# A study of Conventional Protocols applicable to the emerging IoT Systems and Devices

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*Abstract*—**The era of development of intelligent machines has led to automation at such a level a combination of artificial intelligence and self-operating gadgets are over taking the manual operations. Further, the integration of such intelligence with Internet has extended the horizons of development and research to a new level and has led to development of Internet of Things (IoT) devices. Self-decision-making in-home appliances will make them smart appliances such as smart refrigerators, smart televisions, washing machines and dish washers, smart ACs, etc and are incorporated as "THINGS" in IoTs. Although this development is finding its way to new peaks but the protocols, methodologies and ethics of intercommunication of smart devices is still a work of art for researchers. This paper tends to provide an overview of various protocols of data transmission that are providing possible solutions to various problems that may be faced in secure data transmission, integration and manipulation of data for efficient decision making of smart machines and appliances placed remotely or locally. A comparison of various parameters such as operating frequency, range and data rate has been presented to analyze various technologies for various applications.**

***Keywords— IoT Protocols, Smart machines, Constrained devices***

## I. INTRODUCTION

Internet of Things has extended its horizons over vast number of applications in recent years and still the detailing of its concepts and operations involved in it is an emerging field with numerous possibilities. The thought of interconnecting the devices so called "Things" over the newer or pre-existing internet link without much interference of human being has taken new step towards the intelligent appliances [1]. One of the most important challenge in this regard is the way or method of communication that may be used to communicate the data over the web i.e. protocol that the devices may follow. It is utmost important to generalize these rules and to be accepted worldwide. There are some technologies which have already taken their position while researchers are finding ways for others to be incorporated in IoT [2].

There is a lot of ongoing research to develop algorithms and protocols for IoT devices that must be light weighted so as to put minimum burden over the internet while transmission of data from sensors to decision making circuitry [3]. Although without any distinct boundary, many of these protocols can be classified as mentioned in Table 1.

The emphasis of this study will be on an overview of Network Layer pre-defined Protocols and their applicability on IoT domain. The study will also cover the system architecture of two Application Layer protocols (CoAP and MQTT) that are recently used to implement efficient data communication between IoT devices.

TABLE I. LAYERED STACK OF PROTOCOLS [1][2]

| | |
|---|---|
| *Application Layer* | Constrained Application Protocol (CoAP) |
| | Advanced Message Queuing Protocol (AMQP) |
| | Message Queuing Telemetry Transport (MQTT) |
| | Extensible Messaging and Presence Protocol (XMPP) |
| | Data Distribution Service (DDS) |
| *Transport Layer* | Transmission Control Protocol (TCP) |
| | User Datagram Protocol (UDP) |
| *Internet Layer* | Internet Protocol Version 4/6 (IPv4/IPv6) |
| | Routing Protocols |
| | 6LoWPAN (Low-Power Wireless Personal Area Networks) |
| | Time slotted Channel Hopping (6TiSCH) |
| *Network Layer* | IEEE 802.15.1 (Bluetooth) |
| | IEEE 802.15.4 (LR-WPAN) |
| | IEEE 802.11 (Wi-Fi) |
| | IEEE 802.3 (Ethernet) |
| | IEEE 802.16 (WiMAX) |
| | IEEE 1901.2 (PLC) |
| | Long Range Radio Wide Area Network (LoRaWAN) |

## II. NETWORK LAYER PROTOCOLS

Although in addition to the enlisted protocols in the stack, there are many others that are used by researchers to find their optimum use in Internet of Things, yet the researchers are finding IEEE defined standards in Network Layer of Table 1 as more suitable for IoT applications because of their reliable architecture. These IEEE standards are summarised below with respect to their properties.

- *Bluetooth*

One of the versatile communication technologies used in IoTs for short range data transmission is Bluetooth and has found its applications in many consumer products and in house "Things". Even the wearable products such as smart wrist bands, smart rings, etc can be attached to smart phones through Bluetooth for transmission of sensor data. Keeping in view the energy constraint, a new technology has been incorporated named as Bluetooth Low-Energy (BLE)[5]. It is also called smart Bluetooth purposely designed for IoT Devices and applications. It is important that the devices that are to be used for BLE are to incorporate the Bluetooth Core Specification Version 4.0 or higher. The compatibility is also provided to support the internet through 6LoWPAN directly for the smart Bluetooth sensors. Its operating frequency is 2.4GHz (ISM) and the operating range is between 50m to 150m which is useful for "Things" placed at a shorter distance and can transfer the data up to 1Mbps approximately [2][5].

