Internet of Things: Survey and open issues of MQTT Protocol

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***Abstract*— Internet of Things (IoT) is based on a wireless network that connects a huge number of smart objects, products, smart devices, and people. It has another name which is Web of Things (WoT). IoT uses standards and protocols that are proposed by different standardization organizations in message passing within session layer. Most of the IoT applications protocols use TCP or UDP for transport. XMPP, CoAP, DDS, MQTT, and AMQP are grouped of the widely used application protocols. Each one of these protocols have specific functions and are used in specific way to handle some issues. This paper provides an overview for one of the most popular application layer protocols that is MQTT, including its architecture, message format, MQTT scope, and Quality of Service (QoS) for the MQTT levels. MQTT works mainly as a pipe for binary data and provides a flexibility in communication patterns. It is designed to provide a publish-subscribe messaging protocol with most possible minimal bandwidth requirements. MQTT uses Transmission Control Protocol (TCP) for transport. MQTT is an open standard, giving a mechanisms to asynchronous communication, have a range of implementations, and it is working on IP.**

Keywords—MQTT, IoT, application layer protocols, Message Queue Telemetry Transport., Internet of Things

I. INTRODUCTION

The Internet of Things (IoT) has become widely used in latest developments within Radio-frequency identification (RFID), communication technologies, Internet protocols and smart sensors. It is expected that the IoT in the coming years to enable new applications that support the intelligent decision making by linking the various technologies via connecting the physical objects together. This physical objects can allow IoT to act as a human (e.g. think, see, hear, share information, etc.)

The IoT exploits the underlying technologies of these objects to transform it from traditional ones to smarter. Such as Internet protocols, applications, embedded devices and communication technologies. Thus, it is expected that the IoT is to contribute in growing of the world‘s economy and in enhancing the quality of life.

Considered the (IoT) as a system of interrelated computing devices and mechanical machines that are provided with unique identifiers; it has the ability to transfer data over a network without requiring interaction with other objects, such as human or other computer. This concept was used for the first time by Kevin Ashton in 1999.

Another name for IoT is the Internet of Objects, which consists of a wireless communication and a self-configuring network between objects. IoT is a platform for devices to communicate electronically with the world. It became as a description for the number of technologies and research disciplines which allow the Internet to communicate with physical objects in the real world [1, 14 -17].

This paper represents Message Queuing Telemetry Transport (MQTT) protocol that is widely used. Recently, it is being used by famous corporations. Such as, Amazon and Facebook. MQTT represents the M2M protocols, that it is based on publish/subscribe communication pattern. The purpose of this protocol is to use it in devices with restricted memory capabilities and limited processing power.

In 1999, Andy Stanford-Clark of IBM and Arlen Nipper was introduced a protocol for messaging named MQTT (i.e. Message Queue Telemetry Transport). In 2013, the MQTT became standard protocol of the Organization for the Advancement of Structured Information Standards (OASIS).

MQTT protocol connects the networks and devices with middleware and applications. This connection uses machine-to-server (M2S), server-to-server (S2S), machine-to-machine communication patterns, and routing mechanism (one-to-many, one-to-one, many-to-many).

The default MQTT port that worked on is TCP/IP port.1883. MQTT has different types, such as, mosquito, hive-mq, and paho MQTT [13]. Transport Layer Security (TLS)/Secure Sockets Layer (SSL) are security protocols that provide communications security through the computer network that is used in different applications such as email, web browsing, Internet faxing, voice-over-IP (VoIP), and instant messaging.

MQTT considered the most favorable connection protocol for M2M and IoT. It utilizess the publish/subscribe pattern to provide simple implementation and flexible transition. Figure1 presents the publish/subscribe pattern for MQTT.

