IEEE Access
Multidisciplinary : Rapid Review : Open Access Journal

Received June 15, 2020, accepted June 25, 2020, date of publication June 30, 2020, date of current version July 20, 2020.
Digital Object Identifier 10.1109/ACCESS.2020.3006036

Interoperability and Data Storage in Internet of Multimedia Things: Investigating Current Trends, Research Challenges and Future Directions

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ABSTRACT Internet of Things (IoT) has widely been accepted as a promising paradigm for connecting a large number of resource-constrained miniature sensor nodes that have the ability to sense the deployed environment. They have found their applications in various aspect of our daily lives. However, these nodes are mostly restricted to sense only the scalar data. Nowadays, multimedia sensor nodes are gaining significant attention due to their ability to collect scalar as well as multi-dimensional data. These nodes are considered as the foundation of Internet of Multimedia Things (IoMT) and are shaping the perception of IoT. Multimedia data have stringent requirements in terms of reliability, latency, storage, bandwidth, and Quality of Service (QoS). To provide seamless and interoperable communication in IoMT, the underlying protocol stacks need to fulfill these stringent requirements. However, the heterogeneous nature of multimedia sensors makes interoperability a challenging task to fulfill. To understand the challenges faced by seamless and interoperable communication in IoMT, we provide a comprehensive review of the existing protocol stacks of IoMT and analyze their feasibility for multimedia streaming applications. Data storage of multimedia applications is another area that requires immediate attention of the research community. For this purpose, we study cloud as an entity to facilitate multimedia applications of IoMT. The instances of multimedia cloud are analyzed and a number of shortcomings are identified that pave the way for edge computing in IoMT. Finally, we present a case study that shows the significance of our work. The case study portrays an in-home patient monitoring system with an interoperable communication among the connected multimedia streaming devices at home, and healthcare practitioners at hospital. The case study also highlights the importance of uninterrupted data storage and retrieval at the network edge and multimedia sensor nodes.

INDEX TERMS Internet of Things, Internet of Multimedia Things, interoperability, protocol stack, cloud computing, edge computing.

I. INTRODUCTION

The Internet of Things (IoT) enables the integration of physical world with the virtual world via the sensor-embedded smart devices [1]. Today, the IoT expands to a vast majority of applications that include healthcare [2], transportation logistics [3], smart farming [4], industrial automation [5], etc. Though, the emergence of various applications has changed the definition of ‘‘Things’’, the main objective still remains unchanged: a sensor senses the physical world without human intervention. Advances in wireless technologies and an increasing number of physical objects integrating with the Internet are enabling the transition of Internet into a fully service-oriented future Internet [7]. At this stage, we are in the

The associate editor coordinating the review of this manuscript and approving it for publication was Kuo-Hui Yeh.

post-personal computers era, where smartphones and other handheld devices are overtaking desktops. This transition enables our environments to be more interactive and informative. Today, the number of physical objects connected with the Internet has surpassed human population [12]. It is estimated that around 20 billion physical devices will be interconnected with the Internet by 2025 [13]. More and more devices are integrating with the Internet. This integration and interoperable communication will generate an enormous amount of multimedia and non-multimedia data that need to be stored, processed, analyzed and transmit in a very systematic manner.

With the advent of multimedia data and the Internet connectivity of their associated objects, Internet of Multimedia Things (IoMT) is gaining momentum nowadays [14]. Multimedia objects such as Smartphone or laptop-controlled drones enable the firefighters and border patrol agents to conduct numerous operations [15]. These drones can also assist in aerial surveying to maintain infrastructure by examining power lines, and roads or even conducting geologic surveying [16], [17]. Communication protocols e.g. Real-time Transport Protocol (RTP) [18] and Real Time Streaming Protocol (RTSP) [19], support is often built right into the drone software and is a common way to access a drone's video feed. Body cameras [20] are another use case gaining more and more attention nowadays. Body cameras uses RTP to assist law enforcement agencies and first responders in conducting important security operations. These agencies depend upon real-time information to determine what is happening and respond to the situation on time [21]. Robots also generate a huge amount of multimedia data. From underwater submersibles [22], industrial automation [23], healthcare [24], [98] to agriculture [25], robots are being created for a variety of multimedia applications.

Despite the enormous potential of multimedia applications in an IoT infrastructure, their integration with the IoT is a challenging issue that is yet to be resolved [26]. The objects in these applications such as smart surveillance cameras, robots, drones, and multimedia wearables generate an enormous amount of data that demand sufficient bandwidth from the resource-constrained IoT devices. Moreover, they require considerably higher CPU time, storage and mostly unable to tolerable delay. Unlike conventional traffic flows of IoT applications, multimedia applications depends on data flows that have diverse features and characteristics [27]. Data flows, also known as streaming flows, are delay-sensitive and demand low latency and high throughput for the transmission of data. As a result, intermittent or interrupted connectivity poses significant challenges during multimedia streaming [28]. Apart from data flow reliance, multimedia applications need special consideration in term of packet loss detection, out of order packet delivery and jitter compensation. Hence, special considerations need to be in place while handling multimedia applications and services. One option is to adopt the existing streaming protocols for supporting multimedia applications and their data flows in the IoT context. However, the existing protocols were not designed based on the characteristics, requirements and limitations of IoT devices and technologies [29]. Similarly, little efforts were made for the interoperability of multimedia applications [30]. Heterogeneity of multimedia devices makes interoperability a challenging task in these applications. The multimedia sensors and their connected devices come from different manufacturers and are mostly incompatible with each other. Hence, there exists greater demand and potential for efficient streaming approaches to reuse the available IoT protocols and their underlying network stacks.

In IoMT, there are a number of applications that generate voluminous multimedia data that cannot be handled efficiently by RTP and RTSP. There is a need to either configure the existing IoT protocol stack or develop new ones. Although, cloud computing has the capability of providing a virtual infrastructure for these applications [31], the need for configuration of existing protocols still remain there. As far as the multimedia data is concerned, cost-based models are able to facilitate it [32]. These models will enable accessing the applications from anywhere around the world which is one of the main objective of IoT. The goal and objective of IoT is "Anytime, Anything and Anywhere", i.e., any object will be connected anywhere and all the time [64]. This goal will make the concept of ubiquitous computing a reality with the emergence of fully integrated smart environment. Cloud computing has the ability to provide on-demand services, resource pooling, rapid elasticity, and ample amount of storage to the underlying IP-enabled networks [34], [95]. However, cloud computing is unable to meet the demands of multimedia sensor nodes when it comes to latency and network connectivity. Most of IoMT applications are delay-sensitive and require quicker responses from cloud. Besides, the cloud data centers expect these devices to have ample storage, processing, and transmission power. These shortcomings have led to the emergence of edge computing that allows much faster responses with the availability of caching facility.

In literature, there exists few surveys that deal with the challenges faced by multimedia communication over wireless links. These surveys are mostly domain specific, i.e., content-based [35], application demand-based [36] and device's requirement-based [37]. However, a compact study for interoperable transmission of multimedia streams generated by heterogeneous devices is missing. Besides, the storage requirements of these streams is also missing in the literature. The major contributions of this survey are as follow.

1) We provide a comprehensive review of various communication protocol stacks used in the context of IoT. Based on this review, we examine their configuration for multimedia traffic of heterogeneous devices to provide seamless and interoperable communication in IoMT. For this purpose, a thorough analysis of protocols at various layers is made.
2) We examine cloud as an entity to facilitate the multimedia applications of IoMT. Various instances of multimedia cloud are comprehensively analyzed.

Besides, storage and processing at the multimedia cloud are also reviewed for numerous applications. Based on this analysis, numerous shortcomings are identified that led to the emergence of edge computing for IoMT applications.

3) We present a case study of in-home patient monitoring system that reflects the significance of our work. We highlight the importance of protocol stack for interoperable communication in a healthcare ecosystem that comprise heterogeneous multimedia devices. The abundance of resources of cloud data centers has an important role in this context. Seamless and interoperable communication among the connected devices literally means plethora of data streams that require ample amount of storage, processing, and bandwidth. The role of edge computing cannot be ignored as the underlying application has extremely sensitive data and demands quicker responses.
4) Finally, we provide a comprehensive list of research challenges and open research gaps present in the existing literature pertaining to communication protocols and the multimedia cloud of IoMT.

The rest of this article is organized as follows. In Section II, we provide a brief overview of the basic building block of IoMT, i.e., Wireless Multimedia Sensor Networks. In Section III, an overview of multimedia communication in the IoMT context is provided. A brief description of protocols at various layers, their underlying operational mechanisms and interoperability for multimedia applications along with open research challenges are highlighted. In Section IV, cloud is studied in the context of IoMT with detailed discussion on data communication, storage, processing and open research challenges in multimedia cloud. A case study of in-home patient monitoring system in the context of interoperable communication, cloud data storage, and edge computing is discussed in Section V. Finally, we conclude this survey by providing future research trends and directions in Section VI.

II. WIRELESS MULTIMEDIA SENSOR NETWORKS

IoMT can potentially reach to a vast array of areas and touch people's lives in various ways. For example, governments can allow its citizens to upload real-time multimedia data using some smartphone applications to report about the road and traffic conditions within the cities. The real-time multimedia streaming information can be applied to the current emergency response services, e.g., 000 in Australia and 911 in United States of America. It will allow an emergency response service to provide detailed information about the nature or severity of an incident, e.g., burglary, accident or domestic violence, provided that the caller can transmit video and/or image(s) of the incidence or incidence site. The existing research in IoT focuses mainly on sensing, actuating, and networking techniques. However, it does not take into account the challenges posed by multimedia communications between the real-world physical devices [27]. The current trend is moving the devices/things away from non-multimedia data support to multimedia streaming, especially video streaming. Therefore, it is important to have an understanding of multimedia streaming and the sensor embedded in these devices, multimedia sensor nodes in this case.

