Perspective—6G and IoT for Intelligent Healthcare: Challenges and Future Research Directions

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Perspective—6G and IoT for Intelligent Healthcare: Challenges and Future Research Directions

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Due to the rise of connected devices, a decentralised, patient-centred paradigm is being adopted in healthcare as an alternative to the traditional hospital and specialist-focused approach. As the healthcare sector expands, more applications will be connected to the network, producing data of various shapes and sizes that will allow for customised and remote healthcare services. Future intelligent healthcare will include a combination of 6G and the Internet of Things (IoT) that will address current limitations related to cellular coverage, network performance and security issues. This paper discusses and sheds light on prospects, associated challenges and future directions.
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Despite recent technological advancements, dealing with disasters remains challenging, especially when they directly endanger human health, like the recent COVID-19 pandemic. Due to the lack of preparedness, the hospitals could not handle the volume of patients. Numerous people were unable to receive medical attention worldwide due to a lack of access to crucial medical care after the pandemic declaration. COVID-19 demonstrated that an increase in patient numbers, a lack of medical services, a failure to prevent infection, and a late response caused the healthcare system to collapse. Even in the most developed nations in the world, healthcare systems that provide prompt and secure medical facilities for staff and patients struggled to lessen the damage. Furthermore, the COVID-19 pandemic has made people aware of the benefits of telemedicine and lowered the danger of virus transmission by visiting hospitals and receiving treatment from qualified specialists.

We are stepping into the era of intelligent and connected smart healthcare, where the sensors will be attached to the body externally or internally. Smart healthcare delivers healthcare services using smart devices (e.g., smartphones, smartwatches, wireless smart glucometers, wireless blood pressure monitors) and networks (e.g., Body area network). Smart devices process health information gathered from various sources, including sensors, body implants and biomedical systems.[1] In short, smart healthcare enables people from various backgrounds and walks of life (e.g., doctors, nurses, patient caretakers, family members, and patients) to access the right information and obtain the right solutions, with the goal of minimising medical errors and lowering costs. The number of connected healthcare applications and devices will generate data in various sizes and formats. As a result, such a massive amount of health-related data could increase human well-being, be critical in combating future pandemics and diseases and provide early diagnosis. Supporting such a large number of healthcare devices and hospitals with sensor-based applications will necessitate implementing a reliable and scalable communication network infrastructure. The network will face stringent demands in terms of bandwidth, data rate, and latency, among other things. Additional use cases, such as remote surgeries and tactile Internet, will increase the demand for ultra-reliability and low-latency communications.

The future 6G-enabled IoT networks are projected to serve smart healthcare applications with ultra-low latency, high throughput, ultra-high reliability, high density and energy efficiency. Work relating to developing the future 6G network, services, and requirements has already been initiated. During the standardisation of 5G technology, three areas were looked into: massive machine type communications (mMTC), improved mobile broadband, ultra-reliable and low latency communications (URLLC) and Enhanced mobile broadband (eMBB).[2] Despite offering several new benefits, 5G networks still have significant limits in mobile traffic capabilities, device density, and latency required for healthcare and other applications in general. Table I presents a comparison between the capabilities, enabling technologies and use cases of 5G and 6G. 6G networks will continue to work in a similar direction, expanding the scope and capabilities for 5G with massive URLLC, connectivity and coverage for smart devices.[3] With the following distinctive requirement, 6G for IoT can deliver a new level of network services:

1. Supporting mobile traffic up to 1 $Gb\ s^{-1}/m^2$ to satisfy super high data rate requirements and massive device density in a geographic region.
2. To meet the needs of haptic applications, such as e-health and remote surgery, achieving extremely low network latencies (10–100 μs) is necessary.
3. Provide extremely high data rates of up to 1 *Tb/s* to support data-intensive applications such as ultra-high definition videos and Augmented and Virtual Reality (AR/VR) applications.
4. Achieving a very high device connectivity density of $10^7 devices/km^2$, which is beneficial for the implementation of incredibly dense IoT networks

