The Fight against the COVID-19 Pandemic with 5G Technologies

Yushan Siriwardhana, *Student Member, IEEE,* Chamitha de Alwis, *Member, IEEE,* Gürkan Gür, *Senior Member, IEEE,* Mika Ylianttila *Senior Member, IEEE,* and Madhusanka Liyanage, *Senior Member, IEEE*

***Index Terms*—5G, IoT, COVID-19, Healthcare, Pandemic**

***Abstract*—The COVID-19 pandemic has affected the world in an unexpected manner. The human race is battling against the pandemic while schools, universities, industries, hospitals and governments are seeking new methods and technologies to seamlessly continue their usual operations. In response, this paper presents how 5G and IoT (Internet of Things) related technologies can be efficiently utilized and developed to fight against the COVID-19 pandemic. Several use-cases on how 5G and IoT can be enablers to provide innovative solutions in the areas of telehealth, contact tracing, education, retail and supply chains, e-government/ remote office/ information sharing, smart manufacturing and factory automation, e-tourism and entertainment are presented along with their technical requirements and challenges. It is envisaged that the proposed solutions will be instrumental to facilitate the usual lifestyle, work and other day-to-day activities of humans in the post-pandemic world.**

I. Introduction

The spread of Coronavirus Disease (COVID-19) due to Severe Acute Respiratory Syndrome Coronavirus 2 (SARS-CoV-2) virus [1], caused substantial changes in the lifestyle of communities globally. By mid August 2020, over twenty million positive cases in total were identified affecting more than 180 countries and resulting over 750,000 deaths. World Health Organization (WHO) declared COVID-19 as a pandemic due to its alarming level of global spread. Healthcare sectors of the countries were affected immediately, urging governments to take immediate control actions, such as isolating highly affected regions, ceasing the cross border traffic between countries, closing the schools, workplaces, and common places, restricting the movements of general public by advising them to stay at home as much as possible. These control actions had a significant impact on the social life and the economies. Presently, countries are putting their strategies into action to return to the regular lives step by step. However, many countries still have unresolved COVID-19 cases, and report new cases in a daily basis. Therefore, governments must ensure that the "re-opening" will not result in a "re-emergence" of COVID-19 disease.

Under the prevailing conditions and in a post COVID-19 world, societies face numerous challenges in different sectors including healthcare, education, manufacturing, supply chain management, service delivery, travel and tourism. For instance, overload of healthcare facilities due to exponential increase of COVID-19 patients and inability to provide regular patients with medical assistance due to restricted movements are important obstacles for the healthcare sector's battle against COVID-19. Similarly, delays and the increased resource requirement for manual contact tracing, and unavailability of efficient and automated contact tracing applications hinder the actions for controlling the spread. It is the duty of multiple parties including engineers, technology managers, healthcare workers, government authorities, students, researchers and the general public to act with their fullest potential to control the prevailing situation. Digitalization and the application of information and communication technologies will be imperative to not only to safeguard, but also to manage the post COVID-19 world. The novel technologies such as Artificial Intelligence (AI), Big Data, 5G communications, cloud computing and blockchain can play a vital role to facilitate the environment fostering protection and improvement of people and economies. To implement these promising solutions and realize their benefits, technology and engineering managers will have to tackle important challenges and carry out elaborate managerial duties regarding cost, scope, quality, resource and risk management. The wide spectrum of challenges due to COVID-19 under each sector that can be addressed using 5G based solutions are explained in Table I.

5G wireless communication networks are a paradigm shift from the present 4G networks which will be highly instrumental to provide universal high-rate coverage and a seamless user experience. The Mobile and wireless communication Enablers for the 2020 Information Society (METIS) project [9] has come up with 5G requirements leading to the following technical objectives compared to 4G and shown in Figure 1:

- 1000x higher mobile data volume per area;
- 10x-to-100x higher number of connected devices;
- 10x-to-100x higher user data rate;
- 10x longer battery life for low power massive machine communications

Yushan Siriwardhana and Mika Ylianttila are with the Center for Wireless Communications, University of Oulu, Finland. e-mail: {firstname.lastname}@oulu.fi

Chamitha de Alwis is with the University of Sri Jayewardenepura, Sri Lanka. e-mail: chamitha@sjp.ac.lk

Gürkan Gür is with the Zurich University of Applied Sciences, Winterthur, Switzerland. e-mail: gueu@zhaw.ch

Madhusanka Liyanage is with the School of Computer Science, University College Dublin, Ireland and the Center for Wireless Communications, University of Oulu, Finland. e-mail:madhusanka@ucd.ie

This work is partly supported by European Union in RESPONSE 5G (Grant No: 789658), Academy of Finland in 6Genesis (Grant no. 318927) and Secure Connect (Grant No. 296693) projects.

