

KAMALRULNIZAM BIN ABU BAKAR received the Ph.D. degree in computer science from Aston University, U.K. He is currently a Professor with the School of Computing, Faculty of Engineering, Universiti Teknologi Malaysia, Johor Bahru, Malaysia. He is the Deputy Dean of research and innovation. He is a Professional Member of the IEEE and the ACM. He is a referee of many scientific journals and conferences. His specialization include mobile, grid and wireless computing, and information security.

ADNAN AHMED ARAIN received the M.E. degree in computer systems engineering from QUEST, in February 2012, and the Ph.D. degree in computer science from UTM, in 2015. He is currently an Assistant Professor with the Department of Telecommunication, Quaid-e-Awam University of Engineering, Science and Technology (QUEST), Nawabshah, Pakistan. He is a Professional Member of the Pakistan Engineering Council (PEC) and a regular Reviewer of well reputed ISI-indexed journals. His research interests include routing in ad-hoc networks, security, trust management in ad-hoc networks, and QoS issues in sensors and ad-hoc networks.

KHALED MOHAMAD ALMUSTAFA received the B.E.Sc. degree in electrical engineering, and the M.E.Sc. and Ph.D. degrees in wireless communication from the University of Western Ontario, London, ON, Canada, in 2003, 2004, and 2007 respectively. He is currently an Associate Professor with the Department of Information Systems, the College of Computer Science and Information Systems (CCIS), Prince Sultan University (PSU), Riyadh, Saudi Arabia, where he served as a General Supervisor of the Information Technology and Computer Services Center (ITCS). He has served as the Chairman of the Department of Communication and Networks Engineering (CME) and the Vice Dean of the College of Engineering, PSU. He is currently the Director of the Research and Initiatives Center, PSU. His research interests include error performance evaluation of MIMO communication systems in partially known channels, including adaptive modulation, channel security, text recognition models, and control systems with renewable energy applications as well as features selections and data prepossessing.

TANZILA SABA received the Ph.D. degree in document information security and management from the Faculty of Computing, Universiti Teknologi Malaysia (UTM), Malaysia, in 2012. She has full command on a variety of subjects and taught several courses at the bachelor's and master's degree level. She is currently serving as an Associate Professor and the Associate Chair for the Information Systems Department, College of Computer and Information Sciences, Prince Sultan University, Riyadh, Saudi Arabia. Her primary research interests include medical imaging, MRI analysis, and soft-computing. She has above one hundred ISI/SCEI publications that have around 3145 citations with H-index 37. Her mostly publications are in the biomedical research published in ISI/SCIE indexed. Due to her excellent research achievement, she is included in Marquis Who's Who (S & T) 2012. On the accreditation side, she is a skilled lady in ABET and NCAAA quality assurance. She is the Leader of artificial intelligence and data analytics (AIDA) and an active professional member of the ACM, AIS, AAAI, and IAENG organisations. She is the PSU WiDS (women in data science) ambassador at Stanford University. She received Best Student Award from the Faculty of Computing, UTM, in 2012. She is currently an Editor and a Reviewer of reputed journals and on the panel of TPC of international conferences.

KHALID HASEEB received the Ph.D. degree in computer science from the Faculty of Computing from Universiti Teknologi Malaysia (UTM), Malaysia, in June 2016. He is currently an Assistant Professor with the Department of Computer Science, Islamia College University, Peshawar, Pakistan. His research areas include wireless sensor networks, ad-hoc networks, network security, the Internet of Things, software-defined networks, and sensors-cloud. He is a regular Reviewer of many reputed international journals and conferences.

NAVEED ISLAM received the Ph.D. degree in computer science from the University of Montpellier II, France, in 2011. He is an Assistant Professor with the Department of Computer Science, Islamia College University, Peshawar, Pakistan. His research interests include computer vision, information security, machine learning, artificial intelligence, and wireless sensor networks. He is the author of numerous international journals and conference papers. He is a regular Reviewer of the IEEE, Elsevier, and Springer journals.

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