



PACKET ERROR RATE ENHANCEMENT OF SMART CITY IOT NETWORKS VIA PEER-ASSISTED RETRANSMISSION

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ABSTRACT

Internet of Things (IoT) is rapidly expanding in smart city usage in applications such as smart traffic systems, power management, ecological monitoring, security in cities, and some more vital services. Quality of connectivity and response time have significant effects on how well these systems function. It is thus the crucial factor with respect to their functioning performance. The emerging requirement is then for IoT technologies with enhanced connectivity efficiency and data-loss minimization capabilities. To reduce Packet Error Rate (PER) higher Quality of Service (QoS) levels are used but at the expense of imposing more load on the broker which should serve multiple publishers and subscribers. In this paper, it is proposed to improve the PER at a target subscriber by the assistance of a peer neighbor subscriber. The conducted tests show the capability of the proposed Peer-Assistance (PA) scheme to enhance PER up to 65% with respect to conventional QoS schemes tested under the same conditions. Although, this enhancement is at the expense of an increase in system latency, it provides a useful trade-off enabling design customization to suit the requirements of the specific application. Moreover, the proposed PA scheme introduces a mechanism that redistributes the retransmission load from the broker to neighboring subscribers, thereby enhancing the broker's availability to serve its clients.



KEYWORDS

Peer Assistance (PA) Scheme, Packet Error Rate (PER) Improvement, Internet of Things (IoT), Smart Cities, Latency, Quality of Service (QoS).

1. INTRODUCTION

With the modern digital era, the Internet of Things (IoT) has emerged as a revolutionary technology that enables physical objects with network connectivity, software, and sensors to exchange and transmit data (Yew et al., 2020; Mia et al., 2025). The world being connected enables automation, smart decision-making, and enhanced system efficiency in most sectors (Ferrari et al., 2018; Barznji and Ameen, 2021).

A key enabler of communication within IoT networks is the Message Queuing Telemetry Transport (MQTT) protocol (Jara Ochoa et al., 2023). MQTT is a light-weight and efficient messaging protocol based on the publisher-broker-subscriber model and is therefore especially suited for use on low-resource devices and bandwidth-constrained networks. MQTT enables devices (publishers) to send messages to a central broker (Domingues et al., 2024), which forwards the messages to devices (subscribers) that have subscribed to given topics (Saleem et al., 2024; Al Hanif and Ilyas, 2024).

MQTT also supports different levels of Quality of Service (QoS) for message reliability during message delivery (Pham, Le and Nguyen, 2022). QoS 0 provides no acknowledgement of delivery of messages and may lose data, QoS 1 assures arrival of the message but may duplicate it, while QoS 2 provides the most reliable one with no loss or duplication (Ali et al., 2022). The integration of IoT, MQTT, and QoS mechanisms plays a key role in developing smart cities with better urban lifestyle through technology. Applications such as smart traffic management (Lilhore et al., 2022), environmental surveillance (Pal, Ghosh and Bhattacharya, 2017), smart street lighting, public safety (Gupta, Khera and Turk, 2021), and intelligent parking rely on MQTT to facilitate efficient exchange of data (Ashhwath, Rohitram and Sumathi, 2021; D'Ortona, Tarchi and Raffaelli, 2022). QoS functionality also ensures guaranteed timely and safe delivery of messages, which helps in real-time decision-making as well as optimizes resources.

Despite the advantages of IoT systems and effectiveness of the MQTT protocol, technical problems like high Packet Error Rate (PER) and latency still haunt their performance (Pawar et al., 2023; Alshammari, 2023), especially in critical applications like healthcare (Alshammari, 2023), smart cities (Hasan, 2022; Al-Turjman, Zahmatkesh and Shahroze, 2022; Syed et al., 2021; Nassereddine and Khang, 2024), and industrial automation (Pawar and Patil, 2022). PER leads to data loss or corruption, which can be fatal in applications like remote patient monitoring, where real-time precision is vital (Alshammari, 2023; Jeddou et al., 2022). Similarly, high latency gets in the way of timely data delivery, affecting systems that rely on

real-time decision-making, e.g., traffic control or disaster response, and reduces their overall effectiveness.

