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5G-Based Smart Healthcare Network: Architecture, Taxonomy, Challenges and Future Research Directions

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ABSTRACT Healthcare is undergoing a rapid transformation from traditional hospital and specialist focused approach to a distributed patient-centric approach. Advances in several technologies fuel this rapid transformation of healthcare vertical. Among various technologies, communication technologies have enabled to deliver personalized and remote healthcare services. At present, healthcare widely uses the existing 4G network and other communication technologies for smart healthcare applications and are continually evolving to accommodate the needs of future intelligent healthcare applications. As the smart healthcare market expands the number of applications connecting to the network will generate data that will vary in size and formats. This will place complex demands on the network in terms of bandwidth, data rate, and latency, among other factors. As this smart healthcare market matures, the connectivity needs for a large number of devices and machines with sensor-based applications in hospitals will necessitate the need to implement Massive-Machine Type Communication. Further use cases such as remote surgeries and Tactile Internet will spur the need for Ultra Reliability and Low Latency Communications or Critical Machine Type Communication. The existing communication technologies are unable to fulfill the complex and dynamic need that is put on the communication networks by the diverse smart healthcare applications. Therefore, the emerging 5G network is expected to support smart healthcare applications, which can fulfill most of the requirements such as ultra-low latency, high bandwidth, ultra-high reliability, high density, and high energy efficiency. The future smart healthcare networks are expected to be a combination of the 5G and IoT devices which are expected to increase cellular coverage, network performance and address security-related concerns. This paper provides a state-of-the-art review of the 5G and IoT enabled smart healthcare, Taxonomy, research trends, challenges, and future research directions.

INDEX TERMS 5G, smart healthcare, software-defined network, network function virtualization, the Internet of Things (IoT), device-to-device (D2D), ultra reliability and low latency communications.

I. INTRODUCTION

Smart healthcare has a significant role in the economy. In Europe, the average spending on smart healthcare is approximately 10% of gross domestic product (GDP), and up to 99 billion Euros of healthcare cost can be saved through smart healthcare by 2020. In smart healthcare, internet of things (IoT) plays a pivotal role to improve and deploy a diverse range of applications, including smart medication, telemedicine, assisted the living, as well as remote and onsite monitoring of assets in hospitals, patients behavioral change and treatment compliance [1], [2]. According to a survey, IoT in healthcare will be about 117 billion US Dollars market by 2020 [3]. A diverse range of smart healthcare applications that integrate wireless mobile networks has been proposed in the literature. In [4], smartphone using the next-generation wireless mobile network, namely 5G and IoT based approach has been proposed for continuous monitoring of chronic patients. In [5], a mobile health system using 5G and IoT has been proposed for constant assessment and monitoring of diabetes patients. In [6], wearable devices using IoT has been submitted to support smart healthcare applications

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(e.g. remote monitoring, remote medical assistance). Wearables devices (e.g., sensors, smart watches, smart clothes) collect information, such as heart rate, amount of sleep, and physical activities for continuous health monitoring (e.g., heart rate, blood pressure, blood sugar level). In [7], mobile gateways using IoT has been proposed for intelligent assistance in mobile health environment such as continuous monitoring of chronic patients (i.e., continuous remote health monitoring in real time). In [8], IoT is considered for medical application to support remote monitoring of patients with chronic diseases. In [9], wearable devices have been proposed for supporting communication between wearables and cloud server, that is a virtual server (rather than a physical server) operating in a cloud computing environment and can be accessed remotely via the internet. wearable devices collect information, such as heart rate, amount of sleep, physical activities and send to the cloud server through the internet. 5G and IoT have the potential to boost the use of smart healthcare applications.

A. WHAT IS SMART HEALTHCARE?

Smart healthcare provides healthcare services through smart gadgets (e.g., smartphones, smartwatch, wireless smart glucometer, wireless blood pressure monitor) and networks (e.g., Body area network, wireless local area network, extensive area network). The intelligent gadgets process health information gathered from numerous sources, including sensors and biomedical systems (i.e., the application having information about medical science such as diagnosis, treatment, and prevention of disease). In short, smart healthcare allows people from different background and walks of life (e.g., doctors, nurses, patient caretakers, family members, and patients [10]) to access the *right* information and obtain the *right* solutions, which are mainly to minimize medical errors and improve efficiency, as well as to reduce cost at the *right* time in the medical field.

B. WHAT IS IoT?

There are different definitions of IoT, and based on the definition from IoT European Research Cluster (IECR) project [2], Internet of Things is dynamic network infrastructure which has the capability of self-configuration on the bases of interoperable and standard communication protocols. In other words, IoT is flexible, complex and dynamic network infrastructure that connects anyone, anything, anytime, anywhere, for any services [11]. The internet of things has numerous applications in healthcare, from remote monitoring to smart sensors and medical device integration. There is now a growing trend in the synthesis of sensors and sensor-based systems with device-to-device (D2D) communications [12]. 5G wireless systems (5G) are on the horizon, and IoT is taking center stage as devices are expected to form a significant portion of this 5G network paradigm. But the technology is still evolving. While one of the challenges of IoT in healthcare is to manage the data from various source, the future of IoT in healthcare application will depend on deriving meaningful insight from gathered data. [13].

C. WHAT IS 5G?

5G is the next generation of the current 4G communication network that can provide more features such as high speed, capacity and scalability of the network. Standards, capabilities and technologies vision for 5G are still under consideration and discussion. International Telecommunication Union (ITU) in 2015, presented their roadmap for 5G in term of 'IMT-2020'. ITU has defined a few parameters which can be considered key capabilities for 5G technology [14].

- Requirement of low latency must be supported (1ms or less than 1ms).
- 10Gbps to 20Gbps data rate must be achieved in different scenarios and condition.
- High dense network must be supported and enable massive machine-type communication.
- High mobility (up to 500km/h) must be achieved in network.

5G and IoT are expected to become important drivers of next-generation smart healthcare. Some of the key technologies in 5G are device-to-device (D2D) communication mmWaves, the macro cell and small cells (e.g., femto, pico and micro) [15]. These technologies address two main challenges in the next-generation wireless mobile network scenarios. Firstly, *ultra-densification* in networks as a results of a large number of devices (or nodes henceforth) within an area (i.e., approximately 10^6 connections per km^2 by 2020 [16]). Secondly, *high energy consumption* as a result of IoT applications that are based on wireless sensor networks. These sensors enable every device in the network to exchange data. These devices require energy to perform processing, sensing, communication and monitoring tasks. However, data transmission between devices consumes more energy. Therefore, a minimum of 10 years of battery life is required for certain applications [17]. Various network layer solutions, including scheduling, routing, and congestion control, along with resource optimization, QoS enhancement, interference mitigation, and energy efficient mechanisms, have been proposed in 5G and IoT to address these two main challenges to support and deploy smart healthcare solution. The proposed solutions have shown to increase throughput (e.g., via high data rate and bandwidth), reliability, energy efficiency, transmission coverage, as well as to reduce delay.

