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A QoS-Gateway-Based Framework for Prioritizing Emergency Data in IoMT Applications

Fathia Ouakasse[1,2*], Afaf Mosaif[2], Said Rakrak[2]

[1] Private University of Marrakesh, Marrakesh 40000, Morocco
[2] Department of Computer Science, Laboratory of Computer and Systems Engineering (L2IS), Faculty of Sciences and Techniques, Cadi Ayyad University, Marrakesh 40000, Morocco

Corresponding Author Email: fathia.ouakasse@gmail.com

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ABSTRACT

The advent of the Internet of Things (IoT) has notably enhanced the quality of life, with significant advancements being made in the e-health domain through the Internet of Medical Things (IoMT). The IoMT, a network comprising medical devices, sensors, and applications, generates voluminous data that frequently necessitate real-time transmission to healthcare providers for effective emergency responses. Presented herein is a framework designed to prioritize this emergent data in IoMT applications. This framework employs a Quality of Service (QoS) gateway for data processing, aiming to ensure high throughput and minimal packet loss. Simulations were conducted, the results of which demonstrate a superior performance of the proposed framework, inclusive of the high-priority gateway, when compared to traditional networks.

1. INTRODUCTION

In the wake of widespread computer and network utilization in every facet of life and the emergence of technologies such as Radio Frequency Identification (RFID) and Wireless Sensor Networks (WSN), an estimation has been made that suggests the connectivity of over 75 billion devices to the internet by 2025 [1]. The Internet of Things (IoT), now nearly ubiquitous, has been instrumental in the exponential increase in internet data traffic. Life has been significantly transformed through the advent of this technology, giving rise to intelligent systems including smart grids and renewables [2-4], smart irrigation [5, 6], and smart transportation [7, 8].

Of particular note is the healthcare sector, where IoT has instigated a significant revolution. The Internet of Medical Things (IoMT), a network encompassing medical devices, sensors, and infrastructural hardware devoted to the medical field, has introduced numerous challenges, making it a focus for researchers. Key challenges include Quality of Service (QoS), energy consumption, security, and data management. Diverse medical devices within the IoMT can be classified into four categories: wearable, in-hospital, in-home, and community IoMT [9].

Statistics reveal that currently, 70% of the top-selling wearables are within the health and wellness sector. Furthermore, it is projected that by 2026, 40% of all IoT-powered devices will be in use. The healthcare industry is anticipated to witness a revenue surge exceeding 135 billion dollars by 2025 [10]. Therefore, worldwide clinics and health organizations are seeking intelligent systems for real-time data collection from various sources. The integration of healthcare and IoMT has spurred significant innovation in medical services, cost reduction, and accurate diagnostics [11].

Healthcare stakeholders have directed their research towards the analysis of big data generated from networks and the enhancement of communication accuracy through stable and reliable communications to support the healthcare data process and manage its constraints and challenges.

However, in clinics and hospitals where critical data is transmitted, real-time data transmission poses a significant challenge. IoT access technologies using constraint objects can cause performance degradation due to network congestion [12], radiofrequency or electromagnetic interference [13, 14]. Thus, the primary challenge in this context is the management of QoS. The research problem centers around the challenges related to data prioritization and QoS management in emergency healthcare scenarios using the IoMT. The objective is to develop an efficient framework capable of prioritizing emergency data accurately, ensuring timely delivery and maintaining the required QoS standards for effective emergency healthcare interventions.

This paper addresses the issue of network mitigation in light of the voluminous data generated and circulated within it. A novel solution for managing and controlling network performance in a medical emergency system is proposed. A high-priority gateway with low packet loss and high throughput is employed for the collection and processing of urgent data to ensure its accurate and timely delivery. The novelty of this proposal primarily lies in the utilization of intelligent techniques, supporting the heterogeneity of objects, their limited capacities, and the great dynamics characterizing the IoT.

The proposed framework operates in three phases, including the management of healthcare data through classification, control of urgent data, and allocation of a gateway for data transmission. This framework also enhances transmission quality by considering parameters like throughput, end-to-end delay, and jitter, in addition to data collection from medical sensors through access networks. Homogeneous networks are assumed to circumvent problems related to the use of heterogeneous network systems, which require multimedia tools and applications to manage and control the QoS of different devices and networks.

