# 5G Smart and innovative Healthcare services: Opportunities, challenges and prospective solutions

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**Abstract**
Due to its abilities to boost productivity, reduce costs and enhance user experiences, smart healthcare is widely recognised as a potential solution to reduce pressures on existing health systems. Since the new era of 5G will unite enhanced connectivity, improved cloud-based storage and interconnection of an array of devices and services, a massive boost in the digital transformation of healthcare is expected. In this transformation process, healthcare services such as medical diagnosis, treatment and remote surgery will be facilitated by a range of technologies such as Internet of Things, Robotics and Artificial Intelligence, among others, that will advance further under 5G. Moreover, real-time health services will become a reality and will offer people with quality care and improved experiences. On the other hand, different challenges can hinder the proliferation of 5G smart and innovative healthcare solutions, including security and heterogeneous devices. This chapter presents how 5G will boost digital transformation of healthcare through delivery and consumption of smart and innovative healthcare services, while probing into key hurdles in the process as well as prospective solutions.

**Keywords**: Smart Healthcare; 5G; Digital Transformation; Cutting-edge Technologies; In-Home Medical Care; Medical Diagnosis, Treatment, Surgery, Emergency Services; Preventive Healthcare;

## 1. Introduction

Due to the rapid growth in human population around the world, huge pressures are being exerted on modern healthcare systems. Consequently, healthcare has become one of the most significant issues for governments, particularly due to the significant demand for medical resources (e.g. personnel, equipment and space) (Yang, et al., 2016). This can further deteriorate in the future due to the progressively ageing population as well as the associated increase in chronic diseases (Baker, et al., 2017), since the global population above 60 years is expected to double in 2050 as compared to 11% of same age group in 2000 (Beard, et al., 2015). Subsequently, healthcare demands are expected to outgrow the capabilities of medical practitioners towards providing safe and quality healthcare in a timely manner, where the global needs and the factual amount of health workforce are expected to increase to 81.8 million and 67.3 million by 2030 as compared to 60.4 million and 43 million respectively in 2013 (Scheffler, et al., 2016). Taking awareness of such needs, resolutions towards alleviating pressures on healthcare systems are needed while ensuring continuity to deliver high-quality healthcare services to at-risk patients.

Owing to its ability to boost productivity, reduce costs and enhance user satisfaction, technology-enabled healthcare or smart healthcare is widely recognised as a potential solution to reduce pressures on healthcare systems (Latif, et al., 2017; Baker, et al., 2017). It can extend consumption and delivery of healthcare services outside the traditional settings ranging from monitoring patient health at distance to even conducting surgeries remotely. As a result of benefits including increased availability, efficiencies and accuracy of medical treatment, smart healthcare has gained increasing attention during recent years (Banerjee & Gupta, 2015). The proliferation of smart healthcare could also be attributed to advances in different innovative technologies (e.g. biosensors, wearables and mobile applications), in addition to communication networks such as the Internet, Wi-Fi and cellular networks. Among these networks, the fifth-generation cellular network technology (5G) is designed to provide a huge step ahead in terms of bandwidth, connectivity and latency, among others. Following worldwide deployment of 5G, consumption and delivery of healthcare services will be enhanced through novel healthcare solutions towards boosting the digital transformation of healthcare and facilitating an ad-hoc orchestration of healthcare services (e.g. medical diagnosis and treatment) through better connecting healthcare stakeholders. As such, in the 5G era, healthcare stakeholders will need to rethink and innovate their concept of healthcare in the process of delivering and consuming related services. For instance, the advent of 5G will enable various innovative solutions in telemedicine, remote surgery and health-based wearable devices, among others, that will offer people with quality care due to enhancements in medical imagery, diagnostics, and treatment. On the other hand, different challenges can hinder the proliferation of 5G smart and innovative healthcare solutions, including security and heterogeneous devices (Tehrani, et al., 2014). This chapter presents how 5G will boost digital transformation of healthcare through delivery and consumption of smart and innovative healthcare services, while probing into key hurdles in the process as well as prospective solutions.

## 2. **Digital transformation of healthcare**: **A conceptual framework**

The widespread deployment of 5G is expected to bring a massive boost in the digital transformation of healthcare, with a myriad of innovations within the various healthcare services where possibilities will be boundless. Digital transformation here entails the integration of digital technologies in healthcare in order to provide and support services such as medical diagnosis, treatment and surgery, among others. Through the integration of such technologies, significant improvements in care quality and patient experiences are possible as well as enhanced operational efficiencies to better address the needs of the progressively growing human population. With advances and adoption of in-home medical care and telemedicine in the 5G era, health-related issues can be more effectively resolved via remote consultation, treatment and monitoring of patients. Similarly, an assortment of cutting-edge technologies including robotics, Internet of Things (IoT), Artificial Intelligence (AI) and Big Data will advance to the next level under 5G towards boosting the digital transformation of healthcare.

In this digital transformation process, various components are involved that add to the complexity of smart healthcare systems. In order to address such complexity, a conceptual framework is recommended for simplistic representation of the constituents and associated links (Demirkan, 2013). Such a conceptual framework is given in Figure 1, that depicts the key building blocks entailed in the consumption and delivery of smart and innovative healthcare services in the 5G epoch. Based on the components of this framework, discussions follow about how deployment of 5G is expected to advance key healthcare services.