Wireless Sensor Networks (WSNs) have experienced a phenomenal growth over the past decade. Miniature sensor nodes are typically deployed in human-inaccessible terrains to monitor and collect time-critical and delay-sensitive events [9]. The rapid development of sensors is coupled with the advances in embedded computing and Micro-electromechanical systems (MEMS), and the availability of inexpensive Complementary Metal Oxide Semiconductor (CMOS) cameras and microphones allows for the emergence of Wireless Multimedia Sensor Networks (WMSNs). WMSN is a network of interconnected sensor nodes that sense the environment, and retrieve multimedia and ordinary data ubiquitously from the physical environment [28]. Multimedia data include still images, audios, videos and even live media streams that are supported by sensor nodes with installed cameras and microphones. Ordinary data, on the other hand, is restricted mostly to numeric values, e.g. temperature or humidity readings captured by sensor nodes. Multimedia data have stringent requirements in terms of delay, throughput, required bandwidth and data rate, respectively [9]. The evolution of wireless multimedia sensor network from wireless sensor network is shown in Fig. 1.

FIGURE 1. Evolution of WMSN from WSN.

WMSNs have found their applications in a wide range of domains such as, intelligent traffic management systems, military applications, surveillance systems, and habitat monitoring. All of these applications are heterogeneous in nature because they require not only non-multimedia but also multimedia information [28]. For these heterogeneous applications, WSN nodes lack certain features and key aspects that can only be acquired with the deployment of WMSN nodes. Some of these key features and aspects as are follows [9].

1) Processing Power: Processing of multimedia information is a computationally intensive operation. As a result, high-end processor, application-specific integrated circuit (ASIC), or field-programmable gate array (FPGA) is used for WMSN nodes. In WSN nodes, simple microcontrollers are used to perform computational tasks.
2) Storage: Local processing of multimedia information requires temporary storage of data during sensing and manipulation. In WSNs, which deal with non-multimedia data only, such temporary storage and high-speed memory are not required.

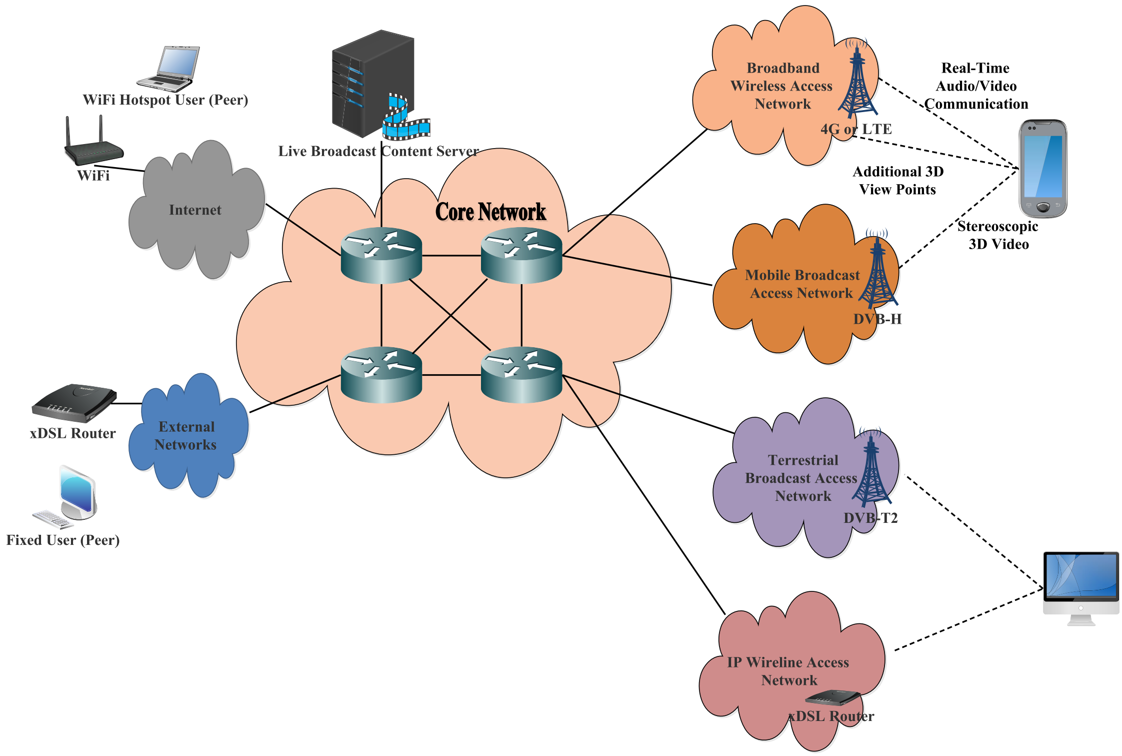

FIGURE 2. Typical wireless multimedia system.

3) Volume of Data: The volume of data in WMSNs is much bigger as compared to WSNs primarily due to the use of video and audio streaming.
4) Communication Standards: Ultra-wideband (UWB) is generally used as a wireless communication standard for sending and receiving multimedia information. In contrast, various WPAN standards such as, Zigbee, IEEE 802.15.4, and near field communication, are widely used for communication in WSN.
5) Routing and Transport Layer Protocols: The difference between the deployed environments and data features of streaming data in WMSNs and non-multimedia data in WSN means that the traditional routing protocols for non-multimedia data do not fit to the requirements of streaming multimedia data. Moreover, transport protocols of WSNs are unable to meet the QoS requirement of multimedia data.

III. MULTIMEDIA COMMUNICATION IN IoMT

Unlike IoT, the IoMT has special requirements for data gathering and transmission. The IoMT architecture suits those devices which have the capability of capturing and transmitting multimedia data. The multimedia data transmission demands sufficient bandwidth and special streaming protocols and algorithms as compared to non-multimedia data which is sensed and transmitted through simple sensor nodes in the IoT systems [38]. Depending on the applications, the multimedia data may or may not be real-time. In IoT-based systems, the ultimate destination for sensed data is a cloud server which can be utilised as a remote and powerful source of computation and storage to provide real-time services. However, if we assume an IoMT data capturing device as a source and cloud as a destination, then the delivery of data from source to destination in real-time over IP-based heterogeneous networks is a major challenge to deal with.

The real-time requirements of multimedia data impose significant burden over IoMT-based systems. These real-time requirements have been achieved successfully over TCP/IP based systems through various protocols such as, HTTP, RTSP, and IP. However, these protocols are designed for TCP/IP enabled devices having enough computing power, memory, and energy resources. In an IoMT, it is assumed that the devices are smart, however, there is no guarantee that they will have ample of computing power, memory, and power backups. The TCP/IP protocols consume a lot of energy during data processing, transmission, security, header checks, and feedback, etc., [39]. Based on these factors, the TCP/IP protocols cannot be applied directly to an IoMT paradigm.

Many organisations such as Internet Engineering Task Force (IETF), Institute of Electrical and Electronic Engineering (IEEE), World Wide Web Consortium (W3C), have proposed a wide range of protocols for various communication systems. IEEE 802.15.4 standard is proposed for low-powered data communication networks [40]. Famous ZigBee wireless network is based on this standard [41]. The MAC layer of this standard supports single channel scenario and

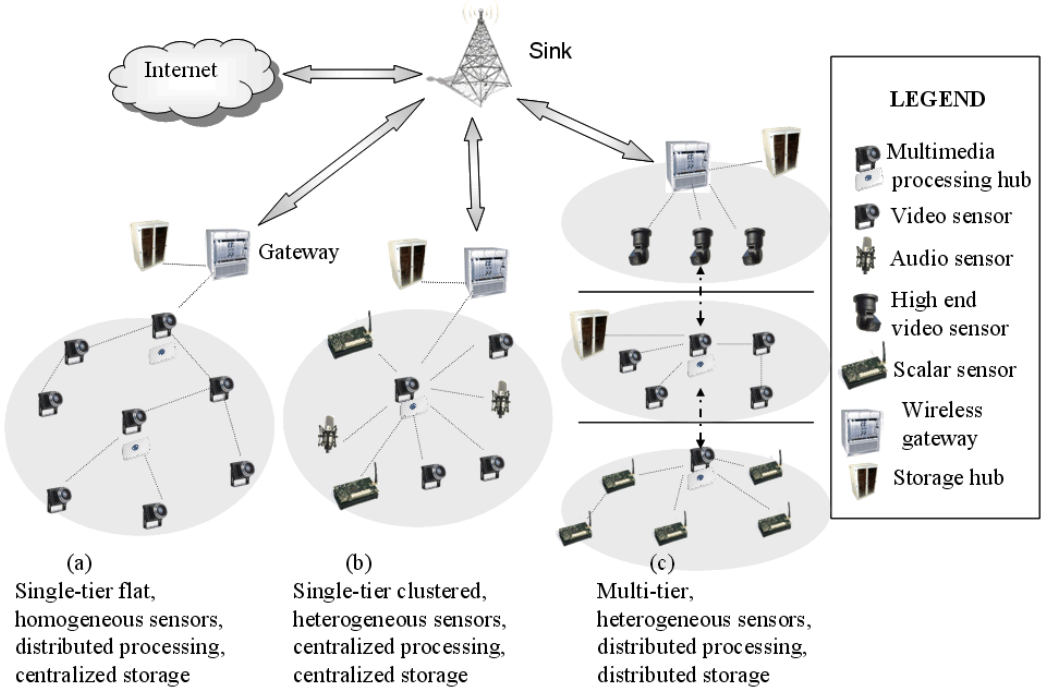

FIGURE 3. Typical wireless multimedia sensor network.