- *ZIGBEE*

Another versatile technology alike Bluetooth is ZigBee. A major property of ZigBee is that it has a base station installed at a higher order which makes the environment more suitable for industrial applications. Based on IEEE 802.15.4 protocol and with multiple profiles such as RF4CE (ZigBee Remote Control) and ZigBee PRO and operating at 2.4GHz with lower data transmission rates within a short infrequent transmission, it creates a reliable wireless network technology for Industrial applications [1][6]. Other properties of Zigbee that enhances its operability is high scalability, high security, higher number of incorporation of nodes, Robust and low power consumption in operation which makes it a very useful option for IoT devices as operating power is a major issue in case of designing a network of Things.

- *Near Field Communication (NFC)*

One of a short-range communication technology for interconnection between two devices up to 10cm connectivity is NFC (Near Field Communication) [2][5]. It enables bidirectional interconnection and transmission of data at comparable lower speed that may range from 100-420Kbps at an operating frequency of 13.56MHz. The technology enables the contactless in information transmission such as card payments for consumers, etc. This technology has a higher end of security due to its efficient transmission and hence can be used in applications where the sensors are placed very near to decision making circuitry of an IoT device [6].

- *SIGFOX*

If communication is to be established between that of Wi-Fi and Cellular technology, SIGFOX is a better option. A main benefit of this technology is that the transmission doesn't require any licensing as its operation is in ISM band which is probably free to use. The data between interconnected Things is transmitted in a very narrow frequency spectrum [7]. It is a very low power consuming technology where the data is not transmitted frequently hence a trade off between low range of transmission of data of Wi-Fi and comparatively expensive cellular technology. This is made possible using UNB (Ultra Narrow Band Technology) [5]. The data transmission is done up to 1kbits/s which makes it possible to consume just 1% of power as compared to cellular and data transmission range can be achievedup to 10Km and the network created is further scalable also. These features make it a better possibility to be used in IoT devices that are placed over a wider area and sensors are operated using battery power for example data collected of a parameter over a city [6][7].

- *Z-WAVE*

Purposely designed for Home Automation, Z-Wave is a RF communications technology consuming low power such as lighting control, Fan control etc. A main feature of this technology is that it operates at a frequency of about 1GHz hence there is an avoidance of interference with other technologies such as Bluetooth and Wi-Fi. The data is transmitted in small segments or packets at rates of 100kbps which makes it much reliable for small applications [4][6][7]. It operates at short range that may be up to 30m. so for short interconnection of "Things" or devices such as appliances of home based on IoT, it can also serve as a very useful platform.

- *NEUL*

On the concept of SIGFOX, NEUL also operates at lower frequency probably up to 1Ghz. It cleverly uses a small portion of White Space Spectrum of Television transmission. This enables it to design a low power consuming and low-cost wireless network with a wider area of coverage and better scalability [1][7]. It accesses Ultra High Frequency (UHF) spectrum band as it was majorly used for analog TV transmission that is overtaken by digital TV transmission. It creates a Wide Area Network up to a diameter of 10Km and is capable of transmitting data at 100Kbps consuming a little power of about 20-30mA. Hence the technology can arise new possibilities for IoT devices placed over a wider area. Hence for IoT network, it NEUL can be a better technology as compared to LTEWAN, 3G, CDMA and GPRS as it is much cost effective [7].

- *6-LOW PAN*

It is an IP based technology basically on IPv6 named as IPv6 Low-Power wireless Personal Area Network (6LowPAN) [7]. This technology defines the Header Compression system and encapsulation of data. One of its major benefit is that technology freely uses frequency band hence can be easily used over the multiple systems and platforms such as ZigBee, Wi-Fi, Ethernet, sub-1GHz Industrial, Scientific and Medical (ISM) band. As known that the introduction of IPv6 has given the freedom by providing unique IP address to almost every device and can be connected to internet. With the use of 6LOW PAN in IoT devices, it extends the possibility to interconnection of huge number of devices over internet with high data transfer rates [5][7].

- *THREAD*

Another newer IPv6-based purposely designed for home automation is THREAD. It is also based on 6LOW PAN. Its primary design is to overcome the drawbacks of

Wi-Fi for home automation setup [1][4][7]. The protocol is based on standards such as for wireless air-interface (IEEE802.15.4), IPv6 and 6LOW PAN, hence find its applications over various IoT devices especially intelligent home appliances. The capability of handling about 250 nodes with a higher grade of data encryption and network authentication.