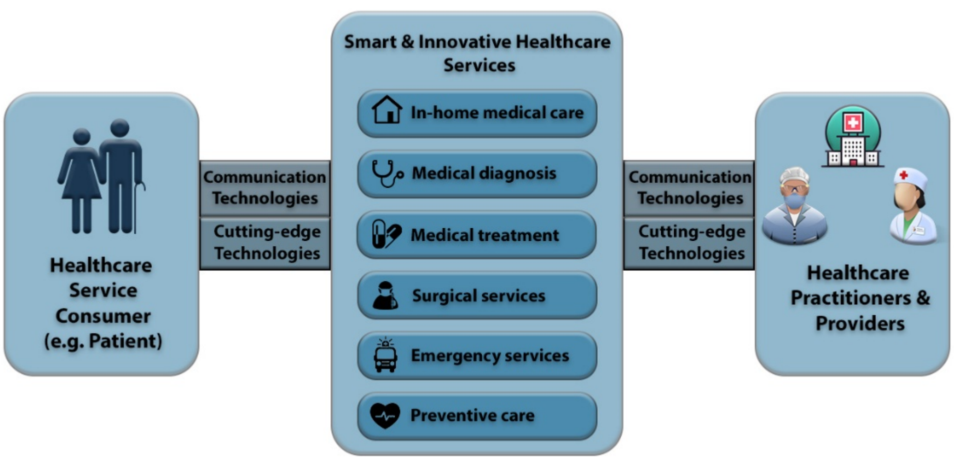


**Figure 1.** Conceptual Framework for Smart and Innovative Healthcare Services in 5G era.

The conceptual framework is based on the needs of healthcare seekers where smart and innovative healthcare services lie at the very centre to cater for such needs, and at both ends, the consumers and providers of healthcare services are present. This also makes it essential to understand key terms to be used throughout this chapter. Whilst healthcare means providing medical care to individuals or a community in an organised manner, healthcare services entail the provision of medical care by medical professionals, organizations and ancillary health care workers to those in need. Examples of healthcare services include medical diagnosis, treatment and surgery, among others and these are provided by a number of healthcare practitioners and providers including nurses, specialists, and pharmacists. Based on these terms, smart and innovative healthcare services involve the delivery and consumption of healthcare services in an innovative, effective, efficient, organised, reliable and timely manner by using emerging and increasingly autonomous technologies while promoting connected entities (e.g. patients and health service providers) that share data and information between themselves.

The delivery and consumption of smart and innovative healthcare services are facilitated by a range of cutting-edge technologies such as IoT, Big Data, AI, Augmented Reality (AR), Virtual Reality (VR) in addition to communication technologies including Wi-Fi and 5G. Since this chapter focuses on 5G, it is important to briefly comprehend the technical specifications and some insights on the ability of 5G wireless communications systems that can aid in digitally transforming healthcare. As compared to 4G, 5G wireless communications envision a huge step ahead in terms of connectivity, network speed, capacity and scalability in addition to reduction in latency and energy consumption (Agiwal, et al., 2016; GSMA Intelligence, 2014), elaborated as follows:

- **High Data Rates.** A key technical ability of 5G wireless communications is high data rate, ranging between 1 and 10 Gbps in real networks (Andrews, et al., 2014). This also represents an increase by hundred times as compared to the 4G technology.
- **Reduced Latency.** As compared to the 10 ms round trip time within 4G, 5G aims at reducing latency to 1 ms round trip time, thus implying an approximate reduction by 10 times (Agiwal, et al., 2016). Within healthcare services, this reduction in network communication delays is expected to enable remotely controlled robots for medical or first-response, in addition to augmented and virtual reality applications that necessitate rapid request-response cycles (Agyapong, et al., 2014).
- **Enhanced Connectivity.** With improved connectivity, billions of connected devices and sensors are expected to be supported within 5G wireless networks, while also enabling access to zettabytes (ZB) of data (Anwar & Prasad, 2018). This is also a means to realise the vision of IoT towards addressing the needs to provide widespread connectivity of devices, while at the same time ensuring higher bandwidth for longer durations within a particular geographical area (Agiwal, et al., 2016). Typical devices connected within such network include smartphones and smartwatches running health-related applications in addition to wearables that enable health monitoring and fitness tracking through real-time sensing of related information.
- **Improved availability and increased geographical coverage.** The next generation 5G systems envision a practically 100% available network in addition to complete geographical coverage irrespective of locations of users (Agiwal, et al., 2016). Even though this is not a technical objective of 5G, the new generation of cellular network technology is expected to provide opportunities for businesses and network operators towards improving availability and increasing geographical coverage (GSMA Intelligence, 2014).
- **Reduced energy use and improved battery life.** Essential requirements of the new generation of cellular networks include reduction in energy usage and improved battery life of connected devices. These requirements do not only help to reduce costs but also promote environmental and ecological sustainability.

## 3. Smart and innovative healthcare services

As smart technology is revolutionising healthcare, numerous advances and innovations are expected in the consumption and delivery of healthcare services. These are discussed in this section with focus on key healthcare services provided by healthcare providers, as also listed in Figure 1.