The research leading to these results partly received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement no 871808 (5G PPP project INSPIRE-5Gplus), . The paper reflects only the authors' views. The Commission is not responsible for any use that may be made of the information it contains.

TABLE I
CHALLENGES OF COVID-19 ADDRESSABLE VIA 5G BASED SOLUTIONS [2]–[7]

Challenges	Description	Possible Solutions	5G Use Case(s)
Impact on healthcare	Due to rapid increment of COVID-19 patients, the capacity of healthcare facilities gets overwhelmed within days and there will be no space to treat new patients.	Remote examinations and treatments	Telehealth
	Medical staff has to be protected while treating to COVID-19 patients to avoid getting infected.	AR based treatment, remote surgery, deployment of robots for patient care	Telehealth
	Regular patients should be protected by isolating the COVID-19 patients or limiting the visits of regular patients to the healthcare facilities	Remote clinical services for regular patients	Telehealth
	Mobile treatment mechanisms face difficulties to cope with the increasing number of patients due to limited manpower and travel restrictions.	Remote examinations and treatments	Telehealth
Not capable of performing contact tracing quickly and accurately	Once a COVID-19 patient is identified, all the close contacts of the patient should be traced and isolated to prevent further spread of the disease. Present contact tracing mechanisms involve significant human engagement and consist a lot of manual tracing of contacts. This needs more time, prevents the identification of all the possible close contacts and hinders the effectiveness of the contact tracing activity.	BLE (Bluetooth Low Energy) based contact tracing using mobiles and wearables, GPS based tracing, mobile phone based tracing	Contact Tracing
Monitor the compliance of self-isolation	The self-isolating individuals should be monitored to ensure they are following the guidelines. No proper automated mechanism exists presently	GPS based, mobile device based tracking, UAV based monitoring	Self Isolation
Impact on education	To enforce social distancing and protect the young generations, almost all the governments temporary closed down schools and universities. As a result, lectures, exams and graduation dates are getting delayed	Remote, web based education and online examinations	Online Education
Supply chain issues	A surge in demand was created for certain medical items such as sanitizers, face masks, Personal Protective Equipment (PPE) and ventilators. Due to the inefficinet supply chain management, such items may not reach the required personals. Moreover, vendors try to control the supply such items to create an maintain an artificial high price. Moreover, day-to-day items such as sanitary items and food can also become scarce due to panic buying.	IoT based supply chain management, Blockchain based solutions	Retail and Supply Chains
Online shopping, delivery and payments	Due to travel restrictions, there is a surge in demand for online shopping for food, groceries and other essential items. It is also challenging to deliver these items. First with limited manpower, second, without physical contact when it comes to the collection of payments	UAV based delivery of goods, contactless payment such as NFC payments	Retail and Supply Chains
Impact on manufacturing	The increased demand of medical supplies and vaccines overwhelms the capabilities of existing factory setting. In addition, social distancing rules will further limit the available manpower at the factories.	Factory Automation, deployment of robots	Smart Manufacturing and Factory Automation
	Some companies have to outsource their production to third parties in different countries. In such cases, the end to end production process should be continuously monitored and regulated to maintain the required product quality	Use of IIoTs for monitoring, Blockchain based solutions	Smart Manufacturing and Factory Automation
Government service delivery	Governments must continue providing essential services such as birth, marriage and death registrations, salary payments, public safety operations regardless of lock-downs. Such service offering is challenging with limited manpower availability due to social distancing rules and outdated extensive procedures	E-services by governments, online payments and invoicing, remote working, mobile services	E-government and Media
Impact on tourism	Most countries have closed the borders and enforced travel bans even within the country. Due to this, travelling and tourism activities are stopped	AR/VR based E-tourism, holograms	E-tourism
Consequences due to travel restriction, mental health issues	The outbreak of pandemic becomes stressful for many people which may lead to serious mental issues. Difficulties to face with new realities such as temporary unemployment or working from home situation, home-schooling of children and lack of physical meetup with friends and families can be overwhelming for many people. People do not get the opportunity to meet their friends and families for an extended period. In addition, adults and children get stressed due the fear of contracting the virus. The containment for house environment for an extended period time with travel restriction may feel restless and anxious	Internet, multimedia services, online movies, video chat and calls, online gaming, holograms	Entertainment

- 10x reduced E2E latency.