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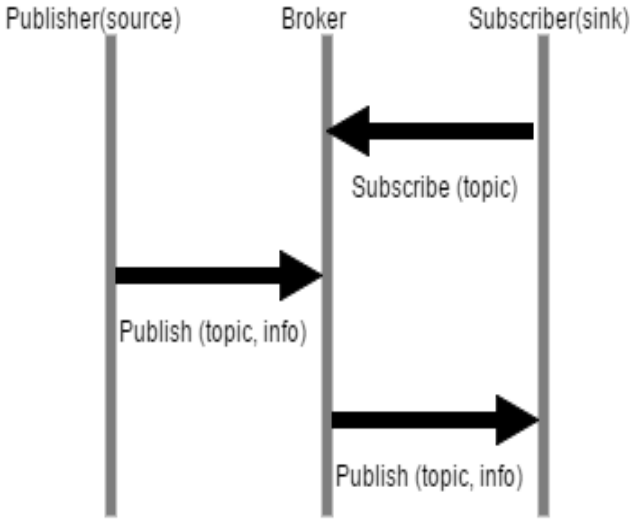

Fig. 1. Publish/subscribe process utilized by MQTT

MQTT appropriate for resource-constrained devices that are used in low bandwidth links or unreliable. MQTT built on the upper of TCP protocol as the Hypertext Transfer Protocol (HTTP). However, it is designed to have a less protocol overhead than HTTP [5], and it delivers the messages using three QoS levels. MQTT have two major specifications. One is MQTT v3.1 and the other is MQTT-SN, which is known as MQTT-S (V1.2) [2]. It is designed to be used use in the wireless communication environment for low bandwidth. Unlike MQTT, MQTT-SN uses the UDP protocol. Recently, start the Amazon supported MQTT protocol in the Amazon Web Services [12].

MQTT is a many-to-many communication protocol, it transfers messages using a central broker between multiple devices. MQTT devices connected to the broker with long-lived outgoing TCP connection, this connection is originally heavy on constrained devices. MQTT does not support the message labeling with metadata or types to help devices to understand it. In MQTT, all devices should be informed in advance by the message formats to enable the communication [9].

This survey contains several parts that explain the MQTT protocol. Section two presents the previous researches about the MQTT. The architecture of the MQTT is presented in section three. . In section four, the MQTT message format is explained, recent usages and MQTT scope are mentioned in section five. The quality of service (QOF) for the MQTT is discussed, where three levels of QOS are presented.. Eventually, the conclusion is presented in the last section.

II. RELATED WORK

The authors of [5] were implemented and designed a common extensible middleware to support future protocols such as CoAP and MQTT and provides a common programming interface. By this common middleware, they made experiments for examining the performance of CoAP and MQTT, in which the bandwidth consumption and end-to-end delay are examined. The result shows that with higher loss rate the MQTT messages have a higher delay than CoAP messages. Also, the results proves that the MQTT has the lower delay than CoAP messages in the lower packet. In addition, the CoAP generates a lower additional traffic than MQTT when the loss rate equal 25% or less and the message size small to guarantee the message reliability.

Babovic, et al in [6], implemented two applications test to give a full insight into the IoT Web application performance. the first application used different communication protocols and message encodings to measure latencies, and the graphics rendering performance during performance comparison for implementing different Web platforms. The second application measured the latency of the message throughput rate and sensor data message delivery that used to compare the web performance of messaging protocols in IoT as (XMPP, DDS, MQTT, and AMQP). The result showed that the HTML5 platform have a higher capability in running IoT Web applications in real-time, the best performance in presentation is for Adobe Flash, and the optimum messaging protocol is for the MQTT for wide range of applications of IoT mWeb.

Mijovic, et al [7], compared the performance of three application layer protocols of Internet of Things (IoT). Those are WebSocket, Constrained Application Protocol (CoAP), and Message Queuing Telemetry Transport (MQTT). The comparison is based on implementing the three protocols in an appropriate way for IoT applications under the same low complexity hardware platform and low cost. The protocol efficiency depends on the performance that is related to the average Round Trip Time (RTT) and the overhead. In each scenario in IoT device, the data is transmitted to the server and waiting for replies. The air interface that is used for communication between the Access Point (AP) and the IoT device was IEEE 802.11.b/g/n that is connected to the last server. The MQTT protocol performance highly depends on the Quality of Service profile.

Next, this paper presents a comparison between some reference papers and surveys to give a full insight into the topic. Table 1 includes ten research papers with their target and the used methodology

Table 2 include the goodness and weakness of these papers from the author opinion.

