Analysis and Modification of IoT Packets

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Abstract: The most important part of the Internet of things is communication among the IoT devices. The Internet of Things covers a huge space of devices, networks and use cases that scale from a single constrained device up to a mass crossplatform devices of embedded technologies and cloud connecting in real time. There are numerous devices emerging into the network which give rise to the various new communication protocols that allow devices to talk each other in more connected ways. Communication protocols in IoT are introduced in order to provide an efficient, reliable and secure communication for different applications.

Depending upon the nature of use, the number of IoT devices uses different protocols such as CoAP, MQTT, XMPP, and HTTP are used. Two of the most promising for small devices are MQTT and CoAP. In this research paper, evaluation and packet analysis of CoAP, MQTT is done on basis of various parameters.

Using various tools, packet analysis and dissection of packets is done for deep analysis to understand the affecting parameters from which security can be compromised in relation to the communication protocol. For that reference, various parameters, flags that are essential for a protocol in an IoT environment are tested using tools and simulators.

Index Terms—CoAP, XMPP, HTTP, MQTT, Packet, Simulation

I. INTRODUCTION

Wireless sensor network has been gaining increasing attention both from the commercial and technical point of views. Devices are increasing day by day in the virtual world of internet. It is estimated that these reaches will increase to 50 billion by 2020

An IoT application typically involves a large number of deployed and interconnected sensors and gateways. The sensors measure the physical environment and send the data to a gateway. The gateway aggregates the data from various sensors and then sends it to a server/broker. Meanwhile, clients that are interested to receive sensor data connection to the server to obtain the data. The integration of sensor devices into the Internet requires an IP-compatible protocol stack which is bandwidth-efficient, energy-efficient and capable of working with limited hardware resources. The lack of optimized application protocols for sensors can cause performance degradation in terms of bandwidth usage and battery lifetime
for wireless sensors. [1]

In this paper, we compare response time, latency between MQTT, CoAP and HTTP measured for different traffic load.

"The Constrained Application Protocol (CoAP) is a specialized web transfer protocol for use with constrained nodes and constrained networks on the Internet of Things. The protocol is designed for machine-to-machine (M2M) applications such as smart energy and building automation. [2]

MQTT- Message Queuing telemetry transport is an internet of things protocol for the machine to machine communication. The protocol was invented by Andy Stanford- Clark & Arlen nipper ciroos Link solution in 1999. MQTT is a clientserver publish/subscribe messaging protocol. It is light weight, open, simple and easy to implement. It is originally intended for unreliable network and restricted resources such as low bandwidth and high latency

II. RELATED WORK

The Constrained Application Protocol is a data transfer protocol for constrained device and networks, like IoT devices. Constraints on nodes not only include the power limitation but also the production cost of that node. A central element of CoAP is that it uses the UDP instead of TCP and defines a very simple "message layer" for retransmission of lost packets. It uses 4-byte of a header followed by the options which are easily parsable at the end. It also provides the future extension without any burden on implementation. The web consists of main three technologies: HTTP/REST, HTML and interworking with HTTP. CoAP uses the REST architectural which helps this protocol to achieve its goals and working with less complexity. CoAP provides its own reliability mechanism by using "confirmable message" and "non-confirmable message". Here confirmable message requires the acknowledgment while non-confirmable message not required to acknowledge. [3]

For communication at the application layer, resourceconstrained nodes are expected to run over Constrained Application Protocol (CoAP). To protect the transmission of sensitive information, Secure CoAP mandates the use of transport layer Security. In this paper author presented Lithe -an integration of DTLS and CoAP for the Internet of Things (IoT). They also provide DTLS header compression scheme that reduces the energy consumption by leveraging 6LoWPAN standard. DTLS header compression like IPHC is applied only within 6LoWPAN networks, i.e. between sensor nodes and the 6BR (6LoWPAN border Router). This is because of DTLS headers are part of UPD PAYLOAD and all information that is required for routing is already extracted in the IP layer. The 6LoWPAN standard defines the header compression and fragmentation mechanisms of IPv6 datagram within IPv6connected WSNs which know as 6LowPAN networks. [4]

Constrained Application Protocol (CoAP) is a recently developed application layer protocol intended to use for communication between limited resource nodes. This protocol based on Representational State Transfer (REST) architecture and support request-response model. CoAP also supports publish — subscribe architecture using an extend GET Method. This means that subscribers will subscribe to a particular subject at URI U. When the publisher publishes data D at URI U, then all the subscribers are notified about the new Values. [5]

This paper describes that how IPv6 will make possible to provide internet connectivity to any object as a communication device and in which web technologies are also helpful in managing this information more attractively. However, these technologies are not much suited for constrained nodes.