5G will mainly support three service classes i.e. enhanced Mobile BroadBand (eMBB), Ultra Reliable and Low Latency Communication (URLLC) and massive Machine Type Communication (mMTC) [10], [11]. eMBB is responsible for providing high bandwidth, high data rates for the 5G users supporting high resolution streaming services, high quality interactive videos. URLLC is responsible for the provision of ultra-low latency services such as Vehicle-to-Vehicle (V2V) communication, remote surgery. mMTC focuses on the massive connectivity of entities including but not limited to humans, sensors, computers, cloud, vehicles, UAVs. The novel 5G networks will be built on key technologies such as Software-Defined Networking (SDN), Network Function Virtualization (NFV), Multi-access Edge Computing (MEC), Network Slicing (NS), Multiple Input Multiple Output (MIMO) systems, and New Radio (NR) [12], [13]. SDN and NFV enable programmable 5G networks to support the fast deployment and flexible management of 5G services. MEC extends the intelligence to the edge of the radio network along with higher processing and storage capabilities. NS creates logical networks on a common infrastructure to enable

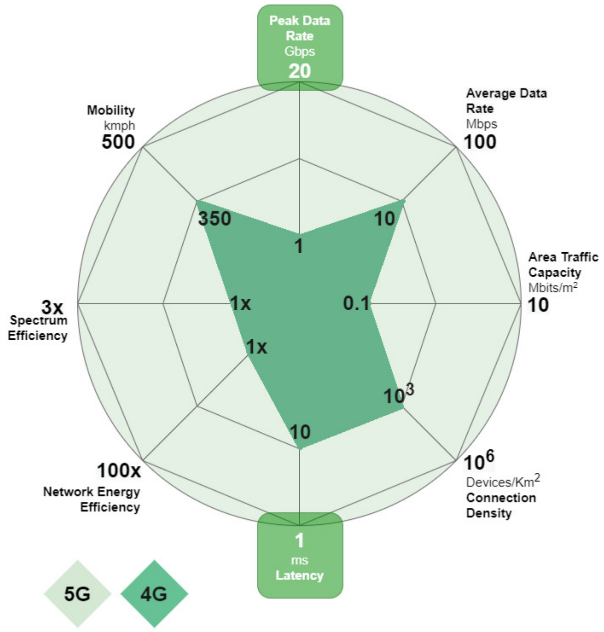

Fig. 1. 5G performance goals [8]

different types of services with 5G networks. MIMO multiplies the capacity of a radio link using multiple transmission and receiving antennas to exploit multipath propagation. NR is a new radio access technology developed by 3GPP for the 5G mobile network.

5G will also provide massive connectivity for the Internet of Things (IoT) which is the collection of heterogeneous physical devices connected to the internet which interact and corporate with each other to collect and share data using different technologies, enabling the development of a plethora of digital services. These devices include but not limited to sensors, actuators, mobile devices, wearables. Application requirements and the device capabilities decide the technologies to be used in IoT based solutions. Examples include low power technologies like Bluetooth Low Energy (BLE), Radio Frequency Identification (RFID), Near Field Communication (NFC), ZigBee, LoRa, NB-IoT.

II. COVID-19 Use Cases for 5G

This section elaborates on 5G based use cases of different sectors as depicted in Figure 2, which could be used to manage the post COVID-19 era. In the post COVID-19 era, restrictions of public movements may still be in place and governments/authorities will recommend utilizing remote solutions to maintain the social distancing. Existing services should be tailored to cater future needs while developing novel solutions to address the specific issues originated with the pandemic. Since 5G plays a major in providing remote solutions, the paper discusses how different elements in 5G technology can be effectively utilized in developing solutions in a post COVID-19 era. Technical requirements of the use-cases are presented in Table II. The table presents relevant 5G applications, expected capacity and latency to deliver a smooth service, number of devices that shall be used and other technical requirements. However, satisfying these requirements to seamlessly provide the services impose a new set of challenges as discussed in Section III.

A. Telehealth

Remote patient monitoring allows healthcare professionals to monitor conditions of patients at their residence or in a remote facility. Data gathered from different sources such as wearable devices attached to the patient's body [14], patient's own smart mobile device and sensors placed in the patient's room can be used for monitoring. The aggregated data from different sources is examined by the healthcare professional to make a judgement on the patient's condition and take relevant actions. Telemedicine provides remote clinical services to patients with the use of high-quality audio and video streams. Remote surgery is extremely useful in a pandemic which enables a surgeon to perform surgical procedures from a remote facility with his surgical console. Actions of the surgeon are replicated on a patient residing in a different location. A robotic mechanism executes the surgical procedure on the patient and proper haptic feedback is sent back to the surgeon. The feedback can be enhanced by integrating the data from different sensors at the operating theatre to ensure the accuracy. Augmented Reality (AR) technology is useful in telesurgery where experienced surgeons guide other surgeons who perform the surgery next to the patient. Robots deployed at the hospitals minimize the human involvement in treating the hospitalized patients, distributing essential items, performing periodic monitoring. AR technology can be utilized to increase the productivity of the service by providing remote guidance.