6G for IoT networks is expected to be a comprehensive, unified network that enables more extensive and diverse access to all modes of communication (terrestrial, satellite, short-range device-to-device, etc).[4] In order to achieve such stringent requirements, 6G will operate at higher frequencies, such as visible light, Terahertz, and mmWave.[5] As shown in Fig. 1, 6G can support a ubiquitous intelligent mobile society by producing massive amounts of data through the Internet of Everything (IoE) and combining it with cutting-edge technologies like Artificial Intelligence (AI), Blockchains, cloud/edge/fog computing, and reflective intelligent surfaces (RIS).[6]

Holographic communication will be one of the most useful applications for the high throughput of 6G,[7] just like virtual and augmented reality (AR/VR) is for 5G. Healthcare applications using 6G will improve virtual and augmented reality experiences by communicating additional sensory information from various sources such as audio, visual, somatosensory and haptic, providing real-time interaction, and accurately presenting 3D images of virtual and real objects. This will allow doctors remotely to examine specific body areas providing better visibility and helpful in case of complex procedures/surgery having high risk. Due to the Intelligent Internet of Medical Things (IIoMT), surgical procedures will be less

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Table I. Comparison between 6G and 5G.

Feature	6G	5G
Mobility Support	Up to 1000 km h^{-1}	Up to 500 km h^{-1}
Peak Data Rate	1 Tbps	20Gbps
Spectral Efficiency	100 bps Hz^{-1}	30 bps Hz^{-1}
End to End Latency	<1 ms	$1-5$ ms
Frequency	1000GHz (1 THz)	3–300 GHz
Healthcare Applications	Extended reality (XR), Holographic-Type Communication (HTC), Tactile Internet	Drone, Virtual Reality (VR), Augmented Reality (AR),
	Connected Robotics and Autonomous Systems, Remote surgery, Brain-computer Interface, Intelligent Wearable Devices, Hospital-to-Home (H_2H) services	
Enabling Technologies	Blockchain, Machine learning and Deep Neural Networks, Reflective intelligent surfaces, Edge Intelligence, Visible Light Communication, and Cell-free smart surfaces.	mmWave, NOMA, Fog, Edge Computing, Software-defined networking, Network Function virtualisation, dense networks

