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The evolving roles and impacts of 5G enabled technologies in healthcare: The world epidemic COVID-19 issues

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ABSTRACT

The latest 5G technology is being introduced the Internet of Things (IoT) Era. The study aims to focus the 5G technology and the current healthcare challenges as well as to highlight 5G based solutions that can handle the COVID-19 issues in different arenas. This paper provides a comprehensive review of 5G technology with the integration of other digital technologies (like AI and machine learning, IoT objects, big data analytics, cloud computing, robotic technology, and other digital platforms) in emerging healthcare applications. From the literature, it is clear that the promising aspects of 5G (such as super-high speed, high throughput, low latency) have a prospect in healthcare advancement. Now healthcare is being adopted 5G-based technologies to aid improved health services, more effective medical research, enhanced quality of life, better experiences of medical professionals and patients in anywhere–anytime. This paper emphasizes the evolving roles of 5G technology for handling the epidemiological challenges. The study also discusses various technological challenges and prospective for developing 5G powered healthcare solutions. Further works will incorporate more studies on how to expand 5G-based digital society as well as to resolve the issues of safety–security–privacy and availability–accessibility–integrity in future health crises.

1. Introduction

The latest wireless mobile phone technology, Fifth Generation (5G), was first widely deployed in 2019. While 5G network is at developing stage, some countries including China, South Korea, the UK and the US commercially deployed 5G networks, and some other developed countries are being expecting to put forward commercial 5G networks by 2025 [1]. Comparing to the existing wireless networks, 5G provides high data rate, lower latency, high volume of devices connectivity with energy efficiency, high reliability and mobility support [2]. Thus, the services offered by 5G mobile networks are generally categorized into three group, namely (i) "enhanced mobile broadband (eMBB)", (ii) "ultra-reliable low latency communications (URLLC)", and (iii) "massive machine-type communications (mMTC)" [3]. In 2019, 67% of the world people have subscribed to cellar devices, of which 65% have used smart phones [4], and 204 billion apps have been downloaded [5]. About 3.8 billion public have eagerly used social media reported in January 2020 [6]. As the number of digital devices connectivity with 5G is dramatically increasing, the extent of variation in exposure to radiofrequency arenas is still under investigation.

In the meantime, the globe is now facing a public health disaster caused by the novel "coronavirus disease (COVID-19)" [7]. China has first identified the virus in December 2019 [8], and many scientists investigated the genetic code of the COVID-19 [9] as well as trying to combat the coronavirus pandemic health emergency. But the COVID-19 outbreak is deadly affected 219 countries and territories with more than 2.8 million deaths and about 132 millions infected cases in the globe, reported on April 05, 2021 [10,11]. As 50 cities in China first commercially deployed 5G wireless networks in October 2019, many people trying to claim the 5G-coronavirus connectivity theory. The pioneer of 5G technology is South Korea and they first offered commercial 5G with mobile hotspot in December 2018 [12]. But the novel coronavirus not get its first start in South Korea, and many countries without having 5G networks, such as Malaysia, India, Bangladesh, Iran, France, Singapore and Nigeria, etc., have been seriously affected by the virus. Thus, it is false claim of the 5G-coronavirus theory, and the novel coronavirus having nothing to do with 5G as well as there is no scientific evidence [13–15]. Several studies have been done and stated that 5G related telecommunications systems do not affect the human immune system [16].

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Table 1
Key sectors in which 5G technology has the potential impacts to handle the epidemiological challenges.

5G applications to assist the COVID-19 impacted sectors				
Healthcare [17]	Education [18]	Transportation [19]	Industry [20]	Agriculture [21]
Telemedicine, Remote surgery, Remote health monitoring, mHealth, Wearables, etc.	Online class, Remote, assessment, Remote conferencing, Distance learning, etc.	Smart transport, Autonomous vehicles, Intelligent maps, etc.	Smart manufacturing, Industrial Internet, Robot-control process, Remote supply and delivery, etc.	Smart agriculture, Smart irrigation, Remote crop monitoring, Farm data acquisition, etc.

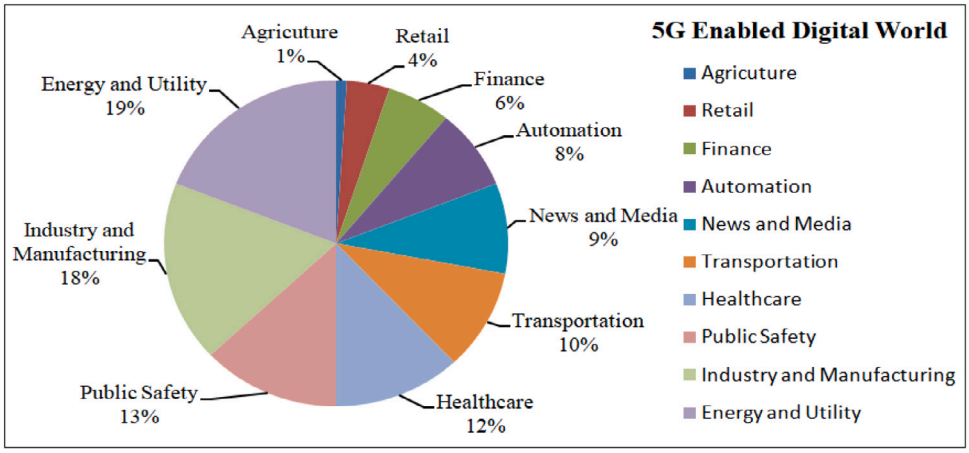

Fig. 1. Sectors that win the most from 5G technology [24].

Table 2
Impacts of 5G enabled digital technologies in healthcare.

5G enabled digital technologies in confronting the COVID-19 pandemic				
AI [33]	IoT [22]	Big data [34] and Cloud computing [35]	Robots and Robotic technology [36]	AR and VR [37]
Analyzing real-time health data and improving diagnosis procedures	Rapidly expanding the number of connected devices and providing a diversity of healthcare solutions	Allowing more data to be transmitted quickly and more reliably to the cloud	Deploying to limit human resources, to relieve pressure, and support effective care	Deploying new consumer devices that support more advanced AR and VR apps

Moreover, 5G technology is anticipated to connect billions of devices with improved performance, and 5G supported applications have the potential to deliver transformative impacts in various sectors (see Table 1), such as healthcare, education, resource management, transportation, agriculture, etc. to handle the challenges caused the COVID-19 pandemic [22,23]. It is estimated that 5G enabled digital market revenues will be USD 1.3 trillion by 2026, and sectors that use most 5G technology is shown in Fig. 1 [24]. Since 2020 the world is the COVID-19 related health crisis, the 5G combined with other advanced digital technologies (see Table 2) can support to tackle the coronavirus challenges in healthcare [25]. These digital technologies including the "internet of things (IoT)" [26,27], "big-data analytics" [28], "artificial intelligence (AI)" that uses "machine learning" and "deep learning" [29,30], and "blockchain technology" [31], are highly interrelated and will be more effective with 5G technology in healthcare applications. This innovative 5G technology will transform together speedy connectivity, cloud-based storage, billions of smart devices, and enhanced medical services in healthcare sector. Thus, 5G will transform the healthcare sector and enable more than USD 1.1 trillion in economic output in 2035 [32].

