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Comparative analysis of application layer protocols in EV charging stations: evaluating HTTP, MQTT, and Websocket Performance Metrics

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ABSTRACT

In the burgeoning domain of electric vehicle (EV) technology, advancing supportive ecosystems is pivotal. There is a marked global uptrend in the adoption of EVs, necessitating a robust network of EV charging stations. The infrastructure and accompanying systems that govern these stations are integral to these stations. Increased utilization escalates the exigency for expeditious service at these charging points. This study undertakes a comparative analysis of three distinct data communication protocols at the application layer, specifically within the context of EV charging stations. The protocols scrutinized include Hypertext Transfer Protocol (HTTP), Message Queuing Telemetry Transport (MQTT), and Websocket. The benchmark for data transmission in this investigation is the delivery of energy information, adhering to the Open Charge Point Protocol (OCPP), a legally standardized open protocol. The data format employed is JavaScript Object Notation (JSON). Data transmission utilizing the three protocols above was intercepted and analyzed using Wireshark, a network protocol analyzer. Parameters such as latency (delay), jitter (variability of latency), and throughput (successful data delivery over a communication channel) were meticulously examined and subsequently represented graphically to enhance the interpretability of the network protocol performance. Despite identical data payloads, the findings reveal distinct transmission characteristics for each protocol. HTTP exhibited superior throughput, peaking at 31,621 bits per second (bps) during real-time data transmission. Conversely, MQTT demonstrated the most favorable latency and jitter metrics, both for real-time and periodic data dispatches. Websocket, however, registered the lowest throughput in real-time transmission, at 4,941 bps. These divergences underscore the importance of protocol selection based on specific performance criteria within EV charging station ecosystems.

1. Introduction

Mitigating the greenhouse effect and urban air pollution is an environmental imperative. A strategic approach towards this goal involves the diminution of reliance on conventional combustion engine vehicles and the transition to electric vehicles (EVs), as substantiated by several studies [1]–[5]. EVs represent a burgeoning and promising sector for future transportation modalities [2], [3], [6], with the potential for expediting the digital transformation of traditional vehicular paradigms. This rapid digitalization stems from the evolving requirements of EV users and the consequential demands placed on the supporting ecosystem [4], [6]–[8]. Integral components of this ecosystem encompass a spectrum of infrastructures such as EV charging stations, their management systems, the requisite power supply networks, and energy storage solutions [2], [6]. These facets are inextricably linked with

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advancements in information and communication technology (ICT) [8]. Given this interdependence, the proliferation of EVs, buttressed by concurrent ICT developments, constitutes a dual-faceted progression that is reshaping the landscape of urban transportation and energy management [9], [10].

Contemporary trends indicate a burgeoning interest in electric vehicles (EVs), commensurate with the growth observed in the EV market [8], [11]. This burgeoning interest invariably escalates the demand for an expanded network of EV charging stations, necessitating advancements in their management structures [12], [13]. A critical component of these structures is the data communication system, which facilitates the bidirectional flow of information between the charging stations and central servers [14]–[17]. The need for efficiency and expediency in the charging processes underscores the imperative for real-time data communication. EV owners benefit from the immediate processing of their transactions, facilitated by the continuous connectivity between the charging stations and the server [18]. This seamless exchange ensures that both entities are apprised of the operating conditions, enhancing charging efficiency [19]. At the forefront of these communication protocols is the Open Charge Point Protocol (OCPP) [19], [20]. As an open standard for network communication between EV charging stations and server-based Charging Station Management Systems (CSMS), OCPP is pivotal in enabling functionalities. These functionalities include but are not limited to, user authentication, real-time charging data transmission, and status updates of the charging infrastructure [20]. The protocol’s openness and flexibility make it an integral part of the digital architecture underpinning the EV charging ecosystem.