D. OUR CONTRIBUTIONS

There have been efforts for reviewing smart healthcare with different aspects in [18]–[22]. Table 1 summarizes the contributions of the research works related to smart healthcare found in the literature. To the best of our knowledge, this paper is first of its kind to present a review on this topic.

In particular, our contribution is to deliver a review of 5G smart healthcare with different aspects as follows:

TABLE 1. Existing survey on smart healthcare.

References	Authors contributions
Qi *et al.* [18]	In this review, the author explored various applications of IoT in smart healthcare from different perspectives (i.e., Blood pressure monitoring, monitoring of oxygen saturation, heartbeat monitoring etc.). Secondly, the author reviewed the existing work of IoT that enable technologies for smart healthcare applications. From various perception, such as infrastructure and current technologies (i.e., Networking, Sensing and Data processing technologies).
Islam *et al.* [19]	In this review, the author focused on IoT-based healthcare technologies and present architecture for healthcare network and platforms which support access to the IoT backbone and enable medical data reception and data transmission. Secondly, the paper delivers detailed research events and how the IoT can address chronic disease supervision, pediatric, care of elderly and fitness management.
Baker *et al.* [20]	In this review, the author presented a new model for future smart healthcare systems, which can be used for both special (i.e., special condition monitoring) and general systems. Secondly, the author presented the overview of the state-of-the-art works related to the component (i.e., wearables and non-intrusive sensors monitoring blood pressure, blood oxygen level and vital signs) of the presented model. Secondly, the author review on short-range and long-range communication standards for smart healthcare.
Mahmoud *et al.* [21]	In this review, the author surveyed on Cloud of Things (CoT), platforms and how to implement it in smart healthcare applications. Secondly, the author review in detail Cloud of Things (CoT) issues related to energy efficiency in smart healthcare applications.
Dhanvijay *et al.* [22]	In this review, the author focused on different IoT-based healthcare systems for Wireless Body Area Network (WBAN) that can enable smart healthcare data reception and data transmission. Secondly, the author presented a detailed review of resource management, power, energy, security and privacy related to IoT-based smart healthcare.

- 5G smart healthcare architecture, considering specific key enable technologies (i.e., Small cells, D2D communication, mmWaves, Software-defined network (SDN), Network function virtualization (NFV) for 5G smart healthcare.
- A taxonomy for 5G smart healthcare, covering communications technologies, requirements, objectives, and performance measures, are presented.
- Review of research work at network layer, including scheduling, routing, and congestion control, applied to IoT based 5G smart healthcare and future research opportunities.
- Challenges and future research direction in 5G and IoT based smart healthcare.

E. ORGANIZATION OF THIS PAPER

The paper is organized as follows. Section II presents 5G network architecture for smart healthcare solution. Section III presents a taxonomy of 5G smart healthcare, covering the communication technologies, requirements, objectives, and performance measures. Section IV presents network layer solutions for 5G smart healthcare. Section V presents open issues. Finally, Section VI presents conclusion.

II. 5G NETWORK ARCHITECTURE FOR SMART HEALTHCARE SOLUTIONS

5G is the next-generation wireless mobile networks that supersede the existing 4G networks. The rest of this subsection presents the architecture, features, and performance enhancement of 5G. Figure 1 illustrate the 5G smart healthcare architecture.

A. 5G ARCHITECTURE

Small cells are low-powered radio access nodes having a range of few meters to a mile in diameter. The numerous types of small cells can play an essential role in many applications of 5G smart healthcare. As smart healthcare applications demand high data rates (e.g., remote surgery required data rate between 137 Mbps to 1.6 Gbps [23]), one of the solution is small cells [24]. Small cells are three types and ranging from shorter to larger they are called femto, pico and microcells. These are considered as small cells as compared to the macro cell, which has about 20 miles of range. Femtocells are used to increase the coverage and capacity within a small vicinity, such as hospital, home etc. It supports up to 30 users over a range of 0.1 km. Picocells provide more coverage and capacity, supports up to 100 users over a scale of 1 km. Picocells are typically deployed to boost the cellular and wireless coverage within a small vicinity. Microcells are challenging to differentiate from picocells, but the coverage area and support more user is the main difference. Microcells can support up to 2000 users within 2 km range. Marco cell is used in the cellular network to offer radio coverage to a wide area of mobile network access. It provides extensive coverage and high-efficiency output [25]. A macrocell is installed on station having high output power, typically in