The 5G enabled digital technology can aid more effective medical research, diagnose and treatment, as well as improved healthcare services for both medical professionals and patients in anywhere–anytime [38]. Fig. 2 illustrates a simple 5G based health platform that assists both the patients and the medical professionals [39]. Since 5G promises super-speed (about 100Mbs) with high data bandwidth and low latency, AI like advanced technologies implemented in 5G networks can enable an intelligent and autonomous functionality to limit the COVID-19 epidemic [40,41]. The IHS Market Ltd has reported that 5G will facilitate more than USD 1.0 trillion in products and services in the worldwide healthcare by 2020 [42]. Also, about 50 billion smart devices and about 212 billion sensors are expected to be supported by the 5G network [43,44]. These health devices, medical wearables, and remote sensors in 5G networks have effective contribution in healthcare to support the health emergency issues caused by the COVID-19 epidemic [45]. Now healthcare is being adopted 5G enabled developing technologies that can assist in health services, improving quality of life, better medical stuffs and patient experiences [46]. It also support the faster transmission of large volume of health data or medical reports [17]. 5G enabled telemedicine is an emerging health service, and it expected that the growth of this market will reach at a "compound annual growth rate (CAGR)" of 16.5% until 2023 [47–49].

The usage of 5G enabled technologies is expanding rapidly with its potential impacts in many fields, and it provides a real-time services more than our expectation [50]. The aim of this study is to focus the 5G technology and current healthcare issues as well as to highlight 5G based solutions that can handle the COVID-19 issues in different arenas. This paper emphasizes the evolving roles of 5G enabled technologies, like AI and machine learning, IoT objects, big data analytics, cloud computing and other digital platforms in emerging applications for handling the current epidemiological challenges. Besides a comprehensive review of 5G enable technologies to combat the coronavirus outbreak, the study discusses various technological and healthcare challenges as well as prospective for developing 5G powered healthcare solutions.

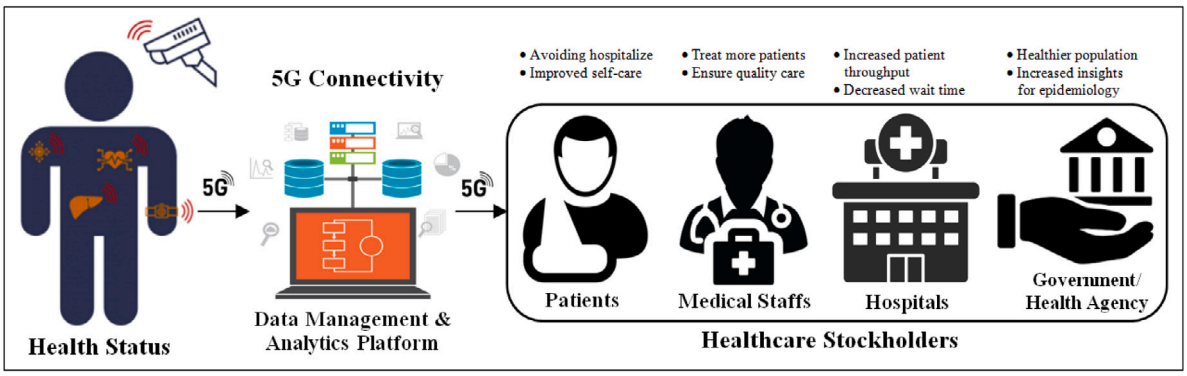

Fig. 2. A simple 5G based health platform for remote patient monitoring and treatment [39].

2. Background

2.1. 5G-coronavirus false theory

Each generation of wireless network standard has introduced a new era of telecommunication, and offered improved data-flow capability and latency. The mobile network just began with first generation (1G) in 1980s, 2G represented the digital transmission in 1991, 3G introduced the mobile telephony world in 2000s, 4G introduced the Streaming Era in 2009, and the latest 5G technology is being introduced the Internet of Things Era [51]. But it was asserted that 3G was deployed in 2003 as the year of the SARS epidemic, 4G was first established in 2009 as the year of the swine flu pandemic, and finally, 5G network was introduced in 2019 that is the year of the COVID-19 outbreak [13,52]. But the truth is that 3G was first unrolled in Japan in 2001 and Japan was not affected at that time. According to the "World Health Organization (WHO)" reports, in 2002 the SARS outbreak began in China before unrolling 3G. In late 2009, 4G network first launched in Sweden and Norway [53]. The Swine flu evolved by the H1N1 influenza virus that was first identified in April 2009 in Mexico and the United States before 4G deployment [54,55]. The first COVID-19 case was identified in China on December 31, 2019, and the coronavirus has rapidly spread around the world in 2020. But 5G was first launched in South Korea on December 1, 2018 [56]. The emerged date of 5G-coronavirus matching is coincidence. Many countries without having 5G networks have seriously affected by the coronavirus [57–59]. Although 3G, 4G and 5G networks were unrolled at the same years to the SARS, H1N1 influenza virus and novel coronavirus outbreaks, the WHO reported that is no scientific study could link between the wireless technology and the virus outbreak [60].

2.2. Impact of the COVID-19 epidemic

The world is still now a health emergency situation due to the COVID-19 caused by the novel coronavirus, which was provisionally named "2019 novel coronavirus (2019-nCoV)" by the WHO in December 2019. Several studies showed that the 2019-nCoV is considered a new human-infecting betacoronavirus [61], and allied with mild clinical symptoms of (i) "severe acute respiratory syndrome (SARS) coronavirus (SARS-CoV)" [62], a novel betacoronavirus that first emerged in China in 2002 [63,64], and (ii) "middle east respiratory syndrome (MERS) coronavirus (MERS-CoV)", was first identified in Saudi Arabia in 2012 [65]. Till now (April 5, 2021) the 2019-nCoV has been reported in 219 countries with 132 millions confirmed cases of "human-to-human transmission" [66]. The outbreak of COVID-19 declared as a pandemic that affected our socio-economic environments and all the sectors of healthcare, tourism and hospitality, education, aviation and transportation, manufacturing and distribution, agriculture and supply chain, electronics and energy, financial markets, etc. It was estimated that the worldwide economy shrink by about 3% due to the COVID-19 pandemic [67]. Some of the COVID-19 affected sectors are highlighted below:

