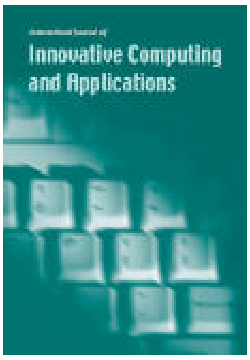

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Implementation of cloud service platform for monitoring charging facility status of electric vehicle based on MQTT

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Abstract: Aiming at the heterogeneous charging facilities of many manufacturers, the difficulty of communication and information sharing among devices, we design a cloud service platform for monitoring the status of charging facilities of electric vehicles. Firstly, the network topology structure of cloud service platform is given. Then, the logical architecture and functions are designed. The information collection, pushing process and security design of the cloud service platform are described in detail. Finally, the implementation and performance tests of the presented system are carried out. The contribution of this paper is that the proposed message queuing telemetry transport (MQTT)-based internet of things middleware can provide remote parameter configuration and information acquisition functions for charging facilities, shield the underlying hardware devices, realise data interaction between the sensor layer and the upper application, and integration of multi-source information of heterogeneous devices. The research results that the present method has the practical application value.

Keywords: electric vehicle; charging facility monitoring; cloud computing; message queuing telemetry transport; MQTT; middleware.

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1 Introduction

With the development of the vehicle with new energy technology and the use of clean energy, electric automobiles have the advantages of less pollution and lower cost, so it is widely obtained the support of the government, enterprises and consumers. Vehicles had become an information infrastructure in current society (Hussain and Beg, 2019). However, electric automobiles have problems such as short mileage and battery charging during the long time of driving. The information infrastructure construction of electric automobile charging has become the key factors to the wide promotion and application of the vehicle with new energy.

With the wide use of electric vehicle, it is easy to cause large-scale accumulation of electric automobiles at the peak of charging, resulting in traffic jams near charging facilities and long waiting time for users to charge. Therefore, Zhang et al. (2018) proposed a charging path planning method for large-scale electric automobiles based on real-time information interaction system, which takes into account the information of traffic and charging station. The experimental results show that the charging facility based on the information interaction can ease the traffic jams near the charging station, reduce the user charge waiting time of the electric automobile and improve the utilisation rate of the charging facility. However, the quality level of different electric automobile charging facilities manufacturers is uneven. The potential safety hazards of the charging facilities are easy to cause the safety problems to the users, the electric automobiles and the charging facilities. How to realise the remote safety monitoring of the charging facilities is the fundamental guarantee for the development of the electric automobile. Chen et al. (2018a) developed a DC charging pile detection vehicle, which can simulate the output current and monitor the voltage of the DC charging pile during the normal charging process. In addition, it can also test its control performance and communication performance, so as to effectively improve the detection efficiency of charging pile equipment. However, the detection vehicle cannot detect charging facilities remotely, which limits its wide range of applications. In addition, intelligent vehicle-to-vehicle charging navigation is also important for remote charging facilities to be made for usage. Different vehicle communication based on VANET or ad hoc network is proposed (Li et al., 2018, 2019b). And more battery models are proposed for vehicle charging (Cao et al., 2018; Hidalgo et al., 2018).

Cloud computing is a distributed computing model, which has been widely studied and used in smart grid information management systems. For example, Liu et al. (2018b) studied and applied the power software testing technology based on cloud computing. Zhao et al. (2018) designed and implemented an intelligent energy-using internet cloud platform with using information sensing and internet technology, and developed a boiler internet of things (IoT) monitoring system. Vehicular cloud becomes a basic facility to enforce the vehicle-to-vehicle communications (Foh et al., 2016; Wu et al., 2018). And big data can be applied in the cloud system for better analysis and usage for different objects (Wu et al., 2016a, 2016b). By integrating 'internet + intelligence', the interconnection of energy-using enterprises had been well achieved.