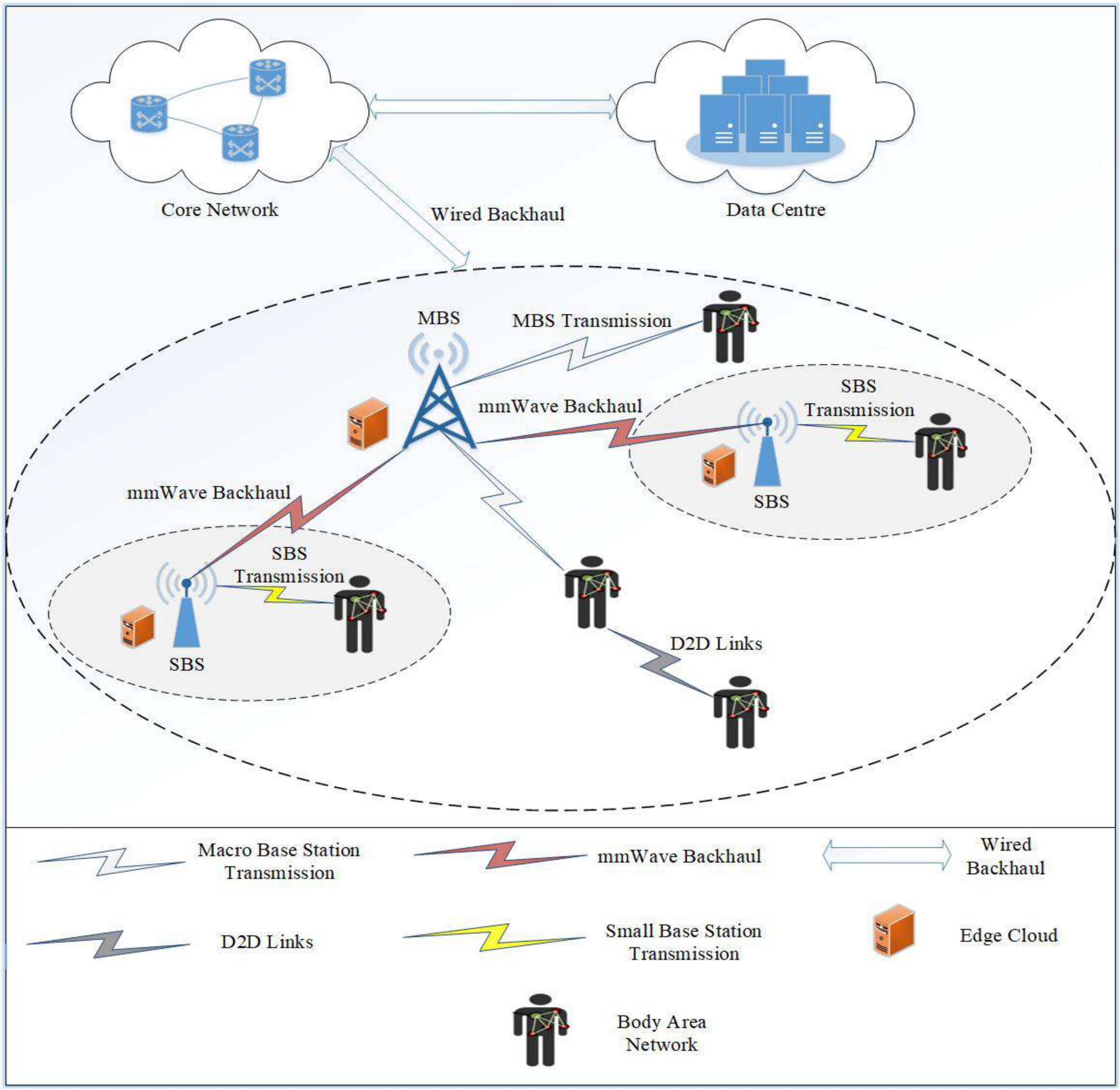

FIGURE 1. 5G smart healthcare architecture.

a range of tens of watts. It supports more than 2000 users in the range of 30 km. By using small cells, the network can increase area spectrum efficiency by reusing of higher frequency. Furthermore, in small-cells control plane and user plane works separately, connectivity and mobility provided by control plane while data transportation provided by user-plane [26]. So the user equipment's (UEs) must be connected with both macro-cell and small-cell base stations simultaneously. Macro-cell base station uses lower frequency bands to provide connectivity and mobility (control plane) and a small-cells base station using a higher frequency to provide high throughput data transport [27]. A cellular network comprising of macro, micro, pico and femto base station is typically referred to as heterogeneous networks (HetNets). These are used to achieve flexible coverage and spectral efficiency. Table 2. shows the summary of small cells.

B. 5G FEATURES AND ENABLING TECHNOLOGIES

G.1 *Device to Device (D2D) Communication*: D2D is a direct communication between two devices in the network without involving the base station (BS) or the

TABLE 2. Summary of small cells.

Cell Types	Cells Radius (Km)	Users	Locations
Femto Cell	0.010 to 0.1	1 to 30	Indoor
Pico Cell	0.25 to 1.0	30 to 100	Indoor/Outdoor
Micro Cell	0.2 to 2.0	100 to 2000	Indoor/Outdoor
Macro Cell	8 to 30	More than 2000	Outdoor

core network. Highly dense network problems can be solved through D2D communications [28]. In D2D communication, each terminal can communicate with each other directly to exchange information or to share their radio access connection. Interference can be reduced by D2D communication, specifically in non-licensed frequency bands [29]. In the 4G network, there is no concept of D2D communication. All communications are routed through gateway and base station. This routing is inefficient, especially when devices are near each other. In the machine-to-machine scenario, where a high number of devices are involved, direct communication between these devices is more sensible. Devices may communicate with each other in unlicensed spectrum outside cellular network by using different technologies such as Bluetooth or WLAN in ad-hoc mode. However, these connections are vulnerable to interference. On the other hand, licensed spectrum guarantees the quality of services if the connection is managed properly. To facilitate connections, these D2D communications require base stations to ignore intra-cell interference [30].

G.2 *Millimeter Waves (mmWaves) communication*: mmWave is the band of spectrum between 20 GHz and 300 GHz. Due to lack of spectrum below 3GHz, the 5G must extend its frequency to the mmWaves band, mostly between 20 GHz to 90 GHz, because there is a huge amount of unused bandwidth. By using mmWaves with small cells will reduce the high path loss problem [31], and will be beneficial for several applications including smart healthcare. mmWaves are now realistic with low cost, and they are finding all variety of advanced uses. Best of all, mmWave take the burden of the lower frequencies and extend wireless communication in the outer limitation of radio technology.

G.3 *Software-defined network (SDN)*: SDN is an architecture which is active, manageable, flexible and cost-effective, to deliver high bandwidth, required for several applications. SDN incorporates several types of network technologies to create the network more agile and flexible, to maintain the modern data centre, virtualized servers and storage infrastructure. SDN networking defines an approach to build, designing and handling networks by separating network control planes and forwarding planes [32]. SDN can support various requirements of smart healthcare in 5G. Some of the use cases handled on cloud depending on operator policies, while immediate response that needs virtual functions are handled on edge cloud.

G.4 *Network function virtualization (NFV)*: NFV is a developing network approach which enables the replacement of expensive dedicated hardware devices, i.e., firewalls, routers with software-based network tools which run as virtual machines on standard servers. 5G must enable d2d communication in smart healthcare, due to which a massive amount of data is predictable to be generated. It is not possible to send all of the generated data to the centralized data center for processing. Therefore, some intelligent decisions are required to manage data at edge cloud and cloud servers. By using NFV, data can be placed in the network based on QoS requirement. This must ensure network scalability and flexibility.

G.5 *Edge computing*: Edge computing is a distributed technology design in which data is processed at the edge of the network, close to the originating source. In future smart healthcare, machines are expected to take decisions and response according to the task. For such responses and decisions, processed data is needed by machines. In many cases, real-time processed data is essential. Edge computing plays an important role in such cases, where decision time is more important [33], especially in 5G based network.

C. PERFORMANCE ENHANCEMENT OF 5G

Table 3 shows a comparison of the characteristics and performance enhancement of 4G and 5G [34].

- Peak data rates can reach up to 10Gbps, and 20Gbps are expected under different conditions and scenarios.
- Ultra-low latency requirement services can be supported (1ms or less than 1ms).
- High mobility can be achieved in the network (up to 500km/h).
- Enable massive machine-type communication and support high dense network.
- Enable 3× more spectrum efficiency and 10× energy efficiency.

TABLE 3. Comparison between 4G and 5G.

Characteristics	Performance enhancement	
	4G	5G
Data Rate	0.01 - 1 Gbps	0.1 - 20 Gbps
Latency (Control plane)	100 ms	50 ms
Latency (User plane)	10 ms	1 ms
Mobility	Upto 350 km/h	Upto 500 km/h
Spectral efficiency	1.5	4.5
Energy efficiency	0.1 mJ per 100 bits	0.1 μJ per 100 bits
Device density	100k/km^2	1000K/km^2

III. TAXONOMY

Figure 2 Illustrates the taxonomy of the 5G smart healthcare. The presented taxonomy is based on the following parameters: communication technologies, requirements, objectives, performance measures and approaches.