I. **Healthcare:** The number of COVID-19 cases is increasing day by day and this deadly disease cruelly affected the healthcare that leads shortage of healthcare facilities and skilled professionals, insufficient accommodation and hospitality, limited testing kits, "personal protective equipment (PPE)", medications, ventilators, ICUs, etc.[68]. Due to the pressure of the coronavirus cases and limited medical facilities, other non-COVID-19 patient's treatments have been disrupted in hospitals [69]. Also, the medical services and treatment bills have suddenly increased in most of the countries to fight the healthcare challenges.
II. **Education:** The pandemic severely affected on-site academic activities, and about 153 countries around the world have closed their educational institutes. It affected about 1.2 billion students learning carriers, reported on May 2020 [70]. Due to the closing of universities, millions of international students left foreign countries that caused negative impacts on education.
III. **Tour and Travel:** Due to the enforcing of lockdown and "movement control order (MCO)", tours and travel are the most badly affected sectors [71]. Reducing the employment, losing jobs and the cancellation of flights have led to billion-dollar loss of the related industries [72].
IV. **Industry:** The stuffs and workers in the manufacturing industries cannot work remotely, and many of the small industries are being stopped their operations due to this pandemic [73]. It is often difficult to implement standards of hygiene and social distancing rules in the industrialized jobs and areas.
V. **Agriculture and Food Supply Chain:** Due to the restrictions on many sectors (like restaurants and hospitality industry) and the reducing of demand, the food supply chains have been disrupted in this pandemic [74]. Especially in poor and developing countries where food preservation facilities are insufficient, farmers are suffering the loss of income and it turned serious impacts on agricultural economy by affecting the areas of food production and supply, livestock production, farmers' income and employment, sales and trade [75].
VI. **Online Platforms and Communication Networks:** As most of the countries in the world are imposing lockdown, the normal operations have disrupted and people working from home using online platforms. The utilization of communication networks is increasing significantly. It is reported that the Internet traffic is increased more than 25% on the typical usage [76]. Table 3 highlights the impacts of the coronavirus pandemic on the existing mobile networks [23].

Thus, the above impacts of the coronavirus outbreak are now affecting the global economy. During this pandemic, losing jobs and decreasing income, restrictions on movement, goods and services have been declined in our social life and normal activities.

Table 3
Impacts of the pandemic on the existing wireless networks.

Impact of COVID-19 on the usage of telecommunication networks				
Capacity limitation [77]	Service disruption [78]	Energy wastage [79]	Cell outages [23]	Rural-connectivity limitation [80]
Increasing network dependency by many sectors, Surging traffic demand and demand shift to residential areas	Increasing demand for high mobility support, Poor support for high mobility broadband services, Need for health services	Increasing number of underutilized base station due to shifting traffic demand, Lack of autonomous base station switching mechanisms	Reducing the number of on-site workers, Attack on telecom engineers on-site, Damage to base station equipment	Limiting in deployment of network, Erratic electricity supply, Low profit compared to investment

2.3. Current healthcare system

The existing healthcare system is facing a number of challenges and problems. Major global challenges include lack of healthcare services and facilities, lack of digital resources and limited access, lack of quality treatment and high costs, lack of digital devices and systems, etc. [17,81].

I. **Challenges with EHRs and Universal Access:** The "Electronic Health Record (EHR)" stores patient's health information electronically that can be shared securely with multiple users to provide quality service in integrated health from anywhere in the world [82,83]. The main problem in the existing system is that hospitals and medical staffs are not connected to the EHR system, and thus, the patients"ô record is constrained within clinics and laboratories. In poor and developing countries, the deployment of universal healthcare system is very challenging due to several reasons such as limited medical equipment and resources, lack of skilled professionals, as well as poor people unable to afford medical services [84,85].
II. **Limited Resources and Healthcare Facilities:** Many countries are now suffering the insufficient medical services in fighting the COVID-19 outbreak due to shortage of hospitals and accommodation, insufficient healthcare supplies and medications, shortage of skilled staffs and digital systems. About 57 countries are seriously facing the shortage of medical professionals [84,86], and it is estimated that the world will have a lack of 12.9 million healthcare staffs by 2035 [87]. Thus, it requires the deploying of telemedicine and e-Heath services to support medical staffs as well as patients.
III. **Challenges in Health Information Systems:** As the existing healthcare is suffering troubles in universal health information systems, the development of "information communications technology (ICT)" tools will have a great transformation in the whole healthcare system. It can connect multiple medical devices and equipment, process heterogeneous health data, optimum allocate available resources, automate financial transactions and management to provide efficient healthcare services, like remote surgery, wellness monitoring applications, etc. [88,89].
IV. **Lacks in Developing Intelligent Healthcare Solutions:** The existing healthcare is suffering for poor data-driven practices in patients assessment in which both patients and staffs are restricted to utilize proper medication procedure and digital devices [90]. It sometimes causes over-or under-estimated effects of undesirable drug reaction. The development of intelligent healthcare solutions can provide the best care to the patients as well as to ensure safe and quality services.

2.4. 5G technology and health issues

5G follows the advancement of 2G, 3G and 4G wireless network standards [91,92]. 2G was suitable for calls and text-messages with very-low speed. Beside calls and messaging, 3G also supported data and the Internet services with the speed over 5 Mbps. The existing 4G network supports faster connectivity with the speed over 10 Mbps, and allows multiple connections of digital devices. The latest 5G technology is expected to have three major features over the existing 4G network [93], such as (i) super-fast connections and speeds (about 10 to 20 Gbps data upload/download speed), (ii) large capacity of users and devices connectivity (up to 1 million devices per square-kilometer), and (iii) very-low latency or very-fast responsiveness (about 1 mSec). Various technologies, such as "Device-to-Device (D2D) communications", IoT, "Massive Multiple Input-Multiple-Output (MIMO)", "millimetre-wave communications", full-duplex transmissions, "Unmanned Aerial Vehicles (UAV)" and drone communications are utilizing 5G networks to provide coverage in urban and rural areas [94]. Healthcare, smart-cities, transportation and manufacturing are the major application areas, in which 5G has the potential to offer the more designated services and advanced applications.

The US, China, Japan and South Korea are the leading countries in 5G deployment and development [95], where 5G home-services and some big applications have been developing in many cities [92]. South Korea has demonstrated 5G technology in February 2018 Winter Olympics. They have been rising their 5G networks and expected 5G deployment all over the country by 2022–2023. China has launched commercial 5G networks in 2019, and is expanding 5G communication as its 'Made in China 2025' plan in research and development strategies. Japan has launched a commercial 5G network in 2020. Austria, Spain, Switzerland, and some other European countries have been launched 5G services and planned to expand the networks. It is expected that the 5G cloud will cover one-third of the world population with about 1.8 billion connections by 2025 [22,96].

5G is a radiofrequency (RF) based technology that uses electromagnetic spectrum (same as 4G spectrum) to transmit information involving radiations (the emission of energy) [97]. Radiation is characterized by the levels of power on the "electromagnetic fields (EMF)", and separated into two groups, such as ionizing (or higher frequency radiation) and non-ionizing (or lower frequency radiation) [98,99]. Ionizing radiation includes UV-rays, X-rays and gamma-rays, and the excess energy emitted from this radiation damages cells (i.e., breaks the chemical bonds in DNA) and causes cancer. 5G involves non-ionizing radiation (microwave and millimeter wavelength radiation), and this radiation does not emit enough energy that directly damages cells [100].

