Jurnal Kejuruteraan 35(3) 2023: 551-556
https://doi.org/10.17576/jkukm-2023-35(3)-02

Review of 5G Wireless Cellular Network on Covid-19 Pandemic: Digital Healthcare & Challenges

Chia Chao Kang*, Yee Heng Teh, Jian Ding Tan, Mohammad Mahdi Ariannejad & Siti Balqis Samdin

[a]*Department of Electrical and Electronics Engineering, School of Electrical and Artificial Intelligence, Xiamen University Malaysia, Sepang, Malaysia*

**Corresponding author: chiachao.kang@xmu.edu.my*

Received 9 September 2022, Received in revised form 4 November 2022
Accepted 14 December 2022, Available online 30 May 2023

ABSTRACT

Since the coronavirus disease (COVID-19) began in 2020, it has changed the way people live such as social life and healthcare. One of the simplest ways to avoid wide spread of the virus is to minimize physical contact and avoid going to a crowded place. Besides that, it also has prompted countries across the world to employ digital technologies such as wireless communication systems to combat this global crisis. Digital healthcare is one of the solutions that play a crucial role to support the healthcare sector in order to prevent and minimize physical contact through telehealth and telemedicine such as monitoring, diagnosis and patient care. 5G network has the potential to advance digital healthcare along with its key technology such as enhanced Mobile Broadband (eMBB), Ultra Reliable and Low Latency Communication (URLLC), and massive Machine Type Communication (mMTC). Despite the benefits of digital healthcare by leveraging the 5G technology, there are still challenges to be overcome such as privacy protection issues, 5G deployment and limited connectivity. In this review, it highlights the relevance and challenges of 5G wireless cellular networks for digital healthcare during the COVID-19 pandemic. It also provides potential solutions and future research areas for researchers on 5G to reduce COVID-19 related health risks.

Keywords: 5G Network; COVID-19; Digital Healthcare; Contact Tracing

INTRODUCTION

COVID-19 due to Severe Acute Respiratory Syndrome Coronavirus 2 (SARSCoV-2) (Lai et al. 2020). This disease has spread throughout the world and brought a lot of negative impacts on economies, healthcare services, social interactions, etc. The surging cases of COVID-19 across the globe have burdened the healthcare sectors such as healthcare waste (Rodzi et al. 2021). The lack of healthcare worker, medical equipment for treating COVID-19 patients and hospital bed capacities is some of the largest challenges that need to be overcome during the COVID-19 pandemic. All these negative impacts have caused people over the globe to change their lifestyles dramatically. COVID-19 outbreak which turns out to become a pandemic due to the virus can be spread easily. According to World Health Organization (WHO), when an infected person cough, sneeze, speak, sing, or breathe, he or she can spread the virus into the air. People around can be infected by inhaling or contacting the aerosols or droplets that contain the virus. Evidence from WHO shows that close interaction between people is the primary path for the virus to be spread. Besides that, poor ventilation or a crowded indoor environment is another way for the virus to spread easily. As such, simple prevention of being infected that could be taken are minimizing physical contact and avoiding going to a crowded place.

Traditionally, healthcare services are delivered physical whereby individuals will meet the clinicians. Nowadays, many industries have transformed due to technological advancements in information and communication technologies or digital and networking. Healthcare services are undergoing digital transformation into so-called, digital healthcare. Digital healthcare is to deliver healthcare to the public digitally. The term digital healthcare covers a wide range of services, applications and products. Telehealth, telemedicine, and contact tracing are examples of digital healthcare. Digital healthcare can be an aid to combat the COVID-19 pandemic as it can deliver healthcare services digitally without any physical contact.

Internet is the key to the advancement and success of digital healthcare. Mobile broadband is one of the ways to connect to the internet. In recent years, countries around the world are rolling out the 5G cellular network and it is transmitted continually for 24 hours using a different transmitter. (Kang et al. 2016). 5G network can be an aid to digital healthcare during the COVID-19 pandemic. Thus, this paper aims to discuss the relevance and challenges of 5G wireless cellular networks for digital healthcare during the COVID-19 pandemic.