is not suitable for multi-hop communication. The concept of IoMT is ad-hoc and uses multi-hop transmission for long-haul multimedia communication. Thus, IoMT demands significant modifications to the MAC layer of 802.15.4. Time Synchronised Mesh Protocol (TSMP) was introduced to support multi-hop communication in IoT-based mesh systems [42]. It uses Time Division Multiplexing (TDM) concept and stays in an extremely low-powered mode. However, this protocol is feasible only for random and non-multimedia data transmission. Another low-powered protocol, IPv6 over Low-power Wireless Personal Area Network (6LoWPAN) was proposed for IoT-based systems [43]. Due to its low bandwidth requirements, it is suitable for short-range non-multimedia data transmission. IETF introduced a routing protocol for low-powered and lossy WSNs, formally known as RPL [44]. It is a dynamic routing protocol and supports IPv6 only. The design of RPL is very similar to 6LoWPAN and shares almost similar characteristics. IETF also introduced Constrained Application Protocol (CoAP) for application layer of IoT systems [65]. It was designed for simple and resource-constrained devices, e.g., wireless sensor nodes. It simplifies the HTTP functionalities and provides support for multi-casting with less overhead. Due to its support for UDP, it can be modified and utilised for multimedia communication in IoMT. Table 1 summarises various layer-wise protocols proposed for IoT systems.

The IoT architecture was proposed for connecting small and smart sensor-based devices through an IPv6-based Internet. The current research in an IoT domain addresses various challenges pertaining to energy consumption, hardware

TABLE 1. Characteristics of PHY protocols.

PHY Protocol	Spreading Technique	Radio Band (MHz)	MAC Access	Data Rate (bps)	**Scalability**
IEEE 802.15.4	DSSS	868, 915, 2400	TDMA, CSMA/CA	20K, 40K, 250K	65K nodes
BLE	FHSS	2400	TDMA	1024K	5917 slaves
EPCglobal	DS-CDMA	860, 960	ALOHA	5k to 640K	-
LTE-A	Multiple CC	Varies	OFDMA	1G (Up), 500M (Down)	-
Z-Wave	-	868, 908, 2400	CSMA/CA	40K	232 nodes

limitations, availability of low data rate, short-range communication, and data redundancy, in its proposed architecture by dealing with non-multimedia data only [45]. The specific requirements of multimedia data makes it a special case in IoT architecture. The future of IoT belongs to multimedia data. Both, devices and users will be generating real-time multimedia data. In the following subsections, we review the existing communication stack of an IoT and its potential uses for real-time multimedia data communication. The protocols in an IoT communication stack are designed for short-range transmission, low bandwidth consumption, and non-multimedia data only. Thereby, for IoMT implementations, we recommend either to upgrade the existing IoT protocols for multimedia support or to propose and design new algorithms and protocols for multimedia technology.

A. PHYSICAL/LINK LAYER

In this section, we summarize some of the well-known protocols used at the physical and link layer.

1) LONG TERM EVOLUTION-ADVANCED

Long Term Evolution-Advanced (LTE-A) is a combination of multiple cellular protocols and is suitable for M2M and IoT data communication over a short-range [46]. This protocol is based on Orthogonal Frequency Division Multiple Access (OFDMA) concept and has the ability to support up to five 20 MHz transmission bands at a time. Networks built on LTE-A technology comprise two parts, i.e., a core and a radio. In the core part, mobile devices and the IP-based communication are dealt with. On the other hand, radio part deals with wireless and radio communication. Like traditional wireless networks, this protocol operates through a base station, which is one of the component of its radio part.

Despite its support for MHz-level bands and radio communication, it cannot be applied directly to IoMT. There are two major limitations of this protocol. First, it is suitable for a small number of devices and is unable to deal with network congestion, especially when thousands of devices in an ad-hoc mode are transmitting and receiving multimedia data. Second, the support for QoS is compromised in this protocol, which is a challenge for real-time multimedia communication. Based on these two limitations, it might be suitable for non-multimedia-based data communication but cannot be utilised for multimedia communication without significant modifications.

2) RFID

Electronic Product Code global (EPCglobal) is a global organisation which develops and manages Electronic Product Code (EPC) and RFID [47]. A combination of EPC and RFID is considered as a promising standard for an IoT-based communication due to its scalability and reliability. The RFID system consists of a tag (RF signal transponder) and a tag reader. In RFID, the tag's number is sent through radio waves to a tag reader. The tag's number is passed over to an application, known as Object-Naming Services (ONS), that verifies the tag from a tag database [48]. The RFID operation is shown in Fig. 4.

Due to its scalability and reliability for the future IoT products, it has some technical and ethical issues. The RFID devices are manufactured by various companies across the globe and some RFID devices are never meant to leave their network, which makes them non-suitable for mobile communication, especially in IoMT. Due to the electromagnetic spectrum used by RFID systems, it is relatively easy to jam these systems at pre-determined/appropriate frequencies. Jamming becomes a serious issue in IoMT applications like hospitals, military, and security. The RFID reader cannot respond if signals from more than one device overlap.

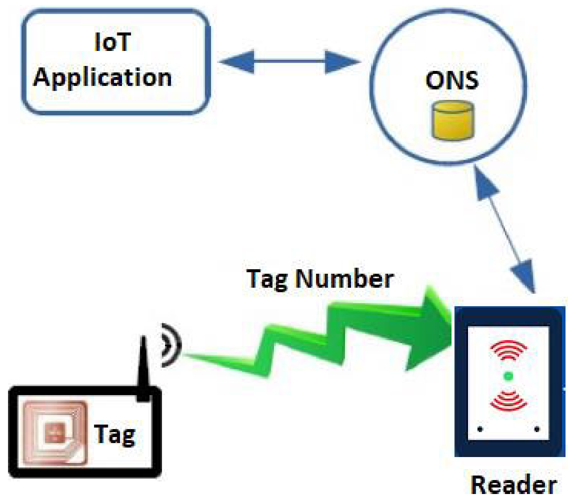

FIGURE 4. RFID operation.

In the IoMT, it is quite often that one device may communicate with more than one device at a time. RFID tags can be read without consumer's knowledge and can cause severe security issues in the IoMT applications [49].

3) Z-WAVE

Z-Wave is a low-powered wireless communication protocol. It was designed by ZenSys and later, modified and improved by Z-Wave Alliance [50]. It is designed for home automation and remote access. It supports point-to-point communication up to 30 meters range and operates in a 921.42 MHz band in Australia and New Zealand. It provides reliable communication through Acknowledgement (ACK) messages. Its transmission style is based on source routing in which data packets contain the route information [50].

Although it is low-powered and reliable protocol, it has its own limitations. The initial version supported a data rate up to 40 kbps while the latest version can support up to 200 kbps [51]. However, in case of multimedia communication where the volume of data is quite huge, data rate of 200 kbps is insufficient. This protocol is suitable for non-multimedia and small-sized data transmissions only. It is unable to support a relatively larger number of devices located in close vicinity. For practical implementation, it is recommended by the manufacturers that the deployment should not exceed 30-50 nodes inclusive of the relay nodes. The IoMT systems cannot rely on such small number of nodes for multimedia transmission. The routing information in the data packets and ACK messages increases the transmission load and is not suitable for real-time multimedia communication. The maintenance of Z-Wave-based networks demands effort and manual up-gradations whenever a node joins or leaves the network. On the other hand, IoMT is based on an ad hoc concept, where the IP-enabled devices are expected to be smart enough to adjust themselves according to the network scalability.

4) IEEE 802.15.4

This standard covers both Medium Access Control (MAC) and Physical layer (PHY). It was designed to support low cost, low-powered, and high throughput-based wireless communication at a low data rate. Due to its features, it is considered as an ideal platform for WSN, IoT, and M2M communication. One of its promising feature is to support large number of devices, i.e., approximately 65k, at a time. Other popular features include authentication and security. This standard supports a data rate of up to 250 kbps and uses CSMA/CD to avoid network collision. It can also support master and slave node scenario, where a master node has higher authority as compared to slave nodes as shown in Fig. 5. It can support different networking topologies such as, mesh, star, and clusters [40].

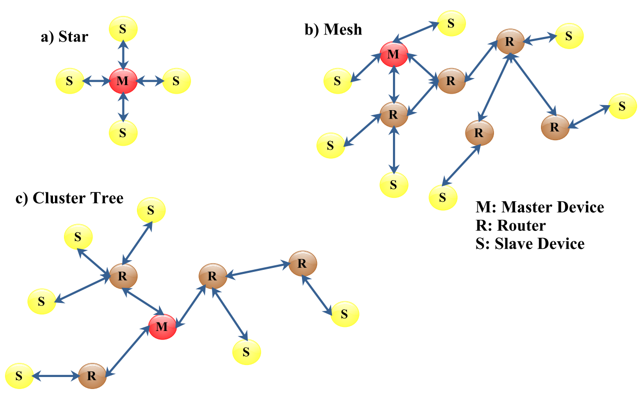

FIGURE 5. Topological architecture.