Research done in this paper provides a clear picture of what has been achieved so far in the evaluation and development of the Constrained Application Protocol. CoAP uses an interaction model similar to the client/server model of HTTP. CoAP is designed for constrained environments and therefore it introduces low header overhead and reduced parsing complexity. Other features of CoAP includes User Datagram Protocol (UDP) binding to avoid costly TCP handshake. Four different message types- CONFIRMABLE, NON-CONFIRMABLE, ACKNOWLEDGEMENT and RESET. Unicast and multicast requests, where multicast request useful for Group Communication. Large file transfer Support. URI base resource representations for example coap://server.com/info. [6]

Wireless sensor networks typically consist of a sensor device and gateways and these nodes are operated on limited resources, which require such protocol which will fulfill the requirement and use limited resources. Communication is the main requirement for the data exchange in these nodes. And MQTT is the protocol to fulfill such requirements. [7] Message Queue Telemetry Transport (MQTT) protocol is an application layer protocol designed for limited resource nodes. It uses the topic based publish-subscribe architecture. That means only when a client C subscribe for a particular topic T then only it receives the message M.MQTT relies on TCP and have lower protocol overhead when compared to HTTP. For the reliability purpose, there is three Quality of service (QoS) levels.

- Level 0- QoS level 0 that means that message is delivered at most once and an acknowledgment of reception is required.
- Level 1- QoS level 1 means that every message is delivered at least once and an acknowledgment of message is required.
- Level 2- QoS level 2 a 4-way handshake mechanism is used for the delivery of message exactly once. [5] Wireless Sensor Networks(WSNs) have various challenges compared to traditional networks. To answer such challenges new methodologies are required. One of the methodology is data-centric communication, which is the publish- Subscribe messaging system. Here, MQTT-S is an extension of the open publish-subscribe protocol Message Queuing Telemetry Transport. MQTT-S is designed in a way that it can be run on low-end and battery-operated sensor devices and run based networks.Publish/Subscribe System: In this system, the interested nodes are required to register on the subscription, and they are known as a subscriber. And nodes which produce certain information are known as publishers and the entity which ensure that data communication is done in between is known as a broker. [8]

MQTT is an open protocol developed and released by IBM. To ensure the reliability of message transmission, MQTT supports three levels of QoS. In this paper, the author analyzed MQTT message transmission protocol process which consists the real wired/wireless publish client, subscriber client, and broker server. In the simulation, a message has been analyzed upto end-to-end delays and loss in the number of the message during communication. MQTT was originally intended for unreliable networks with restricted resources such as a battery and low bandwidth. Here are one broker and two clients, one known as a subscriber and other known as a publisher. In these two, the broker act as an intermediary to send the message between publisher and subscriber. The Subscriber for a topic and whenever publisher publishes the topic value, the broker mediates to the subscriber. The subscriber can subscribe to topics when it finds interesting to any topic. The experiments are done in a realistic environment, using the simulator OMNeT++. It also suggests, correlation analysis of end to end delay and message loss under different QoS levels and payloads. The Experiment results suggest that end-to-end delay is mainly associated with message loss under different payloads. [9]

In this paper author considered an example of automotive use case with an AVL Particle Counter(APC) as node. The APC transmits its status information by means of fingerprint via publish-subscribe protocol i.e. Message Queue Telemetry Transport (MQTT) to an information broker which located at AVL backed. In threat analysis author focuses on the MQTT routing information and identify two elementary security goals in regard to client authentication. And also proposed a system architecture that incorporate hardware security controller that processes the TRANSPORT LAYER SECURITY (TLS) client authentication step. In this paper author specifically address the data security aspects of the data acquisition form AVL Particle Counter. As APCs send their maintenance information, the socalled device fingerprint to a central broker. And author used publish — subscribe based Message Queue Telemetry Transport (MQTT) protocol to send data to remote location. Further production line data is may be highly sensitive and confidential so this concern must be resolved. And further different parties have different node specification and there requirement also differs. To address these problems author opted this way 1) Only APCs which are cryptographic authenticated are allowed to communicate with the broker which is located in backend. 2)Broker must limit access to the retrieval of information from itself via MQTT to the initial publisher of information. A central concept of MQTT are topics. [10]