5G WiFi is an evolution from the 4G WiFi and it is available everywhere and anytime (Kang et al. 2016). 4G networks face many challenges due to the increasing internet access through intelligent devices and multimedia applications. Therefore, 5G networks are the solution to the challenges faced by 4G networks. Table 1 shows the comparison between 5G and 4G in terms of performance such as area capacity, average data rate and others (Ezhilarasan and Dinakaran, 2017). International Telecommunication Union (ITU) grouped 5G new radio architecture of 2020 into three main categories namely – eMBB, URLLC and mMTC as shown in Table 2 (Erunkulu et al. 2021). eMBB provides high bandwidth and data rates that can support high-resolution and high-quality streaming. URLLC provides ultra-low latency in communication which can support remote real-time operation. The 5G network is built on top of existing technologies such as Massive Multiple Input Multiple Output (MIMO), Software Defined Networking (SDN), Network Function Virtualization (NFV), Multi-access Edge Computing (MEC) and Network Slicing (NS) (Liyanage et al. 2015; Barakabitze et al. 2020; Osseiran et al. 2014). MIMO allows the same radio channel to send and receive multiple data signals simultaneously by using additional transmit and receive antennas. Programmable 5G networks are made possible by SDN and NFV which allows fast deployment and flexible management of 5G services (Siriwardhana et al. 2021; Siriwardhana et al. 2021). MEC provides services and computing functions on edge nodes which makes application services and content closer to users. NS creates logical "slices" on a common infrastructure that enables 5G service providers to build virtual end-to-end networks tailored to application requirements.

TABLE 1. Comparison between 5G and 4G in terms of performance (Ezhilarasan & Dinakaran, 2017)

Key Performance/Mobile Broadband Generation	5G	4G
Network Energy Efficiency (times)	100	1
Area Capacity (Mbps/m^2)	10	0.1
Peak Data Rate (Gbps)	20	1
Average Data Rate (Mbps)	100	10
Spectrum Efficiency (times)	3	1
Mobility (km/h)	500	350
Latency (ms)	1	10
Connection Density (devices/km^2)	10^6	10^3

TABLE 2. Key performances offered in 5G technologies.

5G Technology	5G Key Performance
eMBB	Network Energy Efficiency
	Area Capacity
	Peak Data Rate
	Average Data Rate
	Spectrum Efficiency
eMBB and URLLC	Mobility
URLLC	Latency
mMTC	Connection Density

POTENTIAL USE CASES OF 5G IN DIGITAL HEALTHCARE DURING COVID PANDEMIC

5G network availability shall improve internet accessibility which provides the public with a new way of connecting to the internet. As such, 5G can be a catalyst to digital healthcare for combatting the COVID-19 pandemic by minimizing physical contact between patients and clinicians (Saeed et al. 2020).

TELEHEALTH AND TELEMEDICINE

Telehealth is the use of information, communication and telecommunication technologies to provide remote healthcare services (Dorsey and Topol, 2016). Telehealth can refer to both clinical and non-clinical healthcare, but it most commonly refers to non-clinical healthcare. Examples of non-clinical healthcare services are health education, public health and health administration. Generally, telehealth services can be divided into three categories which are video consults & conferencing, mHealth and remote patient monitoring such as Healthcare 5.0 (Shah et al. 2022). Telemedicine is similar to telehealth, but the scope of telemedicine is specifically narrowed down to only clinical healthcare. Telemedicine can be thought as a subset of telehealth as telehealth refers to a wider scope of remote healthcare services than telemedicine.

The COVID-19 pandemic has enforced schools, institutions and universities to make classes go online. This is not an exception to medical education. Online video conferencing serves as the medium to deliver medical education. An example of medical education is a remote training session broadcast from an academic medical centre to physicians at a provider facility. Patients who only demand consultation from clinicians can make it through online video consultation instead of meeting the clinicians physically. Thus, this can reduce the chance of spreading the virus.