### 3.1 In-Home medical care

5G and cutting-edge technologies provide opportunities to decentralise healthcare facilities and extend consumption and delivery of healthcare services outside the traditional settings whereby moving the point of care closer to the patient. This will enable a patient to assume a more active and independent role in taking care of his/her own personal health at home whereby promoting ambient-assisted living. Among the cutting-edge technologies, wearables, implantable medical devices and mobile robotic home assistants have important roles to play in enabling in-home medical care. Wearables and implantable medical devices have sensing or actuation capabilities and can either be worn, carried, implanted in the body or beneath the skin, placed within different parts of the body as intelligent patches or even be running through the blood stream. While sensing devices are meant for measuring certain internal or external parameters related to the human body (e.g. monitoring blood pressure, heart-beat and emotions), actuators interact with the human body (e.g. pump correct dose of medicine into body) based data obtained from sensors or other sources. As such, these devices can sample, monitor, process, control and communicate essential information in real-time to the patient or medical staff (Milenković, et al., 2006). In terms of applications, although relevant for all age groups, the use of these devices can provide elderly people with a sense of comfort for monitoring physiological issues and early detection of abnormal health scenarios. Likewise, with the help of baby monitors, mobile applications and other smart health solutions, parents can keep track of baby body's movement, respiratory patterns and even moisture levels in diapers (e.g. through smart diapers). Due to their prospects, various such devices are proliferating at an unprecedented rate (Dunn, et al., 2018) for providing assistance in numerous health and medical issues, namely, cardiovascular and gastrointestinal monitoring, pulmonary health conditions, mental health issues and maternal care. With 5G, there will be opportunities for further diffusion of such medical devices due to the support for a huge number of connected devices that communicate at high bandwidth and ultra-low latency in addition to robust mobility support (Lema, et al., 2017). Likewise, there are prospects for the proliferation of mobile robotic home assistants such as the Care-O-bot to extend their services to medical ones in the 5G era. This will enable provision of in-home medical care assistance by robots where key features range from health monitoring to basic in-home treatment and provision of emergency healthcare services. Although meant for all ages, such mobile robotic systems can assist individuals who lack mobility (e.g. elderly people and patients with some disabilities) and if connected to the medical network and healthcare practitioners, further opportunities for in-home medical care will arise.

Moreover, with the expected rapid expansion of telemedicine between 2017 and 2023 at an annual rate of 16.5% (Vaidya, 2017), opportunities arise in the 5G era for the application of telepresence, tele-auscultation, teleconsulting and telemonitoring to deliver in-home medical care. With 5G, doctors could be sitting in their clinic or at home while teleconsulting patients located in various parts of the world and benefit from high-definition video streaming within teleconsultation software and video conferencing tools in the 5G era. In this endeavour, reliable diagnostic tools can be promoted by doctors providing remote consultation in order to acquire diagnostic reports at distance. In this endeavour, mobile applications can be helpful. Millions of such applications have been developed for smartphones and tablets since the first appearance of such devices where over 100,000 health-related apps have already been published in platforms including Google Play and Apple App Store. It was also found that one out of five smartphone users have downloaded a medical or health-related app where the most popular ones relate to fitness and diet monitoring (Fox & Duggan, 2012). In the 5G epoch, with further adoption of smart phones in developing countries and rural areas, there are avenues for more mobile applications to address different health issues, languages and diagnostic methodologies. In relevant cases where the patient does not have measurement devices (e.g. blood pressure monitors), alternatives for the use of sensors from mobile devices or mobile applications can be investigated by the research and development community. For instance, mobile application that analyses selfie videos to measure the blood pressure of individuals can be an alternative for patients who do not have blood pressure monitors. Likewise, mobile Augmented Reality (AR) based diagnostic applications can also be utilized at distance and provide healthcare providers with diagnostic reports. Such applications relate to examining different parts of the human body through the camera of mobile phones (to scan details) while providing real-time information on the screen of the same device. For instance, diagnostic AR-based applications could be used to detect optical issues, skin problems and dental concerns, among others. In addition, with a plethora of online platforms for discussions on medical issues, people can exchange experiences pertaining to diagnosis and medical treatment or even seek advices from the community. Due to their usefulness, mobile-based diagnostic tools have started to become part of the professional practice of many medical practitioners and healthcare workers with existing 4G networks, and 5G can bring enhanced communication that will further improve diffusion of such diagnostic tools (West, 2016).

In addition, 5G is expected to make significant contributions in the expansion of medical Internet of Things and Body Area Networks (BANs) towards envisioning *totally connected healthcar*e (Jones & Katzis, 2018). With these technologies, rather than relying for patients to report values such as blood pressure as well as how these values varied temporally, doctors can obtain real-time monitoring data presented in visually attractive forms to help early diagnosis of diseases (Al-Turjman, et al., 2019). These technologies have huge prospects in providing smart healthcare services in the 5G era and have the potential to diagnose various life-threatening diseases through real-time patient monitoring such that timely actions could be taken. With more connected entities in the 5G era, smarter and innovative services could proliferate including automatic ordering and delivery of drugs based on treatment records, crowd sensing for medical supports and home-care assistance.

### 3.2 Medical diagnosis

Early diagnosis of diseases in the 5G era will be facilitated through the use of wearables, implantable medical devices, healthcare monitoring devices, mobile robotic home assistants as well as mobile-based diagnostic tools, as discussed earlier. In addition, two approaches are particularly helpful in medical diagnosis, notably, medical imaging and laboratory tests, which have opportunities to advance further under 5G.

During the previous decades, medical imaging (e.g. X-rays, magnetic resonance imaging (MRI) and computerized tomography (CT) scan) has significantly influenced medical practice whereby improving diagnosis of diseases and treatment (Comaniciu, et al., 2016). Through medical imaging, visual representations of body parts (e.g. organs, bones and tissues) are created and these are utilized for analysis, diagnosis of medical issues and medical intervention. The fifth generation mobile networks enables rapid sharing of diagnostic details and medical imaging whereby creating avenues for developments in remote and cooperative diagnosis. This will enable medical practitioners to send or receive high quality medical images quickly when seeking expertise and second thoughts from doctors practising in a different geographical location. Similarly, patients from rural areas or in developing countries will be able to better communicate their medical diagnoses as well as relevant images to specialists based abroad whereby reducing the need for travel in order to access quality medical support. Through remote collaborative medical diagnosis, medical practitioners are able to benefit from enhanced knowledge as well as increased innovation in practice, and patients are able to benefit from improved quality of diagnosis and treatment (Morley & Cashell, 2017). In addition, a mixed approach involving medical practitioners and machines can reliably improve diagnostic performance. The increase in the use of medical imaging within the 5G era provides opportunities for the application of AI techniques to screen and analyse medical images, while also comparing with previous cases in order to improve detection of medical issues.