Prevailing research underscores the significance of enhancing data communication systems at EV Charging Station (EVCS), contributing vital knowledge to the field. To substantiate the development of the current study, a comprehensive review of antecedent research is imperative. The literature reviewed pertains predominantly to EVCS's data communication systems and performance evaluation of data transmission. Several precursory studies have delved into the frameworks of data communication systems and the performance metrics of data communication protocols within EV charging stations. For instance, one investigation delineated the data communication processes between EV charging stations and servers, utilizing Amazon Web Services for implementation [21]. The study yielded insights into CPU and memory utilization across a designated array of EV charging stations. However, it did not extend to evaluate the performance of the data communication system. Another scholarly work surveyed and contrasted the challenges and protocols at the application layer within the Internet of Things (IoT) technology for smart farming [22]. It undertook a literature review of seven application layer protocols — MQTT, CoAP, XMPP, AMQP, DDS, REST-HTTP, and Websocket — applied to smart agriculture, providing comparative data on latency, energy consumption, throughput, and bandwidth requirements. However, the study concentrated on literature comparison rather than presenting empirical data on protocol performance at the application layer and was explicitly focused on innovative agricultural technology implementations.

Furthermore, a different study explored the deployment of MQTT within EV charging systems [23]. This research aimed to modify the MQTT protocol for efficacy in EV charging station data communications. Nevertheless, it did not employ the standardized OCPP protocol for data transmission and omitted an assessment of the implemented MQTT protocol's performance.

This research is devised as a contribution to existing scholarly work in data communications for electric vehicle charging infrastructure. It zeroes in on deploying a data communication system that adheres to the Open Charge Point Protocol (OCPP) guidelines. The study examines three predominant protocols at the application layer, which were judiciously selected to mirror current trends in protocol utilization—a selection informed by the analysis of recent data from Google search trends. The protocols under investigation include Hypertext Transfer Protocol (HTTP), Message Queuing Telemetry Transport (MQTT), and Websocket. The focal point of this empirical study is the transmission of charging data, including voltage, current, power, and energy status, all within the purview of the OCPP. This data is conveyed using the three selected protocols—HTTP, MQTT, and WebSocket. Subsequent performance evaluation of these protocols is conducted through the network protocol analyzer, Wireshark. This analysis encompasses critical performance metrics such as delay, jitter, and throughput, thus comprehensively assessing each protocol's efficacy within the specified application layer context.

2. Method

In this section, we delineate the methodological approach adopted to ascertain the most efficient data communication protocol for use within electric vehicle charging station systems. Our research is specifically structured to facilitate a comparative analysis of three application layer protocols: HTTP (Hypertext Transfer Protocol), MQTT (Message Queue Telemetry Transport), and WebSocket. The experimental design is crafted to evaluate these protocols' operational efficiency, reliability, and suitability for the intended application. To achieve this, we will implement each protocol in a simulated environment that closely mirrors electric vehicle charging stations' network conditions and communication demands. The protocols will be scrutinized under scenarios reflective of real-world usage, including stress tests to evaluate performance under high demand and tests to measure resilience against common network issues such as latency and packet loss. Each protocol's throughput, latency, and jitter will be compared. The data will be collected and analyzed systematically to ensure the accuracy and reproducibility of results. Through this rigorous examination, the research aims to identify which protocol provides the optimal balance of speed, stability, and data integrity in the context of electric vehicle charging station communication systems. The findings will contribute valuable insights into selecting appropriate communication protocols for the burgeoning electric vehicle infrastructure:

2.1. Performance Characterization of Data Communication Systems

In previous research, one way to determine the performance characteristics of a network consists of several parameters, including latency, throughput, and jitter in data transmission. Delay is the time it takes for a packet to be sent from one device to another. Long queues or taking other routes to avoid routing congestion cause delays in the packet transmission process in computer networks. Distance, physical media, and traffic jams can cause delays. To calculate the delay for a sent packet, divide the period by the sent packet. The following equation can be used to calculate the average value of latency.

$$\text{Average Latency (ms)} = \frac{(x_1+x_2+\cdots+x_n)}{n} \tag{1}$$

Where:

x = latency value of data transmission (in ms)

n = the amount of data transmission latency

Meanwhile, Throughput is the actual bandwidth measured during file transmission. In contrast to bandwidth, which has the same units of bits per second (bps), throughput describes the actual bandwidth at a particular time and under certain conditions and networks used to download files of a specific size. Throughput is calculated by dividing the total number of successful packet arrivals observed at the destination during a specific time interval by the duration of that time interval [24], [25]. The following equation can be used to calculate throughput values.