The WHO deployed an international project on EMF in 1996 [101], and the project investigated the health impacts of exposure to frequency radiations in the range of 0 to 300 GHz [102]. Most of the study did not find a link between RF signals from cellular towers or phones and diseases. From some investigations in 2011, the WHO said the radiation from cellular might cause some brain cancers [103]. But radiation does not cause a virus. The international radiation watchdogs, the `IEEE (Institute of Electrical and Electronics Engineers)" and the "ICNIRP (International Commission on Non-Ionizing Radiation Protection)" [99] have been conducted the research to set safety guidelines for the usage of 5G frequency, and they confirmed that the frequencies at which 5G will be deployed will be safe for human [97,104,105]. Moreover, the WHO is conducting a study on the health impacts of exposure to RFs covering 5G. They will analyze technical facts related to health risks from 5G radiation, and publish the review report by 2022 [106].

2.5. 5G healthcare opportunities

5G connectivity is improving the healthcare services in different ways [17] by enabling home healthcare, digitizing pathological analysis, handling patients' information files, enabling remote surgery and medications, enabling healthcare training and therapeutic, enabling secure staff–patient communication and management, etc. [107,108]. The promising aspects of 5G will also have the strength in the future of medicine and treatment advancement [109], and the utilization of advanced technology in healthcare has been reviewed in several studies [110–113]. A few aspects of the newly commercialized 5G technology relevant to healthcare services, that have potential influences in limiting the COVID-19 pandemic, are highlighted below.

I. **In-home Healthcare Services:** Due to limited number of hospitals, high costs and long waiting in the pandemic, the patients want to be treated at home, if they are not seriously affected. 5G is helping to improve the home healthcare services, like online health consultancy, remote health monitoring via digital devices over a secured 5G mobile network.
II. **Digital Pathological Analysis:** 5G is being supporting to develop smart hospitals by improving digital pathology and diagnosis. The healthcare has already experienced the 5G powered computed tomography (CT) scanning remotely in real time [114]. The medical specialists will be able to utilize 5G networks to access the large volume of health data obtained during diagnosis or surgery from anywhere in any time.
III. **Remote Surgery and Medications:** The promising features of 5G will revolutionize on online treatments and surgery. The 5G healthcare innovations include telemedicine, tele-surgery or robotic-surgery, remotely emergency care, etc. The 5G based telemedicine provides a remote consultation platform, in which the health professionals can treat the patients effectively. The tele-surgery provides a real-time operation, and the surgeons can perform remote surgery using surgical devices through 5G networks [115]. 5G connected ambulances or mobile clinics in rural areas could enable AR assisted operations to serve the patients with appropriate critical care.
IV. **Healthcare Training and VR Therapy** 5G also augments the prospect for distant training with audio–visual and real-time communication. Virtual reality (VR) with 5G has already transformed many aspects in healthcare industry. The medical professionals and students are using 5G enabled high-end VR to simulate operations, and clinics are using an innovative VR therapy to assist patients, recover from chronic pain or injuries [116].
V. **Healthcare Research and Education:** The 5G technology revolutionizes the link among researchers/scientists, patients, and medical centers. It will be achieved by establishing the environment with 5G based IoT and ICT tools, intelligent platforms, multi-access edge computing (MEC), cloud computing and big-data analytics to power the facility for research, treatment and wellness education [117].

2.6. 5G enabled technologies in healthcare

Now-a-days, the advanced digital technologies are being transformed in healthcare to handle the world epidemic COVID-19 [118]. The promising 5G enabled digital technologies, such as IoT, AI, Big Data Analytics and Cloud Computing, Blockchain, etc. have been augmented the public-health strategies [25] to fix the current healthcare limitations and confront the coronavirus disease (COVID-19) pandemic [34].

I. **IoT Aided Healthcare Advancement:** We are observing the growth of IoT aided systems, and it is projected that more than 20 billion devices/sensors will be allied to the Internet by 2020 [119]. These devices can convey information to the cloud that enables a uprising automation with resource utilization and energy efficiency [120]. While the existing 4G networks support only 4000 devices per square kilometer, 5G can connect up to a million devices per kilometer. Thus, IoT with 5G standards is revolutionizing the existing healthcare with a diversity of solutions [121], such as remote health monitoring and diagnostics, remote medications and treatment, telemedicine and telesurgery, patient information management, emergency caring, and much more.
II. **Big Data for Healthcare:** 5G digital world enables the connectivity of billions of devices and expert systems. These digital devices and technologies relevant to healthcare produce a variety of "electronic health record (EHR)", referred to as big data in healthcare [120]. These devices are being utilized in monitoring our daily life, such as constant monitoring of heartbeat and movement, blood-pressure, body-temperature, oxygen-concentration in blood, glucose, human activities and emotions, etc. This large volume of medical data can be used for insights analysis in various aspects of human life, developing a patient-centric personalized healthcare system, studying the viral activity, as well as preparing health guidelines for public-health policy and planning, monitoring and controlling the viral outbreak in the pandemic [122,123].
III. **AI in Healthcare:** The real era of AI (machine learning and deep learning) will arise with the deployment of 5G technology. It would be more reliable to utilize machine learning techniques and expert systems for analyzing real-time health data in could platforms using 5G networks [124]. It is now emerging reality that machine learning and deep learning approaches are being developed in improving diagnostic procedures, especially for the detection and diagnosis of COVID-19 cases [125–127].
IV. **Robots and Robotic Process in Healthcare:** The robots and robotic automations are being developed to limit the human resources, to relieve pressure of health professionals as well as to enhance diagnostic capabilities with the help of 5G connectivity in this pandemic situation [128]. We have already experienced that 5G powered robots can deliver drugs and meals to patients, inform patients to take medications, measure body temperature, help to ensure social distancing, etc. 5G enabled unmanned vehicles or drone can assist healthcare services in the critical zones. The robot-assisted therapy and surgery with 5G networks have great potentials in remote medications and surgery to treat the patients [129–132].
V. **Other Digital Technologies in Healthcare:** Recent advancements in sensing technologies (microelectronics and nanofabrication) and wearable computing, bio-engineering and computer-aided surgery, virtual reality (VR) and tactile Internet, smart devices and digital platforms with 5G compatibility have enabled a dramatic development in the healthcare systems [109,133]. Various social-media platforms, like Facebook, Twitter, Youtube, WhatsApp, Instagram, are currently used by the public to receive real-time updates as well as by the healthcare authorities to take initiatives and clarify uncertainties about COVID-19 pandemic [25,134,135]. Furthermore, some AI enabled systems, like facial thermal imaging system, have been implemented to detect high-temperature person at various screening points, such as shopping malls, airports, train stations, bus terminals, etc. [136–139].