Laboratory services are also essential in medical diagnosis whereby providing vital information to medical practitioners following medical tests (e.g. blood test and urine test). With improved connectivity in the 5G era, enhanced interconnectivity between laboratories in different geographical areas can enhance access to a huge number of lab test reports. Value could be generated from these reports through application of data analytics and artificial intelligence. For instance, following a lab test of a patient, results could be compared with the database of reports to identify associations and enhance interpretation of results. The availability of large amount of data is considered beneficial to machine learning algorithms since more training data improves accuracy of results following application of these algorithms (Holzinger, et al., 2015). In addition, platforms and applications for patients to analyse their lab reports could emerge whereby enabling patients to upload their lab reports and obtain support to interpret values as well as medical advices from practitioners.

### 3.3 Medical treatment

Data-driven technologies form the core of the digital health revolution and improved connectivity under 5G era will generate an increased volume and variety of data that can be leveraged to better personalise treatments provided to patients. Exploitation of these data can help to determine the most appropriate or effective treatment to be provided to a patient while considering the various factors related to the patient (e.g. blood group, blood pressure, etc.) and the medical condition being treated. Even if a treatment course has started, AI techniques could be applied to data obtained from health monitoring devices and wearables to further assess the performance of the medication being taken in order to prevent any side effects or to even change medications at an early stage. In other words, the application of data analytics and AI techniques (e.g. machine learning, deep learning and cognitive computing) can find associations between factors investigated while better representing and enabling interpretation of complex medical data. In addition to determining the performance of the treatment to be provided to patients, AI techniques (e.g. linear regression and artificial neural network) can also be used to improve estimations of treatment expenses thereby supporting decision-making by patients and medical practitioners. Moreover, with advances in AI and robotics, the use of robotic prosthetics and bionic body parts are also expected to revolutionise healthcare where neutrally-controlled organs can replace and restore different capabilities of patients who have non-functioning or amputated body parts.

Moreover, medications are essential during treatment and adherence could be followed more effectively by doctors in the 5G era. In order to better guide prescriptions, clinical research databases (e.g. ClinicalTrials.gov) could be utilized by medical practitioners to verify and obtain answers pertaining to drug interactions, risk factors and indicator thresholds, among other factors. Furthermore, the prescription of smart pills or ingestibles enable medical practitioners to remotely monitor whether patients are taking medications correctly, with the proper dose, frequency and timing. When such smart pills are ingested by the patient, essential information about medication adherence are transmitted wirelessly and is accessible by the patient, caregiver or even family members on their smartphones. In case the patient forgets to take medications, such smart systems also enable notifications to be sent. In addition, while various brands of drugs are available on the market, prescription of genuine ones are important. Counterfeit medicines are extremely hazardous for the human organism. In the 5G era, opportunities arise for Blockchain-based applications for medical practitioners to check for counterfeit illegal medicines through the medical logistic chains. Such applications could be utilized during medical consultation when doctors prescribe drugs to patients.

Additionally, continuous professional development is recommended for doctors in order to enable competent practice and this could be achieved by periodically undertaking a range of accredited educational activities to further build key skills and acquire new knowledge on innovative diagnostic techniques and treatments, among others. In addition to online and mobile learning, two cutting-edge technologies that have huge potential in medical training under 5G include AR and VR (Jun & Kim, 2017). Augmented reality has shown prospects to assist in medical training and surgical procedures whereby enabling computer-generated images or 3D models to be overlaid on real-time patient body parts, models or even images of body parts in order to visualize unapparent anatomical details while obtaining key information. In addition to enable visualisation of human anatomical structure, AR has been utilized to teach about 3D lung dynamics and training laparoscopy skills to medical doctors. While AR is commonly used to educate medical professionals whereby simulating critical situations within a safe environment (Botden & Jakimowicz, 2009), its use in medical education can considerably increase attractiveness and engagement during learning of different concepts whereby complementing books with 3D models through which learners can interact with. On the other hand, virtual reality enables user immersion into a computer-generated virtual world where the real-world environment surrounding the user is replaced by a virtual one. Together with the integration of haptics and novel interaction technologies, VR has been utilized in medical education whereby simulating dental, bone, eye and minimally invasive surgeries in the past (Ruthenbeck & Reynolds, 2015). As augmented and virtual reality have started to benefit from data streaming technologies and wireless networks during recent years, bandwidth and latency have been key barriers that inhibit high fidelity telepresence and collaborative applications that implement these technologies (Orlosky, et al., 2017). As such, with massive improvements in bandwidth and latency made possible through 5G, fully-immersive AR and VR applications for medical training will emerge that enable 3D models, videos and information to be retrieved in a timely manner from remote servers for real-time display.

## 3.4 Surgical services

In the 5G era, key developments in surgical services relate to surgical telementoring and remote surgery. In surgical telementoring, real-time guidance and assistance on surgical procedures are provided by an expert surgeon to another practitioner located at a remote location. In this telemedicine concept, assistance provided by the expert surgeon can vary from verbal feedback given when watching a real-time video stream of surgical procedures to even taking control over the procedure through some robotic device such as a robotic arm. In addition to providing care to patients located remotely, surgical telementoring can help professional development of junior practitioners while also fostering networking and collaboration. In the past, surgical telementoring systems were hindered by low transmission speed and latency, where adverse consequences on surgical performance were raised (Fabrlzio, et al., 2000). Even with 4G, a lag time of 0.27 seconds was noted which hampers some real-time features in surgical telementoring (Houser, 2019) as a shorter delay of 0.25 is recommended for more interactive mentoring scenarios within such systems (Lema, et al., 2017). The latency period of just 0.01 seconds in 5G has established a key milestone in telementoring. As such, 5G provides opportunities for a vast number of surgeries to be telementored while also advancing robotic telementoring platforms.