$$\text{Average Throughput (bps)} = \frac{(x_1+x_2+\cdots+x_n)}{n} \tag{2}$$

Where:

x = throughput value of data transmission (in bps)

n = the amount of data transmission latency

Then, jitter is a variation in the delay time of sequential packets, which is usually caused by the density of the data communication system in a network [26]. Jitter can also significantly affect real-time services/applications in data transmission. A jitter with a small value may be acceptable, but if it increases, the data transaction process between the charging station and the server will also be disrupted [27], [28].

2.2. Network Architecture

The network architecture used in this research can be seen in Fig. 1. In the network architecture, three entities and one tool capture the data. The first entity is an electric vehicle being charged at the second entity (electric vehicle charging station). The data recorded by the electric vehicle charging station is data on voltage, current, power, and energy used when charging the electric vehicle after the process—authorization and transactions from verified electric vehicle users

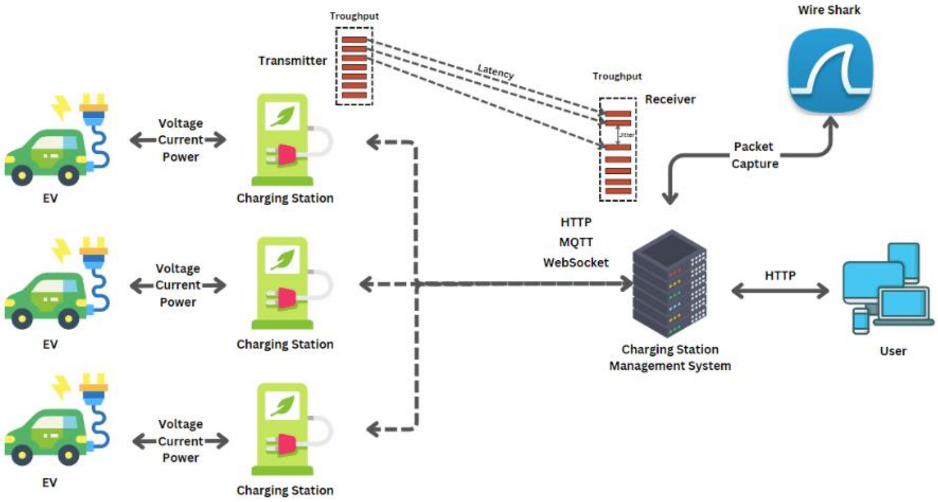


Fig. 1. Network System Architecture

The authorization and verification process is carried out by the electric vehicle charging station with a server (Charging Station Management System) via a specific network protocol [29], [30]. Wireshark then captures the delivery data to analyze speed, delay time, and network throughput [31].

Analysis of sending data from electric vehicle charging stations to the server (Charging Station Management System) in this research was carried out at the outermost network layer, namely the application layer. As previously mentioned, the data communication protocol at the application layer studied uses HTTP, MQTT, and WebSocket data communication protocols. Then, for the data transport layer in this research, the TCP / IP protocol uses IPv4 at the network layer. Then, data communication is carried out wirelessly (without cables) with the device hardware that meets the IEEE 802.11n standard as its wireless communication. More details can be seen in Fig. 2.