These challenges are exacerbated by situations such as network congestion caused by numerous connected devices, packet loss caused by unstable wireless links, and the inability of default MQTT QoS levels to adapt to changing network conditions. Additionally, the constrained resources of IoT devices and potential security breaches of communication channels also compromise data integrity and system reliability.

Handling such issues is required to make the MQTT-based IoT systems robust. Thus, it is increasingly essential to have adaptive and smart solutions that can adaptively control the level of QoS, prevent packet loss, reduce latency, and optimize overall system performance dynamically in real time.

Different research works have investigated the problems of PER and latency in MQTT-based IoT communication systems (Seoane et al., 2021), especially in high-reliability applications like remote health monitoring and smart city infrastructure. The research works have identified primary causes of communication inefficiencies like network congestion, interference of wireless signals, and limited capabilities of resource-constrained IoT devices.

It has been proven that the greater the number of devices connected, the higher the packet loss due to congestion and interference, resulting in system performance degradation (Ali, Hong and Cheung, 2024; Ashaari, Kassim and Ab Rahman, 2021). Additionally, the default QoS levels of the MQTT protocol (QoS 0, QoS 1, and QoS 2) are not always sufficient to ensure guaranteed message delivery under the influence of dynamic network conditions, especially in real-time systems (Dilek et al., 2022; Palmese, Redondi and Cesana, 2022; Shahri, Pedreiras and Almeida, 2021). Comparative analyses of several open-source MQTT brokers like Mosquitto, Erlang /Enterprise Message Queuing Telemetry Transport Broker (EMQX), and RabbitMQ in edge computing environments have shown significant performance degradation with message size, number of clients, and adverse network conditions like latency and packet loss (Dizdarevic, Michalke and Jukan, 2023). The impact of payload size, client density, and QoS levels on MQTT performance in resource-limited IoT environments has also been investigated, showing the need for dynamic QoS configuration for optimum performance (Puthiyidam and Joseph, 2024).

For controlling untrustworthy data transmission over time-varying wireless channels, an adaptive Automatic Repeat Request (AdARQ) error-constrained technique is proposed. It adaptively switches between Hamming codes and Selective Repeat (SR ARQ) under feedback, and simulation results show improved throughput and reliability compared to traditional

methods with low system complexity (Bulo, Sonalika and Krishna, 2024). The performance of the EMQX broker-based MQTT protocol on IoT networks has been verified with focus on message rates and QoS values and has shown low latency and high scalability, which are the prerequisites for IoT applications (Kashyap, Dev and Sharma, 2024).

Other studies have addressed the issue of ensuring IoT system reliability by describing techniques such as fault tolerance, reliable communication protocols, data integrity, predictive maintenance, and power efficiency techniques. These are directed towards enhancing system reliability, despite ongoing issues such as increasing complexity, resource constraint, and interoperability issues (Singh et al., 2025). A novel protocol, Centralized MQTT-based Communication framework (CMQC), has been designed to outperform traditional protocols such as MQTT, Transmission Control Protocol (TCP), and Constrained Application Protocol (CoAP) in massive Unmanned Aerial Vehicle (UAV) networks that are subject to high latency and outdated updates. The results indicate that CMQC improves network efficiency with reduced jitter and latency and thus is a suitable protocol for real-time applications (An, Joo and Kim, 2025).

These collectively point out the insufficiency of traditional MQTT QoS mechanisms in real-time unreliable network conditions. They justify the need for adaptive, low-overhead, and distributed enhancement to ensure persistent message delivery as well as efficient resource usage in MQTT-based IoT networks.

To reduce message delivery and error in packets, this research introduces a Peer-Assisted (PA) ARQ mechanism that enables cooperation amongst subscribers within the same network segment through local communication. When a packet is sent by the broker, it may happen that some of the subscribers receive the packet correctly and others do not due to noise. Subscribers who receive the packet correctly cache it temporarily. When the target subscriber fails to receive the packet, it can request assistance, and a local subscriber who possesses a valid copy forwards it locally, adding reliability without overloading the broker.