3. 5G based solutions in limiting COVID-19 outbreak

3.1. Aspects of 5G technology in healthcare

A few aspects of 5G technology (see Fig. 3), those have great potentials in healthcare advancements, are highlighted below:

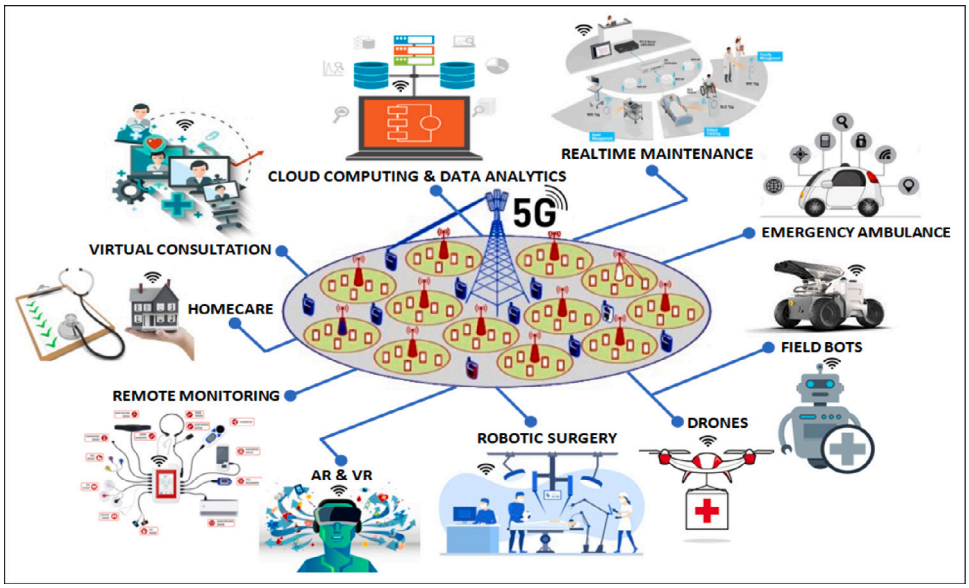

Fig. 3. Few aspects of 5G interconnected technologies in healthcare to tackle the pandemic [140].

I. **Telemedicine:** Telemedicine requires a reliable and faster network connectivity that will offer quality video and real-time communication. 5G standards can enable proper telemedicine environment that augments online health consultancy [141]. It is estimated that the telemedicine market will raise yearly growth of 16.5 percent from 2017 to 2023 in healthcare [47]. 5G also meets the teleconferencing requirements to enable medical experts to treat patients efficiently from anywhere in anytime.

II. **Telesurgery:** As 5G is a very-low latency and super-fast network, it enables telesurgery or remote medical operation. A health surgeon in China first performed a 5G-assisted remote surgery using da Vinci surgical robots on animal in January 2019 [142]. In March 2019, a telesurgery using 5G mobile network was first performed remotely on human brain in China [115]. Moreover, 5G capabilities can improve the surgical robots and robotic process that can enhance the surgeon's capabilities in the pandemic.

III. **Internet of Medical Things (IoMT):** 5G network infrastructure is able to connect a billion of digital devices and wearable medical equipments (i.e., IoMT objects) that allow a link between physical and digital worlds, and facilitate real-time analytics to improve health outcomes. It can gather a large volume of health data and store on a cloud as well as assist online accessibility to the users, medical professionals and researchers. The world has already experienced a number of IoMTs and health applications (for instant, 5G thermal imaging systems, smart diagnostic tools, therapeutic kits, etc.) as a part of the emerging 5G innovations in the pandemic [138,143,144].

IV. **Remote Diagnosis and Treatment:** 5G connectivity is revolutionizing in continuous contagion monitoring and remote diagnosis from anywhere in this pandemic [132,145]. It also enables digital medicine that can share a high-volume of health information across a worldwide network of health specialists for caring patients. In January 2020, China has first developed 5G remote diagnosis and treatment system [146] that can support remote diagnosis and treat patients in this pandemic.

V. **Digitized and Data-Driven Platforms:** Many developed countries, like China, Japan, South Korea and the US, are rapidly set up their specific 5G wireless networks for digitalized, data-driven and Cloud-based emergency platforms that can assist the COVID-19 treatment in hospitals [147,148]. These digital platforms support the healthcare systems in the context of improved response times, remote monitoring, data analysis and diagnosis, resource allocation, etc.

3.2. 5G powered major solutions

The emerging innovations using digital technologies rely on a reliable telecommunication infrastructure and high-speed Internet connectivity. The integration of 5G enabled technologies is a transformation of the person-centered care models to the community-based approaches [149,150]. It offers a real-time health solution for the whole population [151]. Some of the pioneering healthcare solutions using 5G enabled digital technologies in response to the COVID-19 pandemic are highlighted in the following sub-sections.

3.2.1. 5G-powered ehealth approach

An innovative eHealth approach [45] has been developed using 5G communication technologies. The mechanisms implemented in eHealth are used for acquiring health data from a variety of sources through IoMTs, processing data, and storing the processed data to the cloud through eHealth 5G platform. As shown in Fig. 4, the eHealth model comprises of the three main modules, such as (i) Data acquisition from heterogeneous sources including IoMT devices, (ii) 5G virtual platform including data management mechanisms and data storage, and (iii) 5G communication and integration allowing a connection between the physical systems and the 5G virtual platforms. This 5G-powered eHealth system can support to improve the real-time healthcare services in this pandemic.

Step 1. **Data Acquisition from Heterogeneous Sources:** A variety of IoMT devices are connected together through the established 5G network. The first step involves the gathering of data from heterogeneous sources via these devices with appropriate specifications (hardware and software). The composed data from different systems and devices are utilized by either (i) the patients for in-home monitoring, or (ii) the health specialists for analyzing and assessing the patient's health status in laboratories and hospitals, or (iii) the patients for outdoor activities.