This paper deals with a lightweight implementation of eXtensible Messaging and Presence Protocol (XMPP) protocol for the Contiki operating system. To achieve these objective author implementation is based on the INTERNET PROTOCOL (IPv6) and XMPP. IP was thought to be too complex and power consuming but with advance chip integration and relative software implementation, it becomes reality. The author followed the IPv6 standards and the application protocol XMPP which provide push-based notification that is appropriate for the event based paradigm of low power operating system. XMPP provides functionality such as short instant messaging, presence, publish-subscribe and also provide the authentication and encryption required for protection of the data. In this paper author first introduced the XMPP benefits for low power wireless sensor network devices and then introduces the Contiki Operating System which is a real-time OS and at last represented their lightweight implementation on XMPP. XMPP uses a federated, decentralized client—server model, where each user connects to the server that controls its own domain i.e. no central authoritative server like MSN, ICQ messengers. XMPP is a very good protocol as it can adopt a broad range of needs from small infrastructure, to large social systems like Google Twitter, Facebook is using XMPP to distribute messages in real-time. XMPP is authors lightweight, open-source implementation of the XMPP protocol for the Contiki operating system. And it enables users to communicate and interact with highly constrained devices which support Contiki. Using this implementation, users can already interact directly with nodes supporting Contiki, receiving information, data or alerts whenever it is necessary — all with a standard XMPP client. In this paper author describes how future version of XMPP will also fully support service discovery, publish subscribe and semantic annotation, enabling more sophisticated services and scenarios to be created, where several sensors or other low power constrained smart devices can exchange, share and combine information to enhance this application space. [11]

This paper provides an overview of the Internet of Things (IoT) with importance on enabling technologies, protocols, and application issues. The IoT is enabled by the latest developments such as RFID, Smart Sensors, and Communication Technologies. The author describes that current phase is the revolution of the internet, Mobile, and MACHINE TO MACHINE (M2M) technologies are the first phase of IoT. IoT is a like bridge between the diverse technology which enables to connect physical devices/nodes/object and together in support of intelligent decision-making. The author first provided the basic details of IoT and then given the enabling technologies, protocol standards, and applications. Compared different survey paper related to this field and provided indepth summary of IoT devices and relevant protocols. The author also provided details about some of the key challenges represented in recent literature and provided the summary of the research work. A growing number of physical devices are being connected to the Internet at unprecedented rate realizing the idea of the Internet of Things(IoT). A basic example of this is Smart Homes(Monitoring and Control Systems). The author says IoT can play a remarkable role and improve the quality of our lives. In this paper author also focuses on Market Opportunity of IoT which shows: The IoT smart objects are expected to reach 212 billion entities deployed globally by the end of 2020. And Healthcare and manufacturing applications are projected to form the biggest economic impact. [12]

Author explain whole IoT Architecture which include following five layers

- Objects Layer
- Object Abstraction Layer
- Service Management Layer
- Application Layer
- Business Layer

Six main elements needed to deliver the functionality of the IoT:

- Identification
- Sensing
- Communication
- Computation
- Services
- Semantics.

III. PROTOCOL OVERVIEW

A. MQTT

MQTT is a pub/sub messaging protocol designed for lightweight M2M — Machine 2 Machine communications. Andy Stanford-Clark and Arlen Nipper of Cirrus Link authored the first version of the protocol in 1999. MQTT is lightweight, open source, simple and easy to implement.

MQTT runs over TCP/IP or over other network protocols that provide ordered, lose less, bi-directional connections. Sensors and actuators communicate with the application through MQTT message broker. Talking about architecture, MQTT has a client/server model, where the sensor, actuator are clients and connects to a server, known as a broker over TCP. [13]

Every message is published to a Topic which is stored in broker over TCP. Clients (Sensors, actuators) may subscribe to multiple topics. Every client subscribed to a topic receives every message published to the topic

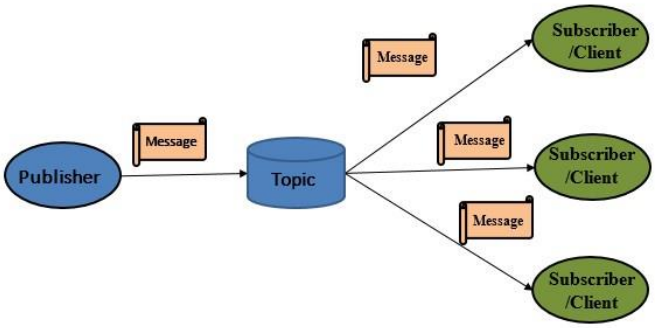

Fig. 1. MQTT Protocol

1) Features of MQTT*:*

a) Application-level QoS: An MQTT client provides three qualities of service for delivering the messages. The quality of the service of publisher might be different from quality service of the subscriber.