Most of the existing studies are designed for specific devices, which cannot solve the problem of information exchange among the charging facilities of various manufacturers at present. Besides, it cannot serve the remote information sharing service of charging facilities in cloud environment. IoT technology is essentially an extension of internet technology (Pethuru and Anupama, 2017), which realises the information exchange between any objects. At present, it has entered the era of industrial IoT application and development (Lian et al., 2018; Yin et al., 2018). The development of IoT technology and big data research provide the key application technology support for intelligent application of smart grid (Huang et al., 2018; Liu et al., 2018a). An intelligent home energy management architecture based on big data analysis of internet of things is designed in Singh and Yassine (2018). Message queuing telemetry transport (MQTT) is a lightweight message transmission protocol of internet of things for publish and subscribe service (Hillar, 2017; Oliveira et al., 2018). Many IoT devices use MQTT for real-time information exchange through the traditional internet, which is more reliable and lower network bandwidth consumption than using the traditional HTTP protocol to transmit internet of things information. Maase et al. (2018) developed an assessment platform based on charging data, in which the specific location information about the performance of charging infrastructure is visualised. Chen et al. (2018b) established a two-stage model for optimising the EV's charging and charging pile's selection.

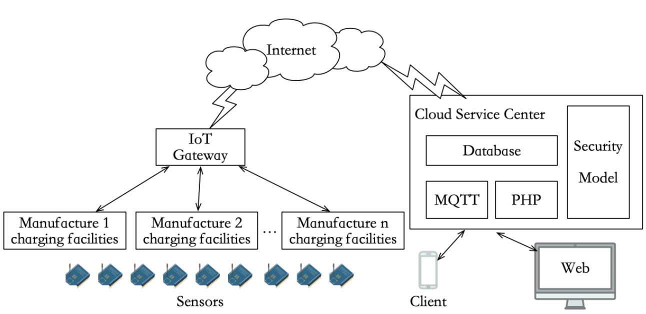
In this paper, based on the MQTT protocol, we design a cloud platform that supports the information acquisition and data sharing of the charging facilities of electric automobiles with different manufacturers. It realises the information interconnection among the charging terminal devices, effectively promotes information management and construction of charging facilities, and provides network information service technology support for the application of the electric automobile under the 'internet + environment'. The contribution of this paper is that the proposed MQTT-based internet of things middleware in the cloud platform can provide remote parameter configuration and information acquisition functions for charging facilities in smart grid environment, shield the underlying hardware devices, realise data interaction between the sensor layer and the upper application, and realise the integration of multi-source information of heterogeneous devices. The research results have important application value for improving the automation level of electric vehicle charging facilities monitoring and the real-time information interaction among heterogeneous devices of electric vehicles.

The rest of the paper was organised as follows: the network topology of cloud service platform for monitoring charging facility of EV was built in Section 1. In Section 2, we gave the details of the presented cloud platform. Section 4 mainly describes the designations of the detailed modules. The results were analysed in Section 4. Finally, Section 5 concluded this paper.

2 Network topology of proposal cloud service platform

The cloud service platform for monitoring electric automobile charging facility based on MQTT aims at information sharing service to realise the transmission, storage, query, push and services of sharing data among different users. Figure 1 shows the overall network topology of cloud service platform for electric automobile charging facilities monitoring, including data acquisition, transmission, storage and information sharing models. The charging facilities of each manufacturer use current, voltage, temperature and other types of sensors to collect the information of charging facilities, and transmit the information to the cloud platform through the IoT gateway. IoT gateway supports various networks (such as WiFi, NB-IoT, LoRa, 3G, 4G, 5G, etc.) to connect charging facilities, and transmits information to cloud service centre through MQTT protocol. The data is received and resolved through the MQTT protocol with cloud service centre, and then stored in the database of the cloud platform. The cloud service centre uses MQTT to push the subscribed information to the related client. The web information is visualised by PHP technology to provide services for the upper application. It can provide API and Web services for electric automobile users, charging facilities manufacturers, equipment safety monitoring departments, power enterprises and so on. The security module of the whole platform design ensures the data security, equipment security and platform reliability by carrying out security protection mechanism for all aspects of the cloud service platform. The following are detailed technical introductions to the monitoring cloud service platform of electric automobile charging facilities designed in this paper.