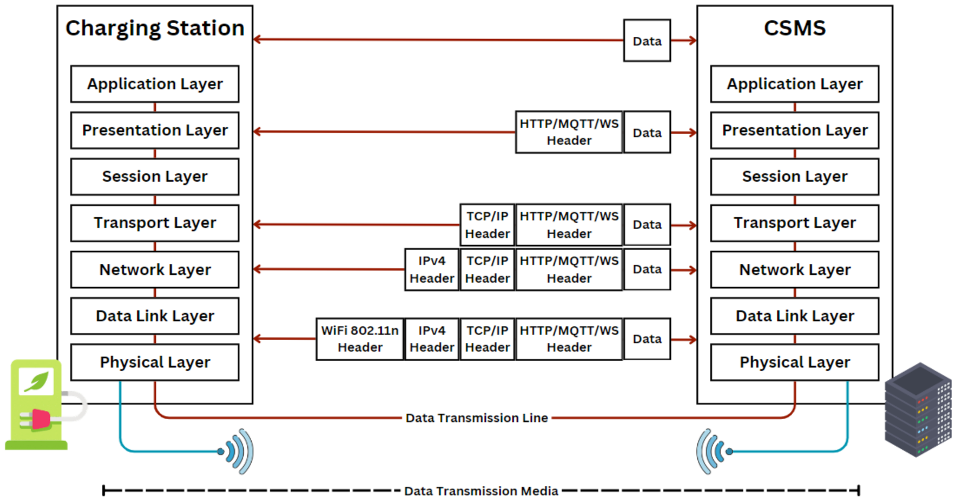


Fig. 2. OSI Data Communications Layer

2.3. Data Communication between Public Electric Vehicle Charging Stations and CSMS

One of the data communication protocols that is currently standardized is the OCPP data communication protocol. The OCPP (Open Charge Point Protocol) data communication protocol allows electric vehicle charging stations to be easily accessed with published data communication rules. Several development versions of this protocol have been developed, from version 1 to version 2. The OCA (Open Charge Alliance) continues developing this protocol to continue developing features that make it easier for users and developers to use and create electric vehicle charging stations.

Some of this communication protocol's features are data communication flow at electric vehicle charging stations, firmware management so that the software installed on the controller can be updated, diagnostic data at electric vehicle charging stations, and data authorization management for users or charging station owners. Electric vehicles, as well as managing additional innovative charging features for electric vehicle charging stations that can support these features and many others [30], [32]. This research considers the data format used in the OCPP data communication protocol. The data format used is defined in JavaScript Object Notation (JSON) format according to the data sent on the OCPP protocol. The OCPP version used is version OCPP 2.0.1, and the data used in this research is data on the delivery of voltage, current, and active power when charging an electric vehicle. Based on documentation from OCPP, sensor data sent periodically when charging an electric vehicle consists of connector ID, transaction number, time record, sensor unit, and sensor value. For more details, see the Fig. 3.

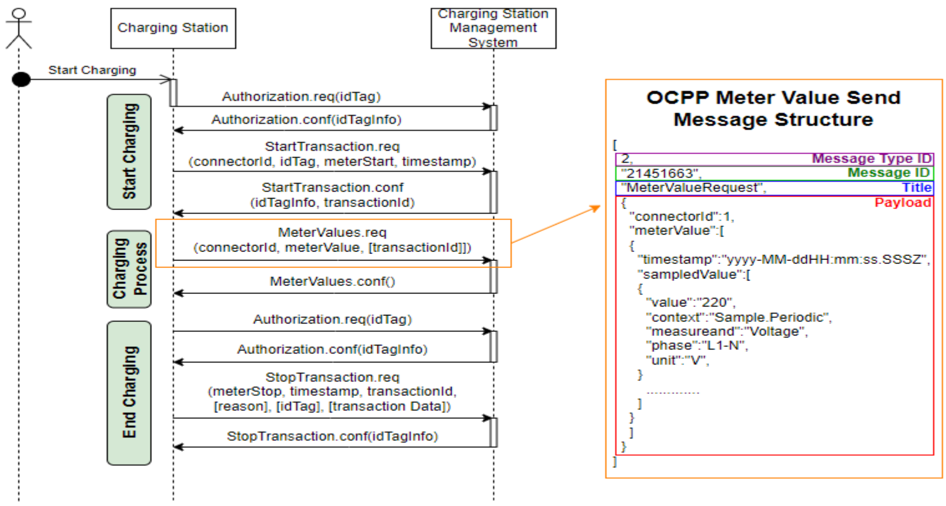


Fig. 3. Data transmission process

2.4. HTTP, MQTT, and WebSocket protocols at the Application Layer

As previously explained, this research uses three different protocols at the same layer, namely the application layer. The communication protocols used in this research are the HTTP, MQTT, and Websocket data communication protocols. Sequence diagram show as Fig. 4.