## III. Application Layer Protocols

Apart from these technologies, there are certain other Application layer protocols that are defined by European Telecommunications Standards Institute (ETSI) and Institute of Electrical and Electronics Engineers (IEEE)[8] These can be summarised as below.

- *CoAP (Constrained Application Protocol)*

The CoRE (Constrained RESTful working group) of Internet Engineering Task Force (IETF) has worked on the designing internet application-based protocol especially for constrained devices and has come up with CoAP. A major application of this protocol is to establish efficient communication between same or different constrained networks (connected to internet) as well as internet nodes and the devices. So, its application also extends to Hyper Text Transfer protocol (HTTP) based IoT systems. Collectively, a RESTful architecture similar to HTTP with light weighed operation due to use of User Datagram Protocol (UDP) helps in providing a versatile solution for easy data transfer in IoT devices[8][9].There are two basic QoS (Quality of Service) systems used in CoAP protocol i.e. confirmable message, in which there is a reliable retransmission mechanism to compensate and resend data whenever there is a loss of data packet using the acknowledgement method, built in the system itself. this improves the reliability of overall system as the destination send an acknowledgement on receiving data and non-conformable message in which the data once sent is forgotten and no acknowledgement procedures are followed [1][2][7]. There is no surety of data reception and retransmission is not feasible. The CoAP Protocol is used in constrained IoT devices by many researchers and the development in the optimization of the protocol for low power consuming long-range real time-based communication system especially designed for IoT environment is at its peak [2][10].

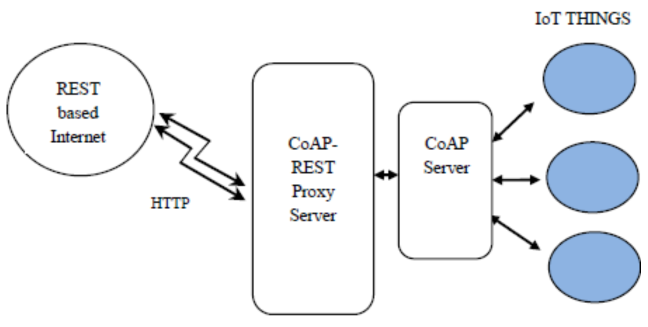


Fig. 1. Functional block of CoAP Protocol [7][8][11]

The number of "Things" grow at a greater rate day by day and the thrust of efficient and reliable system is also a dire need of time. Hence CoAP environment hybrid with light weighed security system might be capable of handling the enormous amount of data at higher speeds [2][11].

- *Message Queue Telemetry Transport (MQTT) Protocol*

A versatile protocol purposely developed for remote monitoring of IoT devices by Arlen Nipper of Arcom and Andy Stanford-Clark of IBM is Message Queue Telemetry Transport (MQTT), a messaging protocol [2][9]. Its primarily collects data from various randomly or regularly deployed devices and sensors and communicate it to centralized infrastructure and middleware following a hub-and-spoke architecture hence providing a reliable communication stream for data transfer through Transmission Control Protocol (TCP) [2][11].

The protocol has a channelized operation from data generator (Publisher) to end users (Subscribers) through intermediate circuitry (Broker) that supervises, controls and ensures the authentic delivery of the data. Due to the authenticity provided by MQTT protocol its applications in IOT systems are growing exponentially [11]. The Broker works on Advanced Message Queuing Protocol (AMQP) by following process through Exchange: to receive data from the Publisher, Message Queue: to store the data queue until message is successfully delivered and Binding: to establish the link between the queue and subscriber.

There are three basic QoS (Quality of Service) systems used in MOTT protocol.

*QoS0:* In this approach a message is sent only once hence follows "At Most Once" approach. The data is communicated by a publisher to broker and there is no acknowledge awaited in response. Hence any packet not received by broker and lost during transmission is lost permanently [12][13].

*QoS1:* In this approach a message is sent once, and reply is awaited hence follows "At Least Once" approach. To rectify the problem faced in QoS0, here a publisher keeps waiting for Acknowledge signal "APUBACK" from a broker side. The procedures of retransmission of data are followed if the "APUBACK" signal is not received up to stipulated time interval hence the reliability of transmission is achieved but overhead is increased [12][13].