Remote patient monitoring and mHealth can avoid unnecessary visits for healthcare workers and patients. In hospitals, doctors or nurses are required to visit patients to monitor their health. This action will increase the chances of spreading the COVID-19 virus in hospitals. Smart devices such as wearables, mobile phones or sensors can be used to collect data (Poongodi et al. 2019) from patients for health monitoring and forward the collected data to a central server so that healthcare professionals can monitor patient's health without paying a visit to patient rooms (Mahajan et al. 2020). This technique of collecting patients' health data can be extended to remote monitoring in which patients can be monitored remotely from their residence or in a remote facility by healthcare professionals. Besides that, the present state of the electrocardiogram (ECG) system is a non-invasive way to assess the electrical activity and rhythm of the heart that involves placing electrodes on the surface of a human body which connecting them via cables to the ECG monitoring device. Wireless ECG monitoring is now possible via 5G transmission protocols built on wireless sensor networks that provide accurate and real-time monitoring. Other than that, electronic medical records (EMRs) based on the 5G blockchain are another significant application and attractive in digital healthcare that aims to speed up patient information access while enhancing data quality & privacy, scalability and interoperability compared to paper-based records.

Telesurgery is a field that branches out from telemedicine. Telesurgery allows surgeons to perform remote surgical procedures. This technology is useful in combating the COVID-19 pandemic because it isolates the patient and surgeon, reducing the risk of COVID-19 infection. A surgical procedure can be performed with the aid of a robotic mechanism that mimics the surgeon's actions and proper haptic feedback is sent back to the surgeon. Haptic feedback is meant to ensure surgical procedure accuracy by integrating the data collected from sensors at the operating theatre. The other method to perform remote surgery, which is known as telementoring that done by experienced surgeons remotely guiding surgeons on the patient's side to perform the surgery. Virtual reality can enhance the telementoring process as it allows the guiding surgeons to have a proper visual on the entire operation. A pilot study on real-time telementoring involving an orthopedic surgeon guiding four physicians through leg fasciotomies. It has been determined that surgical telementoring is feasible and has been successfully used in two distinct patients, enabling two-incision leg fasciotomies to be carried out in a remote setting. (Talbot, 2017). A case report from (Lacy et al. 2019) has demonstrated that laparoscopic high and low anterior resections can be performed using telementoring.

POTENTIAL OF 5G IN TELEHEALTH AND TELEMEDICINE

5G networks offer mMTC service which allows heterogeneous IoT integration into the network without any gateway. 5G has a millimeter wave spectrum that is radiated by the communication system (Chao et al. 2014) which means it can deploy ultra-dense small cell networks that could cover the indoor environment. Merging the existing technology such as massive MIMO and beamforming could provide high data rates for more users. These technologies lead to better localization for the indoor environments (Palacious, 2019) which is essential for the realization of mHealth and remote patient monitoring in smart hospitals that have 5G connectivity (De Silva et al. 2022). 5G networks can support an average data rate of 100 Mb/s through its eMBB service. This would allow smoother video streaming for video consultation and video conferencing. A German study shows that a 5G network can achieve the minimum requirements for data volume, rate and latency for video transmission during telesurgery (Jell et al. 2019). Latency is one of the most important factors for telesurgery as telesurgery is a real-time operation that has tolerance to low latency. URLLC offered by 5G network can reduce the latency to an acceptable level. Local 5G operators can deploy core and access networks within hospital premises to achieve ultra-low latency within the hospital which is beneficial for telesurgery within the hospital.