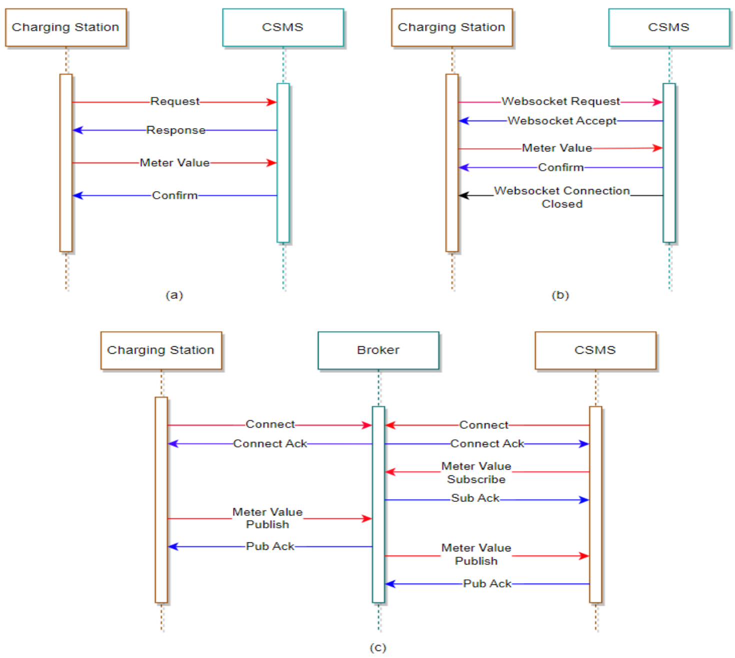
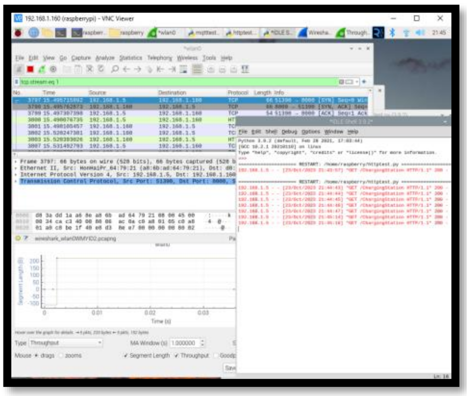


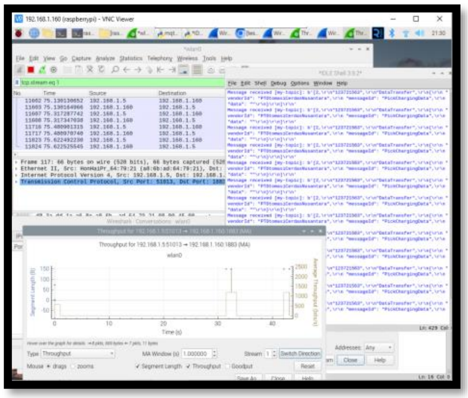
Fig. 4. Sequence diagram (a) HTTP (b) Websocket (c) MQTT

2.5. Sniffing Data

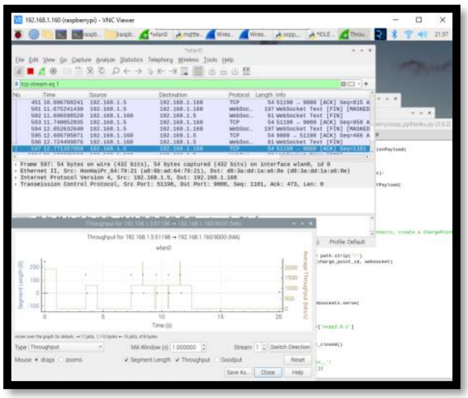
Wireshark can be used to analyze traffic or sniff data on a network [33]. Wireshark is a data packet analysis tool published publicly (freely). Wireshark is also widely used by network administrators and cyber security experts for several things, such as solving network problems, analyzing data packets on the network, developing applications, and developing data communication protocols [31]. This research uses Wireshark to obtain data on data transmission times, jitter, throughput, and packet loss, which can then be used to analyze the performance of several data communication protocols used at electric vehicle charging stations further [34]. Fig. 5 is an example of data sniffing with Wireshark.