On the other hand, in remote surgery or telesurgery, the entire surgical procedure is controlled by a surgeon from a remote location and the procedure normally involves utilization of robotic systems. Since its first application in medicine in 1985, robots have slowly integrated into operation rooms of many hospitals around the world (Beasley, 2012). Among the surgical robots, the da Vinci Surgical System is considered as the most popular one where over 4000 units have been installed around the world whereby facilitating more than 5 million surgeries using a minimally invasive approach. Throughout the surgical procedure tele-operated by this medical robotic system, a surgeon sits at a special console within the same room as the patient and is able to view the operative field through 3D small cameras while at the same time manipulating surgical instruments attached to robotic arms to perform the surgery. Robotically-assisted surgery have been successful in different medical disciplines including laparoscopy, orthopaedic surgery and neurosurgery. The use of robotic systems within surgery brings different advantages including improved precision, flexibility and control, in addition to remote access to surgical sites (Burgner-Kahrs, et al., 2015). Although during the past decade, there has been some use of surgical robots, 5G provides opportunities for more substantial growth of such robotic systems in order to enhance the benefits of minimally invasive surgery, while also creating avenues for their applications in new types of surgical procedures (Beasley, 2012). For instance, use of surgical robots can be extended such that expert surgeons having specialised robotic consoles within their offices can conduct surgical procedures on patients located in a remote location (e.g. operation room in a different building or even hundreds of miles away within a different hospital). In the past, such types of operations were limited due to the maximum delay of 150 ms that remote tele-surgery can tolerate (Lema, et al., 2017). However, the ultra-low communication delay within 5G addresses this concern where commands from robotic arms and systems can be transmitted smoothly. Furthermore, due to high bandwidth possible with 5G, surgeons operating surgical robots will be able to benefit from high-definition view of the operative field in real-time. These advances in telesurgeries will not only improve access to expert surgeons through reduced travelling needs for performing surgeries, but will also provide surgical services to patients located within rural areas or in developing countries whereby improving collaboration between surgeons.

Furthermore, the surgical world could also benefit from the application of innovative technologies including AR to either train doctors on surgical procedures or to augment body parts of patients during operations by overlaying computer-generated information (e.g. text, images, models and videos of body parts). This technology has been successfully implemented to assist with laparoscopic surgical procedures (Fuchs, et al., 1998), breast-conservative cancer surgery (Sato, et al., 1998) and liver surgery (Hansen, et al., 2010), among others. With 5G, further opportunities will arise pertaining to development and deployment of AR applications to be used during medical education or even within the distinct phases of any surgical procedure (referred as perioperative period) that consist of the preoperative, intraoperative and postoperative phases. For instance, in the preoperative phase, this technology could be used to improve planning of surgical procedures towards diminishing adverse clinical happenings that can affect postoperative outcomes. Even during the intraoperative stage, 3D models can be overlaid on body parts needing surgical procedures to enable surgeons virtually explore, simulate and apply corrective procedures towards guiding operations. Finally, in the postoperative phase, outcomes could be compared with initial stages towards generating reports and even assessing outcomes of surgical procedures.

### 3.5 Emergency services

In emergency cases, race against time is primordial to provide adequate pre-hospital care, transport the patient to the hospital in a timely manner in addition to ensuring the emergency team is prepared for reception and treatment of the patient. In relation to emergency services, widespread deployment 5G is expected to provide various opportunities and benefits (Zhang & Pickwell-Macpherson, 2019). To start with, innovative architectures for emergency healthcare systems involving 5G is expected to emerge that leverage the benefits provided by 5G while interconnecting various components (e.g. stakeholders and other enabling technologies). Instead of waiting for an emergency to occur, advances in health monitoring and diagnostics discussed earlier can help early detection of medical issues so that care could be provided in a timely manner. In other words, information retrieved from wearables and monitoring devices attached to patients can be connected to AI driven early warning systems that can notify the medical team or the nearest medical centre in a timely manner so that emergency actions could follow. In Tele-home-care situations, doctors can even provide medical assistance (e.g. advice or control wearables) while waiting for ambulance and emergency team to reach the site (Oleshchuk & Fensli, 2011). Furthermore, widespread rollout of 5G will foster developments in intelligent transportation systems and this can improve services provided by emergency vehicles (e.g. transporting patients to hospital quicker). Even within ambulances, 5G provides opportunities for additional features including high-definition video communication with medical experts, improved connection with hospital and emergency departments, collection and transmission of observational data within the vehicle to improve diagnosis and even treatment. With early transmission of medical reports from the ambulance itself, the emergency team at the hospital can be better prepared (e.g. preparing operation room or medical devices needed) so as to provide immediate medical care, while also reducing chances for the situation to worsen.