For short-range and non-multimedia data transmission, it is considered as one of the best available option for IoT. IoMT, on the other hand, requires much higher resources. Features like low-powered consumption, security, and support for large number of devices are quite attractive for IoMT. This protocol does not guarantee for QoS provisioning, which is one of the top priority requirements in any real-time multimedia communication system. Low data rate, i.e., 250 kbps, is insufficient for multimedia-based services and will require additional services such as, data fragmentation and reassembling, to transmit multimedia data at such low data rate channels. These additional services not only disturb the real-time constraint, but also put extra processing load on data sending devices. Newly introduced standard IEEE 802.11ah is considered as an alternative to IEEE 802.15.4 for providing long-range data transmission with an increased data rate [52]. This standard is expected to be finalised and launched in market by 2016 and may become an initial step for IoMT-based systems. Table 2 summarizes the comparison between IEEE 802.15.4 and IEEE 802.11ah.

TABLE 2. 802.11ah Vs. 802.15.4.

Features	802.11ah	802.15.4
Network Support Frequency	Sensor, Backhaul Sub-1 GHz	Sensor 2.4 GHz
Channel Access	RAW (Restricted Access Window)	CSMA/CA
Maximum Data Rate	40 Mbps	250 Kbps
Maximum Range	1 kilo meters	100 meters
Power Saving	TIM (Traffic Indication Map), DTIM (Delivery Traffic Indication) Map TWT (Target Wake Time)	Sleep-wake strategy
Relay	Relay Access Point (AP)	Full Function Device (FFD)

B. NETWORK LAYER

In case of data transmission over the Internet, a data packet needs to pass through many networks on its way from source to destination. To understand the data link strategy of each network along the path, an *IP-over-X* scheme is required. This scheme maps the data packets coming from lower layers to an IP layer. In case of IoT, the IETF has introduced 6LoWPAN, which transmits data packets through IPv6 over IEEE 802.15.4 networks.

In IoT, the 6LoWPAN faces many challenges during the routing procedure, e.g., error-prone links, limited energy, mesh networks, mobility, and low processing power [43]. The working strategy of 6LoWPAN and IPv6 needs to be compatible with each other to fulfil real-time application requirements. To face these challenges, IETF has introduced a group known as Routing Over Low power and Lossy Networks (ROLL) [53]. To meet the aforementioned conditions, this group has introduced an IPv6 protocol, known as Routing Protocol for Low-power and Lossy Networks (RPL) [44]. Initially, the development of Lightweight On-demand Ad-hoc Distance-Vector routing (LOAD) [54] was suspended by 6LoWPAN working group due to its focus on the experimental results of ROLL and RPL. Later on, in November 2012, Alliance group superseded LOAD and introduced it as LOADng, an alternative for RPL.

1) 6LoWPAN

Wireless Personal Area Networks (WPANs) possess specific characteristics such as, variable length of addresses, support for mesh and star topologies with low-bandwidth, support for large number of devices, ad-hoc networking, low-cost, and energy consumption [55]. Due to the standard Maximum Transmission Unit (MTU) size of 1280 bytes of an IPv6 and longer header of 40 bytes [56], it cannot be applied directly over WPANs. IETF research group has put sufficient efforts to join the features of IPv6 and IEEE 802.15.4 and the result is 6LoWPAN. In order to create a compatibility level, an adaptation layer is used by 6LoWPAN between IPv6 and MAC layer of IEEE 802.15.4. A list of headers is used along with 6LoWPAN-encapsulated datagram to transport it over MAC layer of IEEE 802.15.4. 6LoWPAN uses compression technique, i.e., *LOWPAN_NHC*, to compress IPV6 header before transmitting the IPv6-based data packet

TABLE 3. Comparison between IPv6 and 6LoWPAN header fields [103].

Header Field	IPv6 Header Length	6LoWPAN HC1 Length	Explanation
Version	4 bits	-	For IPv6 communication assumption
Traffic Class Flow Label	8 bits 20 bits	1 bit	0 denotes Not compressed. 1 denotes compressed. Traffic and data flow are labeled 0.
Payload Length	16 bits	-	derived from the MAC's frame length or datagram size of adaptation layer (fragmentation header of 6LoWPAN).
Next Header	8 bits	2 bits	Compressed when the packet uses TCP, UDP, or ICMPv6 (Internet Control Message Protocol version 6).
Hop Limit	8 bits	8 bits	The only field always not compressed.
Source Address Destination Address	128 bits 128 bits	2 bits 2 bits	If the destination as well as the source IPv6 addresses are within the local link, their 64-bit network prefix is compressed to a single bit, and each has a value of 1. Another single bit is set to 1 for indication that 64-bit interface identifier is elided for the destination to derive it from corresponding LLA (link layer address) in a link layer frame or MAH (mesh addressing header).
HC2 Encoding	-	1 bit	The HC1 header is followed by another compression scheme.
Total	40 bytes	2 bytes	Fully compressed, the IPv6 header is reduced to 2 byte by HC1 encoding.

over IEEE 802.15.4 [57]. The source and destination port addresses can also be compressed if required. In short, without proper compression, IPv6-based communication is not possible over IEEE 802.15.4 networks. Table 3 summarises the comparison between the headers of IPv6 and 6LoWPAN.

As stated before, the main purpose of 6LoWPAN is to transfer IPv6 packets over IEEE 802.15.4 networks. To achieve this goal, 6LoWPAN applies compression and fragmentation over IPv6's packets. Along with the existing limitations of IEEE 802.15.4 for multimedia data communication, 6LoWPAN adds further restrictions for multimedia streaming in IoMT. The process of compression and fragmentation has a direct relationship with latency in multimedia communication. Higher the compression and fragmentation during transmission, higher will be the latency during multimedia communication. Compression of data means the elimination of redundant information from useful data. The eliminated information cannot be retrieved directly unless retransmission takes place. Due to its large volume, multimedia data is always compressed before transmission and is transformed into bit stream, which is sensitive to bit errors. A single bit modification/deletion can cause severe problems. Therefore, the compression phase of 6LoWPAN is not recommended for payload section of IPv6-based data packet. If we assume that the compression phase of 6LoWPAN is restricted only to the header, it means fragmentation phase will be applied to payload of IPv6. The standard MTU size of IPv6 is 1280 bytes, 40 bytes out of which is reserved for header and 8 bytes are reserved for the fragmentation header. Therefore, the length of payload supported by IPv6 is 1232 bytes, while 6LoWPAN supports only 80-100 bytes. Conversion to such a smaller payload demands many fragmentations. The fragmentation and re-fragmentation process produces delays which are not suitable for real-time multimedia communication.

2) RPL

RPL is based on distance vector-based routing over IPv6 and is designed for Low-powered and Lossy Networks (LLNs) [44]. Such networks have limited energy and computing resources. However, there is still a need to propagate necessary routing information among the nodes of a network. To minimize energy consumption, the RPL uses a slow and dynamic process to deal with network inconsistencies. The routing inconsistencies are detected by including the routing information within the datagram. To avoid network loops, there is a mechanism in RPL to detect data-path loops [58]. To maintain network topology, RPL contains four types of control messages, i.e., Destination Oriented Directed Acyclic Graph (DODAG), DODAG Information Solicitation (DIS), DODAG Information Object (DIO), Destination Advertisement Object (DAO), and DAO-ACK [59]. As the LLNs mostly contain battery-powered devices, the total number of control messages needs to be controlled. The RPL controls these messages with the help of Trickle algorithm [60]. The control messages will be lower in case of stable links as compared to frequently changing topologies.

RPL defines three data communication types which are, Point-to-Point (P2P), Point-to-Multipoint (P2M), and Multipoint-to-Point (M2P). Among these three types, the P2P demands memory requirements, energy consumption, and direct path information from the entire network and is one of the major weaknesses of RPL. In case of multimedia communication, direct paths are always preferred as compared to indirect paths, which cause latency in real-time communication. This weakness of RPL makes it incompatible for

P2P multimedia communication in IoMT systems. The main objective of Internet is to avoid a single point of failure. In other words, if one or more routers fail, the remaining operational routers within the network need to provide constant connectivity.

In case of RPL, the DODAG root is assigned the task of maintaining sufficient information of routes to all possible destinations in the network. If DODAG root fails due to any reason, the remaining routers within the network may not be able to work as DODAG root due to insufficient resources. This failure causes single-point-to-failure scenario and becomes the second weakness of RPL [61]. This scenario is highly critical for IoMT networks and causes a breakdown in the entire multimedia communication between the sources and destinations. The header management in DODAG is inefficient and may consume significant amount of bytes from the MTU of an IEEE 802.15.4 packet. This situation leads to fragmentation, which is not required for multimedia communication in IoMT and is considered as the third weakness of RPL. The fourth weakness of RPL is the lack of support for bi-directional communication. The bi-directional communication is compulsory in many IoMT applications such as, automation, surveillance, traffic management, and security. The RPL claims "*no loop in the network*". The loops will be generated once the data is transmitted. Once the loop is detected, the loop elimination procedure will be triggered. Obviously, the data packets need to be buffered until the issue is resolved, thus becoming the fifth weakness of RPL. In case of multimedia communication, the data packets cannot be held longer due to their limitations imposed on the storage capacities of IoMT devices. This situation deteriorates the network performance and packets will drop frequently.

3) LOADng

The base for LOADng is Ad hoc On-demand Distance Vector routing (AODV). It is an internetworking protocol for Personal Area Networks (PANs). It is a reactive protocol and its main operations are Route REQuests (RREQs) generation by LOADng router to find paths to a specific destination, Route REPlies (RREPs) from destination upon successful arrival of RREQs, and unicast transmission of RREQs at hop-by-hop level [54]. It also supports one-hop transmission if the destination cannot be reached. It operates on the top of the adaptation layer and creates a mesh network underneath. For route discovery, it broadcasts RREQ packets. Overall, LOADng discovers route, manage data structures, and maintain local connections.