Step 2. **5G Communication and Integration:** The 5G infrastructure development of the eHealth system comprises of two steps, the 5G communication and integration, which allow the connection between the real world and the virtual world. The data gathered from digital devices takes place at high reliable edge-nodes in the physical systems. These edge-nodes in the physical systems are being connected via a "5G radio access network (5G-RAN)" [152]. This network enables the data analysis inside the eHealth platforms. Thus, the 5G based eHealth

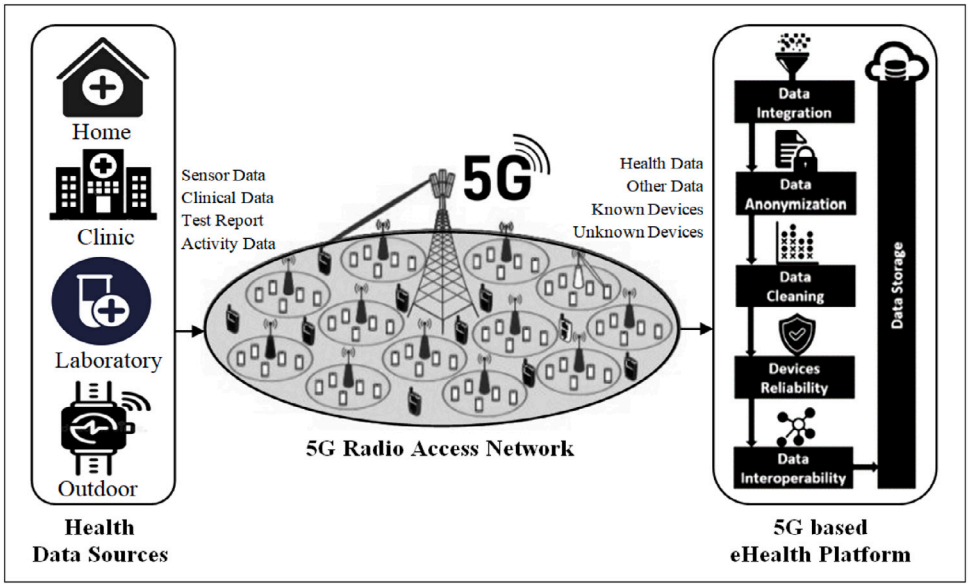

Fig. 4. A typical architecture of 5G enabled eHealth Platform [45].

platform has been developed using an appropriate integration of "virtual network functions (VNFs)" [153,154] and "software defined network (SDN)" [155] technologies. This platform is able to offer network virtualization, automation and creation of new services over virtual resources.

Step 3. **Data Management Mechanisms and Storage:** The 5G SDN with virtual networking platform provides all the data management mechanisms, such as data integration, data anonymization, data interoperability etc. All the gathered data after transformations (such as, data integration [156], anonymization [157], cleaning [158], source reliability [159], and data interoperability [160] procedures) is transfigured to a common format, and reserved into the eHealth database. This transformation is a prerequisite for the effective Health platform, which can support the virtualization of different eHealth platforms running in different entities, such as in-home, hospitals, clinics, laboratories, etc.

3.2.2. *Real-time mobile health (mHealth) platforms*

It is very important to know about the public-health related information to forecast the outbreak during the different phases of the epidemic. Mobile technology can assist the estimation of the viral outbreak, and provide emergency treatment during the pandemic. A eHealth platform using mobile technology is referred to as mHealth (mobile health) system. A simple mHealth system is graphically presented in Fig. 5 [159] that enables to connect a variety of digital devices, such as smartphone, tablet, iPad, smartwatch, wearable, etc. It can share the health information and applications to treat the patients in the emergency situations. These devices are generally connected through Wi-Fi, "global positioning system (GPS)", and high-speed telecommunication networks (5G networks).

Thus, the mHealth system using 5G wireless network and cloud-based technologies can support to enhance the emergency treatment, health research activities, and other healthcare services in the COVID-19 pandemic [161,162]. Some of the potential services of the mHealth platforms are highlighted below:

(i) Video conferencing and text messaging, through which a patient can consult a doctor to get precise guidance for the distant treatment.

(ii) Contract tracing, through which the patient database can be used for tracing infected patient's location in case of communal spread of the coronavirus disease.

(iii) Telemedicine offers the health consultation to treat the patient remotely. Thus, it facilitates both the health professionals and patients to prevent the transmission of infectious diseases.

(iv) Health apps provide the self-monitoring of individual's health status using wearable devices that can be securely shared with the health professional for proper medications and treatments during the outbreak.

The healthcare agencies and governments in different countries are being used this type of real-time mHealth platform using 5G mobile technologies for controlling the spread of COVID-19 epidemic [163]. Another mobile technology based system is presented in Fig. 6 [159]. The designated system assists in tracking and monitoring of COVID-19 infectious people and giving alerts to the public, as follows:

Step 1. The system collects the information from the network tower to which user smartphone is joined. The apps use this information in tracking and monitoring the individual's movement, and aware the emergency situations. The apps also assist the users in better understanding of the COVID-19 spreading [164].

Step 2. Using the mHealth database, the healthcare agency announces for infected people and their family to take the isolation, and do the testing procedures at the earlier stage of the COVID-19 infection. The database of the identified COVID-19 cases can help in contract-tracing during future outbreaks. It can help to inhibit the social interventions by restricting the social contact, outdoor movement, public gathering, etc.

Step 3. The real-time data from the mHealth system can help to estimate the infected cases and death as well as to understand the nature of infection. The chance of future outbreaks depends on this estimation. The major affected areas are declared as red zones, and it can assist to declare the full restrictions on movement and public gathering, the closing of offices/institutions, etc., in the red zones [165,166].

3.2.3. *5G enabled telemedicine and virtual health environment*

Telemedicine supports long distance healthcare services using ICT tools and high-speed Internet connectivity (5G networks). It can adopt the existing health systems and infrastructure [167] to enhance the treatment procedures in hospitals [168]. 5G also helps to entail durable health education and training, consultancy, and managerial meetings

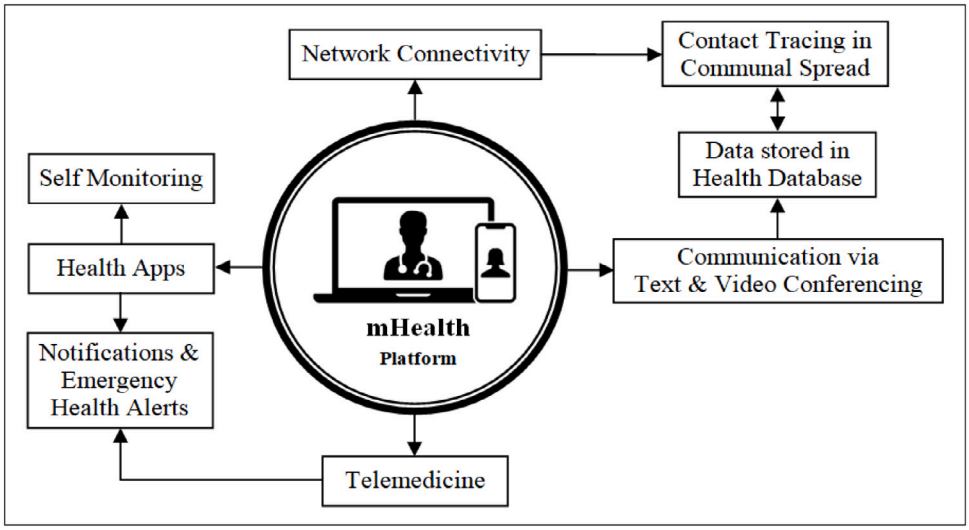

Fig. 5. mHealth in various application domains.