Role of 5G: 5G enables direct integration of heterogeneous IoT devices into the network via mMTC service, without WiFi or additional IoT gateways. It also supports 10x longer battery life for devices in mMTC and 100x higher device density. Since the remote monitoring of patients requires integration of various low power devices, 5G services can be effectively utilized to build a proper remote monitoring infrastructure for patients. A remote clinical service (telemedicine) which requires 4K video streaming at 25 fps (frames per second) needs a data rate of 8-16 Mpbs. This is realizable with 5G networks via eMBB which supports an average data rate of 100 Mbps. A Local 5G Operator (L5GO) deployment at the healthcare premise is suitable for catering URLLC use case like remote surgery. The ultra-low End-to-End (E2E) latency requirement of a use case like remote surgery [15] is achievable with 5G networks making the application viable. An AR assisted telesurgery require both high bandwidth and ultra-low latency. To avoid cyber-sickness of AR communication, E2E latency should be less than 50 ms [16]. Defining a network slice for AR ensures the service levels and adds extra privacy and security to the data stream. Utilizing robots to assist the patients in hospitals requires precise coordination with a controlling server and between robots, calling for mMTC services of 5G. The coordination and communication between robots happen locally and exact details are mostly irrelevant beyond the premises. Establishing a MEC server to manage the robots guarantees the service levels, provides ultra-low

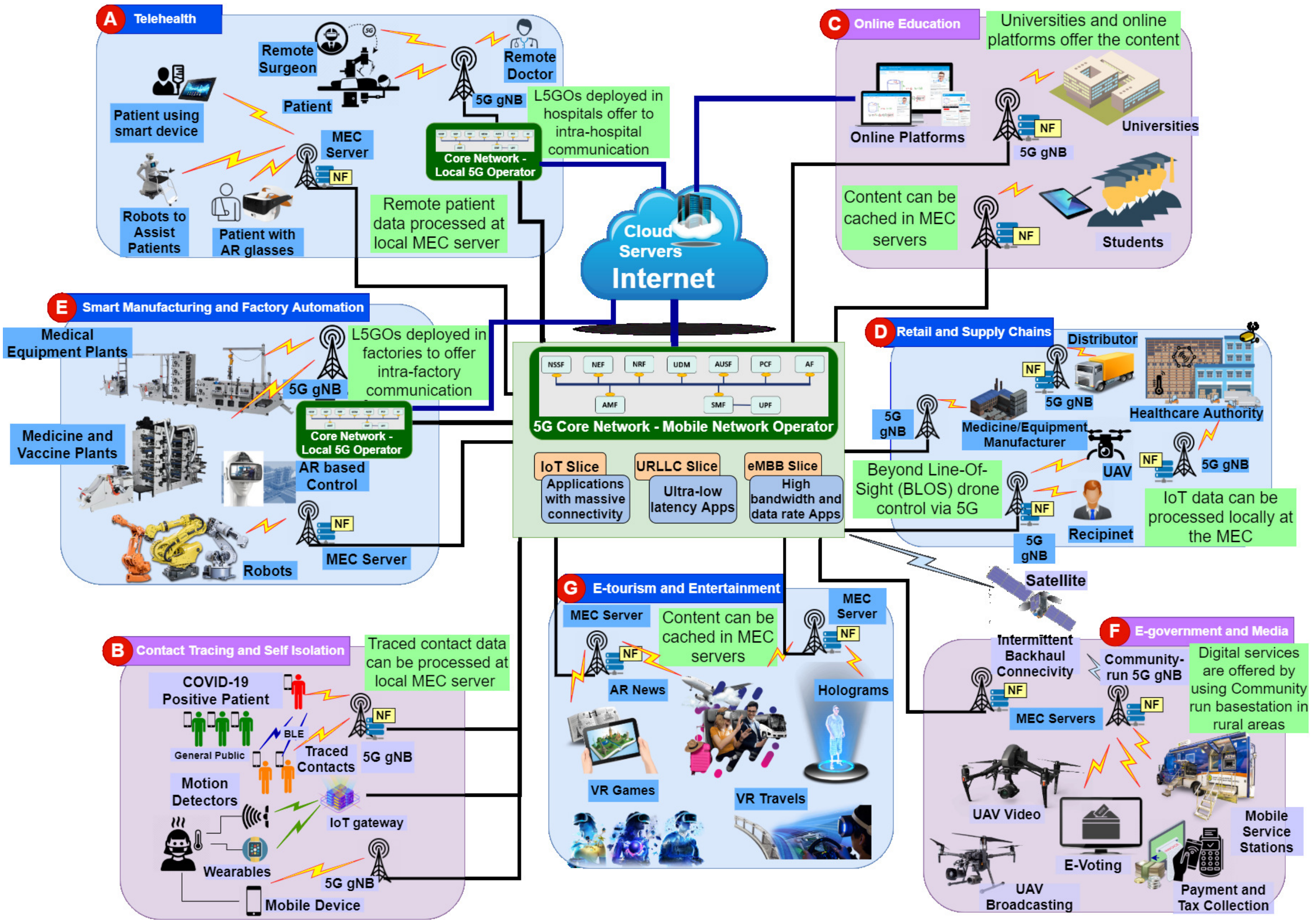

Fig. 2. 5G Use Cases to Fight against COVID-19.