CONTACT TRACING AND SELF-ISOLATION

The purpose of contact tracing is to isolate people who were recently identified as in close contact with COVID-19 infected individuals. By doing so, the spread of the virus can be reduced. Manual contact tracing is ineffective as cross-checking the data manually is time-consuming and prone to human errors. Besides that, manual systems for controlling the spread of COVID-19 deeply depend on patients' collaboration in reporting their recent closed contacts. In fact, contact tracing does appear in public health procedures before the COVID-19 pandemic, but it was not automated or partly automated through data collection from smartphones or other smart devices (Braithwaite, 2020). The such tracing concept is indeed digital contact tracing.

Digital contact tracing can mitigate the ineffectiveness of manual contact tracing by collecting mobile smartphone/smart device users' data and analyze using computational methods. Bluetooth Low Energy (BLE) based is an automated contact tracing strategy. A BLE-based device can be either smartphone or another smart device such as wearables that utilize a gyroscope (Mohamed et al. 2022). BLE-based solutions in contact tracing work by identifying close infected contacts in the range of a few meters. This can be done through periodic advertisements with unique IDs and compatible devices within range that can capture and store important information such as timestamps or GPS location data. Identifying close contact within a few meters is the biggest advantage of the BLE-based solution over GPS-based solution as a GPS-based solution could not identify close contact within a few meters (Sattler, 2020). Mobile contact tracing applications can issue self-isolation

instructions to people who have been in close contact with an infected individual recently. The application can collect location data from people who have been identified and called for self-isolation to make sure they are not violating self-isolation guidelines.

POTENTIAL OF 5G IN CONTACT TRACING

The main potential of using 5G in contact tracing is that 5G can cater massive connections from IoT devices to collect users' location history. 5G-enabled IoT devices can connect to the 5G network using mMTC services which can improve the efficiency of contact tracing applications. Furthermore, 5G network for mMTC provides a longer battery lifecycle for low-power IoT devices.

CHALLENGES OF DIGITAL HEALTHCARE

Despite the benefits that digital healthcare could bring to the public, privacy is one of the challenges that need to be overcome. Patients often disclose personal information to the doctor that they would not like to share with others. Such information may be leaked to outside parties who maliciously observe the video consultation session (Wrape and McGinn, 2018). Telehealth practitioners are recommended to protect patient's personal information through encryption, enable protections against adware & malware and set up strong firewalls (Barnett, 2019).

Threats to data privacy in mobile applications are profiteering (Parker et al. 2019). Mobile application companies are frequently collecting data from users such as behaviours, usernames, passwords, contact information, age, gender, location, International Mobile Equipment Identity (IMET) and phone numbers. These data could be misused by selling to third-party advertisers (Martinez-Martin & Kreitmair, 2018) which is a serious privacy violation (Hall and McGraw, 2014). As such, digital health mobile application is encouraged to use minimum protected health information, acknowledge limits of confidentiality to users, and minimize disclosures within mobile applications (Karcher and Presser, 2016).

Apart from privacy concerns over digital healthcare, security is another issue that needs to be addressed in digital healthcare. Since that digital health in 5G will adopt a large number of IoT-based systems, the vulnerability of IoT-based system needs be addressed. IoT-based systems are prone to denial-of-service attacks, structured query language injection, spoofing, eavesdropping and replay attacks. These attacks and security breaches can affect security applications, authorization, authenticity and privacy (Hong, 2019). Electronic health records and patient health records are always targeted by data hackers. Electronic health record data has become easier to breach through the advancement in the digital healthcare system (Idrees et al. 2021). Thus, researchers have been investigating the use of blockchain technology in digital healthcare. Blockchain is a type of distributed ledger that defines a decentralized trust-less security model which in contrast to the centralized healthcare system being used nowadays. In theory, blockchain technology is promising in securing and protecting digital data. However, choosing the right type of blockchain for medical data sharing is important and there are existing problems in blockchain-based medical data management to be overcome (Jin et al. 2019).