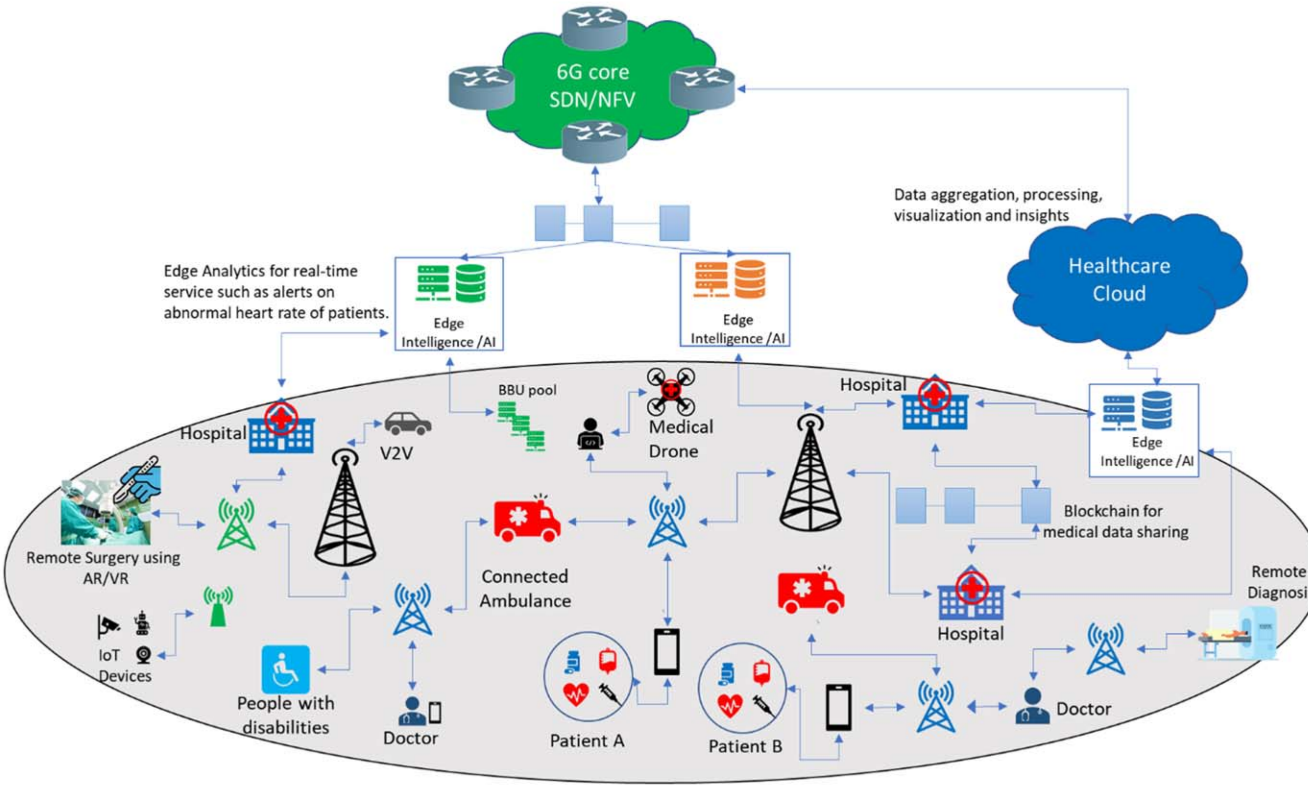

Figure 1. 6G Enabled-IoT for future Smart healthcare.

restricted by time and distance. To assist distant physicians, IIoMT will employ holographic and tactile communication in addition to augmented and virtual reality.[8] 6G robotics can be used to implement remote surgery so that distant doctors can manage the procedure via robotic devices with millisecond latency and ultrahigh reliability. UAVs can address delayed healthcare response rates to deliver healthcare supplies (e.g. surgery tools, medicines etc) from hospitals in different geographical regions in case of emergencies, thereby avoiding road traffic delays and providing timely assistance. Implants and on-body sensors can communicate and transfer data in real-time with extremely high reliability and availability to edge devices or cloud centres for short- and long-term medical analysis. 6G-IoT networked ambulances can stream real-time video transmission moving at reasonably high speeds to physicians and paramedics from the hospital to provide medical support and quick intervention to save lives.

Challenges and Future Directions

For healthcare to succeed in the future, many significant hurdles must be overcome for the 6G-enabled IoT network. The challenges of dealing with massive amounts of data, power supply, constrained IoT devices, and other areas of hardware development have been emphasised.

Security and privacy.—Integration of healthcare devices to 6G-enabled IoT networks exposes them to wireless interface attacks, such as unauthorised data access, risks to integrity, and Denial of Service (DoS) to healthcare applications and data centres. As the number of connections between devices grows, so do the security and privacy risks.

Data communications and data management centres are particularly vulnerable to DoS attacks, hijacking, spoofing attacks, and eavesdropping attacks. For instance, implantable cardiac devices connected to the internet risk being hacked, changing how they function and having the data they transmit hijacked. Therefore, risk mitigation must be considered to ensure high security and privacy for 6G-IoT. The Blockchain approach becomes more relevant in the 6G era because IoT networks are decentralised and distributed, ideally suited to the Blockchain's decentralisation feature while at the same time providing security features such as anonymity and integrity.[9]