Figure 1 The network topology of cloud service platform for monitoring charging facilities (see online version for colours)

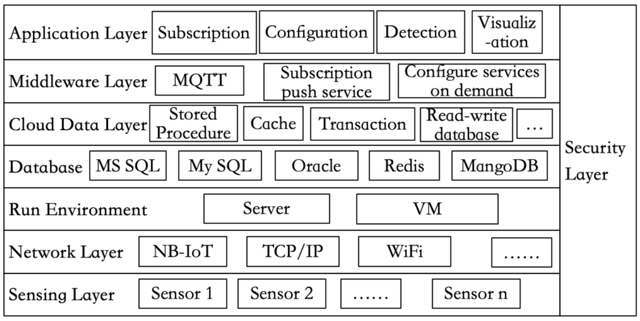


3 Design of cloud service platform

3.1 Logical architecture of cloud service platform

The logic architecture of the designed cloud service platform is shown in Figure 2. It is mainly divided into the sensing layer supporting various sensors, the network layer for network transmission, the running environment of the server, the database layer for storing data, the cloud data layer for cloud data processing, the MQTT middleware layer, the upper application layer and the security layer for ensuring security services.

Figure 2 Cloud services platform logic architecture



- Sensing layer: this layer is the raw data information which collected by the sensor of charging facility, such as current, voltage, equipment status and so on.
- Network layer: the source data collected by the charging equipment of each manufacturer is transmitted to the cloud platform through the network (such as 3G, 4G, NB-IoT, WiFi, etc.) for the cloud platform to receive and store data information.
- Cloud data layer: this layer can analyse and format the data which received by the cloud platform, and then store the data in the cloud database and provide the data access service of the remote terminal.
- Middleware layer: in view of the problems of the heterogeneous charging facilities of major manufacturers, the difficulty of communication and interaction between equipment information, the lack of real-time information sharing, MQTT is a lightweight message publishing and subscription protocol. The designed internet of things middleware based on MQTT can provide remote parameter configuration and information collection functions for each charging facility among different manufactures, and shield the underlying hardware devices. Beyond that, it realises the data interaction between the sensor layer and the upper application, and also achieves the integration of multi-source information of heterogeneous devices. In addition, this layer can provide different information services according to the different application requirements.

- Application layer: it provides user registration, login and management, and also by using MQTT protocol to provide heterogeneous terminal subscription, push and management, and also other special services.
- Security layer: this layer is to ensure the secure transmission of communication process data. Users with different permissions to query cloud platform services will also get different access information.
- Database: it supports different types of databases and provides data storage to each manufacturer, such as MySQL, Redis, MongoDB, Oracle, and so on.
- Running environment: it supports independent deployment of cloud platforms, or third-party virtual machine environments deployment of cloud platforms to provide services.

Through the application of MQTT protocol to collect the monitoring data of electric automobile charging facilities, the electric automobile charging facility monitoring cloud service platform based on MQTT can effectively push the collected data information to the electric automobile users in time and effectively after processing through the cloud platform, especially in the charging peak period, it can provide relevant information to users in time to avoid traffic jams or charging waiting time. In the aspect of remote equipment detection, it can effectively be compatible with the equipment of major manufacturers. Besides, it provides security authentication function to ensure the network access security of electric automobile users and power enterprise facilities.

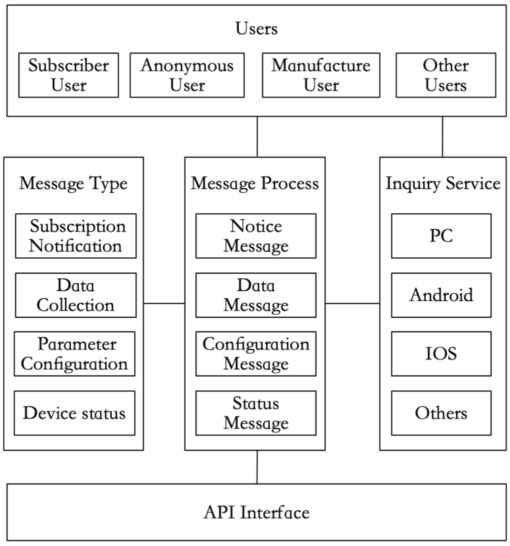
3.2 Functions design of the proposed cloud service platform

Because the charging facilities information types of each major manufacturer are different, the message type pushed by this cloud platform based on MQTT protocol is designed as follows: subscription notification, data collection, parameter configuration, device status. The cloud platform supports pushing various types of messages to subscribed users or enterprises, and supports PC, Android, IOS and other mobile terminals for query services. Besides, the cloud platform also provides APIs which are customised to add functions according to the needs of major manufacturers. The functional block diagram of the cloud service platform designed in this paper is shown in Figure 3.