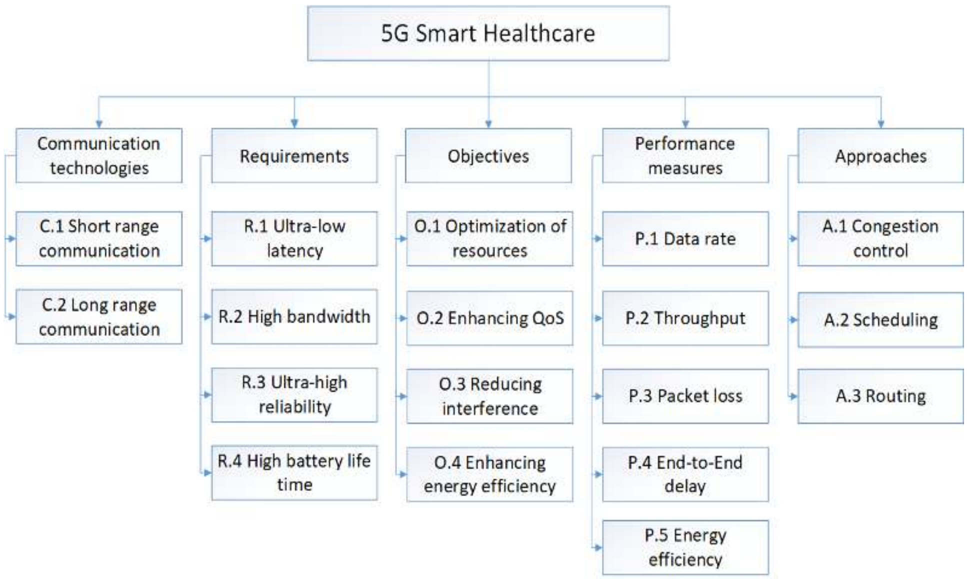

FIGURE 2. Taxonomy of 5G smart healthcare.

A. COMMUNICATION TECHNOLOGIES FOR SMART HEALTHCARE

Smart healthcare depends on various short range and long range communication technologies to transport data between devices and servers [35]. Most of the short-range wireless technologies are Wi-Fi, Zig-Bee, Bluetooth and Wireless Metropolitan Area Network (WiMAX) which are primarily used for short communication in smart healthcare such as BAN (Body Area Network). Wide range technologies like as GPRS and Mobile Communication (GSM), LTE Advanced, Long-term Evolution (LTE) are used to transport data from local server to base-station in smart healthcare. Moreover, LTE-M is proposed to accommodate the need of IoT devices in cellular networks. In release 13, 3GPP wants additionally enhance battery lifetime, coverage and device complexity [36]. Other than existing protocols, LoRa partnership institutionalizes the LoRaWAN protocol to support smart healthcare applications to guarantee interoperability between many operators. Besides, SIGFOX is ultra-tight band radio technology having a full star-based framework which offers a highly versatile worldwide network for smart healthcare applications with very low power utilization [37]. A comparison of significant communication technologies is shown in Table 4.

B. REQUIREMENTS FOR SMART HEALTHCARE

R.1 *Ultra-low latency*: Ultra-low latency defines network, which is optimized to process huge amount of data packet with a very low tolerance for delay (latency) [38]. Some of the smart healthcare applications required very low latency. For example, in telesurgery, during communication latency impact the operation of robotic instruments. Less than 200 ms end-to-end latency is acceptable for future telesurgery [39]. However, the inherent latency of robotic systems is almost less than 100 ms. The 5G network can minimize latency up to 1 ms, which can lead to new telesurgery applications with strict latency requirements. In future, modern solutions might be possible in the healthcare environment. For example, surgeons can perform operations with robots virtually from anywhere in the world [40].

R.2 *High bandwidth*: Bandwidth is the capability of wireless or wired network communication link to send a high amount of data from one point to another in a given amount of time over a network [41]. Biomedical sensors can send a limited amount of information due to restricted bandwidth in current 3G and 4G network, especially in real time monitoring applications [42]. A key feature of the 5G network is to support higher frequencies (including above than 10 GHz frequencies). More spectrum is available by using these frequencies, which leads to very high transmission rates (on the order of Gbps). Physicians can see high-resolution pictures remotely and deployed healthcare solution with ultra-high-definition (UHD) content through the high-speed 5G network. Furthermore, the 5G network can allocate bandwidth in a scalable and flexible way during communication, which can enable D2D solutions in medical field [43]. Smart gadgets can be used by these solutions, such as wearables sensors, medical devices and medical monitoring equipment's.

R.3 *Ultra-high reliability*: Reliability is related to the capability of a network to carry out preferred operation with very low error rates. Deployment of numerous biomedical sensors with IoT capabilities generates more data that could exceed network capacity [44]. Therefore, the large number of connection and massive data capacity must be supported by the new communication infrastructure. Signaling traffic and transmission from massive number

TABLE 4. Comparison of available wireless communication technologies for smart healthcare.

	Technology	Types	Frequency	Data Rate	Range	Power Usage
C.1 Short Range Communication	NFC	PAN	13.56MHz	100-400 kbps	10cm	Very Low
	Bluetooth 4	PAN	2.4GHz	1Mbps	0.1Km	Low
	Bluetooth 5	PAN	2.4GHz	2Mbps	0.25Km	Very Low
	Z-Wave Alliance	LAN	900MHz	9.6/40/100kbps	30m	Very Low
	Wi-Fi	LAN	2. 4GHz and 5GHz	802.11(b)11M; (g) 54M; (n) 0.6, (Gac) 1Gbps	50m	Low-High
	ZigBee	LAN	2.4GHz	250kbps	10-100m	Very Low
C.2 Long Range Communication	WiMAX	WAN	10 - 66GHz	11-100Mbs	50km	High
	LoRa	WAN	868/915 MHz	50 kbps	25Km	Low
	LoRaWAN	WAN	Various	0.3-50 kbps	2-5 km (Urban) 15 km (Sub urban) 45 km (rural)	Low
	Sigfox	WAN	868/915MHz	300bps	50Km	Low
	4G	WAN	800, 1800, 2600MHz	12Mbps	10Km	High
	5G	WAN	Lower Bands	3.6Gbps	10Km	High
	5G	WAN	Higher Bands	10Gbps	<1Km	High
	NB-IoT (NB1)	WAN	900MHz	250kbps	35km	High
	EC-GSM	WAN	900MHz	140kbps	100Km	High
	LTE-M (M1)	WAN	700, 1450 - 2200, 5400MHz	0.144Mbps	35km	High

of biomedical devices with different traffic patterns must be handled by new network infrastructure. Scalability is the main requirement in smart healthcare because the network must allow to increase or decrease of nodes without affecting network performance [45]. Therefore, massive MTCs (Machine Type Communications) with wide range coverage needs a scalable and flexible network.

R.4 *High battery life time*: Battery lifetime is a measure of nodes battery performance and longevity, Which improve the network lifetime. To connect large numbers of sensors and biomedical equipment's, low-cost devices with high battery life is important [46]. For continuous remote monitoring, the aim is to connect self-sustainable devices in the network for the full duration of medical operation [48]. In 5G, low-power sensors are intended to work on the same battery for 10 years [47]. Therefore the network lifetime must be improved.