(a)



(b)



(c)

Fig. 5. Packet Header (a) HTTP (b) MQTT (c) Websocket

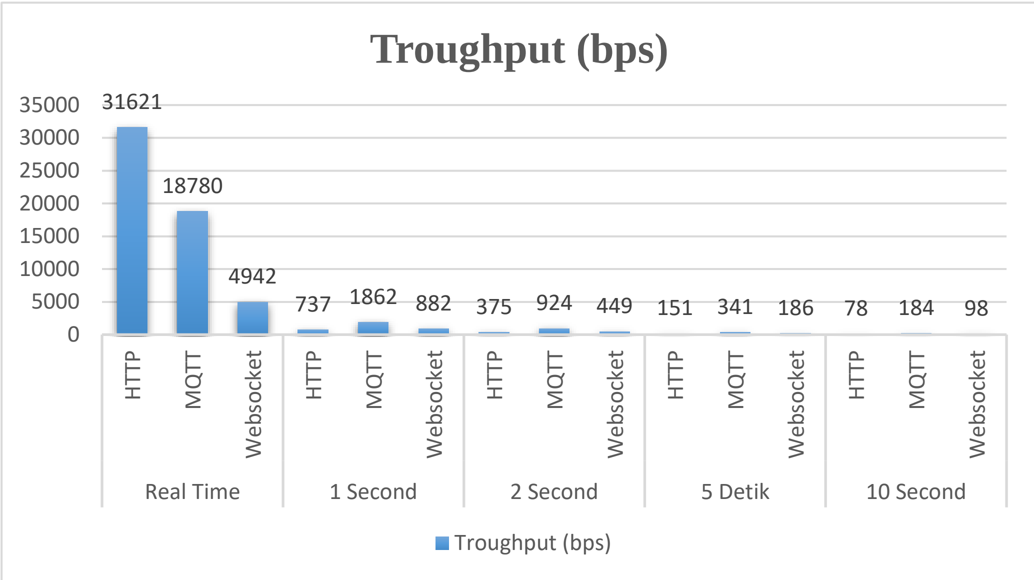
3. Results and Discussion

This section delineates the outcomes of comprehensive system testing utilizing the HTTP, MQTT, and WebSocket protocols, assessed under varying data transmission delays. The graphical representation in Fig. 6 elucidates the comparative analysis of these three protocols, considering metrics such as throughput, latency, and jitter. The data were categorized based on temporal factors, distinguishing between real-time and periodic transmissions over 1, 2, 5, and 10 seconds. The collection of data was conducted over 10 minutes after the initiation of data transmission.