CHALLENGES OF 5G NETWORKS

Telecommunication networks have evolved into IP-based open architecture since 4G Long Term Evolution (LTE). 5G networks are adopting the same architecture which leads to more vulnerabilities to a full range of IP and web-based attacks including hacking (Liyanage et al. 2018). In 5G networks, edge computing is introduced by setting up multiple base stations to process user data. The role of the base stations can be an intermediary to transport data or serve as a small local server. The implementation of edge computing is creating more opportunities for hackers as there are many base stations acting as a server rather than central servers.

Quantum Key Distribution (QKD) is one of the promising solutions to security threats in 5G networks. QKD can generate unpredictable random numbers for cryptographic keys based on the behaviours of subatomic particles like electrons and photons (Abellan and Pruneri, 2018). This can greatly enhance the security of 5G network as cracking the cryptographic keys based on QKD is impractical. In South Korea, Samsung Electronics collaborate with SK Telecom to build smartphones (Lee, 2007) that embed with a quantum random number generator that can generate random quantum keys for SK Telecom users to make mobile payments and other verification services safely. Quantum technology in network security may not be reaching global consumers so soon, but it seems to be playing an important role in the future of 5G network security. Table 3 shows the summary of 5G challenges for digital healthcare.

TABLE 3. Summary of 5G challenges for digital healthcare

Case	Challenges faced	Authors and year
Telemedicine	Follow up visit of patient require low latency 4k/8k video streaming	Hossain, M.S., 2020
Telehealth	Lacked of resources (i.e: hospital capacity high demand, new guidelines imposed by authorities) due to existing COVID-19	Anthony Jnr. 2021
Data Privacy	Information may leak to outside parties	Hall and McGraw, 2014
Security	Prone to denial-of-service attack	Hong, 2019
Contact Tracing	Ineffectiveness of manual contact tracing by collecting mobile smartphone/smart device user's data	Soldano, G.J, 2021

CONCLUSION

Healthcare workers are at high risk of contact with the COVID-19 virus. Protection and prevention of the COVID-19 virus are required to support the health of workers and to prevent the tumble of healthcare system. Digital healthcare such as telehealth and telemedicine provide a great solution for isolating individuals and thus, minimizing physical contact. Contact tracing and self-isolation can control the spread of the virus. 5G technology such as eMBB, URLLC, and mMTC are the keys to realize the evolution of digital healthcare. The benefits of digital healthcare leveraging the 5G technology in combatting COVID-19 pandemic are promising, but there are challenges for both 5G and digital healthcare to overcome. In the post-pandemic of COVID-19, digital healthcare is encouraged to be continued in practice as it can improve the quality of healthcare services, improve population health and overall healthcare efficiency.

ACKNOWLEDGEMENT

The author gratefully acknowledges financial support by Malaysian Ministry of Higher Education under Fundamental Research Grant Scheme: FRGS/1/2022/TK08/XMU/02/10 and Xiamen University Malaysia under Research Fund Grant No: XMUMRF/2021-C7/IECE/0018.

DECLARATION OF COMPETING INTEREST

None

REFERENCES

Abellan, C. & Pruneri, V. 2018. The future of cybersecurity is quantum. *IEEE Spectrum* 55(7): 30-35.

Anthony Jnr, B. 2021. Implications of telehealth and digital care solutions during COVID-19 pandemic: A qualitative literature review. *Informatics for Health and Social Care* 46(1): 68-83.

Barakabitze, A. A., Ahmad, A., Mijumbi, R., & Hines, A. 2020. 5G network slicing using SDN and NFV: A survey of taxonomy, architectures and future challenges. *Computer Networks* 167: 106984.

Barnett, J. E. 2019. The Ethical Practice of psychotherapy: Clearly within our reach. *Psychotherapy* 56(4): 431–440.

Braithwaite, I., Callender, T., Bullock, M., & Aldridge, R. W. 2020. Automated and partly automated contact tracing: A systematic review to inform the control of covid-19. *The Lancet Digital Health* 2(11): 607-621.

Chao K.C., Ain, M.F. & Zubir, I.A. 2014. Modeling and simulation using circular spiral antenna array for RF harvesting. *IOSR Journal of Electronics and Communication Engineering*: 2278-8735.