C. OBJECTIVES FOR SMART HEALTHCARE

O.1 *Optimization of resources*: Resource optimization techniques are used to minimize energy consummation while maximizing network lifetime [49]. Resource optimization techniques play an important role in 5G based smart healthcare network. A huge number of IoT devices in smart healthcare will produce a massive amount of data and consume more bandwidth of the network. Improper resource optimization can lead to several issues in network [50]. Network resource optimization must be able to guarantee optimal usage of system resources, to increase network efficiency without taking extra software or hardware. Resource optimization in one of the key objectives for smart healthcare.

O.2 *Enhancing QoS*: Quality of service (QoS) refers to the ability of the network to achieve high bandwidth and handle other network performance such as error rate, latency and uptime. QoS also includes managing and controlling network resources on priority basis for a different type of data (audio, video, files) in the network. The main goal of QoS is to provide priority to networks, including low latency, dedicated bandwidth, controlled jitter and enhanced loss characteristics [51]. Enhancing QoS is one of the critical objectives of smart healthcare because smart healthcare has different types of data with different priorities.

O.3 *Reducing interference*: The concept of frequency reuse can be used in the smart healthcare system to achieve optimized resource utilization. Along with this, user throughput densification and traffic capacity can be improved in the network. Therefore, with the densification and frequency reuse, there can be more enhancement in terms of efficient load sharing between macro cells and local access networks. These advantages come up with different problems such as load and density of network increased from co-channel interference [52]. Therefore, co-channel interference poses a threat, which effect smart healthcare system. Hence efficient interference schemes are required.

O.4 *Enhancing energy efficiency*: Energy efficiency has become the main criterion for designing smart healthcare network, not just due to the environmental concerns, but also because of the nature of IoT devices participating in the network. Due to the density of access point in the network increases the energy consumption of the network [53]. Therefore, to reduce operational cost, it is important for network operators to minimize the energy consumption of a network. However, batteries capacity keeps increasing, which is not enough to satisfy user expectations. Therefore, energy efficient schemes are required to increase the lifetime of the devices deployed in the network [54].

D. PERFORMANCE MEASURES

P.1 *Data rate* is the speed of transferred data form source to destination in network.

P.2 *Throughput* refers to the packets transferred per unit time. It is the performance of a task completed by the network in a specific time.

P.3 *Packet loss ratio* is the average loss of packets during transmission between source to destination in the network.

P.4 *End-to-End delay* is the time taken for transmission of packets across the network between source to destination.

P.5 *Energy required* by the source/destination to transmit/receive data. Therefore, energy efficient routing protocols is required.

IV. RECENT STUDIES ON 5G AND SMART HEALTHCARE

Many of studies explore the potential of 5G to improve smart healthcare applications. Some of them are given below.

A. CONGESTION CONTROL SCHEMES

In [55], a priority rate-based routing protocol (PRRP) is proposed for congestion control in low-resource bandwidth networks such as wireless multimedia sensor networks. Due to the high bandwidth demand for multimedia traffic, congestion may easily occur in low-resource bandwidth networks. Congestion can waste scarce resources such as the energy of nodes, and affect application specific QoS requirements, which can easily result in the poor visual and sound quality of the transmitted images, audio and video for the healthcare application (e.g., remote surgery, remote health monitoring). The main objective of the scheme is to enhance the QoS (O.2) by reducing congestion in the network. PRRP uses a hop-by-hop technique for congestion control. PRRP enables congestion detection and notification, as well as rate adaptation. PRRP uses buffer occupancy. The maximum and minimum value of the threshold is used to calculate the value of congestion at each node. Hence, there are three possible cases. *Firstly*, the congestion value is less than the minimum threshold, which indicates no congestion, so the source node congestion protocol considers the energy levels of the upstream nodes and less congested node. Therefore, it sends traffic to them, which maintains the data rate. *Secondly*, the congestion value is between the minimum and maximum threshold, which indicates a moderate congestion level. So, the data send to the node according to buffer size, energy level, or to be sent to another node to avoid congestion by adjusting the data rate. *Thirdly*, the congestion value is more than the maximum threshold, which indicates a high congestion level, and so the child node reduces the data rate. The protocol is suitable for applications in 5G smart healthcare. PRRP has shown to increase throughput (P.2), and reduce packet loss rate (P.3) and end-to-end delay (P.4).

In [56], a congestion control based on reliable transmission (CCRT) scheme for real-time streaming media services (e.g., remote surgery) is proposed to avoid congestion. CCRT use priority-based congestion control mechanism for reliable transmission for serious information. The main objective of the scheme is to enhance QoS (O.2) by congestion detection mechanism based on the queue variation rate and the queue length in the network. Each packet has either low, medium or high priority in a queue, which helps to prioritize high-priority packets for reliable transmission of these packets. Receiver node detects congestion based on two criteria. Firstly, the *queue length* is adjusted as High, Medium and Low. Arrived packet is added to the tail of the queue according to the packet type. High priority packet gets service first make sure of emergent information's low latency and high reliability. Medium and low priority packets wait until the high priority queue empty. Secondly, the *queue variation rate* represents positive and negative. Positive queue variation rate represents the larger amplification of queue length, which indicates that congestion level increases in the next time instant; while negative queue variation rate represents that the queue length becomes smaller, which indicates that congestion level reduces in the next time instant. In addition, a queue variation rate of more than a maximum threshold can cause congestion. So, the receiver node adjusts the data rate based on the congestion detection method of queue variation rate. CCRT has shown to increase throughput (P.2), and reduces packet loss (P.3) and end-to-end delay (P.4).

In [57], a congestion control and energy balance based on hierarchy (CcEbH) scheme is proposed to avoid congestion in highly congested network with limited resources (e.g., continuous health monitoring). The main objective of the scheme is to enhance the QoS (O.2) by reducing congestion in the network. Firstly, CcEbH arrange the network into hierarchical, from a single node in a network (e.g., a sink node in a wireless sensor network), so each node can be an upstream (or a node at the upper hierarchical level), a downstream (or a node at the lower hierarchical level), and a similar hierarchical level node. Congestion at a node can be detected based on its queue size, whereby the incoming data rate is greater than the outgoing data rate. The upstream nodes can probe the buffer occupancy (or queue size) of the downstream nodes. The upstream node can select a downstream node with lower congestion level. So, when a downstream node becomes congested (e.g., buffer occupancy is greater than the queue length of the upstream node by 20% of total buffer size) another downstream node is selected to receive data collect and forward packets. CcEbH has shown to reduce energy consumption (P.5).

