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Data-Centric Load and QoS-Aware Body-to-Body Network Routing Protocol for Mass Casualty Incident

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ABSTRACT Triage is the most important requirement of Mass Casualty Incident (MCI) where monitoring the vital signs of casualty is the crucial aspect to assess the severity of their current medical conditions. One of the most significant challenges in the triage center is to provide effective remote monitoring of vital signs of mass casualties. To overcome this challenge, there is a necessity to design a dynamic routing protocol that supports data-centric quality parameters such as delay and reliability as well network-specific quality parameters such as throughput and network lifetime over an ad hoc network. The proposed protocol handles data-centric quality parameters by jointly considering the link and node cost of the neighboring nodes. Further, the protocol handles network-specific quality parameters by including load distribution along with buffer management based on the medical condition of the casualties and beaconless routing mechanism. Furthermore, the proposed approach focuses on the transmission of vital signs of critical casualties while also avoiding network congestion and extending network lifespan. The experimentation results show that the proposed protocol is efficient in handling end-to-end delay, the packet transmission ratio of the critical casualties vital signs as compared to the existing state-of-the-art approaches.

INDEX TERMS QoS provisioning, load balancing, network congestion, routing protocols, wireless body area networks, body-to-body networks, mass casualty incident, emergency medical services.

I. INTRODUCTION

Unfortunately, every year there are disasters, and many people are wounded and killed in these incidents. At disaster scenes, the number of casualties normally exceeds the number of medical personnel. In such cases, it is impossible to provide all the casualties with appropriate medical treatment. Therefore, to save as many lives as possible, by evaluating their medical conditions and vital signs, we need to prioritize (triage) the casualties for care and further treatments. While manual triage is the most accurate approach based on clinician evaluation, it can take a long time for a limited group of clinicians to decide the circumstances of many unfair conditions directly. The manual triage process also suffers from other limitations i) Vital signs can not be monitored continuously ii) depending on the present physiological state, they do not indicate present priority iii) triage officers are having trouble gathering the general physiological conditions of the casualties and iv) triage officers spend a lot of time recording physiological circumstances by pen because one casualty is required to triage within 60 secs. This poor condition leads to an increase in mortality number due to the a large number of victims triaged by the limited number of medical professionals.

To efficiently handle mass casualties, it is important to implement technology for real-time tracking and triage of the casualties. Using portable biomedical wireless sensor motes(nodes), the rapid growth of wireless technology enables continuous health monitoring of casualties. These small wearable devices are deployed on a casualty, which is restricted in memory, resources, computing, and communication capabilities. They self-configure to form a networked cluster called Wireless Body Area Networks(WBAN) [1] that can track vital signs such as Electrocardiography (ECG), Temperature, and Respiratory Rate(RR) etc. continuously [2].

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Although previous studies have suggested strategies for accessing real-time patient health data and delivering emergency services[3]. Current studies on wireless health care systems have focused largely on the implementation of a one-WBAN system. However, for real-time triage, which is the process of prioritizing multiple casualties based on the severities of their condition at the Mass Casualty Incident (MCI), accurate and continuous collection of multiple casualties key signs through ad hoc wireless communication is essential.

Hence, the wireless ad hoc networks for handling MCI must provide robust, pervasive communication that is adequate to facilitate the transmission of essential vital signs. The use of ad hoc networks for MCI management must therefore be endorsed by: i) Data-centric QoS: where each vital sign must be presented with the specific QoS criteria based on the casualty's medical condition and the abnormality of the vital signs. ii) Network lifespan: Attempts should be made to reduce power consumption at nodes to maximize the network lifetime. Since ad hoc network nodes used to relay the vital signs of the victims have limited battery power, which must be used wisely to extend the longevity of the network. iii) Network throughput: Owing to the constant monitoring of a large number of vital signs of casualties, traffic is likely to increase. As a consequence, the network becomes congested and collisions take place. Retransmission further aggravates the congestion. This reduces the network throughput and depletes energy at the node unnecessarily. Thus, congestion in the network must be minimal to achieve higher performance.

However, no approach based on prioritizing the data transmission of the casualty through the wireless channel by jointly considering

- Casualties current medical condition
- Quality of Service (QoS) based on vital sign criteria
- and Unique network QoS criteria

has done. We, therefore, suggest a new wireless communication approach that is based on the following facts, i) collects and prioritizes the transmission of vital signs using WBANs, and ii) transfers the acquired casualty data to triage (control) center reliably along with improving the network lifetime along with reducing the network congestion. As a result, in this work, we suggest a new data priority aware, data centric, and network-specific QoS routing protocol for the system involving multiple WBANs to facilitate real-time monitoring and triage of casualties at MCI. We assume that the sensor-based device already diagnoses the casualties' medical condition and thus a casualty is classified into one of the four classes based on the qSOFA [3] medical score process, as shown in Table 1.

The system can track vital signs from multiple casualties on an ongoing basis and prioritizes data transmission effectively based on patient class and QoS criteria for vital signs and network. By quickly identifying the casualties whose physiological conditions are deteriorating, we expect our proposed real-time transmission and triaging system to save many lives.

TABLE 1. qSOFA score and corresponding clinical criteria [3].

qSOFA Score	Severity Level	Clinical Criteria
qSOFA - 3	High	GCS <14 AND RR >= 22 AND SBP <= 100
qSOFA - 2	Medium	GCS <14 AND SBP <= 100
qSOFA - 2	Medium	RR >= 22 AND SBP <= 100
qSOFA - 1	Low	GCS <14 OR RR >= 22 OR SBP <= 100
qSOFA - 0	Not Severe	GCS >= 14 AND RR <22 AND SBP >100

TABLE 2. Abbreviations used in the system definition and construction.

Abbreviation	Description
MCI	Mass Casualty Incident
QoS	Quality of Service
WBAN	Wireless body area network
qSOFA	Quick Sequential Organ Failure Assessment
BBN	Body-to-Body Network
CC	Control Center
RREQ	Route Request packet
CP / Cri	Critical Packet
DP / Del	Delay sensitive Packet
RP / Rel	Reliability sensitive Packet
BE / Best	Best Effort Packet
Lk	Link
Pth	Path
Cst	Cost
Pkt	Packet
Cur	Current
Trf	Traffic
Pri	Primary
Sec	Secondary
Nd	Node
$Nb\_lst(i)$	List of neighbors for Node 'i'

Table 2 lists the abbreviations that are used in the proposed system definition and construction. The remainder of this paper is structured as follows. In section 2, we describe the related work. Then, Section 3 presents the proposed routing protocol. In Section 4, experimental results demonstrating the quality of the proposed protocol is presented. Finally, we conclude this paper with a summary and some future remarks.

II. RELATED WORK

Related work is divided into two sections which are QoS aware routing protocols for WBAN, and WBAN for remote monitoring in an emergency scenario. First Section relates to characteristics of QoS-aware routing protocols. Second Section provides the application of WBAN for an emergency medical scenario.

A. QoS AWARE ROUTING PROTOCOLS IN WBAN

Elhayatmy *et al.* [4], and Salayma *et al.* [5] have reviewed the issues regarding reliability and fault tolerance as they are the main requirements while carrying the critical data related to human life through the network. Hammood *et al.* [6] have proposed a cooperative method to transmit the emergency data reliably in WBAN. Rajendran *et al.* [7] have proposed an ant-colony approach to determine the shortest path to reliably transmit an emergency message to the control center. Also, to enhance the lifetime of the network. Nepal *et al.* [8] and Dangi *et al.* [9] have proposed a modified MAC protocol to handle the emergency data and ZigBee MAC protocol to transmit the normal data within the hospital using WBAN.

Manickavasagam *et al.* [10] have proposed an optimal packet routing based on the greedy algorithm in the transmission of emergency data. The optimal selection of the forwarding node is based on the forwarding node's propagation delay and available bandwidth. Ibrahim *et al.* [11] have proposed a linear programming method based energy-efficient routing protocol to transmit the medical data by focusing on reliable and delay requirements during transmission of the emergency data.

Awan *et al.* [12] have proposed a packet priority-based routing protocol for the WBAN. Emergency packets are routed by considering node energy and reliability parameters. Normal packets are routed by considering residual energy, and congestion on the forwarder node. khuhro *et al.* [13] have applied the reinforcement learning technique for the dynamic routing protocol. Each node individually computes the next hop based on residual energy, queuing delay, link reliability, and the minimum distance to the next node. The reward function depends on the above-mentioned QoS parameters. Anwar *et al.* [14] have proposed a routing protocol for WBAN, which identifies the best next-hop based on node energy, hop counts, link efficiency, and distance to the coordinator node. They have not considered the packet priority. Vetale *et al.* [15] have proposed QoS aware routing protocol for WBAN by considering four types of packets namely critical, delay-sensitive, reliable packets, and normal packets. The protocol finds the suitable best path based on the QoS parameters like path loss, link reliability, link delay, and temperature of the node.

Kuma and Raj [16] have proposed a QoS routing protocol for WBAN to support the transmission of delay-sensitive packets. The next hop is selected based on the queuing, transmission, propagation, and processing delay of the neighbor node. Wang *et al.* [17] have proposed a cross-layer routing protocol based on link quality prediction. The proposed link quality estimation is based on historical and current predicted values. Whenever the predicted link quality value is more than the standard value then the transmission power of the node is reduced to save the node energy. Further, high prioritized data is routed by combining increased transmission power and random back-off time. Elhadj *et al.* [18] proposed cross-layer routing protocol for WBAN. They have categorized medical data as emergency data, delay-sensitive data, and normal periodic data. MAC frame structure is modified and back-off time is identified based on the priority of the data by giving importance to the emergency data. In route establishment phase path is identified based on data priority and MAC slot. The protocol ensures low delay and reliability of the emergency data. X. Liang *et al.* have designed a reinforcement learning-based QoS-aware routing protocol (RL-QRP) using geographic information and a distributed Q-learning algorithm [19], wherein the optimal routes can be identified through experiences and rewards without maintaining the network state information. They have considered End-to-End delay and packet reception rate QoS requirements.