The main objectives of the framework involve managing practical challenges related to data classification and prioritization, real-time analysis and decision making, resource management and QoS assurance, and integration with existing healthcare systems. Addressing the issues of data prioritization and QoS management in emergency healthcare using IoMT has significant practical implications such as improving patient outcomes, enhancing resource allocation, time-sensitive interventions, seamless integration, scalability, and generalizability.

The effectiveness of our framework was assessed through simulations using the Common Open Research Emulator (CORE) and a Multi-Generator (MGEN) for data generation. The simulation results demonstrated that our framework, which incorporates a high-priority gateway, outperforms traditional networks (without a gateway). The simulations provide empirical evidence supporting the improved efficiency and effectiveness of our framework in handling network traffic and prioritizing critical data.

The remainder of this paper is organized as follows: Section two reviews a set of communication network technologies with QoS management. Section three reports some related work to QoS management within an IoMT system. Section four presents our framework. The final section presents conclusions and future works.

2. COMMUNICATION NETWORKS AND QOS MANAGEMENT

2.1 Communication networks

Hospitals face difficulties and challenges in implementing IoT healthcare systems and their applications. This is due to the nature of the generated sensitive and confidential data. Indeed, unlike demotic automation and industrial processes, healthcare applications are critical and may require physical or virtual intervention in real-time. The challenge is therefore to receive timely information about events of interest so that real-time interventions can be made.

IoMT are lightweight devices with constrained resources designed to address healthcare applications and manage constraints in terms of computing, memory, and energy [15]. Although IoMT has increasingly been used and proved its effectiveness in gathering data from smart sensors and controlling constrained devices, the issues of network congestion and network overload might lead to the loss of packets, latency, and signal deterioration.

Vast volumes of data featuring diverse content and formats distinguish IoMT systems. Effectively, these data streams necessitate adept and swift processing, underpinned by sophisticated techniques, algorithms, tools, and models. This innovative paradigm is bolstered by the evolution of multiple technologies, including wireless communication, internet connectivity, cloud computing, machine learning algorithms, and extensive data analysis methodologies.

In Figure 1, we present a set of communications technologies used in smart networks and their classification.

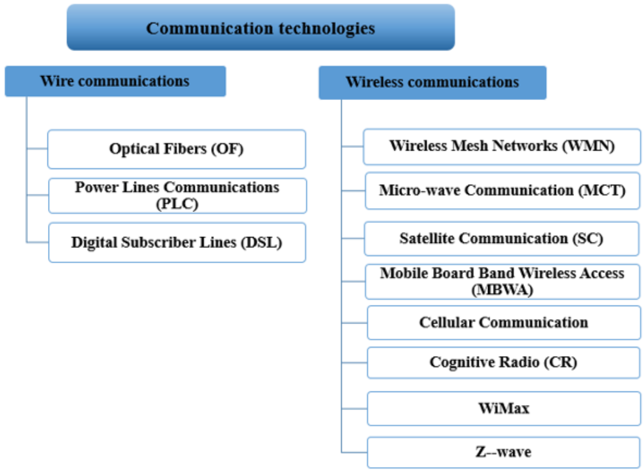

Figure 1. Communication technologies classification

2.2 QoS characteristics of network traffic

Network traffic padding and network congestion are two factors that break the data traffic flow and cause communication latency. When it is about sensitive or critical data, it is important to define a QoS policy to ensure that urgent data will be received without latencies. QoS refers to the set of parameters that define the level of performance, reliability, and efficiency of a network or service. It encompasses various characteristics such as throughput, latency, reliability, availability, and scalability. In the context of IoMT applications, QoS plays a crucial role in ensuring the seamless and efficient management of emergency and critical healthcare data. This technique helps to reduce commonly encountered quality degradation issues. Four characteristics of network traffic are used to measure QoS. These characteristics are as follows [16]:

- Bandwith: the maximum speed a link can reach is expressed in bits per second (bps). QoS helps analyze which applications need more bandwidth than others do.
- Packet Loss: when packets fail to reach their destination due to heavy network overload or network congestion, packet loss occurs. Here, with QoS, it is possible to choose which packets to drop.
- Latency: is the total time taken by a packet to traverse the network from the source to the destination. This is also called a one-way delay. The time taken from a source to the destination and back is called the round-trip delay. There are different types of delays [17]:
  - ✓ Processing delay: Depending on each device, processing delay is the time taken by a device to perform the required tasks to forward the packet.
  - ✓ Queuing delay: generally, before a transmission and when an interface is congested, the packet might wait for a time. The time waited by a packet in the queue before it is transmitted is called the queuing delay.
  - ✓ Serialization delay: the time needed to transfer all bits of a frame to the physical interface for transmission.
  - ✓ Propagation delay: the time required a frame bits to cross a transmission media (optical fiber, satellite link…)
- Jitter: This phenomenon refers to the time delay in the sending of data packets due to network congestion or

route variation.