In [58], a healthcare aware optimized congestion avoidance (HOCA) scheme is proposed to avoid congestion for healthcare applications, such as medical emergencies or monitoring vital signs of patients, because of the importance and criticality of transmitted data. The main objective of the scheme is to enhance energy efficiency (O.4) by reducing congestion in a network. Each packet has either low (i.e., requires low data rate (P.1)) or high (i.e., requires high data rate (P.1)) priority. There are four main steps for a sink node (e.g., a medical center) to gather data or events from nodes embedded in patients. *Firstly*, the sink node broadcast a request for data to nodes. *Secondly*, nodes embedded in patients reply to the sink node with data and events by specifying the level of their importance. *Thirdly*, the sink node selects final node based on the specific level of importance and establishes multiple-path (i.e., spreading of traffic over multiple paths from source to destination node in the network) routes towards the selected node to reduce congestion. *Fourthly*, the selected node senses the event and generate the packet. High priority packet selects next hop from high priority table (i.e., pre-defined) to send data while low priority packet selects from low priority table (i.e., pre-defined). HOCA has shown to reduce energy consumption (P.5) to provide a longer network lifetime P.5), and reduce end-to-end delay (P.4).

In [59], a window-based rate control algorithm (w-RCA) is proposed to adjust a source node sending rate (i.e., the window size of unacknowledged packets) and a destination node's buffer size for achieving a balanced trade-off between peak-to-mean ratio and standard deviation in order to optimize the QoS (O.2) of video transmissions for telesurgery. Edge computing (G.5) is used as it enables cloud computing capabilities and IT services at the edge server, in a wireless mobile network. Machine-based algorithms (i.e., is based on computer programs which can access data and use it learn for themselves) [60] are used to configure buffer (i.e., temporary storage) capacity for upcoming frames. Which leads to smooth video transmission over a single-hop from a remote location (e.g., for anywhere in the internet coverage) in 5G networks. The proposed scheme optimizes network parameters, including the peak-to-mean ratio, the standard deviation of delay, and jitter. Different protocols (i.e., Transmission control protocol, User datagram protocol, Session description protocol etc.) are used on both client and server side in the scheme for exchanging video frames. The proposed scheme has shown to reduce end-to-end delay (P.4) and jitter (P.3) in video transmission.

B. SCHEDULING SCHEMES

In [61], network slice based 5G wearable networks is presented, to improve the network resource sharing and energy-efficient utilization. The main objective of the scheme is to optimize the resources (O.1) and energy efficiency (O.4) of the network by deploying Software-defined network (SDN) (G.3) and Network function virtualization (NFV) (G.4). SDN handle both control and data plane, to provide flexible control of network flow consequently. NFV distributes the function of the network into various functional areas with the help of virtualization technology, and work over software, rather then physical hardware. Therefore, distributed coordination of storage, communication resources and computing can be realized through network slicing, which can provide low latency (R.1) requirement and reduce end-to-end delay (P.4). Further, a data-driven resource management framework is presented, based on a cognitive service engine, the cognitive resource engine, and the global cognitive engine. The cognitive resource engine deployed at the infrastructure layer to allocate resources through a machine learning algorithm in an efficient way. By using a machine learning algorithm, cognitive service engine implemented at wearable service layer to cognition user services by acquiring service data. The global cognitive engine is deployed to realize tight coupling between resources and services to improve utilization QoE of users and resources (O.1).

In [62], a network service chaining (NSC) model is presented to flexibly integrate SDN and NFV to automate virtual network devices, rather than using manual connections, for healthcare services in 5G. The main objective of the scheme is to enhance QoS (O.2). The model works in collaboration with the software-defined network (SDN) (G.3) and network function visualization (NFV) (G.4) technologies. The model integrates with both advanced technologies, to provide fast services (i.e., lower delay) in 5G environment with the help of different types of communication protocols, including routing scheme for low-power loss-networks, Open Flow constrained application protocol (CoAP) for messaging, and transport layer security (TLS) server for security enhancement, to enable operation of smart devices. Moreover, Wi-Fi, cellular technologies, (See TABLE 4) small base-stations (i.e., macro, pico, femtocells) (See TABLE 2) are used to provide better Quality of Service (O.2) to smart devices. Further, a secure model with Kerberos (i.e., secure communication protocol allow node to communicate another non-secure network securely.) authentication server is presented, to secure the cloudlet mesh from the DDoS attack. TLS (Transport layer security) protocol is deployed into the server to provide secure communication between communication parties. The model has shown as increasing QoS (O.2) by decreasing end-to-end delay (P.4) with high security.

In [63], 5G cognitive system (5G-Csys) is proposed. The main objective of the scheme is to enhance the QoS by achieving ultra-low latency (R.1) and ultra-high reliability (R.3) in the heterogeneous network for cognitive applications (i.e., Remote surgery). The system consists of a resource cognitive and data cognitive engine. The resource cognitive intelligence, based on the learning of network contexts (i.e., software-defined network) by cognize the resources in the network, to achieve required ultra-low latency and ultra-high reliability of the system. The data cognitive engine leverage machine and deep learning algorithms (i.e., is based on computer programs which can access data and use it learn for themselves [60].) to analyze healthcare data e.g., speech emotion recognition. The proposed system has shown to achieve QoS (O.2) by reducing end-to-end delay (P.4) in the network.

In [5], 5G-based Smart Diabetes scheme is presented. The main objective of the scheme is resource optimization (O.1) to provide better QoS (O.2) for real-time monitoring of patients remotely. The scheme consists of three layers; Sensing layer collects data from different resources (i.e., sensors) in real time. The personalized diagnosis layer process the collected data with modern machine learning algorithms (i.e., is based on computer programs which can access data and use it learn for themselves [60].) to analyses the disease. The data sharing layer shares the data on social space and data space through the social network using the 5G network, to the doctors and relatives of the patient. Emerging 5G network with the smartphone and wearable medical devices (i.e., smart clothes) are used in the scheme. The scheme is shown to be highly accurate by reducing packet loss (P.3) and end-to-end delay (P.4).

In [64], 5G small cells (i.e., femto, pico, microcells) network approach is presented to enhance the QoS (O.2) by achieving a high data rate (P.1). Transmission of the medical ultrasound video stream from moving ambulance to hospital uplink is considered in the case. A heterogeneous network, containing macrocell with eNodeB coexisting with a small mobile cell is considered. A small cell network is deployed in the ambulance name as mobile small cells which allow users to move around and connect to the operator's network in the vicinity. It utilities a standard radio interface technique (e.g., FDMA (frequency division multiple access), TDMA, CDMA, and OFDMA (orthogonal frequency division multiple access)) to connect with the serving macrocell base station (eNodeB). LTE-Sim, system level simulator, is used to obtain the results. From the result it shown that the network improves the QoS in term of throughput (P.2), Packet Loss Rate (PLR) (P.3) and end-to-end delay (P.4).

