The Taxonomy of IoT Protocols, Standards, Functional Blocks and Enabling Technologies

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ABSTRACT

The features of the Internet of Items, things in IoT, IoT protocols, a functional block, supporting technologies, and IoT protocol comparison are all covered in this research. Sensors, hardware devices, communication technologies, supporting technologies, and algorithms are all being developed for the Internet of Things. It interacts with sensors such as fire alarms, monitoring systems, logistics systems, and health-care systems. These are linked via a physical gadget that allows users to handle them from afar. The internet and machine-to-machine technologies have seen a recent transformation. This article begins with a quick review of the Internet of Things. The characteristics of the Internet of Objects are then described, which include connection, dynamic, self-adapting, scalability, architecture, intelligence, identity, safety, things, data, communication, and action. Compare and contrast the other papers in the domains of Things in IoT and protocols with the important information that allow the researcher to rapidly grasp how to supply the functionality. We also gave a rundown of the functional blocks and supporting technologies that are relevant to parts of a wireless sensor network, cloud, big data analytics, and embedded system. Finally, we look at how different IoT protocols compare.

Keywords

Internet of Things (IoT); Characteristics; Things in IoT; Protocol; IEEE 802.3; IEEE 802.11; IEEE 802.15.4; IEEE 802.16; Wireless HART; Bluetooth Low Energy; 2G/3G/4G mobile communication; IPv4; IPv6; 6LowPAN; TCP; UDP; HTTP; CoAP; Web Socket; MQTT; XMPP; DDS; AMQP; Functional Block; Enabling Technologies; Protocol Comparison

1. INTRODUCTION

In the current scenario of digitalization, IoT plays an advance and transformation role in electronics, wireless communication, and networking technologies. These improve the complexity of cloud services and structure. IoT accesses and controls the sensors, hardware devices, and equipment using networks or the internet. The concept of IoT implements the connection and data exchange between various devices and sensors.

These devices collect diverse data from sensors and the cloud. So, all of these IoT devices are speedily increasing day by day. How to utilize the perfect information to the devices is the major challenge for the IoT. To overcome the challenges of the IoT, research technology is proposed to integrate various types of services, real-time use cases, and accuracy. The rest of this paper provides a brief of characteristics of IoT, Things in IoT, IoT protocol, IoT functional blocks, IoT enabling technologies, and IoT protocol comparison. The characteristics include the aspects of connectivity, dynamic and self-adapting, scalability, architecture, intelligence and identity, safety, data, communication, and action with things in IoT. In protocol, we have described the brief details of IoT protocol that pertain to the various protocols by using the layered approach. We have also discussed the IoT function block that concerns the approach of the device, communication, service, management, security, and application. This paper also contains the IoT enabling technologies that covers various fields such as wireless sensor networks, cloud computing, big data analytics, communication protocol, and embedded system. The final aspect of this paper works on the comparison of different protocols.

2. INTERNET OF THINGS

The concept of IoT was proposed in 1970. Internet of things is a collection of various sensors, hardware devices, tools, and technologies. In the current years, IoT has become the most popular technology by connecting different kinds of the object like smart homes, healthcare, logistics, and various monitoring systems. The thing is connecting via a simple network or the internet. IoT collects the data from sensors and stores it in the cloud. IoT makes the environment easier and smarter. It is an advanced automation and analytics system that deals with machine learning and artificial intelligence, sensors, and networking for services and products. These also face some challenges in data security, privacy, software complexity, integration with artificial intelligence, and machine learning. [1]-[20]

3. CHARACTERISTICS OF THE IOT

The Internet of Things (IoT) is a technology that allows people to link smart gadgets to execute various functions. Connectivity, dynamic and self-adapting, scalability, architecture, intelligence and identity, safety, things, data, communication, and action are all part of the IoT's functioning.