Low power and low-cost communication.—IoT devices for smart healthcare often have a compact footprint and are connected to several sensors. These devices need to be powered continuously, which poses a serious cost and battery life problem. Devices must have low power consumption and low-cost features to overcome these problems in smart healthcare. Therefore, energy-efficient algorithms are needed for devices to communicate with one another while using less energy. Development in the field of microelectronics, wireless communication, and energy harvesting in this area is a possibility. For example, sensors implanted in the body can harvest solar energy from ambient light for healthcare monitoring using a Bluetooth-enabled low-energy module in a transparent silicon enclosure.[10] Furthremore, new materials such as MXenes-based intelligent biosensors can further revolutionise the implants by determining diverse biomarkers/pathogens related to fatal and infectious diseases that does not require external power.[11]

Resource constraints of IoT devices.—For edge intelligence and URLLC data transmission, wearable sensors, intelligent healthcare devices, and mobile devices should be able to perform AI tasks. Some IoT sensors and implants are unable to satisfy the relevant computational requirements due to hardware, memory, and power resource limitations. Therefore, hardware-based AI training solutions on nano IoT devices and integrated wearables will be necessary for future intelligent 6G-enabled IoT networks, such as intelligent-enhanced life assistance services.[12]

Healthcare data analytics.—With billions of connected devices, smart healthcare will generate enormous amounts of data and information that need to be analysed. This data may include specifics about individual users' private information (such as patient data) and information about the local surroundings (i.e., ECG, Heart Rate monitoring). To examine this data, intelligent algorithms and procedures are needed to safeguard user privacy and confidentiality while deriving important insights that can be used for other cases. For instance, data generated by locally linked devices can be analysed effectively with the help of Federated learning algorithms.[13]

Estimation and channel modelling of THz communication.—Developing reliable channel models for THz communications is crucial for developing effective wireless communication systems in the THz range. When simulating a THz channel, it is crucial to consider factors such as the spatial non-stationarity over ultra-massive antenna arrays, near-field effect, mutual coupling effect, and the highly frequency-selective path loss caused by the absorption loss of oxygen and water-vapour molecules. Therefore, it is preferable to have channel estimation algorithms that need minimal computational resources for THz communication systems with large arrays of antennas.

Intelligent spectrum sharing.—Device-to-device communication, in-band full-duplex communication, non-orthogonal multiple access, and spectrum sharing in unlicensed space are just a few of the spectrum-sharing technologies that may be employed in 6G-enabled IoT networks. Distributed and effective interference avoidance/mitigation strategies are needed to improve the system performance while managing large numbers of connections in 6G applications. The effectiveness of blockchain technology and deep learning as approaches for flexible spectrum sharing is attractive. Therefore, developing new frameworks and protocols for intelligent spectrum sharing is vital.

Data ownership and ethical concerns.—Healthcare data is extremely sensitive and personal information. Even though the smart healthcare device will improve the quality of life, several concerns surround data ownership. For example, A digital pill with embedded sensors can give caretakers and clinicians access to whether the medication is taken on time via a web-based interface. This can assist medical professionals in determining whether or not patients adhere to their treatment plans. However, insurance companies might be able to monitor how and when patients are taking their drugs and deny coverage to those who do not follow the prescription. Some of the problems that need to be addressed at the policy-making level depend on what is being collected, how frequently, whether users give informed consent in advance, and if they have an easy means to decline collection or prohibit businesses from selling their data.

Conclusions

Future healthcare networks will allow medical professionals to collaborate in real-time using technology like Holographic communication, perform remote surgery and analyse the data generated by smart IoT devices to better diagnose and provide patient care. Existing communication technologies cannot meet the complex and dynamic demands placed on communication networks by a wide range of smart healthcare applications. The development of 6G-IoT networks and applications is still in its early stages. In light of this, it is anticipated that 6G will revolutionise the existing IoT infrastructures and introduce new levels of service, quality of living and user experience in future healthcare applications. This paper examined the core technologies and areas of 6G-enabled IoT networks and provided future research directions.

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