De Silva, R., Siriwardhana, Y., Samarasinghe, T., Liyanage, M. & Ylianttila, M. 2022. Deployment Options of 5G Network Slicing for Smart Healthcare. *19th IEEE Annual Consumer Communications & Networking Conference* 749-750

Dorsey, E. R. & Topol, E. J. 2016. State of Telehealth. *New England Journal of Medicine* 375(2): 154–161.

Erunkulu, Zungeru, A. M., Lebekwe, C. K., Mosalaosi, M.& Chuma, J. M. 2021. 5G Mobile Communication Applications: A Survey and Comparison of Use Cases. *IEEE Access* 9: 97251-97295.

Ezhilarasan, E. & Dinakaran, M. 2017. A Review on Mobile Technologies: 3G, 4G and 5G. *2017 Second International Conference on Recent Trends and Challenges in Computational Models (ICRTCCM)* 369-373.

Hall, J. L. & McGraw, D. 2014. For telehealth to succeed, privacy and security risks must be identified and addressed. *Health Affairs* 33(2): 216–221.

Hong, S. 2019. Security Vulnerability and Countermeasure on 5G Networks: Survey. *Journal of Digital Convergence* 17(12): 197–202.

Hossain, M.S., Muhammad, G. & Guizani, N. 2020. Explainable AI and mass surveillance system-based healthcare framework to combat COVID-I9 like pandemics. *IEEE Network* 34(4): 126-132.

Idrees, S. M., Nowostawski, M., Jameel, R. & Mourya, A. K. 2021. Security aspects of blockchain technology intended for industrial applications. *Electronics* 10(8): 951.

Jell, A. *et al.* 2019. 5th-Generation Mobile Communication: Data Highway for Surgery 4.0. *Surgical Technology International* 10(35): 36-42.

Jin, H., Luo, Y., Li, P. & Mathew, J. 2019. A Review of Secure and Privacy-Preserving Medical Data Sharing. *IEEE Access*, 7: 61656-61669.

Kang. C.C., Mohd F. A., Ali MJ. Z. & Ihsan A. Z. 2017. Lumped element equivalent circuit modelling for RF energy harvesting antenna array. 9th International Conference on Robotic, Vision, Signal Processing and Power Applications, *Springer*, 455-461.

Karcher, N. R. & Presser, N. R. 2016. Ethical and legal issues addressing the use of Mobile Health (mHealth) as an adjunct to psychotherapy. *Ethics & Behavior* 28(1): 1–22.

Kang C.C., Ain, M.F., Jaafar, A.M. & Marzuki, A., 2016. Corporate feed with dual segment circular polarized array rectenna for low power RF energy harvesting. *Journal of Engineering Science and Technology* 11(6): 796-805.

Lacy, A. M., Bravo, R., Otero-Piñeiro, A. M., Pena, R., De Lacy, F. B., Menchaca, R. & Balibrea, J. M. 2019. 5G-assisted telementored surgery. *British Journal of Surgery* 106(12): 1576–1579.

Lai, C. C., Shih, T. P., Ko, W. C., Tang, H. J., & Hsueh, P. R. 2020. Severe acute respiratory syndrome coronavirus 2 (SARS-COV-2) and coronavirus disease-2019 (COVID-19): The epidemic and the challenges. *International Journal of Antimicrobial Agents* 55(3): 105924.

Lee, I., 2007. Successful Innovation of the Korean Mobile Communications Industry and SK Telecom's Role. SK Telecom Report.

Liyanage, M., Gurtov, A., & Ylianttila, M. 2015. *Software defined mobile networks (SDMN) - beyond LTE network architecture*. John Wiley & Sons Incorporated.

Liyanage, M., Salo, J., Braeken, A., Kumar, T., Seneviratne, S. & Ylianttila, M. 2018. 5G Privacy: Scenarios and Solutions, *2018 IEEE 5G World Forum (5GWF)* 197-203.