Razzaque *et al.* have proposed QoS-aware multi-objective routing protocol to support traffics in WBAN [20]. The modular approach of the protocol mainly considers reliability and delay QoS metrics. The protocol uses a multi-objective ''Lexicographic Optimization'' (LO) approach to balancing the trade-off between node energy and packet progress towards the destination while selecting the next hop along the path. Khan *et al.* [21] have proposed energy and QoS-aware routing protocol for the indoor hospital management system to display the patient's data on a particular Medical Display Coordinator (MDC). The protocol handles three categories of data namely ordinary, delay-sensitive, and reliability sensitive, and maintains a different path for each category of data concerning individual MDC. Djenouri *et al.* have proposed QoS and geographical routing protocol for Body Area Network (LOCALMOR) [22]. The protocol categorizes the data as critical, reliable, delay, and normal. Different modules are used to handle each category of data. Reliability is achieved by blindly duplicating the packets towards primary and secondary sinks.

Muhammad Mostafa *et al.* have proposed QoS and Thermal aware routing protocol for Body area networks [23]. A modularized approach is used to transmit critical, delay, reliable, and normal packets. The scheme does not differentiate between critical and delay-sensitive packets while scheduling since the scheme maintains only two queues (Delay and reliability sensitive Queues). Anjum *et al.* have proposed Packet Priority and Load aware MAC Protocol for QoS Provisioning in Body Sensor Networks [24]. The Scheme schedules the transmission based on the packet priority, such as Critical, Delay driven, Reliability driven, and Ordinary data packets. MAC protocol structure is modified based on the traffic load at the node. Bhandari *et al.* suggested a data priority aware MAC protocol wherein the CAP channels are divided into four phases and channel allocation is determined by contention [25]. The emergency-based biomedical sensors, access to all phases of the CAP period. Non-medical data, on the other hand, have been denied access to the dedicated emergency data channels. Ababneh *et al.* have proposed adaptive routing and bandwidth allocation protocol for the Body area network [26]. The protocol selects the shortest and energy-efficient path for the transmission of emergency data. Bandwidth is allocated based on the priority of the packet. Yaghmaee *et al.* have proposed a dynamic prioritization of vital signs by the central server based on the type of vital signs such as ECG, BP, HR(Heart Rate), and ST(Skin Temperature) [27]. The authors have performed congestion control at the relay node by assigning different bandwidths to the child node (i.e WBAN coordinator) based on the congestion level of the relay node and the priority of child nodes.

Liang *et al.* have designed a QoS-aware routing protocol for biomedical sensor networks to provide QoS support and prioritized data routing service in the network using a cross-layered modular approach [28]. The protocol provides feedback on network conditions to user applications so that the application service level can be adapted to obtain the highest robustness and adaptability. The designed framework is suitable for small-scale networks and performs sound in terms of reliability and latency. Mkongwa *et al.* [29] have proposed a two-stage cross-layer QoS aware routing protocol for WBAN. The protocol improves the performance parameters by adjusting the contention window and back-off mechanisms in the MAC layer. The result shows the improvement in network throughput, packet reception rate, energy efficiency, and network lifetime. However, the authors have not categorized the data as critical and non-critical and thus not considered data-centric routing that can provide differentiation in route selection between the different category of data packets.

Zuhra *et al.* [30] have proposed a multi-constraint, QoS-aware intra WBAN routing protocol for WBAN's healthcare application to reduce end-to-end latency, packet drop ratio, and retransmission rate while transmitting critical data. The authors combined link latency, link delivery ratio, and link interference ratio metrics to discover the optimal route. Authors have not focused on network lifespan which is crucial for handling transmission of vital signs of mass casualties.

Faheem *et al.* [31] have proposed a multiobjective routing protocol for BASNs-based IoT healthcare applications. The proposed scheme minimized local search problems in BASNs by using a novel, multiobjective lion optimization mating architecture to find the best routing paths between the source and the destination. Their results show better performance in terms of high packet transmission ratio, low latency, packet error rates, and network energy usage, at the cost of data redundancy. The authors do not support differentiated services for vital sign transmission based on vital sign priority.

Random Contention-based Resource Allocation (RACOON) MAC protocol [32] is designed to support the QoS for multiple mobile wireless body area networks (WBANs). It uses two separate channels: one for inter WBAN, to exchange the resource negotiation messages between the WBANs, and the other channel is for intra WBAN, to transmit polling messages and data packets within a WBAN. They have considered inter-BAN interference and inter-BAN priorities. Inter-coordinator negotiation is an iterative bandwidth control scheme based on the total number of emergency sensor nodes. RACOON provides improved delay performance and power control though, it does not address the reliability and throughput performance parameters.

Most of these routing protocols are designed to handle data transmission within a single WBAN. Although, they have supported the transmission of the emergency data, few works such as [8], [9], [16], [33] have supported only delay requirement for the transmission of emergency data. There are few more works in single WBAN that have supported reliability requirements along with the delay support for the emergency data however they have not considered the network congestion control. Table 3 shows the protocols focus on data-centric and network-specific QoS in the transmission of medical data.

B. WBAN FOR REMOTE MONITORING AT EMERGENCY SCENARIO

Arbia *et al.* [34] have designed an IoT-enabled end-to-end emergency and disaster relief system that focus on reliability issues of data transmitted between the control center (CC) and rescuers. The system is evaluated by end-to-end delay and throughput. Ray and Turuk *et al.* [35] have proposed a wireless ad hoc communication framework that includes three protocols namely, multi-channel MAC protocol, multi-path routing protocol, and topology management scheme. The purpose of the multi-channel MAC protocol is to alleviate the congestion problem, improve throughput, and reduce the packet transmission delay. Multi-path routing protocol provides reliable communication and prolongs the network lifetime at the post-disaster scene. Arbia *et al.* [36] have proposed a beaconless routing protocol for two-way data transmission between rescuers and CC, where WBAN is deployed on the rescue team members at the disaster. The protocol selects the optimal route based on path delay and path link quality. The protocol may select the same shortest path leading to an imbalance in node energy consumption.

Hamida *et al.* [37] have designed a ubiquitous wireless communication and monitoring system enabling rescue and life-critical operations in a post-disaster scenario. The work adapts existing BAN protocols to B2B networks to improve the network performance parameters like a network lifetime, scalability, and interoperability between multiple operating WBANs. Further, they aimed at cross-layer protocol design to support diverse application data rates and QoS. George *et al.* [38] have proposed a topology-aware routing protocol using a multi-channel concept called Distress-Net. Distress-Net integrates different types of networks formed in a post-disaster scenario. WBAN is deployed on responders to monitor their health status during rescue operations. A mobile node called VehicleNet forwards the consolidated WBAN data towards the CC. VehicleNet avoids network partition. DistressNet uses two types of Routing: an on-demand routing scheme to adaptively balance energy efficiency and E2E delay-based routing for the transmission of critical messages. Using mobile VehicleNet nodes, safety-critical messages are flooded from the network core to disconnected networks.

Silvia *et al.* [39] have proposed a wearable object system for the remote monitoring of vital signs by health professionals. The device uses a photoplethysmograph(PPG) to obtain heart and respiratory rates from patients. A method has been proposed to infer the number of breaths per minute from the PPG signal. Joao *et al.* [40] have presented a solution to improve clinical triage with a network of Wireless Sensor Tags based on pulse oximeters followed by automated clinical analysis. A central unit monitors these readings and coordinates a first aid team, providing updated information on clinical status and patient location, if a critical condition is identified. Hussain *et al.* [41] have proposed a people-

TABLE 3. Comparisons of QoS-aware routing protocols in WBANs.

Type of the Network	QoS support	Type of Data	Congestion Support	Network Lifetime
Single WBAN	Reliability and Delay [6]	Emergency and non-emergency Data	[12]	[11], [12], [17] [7], [20], [33] [21], [22], [26]
	Delay and Reliability [7]	Emergency data		
	Modified MAC protocol with only Delay support [8]	Emergency and Normal data		
	Propagation delay and Available bandwidth-based next hop selection [10]	Emergency and Normal data		
	Modified MAC protocol for emergency data transmission with only delay support [9]	Emergency and Normal data		
	Delay and reliability consideration for the Emergency data, Energy and congestion consideration for the normal data [12]	Emergency and Normal data		
	Node energy, link efficiency and hop count [14]	No data priority		
	Link reliability, link delay, and temperature of the node [15]	Emergency, Reliable, Delay and Normal data types		
	Queuing, transmission, propagation, and processing delay of the next-hop [16]	Delay sensitive and Normal data types		
	Cluster-based transmission for normal data and direct transmission for emergency data [33]	Emergency and normal data		
	Increased transmission power and random back-off time modification for emergency data transmission [17]	Emergency and Normal data		
	MAC frame structure is modified to support delay and reliability for the Emergency data [18]	Emergency, Delay, and Normal		
	Delay and Reliability support [20]	Critical, Delay, reliable and Normal data		
	End-to-End delay, Duplicate paths, and node energy parameter-based path support for the delay, reliable and normal packet transmission rep. [21]	Delay, reliable and Normal		
	Multi-sink single path for reliability, Packet velocity for delay-sensitive and node energy for the normal packet [22]	Emergency, Reliable, Delay and Normal data types		
	Based on packet types MAC frame structure and Back-off values modified [24]	Emergency, Reliable, Delay and Normal data types		
	Emergency data is transmitted using energy-efficient shortest path along with bandwidth support [26]	Emergency and Normal data		
Multiple WBANs	Channel allocation based on the priority of the WBAN coordinator [32]	Patient priority is based on the number of sensors sending the abnormal data in a WBAN	DLQoS, [27]	DLQoS
	Multiple copies for Reliability, End-to-end delay for Delay and Energy based path for Normal data [21]	Reliable, Delay and Normal Data		
	Bandwidth allocation based on the priority of the patient i.e, each WBAN [27]	Emergency and Normal Patient		
	Proposed Routing protocol (DLQoS)	Critical, Delay, reliable and Normal data		

centric sensing framework for the healthcare of elderly and disabled people and provide them with service-oriented emergency response in case of abnormal health conditions. They focused on three aspects: a) context manipulation from the mobile device in a people-centric environment; b) emergency response using context base information, and c) modeling mobile context sources as services.