MQTT supports three quality of service levels: -

1) Fire and Forget
2) Delivered at least once
3) Delivered exactly Once

In this research paper, analysis of the protocol is done using the Wireshark. In Wireshark, we have captured the packets based on MQTT protocol and dissected them to do deep analysis.

Some following assumptions are made before doing the protocol analysis. Here we have one publisher, three subscribers, and one broker.

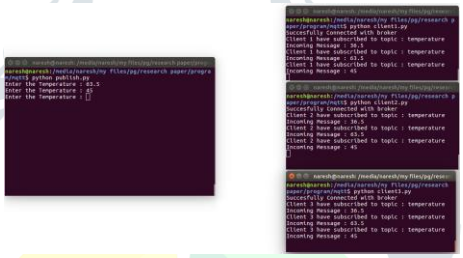

Fig. 2. One publisher and 3 Subscribers connected

QoS 0 — at most Once (Fire and Forget): The minimal level is zero and it guarantees the best effort delivery. A message won't be acknowledged by the receiver or stored and redelivered by the sender. It provides the same guarantee as of the underlying TCP protocol.

Example: Publisher with Source Port: 47485 connected with the Broker at port: 1883

As the QoS is 0, there is no acknowledgment. The only control packet is PUBLISH: Publish Message

After receiving the message Broker sends the message to the 3 clients at destination Port: 38525,60039,34419

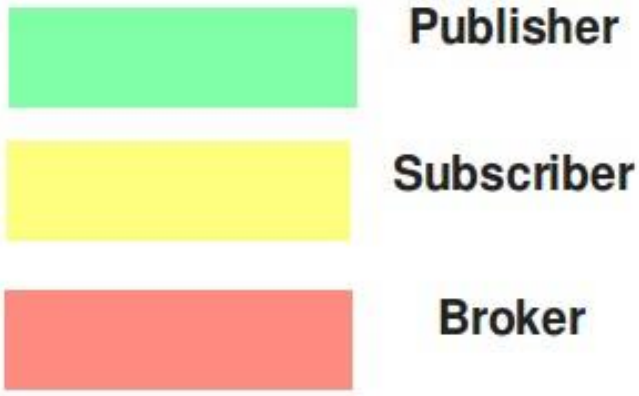

Fig. 3. Color Representation of Publisher, Subscriber, and Broker

mqtt

No.	Time	Source	Src Port	Protocol	Info	Destination	Dst Port
3	0.000062748	127.0.0.1	34419	MQTT	Ping Request	127.0.0.1	1883
4	0.000158011	127.0.0.1	1883	MQTT	Ping Response	127.0.0.1	34419
8	1.912900858	127.0.0.1	47485	MQTT	Publish Message	127.0.0.1	1883
9	1.913075404	127.0.0.1	1883	MQTT	Publish Message	127.0.0.1	38525
11	1.913144519	127.0.0.1	1883	MQTT	Publish Message	127.0.0.1	34419
13	1.913194299	127.0.0.1	1883	MQTT	Publish Message	127.0.0.1	60039
17	1.913748187	127.0.0.1	60039	MQTT	Ping Request	127.0.0.1	1883
18	1.913839157	127.0.0.1	1883	MQTT	Ping Response	127.0.0.1	60039

Fig. 4. Capturing Packet having QoS 0

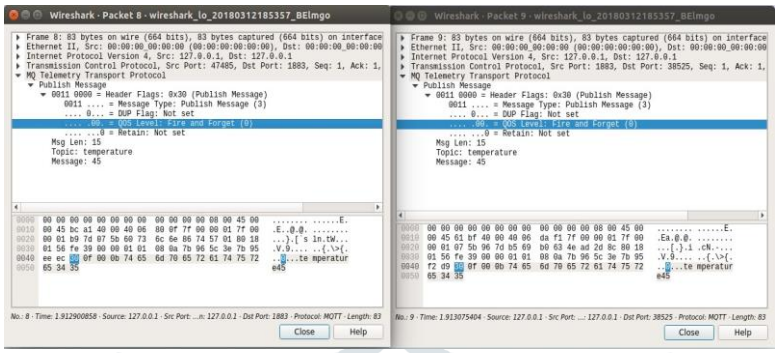

Fig. 5. Wireshark Packet Analysis of the packet having QoS 0

QoS 1 — at least 1 (Delivered at least once): When using QoS level 1, it is guaranteed that a message will be delivered at least once to the receiver. But the message can also be delivered more than once.