Mahajan, A., Pottie, G., & Kaiser, W. 2020. Transformation in healthcare by wearable devices for diagnostics and guidance of treatment. *ACM Transactions on Computing for Healthcare* 1(1): 1–12.

Martinez-Martin, N. & Kreitmair, K. 2018. Ethical issues for direct-to-consumer digital psychotherapy apps: Addressing accountability, Data Protection, and Consent. *JMIR Mental Health* 5(2).

Mohamed, N.A., Zulkifley, M.A., Kamari, N.A.M. & Kadim, Z., 2022. Symmetrically Stacked Long Short-Term Memory Networks for Fall Event Recognition Using Compact Convolutional Neural Networks-Based Tracker. *Symmetry* 14(2): 293.

Osseiran, A. *et al*. 2014. Scenarios for 5G mobile and wireless communications: the vision of the METIS project. *IEEE Communications Magazine* 52(5): 26-35.

Palacios, J., Bielsa, G., Casari, P. & Widmer, J. 2019. Single- and Multiple-Access Point Indoor Localization for Millimeter-Wave Networks. *IEEE Transactions on Wireless Communications* 18(3): 1927-1942.

Parker, L., Halter, V., Karliychuk, T. & Grundy, Q. 2019. How private is your mental health app data an empirical study of mental health app privacy policies and practices. *International Journal of Law and Psychiatry* 64: 198–204.

Poongodi, T., Krishnamurthi, R., Indrakumari, R., Suresh, P., & Balusamy, B. 2019. Wearable devices and IOT, *A Handbook of Internet of Things in Biomedical and Cyber Physical System* 245–273.

Rodzi, R.M., Nopiah, Z.M. & Basri, N.E.A., 2021. General Scenario of COVID-19 Pandemic Waste Management in Malaysia: A Review. *Jurnal Kejuruteraa*n 817-830.

Sattler, F., Ma, J., Wagner, P., Neumann, D., Wenzel, M., Schäfer, R., Samek, W., Müller, K. R. & Wiegand, T. 2020. Risk estimation of SARS-COV-2 transmission from Bluetooth Low Energy Measurements. *Digital Medicine* 3(1): 1-4.

Saeed, N., Bader, A., Al-Naffouri, T. Y. & Alouini, M. –S. 2020. When wireless communication responds to covid-19: Combating the pandemic and saving the economy. *Frontiers in Communications and Networks* 1.

Shah, S.H.A., Koundal, D., Sai, V. & Rani, S. 2022. Guest Editorial: Special Section on 5G Edge Computing-Enabled Internet of Medical Things. *IEEE Transactions on Industrial Informatics* 18(12): 8860-8863.

Siriwardhana, Y., De Alwis, C., Gur, G., Ylianttila, M., & Liyanage, M. 2020. The Fight Against the COVID-19 Pandemic With 5G Technologies. *IEEE Engineering Management Review* 48(3): 72-84.

Siriwardhana, Y., Gur, G., Ylianttila, M., & Liyanage, M. 2021. The role of 5G for digital healthcare against COVID-19 pandemic: Opportunities and challenges. *ICT Express* 7(2):244–252.

Soldano, G.J., Fraire, J.A., Finochietto, J.M. & Quiroga, R. 2021. COVID-19 mitigation by digital contact tracing and contact prevention (app-based social exposure warnings). *Scientific Reports* 11(1):1-8.

Talbot, M., Harvey, E. J., Berry, G. K., Reindl, R., Tien, H., Stinner, D. J., & Slobogean, G. 2017. A pilot study of surgical telementoring for leg fasciotomy. *Journal of the Royal Army Medical Corps* 164(2): 83–86.

Wrape, E., & McGinn, M. M. (2018). Clinical and ethical considerations for delivering couple and family therapy via Telehealth. *Journal of Marital and Family Therapy* 45(2): 296–308.