Sung and Chang [42] have developed a novel remote health care system based on Wireless Sensors Network System (WSNs) and Radio Frequency Identification (RFID) technologies. Improved Particle Swarm Optimization (IPSO) is applied to build a personal physiological signal sensing system based on persons' age which finds abnormality in the vital signs. Physiological changes are identified at any time via a self-health examination, promoting early diagnosis and treatment. The IPSO scheme is used to increase the efficiency and accuracy when searching for at-risk groups and the system informs medical personnel immediately.

Lamprinakos *et al.* [43] have integrated vital signs monitoring (Tele-health) with behavioral analysis based on home care sensors (Telecare) to follow-up the patient's health status based on a set of monitored parameters per disease. A key aspect of the platform is its Service Oriented Architecture middle-ware that collects data from heterogeneous Telecare and Tele-health gateways and provides the upper service layers with a unified and standards-compliant message. Salman *et al.* [44] have considered multi-sources: vital sign sensors and text-based inputs from wireless and pervasive devices of Wireless Body Area Network. The proposed framework is used to improve the health care scalability efficiency by enhancing the remote triaging and remote prioritization processes for the patients based on the data fusion method. They have not considered the patient priority during the vital sign transmission.

Martín-Campillo *et al.* [45] have compared and contrasted the efficiency of the most significant opportunistic routing protocols in realistic disaster scenarios. They have selected four opportunistic routing protocols for emergency scenarios: Epidemic, MaxProp, PRoPHET, and TTR and evaluated based on different values of the number of nodes, number of messages, and message size, to evaluate their impact on the performance. Xiong *et al.* [46] have designed the comparative study to examine the potential applications of the regional telemedicine network to disaster response. They aimed to (1) provide a conceptual framework to incorporate telemedicine into an emergency response; and (2) determine where it is appropriate to apply quantitative analysis to improve the effectiveness of disaster response activities, potentially measured through treatment capability and time to definitive treatment factors. Their result shows that the performance of the telemedicine-enhanced medical response process is superior to that of the base process in terms of patient mortality.

Cicero *et al.* [47] have studied to determine the feasibility of telemedicine in disaster triage and to determine whether telemedicine affects the accuracy of triage or the time needed to perform triage. Alam and Hamida [48] have made use of WBAN in the disaster recovery process, to monitor the health condition of the rescue team members. Here, WBAN is fitted on rescue members to collect information regarding their health status, movement, and location inside damaged or harsh environments during the rescue operation. Additionally, off-body sensors are used to collect environmental conditions during the disaster rescue process, such as the presence of heat, lightning, fire, toxic gases, smoke, etc., for the ongoing rescue task like search, recovery, evacuation, assistance, etc. Further, using the collected sensor information, the decision-makers at the remote control center will be able to collect real-time and accurate information to better anticipate and manage life-critical and rescue operations.

Olivia *et al.* [49] have discussed the following requirements of the routing protocol deployed at MCI. The transmission of mass casualty vital signs over an ad-hoc network is congested, resulting in packet loss and high node energy consumption. As a consequence, prioritizing the transmission of critical casualty vital signs across the network is crucial. Furthermore, extending the life of the network used to relay the vital signs of the casualties is important. Also, the paper discusses the limitations of the Wireless Sensor Networks, MANET, and routing protocols of public safety networks to carry the vital signs of the casualties at MCI.

Meharouech *et al.* [50] have demonstrated how the single WBAN idea evolved into a cooperative network of multiple WBANs, resulting in the Body-to-Body network (BBN) concept. Following that, current WBAN proposals are addressed, with a focus on candidate WBAN protocols that could be modified and used in BBN's. The authors focused on four intrinsically connected axes that are critical for BBN design namely, the storage and privacy issues, wireless propagation between humans carrying wearable devices, the interference, the heterogeneity of BBN devices, and traffic.

Table 4 shows the goals of the protocols designed for handling the public emergency scenario. Some works focus on the transmission of the medical data in emergency scenarios however, they have not focused on decreasing network congestion and improving network lifetime as they are the main network QoS requirement while handling mass casualty incidents. Also, they have not considered the medical

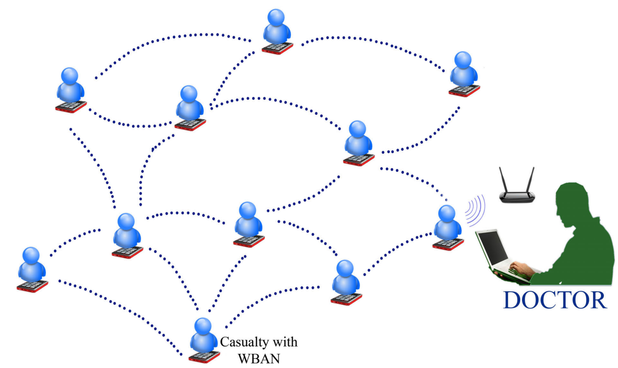


FIGURE 1. Body-to-Body network (BBN) architecture at MCI.

condition of the patient while prioritizing data during transmission. From this summary, we can conclude no work focuses on vital sign monitoring of the mass casualties for real-time triaging and prioritization. Furthermore, there is no emphasis on transmitting the vital signs of mass casualties while considering QoS based on the medical condition of the casualty and focusing on improving network lifespan by eliminating network congestion.

III. PROPOSED ROUTING PROTOCOL FOR MASS CASUALTY INCIDENT

The proposed routing protocol for Mass Casualty Incident involves efficient handling of the casualties at the incident location by real-time monitoring of the casualties using WBAN.

As shown in Figure 1 the proposed Mass Casualty Incident management framework includes ad hoc BBN setup and triage center or control center which act as a sink node. At sink node medical professionals remotely and continuously monitor the health condition of the casualties for triaging. The BBN ad hoc network is formed by deploying WBAN on each victim. Hence, each victim has the BAN coordinator and acts as a source node. A single BAN coordinator periodically generates the vital sign readings and with the help of neighbor BAN coordinators forwards the data towards a single sink. Since WBAN is deployed on the casualty hence static ad hoc network is considered. Each WBAN has sensors to collect vital signs namely SBP (Systolic Blood Pressure), GCS (Glasgow Coma Scale), and RR (Respiratory Rate). Collected vital signs are processed by the WBAN coordinator using a medical score called qSOFA to find the current medical condition of the casualty. Based on the severity level of the casualty shown in Table 1, anomalies in the sensed medical data and characteristics of the data [20] (such as delay or reliability requirement of the data during the transmission), the sensed data are categorized as critical, delay-sensitive, reliability sensitive and best-effort data.

Considering the data categorization, the proposed routing protocol supports data-centric QoS (such as critical, delay, reliability, and best effort) along with the network-specific QoS. For the transmission of critical casualty data, network-specific QoS such as network lifetime and network

TABLE 4. Emergency network design goal.

Paper	Type of data	Design Goal
[35]	Non-medical data	To mitigate the congestion along with reduction in transmission delay, multi path reliability support to improve the network throughput
[36]	Both types of data using BBN	Optimal route construction based on path link quality and path delay
[34]	Medical data from the Rescue members using BBN	Focused on network throughput, end-to-end delay and link quality during transmission
[38]	WBAN on rescuers to monitor medical data	Avoids network partition, End-to-end delay, balance energy efficiency, reliability using transmission of multiple copies
[40]	Medical data from the casualties	Sensor network based continuous monitoring of the casualties for the clinical triage process
[44]	Medical data from the multiple patients	Remote triaging and prioritization is done at the server side.

throughput are essential. One way to handle the network-specific QoS is by reducing the data transmission of the unimportant data and balancing the traffic load in the network. Focusing on these requirements for the routing of the casualties data at MCI the proposed routing protocol has the following contributions:

- Routing protocol has the Beaconless Route discovery feature that helps in improving network lifetime
- Data priority aware Scheduling that supports efficient handling of transmission of the critical casualties data compared to non-critical ones
- Data priority and data characteristics aware data-centric QoS support
- Network-specific QoS support using traffic Load distribution and Traffic load aware buffer management features based on the predicted load in the network

In the next section, the proposed QoS-aware routing protocol to transmit the vital signs of the casualties towards the control center is discussed.