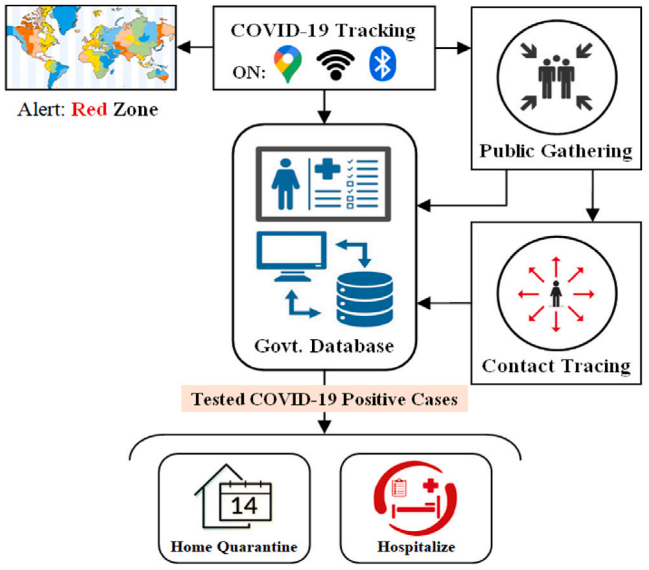

Fig. 6. Illustration of mobile technology based COVID-19 tracking system.

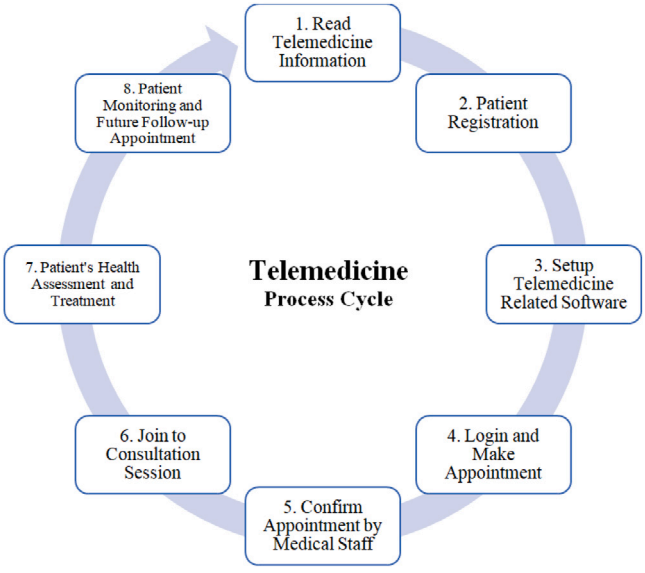

Fig. 7. Structure of a typical telemedicine process lifecycle [141].

using virtual platforms [169]. Fig. 7 illustrates a typical telemedicine process lifecycle that starting with reading telemedicine information and patient registration, and ending with the future follow-up appointment for monitoring patient's health [141].

Though the doctors utilize virtual platform during online consultation, they try to create the almost real environment as much possible, and maintain confidentiality patient's privacy and agreement [170]. During online session, they must keep professionality in nature and build a patient–physician relationship [170–172]. They also ensure the telemedicine service within the patient's health coverage. The patients also will be notified if they use any third-party application during virtual consultation regarding the privacy or cyber security issues. Beside high-speed network, the system requires better supporting tools, like smart devices with camera and microphones, proper lighting, noise-free environment, etc., for virtual examination at the both ends [172,173]. Telemedicine ensures a user-friendly and comfortable virtual platform for both the patients and the doctors as well as provides an improved virtual treatment process.

3.2.4. 5G enabled unmanned autonomous systems

The ongoing COVID-19 pandemic presents itself as a critical challenge for the ICT industries. The autonomous or semi-autonomous systems, like unmanned vehicles, drones, robots, etc., are being developed to assist the controlling of COVID-19 crisis by minimizing the social contact [112]. This "unmanned autonomous system (UAS)" involves a 5G wireless network that connects the system automaton to the cloud, and a management module for the operations [174], as shown in Fig. 8 [112]. Limiting the pandemic, these 5G enabled autonomous systems are being utilizing mainly for two purposes, such as (i) limiting the COVID-19 outbreak, by measuring body temperature, sterilizing the infected areas, delivering and communication remotely, (ii) security patrol, by facial recognition and other object detection.

A. **Epidemic Prevention Robots:** 5G-powered smart robots using thermal imaging technique are being employed to control the spread of the virus in many countries [175]. These robots were developed by integrating 5G technology, cloud computing and computer vision to accomplish the emergency tasks, like face recognition, temperature screening, etc. in the pandemic [176].

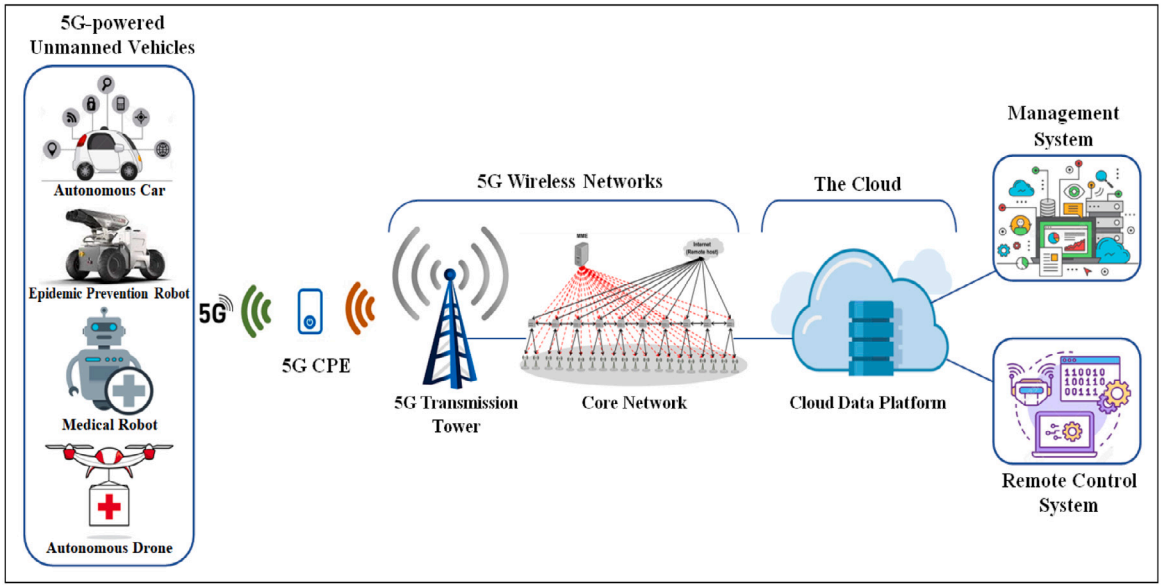

Fig. 8. 5G Enabled Unmanned-Vehicle Automation System [112].

The 5G-enabled robots and drones with smart vision sensors have been utilized to patrol the risks zones. They have the ability to track multiple target objects simultaneously while patrolling. They can also monitor the spread of sickness, notify public to wash their hands, detect and notify for wearing masks, etc.