Example: Publisher with Source Port: 44131 connected with the Broker at port: 1883

As the QoS is 1, We will get acknowledgment, Control Packet used are PUBLISH and PUBACK : Publish Acknowledgment

After receiving the message Broker sends the message to the 3 clients at destination Port: 32917,44795,40349

mqtt

No.	Time	Source	Src Port	Info	Destination	Dst Port	Protocol
76	22.141346826	127.0.0.1	44131	Publish Message	127.0.0.1	1883	MQTT
77	22.141476201	127.0.0.1	1883	Publish Ack	127.0.0.1	44131	MQTT
79	22.141556521	127.0.0.1	1883	Publish Message	127.0.0.1	32917	MQTT
81	22.141621073	127.0.0.1	1883	Publish Message	127.0.0.1	44795	MQTT
86	22.142073743	127.0.0.1	44795	Publish Ack	127.0.0.1	1883	MQTT
88	22.142157975	127.0.0.1	32917	Publish Ack	127.0.0.1	1883	MQTT
89	22.142488869	127.0.0.1	1883	Publish Message	127.0.0.1	40349	MQTT
93	22.142863593	127.0.0.1	40349	Publish Ack	127.0.0.1	1883	MQTT

Fig. 6. Capturing Packet having QoS 1

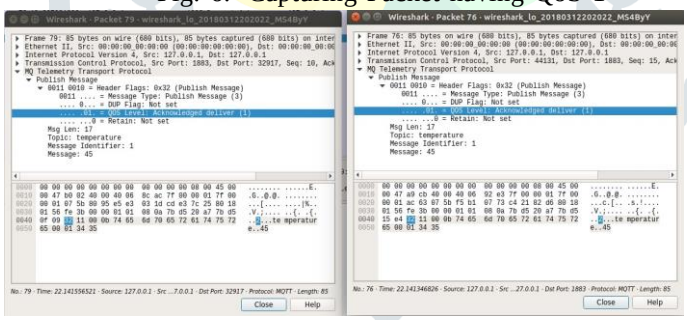

Fig. 7. Wireshark Packet Analysis of the packet having QoS 1

QoS 2 — Exactly Once (Delivered exactly Once): The highest QoS is 2, it guarantees that each message is received only once by the counterpart. It is the safest and also the slow quality of service level. The guarantee is provided by two flows there and back between sender and receiver.

Example: publisher with source port:44107 connected with the boarder at port:1883.

As the QoS is 2, We will get acknowledgment, control package used are PUBLISH, PUBREC: Publish Received, PUBREL: Publish release, PUBCOMP: Publish Complete.

After receiving the message broker sends the message to the client at destination port:48877, 44449, 48107

mqtt

No.	Time	Source	Src Port	Protocol	Info	Destination	Dst Port
5	3.620623921	127.0.0.1	44107	MQTT	Publish Message	127.0.0.1	1883
6	3.620732257	127.0.0.1	1883	MQTT	Publish Received	127.0.0.1	44107
10	3.621106414	127.0.0.1	44107	MQTT	Publish Release	127.0.0.1	1883
11	3.621244384	127.0.0.1	1883	MQTT	Publish Complete	127.0.0.1	44107
12	3.621306306	127.0.0.1	1883	MQTT	Publish Message	127.0.0.1	48867
14	3.621366926	127.0.0.1	1883	MQTT	Publish Message	127.0.0.1	44449
16	3.621427175	127.0.0.1	1883	MQTT	Publish Message	127.0.0.1	48107
22	3.621819095	127.0.0.1	44449	MQTT	Publish Received	127.0.0.1	1883
24	3.621855962	127.0.0.1	48867	MQTT	Publish Received	127.0.0.1	1883
26	3.621922798	127.0.0.1	48107	MQTT	Publish Received	127.0.0.1	1883
27	3.622079872	127.0.0.1	1883	MQTT	Publish Release	127.0.0.1	48867
28	3.622117615	127.0.0.1	1883	MQTT	Publish Release	127.0.0.1	44449
29	3.622164065	127.0.0.1	1883	MQTT	Publish Release	127.0.0.1	48107
36	3.622579116	127.0.0.1	44449	MQTT	Publish Complete	127.0.0.1	1883
37	3.622606155	127.0.0.1	48867	MQTT	Publish Complete	127.0.0.1	1883
38	3.622614044	127.0.0.1	48107	MQTT	Publish Complete	127.0.0.1	1883