The proposed PA scheme is expected to minimize the PER through the capability of nearby subscribers to handle retransmissions, thus lessening reliance on the broker. The local recovery process minimizes latency and offers real-time responsiveness. It also increases QoS adaptability through dynamic responsiveness to network conditions without alteration of the MQTT structure. Further, by offloading retransmission activity from the broker, the solution optimizes network utilization of resources and scalability.

This paper is structured as follows: Section 1 provides an introduction to the main concepts of the IoT, the MQTT protocol, and QoS, along with their applications and key communication

challenges, particularly PER and latency. Section 2 presents the system model, describing the roles of the publisher, broker, and multiple subscribers within the proposed IoT network architecture. Section 3 introduces the proposed PA ARQ mechanism, explaining how neighboring subscribers assist in recovering lost packets. Section 4 outlines the research methodology used to implement and evaluate the proposed technique, including the simulation environment and performance metrics. Section 5 discusses the simulation results, comparing the performance of the proposed approach with standard MQTT QoS levels in terms of packet delivery, latency, and energy efficiency. Finally, Section 6 concludes the paper and suggests potential directions for future research.

2. SYSTEM MODEL

The focus of this work is to improve the PER in the downlink of a target subscriber with the aid of neighboring subscribers. The considered IoT network consists of publishers denoted as P_i for $1 \leq i \leq n$, a broker and more than two subscribers denoted as S_j for $1 \leq j \leq m$, all wirelessly connected, as shown in Fig.1. Without loss of generality, a publisher periodically feeds data packets to a topic in the broker. Then, on the request from a subscriber to get data from the topic, the broker broadcasts data packets to be received by the target subscriber. Practically, every wireless link is subjected to noise and channel impairments. In this work, the publisher to broker link is assumed to be perfect, while the broker to subscribers S_1 and S_2 links are subjected to different levels of noise.

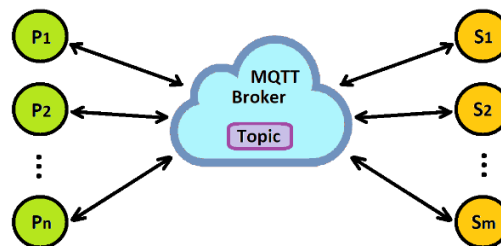


Fig.1 System model

The system assumes that subscribers belonging to the same section of the larger IoT network can communicate through local links. So, when the broker broadcasts a data packer, these subscribers receive it and take place in assisting the target subscriber to correctly receive the sent packet. This IoT packet delivery is based on the MQTT protocol which allows the subscribers to use different QoS levels.

3. PROPOSED PEER-ASSISTED ARQ

The basic concept of the proposed PA ARQ technique is to involve subscribers that successfully receive a packet to assist the target subscriber to obtain it. However, subscribers may operate at different QoS levels, and the links connecting them to the broker can experience varying

degrees of noise. This results in the possibility that a broadcasted data packet is correctly received by one or more subcarriers when the intended subcarrier fails to recover the packet. Therefore, as shown in Fig.2, the proposed peer-assisted technique operates as follows: on the correct receipt of a data packet, the non-intended subcarriers keep a copy of this packet for a predefined time. If the intended target subcarrier (S_t) succeeded in correctly receiving the packet, then the assisting subscriber (S_a) just discard the copy after the predefined time period has elapsed. Otherwise, when the intended subscriber fails to receive the packet, then it initiates an assistant request to the neighboring subscribers to get a correct copy of the packet if still available.

By the proposed PA scheme, a subscriber with noisy channel or using a low QoS level due to resource constraints, can benefit from neighboring subscribers that are exposed to less noise or their available resources let them use higher QoS options. Although this proposed scheme does not fully guarantee the correct reception of packets, it can significantly reduce the packet error rate while avoiding increasing the burden on the broker. These are key performance improvement factors in many IoT based applications such as smart cities, remote health care and industry.