3.1. Connectivity

Connectivity placed an important role in the field internet of things and its architecture. All the things of the IoT are connected with the internet of things infrastructure. All the internet of things devices including sensors are and hardware devices are easily connected within IoT Infrastructure.[21]-[45]

3.2. Dynamic and self-adapting

The devices of the internet of things are placed an important role in every type of scenario of the real world. These devices are much compatible and adaptable in various types of formations that’s why it is called self-adapting. .[21]-[45]

3.3. Scalability

IoT devices are more scalable to use and users can design the devices as per the requirement. In simple terms, the current scenario of IoT easily automates the things of the various hardware devices and sensors. The design of the device and its compatibility played a major role in the various Infrastructure of the IoT. .[21]-[45]

3.4. Architecture

The architecture of the IoT placed a major role but these devices are not homogeneous. These devices must be hybrid and compatible in every type of scenario. Internet of things is not just a branch of any domain. It should be a separate domain that considers multiple branches of various domains and these branches are working on various scenarios. [21]-[45]

3.5. Intelligence and Identity

The identification and intelligence played an important role in tracking the various types of IoT devices, sensors, and processes. It helps us to solve the query regarding devices and processes. It is also used to resolve queries. IoT devices collect information using various machine learning algorithms. .[21]-[45]

3.6. Safety

Someway the IoT devices are dangerous to use and implement in the real-world scenario because these devices are interconnected with various devices which are connected to the internet. This is also harmful to our network or the user. That's why security placed a major role because the network is not secure at that time there may be some risk factors for securing the network. .[21]-[45]

3.7. Thing

In the structure and the field of the internet of things, the devices, sensors, and hardware components are connected and designed with compatibility formations. The current IoT devices are compatible with any of the hardware and sensors or any sensing devices. So, for this, the things can be easily connected. [21]-[45]

3.8. Data

Data on the internet of things placed a major role in every scenario of the real world because all the devices have to collect the data and they are working with the various data of the sensors and hardware devices. .[21]-[41]

3.9. Communication

In the domain of the internet of things, things are connected, so that we can process data and also analyze the data. If the things are properly connected, so we can communicate in large and short range of distance. .[21]-[45]

3.10. Action

Automation in the internet of things placed an important role to do proper action with an accurate action plan of implementation in the field of the real-world scenario. .[21]-[45]

4. THINGS IN IOT

Things in the IoT play a major role to do any physical activity. In this, all the activity has a specific identifier number or a system that is used to transmit the data over the network. In the current scenario, things are connected and increasing rapidly to the updated hardware devices, sensors, and software. So, it increases the capacity of the connected devices and also increases the performance network with the extension of IPv6.Things are connected with newly arrived technologies that allow the user to transmit and receive the data. These things are working on mainly in four processes. First is capturing the data, second is sharing of data, third is the processing of data and action on the data. So, all these processes are connected with things that are connected with various domains or areas. [1]-[19]

5. IOT PROTOCOLS

The Internet of Things (IoT) technology stack is incomplete without IoT protocols. Hardware would be rendered useless without IoT protocols and standards. This is because IoT standards allow hardware to communicate with one another. Most of the time, the industry's focus is on communication. While communication between devices, IoT sensors, gateways, servers, and user apps is critical to the IoT, it would be impossible without the correct IoT protocols.

5.1.PHYSICAL AND NETWORK ACCESS LAYER

Cellular, wifi, and Ethernet are examples of IoT network technologies to be aware of towards the bottom of the protocol stack, as are more specialised solutions like LPWAN, Bluetooth Low Energy (BLE), ZigBee, NFC, and RFID.

5.1.1 IEEE 802.3

802.3 is one of the IEEE protocols which is working on ethernet technology. It is working on the local area network. The ethernet technology is working on the physical layer and the data link layer of the OSI model. The format of this protocol covers the preamble, frame delimiter, destination address, source address, length, data, padding, and cyclic redundancy check. It uses all three types of cables including co-axial, twisted pair, and fiber-optic cable. [46]-[88]

Preamble	SOP	D. A.	S. A.	Data + Padding	CRC

Table 1. Header

5.1.2 IEEE 802.11

802.11 is one of the highly used wireless frequency standard which uses the radio signals for transmitting the data in the form of signals. It uses local area network connectivity with the feature of the wireless technology. The architecture of this protocol covers the stations, basic structure set, extended service set and distribution system. The format of the 802.11 covers the frame control, distribution, address fields, sequence, data and check sequences. [46]-[84],[89]-[91]