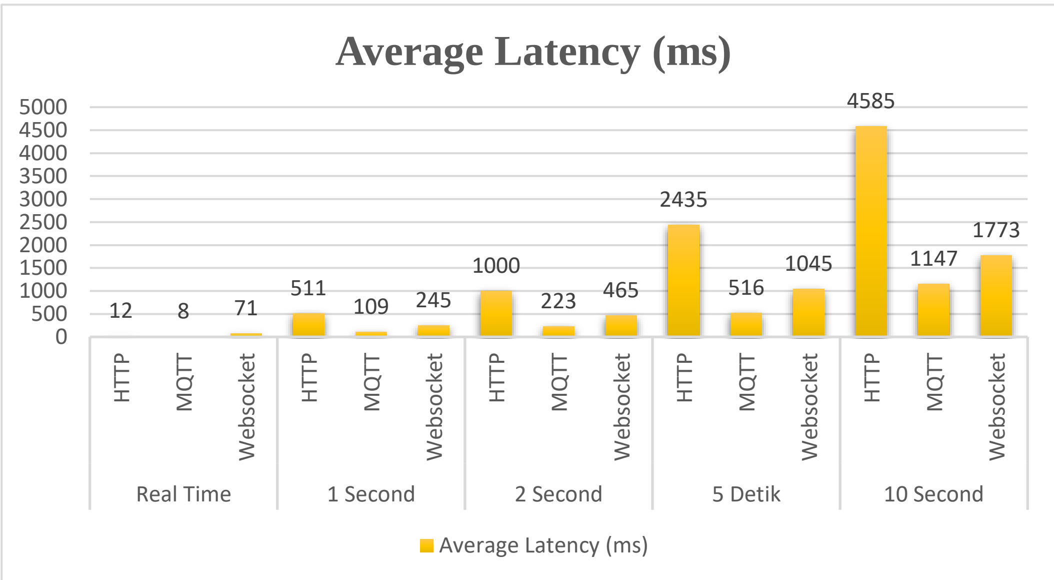
The empirical findings reveal that the HTTP protocol exhibits the highest throughput, registering 31,621 bytes per second in real-time data transmission scenarios. Contrastingly, periodic testing revealed a diminution in throughput for the HTTP protocol, positioning it inferior to the alternative protocols under comparison. Conversely, the MQTT protocol demonstrated superior performance in terms of latency, with a minimal delay of 8 milliseconds during real-time data transmission. This trend persisted across periodic data dispatches, where MQTT consistently outperformed its counterparts, maintaining the lowest average latency values at 109 ms, 223 ms, 516 ms, and 1147 ms for the respective 1, 2, 5, and 10-second intervals.

Furthermore, the MQTT protocol was identified as having the lowest jitter value at 14 milliseconds for sequential real-time data transmission. In scenarios of periodic data conveyance, MQTT upheld its leading position, evidencing the lowest average jitter values of 169 ms, 390 ms, 983 ms, and 2231 ms across the designated temporal ranges. This comprehensive assessment underscores the protocol-specific dynamics in handling data transmission, reflecting their respective efficacy and suitability for different communication needs.

In this study, we found that the data transmission system at electric vehicle charging stations based on data standards from OCPP uses three protocols at different application layers, which have their characteristics where the MQTT protocol has a lower data transmission latency value compared to the other two protocols even though the HTTP data communication which has the highest data transmission throughput value when data is sent in real-time. Then, for periodic data transmission, the MQTT protocol is better than other data communication protocols, with the highest throughput value and the lowest latency and jitter values. This shows that the data transmission system's character is different by using protocols at different application layers.



(a)



(b)