### 3.6 Preventive care

Preventive care is another essential service within healthcare systems and principally involves advising people to prevent potential medical issues in addition to screenings at different levels in order to prevent health-related problems. Motivated by a data-driven healthcare, the application of sophisticated AI-techniques and data analytics is expected to provide incentives in preventive healthcare and early diagnosis of diseases with lesser available symptoms (Ukil, et al., 2016). Due to its essential role in predicting, preventing and managing undesired health conditions, data is a critical resource in the healthcare sector and historically, this sector has been generating huge volume of data. Since data is widely considered as a valuable asset, generating meaningful information from data sourcing from different origins is even more valuable. The rising flood of data to be generated with 5G provides opportunities to big data scientists to determine co-relations, comprehend patterns and analyse trends towards early identification of diseases at different levels (e.g. patient-level and national-level) in order to improve decision-making, enhance care, save lives and lower costs. At the patient-level, predictive modelling techniques could be applied to patient-related data obtained from different sources including wearables and monitoring devices to improve diagnosis and guide prescription of medicines (Clifton, et al., 2013). For example, with GoCap, diabetes patients can automatically log insulin doses and medical practitioners can view the shared logbook in real-time and the data enables early identification of problems and to tweak dosages if needed. Data analytics can even help medical practitioners improve their knowledge and enhance decision making in response to medical emergency following data mining techniques applied to a vast amount of biomedical literature available from books, journals and medical reports, among other documents (Ukil, et al., 2016). Even at a broader level (e.g. in a particular region, country, continent or even globally), data analytics and AI techniques provide opportunities to better profile diseases and identify predictive events (outbreaks, epidemics and pandemics). For example, big data analytics has become an important tool in the fight against influenza where respiratory illnesses related to seasonal flu kill between 291,000 and 646,000 people yearly around the world (WHO, 2018). With over 700,000 flu reports received by the Centres for Disease Control and Prevention (CDC) on a weekly basis that document details on sickness, treatment provided and outcome of treatment, the CDC has created an application called FluView that provides real-time view of how this disease is spreading spatially and temporally. In the same application, information on locations of patients combatting flu is provided as well as remedial information to caregivers (e.g. vaccines and antiviral medications). Likewise, in the 5G era, the explosion in data due to enhanced connectivity provide opportunities for better-informed decision making for a range of medical issues following application of the discussed techniques.

## 4. Challenges of Smart Healthcare and prospective solutions

Even though 5G will bring a massive boost in the digital transformation of healthcare, various challenges can hamper delivery and consumption of the smart and innovative healthcare services discussed earlier. Rather, smart healthcare in the 5G era can experience the phenomenon where potential problems can grow proportionally to the benefits provided by this powerful communication technology.

### 4.1 5G Challenges and deployment issues

Since 5G is a complementary technology and is expected to work together with other communication technologies, smart healthcare solutions will be adversely impacted by their associated limitations as well as deployment issues of 5G. Key 5G issues that need further attention include deployment in dense heterogeneous networks, multiple access techniques as well as full-duplex transmission (Li, et al., 2018). In order to deploy 5G wireless networks, significant investments will be needed to install the required infrastructure (e.g. deploying thousands of new cell sites) as well as to upgrade required software, which could be a challenging process for wireless providers facing financial difficulties. For healthcare solutions to take full advantages of 5G, ubiquitous and reliable coverage is needed. Failure to install a fully-reliable infrastructure by service providers would raise important concerns. Moreover, to take advantage of the technical features of 5G, existing devices utilized for healthcare applications (e.g. smartphones, medical imaging machines and surgical robots) that are not compliant with 5G will need to be replaced if upgrades are not possible and this would be costly for healthcare institutions. As key solution, effective deployment strategies backed up with cost-benefit analyses need to be devised by key stakeholders to better plan key phases until 5G is fully deployed.

### 4.2 Issues with smart devices

As 5G has been designed for mass connectivity to support billions of connected devices, various healthcare-related devices such as wearables and sensors are expected to proliferate at a remarkable rate on the market (Dunn, et al., 2018). It is expected that solution providers and manufacturers of such healthcare devices remain competitive on the market by continuously rethinking their strategies and adopting innovation models. Since these devices are fabricated by different manufacturers, interoperability is a major challenge for systems involving heterogeneous devices that can hinder connection and communication between such devices (Akpakwu, et al., 2017). Heterogeneous devices can also generate ambiguous data thus making it difficult for humans, machines and software agents to process, interpret and integrate in health-related information systems. In case of inaccuracies leading to failure for certain devices to communicate potential medical issues as it should have been, problems regarding liability and responsibility can also arise in case of lack of policies.

Since interoperability issues within heterogeneous systems are principally due to lack of universal standards, standardisation bodies should come up with standards that manufacturers of healthcare devices should adhere to (Ahad, et al., 2019). Until such solutions are devised, manufacturers and developers of smart health devices and systems need to identify interoperability issues at various levels (e.g. in terms of application, devices or communication) and appropriate conversions conducted wherever possible. As a prospective solution to work with and integrate data from heterogeneous devices, manufacturers can provide semantic annotation of the data whereby describing key aspects such as what the data means, their origin, properties and what key fields represent, among others. As for accuracy of results provided, further testing strategies could be adopted by manufacturers to test their products under various conditions. Also, medical practitioners should recommend only devices known to provide results with the highest accuracy. Upon implementation of such standards, suppliers and buyers of these healthcare devices need to ensure that only devices that adhere to these standards are procured and deployed. Platforms that verify adherence to standards as well as authenticity of devices would be helpful in the process. Moreover, regulatory bodies could come up with stronger laws and policies that prevent manufacturing and adoption of counterfeit and sub-standard medical devices.

### 4.3 Software/application related issues

With the benefits provided by 5G, there will be a considerable increase in the number of health-related software (e.g. diagnostic tools and health information systems) as well as mobile applications for use by doctors and patients. The availability of a multitude of tools is challenging in the way that users can be confused about which tool to use where some published applications can also be from untrusted sources. Also, software that have reached the end of their lifetime and that have limited compatibility with devices should also be progressively discontinued in order to avoid associated vulnerabilities.