By considering these QoS characteristics in managing emergencies and critical healthcare data within IoMT networks, healthcare providers can ensure that the right information is delivered at the right time to the right people. This enables prompt decision-making, rapid response, and potentially life-saving interventions. QoS-driven approaches in IoMT networks support the efficient management of emergencies, enhance the quality of healthcare services, and improve patient outcomes.

3. RELATED WORKS

In this section, we aim to review related works that focus on the management of emergencies and critical healthcare data in the context of IoMT networks. The scope of the review encompasses studies that address the challenges of emergency data prioritization and QoS in IoMT applications. The ultimate goal is to establish the foundation for the proposed emergency data prioritization and QoS framework in this study.

In the study of Abujassar et al. [18], authors propose a new Smart-Rout Control algorithm called s-RCA based on the number of hops and link delay between a source and a destination. This algorithm aims to create a virtual smart path to transfer data between source and destination. The authors prove that this algorithm provides a reliable connection to be used in healthcare surgery to ensure the reception and execution of instructions instantly and without any delay. The new s-RCA has the adaptability to integrate seamlessly with an existing routing protocol to track the primary path and monitor emergency packets received in node buffers, for direct forwarding via the demand path, with extended features.

However, Kishor et al. [19], propose an algorithm to improve the QoS over a heterogeneous network using a reinforcement learning-based multimedia data segregation (RLMDS) algorithm and a computing QoS in medical information systems using a Fuzzy (CQMISF) algorithm in fog computing. The proposed algorithm aims to classify the healthcare data and select the optimal gateway to transfer it. The authors perform simulations to validate the improvement and prove the overall accuracy.

On the other hand, in Sodhro et al. [20], the authors contribute in three distinct ways. Firstly, they propose a novel Adaptive QoS Computation Algorithm (AQCA). This algorithm is designed to ensure equitable and effective supervision of performance metrics such as transmission power, duty cycle, and route selection. Secondly, they add a framework for QoS computation in medical applications at the physical, Medium Access Control (MAC), and network layers. Thirdly, they develop a QoS computation mechanism with the proposed AQCA and quality of experience (QoE).

Furthermore, in Lee et al. [21], the authors study the problem of how to design a medical-grade Wireless Local Area Network (WLAN) for healthcare facilities. They prioritize medical applications according to their medical urgency and propose a mechanism to ensure priority for each traffic category by focusing on the performance of real-time patient monitoring applications and determining the optimal contention window size that can significantly improve the throughput performance.

They introduced Weighted Diagnostic Distortion (WDD) as a medical QoS metric to evaluate performance from a medical perspective.

Besides, in Peng et al. [22], the authors discuss the use of fog computing instead of cloud computing due to IoT application constraints in eHealth in terms of real-time and low latency.

They add that fog computing is very useful for the prognosis and diagnosis of diseases in the eHealth industry. Thus, fog-computing features like low privacy, security, latency, mobility, and bandwidth ensure a network QoS.

Overall, this review of related works will provide the necessary background and context for the subsequent discussion of the proposed emergency data prioritization and QoS framework. In Table 1 a summary of different contributions is presented.