Table 2. Header

Frame Control	Duration	Ad1	Seq.	Data	CS

5.1.3 IEEE 802.16

802.11 is also known as WiMAX. It is a protocol that provides a high-speed data transmission rate over a wide range of a network. WiMAX stands for Worldwide Interoperability for Microwave Access. This technology is used for multipoint network addressing. WiMAX technology is used to install the high-speed network at the cheapest cost but it needs some time to install the devices in the rural areas. This standard is mostly used for wireless metropolitan area networks. It uses key factors like orthogonal frequency division multiplex and multiple input multiple output methods. It includes the fields like EC, Type, CI, EK, Length, Connection ID, Header CRC, Data, and CRC. [46]-[84],[91]-[94]

Table 3. Header

0	EC	TYPE		CI	EK	1	LENGTH	C-ID	H-CRC	PAYLOAD	CRC

5.1.4 IEEE 802.15.4

802.15.4 is one of the protocols which works on low-rate wireless personal area networks. This protocol is working on low complexity with long battery life and low transmission rate. This protocol is working on the physical and data link layer of the OSI model. The frame format of this protocol includes the synch header, PHY header, MAC protocol data unit and PSY service data unit. [46]-[84],[95]-[97]

Table 4. Header

SHR	PHR	MPDU	PSDU

5.1.5 IEEE 802.15.4E

802.15.4E is one of the standards which is a mac amendment of the existing protocol IEEE 802.15.4. This protocol enhances the functionality, compatibility, and modification of IEEE 802.15.4. This protocol supports synchronization. Channel hop is low cost and also supports low power communication. The features of IEEE 802.15.4E include slot frame structure, scheduling, synchronization, channel hopping, and network formation. [46]-[84],[95]-[97]

Table 5. Header

802.15.4 MAC Header						MAC Payload
Frame Control	Seq. Number	Dest. PAN ID	Dest. Address	Source PAN ID	Source Address	Frame Payload

5.1.6 IEEE 802.11AH

802.11AH is one of the IEEE standards which is working on low energy. It is a part of the IEEE 802.11 standard. This protocol enables low-rate bandwidth mode and high bandwidth mode. Low-rate mode suitable for IoT applications, sensors, and devices. High-rate mode enables the ER applications, devices, and power amplifiers. This protocol is also known as WiFi HaLow. This protocol supports a large number of stations, power saving, compact mac header format, and mac mechanism. [46]-[84][98]

Table 6. Header

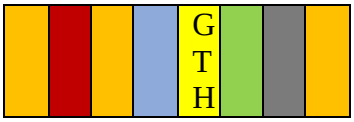
NDP CMAC	ACK ID	More Data	Idle Indication	Durations	Relay Frame	Reserved

5.1.7 Wireless HART

Wireless HART is working on the time division multiple access. It is a secure and reliable. In this the mac protocol used for the proper transmission of data using encryption methods. It is a wireless protocol which provides the proper measurement, control and asset management. These devices use the frequency IEEE 802.15.4 standard. Wireless HART is a subset of one of the HART standards. This network is working on mesh topology. The main concern to use this mesh topology is to provide redundant data pathways. In this protocol a network administrator responsible in all types of process including configuration and scheduling. This protocol is working on various layers including physical layer, data link layer, network layer and application layer. The components of Wireless HART technology include the repeater, adaptor and handheld terminal. [46]-[84][99]

Table 7. Header

PREAMBLE	SFD	ADDRESS	COMMAND	DATALEN	STATUS	DATA	CHECKSUM



5.1.8 Bluetooth Low Energy

Bluetooth is one of the low-power energy protocols for connecting the hardware devices and sensors over a short distance of 2.4 GHz ISM band. BLE was introduced Bluetooth 4.0 in 2010. The Bluetooth special interest group introduced two trademarks for single-mode devices and multimode devices. The frame format of this protocol includes the preamble, access address, protocol data unit, and CRC. [46]-[84][101][102]

Table 9. Header

Preamble	Access Address	Protocol Data Unit	CRC

5.1.9 2G/ 3G/ 4G Mobile Communication

2nd generation of the mobile network is based on Global System for Mobile Communication. It allows the user's capability to achieve their goal via multiplexing. This generation of the mobile network is working on the digital network, so users can send multimedia messages with better voice quality. It uses the bandwidth of 30kbps to 200kbps and the data speed of 2G network is 64kbps. [46]-[84],[103]-[105] 3rd generation of a mobile network is working on Universal Mobile Telecommunication System. UMTS is one of the core network architectures. The third-generation network increases the speed of the overall network compare to the previous network. It improves the speed, bandwidth, and data transfer rate. [46]-[84],[103]-[105]4th generation of the mobile network focuses on the Multiple Input Multiple Output and Orthogonal Frequency Division Multiplexing. This network supports multimedia calling with high speed, capacity, and low cost. It is a global multihop network. [46]-[84],[103]-[105]