latency, adds extra security and privacy, and reduce congestion in the infrastructure network beyond the MEC server. Figure 2 - (A) illustrates the possible deployment of L5GO and MEC servers at the hospital premises to support remote surgery, remote patient examinations and treatments, AR applications and robot control. L5GO deployment allow to deploy the core and access networks within the hospital premises.

From a managerial perspective, the implementation of such a telehealth infrastructure is practically challenging in terms of complexity and cost. The engineering management should adopt a total life-cycle approach not just considering the capital expenses for such implementations, but operational costs which can be burdensome in the long term. Moreover, the stringent QoS requirements for telehealth applications require a very integrated and pervasive monitoring and management framework.

B. Contact Tracing and Self Isolation

BLE based contact tracing is a better alternative for manual contact tracing which requires a lot of human involvement. A BLE based wearable device advertises an ID periodically and the other compatible devices capture and store with the important details such as timestamp, GPS location data. Once an infected COVID-19 patient is detected, the BLE solution provides the IDs of the close contacts over a defined period. BLE based solutions identify the contacts in the range of few meters, whereas pure GPS based solutions cannot [17]. Mobile device based self-isolation monitoring ensures that the traced contact or the infected COVID-19 patients follow the guidelines. Once the authorities have the knowledge of self-isolation location, random location data using GPS can be captured and analysed to verify the person is following the guidelines during his period of self-isolation. Unmanned Ariel Vehicles (UAV) based solutions can monitor patient condition and self-isolation compliance from a distance. Measuring body temperature via infrared thermography, identifying the person via face recognition algorithms can be used in UAV based solutions.

Role of 5G: BLE based IoT devices can be directly connected to 5G network using mMTC services rather than connecting via intermediate gateways, making contact tracing applications more efficient. The longer battery life supported by the 5G network for mMTC provides an advantage for low-power IoT devices. A MEC server deployed at the base station can process the contact tracing data locally. A summarized data set can be sent to the cloud servers for the use of central authorities. A dedicated 5G network slice-based implementation preserves privacy and adds security for the sensitive data.

UAVs directly connected to 5G networks via mMTC service can be controlled by a MEC server [18] deployed at the 5G base station, increasing the scalability. Figure 2 - B illustrates this scenario to deploy MEC servers at the 5G base stations to process data locally. Moreover, it shows how 5G IoT devices establish the direct connectivity with the 5G network.

In addition to conventional management challenges, the main implication for contact tracing and self isolation for engineering managers is the proper and adequate handling of privacy and security issues, and then the clear communication of how they are handled to the public and public bodies, i.e., communication management. The privacy-protection regulations such as GDPR in Europe are also important factors on how these systems are implemented and managed.

C. Online Education

Online education platforms offered by universities and schools provide the opportunity for the students to carry out their education without interruptions. These platforms allow real-time interaction between the students and the teacher using high quality videos to replicate the classroom experience. AR and VR based distance learning solutions [19] allow students to guide through the educational programs themselves from their homes. Online examination platforms introduced by universities and schools support the students to complete their examinations according to the timelines. Examiners can monitor each student via a high-quality video stream, provide clarifications and instructions, and answer the questions of the students during the exams to make sure that they follow the guidelines.

Role of 5G: 5G services provide better indoor connectivity with small cell Next-generation Base Stations (gNB) using mmWave frequencies, leading to assured connectivity anytime anywhere. Real time online teaching needs low latency HD/4K video streaming which is provided by URLLC and eMBB services in 5G [20]. The AR and VR based educational content can be cached at 5G MEC servers enabling students to stream the contents with low latency. SDN and NFV technologies can be used for fast and dynamic deployment of such content at the MEC servers based on the demand of a particular geographical area. Figure 2 - C depicts the use of online platforms via 5G network for remote education and the MEC based caching of popular content for fast streaming.

The technical managers responsible for the implementation and operational management of such solutions have to be diligent about the user experience since online education has to serve a diverse user base with different levels of technical knowledge and connectivity capabilities. Additionally, the incumbent education practices are heavily geared towards presence based teaching and rely on infrastructure and content appropriate for that mode. Therefore, integration management for legacy systems is an important requirement for realizing online education in 5G ecosystem.