3.3 Information collection and push process design of cloud service platform

In the cloud service platform, it stored multi-source heterogeneous big data from various manufacturers. After collecting through the internet of things gateway, the information is uniformly formatted through an information processing module and transmitted to the middleware of the cloud platform by using MQTT protocol, and then stored in the cloud database after information processing through the middleware of the cloud platform.

Figure 3 Functional design of cloud service platform



The database reading and writing module provides the API interface for each MQTT user service to call the service. MQTT client supports user subscription, query, manufacturer's remote detection of the device and the collection of configuration information and instruction. Figure 4 shows the information collection and push process of the designed MQTT-based cloud service platform.

Figure 4 Information collection and push design of cloud service platform based on MQTT

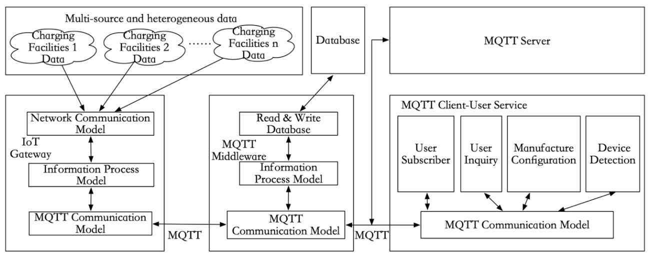
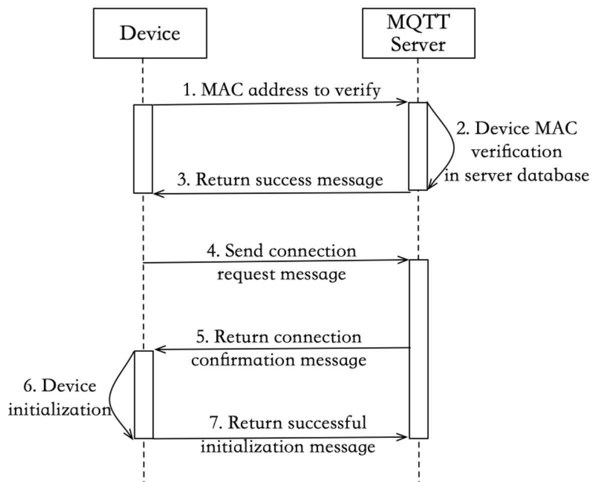


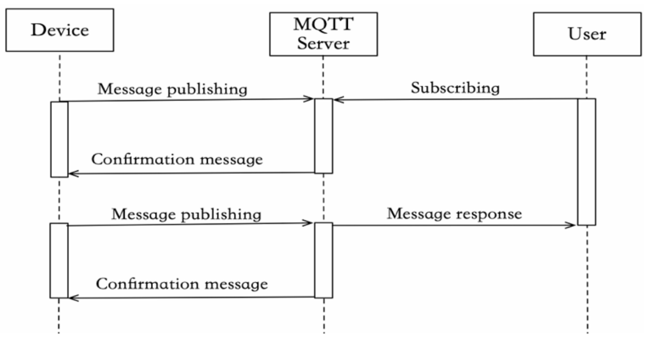
Figure 5 The flow diagram of device initialisation



When the charging facility device connects to the server for the first time, it needs to send a connection establishment message. The MQTT server needs to verify the identity of the device. After confirmation, it can connect to the MQTT server. Each device has a unique MAC address. When the device is connected, it provides the MAC address as the device's unique security identifier (Nizzi et al., 2019; Xiao et al., 2018). After passing the authentication, the manufacture users and device can subscribe and publish the message, and regularly send the heartbeat message to maintain normal communication with the MQTT server. Figure 5 is the flow diagram of device initialisation when the device connects to the MQTT server.