Table 1. Summary of contributions

Works	Objectives	Handled Issues	Application Fields
[18]	Smart-Rout Control Algorithm (s-RCA) based on m-QoS	Improving m-QoS for reliable connection in real-time surgery	Tele-surgery
[19]	The use of RLMDS with Fuzzy CQMISF	Improving QoS over a heterogeneous medical network	healthcare data
[20]	Adaptive QoS Computation Algorithm (AQCA)	Monitoring performance indicators: route selection, duty cycle, and transmission power during medical data processing	Emergency medical services
[21]	Medical-grade quality of service (QoS)	Prioritizing medical applications according to their medical urgency	Hospital
[22]	Remote monitoring	Promoting the prognosis and diagnosis of diseases in the eHealth industry	eHealth
[23]	IoT system for the medical field using Sigfox	Quality medical services Accuracy of sending and receiving signals of various targets	Healthcare data in hospital
[24]	Framework using telemedicine techniques for patients monitoring	Real-time monitoring of patients far from the hospital	Telemedicine

4. QOS CONTROL USING A HIGH-PRIORITY GATEWAY

4.1 Proposition overview

With the advancement of communication devices and technologies, the use of IoT in the medical field has achieved a real revolution and great achievements. IoMT has merged hospitals, and its applications have engrossed substantial attention. However, unlike other fields where the collection of IoT data is not critical in terms of emergency and real-time interventions, IoMT data is characterized by its sensibility and delicacy. Indeed, IoMT generates ceaselessly a large amount of data and notifications, which is characterized by volume, velocity, variety, and veracity. Besides, medical sensors are deployed near each other. All these aforementioned characteristics might lead to network congestion, a high probability of collision in data transmission, and traffic overload. Therefore, it is important to ensure a good QoS for network communication, to make sure that nodes profit from the bandwidth afforded, enable IoMt devices to exchange real-time data with servers and reduce the network congestion effects.

In a traditional network, to ensure QoS, the router can be configured to use the afforded bandwidth. For example, in place of using the FIFO approach, where the packets are served on a first-come first-served basis, the integration of QoS different queues can be created. Thus, each type of traffic is assigned to a different queue [17]. This is to avoid delays. Nevertheless, some of these delays, like the propagation delay, are inevitable. In this case, it might be possible to influence the queuing delay by creating a priority queue that is always served before other queues. In the same context, we propose an adaptive system for resource allocation in an IoMT network deployed in emergency rooms. Our system relies on using a high-priority node as a gateway to guarantee the QoS for urgent data transmission. The interaction between the different components of our proposal and the placement of the high-priority gateway is drawn in Figure 2.

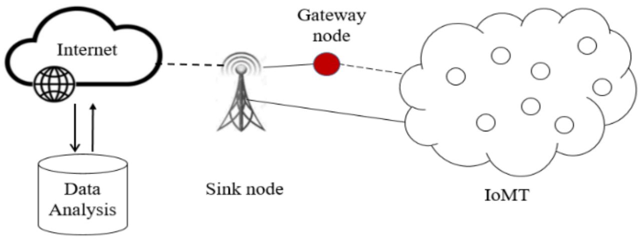

Figure 2. Gateway interaction with IoMT components

4.2 High-priority gateway node

In the previous subsection, we presented an overview of our proposal, which is based on an IoMT network, shown in Figure 3, deployed in emergency rooms and uses a high-priority node as a gateway to guarantee the QoS for urgent data transmission.

Our proposed system operates in three phases: collecting health care data, selecting critical and urgent data, and forwarding the critical and urgent data to the gateway to ensure the required QoS, taking into account parameters such as high throughput and low latency. In Figure 4, we draw a flow chart of our proposal.

Our network is based on several autonomous medical sensor nodes that communicate in order to provide efficient data to the end-user system.

As shown in Figure 2, the gateway node is placed between the IoMT network and the internet. Hence, each critical data detected in a medical device will be declared as urgent data, and the IoMT device will send this gathered data directly to the gateway. It is important to note that our gateway has a high priority for transmission compared to the other nodes in the network. Thus, the urgent data transmitted through it is forwarded first to the Sink node for further processing and decision-making.

4.3 Data collection and transmission

For proper performance evaluation from a medical viewpoint, we introduce a policy topology to sort collected data as a medical QoS metric to effectively measure medical emergencies as well as promote health assessment, physical checkups, and curative treatment modification.

This aims to increase the QoS parameters like end-to-end delay, throughput, packet loss, and jitter in medical networks to process urgent data. Furthermore, situations requiring a real-time intervention can be processed perfectly at more proficient sensor nodes in the way that only the accurate and critical information is prioritized.

In Figure 5, a proposed architecture for QoS management in medical sensor networks is presented. In addition to data analysis, the gathered data can be organized with policy topology depending on the denotation of gathered parameters from medical perspectives.