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TABLE I. THE COMPARISON BETWEEN RESEARCH PAPERS ABOUT THE MQTT IN TERMS OF THEIR TARGETS AND METHODOLOGIES(1)

Paper	Target	Methodology
Toward better horizontal integration among IoT services [1]	To define a rule-based intelligent gateway that bridges the gap between existing IoT (Internet of Things) protocols to enable the efficient integration of horizontal IoT services.	Elaborates on the proposed intelligent IoT protocol gateway. proposes to revisit the MQTT protocol with the aim of providing it with a hybrid architecture that would allow it to operate on various M2M as well as M2S and S2S scenarios
Internet of things: A survey on enabling technologies, protocols, and applications [2]	provided an overall summary that helps the researchers and application developers to get rapidly how to insert the different protocols together to deliver the required functionalities without the need to go during RFCs and the standards specifications	Classifies the IoT protocols into four categories. Provides the QoS criteria and issues, and presented an interplay between the IoT and big data. Uses the use cases to illustrate typical protocol integration scenarios
Performance evaluation of MQTT and CoAP via a common middleware [5]	examined the performance of CoAP and MQTT from where bandwidth consumption and end-to-end delay	Made experiments by using extensible middleware to support protocols such as CoAP and MQTT and provides a common programming interface.
Web Performance Evaluation for Internet of Things Applications [6]	to give a full insight into the IoT Web application performance of messaging protocols in IoT as (XMPP, DDS, MQTT, and AMQP), and the impact of each of the described technologies on the performance of the real-time IoT Web applications.	Implements two test applications. The first application measures latencies and the graphics rendering performance. The second application measures the latency of the message throughput rate and sensor data message delivery
Comparing application layer protocols for the Internet of Things via experimentation [7]	comparing the performance of three application layer protocols(WebSocket, CoAP, and MQTT)	The experiment applies the same low complexity hardware platform and low cost in all protocols, and uses a popular STMicroelectronics Nucleo-F411RE development board
Application layer protocols for the Internet of Things: A survey [8]	To confirm a reliable balance among objects and things in application layer protocols	Focuses on message exchange between applications and the internet. provides a comparison among protocols based on transport layer used, architecture and communication model
A web-based IoT solution for monitoring data using MQTT protocol [10]	to facilitate monitoring of different manufacturing process in a mentioned area using IoT technologies	Implements the system in a tobacco drying kiln type SD – 78/2 (7270mm x 3150mm x 2850mm) with two chambers and integrated wood burning stove TD – 80. An open source MQTT Mosquito broker installed on Linux server that used to multicast data to the subscribed devices.
Performance evaluation of M2M protocols over cellular networks in a lab environment [11]	evaluate the transmission times and analyzing potentials for optimization of CoAP, MQTT and OPC UA	A laboratory test environment with cellular network emulators for EDGE, UMTS and LTE is used to analyze the protocols
An Assessment of Internet of Things Protocols for Resource-Constrained Applications [12]	To address the limitations of five different communication protocols including CoAP, MQTT, MQTT-SN, WebSocket, and TCP.	Comprises a client and three servers. The used servers are one local and two Amazon Web Services EC2 micro instances in Oregon and Tokyo. The client is a Raspberry Pi 2 model B5 running Debian GNU/Linux 7.8 (wheezy) and JVM build 1.8.0, connected via a wireless LAN.
MQTT based secured home automation system [13]	create a home automation and making it more efficient and secure by using MQTT protocol and ACL for the user	Uses sensors and Raspberry pi B+ model as the network gateway. Implements ACL (access control list) tom provide encryption method for the data

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TABLE II. THE COMPARISON BETWEEN RESEARCH PAPERS ABOUT THE MQTT IN TERMS OF THEIR STRENGTHS AND WAKNESSES (2)