5.1.10 LPWAN

Low-power wireless area networks are one of the wireless wide area network technologies that provide low cost, low power, and wide area coverage needed for vast, granular, and wireless sensor networks. LPWAN interconnects long-range, low-bandwidth, and low-power devices with low bit rates. Data sent over the LPWAN must be small and simple, and it must not consume a lot of power. So, users can send and receive small packets of data at the infrequlent interval. [46]-[84]

5.1.11 Zigbee

Zigbee is one of the wireless local area network protocols that operates on low power energy and low cost IoT networks. The Zigbee protocol has been developed by the Zigbee Alliance. This protocol provides an energy-efficient wireless data solution with a secure and reliable infrastructure. This protocol provides the necessary assistance for master-to-master or master-to-slave communication. [46]-[84]

5.1.12 NFC

The Near Field Communication (NFC) protocol enables short-range wireless communication technology based on RFID technology. This protocol requires at least one transmitting device for data sending and another for receiving. There are two types of NFC protocol: one is passive NFC, and the other is active NFC. Passive NFC sends the information to another NFC device without using its own power. Active NFC is able to do both of these things, i.e., send and receive. These can also communicate with each other, like passive NFC. [46]-[84]

5.1.13 RFID

RFID stands for Radio Frequency Identification. It is a technology that is used to identify and gather all the data and information from all the microchips and tags. This technology captures the digitally encoded data in smart labels and RFID tags. RFID works better than barcodes and megnatic types of sensors. RFID has a built-in sensor that communicates with the devices and reads the data remotely. All RFID tags have their own unique identification number. [46]-[84]

5.2.INTERNET LAYER

Data packets are identified and routed using Internet layer technology (OSI Layer 3). IPv6, 6LoWPAN, and RPL are examples of IoT technologies that are connected to this layer.

5.2.1 IPv4

IPv4 is one of the most using internet protocols. This is a 32-bit address that uses dotted decimal nations formatting. There are four octets in IPv4. It supports unicast, multicast, and broadcast transmission with the variable length subnet mask. In this addressing method, IPv4 binds with media access control. IPv4 comes with three parts of addressing including network part, host part, and subnet. There are five classes of IPv4 including classes A, B, C, D, and E. Exam: 192.168.1.1 [46]-[84],[105]-[112]

5.2.2 IPv6

Internet protocol 6 is one of the protocols which allows communication to take place over the network. It was designed by Internet Engineering Task Force. This expands the area of IPv6 globally. It is a 128bit format of hexadecimal. Mainly it is divided into three parts, one is unicast, second is multicast, and third is broadcast. Example: 3de1:0008:79f3: acb0:0340:82ab:0a34:1010 [46]-[84][113][114]

5.2.3 6LoWPAN

6LoWPAN is the system that sends the packets over the network using IPv6 with IEEE 802.15.4. 6LoWPAN stands for IPv6 over the low-power wireless personal area network. This protocol uses the direct end-to-end connection over a large network. This defines many of the open standards including TCP and UDP. It is built for the lower layer with a low power system. It defines the mechanism like encapsulation and compression over IPv6. Areas of 6LoWPAN applications include general automation, home automation, smart grid, and industrial monitoring. The frame

format of 6LoWPAN includes the frame control, sequence number, and addressing fields (Destination PAN Identifier, Destination address, source PAN identifier, and source address). [46]-[84][115][116]

Table 10. Header

Frame Control	SN	DAI	DA	SPI	SA
MHR					

5.2.4 RPL

RPL (Routing Protocol for Low-Power and Lossy Networks) is a distance-vector protocol that can handle a number of datalink protocols, including those mentioned before. It creates a DODAG (Destination Oriented Directed Acyclic Graph) with just one route from each leaf node to the root, where all traffic from the node is directed. At start, each node advertises itself as the root by sending a DODAG Information Object (DIO). This message spreads across the network, ultimately forming the whole DODAG. When a node communicates with its parents, it sends a Destination Advertisement Object (DAO), which is propagated to the root, who selects where to send it based on the destination. When a new node wishes to join the network, it sends a DODAG Information Solicitation (DIS) request, and the root responds with a DAO Acknowledgement (DAO-ACK), which confirms the membership. Stateless RPL nodes are the most prevalent, however stateful RPL nodes are also possible. A stateless node only remembers its parents. Only root has a thorough understanding of the DODAG. As a result, in every scenario, all communications pass via the root. A stateful node retains track of its children and parents, so it doesn't have to travel via the root while interacting inside a DODAG sub-tree. [46]-[84]