With its attractive features, it is considered as one of the biggest competitor of RPL. Unlike RPL, LOADng supports P2P communication in an efficient manner. All routers in LOADng networks exhibit same behaviour, similar to a traditional Internet. Thus, avoiding the need for a root router. It also supports bidirectional links. The loops are automatically eliminated during transmission because only destination can reply to RREQs. Due to low bandwidth and small-sized packets of IEEE 802.15.4 networks, LOADng makes use of fragmentation which cause delays during real-time multimedia communication. For IoMT systems, this protocol is considered as a suitable option, having fragmentation weakness only. A comparison between RPL and LOADng is summarised in Table 4 [104].

TABLE 4. General features of RPL and LOADng.

Characteristics	RPL	LOADng
Basic Operational Mechanism	Proactive	Reactive
Support for General Traffic Patterns	Unavailable	Available
Specific Requirements for the Root	Yes	No
Bi-Directional Route Check	Unavailable	Available
Loop Freedom	No	Yes
Risk of Fragmentation	Yes	No
Constant Data Packet Header	No	Yes
Metric Support	Available	Available

C. TRANSPORT LAYER

The transport layer is responsible for end-to-end delivery and flow control. Well-known protocols at this layer are Transmission Control Protocol (TCP), a connection-oriented protocol, and User Datagram Protocol (UDP), a connectionless protocol. Reliable protocols like TCP are always preferred but, in case of LLNs, reliability is considered as an expensive utility in terms of energy consumption. Reliability can only be achieved through dedicated paths and acknowledgements. In order to establish such paths and receive acknowledgements, control packets play an important role. These control packets, on the other hand, consume energy and bandwidth. Hence, for networks like LLNs, UDP is considered as a suitable approach. In TCP/IP model, UDP is always used for multimedia communication due to its simplicity and small header. As the concept of IoMT is proposed for multimedia communication, UDP will be used for communication purposes. Due to a small header and small packet requirements by IEEE 802.15.4, the UDP header is compressed and payload is fragmented each time. This leads to processing delays in a real-time multimedia communication.

D. APPLICATION LAYER

At application layer, a variety of applications are supported. These applications demand a diverse range of devices from powerful to resource-constrained. In case of IoT networks, most of the devices are resource-constrained. With the Internet technology, usage of web services has become a norm. Due to the resource-constrained nature of IoT networks, direct implementation of application layer protocols of a TCP/IP suite is not possible. In order to avail services offered by the application layer protocols of a TCP/IP suite, either they need to be modified according to the requirements of IoT networks or new protocols need to be designed. Many protocols are proposed for LLNs, IEEE 802.15.4 networks, and IoT-based systems in the literature [62]–[64]. However, not all these protocols are required and feasible for an IoMT paradigm. In this section, we will discuss CoAP protocol only due to its usage in the IoMT applications.

1) CoAP

Constrained Application Protocol (CoAP) is proposed by the IETF restful environmental working group [65]. It is a web-based transfer protocol and has a very low processing overhead. It is suitable for resource-constrained networks. CoAP works somewhat similar to HTTP, and can translate to HTTP for integration with web services. The main features provided by CoAP are, web services for resource-constrained networks, direct mapping to HTTP, low-processing overhead, simple proxy settings and processing, and support for exchange of asynchronous messages and caching [66]. These features depend on REpresentational State Transfer (REST) which works in a similar way as HTTP to provide resources between the clients and servers. REST is mostly used in social networking mobile applications [68]. CoAP-based services use UDP connection while REST uses TCP connection. This is one main reason that CoAP is readily applicable to IoT-based architectures. Due to the dependency of CoAP on REST services, conversion of proxies between these protocols is relatively easy. The functionality of CoAP is summarised in Fig. 6.

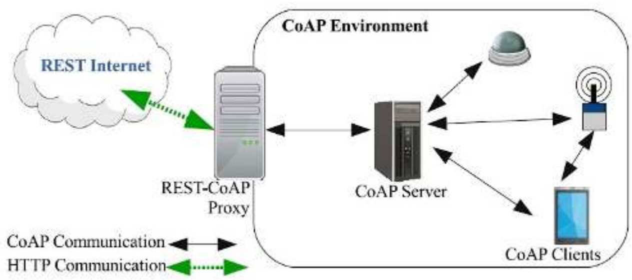

FIGURE 6. CoAP communication.

Although, it is specifically designed for resource-constrained devices and their underlying networks, it has its own limitations. It is designed for one-to-one communication. As a result, it cannot support broadcasting services which is sometimes required to share multimedia information among many users. Another deficiency is the lack of built-in security mechanism. Security is always treated as a sensitive feature in IoMT applications like health monitoring, surveillance, automation, and military. To address the security issue, Datagram Transport Layer Security (DTLS) protocol was introduced [69]. DTLS supports resource-consuming computationally complex cipher suites which require abundant of resources on part of each node. These complex cipher suites do not meet the requirements of resource-starving devices and need to be tailored accordingly based on the specifications of CoAP.

2) MQTT

Message Queue Telemetry Transport (MQTT) [94] was developed to optimize the usage of resources in low-powered smart devices. MQTT provides lower latency, and low-bandwidth consumption for data transmission over unreliable communication networks. It uses a publish/subscribe messaging approach, which is extremely lightweight and feasible for these networks. The use of TCP at the transport layer provides session awareness features to this protocol. MQTT provides a trade-off between the limited resources and reliable communication among the devices. Among all the application layer protocols of IoMT, MQTT provides higher QoS with intermittent-to-seamless connectivity for multimedia streaming applications. MQTT has four main modules: subscriber, publisher, broker, and message. MQTT does not support device-to-device and multicast communication.

3) XMPP

Extensible messaging and presence protocol (XMPP) [96] is inspired from presence information and instant messaging. It has built-in support for voice and video calls, lightweight middleware, collaboration, and content syndication. Besides, it supports generalize routing of XML-type data. It has found its applications in various smart connected devices, e.g. dryers, washers, refrigerators, etc. It uses a very simple addressing scheme and is highly secured and scalable at the same time.

E. SECURITY CONSIDERATION FOR IoMT COMMUNICATION

For seamless and interoperable communication in IoMT, the role of security cannot be ignored. Reliable data transmission is an important consideration for secured cryptographic algorithms [107]. In the context of security, lightweight encryption protocols need to be designed in view of limited resources of sensor-embedded real-world devices of IoMT [108]. Although, there exists a number of secured communication protocols, most of them are designed for the IoT applications only. For IoMT, any designed protocol must ensure data confidentiality, authentication, integrity and non-repudiation of bulky data flows that frequently vary with the passage of time [109]. Most of the IoMT devices come with insufficient security to the market and lack the support of standardized solutions. For these devices, security considerations need to be in place at the time of design rather than at the time of deployment [110]. The IoMT-based networks may be exposed to conventional attacks faced by Internet, e.g. denial of service (DoS). In this context, resilience and service availability are two important requirements. At each layer of the aforementioned protocol stack, security mechanisms are required for interoperable communication among the devices. These mechanisms ensure normal functioning of the devices by preventing various attacks. For example, fragmentation attack at the 6LoWPAN adaptation layer prevents proper reassembly of packets at the target devices. Other security requirements such as privacy, trust, anonymity and liability are also required for wide-spread adoption of IoMT-enabled sensing devices.

F. OPEN RESEARCH PROBLEMS

Based on the IoT communication stack, the following research issues can be addressed for an IoMT communication stack.

- Wireless technology like IEEE 802.15.4 is suitable for non-multimedia data communication only. It does not support multimedia data communication. Multimedia data is always larger in volume and demands higher bandwidth. Although, IEEE 802.11ah can offer higher bandwidth, still it is not sufficient to carry multimedia traffic over long-haul transmission channels. There is a need to introduce network technologies such as, Wi-Fi or WiMAX, to support long-haul multimedia data communication for low-powered devices with QoS support.
- The physical layer protocols in IoT can support data communication at a lower bitrate. They are specifically designed for low-powered embedded device, e.g., sensors. To make these protocols compatible with high data rate technologies, significant modifications are required in the existing physical layer protocols to make them compatible with upcoming wireless technologies.
- The link layer protocols in IoT stack face problems similar to the physical layer protocols. In IoT stack, these two layers work together. As a result, they share similar characteristics. Integration of new technologies with this part, i.e., physical and link layer, of IoT stack is challenging due to combined features of these two layers. The responsibilities of the researchers and developers will become easy if these two layers operate separately and portray individual requirements and functionalities similar to a TCP/IP architecture.
- The routing protocols at the network layer search mostly for energy-efficient and shortest paths for successful delivery of data packets from source to destination over an IEEE 802.15.4 network. However, these protocols treat all applications of IoT in a similar manner. The requirements of multimedia applications are different from other non-multimedia data communication applications. In any real-time multimedia application, QoS provisioning is one of the critical requirements. If the routing protocols are inefficient to support certain level of QoS, it will certainly affect the QoE level. Hence, there is a need to introduce new routing protocols which need to be able to support energy-efficient QoS requirements of any IoMT application.
- There is a need for protocols which should be able to provide energy-efficient and QoS-based multimedia streaming services between various heterogeneous devices. In an IoMT architecture, a multimedia device can be of any type, e.g., camera, smartphone, computer, and multimedia server. It is the responsibility of the underlying communication stack in any communication system to provide error-free communication between heterogeneous devices, a feature currently missing in the IoT stack.
- In IoT, the application layer protocols are designed for non-multimedia data communication over LLNs. In TCP/IP architecture, streaming protocols at the application layer provide error-free streaming services at the expense of resources consumption. With the help of session establishment between the source and the destination, application layer protocols provide a smooth streaming facility. Contrary to this, such type of services are missing in IoT because it is basically designed for short-range and simple data communication. As a result, the IoT architecture cannot provide such services. The concept of IoMT is based on multimedia communication which is incomplete without such application layer services.
- The digitization of physical world has provided a new dimension to the digital libraries [113]. Modern digital libraries include a range of conventional digital objects such as images, audios, videos, software, and text documents. In the IoMT paradigm, smart physical devices play an important role by providing smart services to human beings as well as machines. These devices are the newest type of digital resources augmented with sensing and actuation, computation, storage and networking capabilities [114]. To create effective digital libraries in the IoMT context, a reference metadata model needs to be defined for each smart device to manage it from different perspectives, e.g. provided services, internal status, distributed discovery, and interaction with physical world, systems and users [115]. This model also needs to consider the inclusion of digital devices into complex and dynamic ecosystems of IoMT in view of the bulky data flows and intermittent connectivity [116]. Metadata alone is not sufficient for digital libraries as the protocol stacks of heterogeneous devices use different standards. Interoperability needs to be investigated from digital libraries' perspective for these devices to ensure seamless communication among them.