A growth in the use of automated and intelligent smart healthcare systems are envisaged in the 5G era and proper solutions need to be established to ensure fully resilient and reliable software are being utilized. For instance, in order to reduce time to market or with lack of expertise in the domain, software solutions might not be sufficiently tested and if deployed, the presence of bugs can adversely impact various aspects ranging from reduced accuracy of results to critical failures. In order to address such issues, effective testing strategies can be implemented in addition to comprehensive fault management systems for detection and control of malfunctions in systems such as health information systems (Shladover, 2018). Also, similar to medical devices, software systems within hospitals are typically installed from various vendors giving rise to compatibility issues that can hamper installation, operation and data management (Huyck, et al., 2015). In order to avoid such pitfalls, right from the beginning, medical providers need to ensure that software components are properly designed for smooth integration with existing solutions.

### 4.4 Data-related challenges

With smart healthcare solutions in the 5G era, there will be rapid generation of a huge volume of digital data that also need to be stored. This will make healthcare a key user of big data. With the various aspects related to data in smart healthcare, management and governance are amongst key problems to be dealt with (Kaisler, et al., 2013) and for these, further partnerships will need to be brokered to ensure data-related services are effectively dealt with. In addition, associated challenges will be reflected in terms of the different Vs of big-data, notably, volume, variety, velocity, veracity and value.

Under 5G, voluminous healthcare data will be generated from a variety of sources such as wearables, mobile applications and medical consultation. Storage of an ever-growing amount of data is critical for decision-making pertaining to services such as early disease diagnosis and preventive care. For this, effective data storage strategies are needed that administrate various aspects such as what data is stored, how it is stored, where it is stored, its lifetime and who can access it, among others. Likewise, if proper solutions are not planned beforehand, transportation of data from the storage point to the processing point can be a costly process. This could be avoided by processing the data at the storage location itself and to only transfer results to wherever needed, while also maintaining integrity and provenance of data.

With the integration of multiple health sources towards a connected healthcare, a variety of data (structured, semi-structured and un-structured data) will have to be manipulated. Since the most significant volume of data within healthcare is unstructured, fragmented and rarely standardised (Kruse, et al., 2016), aggregation, storage, processing and analysis will be more challenging. Storage of varying types of data in formats that are incompatible with applications and cutting-edge technologies can lead to interoperability issues, where further efforts are needed for cleansing and processing. In order to address the data variety related issues, metadata protocols as well as semantic models of data integration can be considered (Andreu-Perez, et al., 2015). Another potential solution is standardisation of data, which has its own challenges.

Other key characteristics of big healthcare data include velocity and veracity where velocity relates to the continuous generation of data at a fast speed and veracity is about the conformity to facts and accuracy. Key causes for high velocity in healthcare include high frequency data sources in the form of pervasive sensors as well as social media, in addition to continuous streaming data (e.g. video communication between medical practitioners for telementoring or remote surgeries). For addressing velocity related issues, potential solutions include light-weight processing models and high performance computing. On the other hand, with a large amount of healthcare data available, the accuracy of data reported can be compromised in case of measurement imprecisions, confounding factors as well as inference certitude of outputs. Such inaccuracies in healthcare can lead to imprecisions when diagnosing, providing prescriptions and treatments to patients and can have adverse consequences. In order to address the issue of veracity, causality and uncertainty quantification techniques could be applied to the data. Similarly, self-reported data can be collected in a consistent manner whereby reducing mix-ups (Kruse, et al., 2016).

In order to generate value from the stored data, timely processing and analytics of big data are essential. However, processing of voluminous healthcare data that are stored at various locations can have associated performance issues and introduce delays, thus hampering real-time healthcare and emergency response services. For alleviating performance issues, high-performance or processing intensive systems are recommended, although such systems can be costly to procure and operate. Indexes could also be built right from the beginning while collecting and storing data in order to reduce processing time. Similarly, optimised algorithms and techniques like abstraction into smaller datasets can improve execution time for analytical processing. On the other hand, for big data analytics tools to be successful in smart healthcare, methodological issues still warrant further attention and are hindered by data quality, inconsistencies as well as legal hurdles. In addition, application of big data analytics in smart healthcare necessitate appropriate skill sets and resources, where healthcare professionals working with data will have to improve their knowledge and skills to keep up to date with the fast evolving technologies and techniques. Also, healthcare organisations implementing big data analytics need to be aware of and comply with the various legal issues and standards (Kruse, et al., 2016).

## 4.5 Security and privacy

Security and privacy are major design requirements of smart healthcare solutions under 5G and these will not be without associated challenges (Akpakwu, et al., 2017). Several aspects need to be considered when ensuring security of such solutions in the 5G era to ensure key security objectives including confidentiality, integrity, availability, access control and non-repudiation are catered for. Violation of any of these security objectives can lead to serious consequences whereby even leading to life-threatening situations for patients (Islam, et al., 2015). Furthermore, the amount of medical information gathered on patients including medical diagnosis history, treatments and medical images, among others will increase over time. Due to the sensitive nature of such information, privacy is one of the major challenges smart health solutions can face in the 5G era. Patients need assurances that their health data will not be compromised purposefully by medical service providers and malicious users. Similarly, users of smart health solutions need to know about their associated positive or negative influences whereby ensuring transparency of underlying invisible processes (e.g. operations, data collection and processing as well as any monitoring activities) (Jones, et al., 2015). Likewise, confidentiality of data transmitted between devices to relevant servers should be protected to prevent adversaries from eavesdropping and/or tampering with the medical data. In certain circumstances, ensuring confidentiality of transmitted data will be challenging especially for devices with limited processing capabilities such as sensors, which cannot process strong cryptographic algorithms.