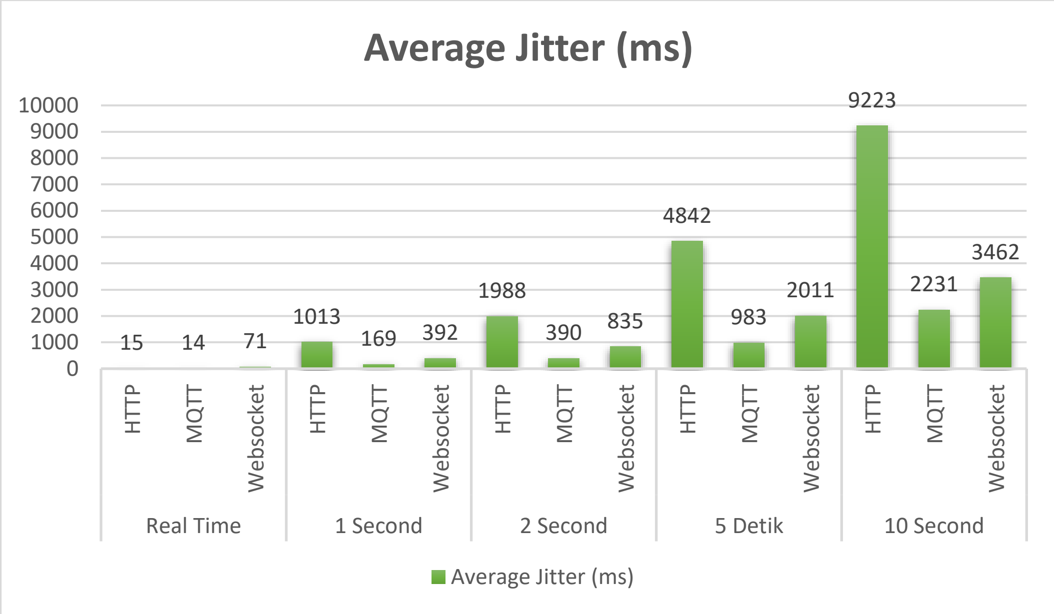


Fig. 6. Data (a) Throughput (b) Latency (c) Jitter

The heterogeneous performance of data communication protocols identified in this research extends beyond technical implications, casting a wider net on societal dimensions. The efficacy of these protocols in expediting transaction processes at electric vehicle (EV) charging stations has a ripple effect on social behavior and urban mobility patterns. Faster and more reliable charging experiences could encourage a more significant segment of the population to transition to EVs, supporting environmental initiatives and reducing the carbon footprint associated with transportation.

In designing EV charging stations, selecting data communication protocols becomes not merely a question of technological proficiency but also of social responsibility. The burgeoning network of EV charging stations will have to manage an escalating volume of data, which, if not handled proficiently, could lead to systemic inefficiencies and a subsequent public reluctance to adopt EV technology. The prospect of extended waiting times and unreliable charging could undermine public confidence in EVs as a viable alternative to conventional vehicles.

As urban centers continue to grow and the imperative for sustainable transport solutions becomes more acute, the need for robust data communication systems to support a high density of charging stations becomes crucial. It is incumbent upon city planners, policymakers, and technologists to collaboratively forecast the growth of EV usage and preemptively address potential data congestion issues.

Moreover, there is a need for an inclusive approach to deploying EV charging stations to ensure that all segments of society benefit equally from advancements in EV technology. The digital divide — the disparity in access to digital technology — could be mirrored in a 'charging divide' if careful attention is not paid to the accessibility and availability of charging infrastructure. Equitable access to charging stations, informed by the performance capabilities of various communication protocols, is essential in avoiding a scenario where EVs become a luxury only accessible to specific demographics.

Finally, the selection and implementation of data communication protocols in EV charging stations transcend technical performance; they become pivotal in shaping the societal landscape, influencing environmental sustainability, and ensuring equitable access to clean transportation solutions. Therefore, this research contributes to the technical discourse on protocol performance and the broader dialogue on sustainable societal progress

4. Conclusion

In conclusion, this research analyzed the performance characteristics of data communication protocols at the application layer, specifically HTTP, MQTT, and Websocket, which are integral to the architecture of electric vehicle charging stations' data communication systems. The findings from the empirical tests reveal distinct transmission characteristics for each protocol when handling identical data payloads. The HTTP protocol demonstrated the highest throughput, achieving a real-time data transmission rate of 31,621 bits per second (bps). In contrast, the MQTT protocol exhibited the lowest latency and jitter, suggesting its efficiency for real-time and periodic data exchanges. Meanwhile, the WebSocket protocol was observed to have the lowest throughput during real-time transmission, with a rate of 4,941 bps. These results have significant implications for designing and selecting data communication protocols in EV charging station infrastructures. They underscore the necessity of protocol selection based on specific performance requirements, which could enhance the charging process's efficiency and user experience. Given these insights, future research could explore the scalability of these protocols across multiple charging stations and investigate their performance in other operational scenarios, such as user data validation and transaction processing.

After the analysis conducted in the current study, future research endeavors may explore data communication systems at electric vehicle charging stations on a broader scale, particularly considering many charging stations beyond the singular framework. The extant research reveals that varying data communication protocols manifest distinct characteristics, indicating that the scalability of charging stations may further delineate these differences. Moreover, the scope of data communication characterization can be expanded to include additional operational facets such as user data validation and transactional processes. These elements are pivotal to the overall efficacy and security of the charging station infrastructure and could benefit from a deeper investigation into their interaction with different communication protocols.

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