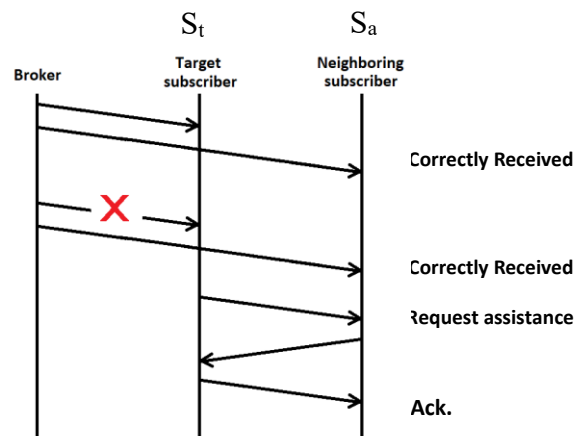


Fig.2 Proposed peer-assisted ARQ scheme

4. METHODOLOGY

The performance of the proposed system is evaluated by computer simulation, under different operation conditions. The performance metrics are the PER, latency and the consumed energy.

The conventional definition of PER is

$$PER_{conv} = 1 - \frac{N_{success}}{N_{total}} \quad (1)$$

where:

$N_{success}$ is the number of packets successfully received from the broker.

N_{total} is the total number of transmitted packets.

For the proposed PA approach, the PER is defined as

$$PER_{PA} = 1 - \frac{N_{success} + N_{recovered}}{N_{total}} \quad (2)$$

where:

$N_{recovered}$ is the number of packets successfully received via peer assistance.

Next, the latency is defined as the average time taken for successful packet delivery. For conventional IoT network it is defined as

$$L_{conv} = \frac{1}{N_{success}} \sum_{i=1}^{N_{success}} T_i^{direct} \quad (3)$$

where:

T_i^{direct} is the time of receiving a packet directly from the broker. It is the sum of the processing time, $t_{processing}$, with the transmission time, $t_{transmission}$.

For the PA scheme, the latency is defined as

$$L_{PA} = \frac{1}{N_{success} + N_{recovered}} \left(\sum_{i=1}^{N_{success}} T_i^{direct} + \sum_{j=1}^{N_{recovered}} T_j^{PA} \right) \quad (4)$$

where:

T_i^{PA} is the time of recovering a packet with the aid of peer subscriber, and it is calculated as $2t_{processing} + t_{transmission} + t_{peer-to-peer}$.

However, both PER and latency have direct effect on the amount of energy spent by a node (broker, S_t or S_a). It depends on four components; the transmission energy (E_{TX}), the reception energy (E_{RX}), the processing energy (E_{PR}) and the idle state energy (E_{idle}). The energy expenditure at a single node is then given as

$$E_{node} = N_{TX}E_{TX} + N_{RX}E_{RX} + N_{PR}E_{PR} + T_{idle}E_{idle} \quad (5)$$

where:

$N_{()}$ is the number of packets.

T_{idle} is the time the node is at the idle state.

Firstly, as a baseline reference system, the system described in Section 2 is simulated under noisy channels and for different QoS options. However, this test case represents the conventional hypothesis of independent subscribers.

Then to evaluate the proposed scheme, the IoT system employing the PA ARQ is simulated. It is evaluated in scenarios where it is expected to enhance system performance. These scenarios include when the QoS level used by the assistant subscriber (S_a) is higher than that in the target subscriber (S_t), while both are subject to equivalent level of noise, as in test cases 2, 3 and 4. In addition, test cases are considered for both subscribers simultaneously using the same QoS level but the noise affecting the broker-assistant subscriber channel (B- S_a) is relatively less than that affecting the broker-target subscriber (B- S_t), as in cases 5, 6 and 7. [Table 1](#) summarizes the test cases.