D. Retail and Supply Chains

IoT based supply chains enable easy identification, tracking and distribution of goods from the manufacturer to the end customer. IoT tags attached to goods update the information on the current status to the central supply chain management system automatically. These are effective to reduce the human involvement in the intermediate distribution centers. Moreover, robots in the warehouses automatically handle the goods at the distribution centers. The final delivery of the items is made with UAVs making it a fully automated supply chain. Blockchain based supply chains [21] will further increase the readability, transparency, security and decrease the cost. This ensures proper delivery of the goods to the final destinations without uneven distribution.

Role of 5G: 5G mMTC services support direct connectivity of heterogeneous IoT devices into the network enabling fully automatic IoT based supply chains. MEC is a suitable platform to process data locally to improve the scalability of the systems, security and privacy of collected data. Goods equipped with special tags connect directly to 5G system increasing the transparency. A decentralization of the blockchain can be implemented easily with the MEC [22]. Beyond Line-Of-Sight (BLOS) drones [23] connected to 5G network can deliver the goods to the final destinations from a distribution point. The control functions of such UAVs can be placed at the MEC to satisfy required E2E latency. The use of 5G in retail and supply chains is depicted in Figure 2 - D where manufacturer, distributor, end consumer are connected to 5G network and the final delivery is made via 5G drones whenever possible. MEC is used to processed the data at the edge of the network.

The implementation and management of a 5G and IoT based end-to-end supply chain itself is a challenging task due to the large number of actors and the data. Entities of the entire supply chain should have the technological readiness to realize this and the technology managers must put significant effort at both planning and execution of the deployment projects. UAV based delivery of goods to geographically distributed end consumers is a multifaceted endeavor due to limitations of the drones, regulations in place, security issues, which calls for the design of solid monitoring and management framework to minimize relevant issues on a regular basis.

E. Smart Manufacturing and Factory Automation

Automated factories operating with less human involvement are equipped with Automated Guided Vehicles (AGVs), sensor networks, and remote operating mechanisms. The sensors monitor present conditions, report important events, and trigger alarms based on abnormalities. Then operators can fix issues, guide the robots remotely. AR based solutions such as remote maintenance solutions [24] contribute to reduction in the number of people on-site. The on-site operator points the device camera to the machines and remote operator guides him via AR.

Role of 5G: 5G offers 100x device connectivity via mMTC to connect sensors, actuators, robots and AGVs. Deployment of Local 5G Networks (L5GO) such as micro Operators (uO) [25], [26] to provide the entire connectivity for the factory adds flexibility, increase scalability and contribute to increase the productivity. MEC servers can also be utilized to place the controlling functions to increase scalability [27].

eMBB and URLLC services enable the communications such as AR based services, which includes HD video streaming with low latency. A L5GO deployment to cater the needs of factory automation is illustrated in Figure 2 - E. AR devices, sensors deployed inside the factory and mobile robots can be served via L5GO supporting intra-factory communication.

The massive connectivity of heterogeneous devices in an industrial IoT system introduces a high degree of complexity in terms of deployment, operation and management. An integrated management system that encompasses installation, operation, maintenance, and diagnostics would facilitate the stable operation of such a collection of heterogeneous devices. Risk management, business continuity and disaster recovery plans should also prepared in advance by technology managers to ensure the continuous operation. Integration management is also an important task for deploying novel technologies into the already-present and proven systems on the factory floor. Efficient and secure integration has to be implemented with a resilience and robustness perspective by the technology management.

F. E-government and Media

Utilization of e-services for payments, tax collection, voting are essential to reduce human interaction. The services should be accessible by the users anytime and anywhere. Mobile service station based cash services provide customers with an alternative way of cash withdrawal instead of visiting ATMs. UAV based broadcasting [28], UAV based video capturing for information services such as breaking news are also possible solutions when travel restrictions are in place. Remote working provides the capability for the employees to work from their homes.

Role of 5G: The anytime anywhere connectivity enabled by 5G services using small cells, MIMO systems, mmWave frequencies is mandatory for the proper functionality of mobile service stations. SDN and NFV enable the fast deployment of e-services because it creates the programmable networks that are dynamic and adaptable based on the demand. Deployment of MEC servers and data processing at the edge adds scalability, increase privacy and security for the collected sensitive data. MEC based control functions can be used to guide 5G drones operated in a localized area. eMBB service supports fast connectivity to transmit video data collected by 5G drones. For the remote areas, community-run local 5G networks [29] directly connected to satellites (e.g. Kuha Mobile Networks) provide a solution to the connectivity problem. Figure 2 - F illustrates the how 5G connectivity enables mobile service stations, e-services and UAV based services. Moreover, it shows how the connectivity for rural areas can be provided via the community-run base stations.