5.3.TRANSPORT LAYER

The transport layer (OSI Layer 4) focuses on end-to-end communication and includes aspects like dependability, congestion avoidance, and ensuring that packets arrive in the same sequence as they were sent. For performance reasons, UDP (User Datagram Protocol) is often used for IoT transmission.

5.3.1 Z-Wave

Z- Wave is one of the protocols used for home automation by using the exchange of various information. This is controlling all process regarding, monitoring of network and hardware and sensors. This protocol is similar to Bluetooth and Wi-Fi. It uses low power consumption for wireless communication. It also extends the ages of the network by using this. The advantages of this protocol include the ability to mix and match devices, less interference & fewer disconnections, and more secure technology. [46]-[84][100]

Table 8. Header

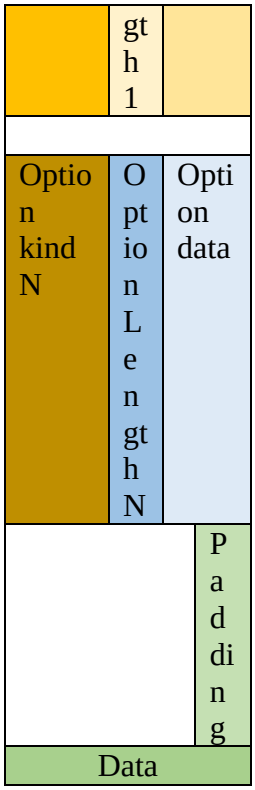
P	M	N	Ap	C
PDU Header	PDU HEADER	etwork Header	plication Payload	hksm

5.3.2 TCP

TCP is one of the protocols that define the communication over the network and exchange the packets within the network. This standard is defined by the internet engineering task force. It is liable for the end-to-end communication over the network and works with the internet protocol which is used to send and receive the data from source to destination. TCP layer is working on the transport layer of the OSI model. IT is a communication-oriented protocol to establish and communicate the data over the network. The services of the application layer include point-to-point communication, stream oriented, full-duplex, connection oriented, reliability and multiplexing. The frame format of TCP includes the source port, destination port, sequence number, acknowledgment number, data offset, reserved, Control bit, checksum, options, padding, and data. [46]-[84][117][118]

Table 11. Header

Source Port			Destination Port
Sequence Number			
Acknowledgment Number			
Dataset	Reserved	ControlBits	Window
Check Sum			Urgent Pointer
Option kind 1	OptionLen		Option data 1



5.3.3 UDP

A user datagram protocol is one of the protocols which is working on packet-switched computer communication within the interconnected network. This protocol is used to send messages to other programs or applications. UDP is transaction-oriented but it is not a secure protocol for transmitting the data. For reliable data transmission users has to use the TCP protocol but it is reliable in terms of latency and bandwidth. This protocol is not followed the proper process for data transmission. The frame format of the user datagram protocol includes a source address, destination address, length, and checksum. [46]-[84][119][120]

