Adaptive IoT Communication Protocols and Edge Optimization for Smart Urban Mobility Systems

Hafiz Humza Mahmood Ramza*, Laura Belli*†, Luca Davoli*†, Gianluigi Ferrari*†
* Internet of Things (IoT) Lab, Department of Engineering and Architecture, University of Parma, 43124 Parma, Italy
† things2i s.r.l., 43124 Parma, Italy
{hafizhumzamahmood.ramzan, laura.belli, luca.davoli, gianluigi.ferrari}@unipr.it

***Abstract*—Optimized communication protocols are required to deal with services, such as energy and traffic management, due to rapid proliferation of smart urban systems in time critical scenarios. This study proposes to optimize communication protocols for large scale Internet of Things (IoT) infrastructures utilizing edge computing architecture. Our proposed protocol is evaluated using co-simulation environments OMNeT++ and SUMO to evaluate adaptive communication via Constrained Application Protocol (CoAP) and MQTT. Our results show that CoAP reduces the amount of time needed for message processing, while MQTT minimizes delivery failures. The results emphasize that following prescribed rules for communication makes urban mobility more flexible and efficient in new city systems.**

***Index Terms*—Smart Mobility, IoT, CoAP, MQTT, Traffic Management, Urban Sensing, OMNeT++**

I. Introduction

Modern transportation infrastructures have encountered significant challenges due to the increasing complexity of metropolitan areas, including increased environmental impact, delayed emergency response capabilities, and increased traffic congestion. Traditional traffic management systems, generally centralized, are not always able to keep up with the changing and unpredictable character of modern traffic flows.

At the same time, modern technologies, such as Internet of Things (IoT) and edge computing, are changing smart mobility, by enabling more scalable, decentralized architectures, allowing faster, more localized decision-making processes.

In this context, a relevant example is the dynamic traffic signal control system proposed in [1] that, by combining the SUMO [2] traffic simulator with the MQTT protocol, exploits predictive modeling and heuristic methods, in the end highlighting the essential importance of communication-oriented solutions to improve urban traffic management efficiency.

In [3], diverse IoT frameworks for smart city applications are analyzed, emphasizing various architectural *trade-offs*. Likewise, in [4] a versatile network architecture easing real-time interoperability across diverse IoT devices is proposed. Then, in [5] the importance of peripheral computing in the context of Intelligent Transportation Systems (ITSs) to enable rapid and localized responses is emphasized, while the implementation of lightweight communication protocols as essential facilitators of scalable and decentralized infrastructure for forthcoming smart cities is investigated in [6]. In particular, this latter introduces an adaptive IoT communication architecture addressing various significant issues of current mobility systems, such as: (i) inflexibility of static communication protocols not working effectively when traffic and network conditions change [4]; (ii) latency problems related to centralized data processing, which can delay urgent communications (e.g., emergency messages and congestion alerts [6]); and (iii) lack of proper prioritization of important data when the bandwidth is limited, which can make essential services less reliable [1].

In order to evaluate the effectiveness of the proposed approach with lightweight protocols (such as MQTT and CoAP), OMNeT++ [7] is employed to simulate dynamic traffic conditions.

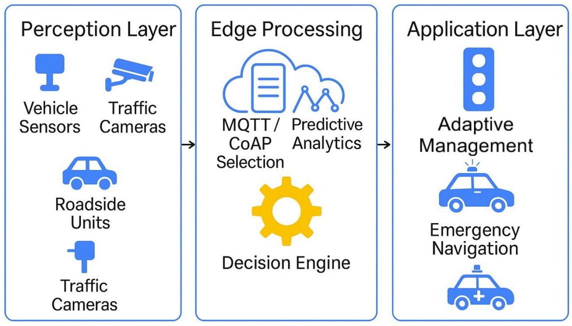

Fig. 1: Layers of the proposed IoT architecture.

II. System Architecture

The proposed system follows a three-layer architecture—namely, *perception*, *edge*, and *application*—as shown in Fig. 1.

Perception Layer: this layer comprises the IoT devices deployed in urban environments, including vehicle counters, traffic and parking sensors, and RoadSide Units (RSUs) gathering speed, congestion, and parking availability real-time data. Then, context and urgency guide the use of IEEE 802.15.4, Wi-Fi, and LTE-V2X [8] to handle data transmission via the Constrained Application Protocol (CoAP) [9].