For engineering managers, one key aspect is the right scope management for the creation and deployment of these 5G-enabled digital services: In order to make them useful and adopted to the greatest extent, the right scope definition (which services targeting which users with what costs) is necessary with the most beneficial and popular ones being deployed first and then gradually extending to less used ones. With this phased approach, the technology and engineering management actors should incorporate the 5G technological concerns such as availability and bandwidths in a location-driven context.

G. E-tourism and Entertainment

AR/VR based e-tourism [30] is an alternative solution in the tourism industry in the post COVID-19 world. A person can enjoy a virtual tour using AR/VR technology without travelling to the actual location. High quality streaming services for movies, entertainment events, sports events provide much needed entertainment opportunities. Advanced online gaming systems based on hologram technology where the players can feel the actual presence in the gaming environment provide immersive gaming experience.

Role of 5G: E-tourism solutions can be enabled by anytime anywhere connectivity provided by 5G using small cells and mmWave frequencies. To realize AR/VR based solutions, high quality streaming, holograms [31], higher bandwidth data connection via eMBB services is a must. MEC can be used to improve the scalability of the systems and address the sudden high usage demands. How to enable those services via 5G is illustrated in Figure 2 - G. The MEC server acts as a cache to support low latency content delivery.

In addition to complexity and technical challenges for 5G-based AR/VR, technology managers should be very cost-sensitive for making these digital services attractive. Although the cost sensitivity of users might have decreased due to lack of access via other means (e.g. actual site visits for touristic excursions) in COVID-19 pandemic era, this is still an important factor for adoption and viability of these services. In that regard, procurement management is also important – the selection of right equipment for the identified scenarios for a satisfactory user experience.

III. Possible Challenges and Solutions

While addressing the general challenges of COVID-19 using the 5G based solutions, new implementation challenges arise. In this section, we present these issues related to topics ranging from privacy to societal aspects, which should be addressed before the deployment of 5G solutions. A discussion on actions for addressing this new set of implementation challenges is also presented.

A. Security and Privacy Issues

A video recording of a telemedicine activity may contain personal information which the patient would disclose only to the medical professional. In addition, automated contact tracing applications aggregate sensitive location data without the owners' knowledge. Sharing such sensitive user data with unauthorized parties such as third-party advertisers is a serious privacy violation [37]. Drones may capture additional information of bystanders without their knowledge. Attempts by adversaries to attack the databases containing sensitive information pose security risks. The integration of IoT networks increases security risks because such low-end devices are comparably easy to hack and vulnerable to Denial-of-Service (DoS) attacks [38]. Massive number of connected

TABLE II
TECHNICAL REQUIREMENT OF USE-CASES [20], [32]–[36]

Use Case	Application	Expected Capacity	Expected Latency	Number of Devices	Other Requirements
Telehealth	Telesurgery	30-50Mbps >1Gbps for holographic rendering	<1ms	10-100 per surgery	Real-time backhaul connectivity Streaming data type >99.999% availability required >99.999% reliability required
	Remote Patient Examination	>500 million visits per year	<1-100ms	1-10 per appointment	Real-time backhaul connectivity Streaming data type
Contact tracing and self isolation	Smart City: Using sensor data for contact tracing	>10-100GB of data per city per day	<1ms	1000-1million per city	Real-time backhaul connectivity Streaming data type
Online education	VR/AR for Education	4-28Gbps	10ms RTT	>0.2 million globally	Real-time backhaul connectivity Stream/Massive data type
	Media On Demand	15Mbps 60 Gbps per km^2	5s (Start application) 200ms (after possible link interruptions)	4000 devices per km^2	Intermittent backhaul connectivity Stream data type >95% coverage
Retail and supply chains	Shopping mall	100Mbps - 1Gbps	<1ms	100-1000 per shop	Real-time/Intermittent Backhaul Connectivity Streaming/historical data >95% availability required
Smart manufacturing and factory automation	Factory cell automation	100,000 Gbps per day	<1ms	>1 million per factory	>10 years battery life per IoT device Packet loss rate $< 10^{-9}$
	Farming	>1GB per farm	Several hours	100-100,000 per farm	Intermittent backhaul connectivity Historical data type >10 years battery life per IoT device
	Smart Energy	>100TB per day	1ms - 10mins	1billion per grid	Real-time/Intermittent backhaul connectivity Stream/Massive data type
E-government/ Remote Office/ Information Sharing	Smart City: Information and Services made available for online access	>10-100GB of data per city per day	<1ms	1000-1million per city	Real-time backhaul connectivity Streaming data type
	VR/AR based Meetings	4-28Gbps	10ms RTT	>0.2 million globally	Real-time backhaul connectivity Stream/Massive data type
	Autonomous vehicles	>100GB per vehicle per day	<1ms	50-200 per vehicle	Real-time backhaul connectivity Streaming/Massive data type >99.999% availability required >99.999% reliability required
	Emergency communications	Small	<1ms	1000-1million per city	Real-time backhaul connectivity Streaming data type >99.9% victim discovery rate >1 week battery life per device
E-tourism and entertainment	VR/AR for E-tourism	4-28Gbps	10ms RTT	>0.2 million globally	Real-time backhaul connectivity Stream/Massive data type