Paper name	Strengths	Weaknesses
Toward better horizontal integration among IoT services[1]	The enhanced protocol alleviates the deficiency in support of QoS and reliability that found in the existing MQTT. It can handle different forms of communications such as M2M, M2S, and S2S.	The Enhanced MQTT model did not apply in real-time IoT systems, authors did not study the security, scalability, or availability of IoT challenges.
Internet of things: A survey on enabling technologies, protocols, and applications [2]	It is enabling technologies, protocols, applications, and the research addresses different aspects of the IoT. It provides a good foundation for researchers.	It is a good survey, it has no weakness from my point of view.
Performance evaluation of MQTT and CoAP via a common middleware[5]	Identifies the Influence of Packet Loss on Delay, Influence of Packet Loss on Data Transfer, Overhead For Various Message Sizes, and Adaptively Changing Protocols for MQTT and CoAP.	The network conditions are not detected at the gateway to decide which protocol better to use.
Web Performance Evaluation for Internet of Things Applications [6]	This survey is a good source for information because it identifies several cases of which application developers should be aware of.	The experiment ignores the process time after message decoding because it heavily depends on applied algorithms, but in the real applications, that time cannot be ignored.
Comparing application layer protocols for the Internet of Things via experimentation [7]	Uses simple devices enabler a fair comparison and realistic performance evaluation.	They did not conduct a longer experiment to prove if WebSocket and CoAP are less resilient to network volatility than MQTT.
Application layer protocols for the Internet of Things: A survey[8]	Evaluates each protocol from the architecture, communication model, and security view point. It also addresses the weaknesses and strengths of each protocol.	There has been no evaluation for all the protocols together in a single experiment.
A web-based IoT solution for monitoring data using MQTT protocol [10]	Proposes an IoT solution for realizing real-time web-based solution that intents to monitor and track temperature and moisture values in the agricultural drying process.	The survey did not present the data that is collect from the sensors.
Performance evaluation of M2M protocols over cellular networks in a lab environment [11]	It provides a full information about the work and the evaluation of three prospective protocols for realizing future real-time smart grid applications.	The OPC UA connection establishment occurs only once at the beginning of the measurement and it is not shown later.
An Assessment of Internet of Things Protocols for Resource-Constrained Applications [12]	It helps IoT application programmers to make an informed decision when choosing network protocols for their resource-constrained applications.	The experiment did not give information about reliability or security of the system.
MQTT based secured home automation system [13]	It shows all the steps and the results of the experiments.	Did not cover every issues for security.

III. THE ARCHITECTURE OF MQTT

MQTT uses the client/server model. Every device that is connected to a server, using TCP known as (broker) message in MQTT is a discrete chunk of data and it is ambiguous for the broker. Therefore, MQTT is a message oriented protocol. The address that the message published to it is called topic. The

Device may subscribe to more than one topics, and it receives all messages that are published to these topics [3].

The broker is a central device between the spoke model and the mentioned hub. The main MQTT broker responsibilities are processing the communication between MQTT clients and distributing the messages between them based on their interested topics [11]. The broker can deal with thousands of connected devices at the same time. Upon receiving the message, the broker must search and find all the devices that own a subscription to this topic [10].

A. MQTT Client:

MQTT client may be any of IoT object that sends or receive data, not just devices. Any device can be a client (e,g, microcontroller, the server). The MQTT client type depends on its role in the system whether it is a subscriber or a publisher [10].

B. MQTT Broker:

The broker is a central device between the spoke model and the mentioned hub. The main MQTT broker responsibilities are processing the communication between MQTT clients and distributing the messages between them based on their interested topics [11]. The broker can deal with thousands of connected devices at the same time. Upon receiving the message, the broker must search and find all the devices that own a subscription to this topic [10].

MQTT architecture contains three components. Those are a publisher, a broker, and a subscriber. The device that is interested in a specific topics registers on it as a subscriber to be informed when the publishers publishing his topics by the broker. The publisher transfers the information to the subscribers via the broker (i.e. the interested entities). It is working as a generator of interested data, then, the authorization of the subscribers and the publishers are checked by the broker to realize the associated security issues [2]. Figure2 present the component of the MQTT architecture.

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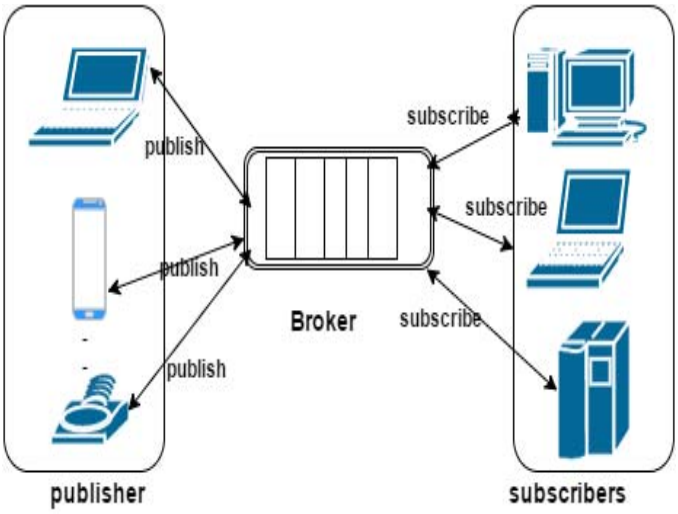