Edge Layer: gateways collect CoAP messages from the perception layer, execute preliminary data filtering, and transmit relevant information using the protocol selected by the decision engine. A decision engine, integrated into OMNeT++, dynamically selects the optimal protocol—CoAP or MQTT—on the basis of factors such as message latency and success rate. Time-critical events (e.g., emergency vehicle routing) are

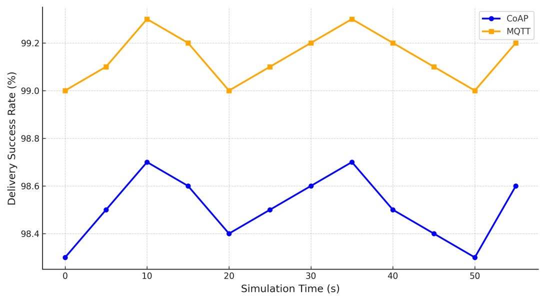

Fig. 2: Delivery success rate.

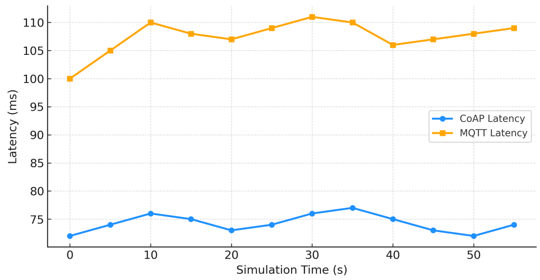

Fig. 3: Latency comparison.

eased by CoAP, whereas MQTT manages periodic, less urgent data transmissions.

Application Layer: this layer can provide mobility assistance services (e.g., signal control, parking guidance, and public transportation coordination). that might leverage real-time data exposed by the edge layer, processed through CoAP or MQTT, and accessed via internal APIs by higher-level applications for context-aware traffic management.

III. Methodology and Results

In order to evaluate the proposed framework, a simulation model has been developed to assess both traffic and network aspects, in detail blending SUMO for traffic modeling with OMNeT++ for wireless communication simulation. The testbed is built using a 4×4 square grid including 16 intersections, each with a traffic signal system. At each intersection, we simulate two vehicles and all these cars have on-board sensors, while each junction is installed with a RSU. The energy sensors send data each 5 s to edge nodes in OMNeT++ that, then, runs the protocol chosen by the user.

Information on traffic is often sent using CoAP since it reduces the response time. However, MQTT supports typical and non-critical updates (e.g., parking information). The selection of the proper protocol is managed by the decision engine developed in OMNeT++, whose key parameters are (i) traffic rate (taken from SUMO), (ii) emergency or routine nature of the message, and (iii) network performance details (including latency and packet loss). Then, the engine decides on the optimal protocol by comparing it to a set of standards and special rules based on the context of the message. The managed information is sent from the edge node to high-level applications by means of routing and scheduling by the node.

Data is collected by running simulations at low, medium, and high traffic amounts, then focusing on end-to-end software reaction times, rate of successful deliveries, and bandwidth consumed by each protocol.

The simulation reveals how both CoAP and MQTT behave differently when traffic changes. As shown in Fig. 2, the message delivery rate for MQTT is very high (99.2% on the average), whereas CoAP has the lowest latency (around 75 ms overall), as shown in Fig 3. These results suggest that protocol-aware communication techniques are valuable in smart mobility platforms for future flexible solutions.

IV. Discussion

These findings show that connecting urban mobility networks via CoAP and MQTT greatly improves both speed and stability. Being CoAP lightweight, it is perfect for speedy updates, while MQTT should be used for safe and continuous regular updates. As a result, both immediate decisions and making the most of resources are improved in situations where Internet bandwidth is reduced. ITSs need vehicles that can go fast and remain dependable to keep up with current demand.

V. Conclusion

In this paper, a framework relying on simulations to adapt IoT communications for urban mobility is presented. CoAP and MQTT protocols are evaluated in changing traffic environments to show that including context awareness results in better performance (in terms of latency and reliability). Next steps involve including V2X features and running the framework on edge tools (as used in practice).

VI. Acknowledgment

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