A. PROPOSED ROUTING PROTOCOL MODULES

The main aim of this research work is to improve the throughput and low delay support for transmission of the critical casualty's data compared to the non-critical ones along with improving the lifespan of the network. The lifespan of the network is increased by reducing the energy consumption of the source nodes in a network. Nodes consume more energy for the data and control packet transmission rather than processing tasks. Hence, this research work tries to reduce the data as well as control packet transmission in the network using proposed adaptive buffer management and beaconless routing mechanisms [36]. Adaptive buffer management mechanism reduces the transmission of low prioritized data (i.e data belongs to non-critical victims) in the network, and the Beaconless routing mechanism eliminates the classical Hello packet broadcasting by all the source nodes in the network. These data and control packet reduction along with the load distribution mechanism avoids network congestion. Avoiding network congestion reduces packet collision thus reduces packet retransmission. Reduction in Packet retransmission reduces the transmission delay, avoids the node's energy consumption along with an increase in network throughput and packet reception rate. Finally, the prioritized data scheduling module along with the support of dropping low prioritized data, and load distribution mechanism helps in increasing the packet reception rate and the low delay support for the critical casualty's data transmission, which is the data-centric specific QoS support.

Figure 2 shows the modules and their interconnections in our proposed beaconless routing protocol which is referred to as 'Data-centric Load and QoS aware (DLQoS)' protocol. The DLQoS consists of a Data priority aware packet classifier, scheduler, Data-centric, and Network-specific QoS routing service module, QoS aware load distribution module, and Load and QoS aware adaptive buffer management module. The process flow in Figure 3 shows the flow between the DLQoS routing protocol modules along with the flow of the routing process. Each coordinator node receives either a DATA or RREQ packet, DATA packet may be from the application layer or the neighbor node. Upon receiving the DATA packet from the application layer node classifies the data as critical or delay-sensitive or reliability sensitive or best-effort packet according to the data categorization criteria given in Table 5. Categorized data are scheduled for transmission based on their priority using the scheduler module. Upon receiving the RREQ packet, the node identifies the two best next hops (primary and secondary next hops) for each data type by the Data-centric and Network-specific QoS routing service module. If identified hops are better than stored hop information then newly identified hops are updated in the routing table and primary next-hop information of all the data types are communicated to its neighbors using rebroadcasting of the RREQ packet. Further, for each data type, transmission load distribution information across primary and secondary hops using the QoS aware load distribution module is identified and stored in the routing table. The Load and QoS aware traffic reduction module finds the ratio of non-critical data to be dropped based on the predicted total data transmission load and predicted critical data transmission load at the node. Finally, the adaptive buffer manager drops the non-critical packets based on the drop ratio identified by the traffic reduction module. These modules are detailed in the following subsections.

B. DATA PRIORITY BASED PACKET CLASSIFIER AND SCHEDULER

The proposed DLQoS routing protocol focus on the efficient transmission of the vital signs of casualty during MCI.

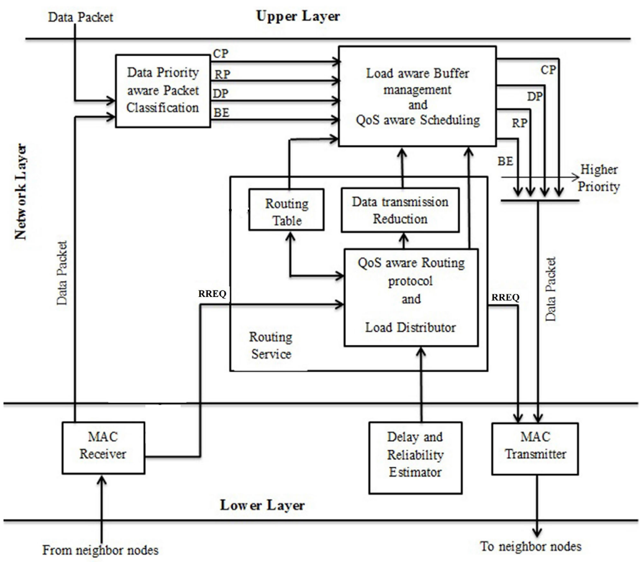


FIGURE 2. Data-centric Load and QoS-aware routing architecture.

At MCI, it is of utmost importance to give preference to the transmission of critical casualty vital signs compared to the rest of the casualties. Consider a situation where a critical casualty's vital sign is dropped or delayed on the way to the control center where health care professionals are prioritizing the casualties for further treatment. In this situation, professionals are unable to identify the criticality of the casualty which might lead to serious consequences like the death of the casualty. Hence, prioritizing the casualty's vital signs during transmission based on the clinical condition of the casualty is important. Further, vital signs of a casualty with a moderate clinical condition need differentiated services based on their data characteristics [20] for example, RR data requires reliable transmission without delay bound. Also, some data of the normal casualty does not require reliable or delay-sensitive transmission provided their values are within their normal range. Hence, based on the casualty's medical condition and vital sign's characteristic, data packets are categorized into four types which are detailed as follows: critical packets which caries critical casualty's vital signs; delay-sensitive packets to carry delay-sensitive vital signs; reliability sensitive packets to carry reliability sensitive vital signs. Finally, the best effort packets to carry normal casualty's vital signs. Further, corresponding QoS support is given for the data transmission known as data-centric QoS support. In this work, the medical condition of the casualty is categorized using clinical criteria given by the qSOFA medical score as shown in Table 1. That is, if the qSOFA score for the casualty is three then the sensed data of those casualties are categorized as critical; if the score is two then those data which are abnormal are treated as critical, and casualty with qSOFA score one, their RR and SBP data is provided with reliability support [34] and their abnormal data is treated as delay-sensitive data. Vital signs of the casualty whose score is zero are treated as best-effort packets. Table 5

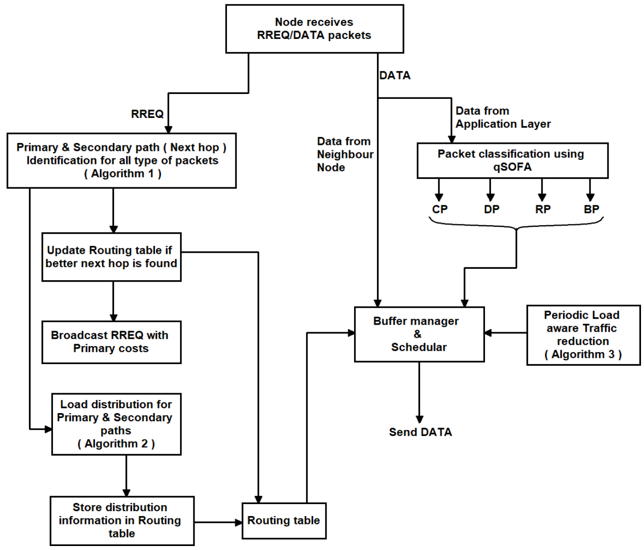


FIGURE 3. Process flow diagram for Data-centric Load and QoS aware routing.

TABLE 5. QoS support according to qSOFA criterion.

Data category	QoS Support
Casualties with qSOFA - 3	Delay and Reliability
Abnormal data of casualties with qSOFA - 2	Delay and Reliability
RR and SBP of casualties with qSOFA - 1	Reliability
Abnormal data of casualties with qSOFA - 1	Delay
Casualties with qSOFA - 0	Best effort

shows the different QoS support based on the above data category.

Further, the order of priority among these four types is defined as follows, critical packets have the highest priority followed by delay and reliable and best-effort packet with the lowest priority. The scheduling module makes use of data priority during the scheduling process. Scheduling is achieved by having a different prioritized queue for each type of traffics. There are four queues each for different data types. Queues are served based on their priority order, i.e critical packet queue is served first followed by delay-sensitive packet queue and then followed by reliability sensitive packet queue and at last, low prioritized normal packet queue is served.

C. DATA-CENTRIC AND NETWORK-SPECIFIC QoS AWARE ROUTING SERVICE

The routing protocol proposed in this work is for handling medical data transmission at MCI. At this incident, vital signs of critical casualty have to be sent immediately to the control center to avoid any disagreeable situation like the death of the casualty. This scenario can be better handled by the proactive routing approach compared to reactive routing. Reactive routing protocol consumes time at each node while forwarding the critical data since the node has to find out the best next-hop and then forward the critical data. Hence this work proposes QoS aware optimal path construction using a beaconless proactive routing approach. Optimal path construction considers both data-centric and network-specific

QoS support. Data-centric QoS identifies the best path suitable for each type of packet (Critical, Delay, Reliability, and Best effort), based on the priority and characteristic of the packet to be forwarded in the network. Network-specific QoS like increasing network lifetime and network throughput which is a very important concern of the network deployed for the MCI can be attained by avoiding network congestion and balancing the network traffic load. Thus, DLQoS the protocol identifies the best two optimal paths (primary path and secondary path respectively) for each type of packet by considering data-centric and network-specific QoS as given in Algorithm 1. The Protocol makes use of Dijkstra's algorithm to compute two optimal paths for each type of packet based on the path cost. The optimal path computation for each packet type which is computed at each node is detailed as follows.

The periodic optimal path construction process is initiated by the sink node by forwarding RREQ packets to its neighbors. Pathfinding initiated by the sink node is better for the considered network model compared to pathfinding initiated by the source node. Since all nodes in our network model are source nodes and pathfinding initiated by the sources generates more number of control packets called HELLO packets, thus overwhelm the network with more loads. The proposed routing is called beaconless since it avoids periodic broadcasting of HELLO packet initiation by all the source nodes thus helps in the reduction of network traffic and energy consumption. The routing process followed by the DLQoS is as follows, the sink node broadcasts periodically RREQ packets with an incremented sequence number. The neighbor node upon receiving the RREQ packet does the best path computation and updates its routing table, and then it rebroadcasts the RREQ again. The RREQ packet header contains the primary path cost values for four categories of packets. Once the RREQ packet is received by a node, the first step is extracting four primary cost field values. Second, computing the path costs for all four categories of packets using the extracted primary cost values and the link cost values. This newly computed value will give the path costs through the neighbor node from which the RREQ message is received. Third, comparing the computed values with the recorded primary and secondary corresponding cost values in a routing table. If the new values are better than the corresponding recorded values then those values are updated in a routing table along with the corresponding next-hop value. Finally, optimized primary cost values are updated in the RREQ and rebroadcast to its neighbors. Thus, the RREQ packet forwarded by each node in the network has its primary path's cost towards the control center for all types of packets. Each node in the network after receiving RREQ packets from its neighbors computes its path cost towards the control center through each neighbor. Then identifies the best primary and secondary (neighbors) paths for each type of packet based on the computed path cost.