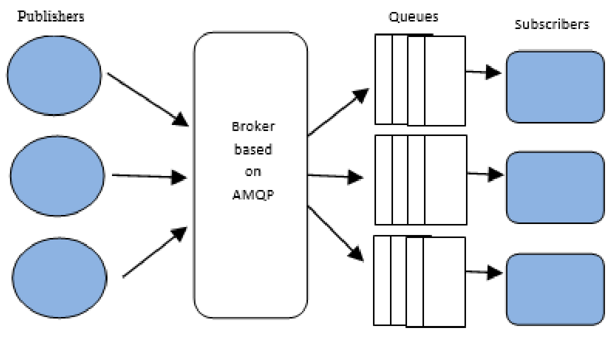


Fig. 2. Functional block of MQTT Protocol [12][13][14].

*QoS2:* In this approach a message is sent only once hence follows "Exactly Once" approach. A similar procedure to that of QoS1 is followed, a publisher keeps waiting for Acknowledge signal "PUBREC from a broker side and sooner this signal is received but in QoS2[12][13].

Publisher also send back acknowledgement signal "PUBREL" to Broker and these same procedures are also followed on Broker side. This also ensures the successfully delivery of packets.

## IV. COMPARISON AND DISCUSSION

The Layer protocol stack shows possible applications of available protocols in mushrooming IoT infrastructure. Keeping an eye on the possible applications of the protocols, a comparative analysis of basic properties of available protocols is depicted in this paper.

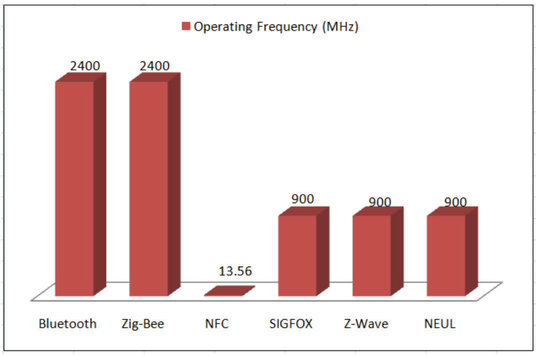


Fig. 3. Comparison of Operating Frequency of Application Layer Protocols (MHz)

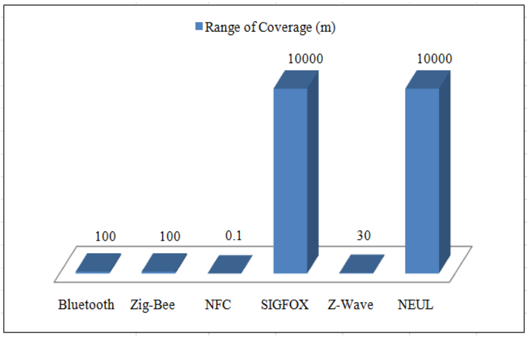


Fig. 4. Comparison of Range of Application Layer Protocols (Meters)

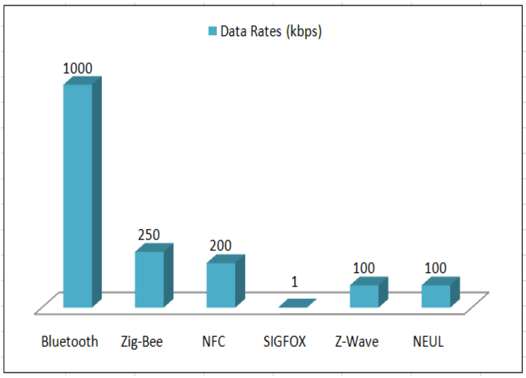


Fig. 5. Comparison of Data Transmission Rates of Application Layer Protocols (kbps)

Figure 4 and Figure 5 shows a comparative analysis of the omni-directional range and Data Transmission Rates of trans-reception of various protocols. It is seen that for a distance between few 100 meters to 10Kms, SIGFOX and NEUL protocols can be used in operation of IoT devices when they might be randomly placed in a remote area although the data transmission rates are at 1kbps for SIGFOX and 100kbps for NEUL that limits their operability especially when real time data communication is concerned whereas Bluetooth systems may provide a very high rate of data transmission but the range is of 100-150m (Smart Bluetooth).

## V. CONCLUSION

The paper gives a comparison of three important parameters i.e. operating frequency, range of trans-reception and data transmission rate. The study also provides a bird eye view for selection of appropriate protocol as per the required application. Due to the fact that a distinct set of rules to govern the communication in IoT machines and devices are under development and research is going on, the traditional transmission protocols in all the network layers can be moulded and a very light weight model of them can be used. Hence a scope of R&D exists to introduce a real time based, efficient, reliable, secure and scalable platform that may be helpful in handling and organizing large amount of data that will be transmitted during the world governed by IoT "THINGS".

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