IV. CLOUD IN IoMT

In IoT and IoMT, large-scale networks covering a wide geographical region are supported. The IoT-based systems produce simple and non-multimedia data only. On the other hand, the data produced by IoMT is multimedia and is larger in volume. This data needs to be processed, maintained, and stored carefully. For such large volumes of data, cloud computing provides an all-in-one platform, i.e., processing, storage, and remote accessibility. However, the involvement of a cloud platform in an IoT/IoMT-based systems is not an easy job and poses many challenges, e.g., management, synchronization, reliability, and enhancement.

For real-time multimedia services, Video Service Providers (VSPs) are shifting their infrastructures to public clouds [70]. These public clouds offer powerful and reliable computing and storage platforms to process large volumes of multimedia data. Alongside computing and storage facilities, these cloud platforms need to support

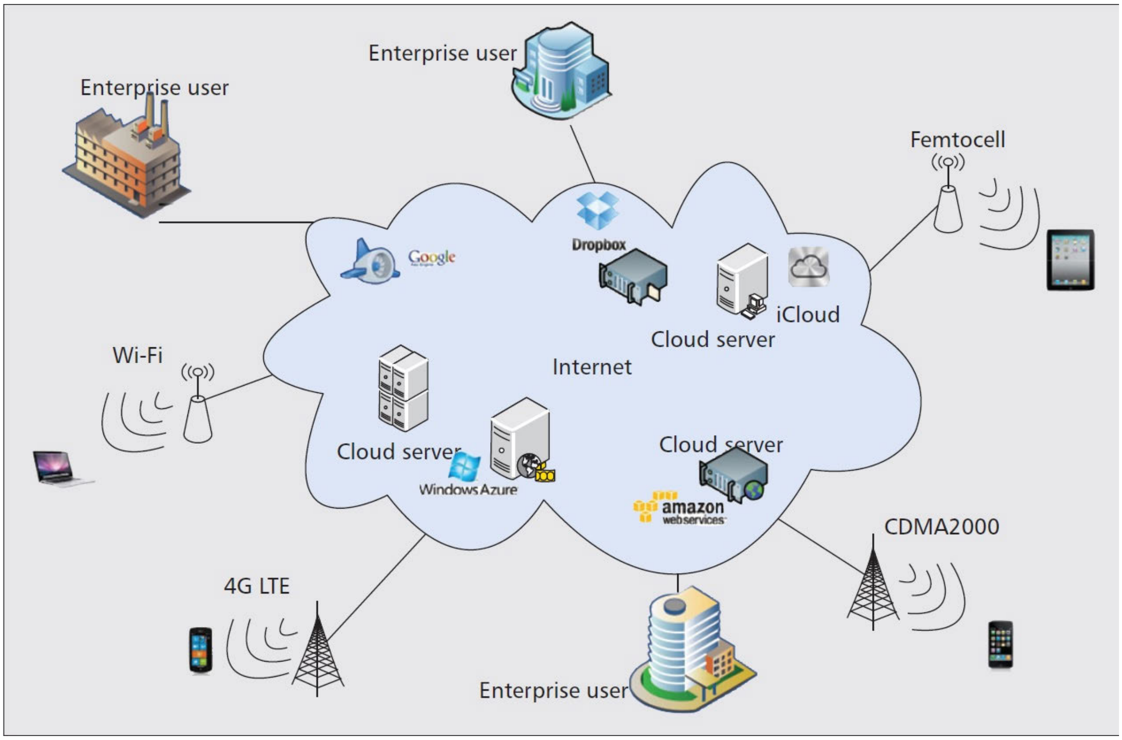

FIGURE 7. Cloud platforms for applications.

application-specific QoS and QoE services [71], [72]. Such integration of cloud computing with IoT/IoMT enables the user to access their desired data anywhere and any time. If the services/applications are properly managed on cloud platforms, users will not only be able to access the data but, will control their systems too. This integration is very useful in applications like remote surveillance, military, and home and industry automation. Services like multimedia over cloud platforms are dependent on three main functions: 1) QoS to support various multimedia services, 2) parallel and distributed processing of multimedia contents, and 3) QoS support for various types of data generating devices and networks with variable bandwidth availability.

Numerous cloud platforms are available in market such as, Amazon, Google, OpenIoT, and GENI. These cloud platforms are designed to support different applications and organizational requirements as shown in Fig. 7. In recent years, Xively, a cloud-based service, became very popular for IoT applications which allows its users to access their sensor data through web services [73]. It provides many services for IoT users and developers such as, real-time access, communication over HTTP, integration with Java and Python, and Ruby libraries for interface and application development. Another similar application is Nimbits which connects embedded devices with the clouds to perform data analysis, connectivity of social networks, exchange of text messages, and web services [74]. Table 5 [112] provides a summary of cloud services currently available for IoT/IoMT. These services include, support for WAN through gateways, configuration support, delivery and billing of services provided by various applications, and application layer protocols.

A. DATA COMMUNICATION IN MULTIMEDIA CLOUD

Big data streams are increasing rapidly at a phenomenal rate in various domains, e.g., sensor data streams, multimedia data streams, and stock exchange data. Processing of such large volumes of data in real-time is a major challenge for real-time decision making, service development, and risk minimization in an IoMT platform [85]. In case of video data, the streams are always continuous in time. Many cloud service providers, e.g., Microsoft, Amazon, and Google offer computational services to process and store large volumes of data in real-time. Their data centers are always distributed across the globe. After the deployment of processing centers for big multimedia data over public clouds, the next step is to manage data transmission between these centers. These data centers are connected through the Internet. Based on that fact, the inter-data center processing comes with an extra processing fee as compared to intra-data center processing which does not charge extra fee. For example, Amazon charges 0.01 USD to 0.2 USD per gigabyte for inter-data center processing while the intra-data center processing is free [75].

In a typical big data stream processing, there is a need to minimize the communication cost between the Virtual Machines (VMs) and data flow in distributed data centers to support real-time processing in IoMT [76]. There is no specific protocol or technique designed/standardised for minimizing the transmission cost between the cloud cen-

TABLE 5. Characteristics of cloud platform for IoT based architectures.

Platform	Gateway	Provision	Assurance	Billing	Application Protocol			
					REST	CoAP	XMPP [96]	MQTT [94]
Arkessa	-	+	+	-	+	-	-	+
Axeda	+	+	+	+	+	-	-	-
Etherios	+	+	+	-	+	-	-	-
LittleBits	-	-	-	-	+	-	-	-
NanoService	+	+	+	-	+	+	-	-
NimBits	-	-	-	-	+	-	+	-
Ninja Blocks	+	-	-	-	+	-	-	-
OnePlatform	+	+	+	-	+	-	-	-
RealTime.io	+	+	-	-	+	-	-	-
SensorCloud	+	+	-	-	+	-	-	-
SmartThings	+	+	-	-	+	-	-	-
TempoDB	-	-	-	-	+	-	-	-
Thingworx	-	+	+	-	+	-	-	+
Xively	+	+	+	+	+	-	-	+

ter. In recent years, researchers have tried to minimize the communication cost through various routing algorithms, processing time shifting, task distributions, VMs placement, and distributed processing [77]–[79]. Routing schemes try to maintain the QoS between data centers in highly dense communication networks. However, these schemes are mainly suitable for non-continuous data. The continuous nature of multimedia data demands synchronous and jitter-free real-time processing. Shifting of processing at different time intervals is not always helpful. This technique is based on probability and is adopted by many Internet Service Providers (ISPs) to manage the traffic load among its customers. Contrary to this, the applications running in IoMT are active 24×7 and demand real-time processing at any time. Thus, such applications are not compatible with time shifting techniques. Although, services like task distribution, VMs placement, and distributed processing are quite common, they are not really helpful because they still demand shifting of data from one data center to another. They can be useful if the priority of applications and targeted data centers for those applications are set in advance. This approach will save the communication cost between the data centers and will require efficient routing algorithms between the data generating sources and designated cloud centers in an IoMT framework. Rather than dealing with massive amount of data, these routing algorithms will only be used for special type of devices and networks, e.g., sensors, relays, mobile devices, etc.