The Generalized measurement for path cost at node N_i through node N_j towards control center is computed for each type of packet is given as follows,

Algorithm 1 Primary and Secondary Path Computation at Node N_i for Each Packet Type

INPUT: $RREQ$ packet from N_j, $\forall N_j \in Nb\_lst(i)$
Each $RREQ$ packet has the best path cost for all 4 types of packets
OUTPUT: For each packet type primary and secondary next-hops along with best path cost.
procedure Data-centric and Network-specific QoS aware Optimal Path Finding
  for each $Pkt\_Type \in \{Del, Rel, Cri, Best\}$ **do**
    for each N_j, $\forall N_j \in Nb\_lst(i)$ **do**
      Measure $Lk\_Pkt\_Type_{i,j}$ as shown in equations (3), (5), (7), (9)
    end for
  end for
  for each $Pkt\_Type \in \{Del, Rel, Cri, Best\}$ **do**
    for each N_j, $\forall N_j \in Nb\_lst(i)$ **do**
      Read $Pth\_Pkt\_Type_j$ from RREQ packet received from Node N_j
    end for
  end for
  for each $Pkt\_Type \in \{Del, Rel, Cri, Best\}$ **do**
    for each N_j, $\forall N_j \in Nb\_lst(i)$ **do**
      Measure $Pth\_Cst\_Pkt\_Type_{i,j}$ as shown in equation (1)
    end for
  end for
  for each $Pkt\_Type \in \{Del, Rel, Cri, Best\}$ **do**
    Select the Primary and Secondary Hops, as shown in equations (11), and (12) respectively
  end for
  for each $Pkt\_Type \in \{Del, Rel, Cri, Best\}$ **do**
    $Pth\_Cst_i.pkt_{type}$ = Path cost through Primary Hop
    Include $Pth\_Cst_i.pkt_{type}$ in $RREQ$ packet
  end for
  Node N_i Rebroadcast $RREQ$ packet
end procedure

$$Pth\_Cst\_Pkt\_Type_{i,j} = \begin{cases} Lk\_Del_{i,j} + Pth\_Del_j & for\ Del \\ Max(Lk\_Cri_{i,j}, Pth\_Cri_j) & for\ Cri \\ Min(Lk\_Rel_{i,j}, Pth\_Rel_j) & for\ Rel \\ Max(Nd\_Load_i, Pth\_Load_j) & for\ Best \end{cases} \quad (1)$$

where $Lk\_Pkt\_type_{i,j}$ is link cost between node N_i and N_j for a particular type of packet, where Packet type is any one of the critical, delay, reliable, or best-effort type. $Pth\_Pkt\_type_j$ is a cost of the best path of the neighbor node N_j (from the control center) computed over all N_j's neighbors. The best path cost computation at node N_i is defined as follows for a different type of packets.

For delay-sensitive packet transmission a path is identified based on summation of link delay cost $Lk\_Del_{i,j}$ as shown in equation (2), over all the links (i, j) along the path. Delay cost at node N_i over link to neighbor N_j, $Lk\_Del_{i,j}$ is computed using elapsed time when an ACK is received from a node N_j as a response to a transmitted delay-sensitive data packet from node N_i [51]. Weighted Moving Average (WMA) formula is used recursively to compute node delay over a past 'T' interval of time as shown in equation (3).

The smoothing factor w can take a value between 0 to 0.4, and in this work, we have considered w=0.2.

$$Pth\_Del_j = \sum_{\forall (j,k) \in path\ links} Lk\_Del_{j,k} \tag{2}$$

$$Lk\_Del_{i,j} = \begin{cases} (1-w) * Lk\_Del_{i,j,old} \\ + w * Lk\_Del_{i,j,cur} \end{cases} \tag{3}$$

In case of reliability sensitive packet transmission, reliability of the path along the neighbor N_j is given as follows,

$$Pth\_Rel_j = \min_{\forall (j,k) \in path\ links} Lk\_Rel_{j,k} \tag{4}$$

where, reliability of the link (j, k), $Lk\_Rel_{j,k}$ is computed using Link Quality Indicator (LQI) as shown in equation (5). The link quality indicator is an indication of the quality of the data packets received by the receiver. In this research work, LQI is a Received Signal Strength Indicator (RSSI) value which is an available link parameter obtained from the physical layer into the network layer during the data reception. The LQI value obtained at the network layer is converted between 0 to 1 using predefined LQI maximum and minimum values of the simulator.

$$Lk\_Rel_{j,k} = LQI_{j,k} \tag{5}$$

For critical data packet transmission, a path with both delay and reliability support has to be identified. Hence, the path cost for transmitting critical data through neighbor N_j is given as follows,

$$Pth\_Cri_j = \max_{\forall (j,k) \in path\ links} Lk\_Cri_{j,k} \tag{6}$$

where, critical cost for each link, $Lk\_Cri_{j,k}$ is computed as follows,

$$Lk\_Cri_{j,k} = 0.5 * Lk\_Del_{j,k} + 0.5 * (1 - Lk\_Rel_{j,k}) \tag{7}$$

For the transmission of normal packets path is selected based on traffic load over the path to balance the load in the network. The traffic load of the path at node N_i along the neighbor N_j is computed as follows,

$$Pth\_Load_j = \max_{\forall j \in nodes\ along\ the\ path} Nd\_Load_j \tag{8}$$

where, load at node N_j, Nd_Load_j is shown in equation (9) measured using past and current number of packets in the buffer at node N_j

$$Nd\_Load_j = (1-w) * Avg\_Traf + w * Cur\_traf \tag{9}$$

where,

$$Avg\_Traf = \frac{\sum_{t=1}^{T} t}{T} \tag{10}$$

Average traffic is the buffer length computed over the past T number of seconds and Cur_traf gives the current buffer length. In equation (9) 'w' is constant smoothing factor, a number usually between 0 and 0.4. In this work, we use w = 0.2.

At node N_i after finding the path cost for all packet types i,e, $Pth\_Cst_{i,j}.Pkt_{type}$ through its neighbors N_j, node selects first best node as a primary hop and second-best neighbor node as a secondary hop. The selection is based on their path cost. Primary and secondary next hops for all type of packets are identified as follows,

$Pri\_Hop_i = N_k$ where,

$$N_k = \begin{bmatrix} Nd\_Max(Pth\_Cst_{i,j}) & \forall j \in Nb\_lst(i) for\ Rel \\ Nd\_Min(Pth\_Cst_{i,j}) & \forall j \in Nb\_lst(i) for\ not\ Rel \end{bmatrix} \tag{11}$$

and $Sec\_Hop_i = N_l$ where,

$$N_l = \begin{bmatrix} Nd\_Sec\_Max(Pth\_Cst_{i,j}) & \forall j \in Nb\_lst(i) for\ Rel \\ Nd\_Sec\_Min(Pth\_Cst_{i,j}) & \forall j \in Nb\_lst(i) for\ not\ Rel \end{bmatrix} \tag{12}$$

The primary hop is the node with the best path cost and the secondary hop is the node with the second-best path value for each type of packet. Finally, primary path cost is considered as best path cost for particular type of packet, $Pt\_Cst_i.pkt_{type}$. Similarly, the node identifies four best costs one for each packet type, and forwards these four values to its neighbors using the RREQ packet, which in turn performs a similar operation to find the best two paths for all types of a packet and forwards primary path cost as the best path towards its neighbor. The working of path computation is shown in the Algorithm 1.

D. QoS-AWARE LOAD DISTRIBUTION

Along with data-centric QoS support for the medical data, another important requirement of BBN deployed for MCI management system is increasing the lifetime of the network as well as critical casualties data throughput in the network which are called network-specific QoS. These requirements can be achieved by handling data transmission in the network by avoiding network congestion. Network congestion causes data to be retransmitted, wasting node energy and thus reducing the network lifespan. One way to avoid network congestion is through the load distribution technique. In this work, as illustrated in Algorithm 2 load distribution is achieved using primary and secondary optimal paths which are identified by the routing service process as discussed in the Algorithm 1. The load distribution module is executed periodically after the construction of primary and secondary paths. Here, route rigidity for both primary and secondary paths for each packet type is measured using traffic load cost, which is computed using the equation 8 and optimal path cost values of the corresponding path (as shown in Algorithm 2, step number 4 to 16). Finally, using route rigidity value, the load of the path is computed and corresponding traffic distribution is found as shown in the Algorithm 2 (step number 17 to 19).