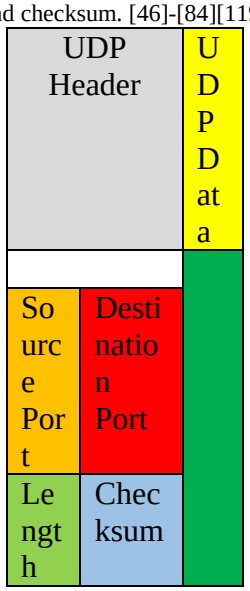


Table 12. Header

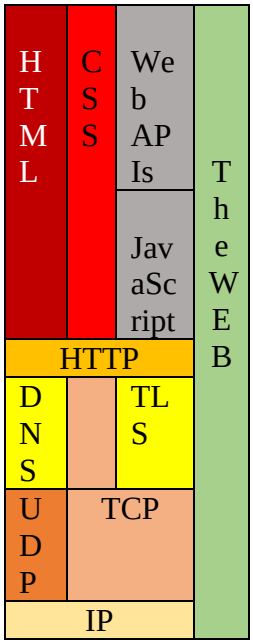
5.4.APPLICATION LAYER

HTTP and HTTPS are frequently used in internet applications, and this is also true in the IoT, where RESTful HTTP and HTTPS interfaces are commonly used. CoAP (Constrained Application Protocol) is a lightweight HTTP protocol that is often used with 6LoWPAN over UDP. MQTT, AMQP, and XMPP are all common messaging protocols used in IoT applications:

5.4.1 HTTP

HTTP stands for Hyper Text Transfer Protocol. It is a protocol that helps the client to access the file worldwide and also encode the content of that file over the network. HTTP is working on the request-response model. In the client-server model, clients send the request to the server and then the server gives the response to the client as per the requirement of the client and server. In this model working of the HTTP depends on the client and server to sends the data in the form of images, videos and applications. It is an application layer protocol and it is working on the TCP model. The frame format of HTTP header includes HTML, CSS, Web APIs, Java Script, DNS, TLS, UDP, TCP, IP and the Web. [46]-[84],[121]-[123]

Table 13. Header



5.4.2 CoAP

CoAP stands for constrained application protocol. It is designed by the internet engineering task force. This protocol is also known as the 'No- Response' protocol. This protocol enables the request-response model for the transmission. In this protocol, the server can decide that the response is given to the client or not. It is also used for web data transfer, machine learning, and network automation. CoAP is working on the low bandwidth with low availability. This protocol has reduced the size of the packet including create, publish, subscribe and manage the data. CoAP uses the REST model to manage the data and the resources with the server. It is not a single specification but it is a whole system of the server. [46]-[84][124][125]

Table 14. Header

VER	T	TKL	CODE	MESSAGE ID
Token (If any, TKL bytes)				
Options if any				
0xff	Payload (if any)			

5.4.3 *Web Socket*

Web Socket protocol is developed by the internet engineering task force. This protocol is also working on a request-response model with full-duplex communication. It is one of the stateful protocols. In this process of client-server, first, they have to do the handshake, if the handshake process finished successfully then after the data transmission process started. With the help of this model, Web Socket enables the bidirectional data sending and receiving process. Web Socket protocol includes the features of connection negotiation, interoperability, message-oriented communication, and sub protocol negotiation. It is one of the versatile, flexible, and reliable protocols. The frame format of the Web Socket includes the browser, Server, http request, http response and with the services of the protocol. This all placed a major role in the field of live scenario and with the help of internet and its network. [46]-[84][126][127]

Table 15. Header

Browser		Server
HTTP Request		
HTTP Response		
Web Socket		

5.4.4 *MQTT*

MQTT stands for Message Queuing Telemetry Transport. It is designed for easy and lightweight protocol with publishing and subscribe model. This protocol is working from end to end with one too many message distribution and decoupling applications and also uses the TCP/ IP data transmission. MQTT is one of the bidirectional and stateful protocols. It is designed for embedded systems for an effective way to do the proper reliable communication. MQTT uses the four types of stages including connection, authentication, communication, and termination. It also includes the qualities with efficient data transmission, low network usage, efficient distribution of data, remote sensing, and messages delivery and optimizes network bandwidth. The frame format of MQTR includes the bits, packet type, dup flag, QoS level, retain, remaining length, variable length header and payload. MQTT is a transport layer protocol. [46]-[84]

Table 16. Header

Bits			
Packet Type	Dup Flag	QoS Level	Retain
Remaining Length			
Variable Length Header			
Payload			

5.4.5 *XMPP*

XMPP stands for extensible messaging presence protocol. This protocol sends the xml elements in the real time scenario. It is open-source protocol for the instant messaging applications. This protocol includes the presence, multi-party chat, voice and video calling, collaboration, lightweight middle way, content syndication, blocking and routing of xml. The qualities of XMPP includes the client- server architecture, persistent tcp connection, asynchronous push messaging, decentralized hosting, messaging protocol, stability & reliability, trustworthy delivery, support for many languages, open source and flexibility. Tis protocol is works on the following technologies including core, jingle, multi-user chat, Pub Sub and BOSH. XMPP is an application layer protocol. [46]-[84][128][129]