Fig. 2. The architecture of MQTT

IV. MQTT MESSAGE FORMAT

For each MQTT, the command of the message header contains a fixed header. This header contains two bytes. Byte one includes the message type and the flags fields (i.e. Duplicate delivery "DUP", QoS level, and RETAIN flag "RETAIN". Byte two consists of the remaining length field which contains a variable header and a payload, which is also required for some messages [4]. Next Figure presents the message format for MQTT protocol.

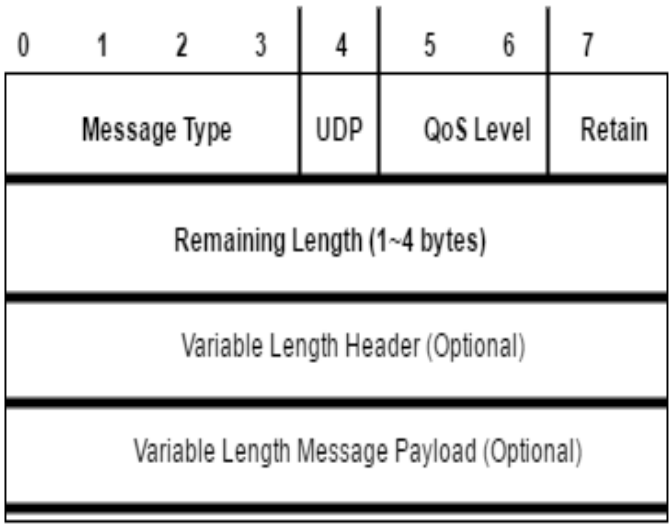

Fig. 3. MQTT message format.

V. MQTT SCOPE

Many applications in various fields use the MQTT. For example, it is being used in health care, Facebook notification, surveillance, and in the energy meter. Therefore, the MQTT protocol is considered the perfect messaging protocol for the M2M communications and in the IoT. The reason behind that is because of its ability to provide routing within a low power, small, low memory and cheap devices that are installed in a low bandwidth and weak networks.

VI. QUALITY OF SERVICE OF MQTT

There are three levels of Quality of Service (QoS) in order to maintain the reliability of messages in the MQTT [5].

Level 0 is called one delivery (at most). the messages is delivered based on the effort of the network Level 1 is one delivery (at least). the message is being sent at least once and the duplicate may exist in messages. The last level is Level 2,which is called one delivering (exactly). an additional protocol is required in this level to guarantee that the message is delivered only once (i.e. Highest level of QoS) [8]. The following table provides a summary of QoS levels and their meanings.

TABLE III. QUALITY OF SERVICE (QOS) LEVELS OF MQTT

QoS level	meaning
level 0	A message is delivered at most once and no acknowledgement of receiving is required
level 1	Every message is delivered at least once and a confirmation of receiving a message is required.
level 2	A four-way handshake mechanism is used exactly once for the delivery of a message.

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TABLE IV. SUMMARIZING OF THE MAJOR INFORMATION OF MQTT

MQTT	
Transport	TCP
Standard	OASIS Standard
Initial Target	Lightweight M2M
Messaging	Publish/Subscribe Request/Response
QoS options	YES
Security	TLS/SSL

VII. CONCLUSION

This paper presents the basic information of the Message Queuing Telemetry Transport (MQTT) protocol. It is one of application layer protocols that is widely used. MQTT supports wide range of applications. However, it has a high latency and a high sampling rate. Recently, it being used by famous corporations, such as, the amazon and Facebook, MQTT represents the M2M protocols and it is based on publish/subscribe communication pattern. The purpose of designing this protocol is to use it in devices with restricted memory capabilities and limited processing power.

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