A portion of the security solutions utilized within 4G will progress directly into 5G, whereas others will need re-engineering (Akpakwu, et al., 2017). Moreover, security frameworks and architectures compliant with 5G wireless networks are needed that account for security management involving heterogeneous devices (Fang, et al., 2017). Similarly, to ensure ethical considerations are respected in the development of 5G enabled intelligent systems and environments, frameworks such as eFRIEND could be used by system designers and developers (Jones, et al., 2015). In addition, cutting-edge technologies and data analytics can also improve efficiency and effectiveness in detecting frauds (Kruse, et al., 2016). On the other hand, to warrant privacy of data and communication among various entities in the 5G era, regulations are needed that govern various aspects such as security of data access, location privacy as well as mutual authentication between patients and medical practitioners. Designers of smart health solutions need to emphasise and ensure that all data are safeguarded. In addition, various other approaches such as privacy-aware routing mechanisms, privacy by design and regular security and privacy assessment could be implemented as prospective solutions (Liyanage, et al., 2018).

## 4.6 Issues with cutting-edge technologies

In the 5G epoch, different cutting-edge technologies such as IoT, AI, AR and VR, robotics among others will help to provide smart and innovative healthcare services while also facilitating the coming of higher-level human computer interactions in healthcare. However, some challenges and limitations of each affiliated technology can adversely influence advances of smart healthcare solutions. A few of these challenges along with potential solutions are summarised in Table 1.

**Table 1.** Challenges and potential solutions with cutting-edge technologies.

| Cutting-edge Technology | Challenge | Potential Solution |
|---|---|---|
| Robotics | Robot ethics (delegation of sensitive tasks, blame for a failure and unemployment) | Regulations, legislation developments and strategic planning |
| | Issues pertaining to implementation of robotic systems (e.g. computer vision related issues and) effective detection of failed hardware parts) | Further technological developments in robotics by R&D community and industry, among others. |
| Mobile healthcare applications | Smartphone platform variability (variability and compatibility issues among platforms and mobile operating systems) | Cross-platform application design and development |
| Internet of Things | Working with devices having limited resources and processing capabilities (Li, et al., 2018). | Lightweight algorithms and solutions. |
| Augmented Reality | Object recognition and tracking issues (Chen, et al., 2017):<br>- low sensitivity and tracking accuracy<br>- challenges with varying object sizes, smooth surfaces and variability of lighting conditions<br>- mismatch of virtual and physical distances | Improvements in AR development tools and libraries. |
| | Performance related issues (overheating of device and latency issues with object detection and overlays) | - Enhancements in object detection and overlay methodologies.<br>- Code optimisation. |
| Virtual Reality | Limitations of technological solutions for multi-user settings (Wiederhold & Riva, 2019) | Development of new tools to cater for multi-user collaborative virtual environments. |
| AI Techniques (Machine Learning, Deep Learning, etc.) | Accuracy and validity of records in dataset can influence training process and outputs produced. | Enhanced evaluation metrics to assess accuracy and validity of training and outputs produced |
| | Processing requirements (duration and speed) for real-time and emergency healthcare services. | Use of high performance systems and optimised algorithms. |
| Blockchain | Scalability issues – Blockchain systems become heavy with an increasing number of transactions | - Storage optimisation of Blockchain<br>- Redesigning Blockchain |
| | Selfish mining - Nodes with high computing power could reverse the Blockchain and the transaction that took place. | Strategies to stop selfish mining. |

### 4.7 Acceptance and adoption

Acceptance and adoption of smart health solutions by end-users (patients and doctors) are crucial and can be challenging at the same time. While technology acceptance is an attitude towards a technology, adoption is the process during which a user becomes aware of a technology, embraces it and utilizes the technology. Since adoption and acceptance of such innovative healthcare solutions depend on various factors such as ease of use, attitudes, convenience, perceived usefulness, cost and demographic factors, among others, failure to consider such factors by device designers may adversely impact acceptance and adoption. Ultimately, user engagement is considered as a critical factor when monitoring and treating medical issues and some solutions such as wearables were claimed to limit user engagement and interaction capabilities, which also are key factors that affect user acceptance (Baig, et al., 2017). In addition, innovations in medical solutions having substantial complexity necessitate more technical skills for operation. If appropriate training is not provided, users may struggle when using such solutions whereby leading to various issues, ranging from inducing errors to even causing damage to the solution if it is a piece of hardware (e.g. medical robot). Over time, a group of users can become overly dependent on smart healthcare solutions and to cater for their needs, designers and developers of such solutions need to consider important aspects such as quality of service, robustness, reliability and dependability.

## 5. Conclusions

5G has the potential to bring a massive boost in the digital transformation of healthcare whereby enabling innovations within the various healthcare services such as medical diagnosis, treatment and surgery. This transformation will be facilitated by an assortment of cutting-edge technologies such as robotics, IoT, AI and Big Data, which will be propelled to the next level under 5G. The convergence of these technologies can bring boundless opportunities in terms of smart healthcare solutions towards reducing pressures faced by medical practitioners and providers due to the large number of medical issues that need attention. For instance, delivery of medical care has prospects to be extended from the traditional settings (e.g. in hospital or by private doctors) towards personalised healthcare accessible remotely to patients with the rapid expansion of telemedicine and wearable technologies, among others. In this chapter, the key opportunities that 5G is expected to bring in healthcare services such as medical diagnosis, in-home medical care, treatment surgery, emergency services and preventive care are discussed. On the other hand, various challenges can negatively impact delivery and consumption of the smart and innovative healthcare services in the 5G era, where potential problems can grow proportionally to the benefits provided by this powerful communication technology. These include 5G's own limitations and deployment issues, challenges associated to applications, medical devices, data and cutting-edge technologies as well as security and adoption related hurdles. These challenges are presented as part of this chapter in addition to potential solutions for overcoming these challenges.

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