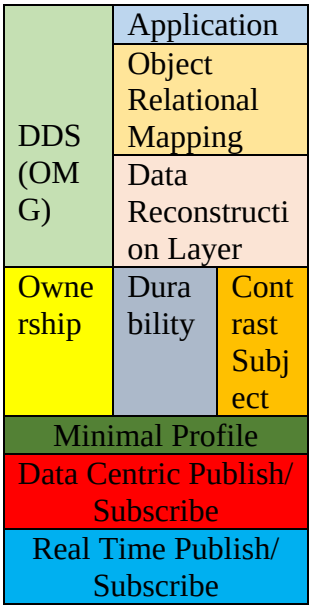
Table 17. Header

XMPP Client		XMPP Server		XMPP Server

5.4.6 *DDS*

DDS stands for Data Distribution Services. It is a middleware protocol for data-centric applications using Object Management Group. It is a flexible, reliable, scalable protocol with low latency data connectivity and scalable architecture. This protocol uses multicast data transmission with high-quality devices and applications. DDS uses the data-centric public subscribe layer for the direct communication from publisher to the subscriber in the live scenario and embedded systems. It successfully allocates various platforms of IoT systems and cloud services by utilizing the minimum resources in the live scenario. DDS works on various services including IoT protocol for M2M communication, data exchange using the publish-subscribe methodology, multicasting process with high-quality applications, and deployed low footprint device to cloud. The frame format of DDS includes the application, object-relational mapping, data reconstruction layer, ownership, durability, contrast subject, minimal profile, data-centric publish/ subscribe, real-time publish/ subscribe, DDS interoperability wire protocol, and UDP/ IP. [46]-[84][130]

Table 18. Header



5.4.7 AMQP

AMQP stands for the advanced message queuing protocol. It is an open standard to communicate between applications and organizations. The protocol manages the process of the entire message with the help of the AMQP protocol. It allows two parties to communicate over a network. AMQP is an application layer protocol with high architecture. The key capabilities indicate organizations, technologies, time, and space. This protocol is working on key features like security, reliability, interoperability, standard and open source. Rabbit MQ is one example of a lightweight, reliable and scalable message broker. AMQP deals with publishers and consumers for sending and receiving the messages by using such a message broker as Rabbit MQ. [46]-[84][130]

6. IOT PROTOCOL COMPARISON

Table 19. IoT Protocol Comparison Table

Protocol	Frequency	Range	Data Rate	Power	Topology	Managed By	System Security
IEEE 802.11 [46]-[84],[89]-[91]	2.4 GHz, 5 GHz, 6 GHz, 60 GHz	Up to 500ft	11Mbps	Low	Mesh	IEEE	Encrypted
IEEE 802.16 [46]-[84],[91]-[94]	10 to 66 GHz	Up to 30miles	120Mbps	Low	Mesh	IEEE	Encrypted
IEEE 802.15.4 [46]-[84],[95]-[97]	868 MHz, 915 MHz, 2.4GHz	Up to 300 ft	250 Kbps	Low	Mesh	IEEE	Encrypted
Wireless HART [46]-[84][99]	2.4 GHz	Up to 750ft	250 Kbps	low	Star or Mesh	HART Communication Foundation companies and ABB	Encrypted
Z-Wave [46]-[84][100]	915MHz 868MHz	Up to 325 ft	9.6 Kbps, 40 Kbps 100 Kbps	Low	Mesh	Z-Wave Alliance	Encrypted
Bluetooth Low Energy [46]-[84][101][102]	2.4 GHz	Up to 300 ft	125 Kbps 500 Kbps 1 Mbps 2 Mbps	Low	PAN	Bluetooth Special Interest Group	Encrypted
2G/ 3G/ 4G Mobile Communication [46]-[84],[103]-[105]	700 MHz, 800 MHz, 850MHz, 1700MHz, 1900MHz, 2100MHz, 2300MHz, 2500MHz	Up to 20 miles	Up to 64 Kbps or 1 Mbps (2G), Up to 21.6 Mbps (3G), Up to 1 Gbps (4G)	High	Star	3GPP	Encrypted
6LoWPAN [46]-[84][115][116]	2.4 GHz	380ft	250 Kbps	Low	Mesh	IEEE	Single Building
Zigbee [46]-[84]	2.4 GHz	Up to 300 ft	250 Kbps	Low	Star, Hybrid, Mesh, Tree	IEEE	Encrypted
LoRa [46]-[84]	169 MHz, 433 MHz, 868 MHz, 915 MHz	Up to 10 miles	27 Kbps, 50 Kbps, 156 Kbps, 624 Kbps	Low	Star	the LoRa Alliance®	Encrypted