C. ROUTING SCHEMES

In [65], handover scheme in 5G, to assist the cellular user in D2D communication (G.1) at the cell edge is presented. The main objective of the scheme is reducing interference (O.3) by managing mobility to minimize end-to-end delay (P.4) during motion of cells. During a handover, nodes (or UEs) can move from one cell to another and form D2D links with neighboring nodes to provide seamless connectivity with better channel quality. eNB is responsible for resource management, power control and D2D session establishment. The eNB generates handover decision based on channel Quality Indicator (CQI). The handover process divided into three steps, in the preparation step, UEs send information to its serving eNB related to channel, which chooses whether to recruit the handover process on specific conditions or not. In the execution step, it is decided to transfer the behavior and information of UEs to other cell or not. In the completion step, acknowledgment is shared between cells and status is updated in new cells about UEs. The scheme is shown energy efficient (P.5).

In [66], device-aware routing and scheduling algorithm (DARA) for device-to-device communication (G.1) in multi-hop network is presented. The main objective of the scheme is the resource optimization of network to increase network lifetime (energy efficiency) (P.5). In DARA Each node decides the amount of data it can handle based on its residual energy and computing power. A network utility maximization (NUM) formula is deployed for the incorporation of devices capabilities. A node decides whether to forward data or not (routing decision) and also switch on the link for the next hop node (scheduling decision). Therefore, algorithms have both routing and scheduling decisions. Test-bed is used for implementation, and the result shows significant improvement in throughput (P.2) as compared to the traditional back-pressure algorithm.

In [67], interference-aware routing (IAR) in 5G for D2D communication (G.1) is presented. The main objective of the scheme is to reduce interference (O.3). The scheme enables the route between source and destination by using nodes on the cell edges. Firstly, the router sends data to present nodes in the edge, then along with cell edge data travels towards the destination. Then lastly data is sent to the destination from cell edge. At each stage, IAR consumes Shortest Path Routing (SPR). Consequently, routes in IAR are longer as compared to the direct shortest path, but IAR has lesser interference overall. The scheme is shown to be energy efficient (P.5) with a high data rate (P.1).

In [68], a secure trust-base relay node selection scheme in 5G for D2D communication (G.1) is presented. The main objective of the scheme is to avoid interference (O.3) by selecting the trusted node for data forwarding. At each node, the trust value is calculated based on experience, particularly the packet successful delivery rate and the decoding error. Each node maintains a trust table to keep track of its neighbors nodes and select a next-hop node based on their updated table. The trust values are considered based on four parameters, namely, buffer capacity, SNR, energy and reliability of devices. The scheme is shown to be energy efficient (P.5).

In [4], 5G based scheme and routing protocol for continuous monitoring of the chronic patient is presented. The main objectives of this scheme to optimize network resources (O.1) to reduce end-to-end delay (P.4) and provide high

TABLE 5. **Summary of an approaches, objectives, performance measures, requirements and communication technologies of smart healthcare schemes proposed in literature for 5G.**

Reference	Year	Approaches			Objectives				Performance measures					Requirements				Communication technologies	
		A.1 Scheduling	A.2 Routing	A.3 Congestion control	O.1 Optimization of resources	O.2 Enhancing QoS	O.3 Reducing interference	O.4 Enhancing energy efficiency	P.1 Data rate	P.2 Throughput	P.3 Packet loss	P.4 End-to-End delay	P.5 Energy efficiency	R.1 Ultra-low latency	R.2 High bandwidth	R.3 Ultra-high reliability	R.4 High battery lifetime	C.1 Short range	C.2 Long range
Sodhro *et al.* [59]	2018			×		×					×	×		×				×	
Hao *et al.* [61]	2018	×			×							×		×		×			×
Chaudary *et al.* [62]	2017	×				×						×			×	×		×	×
Chenanan *et al.* [63]	2017	×			×							×		×		×		×	×
Lal *et al.* [70]	2017	×			×				×							×		×	
Chen *et al.* [5]	2018	×			×	×				×	×	×		×	×		×	×	×
Rehman *et al.* [64]	2018	×	×			×			×	×	×	×					×	×	
De *et al.* [69]	2015		×		×			×	×				×				×	×	×
Orsino *et al.* [65]	2015	×	×				×	×				×	×			×	×	×	
Yaun *et al.* [67]	2017		×				×	×	×	×		×		×				×	
Mishra *et al.* [68]	2016		×			×	×						×			×		×	
Xing *et al.* [66]	2017	×	×		×			×	×	×			×				×	×	
Lloret *et al.* [4]	2017	×	×	×	×	×				×		×	×	×		×		×	×
Tshiningayamwe *et al.* [55]	2016		×	×		×				×	×	×						×	×
Hua *et al.* [56]	2014		×	×		×				×	×	×						×	
Chen *et al.* [57]	2016			×				×					×					×	
Razaee *et al.* [58]	2014		×	×				×		×		×	×				×	×	

bandwidth (R.2) to the user with a guarantee to avoid congestion. The author used a smart phone, wearables devices and 5G network to share data between sensors, smartphone and base station. The author also used machine learning algorithm (i.e., is based on computer programs which can access data and use it learn for themselves [60]) having name decision taking an algorithm to analyze the data to take necessary action. The decision taking algorithm analyses the data and activate the alarm in case of an abnormal situation. The scheme has the ability of data collection in real time with fast response. The author used 4G and 5G in the presented scheme and analyzed the performance. The result shows that 5G increase the throughput (P.2), end-to-end delay (P.4) and network lifetime (Energy efficient)(P.5).

In [69], femtocell network and cloud computing-based scheme is presented. The main objective of the scheme is to optimize network resources (O.1) to achieve a high data rate (P.1). Body sensor network collects data of the user from the sensors and sends to the user's mobile devices, which are registered under a femtocell. Femtocell is used as a low power home base-station with good coverage at the indoor region. Femtocell maintains a database, a received data is verified with the information in the database, and if an abnormality is detected, the data is sent to the cloud through femtocell for further analyzing and access by the doctors. Markov Chain model (i.e., an order of possible events, where every event probably depends only on the state attained in the previous event.) is used in the cloud, to provide the best solution. This femtocell network approach minimizes the consumption of the network resources to achieve high energy efficiency (O.4) and with high security as compared to a macrocell network.

V. OPEN ISSUES AND CHALLENGES

Besides the above-mentioned advances, there are numerous challenges and open research issues in adopting 5G for smart healthcare. The aim of discussing these issues is to provide research direction in this domain for new researchers. Table 6 presents the future research directions and their importance.

A. CONNECTIVITY IN IoT

A smart healthcare network consists of billions of devices. Smart healthcare concept can succeed only if it can provide connectivity to every device present in the network with the capabilities of sensing to produce important information. In smart healthcare, any available communication network can be used by IoT devices, such as Bluetooth, Wi-Fi, cellular network (LTE, emerging 5G). However, guaranteeing connectivity in smart healthcare postures many challenges, such as:

- Guaranteeing connectivity to huge devices deployed in the network in wide range.
- Providing connectivity to high mobility (i.e., high-speed ambulance, carrying patients) devices in the network.