The proposed framework operates in three phases that ensure healthcare data management through classification, control of urgent data and allocation of the gateway for data transmission, and improvement of data transmission quality while taking into account parameters such as throughput, end-to-end delay, and jitter. Besides, data collection from medical sensors through access networks.

So far, the sensor corresponding to the most critical data is considered the most urgent and its corresponding data is forwarded to the gateway node providing a high priority where it will be directly transmitted to the data analysis center before any other data. On the other hand, the health professional can permanently consult the monitoring system via, for example, a browser-based interface in order to track the patient's state, verify if there is any intervention needed, and reconfigure medical parameters or treatments.

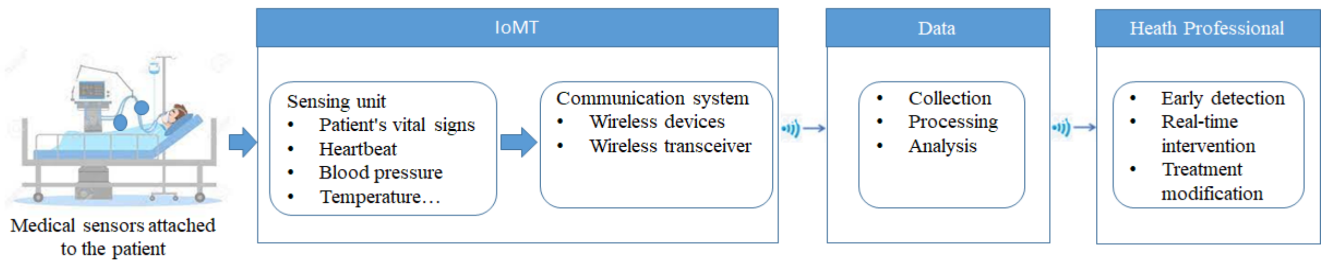

Figure 3. The IoMT system architecture

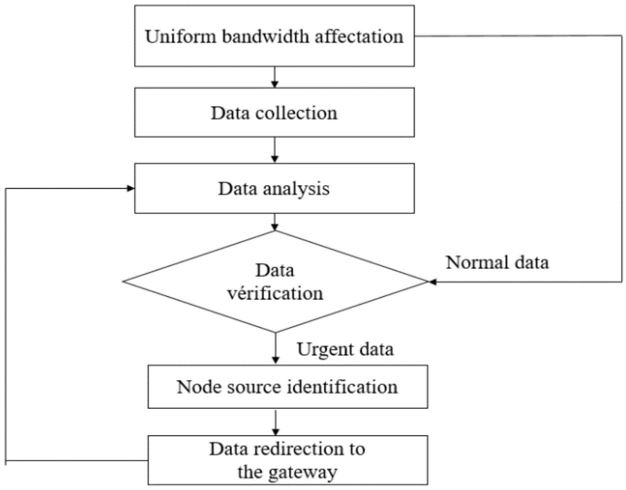

Figure 4. The flow chart of the proposed mechanism

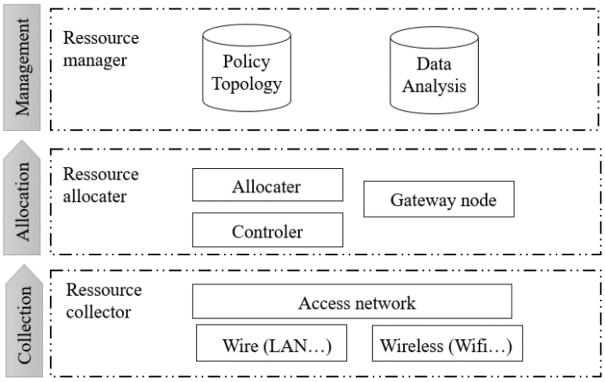

Figure 5. QoS management framework based on high-priority gateway

4.4 Performance evaluation

In the realm of technology, simulation is an invaluable tool that allows us to predict and analyze the performance of complex systems. By harnessing the power of advanced equipment, we have been able to replicate real-world scenarios with the CORE and the data generator MGEN.

The simulation parameters are presented in Table 2.

Table 2. Simulation parameters

Parameter	Value
IoMT devices	20
Retransmission time	1s
Simulation duration	20s
Packet size	Variable according to medical data nature

To evaluate the performance of our proposed emergency data prioritization and QoS framework, we conducted simulations and collected urgent data based on two scenarios. These scenarios were designed to assess the impact of our framework on throughput and jitter, two key parameters in network performance evaluation.