In typical network communication area, in order to ensure the availability of the server or the online equipment, it is necessary to periodically send 'keep alive' message for network communication status detection (Fan et al., 2017). Heartbeat detection mechanism is one of the most important mechanisms in the internet of things and cloud services environment (Hong and Lee, 2017; Kwon and Lee, 2019). The MQTT server will send a control message to the client during the heartbeat cycle, and a response message come back if the client is online; if the message response message is not received after the timeout, the connection of the current device is considered interrupted and the service is unavailable. In this system, the heartbeat cycle is set to 30 seconds. If the device information does not respond within 30 seconds, the connection is closed. Figure 6 shows the timing chart of device and user message push based on MQTT.

Figure 6 The timing diagram of device and user message push based on MQTT



3.4 *Information security design of cloud service platform*

Due to there exists data exchange between charging facilities and cloud platform which is facing data security problems in cloud environment, the data security of cloud service is important for the proposed platform (Kaushik and Gandhi, 2019; Demin et al., 2019; Gou et al., 2017). Using MQTT as the communication bearing protocol, the special message transmission protocol is designed. All packet formats among sensor-based device terminals, IoT gateways and cloud service platforms are encrypted by MD5. The main messages are: registration, login, data collection, device parameter configuration and status query.

Because the original MQTT protocol does not provide message encryption mechanism, it is easy to be attacked in the process of message transmission. In this paper, a MQTT message encryption mechanism based on secure hash algorithm (SHA) (Kim et al., 2006) is designed, which can effectively ensure the security of message transmission among cloud service platform, internet of things terminal equipment and MQTT application terminal. The specific message encryption process is as follows:

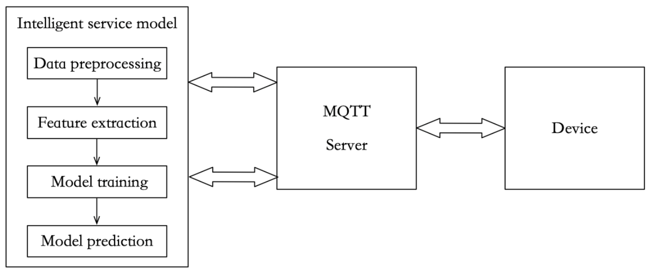
1 attach a new message to the MQTT message that needed to be sent, which is made up by random number and needed to be sent

2 encrypt the new message generated in step 1 by MD5, resulting in a 128-bit summary of information; and then add it to the end of the new message to be sent

3 adjust the length of the message and send it.

After receiving the message, the receiver extracted the last 128 bits of the message, and encrypted the rest of the message again by MD5. The results of the encryption were compared with those of the 128 bits extracted from the message. If it is equal, it means that message has not been tampered with in the process of content transmission and can be used; if it is not equal, it means that message may be tampered with or dropped in the process of content transmission, and the message information transmitted this time needed to be discarded.

Figure 7 The prediction flow chart of intelligent service



3.5 *Design of intelligent service*

The purpose of intelligent service design is to give the intelligence to device. MQTT server can call the intelligent service interface to predict the use behaviour. For example, before the electric vehicle needs to be charged near the charging station, it can call the intelligent service interface to perform the functions of appointment, payment, navigation, etc., which can help to ensure that there are enough charging piles for the user when the electric vehicle arrives. Data mining can maximise the application of data collected by equipment (Li et al., 2019a). Through the data mining of the electric vehicles around the charging facilities and the data collected by the charging facilities themselves, this module makes the equipment more intelligent to interact with users, and provides a way of thinking for the intelligent equipment. Figure 7 is the prediction flow chart of intelligent service. This module is mainly divided into the following parts: data preprocessing, feature extraction, model training and model prediction. The model prediction can use ARMA model (Detti et al., 2019) or other classic prediction algorithms.

4 Performance test

The test environment built is shown in Table 1. The iPhone 8S application realises the function of the mobile terminal's query and subscription service, and the MacBook Pro computer realises the MQTT server function of the simulation cloud platform. The Raspberry Pi 3B is used to achieve the collection of the state information of the charging facilities by the IoT gateway and transmit the status information to the cloud platform through the Wi-Fi.