Table 1 Test cases

Test case	QoS level		Channel noise	
	S_t	S_a	B- S_t	B- S_a
1	0,1,2	0,1,2	high	high
2	0	1	high	high
3	0	2	high	high
4	1	2	high	high
5	0	0	high	low
6	1	1	high	low
7	2	2	high	low

5. RESULTS AND DISCUSSION

All the tests were performed by MATLAB programming to simulate the broadcasting of 10000 16-byte data packets from the broker to the subscribers, as used in lightweight smart city applications (D'Ortona, Tarchi and Raffaelli, 2022; Puthiyidam and Joseph, 2024). Depending on similar simulation test cases from (Jara Ochoa et al., 2023; Jeddou et al., 2022), hypothetical but yet reasonable system parameters were adopted, as shown in Table 2.

Table 2 Simulation parameters

Parameter	Value
E_{TX}	0.05 (J)
E_{RX}	0.02 (J)
E_{PR}	0.005 (J)
E_{idle}	0.001 (J)
Low transmission power (high noise)	-5 dBm
High transmission power (low noise)	5 dBm
$t_{processing}, t_{transmission}, t_{peer-to-peer}$	1 time unit each

The PER is plotted for each test case in Fig.2. The first three bars from the left are the PER at S_t as a baseline system (without peer assistance) for QoS of 0, 1 and 2, under sever noisy B- S_t channel with signal power of -5 dBm. These results show improvement in PER as the QoS level increases. That is at QoS of 2, the target subscriber achieves the best PER. It achieved about 49% reduction with respect to QoS 0 under the same low signal power condition. However, in this test case, the two subscribers are independent of each other, then the same improvement applies to S_a . This justifies the principle of peer assistance, that a subscriber with higher QoS can assist in improving the PER performance of a neighboring subscriber using lower QoS level.

The second three bars are the PER at S_t when PA is applied and both S_t and S_a encounter the same level of noise (signal power -5 dBm), with S_a is using higher QoS with respect to S_t . In test cases 2 and 3, the PA scheme enabled 34% and 46% improvements, respectively, in PER as compared with the baseline system of the same QoS of 0. Moreover, in test case 4, the PER is further improved getting benefit from the initial QoS level of 1 in S_t .

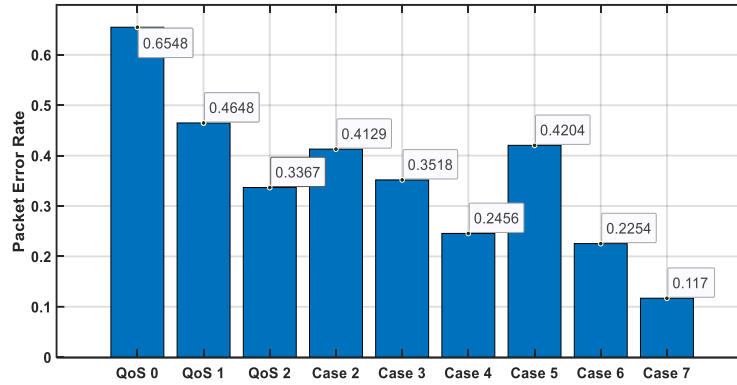


Fig.2 PER at S_t under different test cases

As mentioned before, in test cases 2, 3 and 4, both subscribers encounter the same channel condition. Then the PA scheme is expected to achieve an extra improvement in PER at S_t in cases when the channel between the broker and S_a (B- S_a) is less noisy with respect to the B- S_t channel. This is considered in test cases 5,6 and 7. The PER results show improvements of 36%, 52% and 65% each with respect to the baseline system of the same QoS.

These results have proved the significance of applying the PA scheme to improve the PER performance of target subscriber. However, this improvement comes with trade-offs, as it imposes additional retransmission demands on the assisting subscriber, leading to increased latency and energy consumption.

Fig.3 shows the average latency for the test cases of Fig.2, all normalized to the latency of the baseline system with QoS level 0. It shows a relative increase in latency due to the application of the PA scheme. But fortunately for the best PER cases (cases 4 and 7) this increase is in the order of 30% to 25%. The PER-latency trade-off provides a useful system design degree of freedom that enables the system to be customized to suit the requirements of the specific application.