Algorithm 2 Load Distribution at Node N_i

1: INPUT: Path Cost of primary and secondary paths of all four data types and corresponding path load cost
2: OUTPUT: Load distribution for primary and secondary paths for all type of packets
3: **procedure** Load distribution
4: **for** each $Pkt\_Type \in \{Del, Rel, Cri\}$ **do**
5: **if** $Pkt\_Type = Rel$ **then**
6: $Pri\_Rout\_Rigi = Pri\_Pth\_Load * (1\text{-}Pri\_Pth\_Cst.Rel)$
7: $Sec\_Rout\_Rigi = Sec\_Pth\_Load * (1\text{-}Sec\_Pth\_Cst.Rel)$
8: **else**
9: $Pri\_Rout\_Rigi = Pri\_Pth\_Load * Pri\_Pth\_Cst.Pkt\_Type$
10: $Sec\_Rout\_Rigi = Sec\_Pth\_Load * Sec\_Pth\_Cst.Pkt\_Type$
11: **end if**
12: **end for**
13: **if** $Pkt\_Type = Best\_Effort$ **then**
14: $Pri\_Rout\_Rigi = Pri\_Pth\_Cst.Load$
15: $Sec\_Rout\_Rigi = Sec\_Pth\_Cst.Load$
16: **end if**
17: **for** each $Pkt\_Type \in \{Del, Rel, Cri, Best\}$ **do**
18: $Pri\_Rout\_Dis\_Ratio\_Pkt\_type = 1 - (Pri\_Rout\_Rigi / (Pri\_Rout\_Rigi + Sec\_Rout\_Rigi))$
19: $Sec\_Rout\_Dis\_Ratio\_Pkt\_type = 1 - (Sec\_Rout\_Rigi / (Pri\_Rout\_Rigi + Sec\_Rout\_Rigi))$
20: **end for**
21: **end procedure**

E. TRAFFIC LOAD AND QoS-AWARE ADAPTIVE BUFFER MANAGEMENT

As mentioned in the above section one way to achieve network-specific QoS support is using the load distribution technique. In this work along with load distribution, reduction in the transmission of low prioritized data is also considered to reduce the network congestion thus supporting network-specific QoS. Since packet transmission consumes more node energy compared to processing energy. Thus reducing data transmission is one way to support network-specific QoS like improving network lifetime and reducing congestion thus improving network throughput. In this work, the load and QoS-aware buffer manager of the source node periodically measures the probability of low prioritized packet transmission reduction. The reduction probability is computed using probability of predicted traffic load and predicted critical packets by considering past traffic load over time interval

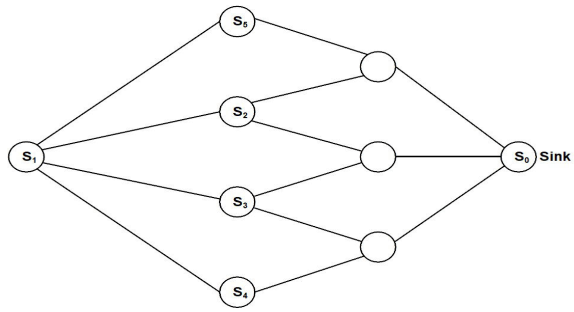


FIGURE 4. Sample BBN with Route discovery at node S1.

'T' seconds as computed in the Algorithm 3 (step number 4 and 5). In step number 9 of the algorithm, the drop ratio which identifies how much percentage of the low prioritized packet has to be dropped from the node buffer is computed, and accordingly, the packets are dropped. Data transmission is reduced only under the scenario wherein, probability of the predicted traffic load is more than 0.6, and the probability of the predicted critical packet is between 0.5 and 0.9. In this work, values are considered based on the assumptions that, traffic load might fall under any one of the three levels i.e low, moderate, and high at any given time and there are four types of packets.

Algorithm 3 Traffic Reduction at Node N_i

1: **procedure** Traffic Reduction
2: $Pred\_Pkts = (1 - \mathrm{w}) * Avg\_Pred\_Traf + \mathrm{w} * Cur\_traf$
3: $Pred\_Cri\_Pkts$: $(1\text{-}\mathrm{w}) * Avg\_Pred\_Cri\_Traf + \mathrm{w} * Cur\_Cri\_traf$
4: $Avg\_Pred\_Traf \leftarrow \frac{\sum_{t=1}^{T} t}{T}$, where t = number of packets in a Queue /sec measured over 'T' seconds
5: $Avg\_Pred\_Cri\_Traf \leftarrow \frac{\sum_{t=1}^{T} t}{T}$, where t = number of Critical packets in a Queue /sec measured over 'T' seconds
6: $Pred\_Traf\_Perc = Pred\_Pkts / Q_{Max}$
7: $Pred\_Cri\_Traf\_Perc = Pred\_Cri\_Pkts / Q_{Len}$
8: **if** $Pred\_Traf\_Perc \geq 0.6$ AND $Pred\_Cri\_Traf\_Perc \geq 0.5$ AND $Pred\_Cri\_Traf\_Perc \leq 0.9$ **then**
9: $Drop\_ratio = Pred\_Traf\_Perc * Pred\_Cri\_Traf\_Perc$
10: **end if**
11: **end procedure**

F. DEMONSTRATION OF ROUTING MECHANISM

Figure 4 depicts a sample BBN. All nodes are source nodes and S_0 is the sink node. The sink node initiates broadcasting RREQ packet periodically, which is received and rebroadcasted by its neighbors. Each node after receiving RREQ packets from its neighbor computes the primary and secondary paths for all types of packets and rebroadcast the RREQ packet along with the computed four primary cost

TABLE 6. Path cost for all type of packets for each neighbor node of S1 node.

Type of Packet	Next hop	Path cost
Delay sensitive	S2	5 ms
Delay sensitive	S3	10 ms
Delay sensitive	S4	8 ms
Delay sensitive	S5	15 ms
Reliability sensitive	S2	0.8
Reliability sensitive	S3	0.2
Reliability sensitive	S4	0.1
Reliability sensitive	S5	0.7
Critical	S2	10.9
Critical	S3	5.5
Critical	S4	7.7
Critical	S5	14.3
Normal Packet	S2	200
Normal Packet	S3	50
Normal Packet	S4	150
Normal Packet	S5	100

TABLE 7. Routing table at node S1.

Packet type	Path	Next hop	Path Cost	Path Load (No. of packets)	Traffic distribution value (%)
Delay	Primary	S2	5 ms	100	0.444
Delay	Secondary	S4	8 ms	50	0.555
Critical	Primary	S3	5.5	150	0.482
Critical	Secondary	S4	7.7	100	0.517
Reliability	Primary	S2	0.8	60	0.833
Reliability	Secondary	S5	0.7	200	0.166
Best effort	Primary	S3	50	50	0.666
Best effort	Secondary	S5	100	100	0.333

values. According to the network scenario given in Figure 4, the primary and secondary pathfinding process at node S1 is initiated after S1 receives RREQ packets from S2, S3, S4, and S5 neighbor nodes. Identifying primary and secondary next-hops for each packet type as given in Algorithm-1 by node S1 is as follows:

Step 1 (Step 5 to 9 of Algorithm-1): S1 computes $Lk\_Del_{S1,j}$, $Lk\_Rel_{S1,j}$, $Lk\_Cri_{S1,j}$, and $Lk\_Load_{S1,j}$ with respect to each node j using Equations (3), (5), (7), (9) respectively, where j = S2, S3, S4 and S5.

Step 2 (Step 10 to 14 of Algorithm-1): S1 reads four primary cost values Pth_Del_j, Pth_Rel_j, Pth_Cri_j, and Pth_Load_j through RREQ packet from neighbor node j, where j = S2, S3, S4 and S5 in this scenario. Node j computes $Pth\_Pkt\_Type_j$ values using Equations (2), (4), (6) and (8) for path delay, path reliability, criticality level of the path and path load cost respectively.

Step 3 (Step 15 to 19 of Algorithm-1): Node S1 computes $Pth\_Cst\_Pkt\_Type_{S1,j}$ with respect to neighbor node j (where j = $S2$, S3, S4, and S5 nodes) for each type of packet using Equation (1). For example the sample values considered for the demonstration is given in Table 6.

Step 4 (Step 20 to 22 of Algorithm-1): With regard to Table 6, S1 selects primary and secondary next-hops for each type of packet based on the path costs. The selected next-hops along with their path cost for eight paths are stored in a routing table of an S1 as shown in Table 7.

Step 5 (Step 23 to 26 of Algorithm-1): S1 includes four primary paths cost values(computed in Step 21) in an RREQ message and rebroadcast it to its neighbors.

TABLE 8. Configuration of parameters.

Deployment	Area	2000 m * 2000 m
	Type	Static and Random
	Number of Nodes	Varies from 10 to 70
Task	Application type	Periodic
	Data Payload (At Application layer)	32 bytes
	Initial Energy	100 Joules
	Traffic type	CBR
Simulation	Time	200 Seconds

Step 6 (Algorithm-2): Table 7 has the column 'path load' which stores the path load along primary and secondary paths for all types of packets at node S1. Path load is computed along each path using the Equation (1) for Best packet type case. Path rigidity value is computed using path load and path cost values along each path (Steps 4 to 16 of Algorithm-2). For all eight paths, the traffic distribution ratio is computed as mentioned in Algorithm-2 (Steps 17 to 20). Table 7 shows the traffic distribution ratio for all the paths of a considered scenario.

The above process is repeated by all the source nodes periodically whenever the sink node sends the RREQ packet. The traffic drop ratio is computed by each node periodically using the steps mentioned in Algorithm-3.

The effectiveness of the proposed routing protocol which is energy efficient along with the data-centric and network QoS support in handling the transmission of casualty's vital sign information at MCI is shown with the help of simulation in the result section.

IV. EXPERIMENT SETUP AND PERFORMANCE ANALYSIS

The performance of the proposed DLQoS routing algorithm is simulated using OMNET++ network simulator and compared with the other two algorithms DMQoS (Data-Centric Multi-objective QoS-Aware Routing Protocol) [20] and ORACE-NET (Optimized Routing Approach targeted for Critical and Emergency Networks) [36]. OMNET++ supports the simulation of the multi-hop wireless network. The configuration of the network parameters is shown in Table 8. Table 9, and 10 shows the dataset for Packet Reception Rate, Delay, Energy and Routing overhead performance metrics.