Fig. 8. Capturing the Packet having QoS 2

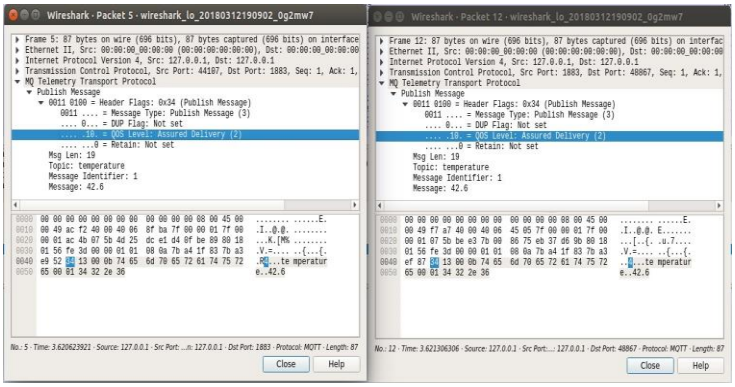

Fig. 9. Wireshark Packet Analysis of the packet having QoS2

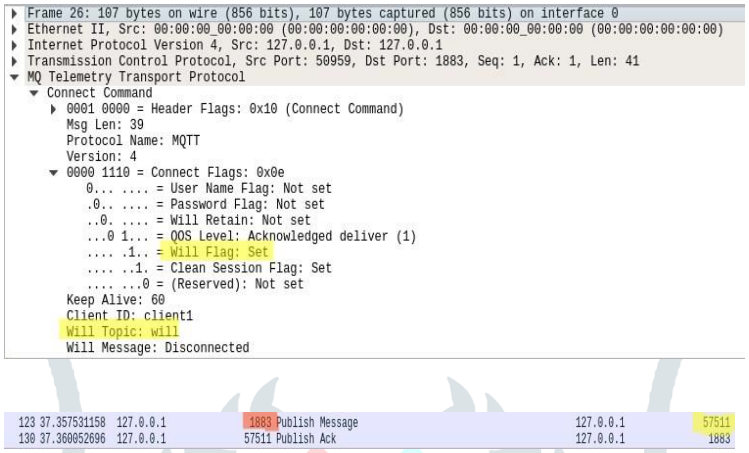

Fig. 11. Wireshark Capturing LWT packets

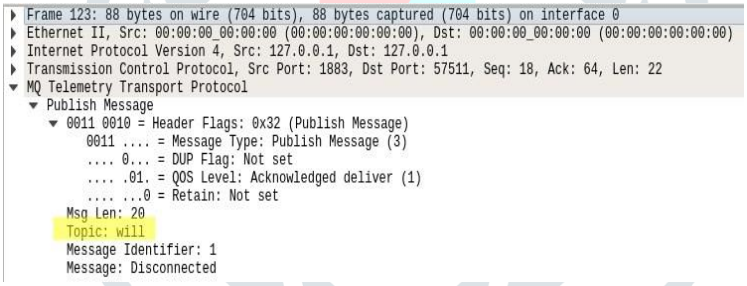

Fig. 12. Broker received LWT Will message

b) Last will and testament: In a wireless sensor network, it might happen that clients will disconnect ungracefully from time to time because they lost connection, the battery is empty or any other imaginable reason. It is good to know if any of the connected clients get disconnected ungracefully or not, in order to take appropriate action.

Specified in CONNECT message with topic, QoS and retain. If the client disconnect abruptly, the broker sends the message to all subscribed clients on the topic, which was specified in the last will message

In this example we setup 3 clients and 1 publisher which are connected with the broker actively. Each of client is specified with an LWT message as a part of connect message. After a successful connection, if any of the clients get disconnected it will send an LWT message to broker.

c) Persistence Session: When a client connects to the broker, it needs to create a subscription for the topics of interest on which message will be published. On reconnection these topics get lost and the client needs to subscribe to the client. The session is identified by the client-id specified by the client on connection establishment.

d) Retained Message: A retained message is a normal MQTT message with a flag 'Retained' set to true. The broker topics again. For a constrained client with the limited number of resources, subscribing the topics, again and again, would be a burden.

This is a normal behavior with no persistence session. A persistence session saves all the information relevant to the will save the message with true flag and the respective QoS for that topic.

The broker doesn't store all the message of the particular topic. It will only store the Last known good value, which means the last message with the retained flag set to true for the topic. Retained messages can help newly subscribed clients to get a status update immediately after subscribing to a topic and don't have to wait until publishing clients send the next update.