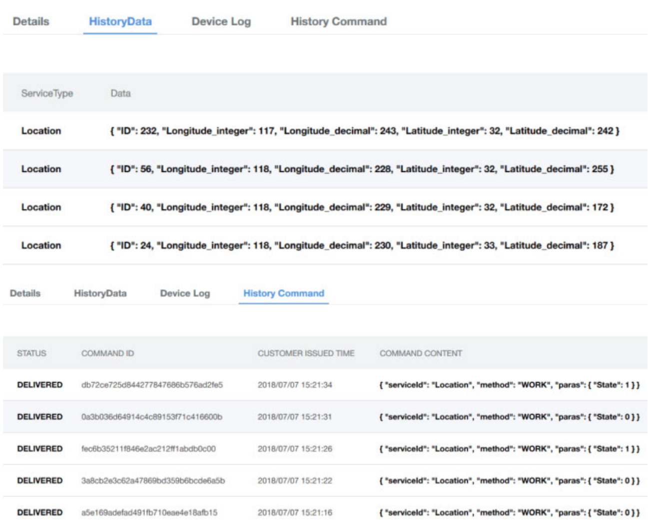
Table 1 Test environment

	Hardware	*Software*
Mobile terminal	iPhone 8S	iOS 12.1
Computer	MacBook Pro	Mac OS 10.14 Mojave Xcode 10
Gateway	Raspberry Pi 3B	Kali Linux

4.1 *Information collected by the MQTT cloud platform*

The test is mainly aimed at the performance of the IoT gateway, the MQTT server of the cloud platform and the mobile side. Figure 8 is the terminal location information and the status of different device which are collected based on the presented MQTT cloud platform. The results show that the proposed platform is effective for remote collecting information and can communicate with different devices.

Figure 8 Terminal location information collected by MQTT cloud platform (see online version for colours)

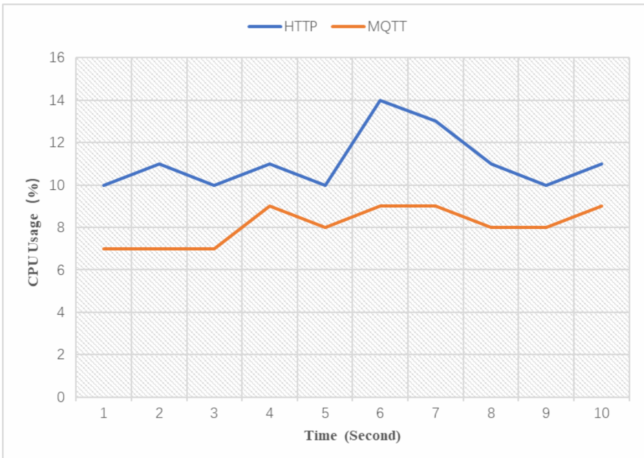


This paper mainly carried on the experiment from the following aspects: the CPU utilisation of the application client and the energy consumption of the cloud platform and the average delay of between MQTT server and client. On the one hand, CPU utilisation of client software was tested by instruments. On the other hand, the platform energy consumption performance evaluation used the activity monitor's energy consumption statistics function in the system to record the influence of MQTT service program on energy consumption. In the experiment, the CPU resources and energy consumption in a certain period of time of the traditional HTTP transmission were compared with the MQTT protocol transmission which adopted in this paper.

4.2 *CPU utilisation*

Saving the energy can enlarge the network life circle and save costs for cloud service (Jeba et al., 2019). Ten times of experimental data statistics were carried out. The CPU utilisation rate of 10 seconds was counted. As shown in Figure 9, it was the average per second of the results of ten times of experiments. When the MQTT client did not have a subscription service, the utilisation rate of the CPU was always 7%. When the data transmission of the subscription response was over, between 8% and 9%. It was due to the need for more CPU resources for information reading, analysis, storage, and display. However, because of the need to maintain the connection in the traditional HTTP transmission, the CPU utilisation rate fluctuated every once in a while, and the utilisation rate increased to about 11% when receiving the collected terminal messages.