B. INSTANCES IN MULTIMEDIA CLOUD

In cloud computing, the computing resources such as, CPU and memory, are allocated in the form of VM instances. One major challenge for Cloud Service Providers (CSPs) is to allocate these resources in an efficient manner to increase the profit. To address this challenge, resource auctions have recently been introduced [80]. Such auctions can help the CSPs to manage their computing resources in a profitable way. In case of IoMT, applications will be using these computing resources to entertain the genuine users with their services. These instances will be issued based on statistics of total number of users of a particular application. These statistics will also cover the usage of those instances at different time slots. Usually, there are different types of computing instances offered by CSPs [10]. The IoMT applications need to hire a pool of different instances to fulfil various requirements of the users. Many large-scale applications, especially related to big data analysis, have heterogeneous demands for resources to maintain their performance levels [8]. However, the decision to bring different types of instances together to meet service requirements still remains an open challenge [99]. There is no such studies to describe the techniques required for bringing different instances together to fulfil the requirements of a specific application.

In case of IoMT, the demand for instances of various types is always there. One possible solution to hire instances of different types is to form a cluster. The said cluster can meet the requirements of those specific applications. The major drawback of this solution is the associated cost. We can never predict the total number of users for that specific application. In such a situation, it will be a waste of resources and will increase the cost [6]. Another solution is the instances on demand. This solution hires the instances of a specific type whenever there is a demand. It saves the associated cost and instances as well. The major drawback of this solution is waiting time. There is no guarantee about the availability of particular instances at a given time. It is possible that some specific instances are occupied at some particular time. This situation will bring down the performance of the application [81]. In IoMT, the multimedia data have many shapes, e.g., audio, video, images, and documents. To manage such diverse range of multimedia data, it is a major challenge for IoMT application developers and service providers to maintain a pool of available instances either from one CSP or from multiple CSPs. The availability of instances has other associated challenges as well such as, maintaining the instances, hiring and releasing time, proper hiring plan to save cost, and maintaining service level to increase the overall profit.

C. STORAGE IN MULTIMEDIA CLOUD

In IoMT, the multimedia data needs to be dealt with carefully. Such massive data requires a scalable storage architecture along with analytical tools, which need to allow users to store multimedia data along with the context information [83]. There is a need for a cloud architecture that should support multimedia processing and storage to support QoS. This scalable and multimedia-aware cloud architecture should also provide categorisation and indexing facilities for its users to properly manage their multimedia data. In any storage system, data integrity and redundancy removal are critical issues [84]. In IoMT/IoT, it is common that the cloud server may get the same type of information from multiple devices. In such a situation, the investors need to spend more money on storage resources. If data is properly handled and filtered, the storage resources can be utilised efficiently. Data security and reliability is another major challenge for cloud-based architectures [81]. In IoMT, almost all applications carry sensitive information. Exposing such information to prowlers can cause severe problems and complications. In recent years, many efforts have been put in place to address such challenges in cloud storage systems [86]–[88]. However, those efforts were mostly dealing with non-multimedia data and need to be reconsidered for multimedia data.

In a surveillance system, the captured shot can be a crucial evidence against a crime. It needs to be reported immediately for a proper action at the cloud end to identify the accused person. Due to large size and mobile access, the criminal record is stored at the cloud server. This record is a sensitive information that needs to be safeguarded with efficient data protection algorithms. Such criminal records are always large in size which cover criminal activities happening around the globe. Efficient storage, indexing, and sorting techniques are required to keep such records updated and efficient to provide required information in real-time [89]. To store and process such sensitive data, a trust factor is required among the user, the application, and the cloud administration as shown in Fig. 8. Other applications of IoMT, e.g., health, military, traffic management, and automation also demand similar techniques for data management at the cloud end.

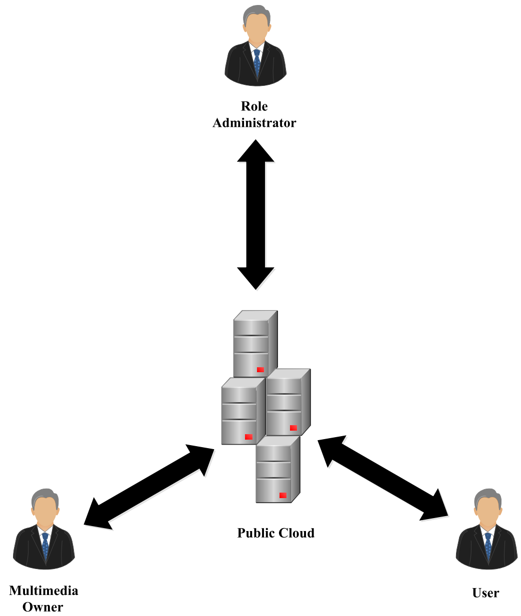

FIGURE 8. Authentication in cloud.

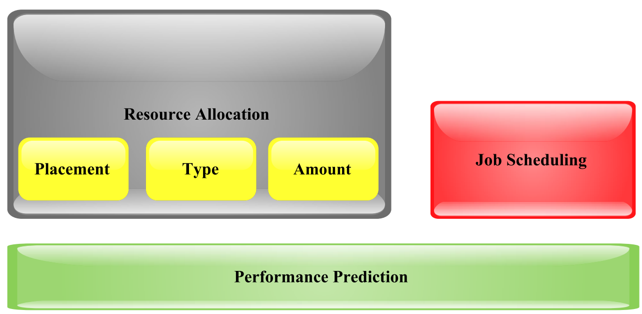

FIGURE 9. Resources allocation and scheduling.

D. PROCESSING OVER MULTIMEDIA CLOUD

In cloud computing, resource allocation and scheduling are two sensitive issues [90]. Resource allocation deals with appropriate allocation of cloud resources to a group of applications. Cloud computing allows its users to request and dynamically release the resources [91]. For better performance, type, amount, and placement of resources need to be decided smartly. Scheduling, on the other hand, maintains the time slots of the allocated resources. This time management is important as the resources are shared and need to be released on time in order to be allocated to other user applications. Resources allocation and scheduling is summarised in Fig. 9.

In IoMT, the data generating devices can be either simple or powerful in terms of computational resources. In traditional multimedia systems, the data is usually encoded once and is decoded multiple times [92]. Based on this fact, the encoder is always complex as compared to the decoder. If combined with cloud computing, the computational complexity of the encoder can be shifted to the decoder on cloud platform [70]. Such simple encoders can allow to incorporate low-powered devices in an IoMT paradigm. Furthermore, low-powered devices can perform basic encoding on multimedia data and send it to the cloud platform. Once the data arrives successfully, it needs to be re-encoded carefully by considering the underlying network, devices, and system computing resources. This re-encoded data can easily be decoded on low-powered devices of IoMT systems. The parallel and distributed nature of cloud computing makes it easier to carry out such complex computing tasks in real-time.

In IoMT, the generated data is multimedia type. Resources requirements and the volume of multimedia data vary from one application to another. For example, surveillance, military, and industrial automation are those applications which generate data 24 $\times$ 7. Their generated data needs to be processed, stored, and reported in real-time. As these applications are operating all the time, their generated data is continuous in time and bulk in volume. On the other hand, applications like home automation, traffic monitoring, and health monitoring are particularly active at certain hours during which the data will be continuous and bulk. In the remaining hours, the applications will either be off or be generating a small amount of data.

E. THE EMERGENCE OF EDGE COMPUTING FOR IoMT

Unlike IoT, the IoMT integrates computer vision, image processing and network capabilities [101]. IoMT has widely been used in automatic behavior analysis, smart surveillance systems and event recognition. Multimedia data captured by the sensor nodes can either be preprocessed at the nodes themselves or can be transmitted to multimedia cloud for processing by utilizing the virtual data centers. Multimedia data, especially video frames, may cause significant delay if preprocessed at the nodes [102]. These nodes, e.g. cameras, have limited processing capabilities and may result in significant processing delay by locally preprocessing the multimedia data, especially the video frames. Moreover, transmission of these video frames to the multimedia cloud may result in network congestion and latency in view of limited available network bandwidth. As a result, neither preprocessing at the nodes nor long-haul transmission to the remote data centers can satisfy the requirements imposed by delay-sensitive video frames. Edge computing has gained significant attention in recent years as it allows distributed computing for preprocessing of video frames and similar multimedia contents [100]. Edge computing reduces the latency experienced by multimedia traffic and minimizes the consumption of bandwidth [105]. Edge servers, located in close proximity of multimedia sensors, process the content and extract useful features via short-range wireless communication channels. These servers conserve the energy of the nodes and have the ability of caching for quick responses. Although, edge computing has significant benefits in comparison to multimedia cloud, numerous challenges still exists [106]. For example, load balancing and optimal selection of servers still remain open research issues. Moreover, task offloading is another challenge faced by the edge computing paradigm. Task offloading deals with proper partitioning of tasks into sub-tasks so that they are allocated effectively to nearby edge servers. Although, numerous research works have been conducted for load balancing and task offloading, they still remain open challenges to be addressed.

F. MACHINE LEARNING IN THE CONTEXT OF EDGE AND CLOUD COMPUTING

The large-scale voluminous multimedia streams generated by IoMT devices provide multiple opportunities to the research community by extracting useful features from them [45]. Cloud data centers have abundant resources to deal with the processing, storage and manipulation of these streams. However, there are numerous challenges that need to be dealt with for smooth and effective operation of these data centers [108], [109]. First, the multimedia streams are much larger in size in comparison to the scalar data and have higher chances of correlation and redundancy. The storage of redundant multimedia streams at the cloud will result in mismanagement of the available resources. Only a small portion of gathered data is useful for the underlying IoMT network and their associated devices. The gathered data need to be mined to extract useful and required features. Second, the transmission of redundant and correlated streams to the cloud adversely affect the operation of IoMT devices. They are resource-constrained and rapidly deplete their energy while transmitting large data streams. Transmitting these streams also has an adverse impact on the network performance as excessive latency, bandwidth and caching would be required [111]. Finally, the intermediate entities such as edge and fog devices cache the responses generated by the cloud data centers [109]. The transmission of redundant data streams from the IoMT devices to the cloud data centers via the intermediate entities will result in caching more responses for the IoMT devices.