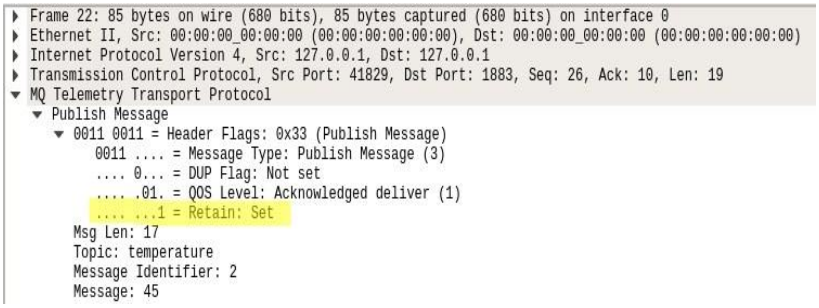

Fig. 13. A Message published with Retain Flag set

e) Security: Security in MQTT is divided into multiple layers such as network level, transport level, application level. The goal of the protocol us to provide a lightweight and easy to use communication protocol for the internet of things. So that's why in the protocol the security mechanism as limited and clearly specified. MQTT brokers may require a username and password authentication from clients to connect. To ensure privacy, the TCP connection may be encrypted with SSL/TLS.

e) Ideal for constrained networks: MQTT control packet headers are kept as small as possible. Each MQTT control packet consists of three parts, a fixed header, variable header and payload. Each MQTT control packet has a 2 byte Fixed header. Not all the control packet have the variable headers, and payload. A variable header contains the packet identifier if used by the control packet. A payload up to 256 MB could be attached in the packets. Having a small header overhead makes this protocol appropriate for IoT by lowering the amount of data transmitted over constrained networks. [14]

2) Drawbacks: MQTT is a very light messaging protocol and cannot support heavy payloads. MQTT is best used to send your sensor data. You cannot send photos or video clips or audio using MQTT. MQTT is unencrypted but can use TLS/SSL for security and encryption; whereas, CoAP works with DTLS (Data Transport Layer Security). Sometimes TLS is not feasible for constrained devices due to insufficient resources. Because of overhead in CPU and bandwidth. If TLS is not possible with your devices, you should think about using payload encryption for your PUBLISH messages and you should at least hash or encrypt the password in the CONNECT message of your client.

B. Coap — Constrained Application Protocol

Constrained Application Protocol (CoAP) is a specialized Internet Application Protocol for constrained devices, as defined in RFC 7252. "The Constrained Application Protocol (CoAP) is a specialized web transfer protocol for use with constrained nodes and constrained networks on the Internet of Things. The protocol is designed for machine-to-machine (M2M) applications such as smart energy and building automation". CoAP can also be used via SMS or mobile communication network. [15]

The CoAP defines a web transfer protocol based on Representational State Transfer (REST) on top of HTTP functionalities. REST represents a simpler way to exchange data between clients and servers over HTTP. CoAP resembles HTTP in terms of the REST model with GET, POST, PUT and DELETE methods, URIs, response codes, MIME types, etc, but one shouldn't think of it as compressed HTTP.

All the nodes of the constraint network communicate with each other with a CoAP communication. To communicate with the HTTP/Internet, a CoAP-HTTP proxy server is used for the communication.

CoAP uses HTTP for simplified integration with the web which enables multicast support, very low overhead and simplicity which is an important factor of IoT and M2M device communication.

CoAP provides a request/response interaction model between application endpoints, supports the built-in discovery of services and resources, and includes key concepts of the Web such as URIs and Internet media types.

1) Features of CoAP:

- Web protocol fulfilling M2M requirements in constrained environments
- UDP [RFC0768] binding with optional reliability supporting unicast and multicast requests.
- Asynchronous message exchanges.
- Low header overhead and parsing complexity.
- URI and Content-type support.
- Simple proxy and caching capabilities.
- Rest Model for small devices [16]

2) Confirmable Message: In CoAP protocol, some of the messages require an acknowledgment. Such messages are known as "Confirmable". When no packets are lost in communication, each message of confirmable type exactly one return message of type Acknowledgement or type Reset.