B. INTEROPERABILITY

Interoperability is an ability of two or more different networks and devices to interconnect with each other for exchanging data. Smart healthcare includes different IoT devices from various range of domains (i.e., remote surgery, ECG monitoring and remote health monitoring). Interoperability plays an important role in smart healthcare, providing connectivity between different devices using different communication technologies. Interoperability between different devices in different domains is a key limitation for IoT success due to lack of universal standards [71]. To overcome the challenge of interoperability must be identified at various levels (i.e., application, devices, communication and network). An artificial intelligent and integrated approach is needed to allow billions of IoT devices to communicate with each other. For instance, FIRARE and oneM2M standardization is working on the interoperability issues in collaboration with different standardization bodies such as OMA, 3GPP and ETSI.

C. LOW POWER AND LOW-COST COMMUNICATION

Generally, IoT devices used for smart healthcare are limited in size and connected with a collection of sensors. A continuous source of energy is required to drive these devices, which presents a severe challenge in term of cost and battery life. To address these issues in smart healthcare, devices must have the features of low power consumption with low cost. Therefore, intelligent algorithms are required, that allow devices to communicate with each other with less energy consumption. Another method is an advancement in wireless communication and micro-electronics domain.

D. BIG DATA ANALYTICS

Big data analytics is a key research direction in smart healthcare. In smart healthcare, billions of devices are connected, which can produce a huge amount of data and information for analysis. This data can consist of information about user private data (i.e., Patient Data) and from the surrounding environment (i.e., ECG, Heart Rate monitoring). Intelligent algorithms and techniques are required to analyze this data. For example, data produced by locally connected devices can be analyzed efficiently by adopting deep learning algorithms. The key issues that must be addressed are:

- During data analysis user privacy must be protected.
- Data secrecy must be provided for sensitive data.
- Infrastructure must be provided to collect, analyze and store a massive amount of data.
- Computation power must be provided to extract information from the data.

E. SECURITY, TRUST AND PRIVACY

Security is required for smart healthcare. Since smart healthcare is based on the internet connectivity of different devices; security becomes an important challenge. Due to constrained nature of IoT device (limited processing and battery life)

TABLE 6. Future research challenges.

Features	Importance	Reseach Challenges	Major Requirements
Connectivity	Guaranteeing that IoT devices from different domains can communicate.	• How to guarantee connectivity of massive IoT devices in a wide range during high mobility? • How to guarantee resource management in highly dense network? • How to utilize power/energy of IoT devices?	• Usage of spectrum efficiently for communication of IoT devices. • Smart usage of communication mediums (i.e., LTE, LTE ADV, WiMAX, WLAN etc.). • Development of intelligent algorithms to provide connectivity to large number of devices deployed in the network in the absence of communication networks. • Development of clustering services to increase resource availability and support mixed workload.
Interoperability	Provides communication platform for IoT devices using different protocols.	• Incorporating devices for retailer locked-in services.	• Universal, integrated and flexible models for IoT devices to incorporate and communicate (i.e., IP, CoAP).
Low-power and low-cost communication	Provides smart healthcare application on large scale, if communication is low-cost.	• How to extend IoT devices battery life?	• Advancement in wireless communication domain and microelectronics to deliver low-cost communication and extend battery life. • Development of artificial intelligence based routing protocols.
Big data	Enhancing performance of IoT network by processing effective information recognized from valid sources. (i.e., analysing patient data can reduce network congestion process).	• Lack of useful tools to process huge amount of generated information. • Resourceful centralized data acquisition and information.	• Big data centralized processing centre. • Public appreciation how to use IoT network resources securely.
Security	Secure environment (attack free) to deploy services.	• Secure integration and deployment of services (cloud-based) at both device and network levels. • Early detection of both outsider and insider threats. • Standardised security solutions without delaying data integrity.	• Identification of vulnerabilities at a various level in the network. which work as entry points for numerous attacks.

TABLE 7. Definitions of all acronyms used in the paper.

Abbreviations	
BAN	Body Area Network
BS	Base Station
CMTC	Critical Machine Type Communication
CoT	Cloud of Things
CDMA	Code Division Multiple Access
CQI	Channel Quality Indicator
D2D	Device-to-Device
ETSI	European Telecommunications Standards Institute
FDMA	Frequency Division Multiple Access
GSM	Global System for Mobile
GPRS	General Packet Radio Service
HetNets	Heterogeneous Networks
IoT	Internet of Things
ITU	International Telecommunication Union
IECR	IoT European Research Cluster
LTE	Long-Term Evaluation
LTE-M	Long-Term Evaluation Advance
LoraWAN	Long Range Wide Area Network
Lora	Long Range
M2M	Machine-to-Machine
mMTC	Massive Machine-Type Communication
MTCs	Machine-Type Communications
MBS	Macro Base Station
NFV	Network Function Virtualization
NB-IoT	Narrowband Internet of Thing
NFC	Near Field Communication
OFDMA	Orthogonal Frequency Division Multiplexing
OMA	Open Mobile Alliance
QoS	Quality of Service
SNR	Signal-to-Noise Ratio
SBS	Small Base Station
SDN	Software Defined Network
TDMA	Time Division Multiple Access
TCP	Transmission Control Protocol
UHD	Ultra High Definition
UEs	User Equipment's
URLLC	Ultra-Reliable and Low Latency Communication
WLAN	Wireless Local Area Network
WBAN	Wireless Body Area Network
WiMAX	Worldwide Interoperability for Microwave Access
Wi-Fi	Wireless Fidelity
3GPP	Third Generation Partnership Project
4G	Fourth Generation
5G	Fifth Generation Mobile Network

it is difficult to implement complex security protocols and algorithms. As a result of this 70% of IoT devices (including smart healthcare devices) are at risk of attack in future. This leads to numerous attacks and threats in term of security and privacy. To design successful smart healthcare in the future 5G network, the following issues must be taken into account.

- For user data, privacy-aware communication must be provided.
- For data integrity and authenticity, a simple and secure communication must be provided between smart healthcare devices and a cloud-based application centre.
- User approval and trust must be ensured by delivering strong privacy.
- Risk assessment must be made in detail to detect present and new attacks.

VI. CONCLUSION

In this paper we have presented a review of recent works along with research opportunities on the networking aspect of 5G and IoT for smart healthcare. We firstly presented an architecture for 5G smart healthcare and the essential techniques (i.e., D2D communication, Small cells, Software-defined network (SDN), Network function virtualization (NFV), mmWaves and Edge computing) to enable 5G smart healthcare. Secondly, we presented the taxonomy of 5G smart healthcare, and analyzed the new requirements (i.e., ultra-low latency, high bandwidth, ultra-high reliability and high battery lifetime) and objectives (optimizations of resources, enhancing QoS, reducing interference and improving energy efficiency) for 5G smart healthcare. Third, we presented a detailed review of network layer solutions, including scheduling, routing, and congestion control, applied to IoT based 5G smart healthcare covering both recent work and future research opportunities. Because of the adaptability and growing nature of computer networks, it was difficult to cover every single approach: however, an endeavour has been made to cover all essential approaches. Finally, we briefly presented the open issues and challenges for future 5G smart healthcare.

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