We simulated a Body-to-Body ad hoc network with one sink which acts as a control center and the rest of the nodes are static source nodes. Source nodes periodically generate the packets. Thus, in a simulation, as the number of nodes increases traffic load is also increased. Hence, we evaluate the impacts of traffic loads in topology on the average end-to-end packet delay and on the average packet reception rate. Table 11 shows the number of nodes and the corresponding traffic load which is considered in this simulation. The first parameter specifies the average end-to-end delay experienced by all types of packets while the second parameter mentions the percentage of the total number of packets received by the sink compared to the total number of packets generated by all the source nodes. Equations for computing average delay (AD) and packet reception rate (PRR) are given in Equation 13 and 14 respectively. Average end-to-end delay is computed as a ratio of total delay experienced by all the

TABLE 9. Dataset for packet reception rate (in %) and delay(in Secs) performance of the protocols.

Figure	Number of nodes	10	20	30	40	50	60	Figure	10	20	30	40	50	60
Figure 5a	DLQoS	97.5	95.8	94	94	92.8	92.3	Figure 5b	0.01	0.06	0.27	0.59	0.8	1.03
	DMQoS	97.6	97	93	92.1	91.9	91.3		0.01	0.07	0.36	0.75	1.1	1.17
	ORACE-NET	97.3	95.7	93.5	92.9	92.1	91.7		0.01	0.05	0.23	0.56	0.72	0.95
Figure 8a	DLQoS	97.5	95.8	95.4	93.6	93	92.2	Figure 8b	0.008	0.07	0.26	0.54	0.71	0.78
	DMQoS	97.3	95.7	93.5	93	92.2	91.7		0.005	0.06	0.25	0.63	0.8	1.03
	ORACE-NET	97.6	96.4	94.1	92.5	92	91.4		0.01	0.08	0.39	0.68	0.96	1.04
Figure 11a	DLQoS	97.5	95.8	94	94	92.8	92.3	Figure 11b	0.005	0.06	0.25	0.5	0.69	0.74
	DMQoS	97.3	95.7	93.5	92.9	92.1	91.7		0.01	0.06	0.25	0.61	0.77	1.01
	ORACE-NET	97.6	97	93	92.1	91.9	91.3		0.01	0.08	0.36	0.66	0.95	0.98
Figure 9a	Reliable Packet	97.6	95.9	94	94	92.8	92.3	Figure 10a	0.01	0.08	0.3	0.62	0.77	0.94
	Critical Packet	97.5	95.8	95.4	93.7	93	92.2		0.01	0.07	0.27	0.55	0.72	0.78
	Delay Packet	97.4	95.9	94.7	93.4	92.8	92.1		0.01	0.06	0.27	0.525	0.71	0.76
	Normal Packet	97.2	95.7	94	93.3	91.8	91.2		0.01	0.08	0.31	0.69	0.955	1.16
Figure 9b	Reliable Packet	97.3	95.8	93.5	92.9	92.1	91.7	Figure 10b	0.012	0.06	0.26	0.63	0.815	1.045
	Critical Packet	97.3	95.7	93.6	92.9	92.2	91.8		0.013	0.06	0.25	0.63	0.81	1.03
	Delay Packet	97.5	95.7	93.7	93	92.2	91.8		0.012	0.065	0.24	0.64	0.74	1.11
	Normal Packet	97.5	95.8	93.7	93	92.2	91.8		0.012	0.06	0.255	0.62	0.78	0.96

TABLE 10. Dataset for energy consumption, network lifetime and routing overhead of the protocols.

		20	30	40	50	60
Total Energy Consumption (Figure 6a)	DLQoS	134.08726	201.97109	270.61815	339.25801	407.11285
	DMQoS	135.39157	203.25739	271.12321	338.82864	406.5718
	ORACE-NET	135.63864	203.53315	271.37987	339.21705	407.06996
Network Lifetime (Figure 6b)	DLQoS	14.91566	14.8536	14.78097	14.754	14.74754
	DMQoS	14.871968	14.80961	14.753439	14.73672	14.7279
	ORACE-NET	14.84506	14.80961	14.73948	14.72982	14.71948
Routing Overhead (Figure 7a)	DLQoS	360	543	831	1,480	1,663
	DMQoS	966	1,246	1,289	1,447	1,727
	ORACE-NET	448	759	936	1,524	1,835
Normalized Routing Overhead (Figure 7b)	DLQoS	0.00776	0.02171	0.04532	0.0766	0.0966
	DMQoS	0.03512	0.06582	0.067	0.0777	0.0977
	ORACE-NET	0.0264	0.0333	0.0458	0.0891	0.1091

received packets by the sink to the total number of packets received by the sink. The end-to-end delay of each packet (Pkt_E2E_Delay) is the sum of the delays experienced at a sequence of intermediate nodes on the way to the destination.

$$AD = \frac{\sum_{i=1}^{n} Pkt\_E2E\_Delay_i}{n} \tag{13}$$

where 'n' is the total number of packets received by the sink.

$$PRR = \frac{Total\ packets\ received}{Total\ packets\ sent} * 100 \tag{14}$$

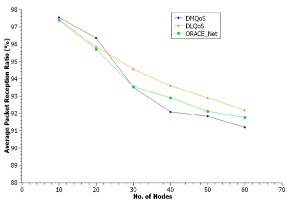
1) IMPACT OF NUMBER OF NODES

In the proposed DLQoS protocol packets are distributed across primary and secondary paths based on the path's current load during the transmission of all types of packets. The distribution of traffic helps in avoiding congestion problems which in turn supports reducing end-to-end delay and increasing packet reception rate. Further, traffic distribution avoids overloading of the node thus resulting in a decrease in energy consumption and an increase in network lifetime. Further, the DLQoS protocol's approach of dropping the low prioritized packets during the heavy load in the network, enhances the QoS support for the critical packets in the network. This way the main concerns of the routing protocol for the emergency network like increasing the throughput of the critical packets, along with data-centric QoS support for other packet types, avoiding network congestion, and increasing the network lifetime are handled by the proposed protocol.

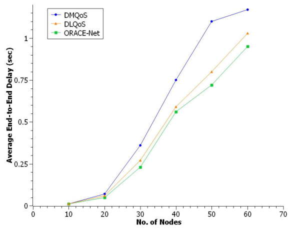
Figure 5a shows the reliability comparison between considered protocols. The result analysis shows that DLQoS

TABLE 11. Nodes and their traffic loads.

Number of nodes	Traffic Load (No.of data packets)
20	4000
30	6000
40	8000
50	10000
60	12000
70	14000



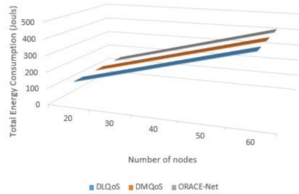
(a) Packet Reception Rate



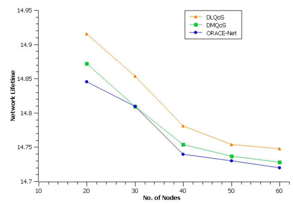
(b) Average End-to-End Delay

FIGURE 5. Performance comparisons of the protocols.

performs better than the rest of the protocols. This is due to the pros of the DLQoS protocol which are discussed in the above paragraph. That is DLQoS performs better since DLQoS has reduced control packets because of its optimized proactive approach which is beaconless (avoids periodic broadcasting of HELLO message by all the source nodes). Further, DLQoS distributes the packets across the network instead of relying on the single best path, finally, low prioritized packets are dropped based on network load. All these points support the reduction of congestion level in the network leading to an increase in packet reception rate and throughput of the network. Further, DLQoS considers the LQI parameter while constructing the best paths. These points support achieving a better packet reception rate for DLQoS. In the case of DMQoS, if there is no suitable next hop is available then the packet is dropped. This is not acceptable for critical packets. Further, packet duplication and reactive routing approach in DMQoS cause more packets in the network leading to an increase in interference problem and network congestion which reduces packet reception rate. In the case of ORACE-Net, the single shortest and reliable path is identified by all the nodes which leads to the selection of the same path by most of the nodes leading to congestion and packet drop. Further, ORACE-Net does not consider the packet priority. Figure 5b shows that in all the protocols as the number of nodes increases, traffic load increases in the network and increasing packets end-to-end delay. Out of all the protocols, ORACE-Net performs better, since it provides a delay-sensitive path for all types of packets compared to DLQoS and DMQoS. ORACE-Net is followed by DLQoS due to the load distribution approach of the DLQoS. Further, compared to other approaches the increase in delay as the load increases is minimum in DLQoS. The end-to-end delay is more in the case of DMQoS due to the following reasons, DMQoS duplicates the reliability sensitive packets which leads to congestion thus resulting in packet transmission delay. The reactive nature of pathfinding in DMQoS leads to packet delay which is not acceptable in case of critical data transmission.



(a) Total Consumed Network Energy



(b) Network Lifetime

FIGURE 6. Consumed energy and network lifetime comparisons.

Figure 6a shows the average consumed energy by the network nodes over the simulation. We have considered the total amount of energy consumed by all the nodes for transmission and reception of all the packets by a source and forwarder nodes until it is received by the sink. Equation 15 shows the computation of the average consumed energy(E) by the network over the simulation. Table 10 shows the total energy consumption by all the protocols over a varying number of nodes. Energy consumption decreases by a small amount as the traffic load is increased since during the low traffic loads packet reception rate is more which increases energy consumption and as the traffic load is increased packet reception rate decreases still the traffic load is more which increases energy consumption.

$$E = \sum_{i=1}^{n} Consumed\_Energy_i \tag{15}$$

where, 'n' is the total number of nodes in the network and $Consumed\_Energy_i$ is the energy consumed by the node 'i' over a simulation.