Fig. 14. Wireshark Packet Analysis

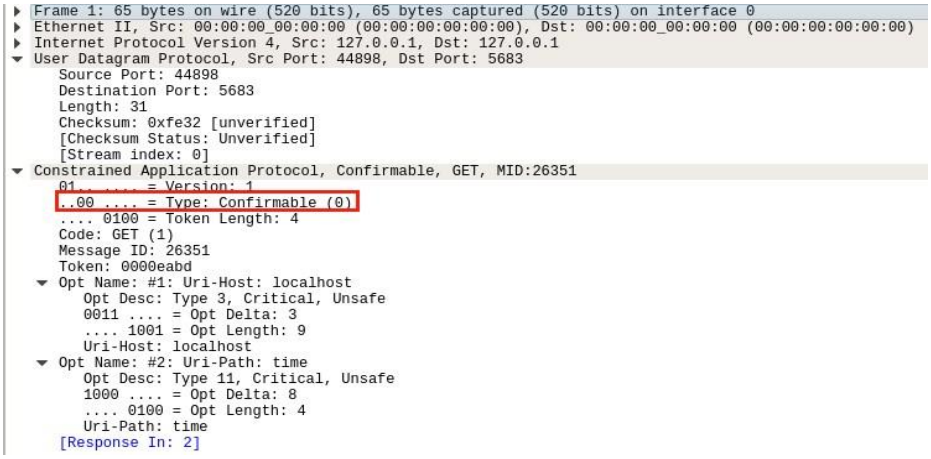

Fig. 15. A message is sent with Type Confirmable

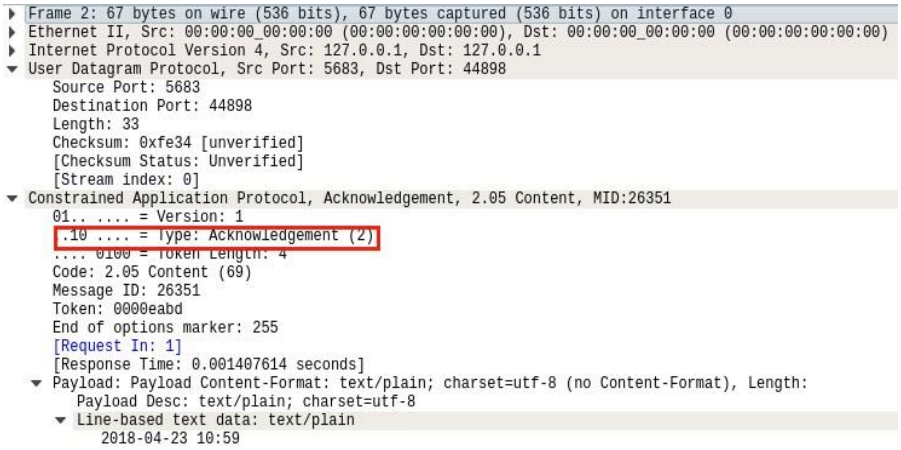

Fig. 16. An acknowledgment message is transmitted

3) Non-confirmable Message: In CoAP protocol some, of the messages do not require an acknowledgment. This is particularly true for messages that are repeated regularly for application requirements, such as repeated readings from a sensor.

IV. CONCLUSION

The research paper highlights the common protocols used in IoT system that includes the thing, cloud, and controller from an end-to-end perspective. Using various tools, The paper focuses on the packet analysis of IoT protocol such as MQTT and CoAP. The use of the protocol depends upon its application. It is observed that each protocol have their own packet

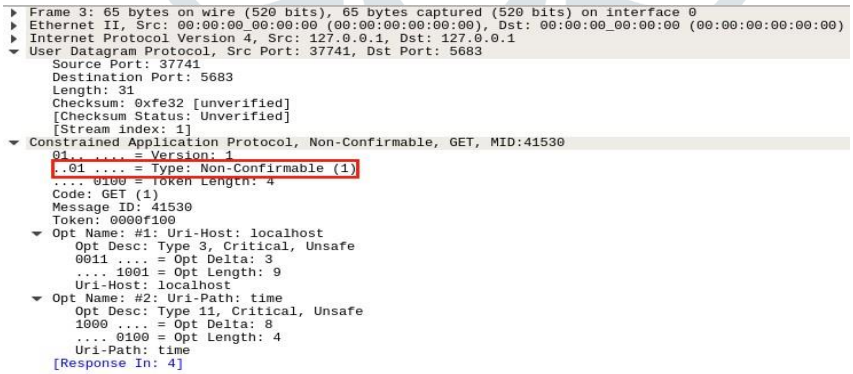

Fig. 17. A message is sent with Type Non-Confirmable

structure and the parameters of the protocol help each protocol to achieve some extra perks from another. This paper captures the packets and do deep analysis on them extract some of the very important parameters and flags that are used in the protocols. Keep security and privacy as a big issue in the picture, the packets can easily be modified and can be transmitted back to the network. Such modification can breach into the security and privacy.

V. FUTURE WORK

There are many protocols that are used in IoT environment according to the need of the applications. IoT due to low in scope capabilities of computational resources and low energy

cannot implement heavy, complex schemes supporting security. Many of the basic security requirements like integrity, privacy, immunity and access control are some of the challenging that IoT environment faces. The implementation of secure protocols and standards are to be done on each layer of IoT. To stop such modification, the new upcoming technologies can be used. The basic concept of security is to cover all the parameters of security

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