Machine Learning (ML) techniques have an important role to extract useful features from the multimedia streams in IoMT [67], [97], [117]. Various ML algorithms are employed at the edge, fog and cloud data centers to extract useful features from the gathered data [100]. The emergence of sophisticated multimedia sensor devices have assured seamless operation of various ML techniques at the devices themselves [92]. These techniques perform deep analytics on a larger pool of available information gathered from the physical environment. They mine useful information and features hidden in gathered data, and facilitate the decision making process. These techniques face numerous challenges as the devices are heterogeneous, and data are generated on large scale containing noise with time and space correlation. There exist numerous studies that focused on the use of ML algorithms and techniques for extracting useful features from multimedia streams. For example, authors in [117] proposed a smart telehealth framework to identify Parkinson disease using K-mean algorithm. The data streams are constantly queried and mined for this purpose. The use of K-mean algorithm ensures that only refined data is stored at the cloud. In [67], the authors proposed an ML-based Code Dissemination by Selecting Reliability Mobile Vehicles in 5G Networks (MLCD) scheme for choosing vehicles that have higher coverage ratios and reliable degrees as code disseminators having limited costs. The use of ML approach enables the extraction of useful features that result in highly refined data to be stored at the cloud. Besides, the proposed scheme leads to an intelligent resource allocation management for vehicular networks [97].

G. OPEN RESEARCH PROBLEMS

In the past, cloud platforms were mostly used to process and store non-multimedia data only. The trend of multimedia cloud has just been started. However, it does not entertain low-powered multimedia and sensing devices of IoMT.

Based on this fact, multimedia cloud services for IoMT-based systems need to address the following challenges:

- Availability of a service in a cloud-based network is the first major challenge. Cloud platforms comprise computing sources which are distributed over a large network. Such networks need to be consistent in service availability and performance. A minor outage of a particular service may cause severe financial problems and disruption in the provisioning of that service. Such disruption in real-time applications like healthcare, surveillance, military, traffic management, and automation, is intolerable and may have severe consequences.
- In cloud-based platforms, the data centers are always distributed at remote geographical locations and are connected through the Internet. Most of the time, there is a need for data migration from one location to another due to the shortage of storage space. Due to best-effort delivery nature of the Internet and real-time requirements of IoMT applications, efficient and QoS-aware streaming protocols are required for the migration of big data streams between data centers.
- Cloud resources are requested and reserved in the form of instances. Proper resource management is required at the user/application end. Misuse of storage and computing resources will cost an ever-increasing investment. To overcome this limitation, the resources need to be hired in on-demand fashion. Smart algorithms are required to monitor the reservation time of cloud resources for specific IoMT applications. In time release of cloud instances will save the cost associated with the resources. There is a need for algorithms to distribute the cloud resources based on the nature of the applications. Time-sensitive IoMT applications should be given higher priority in biding and allocation of cloud resources.
- Data generated by IoMT devices will be diverse in nature. The applications running at the cloud end need to be able to manage and process such diverse data. These applications need to be efficient to extract useful and necessary information from incoming data. The data should be stored and structured in such a way that it can easily be migrated from one storage server to another.
- Data generated by IoMT applications is always large in volume. It needs to be processed in real-time to create space for an upcoming data. High-speed processing can be achieved through parallel and distributed computing. Instead of acquiring new computing resources from CSPs, efficient algorithms need to be designed to process the data in a parallel or distributed computing fashion using the available computing resources.
- Processing and storage of sensitive data on clouds demand proper confidentiality. CSPs are responsible for storing sensitive data in its original form. Since, the applications of IoMT produce sensitive data and send it directly to cloud servers, access to this data by an unauthorised or malicious user needs to be prevented.
- Due to diverse nature of IoMT architectures and devices, there is a need for a balanced connection between cloud computing and IoMT to maintain the reliability of the service. The cloud platform should be able to support a diverse range of IoMT applications and devices to meet the QoS and QoE requirements. Without proper infrastructures, the real-time goals of IoMT applications cannot be achieved.

V. IN-HOME PATIENT MONITORING: A CASE STUDY

In this section, we present a case study for monitoring elderly or disabled patients at their homes. This case study highlights the significance of our work for seamless and interoperable communication among different entities of a healthcare ecosystem, e.g. sensor nodes, e-Health gateways, cloud data centers, and health practitioners. In Fig. 10, medical practitioners and supervisors can fetch health-related data from the sensor nodes via the e-Health gateways that are located at the network edge. In this case, interoperable and seamless communication is highly critical and is governed by the underlying protocol stacks.

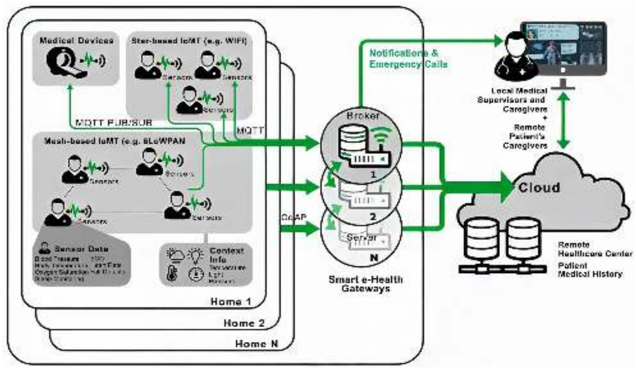

FIGURE 10. In-home patient monitoring.

The patient data is gathered by implemented or body-worn sensor nodes. These nodes are capable to gather a diverse range of data, e.g. electrocardiogram (ECG), heart rate, oxygen saturation, blood pressure, high-resolution biomedical images, etc. The gathered data is transmitted to a Smart e-Health gateways. The data can be supplemented with context-based information, e.g. location, date, time, temperature, etc. This information supplements the patient data for any unusual pattern identification and makes accurate inferences about the current scenario within the sensor-deployed regions. In healthcare applications, context-awareness is crucial for mapping the gathered data with current scenario to predict the present state of a patient. These sensor nodes are not capable to support HTTP protocol at the application layer for transmission of their data, and reception of control commands for invoking various actions. The HTTP protocol incurs excessive delay and resource consumption due to its large packet header. These sensor nodes are mostly resource-constrained and rely on simple protocol stacks. For seamless and interoperable communication between the nodes and e-Health gateways, MQTT, CoAP and XMPP protocols are feasible alternatives. As discussed earlier, they incur significantly low overhead in terms of communication, computation and latency. In this case study, MQTT is used by the sensor nodes and other medical devices to subscribe and publish to the e-Health gateways. Each gateway acts as a broker to leverage the transmission of data to remote cloud data centers. In case of subscriber (SUB), the nodes receive commands from the broker to perform various actions, e.g. data gathering and manipulation. These commands are broadcast by the practitioners, based on the current state of a patient. In case of publisher (PUB), the nodes transmit and publish the data to the broker. There can be N gateways, one each for a given home. In practice, the proposed case study can be implemented with only few gateways. The gateway acts as a broker for MQTT, and as a server for CoAP and XMPP protocols. In either case, each gateway performs the same function: interoperable communication with the sensors and cloud data centers. The protocol stack of each node supports UDP at the transport layer, 6LoWPAN at the network layer, IEEE 802.11.15 MAC at the data link layer, and IEEE 802.15.4 PHY at the physical layer. At the application layer, the nodes can support CoAP, MQTT or XMPP.

In this case study, cloud platform has a pivotal role. We are moving from the world of conventional computing to the world of connected things. The interconnectivity among the emerging applications of healthcare ecosystem is happening at a fast pace. These applications will generates a huge amount of multimedia and non-multimedia data that require sufficient amount of storage, computational power and available bandwidth. Without the support of cloud data centers, it will be impossible to imagine the future of IoMT.

VI. CONCLUSION

In this paper, we reviewed multimedia data traffic in the context of underlying protocol stack and cloud data storage. The heterogeneous nature of multimedia sensors and their IP-connected devices pose numerous challenges for IoMT interoperability and connectivity. These devices come from different manufacturers with different operational behaviors. They use vendor-specific protocol stacks that jeopardize the inter-connectivity among them. For this purpose, we reviewed the existing protocol stacks of IoT and suggested a number of changes for better functionality in the context of IoMT. The voluminous data traffic generated by multimedia devices is another aspect that needs serious consideration. The gathered data need to be processed, maintained, and stored carefully. For such large volumes of data, cloud computing provides an all-in-one platform, i.e., processing, storage, and remote accessibility. However, the integration of cloud platforms in IoMT-based systems is not an easy task and poses numerous challenges such as, management, synchronization, reliability, response time, connectivity, and enhancement. For this purpose, we analyzed cloud in the context of multimedia traffic and proposed a number of solutions for efficient utilization of the available resources. These challenges at the cloud data centers led to the emergence of edge computing that suits the demands and resource-constrained nature of miniature sensor devices. To highlight the significance of our work, we portrayed a case study of in-home patient monitoring system that had an integrated environment comprised of edge computing, cloud computing and IoMT-enabled healthcare devices. In this context, a number of protocol stacks were discussed that have the ability of providing seamless connectivity among the devices of our case study.

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