Figure 6b shows the Network lifetime. Network lifetime is limited by the energy shortage. The figure shows as the number of nodes in the network increases network lifetime decreases. This is because as the number of nodes increases the number of packet transmission increases leading to an increase in node energy consumption for transmitting the packets. Network lifetime(T) is computed as shown in Equation 16.

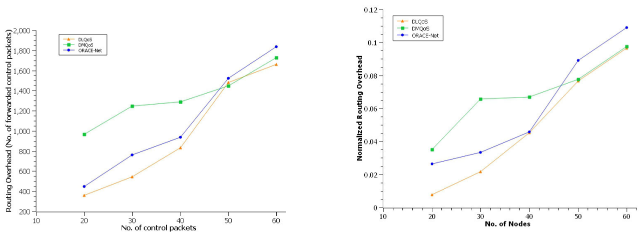
$$T = \frac{\sum_{i=1}^{n} Initial\_Energy_i}{\sum_{i=1}^{n} Consumed\_Energy_i} \tag{16}$$

where 'n' is the total number of nodes in a network.

Figure 7a shows the routing overhead comparison between the considered protocols. The result shows that almost all three protocols show similar performance because of their similar routing process. ORACE-Net and DLQoS make use of beaconless routing. Equation 17 shows the computation of the routing overhead, where 'n' is the total number of nodes in a network.

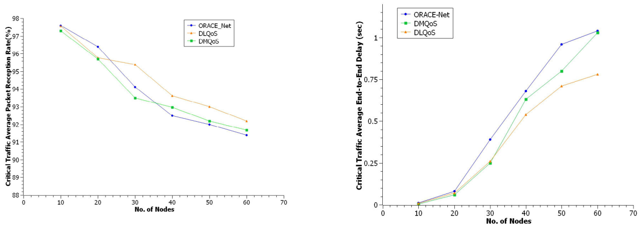
$$\sum_{i=1}^{n} Total\_Control\_Packets\_Forwarded_i \tag{17}$$

Figure 7b shows the normalized routing overhead of the considered protocols, which is computed using the



(a) Routing Overhead (b) Normalized Routing Overhead

FIGURE 7. Routing overhead and normalized routing overhead comparisons.



(a) Packet Reception Rate (b) Average End-to-End Delay

FIGURE 8. Performance comparisons of protocols for critical traffic.

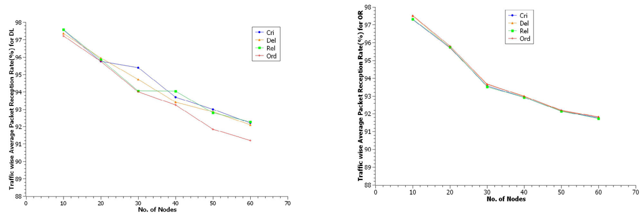
equation 18. Since in DLQoS packet reception rate is more compared to the rest of the protocol hence the normalized routing overhead is lower in DLQoS compared to other protocols.

$$\frac{\sum_{i=1}^{n} Total\_Control\_Packets\_Forwarded_i}{Total\_Received\_Data\_Packets} \tag{18}$$

2) IMPACT ON PACKET TYPE

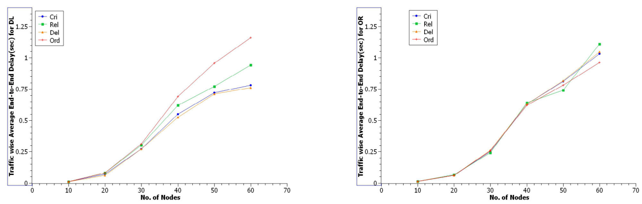
Figure 8a illustrates the performance of the protocols concerning the throughput of the critical packets. DLQoS performs better than DMQoS since in DMQoS critical packets are dropped if suitable delay-sensitive and reliable paths are not available. Unlike DMQoS, DLQoS distributes the critical packets across the best two paths which are selected based on traffic load, delay support, and reliability support given by the paths. Because of packet distribution and the absence of packet duplication in DLQoS, DLQoS is always able to find the best path, unlike DMQoS. Additionally, in DLQoS, if traffic load in the network is high then the adaptive buffer management approach of the protocol helps in reducing the low prioritized packet transmission thus supports an increase in critical packet throughput. In DLQoS throughput of the critical packet is more compared to the other type of traffics, which is a requirement of the medical emergency scenario where importance must be given to the critical packets. DMQoS throughput about critical packets is less compared to DLQoS this is due to the critical packet duplication leading to congestion and also dropping critical packets if suitable paths are not available. In ORACE-Net, they have not considered the priority among the packets. Hence, a critical packet is also treated as a normal packet.

Figure 8b shows as the load increases end-to-end packet delay is increased in all the protocols, this is due to the increase in media contention at each hop resulting in packet delivery delay. In DMQoS and DLQoS critical packets are delivered with less delay compared to other types of packets, unlike ORACE-Net where packet differentiation is not performed. DLQoS takes less delay compared to DMQoS since DLQoS distributes the packets and has less number of control packets due to its optimized beaconless proactive approach compared to the reactive method. DMQoS has a delay due to its reactive nature of pathfinding.



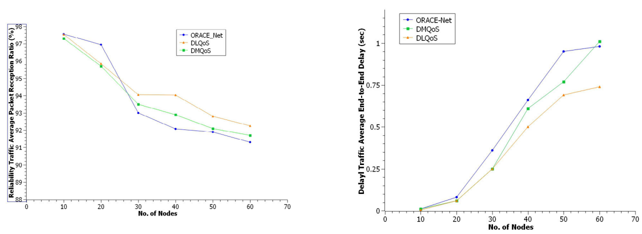
(a) Packet Reception Rate in DLQoS for all types of Traffic (b) Packet Reception Rate in ORACE-NET for all types of Traffic

FIGURE 9. Performance comparisons.



(a) Average End-to-End Delay in DLQoS for all traffic (b) Average End-to-End Delay in ORACE-NET for all traffic

FIGURE 10. Performance comparisons.



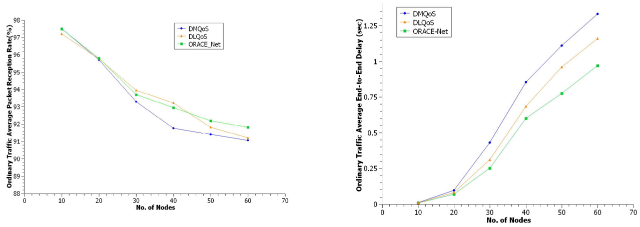
(a) Packet Reception Rate for Reliability Sensitive traffic (b) Average End-to-End Delay for Delay Sensitive traffic

FIGURE 11. Performance comparisons.

The comparison between the DLQoS and ORACE-Net concerning packet type is shown in Figures 9a and 9b respectively. The result shows that DLQoS supports throughput based on the type of packet, unlike ORACE-Net which does not distinguish between the packet types.

Similarly, about delay support as shown in Figures 10a and 10b, DLQoS considers the packet type, unlike ORACE-Net. Hence, in DLQoS minimum delay is for delay packets followed by critical packets and then reliable and finally for the ordinary packets. Critical packets delay is a bit more than delay since for critical packets along with delay, reliability support is also considered while finding the best path. DLQoS also has a prioritized scheduling module in which reliable packets are sent with a higher priority than ordinary packets.

Further, Figure 11a shows that concerning reliability sensitive data DLQoS performs better than the rest of the algorithms, and Figure 11b shows that about delay-sensitive packet DLQoS performs better.



(a) Packet Reception Rate

(b) Average End-to-End Delay

FIGURE 12. Performance comparisons for ordinary traffic.

Figures 12a and 12b show that ORACE-Net performs better than the rest of the protocols about ordinary data packets since irrespective of the packet type ORACE-Net finds the shortest reliable path for all type of packets. However, DLQOS performs better than DMQoS due to the load balancing feature of the proposed work and packet duplication of the DMQoS feature.

Figures 5, 8, 9a, 10a, 11, and 12 illustrate data-centric QoS support, in which priority is given to the transmission of critical victim's data, followed by delay and reliability-sensitive data, by the proposed DLQoS routing protocol. Figure 6a and 6b shows the energy consumption and lifespan of the network support given by the protocol. Overall, the above comparison result shows that DLQoS outperforms in all aspects compared to the rest of the protocols and thus DLQoS is a suitable protocol for the MCI.

V. CONCLUSION

The research work explained in this paper focuses on the automated monitoring framework to capture the vital signs of the MCI casualties. It helps the health professionals to monitor the severe condition of a casualty during the triage process. As a part of the remote monitoring, this paper presents an efficient routing protocol in a Body-to-Body network formed by the multiple interconnected Wireless Body Area Networks deployed at the MCI. The proposed framework is beneficial to handle dynamic issues such as link and node cost, load distribution, network lifetime, congestion control, and Quality of Service for the data transmission. The experimental results indicate that the proposed DLQoS routing protocol is suitable for effective communication during the triage process and provides the optimized requirement of physicians. The proposed protocol is compared with some of the existing approaches and it is found that DLQoS performs better than the rest of the protocols concerning reliability, delay, the average consumed energy, network lifetime along with maximizing throughput for the critical casualties' vital signs, which is the important factor for handling mass casualties. In the future, the focus can be on predicting the casualty's health condition deteriorated and finding the optimum number of medical resources needed to cope with the mass number of different groups of casualties at the MCI.

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