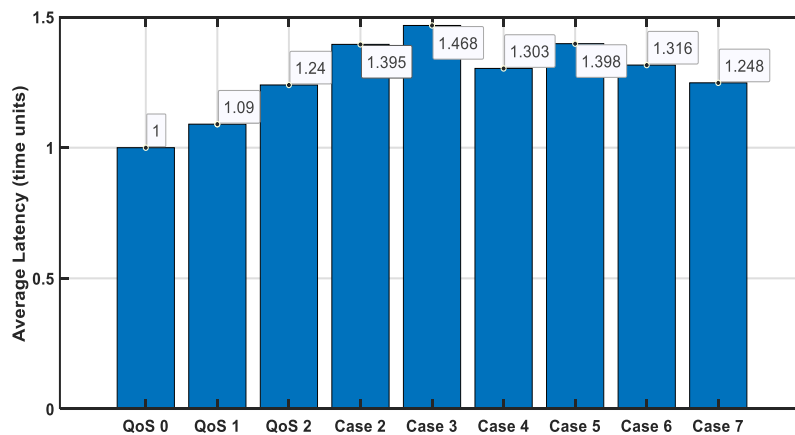


Fig.3 Latency at S_t under different test cases

However, the PA scheme achieves its advantages in terms of PER by involving S_a to assist S_t to recover its data correctly without requesting additional effort from the broker. Consequently, S_a (and, to a lesser extent, S_t) will consume more energy to accomplish this task. Fig.4 shows the energy consumption distribution among S_t , S_a and the broker, for the test cases of Table 1. For the baseline system the S_a is not involved, therefore the results show the energy consumed by just the target subscriber and the broker. Notably due to the nature of the conventional MQTT protocol, the broker consumes more energy as the QoS level increases.

Next, when PA is employed and S_a is involved, significant improvement in PER performance is achieved, off course at the expense of additional energy consumed by S_a . But most importantly, the results perfectly verify the primary objective of PA in enhancing the PER at S_t while avoiding imposing additional processing and transmission load on the broker. That is by comparing baseline system of QoS 2 with test case 3, which have almost equal PER performance, the PA scheme enables about 70% saving in broker energy consumption.

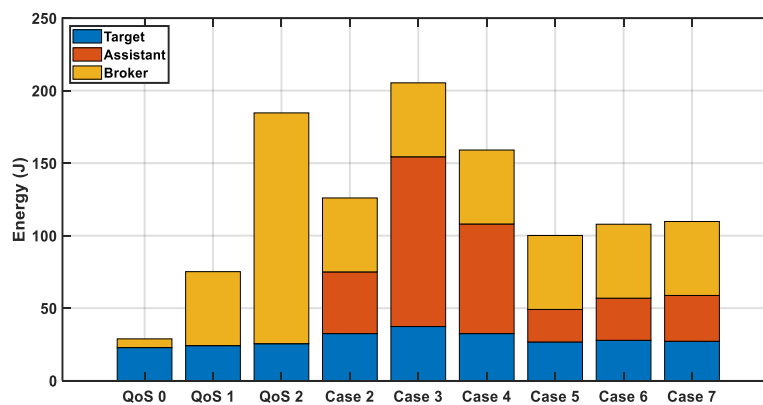


Fig.4 Energy consumption at S_t , S_a and the broker

The PA scheme successfully skews the energy consumption load, required to enhance the PER at S_t , from the broker which should be available to serve multiple subscribers and publishers, to the assistant subscriber S_a . This also contributes to extending the operational life of the broker power supply and saving energy resources that are usually limited. In IoT, the limited role of S_a as compared with the broker, makes the relative increase in its energy consumption reasonable and manageable.

Table 3 demonstrates that while Dynamic QoS (Palmese, Redondi and Cesana, 2022) adapts to network conditions, its broker savings (10-30%) and PER gains (40-60%) are highly variable. The PA scheme achieves more consistent improvements (65% PER, 70% energy savings) by static peer assistance and avoiding Dynamic QoS's tuning overhead. Unlike EMQX (Kashyap, Dev and Sharma, 2024) or CMQC (An, Joo and Kim, 2025), PA requires no infrastructure changes, making it viable for legacy IoT deployments.