In the first scenario, we simulated a traditional network comprising 20 IoMT devices. This scenario represents a typical setup without any specialized mechanisms for emergency data prioritization. Throughput, which measures the amount of data successfully transmitted over the network within a given time, was monitored to evaluate the network's overall urgent data-handling capacity. Additionally, jitter, which quantifies the variation in latency or delay between data packets, was measured to assess the stability and consistency of urgent data transmission.

In the second scenario, we simulated a network that includes a High-Priority Gateway (HPG), which is a key component of our proposed framework. The HPG is designed to prioritize emergency data and ensure its timely delivery. By introducing this gateway, we aimed to investigate the impact of emergency data prioritization on network performance, specifically focusing on throughput and jitter.

Figures 6 and 7 represents the results of our simulation.

As shown in Figure 6, when IoMT devices transmit urgent data in a network equipped with our proposed HPG, after some time, the throughput is higher compared to the network without the HGP. This is because the HGP manages the bandwidth allocation to ensure reliable transmission of urgent data. In the same simulation condition, the jitter is presented in Figure 7. As shown in this Figure, the jitter is lower within a network with our HGP, which means that the urgent data is transmitted with minimal delays.

This shows the utility of our solution in resolving the problem of data prioritization to support the timely and reliable delivery of urgent data in an IoMT network.

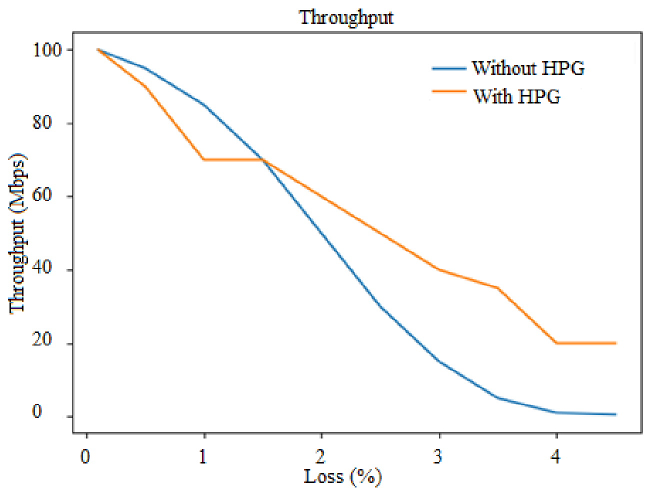

Figure 6. Simulation results: Throughput /packet loss with HPG vs without HPG

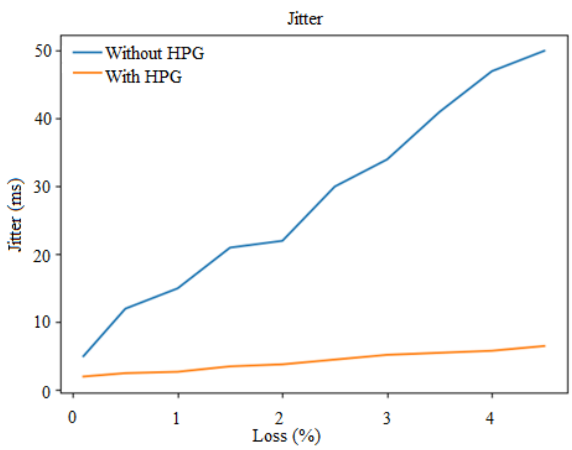

Figure 7. Simulation results: Jitter/packet loss with HPG vs without HPG

5. CONCLUSIONS

In this paper, we introduced a novel framework based on an IoMT network deployed in emergency rooms and uses high priority node as a gateway to ensure the required QoS for IoMT devices generating urgent data. In IoMT networks, the main challenge consists of processing critical and urgent data related to patients to react in real-time. Indeed, using our proposal, the urgent gathered data can be processed and related to representative parameters, which enables faster detection of medical emergencies and real-time critical interventions.

To evaluate the performance of our proposal, we conducted simulations and collected urgent data based on two scenarios. These scenarios were designed to assess the impact of our framework on throughput and jitter. The results showed the effectiveness of our framework. However, we intend in the future to optimize and enhance our framework and test more real word scenarios using other QoS parameters.

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