Figure 9 Comparisons of CPU usage (see online version for colours)



It can be concluded that the MQTT in this paper can reduce the CPU occupation of the mobile terminal while saving the network bandwidth transmission, thus reducing the resource consumption of the client. So that the resource consumption occupied by the acquisition and monitoring of the corresponding power equipment is reduced.

4.3 Energy consumption of the proposed cloud platform

The client used Wi-Fi to access the cloud service platform of the electric automobile charging facility. The results of the energy consumption at the time of using MQTT and HTTP transport information in 10 minutes were recorded. It recorded the energy consumption value of the platform once every second, and the result of energy consumption value per 1 minute selected its average. The Figure 10 shows the experimental results of energy consumption comparison.

As can be seen from the Figure 10, when using HTTP for information transmission, the energy consumption value was above 1.3. And 2 was reached when there was information transmission. However, when the MQTT protocol was used for transmission, it was found that the energy consumption value was basically between 0.8 and 1.2, and the maximum value was not more than 1.2 when the information was transmitted. The experimental results showed that the architecture and method of this paper can effectively reduce the energy consumption of the platform compared with the traditional HTTP.

Figure 10 Comparisons of platform energy consumption (see online version for colours)

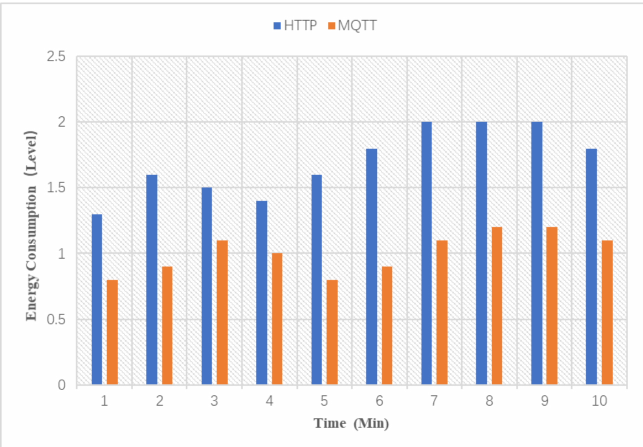


Table 2 Average delay of MQTT server

Numbers of message	*Average delay – no encryption (s)*	*Average delay – encryption (s)*	*Percentage of reply message – no encryption (%)*	*Percentage of reply message – encryption (%)*
1,000	0.34	0.86	100	100
2,000	0.43	0.92	99.6	99.2
4,000	0.51	1.06	99.2	99.0
6,000	0.60	1.22	99.1	98.8
8,000	0.75	1.39	98.5	97.6
10,000	0.87	1.46	97.4	96.8

4.4 Average delay

In order to test the message response delay of MQTT server, the MQTT client is simulated and implemented to connect to MQTT server. The test content of the control message is ‘OK’ and is sent by MQTT client, and the message is divided into two cases: no encryption and encryption. According to the calculation of the percentage of the number of messages sent by the client and the number of message responses, the average delay of the messages, the load performance of the server is evaluated. Table 2 shows the average delay and test results of MQTT server. The test results show that the average delay of MQTT server is less than 1 second with the increase of the number of communication messages without encryption, and less than 1.5 seconds with encryption, and the overall percentage of reply message is over 95%, which meets the security application requirements of equipment information collection in the internet of things environment (Pramukantoro et al., 2017).

5 Conclusions

This paper aims at the problem of information exchange between charging facilities of multi-manufacturer electric automobiles. The corresponding solutions are proposed to solve the problem of multi-manufacturer heterogeneous charging facilities accessing cloud platforms. Through the application of MQTT protocol to access the cloud platform, each charging facility realises the information interconnection among heterogeneous terminals. The monitoring cloud service platform of electric automobile charging facilities based on MQTT can remotely complete the relevant data collection, subscription service and push service of charging facilities. Through MQTT internet of things and cloud platform to achieve real-time measurement of the status of charging facilities, provides feasible network access and security monitoring method for remote detection of charging facilities. The future work will carry on the concrete monitoring analysis to the equipment status, and provide the big data source and the analysis technical support for the remote automatic detection of charging facilities.

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