Table 3 Comparison of PA Scheme with State-of-the-Art Retransmission Approaches

Approach	MQTT QoS 2	AdARQ (Bulo, Sonalika and Krishna, 2024)	Dynamic QoS (Palmese, Redondi and Cesana, 2022)	EMQX (Kashyap, Dev and Sharma, 2024)	CMQC (An, Joo and Kim, 2025)	PA Scheme (Proposed)
Key mechanism	Broker-managed retransmissions	Hybrid coding + feedback-based ARQ	Runtime QoS adjustment	Broker clustering	Centralized MQTT optimization	Peer-assisted local recovery
PER Improvement	~50%	~55%	~40-60%	~60%	~58%	65%
Broker Energy Savings	0%	20%	10-30%	40%	35%	70%
Latency Impact	+15-20%	+25-35%	+5-15%	+10%	+12%	+25-30%
Implementation	Native	High	Medium	High	High	None
Scalability	Low	Medium	Medium	High	Medium	High

Based on the obtained results, this study provides a view to the effects of applying the PA to enhance the PER at a target subscriber. The exact system parameter settings depend on the requirements of the practical IoT based system to achieve the expected performance. IoT-based smart city applications, such as intelligent traffic management, smart healthcare monitoring, and real-time environmental sensing, can significantly benefit from the enhancements provided by the PA scheme. In these applications, reliable data transmission is crucial, as packet loss can lead to incorrect decisions or delayed responses. By employing the PA scheme, smart city networks can achieve up to 65% PER improvement as compared to baseline systems with no peer assistance. For instance, in a real-time traffic monitoring system, where IoT sensors transmit critical congestion and accident data to a central controller, improving PER by this margin ensures more accurate and timely updates. This translates to faster response times for emergency services and optimized traffic flow, potentially reducing congestion-related delays by 20–30%, which compensates for the inherent increase in latency caused by PA. Moreover, in smart healthcare applications, such as remote patient monitoring, a 65% reduction in PER through PA can enhance the reliability of vital sign transmissions, ensuring that healthcare providers receive accurate data with minimal retransmissions, reducing overall latency by up to 25% in critical alerts.

Additionally, the PA scheme's ability to offload retransmission efforts from the central broker to assistant subscribers offers significant energy savings for large-scale smart city IoT deployments. In city-wide air quality monitoring networks, where thousands of sensors continuously report pollution levels, redistributing the retransmission load to local peer devices

can extend the operational life of the central processing nodes. The study findings suggest that shifting energy-intensive tasks from brokers to assistant nodes can reduce broker energy consumption by 70%, allowing it to support a higher number of connected devices without rapid depletion of its power supply. This feature is particularly beneficial for smart grids, where efficient energy management is essential for balancing supply and demand in real time. By optimizing energy use and improving network reliability, the PA scheme enables more sustainable and resilient smart city ecosystems, ensuring that critical services remain operational even under high traffic and adverse conditions.

6. CONCLUSIONS

In this paper the PA scheme has been proposed for IoT based applications to enhance the PER at a target subscriber, S_t , by the assistance of a neighboring subscriber, S_a . The proposed PA avoids increasing the broker burden to keep it available for requests from the other connected devices. Instead, PA relies on retransmission from S_a whose channel condition and/or QoS level is better as compared with S_t .

The tests show significant enhancement in PER by 46% when S_a has a higher QoS level, and by 52% when S_a is exposed to less noise than S_t . This improvement is obtained at the expense of a relative increase in system latency. The PA scheme provides a useful PER-latency trade-off which can be used to adjust system parameters according to the required performance. The PA succeeded to redistribute the energy consumption away from the broker to better comply to resource constraints.

The proposed scheme is promising in smart city applications that benefit from its the improvements and trade-offs. Possible future works can consider developing adaptive resource aware PA for specific IoT based applications and extending PA to more than one S_a .

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