7. IOT FUNCTIONAL BLOCKS

The capability for sensing, actuation, identification, communication, and management is provided by an IoT system, which consists of a variety of functional blocks such as devices, services, communication, security, and application.

7.1. Devices

The devices provide the function of sensing, security monitoring, actuation, and controlling system. [132]-[136]

7.2. Communication

These manipulate the communication between devices, sensors, security mechanisms, and the cloud. [132]-[136]

7.3. Services

Service used for controlling the devices' sensors, security management services, cloud management services, and data publishing services. [132]-[136]

7.4. Management

The management block system provides different kinds of working methodology to control the hardware, sensor, and cloud. [132]-[136]

7.5. Security

Security block controls all security functions such as inbound and outbound scanning and validates all the data, messages, and content. [132]-[136]

7.6. Application

The application allows a communication medium between the user and the IoT system. So, users can supervise the various aspects of this system. [132]-[136]

8. IOT ENABLING TECHNOLOGIES

Standard protocols and networking technologies are largely used in IoT. RFID, NFC, low-energy Bluetooth, low-energy wireless, low-energy radio protocols, and LTE-A are the primary IoT enabling technologies and protocols. In contrast to a typical uniform network of common systems, these technologies enable the particular networking capabilities required in an IoT system.

8.1. Wireless Sensor Network

This environment is used to supervise the environmental and physical condition of wireless network that consists of various systems and network devices. These hardware devices are attached to different types of sensors to coordinate with the network device. The coordinator works as a gateway for connecting WSN to the internet. [137]-[161]

8.2. Cloud Computing

Cloud computing provides the access of the any application or web API over the internet that can be operated by of the any of the remote location. It provides the services such as SaaS, PaaS, and IaaS.[1][2] [137]-[161]

8.3. Big Data Analytics

Big data analytics is a process of collecting, organizing, and analysing the volume, velocity, or variety, and veracity of a large set of data to discover various authentications. Big data collect information from different resources such as social media, sensors, and digital transactions. [1][2] [137]-[161]

8.4. Communication Protocol

Communication Protocol worked as a backbone of the IoT system that enables the connectivity between user and application. This protocol allows the transmission between hardware, sensor, and IoT devices over the network. [1][2] [137]-[161]

8.5. Embedded Systems

In simple terms, the embedded means to attach something to anything. An Embedded system combines the hardware and software used to perform remarkable and specific tasks. These works on many kinds of microcontrollers, microprocessors, memory, networking units, input/ output devices, and storage devices. It gathered or sent the data via the internet. These scenarios are controlled by a real-time operating system with dedicated functions. [1][2] [137]-[161]

9. CONCLUSION

In this paper, we had briefly highlighted the revolution of IoT technologies and how they became increasingly popular and critical in today's scenario. We have also provided comprehensive details of protocols for IoT. Many IoT protocols were developed and standardized by IEEE, ITU, IETF, and other organizations while many more are working on development. This paper aims to provide a brief of different layers of IoT protocol. In addition, we have briefly classified characteristics of IoT, IoT functional block, things in IoT, and enabling technologies of IoT. Finally, we have discussed the comparisons of various IoT protocols that are working on an existing system. The Internet of Things (IoT) and cloud computing will open new doors for global business. It will eventually produce more employment. A lot of data is generated, giving birth to new jobs like data science. Autonomous vehicles (autonomous vehicles) are expected to boost the automation sector. Telemedicine, smart-wearables, EMRs, and distance exams are just a few examples of how the internet is altering healthcare. Augmented reality (AR) and virtual reality (VR) combined with the internet are allowing new heights in many fields.Our creativity is the limit of IoT. From smartwatches to smart coffee machines, it fosters innovation. It's altering our everyday comfort. It may also help us enhance our sustainability. Security and storage are two critical issues to address in the future, in our opinion.

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