B. **Unmanned Cars:** The self-driving vehicles or unmanned cars are being employed to avoid contact between individuals at infected areas, which greatly reduces the risk of infection. Integrating 5G and autonomous driving technology, the cars can perform fully automated and contact-free tasks with improved efficiency [177]. This vehicle is connected to the remote server through 5G network, and used as an intelligent system for disinfection, transportation, patrolling, epidemic prevention broadcasting, etc.

C. **5G Intelligent Robots:** Another type of intelligent robot by integrating 5G and AI technology assists medical professionals to conduct consultations, disinfection, cleaning, and deliveries [178]. The usage of these smart robots can effectively relieve shortages of staffs, which reduce the risks of cross-infection and improve the quarantine-control in the medical centers.

D. **5G-powered Disinfection Robots:** The 5G-powered disinfection robot is designed with a spray sterilization system that can effectively disinfect the contagious area [179]. It can effort autonomously in accordance with a settled disinfection route, setting time, fixed-points, multi-track mobile disinfection and sterilization in the contagious world [180]. Thus, robots are increasingly being deployed at the front lines against the COVID-19 pandemic in order to reduce cross-infection risks and improve work efficiency and quality [181].

E. **5G-powered Intelligent Drones:** 5G-powered drones with AI technology are being utilized for drugs delivery and aerial spraying for disinfection in the virus affected areas [182]. They are being also used to transport samples from patients to medical workers, thus reducing the COVID-19 contagion risks.

4. Challenges and prospective

The real-time super-speed and very-low latency aspects of 5G network offers a variety of new opportunities that support to expand healthcare applications. The literature shows that 5G enabled technologies have the incredible potentials in healthcare to confront the coronavirus pandemic. But it will not be sufficiently transportable geographically to achieve the desired services in some cases [183]. In the context of healthcare services in the current epidemic, the key challenges and the prospective of 5G enabled technologies are described in the following sub-sections.

4.1. Key challenges

I. **Health Risks:** There is a confusion about suspected health risks due to 5G radio frequency [184]. Public in rural areas are being expressing esthetic concerns and worries about super-speedy network's effect. But many organizations, like NIH, FDA, National Cancer Society, WHO, FCC agreed that there is no validity to the worries about it.

II. **5G's Range and Coverage:** Occurring obstructions in 5G network interrupts its range. Thus, 5G networks require more small devices or antennas in short distance apart to get better 5G signal. It is difficult to deploy 5G network in rural areas that remains the most underserved by healthcare institutions.

III. **Deployment Costs:** The effective development of 5G enabled health solutions require availability of good infrastructure for the patients, physicians and clinics. Thus, the costs of 5G establishment, related devices and infrastructure improvements plus increased maintenance costs are a big issue in 5G healthcare applications. It is logically expected that customers will bear a part of those costs, and hence, the patient will be paid the increased cost for their treatment.

IV. **Training and Adaptation of New Technology:** The 5G based health system is gradually delivered through virtually using smart devices and technologies. Both medical staffs and patients require knowledge and skills to adopt new technologies and systems. Thus, proper training is needed to the patients and medical staffs in learning how to use theses new platforms [185]. Many developing countries may not be able to implement a complete 5G-based innovative healthcare solution, specifically in remote and rural areas where the expansion of 4G/5G networks is more difficult [173].

V. **Security Challenges:** Since 5G is capable of fastest data transfer and other healthcare services remotely, security and privacy risks are being increasing day by day. Hence, it requires to give extra attention in 5G security concerns [183] that include

data and device protection, data filtering and digital rights management, patient's data confidentiality, infrastructure and national security, network security, cybercrime and cyber-security, etc. [186,187].

4.2. Prospective

I. **Super-Fast and Accurate Health Services:** The super-fast 5G network can provide quick and reliable transport of large medical data. Low latency feature of 5G technology can provide faster and reliable treatment to the patients remotely, and help surgeons for conducting remote robotic-surgery.

II. **Advancements in Healthcare:** 5G technology can improve personalized and preventive care. 5G powered telemedicine enables real-time health consultancy and emergency treatment. Moreover, a fully-implemented 5G network will enhance medical operations and management as well as quality treatment experiences for both the patients and medical staffs.

III. **Integration of Advanced Technologies:** 5G is being given us the opportunity to utilize "artificial intelligence (AI)", "Internet of medical things (IoMT)", "augmented reality (AR)", "virtual reality (VR)" in healthcare applications. They have the potentials to offer innovative and transformative health facilities as well as enhance real-time treatment and diagnosis procedures.

IV. **Cost Optimization and Safeguard Quality:** The use of 5G-powered technologies, like mHealth technology, telemedicine, IoMTs and wearable devices, or digital health platforms [188] can help patient's living in urban and rural areas by gaining remote access to medical assistance [189]. It will obviously save money by avoiding expensive hospital visit without compromising quality-treatment [190]. It will also offer distant doctor-assistance on diagnosis, and will fulfill the desired service standards for a complete medicinal examination [191].

V. **Advancements in Intervention Management and Administrative Operations:** The new insights of 5G-powered healthcare solutions will provide continuity of health caring without having interrupt in data entry and querying tasks, thus, it is a disruptive process in recording medical information [192,193]. It enables improvements in intervention management by facilitating valuable healthcare resources, like operating theaters, electrocardiogram monitors, and other medical equipments. These valuable assets enable better management as well as ensure safe and efficient administrative operations.

5. Conclusion

The use of 5G network in integrating other digital technologies (like AI and machine learning, IoMTs, big data analytics, cloud computing, etc.) is now a reality in healthcare. From the literature, it is clear that 5G enabled technologies as well as intelligent systems have a prospect to improve healthcare services, such as medical diagnosis, health monitoring, treatment, management, etc. As the 5G poses non-ionizing radiation, there is no significant health risk of 5G RF wave below the recommended safety level. There is no evidence that 5G signal causes the spread of the coronavirus. Moreover, 5G enabled digital technologies have been used for limiting the COVID-19 outbreak, and enhancing the public-health strategies in 2020. Some advanced technology giants are conducting their researches on 5G related applications that will combat against the health risks of any undesirable epidemics. The successful utilization of 5G technology to tackle healthcare challenges will enhance the acceptance of such technologies for other sectors in the future.

As it is a new field of research, some issues are to be considered in deployment of 5G network in healthcare including infrastructure development, technical standards, effective regulations and policy, privacy protection and security, as well as availability of research data. Further works will incorporate more study on how to expand 5G based digital society as well as to resolve some issues, such as safety–security–privacy, availability–accessibility–integrity, and to augment resilience to future health crises. It is also required to compile laws and prepare proper guidelines to deal with ethical and legal counteractions in managing the online services during the emergency situations. With the new technological innovations, 5G network will provide a complete pathway for a smart society with various promising healthcare applications.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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