devices increases the number of entry points for attackers to perform unauthorized operations, i.e. increases the attack surface of the systems [39].

Possible Solutions: To address the privacy challenge, solutions like Privacy-by-Design [40], software defined privacy [41], privacy preserving protocols for for sink node location in telemedicine [42], must be deployed with 5G applications at the design phase. New privacy preserving protocols for contact tracing which utilizes minimal personal data can be introduced. In addition, lightweight and scalable security mechanisms must be designed to secure MIoTs. Encrypted data transmission and distributed security solutions such as blockchain can prevent attackers gain access to the network and protect the collected user data [22]. For a holistic security and privacy framework, these solutions can be built upon and/or integrated into a smart and trustworthy 5G security platform for the overall 5G ecosystem [43]. Such an inherent security platform embedded in 5G can also alleviate security issues for different use-cases in different network segments.

B. Scalability issues

Rapid deployment of new applications such as new mobile services, drone based services, online educational platforms will increase the number of 5G users who access such services while adding extra traffic. This will lead to increased network congestion (e.g. hologram or Zoom software for remote meetings [31]). AR based applications require high bandwidth and low latency. However, a congested network fails to satisfy the service levels required by such applications. This is also valid for drone based video delivery over the network. Manufacturing plants may have to increase the production of specific goods, yearning for the need of quick deployment of extra network resources. Moreover, it is challenging to manage billions of MIoTs [44]. When large number of IoT devices generate ad-hoc data transfers, the network should be scalable to cope with the increased number of traffic events.

TABLE III
USE CASES AND ROLE OF 5G

Use Cases	**5G based Solution**	**Features Introduced by 5G: URLLC**	**eMMB**	**mMTC**	**MEC**	**Network Slicing**	**L5GO concept**	**Dynamic Service Deployment**	**Massive MIMO & mmWave**	**High Reliability**	**Low Energy Usage**	**Related 5G Deployment Challenges**
Telehealth	5G enables application services consisting new AR based haptic feedback to satisfy latency and bandwidth requirements.	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	Legal Issues, Security and Privacy Issues
Contact Tracing	5G offer massive connectivity for IoT devices to collect the traced data.	-	-	✓	✓	-	-	-	-	✓	✓	Legal Issues, Security and Privacy Issues, Pervasive Connectivity Issues, Scalability issues
Education	5G offers higher bandwidth and enable new AR/VR network services.	✓	✓	-	✓	✓	-	✓	✓	-	-	Security and Privacy Issues, Societal Issues, Pervasive Connectivity Issues
Retail and Supply Chains	5G enables UAV based delivery.	✓	-	-	-	✓	-	✓	-	✓	-	Legal Issues, Security and Privacy Issues, Societal Issues
E-government/ Information Sharing/ Media	5G offers fast connectivity for homes and remote areas and the possibility to deploy dynamic services	-	✓	-	✓	✓	✓	✓	✓	-	-	Legal Issues, Security and Privacy Issues, Societal Issues
Smart Manufacturing and Factory Automation	5G supports to realize IIoT concepts	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	Legal Issues, Security and Privacy Issues, Societal Issues
E-tourism and Entertainment	5G enables AR/VR, hologram based solutions	-	✓	-	✓	-	-	✓	✓	-	-	Pervasive Connectivity issues, Scalability issues

Possible Solutions: NS in 5G with dynamic scalability is a possible solution to address this problem. The slices serve similar type of services and they can be made adaptive based on the various parameters such as network traffic load, number of IoT devices presently connected. Deployment of virtual NF based on demand at the MEC servers will provide a solution to the congestion due to sudden increase of localized demands. Dynamic deployment of virtual NF in MEC can modify and manage the resources easily in cases where a certain service is no longer required, and a new service has a higher demand locally.

C. Limited 5G Connectivity

The solutions will bring advantages only if the 5G connectivity is available anytime anywhere. Commercial deployment of 5G networks is still in infancy [45]. Network operators need to deploy these 5G based solutions as soon as possible. The limited deployment of 5G networks and limited availability of 5G devices will be an immediate problem for many countries.

Possible Solutions: Governments and network operators should push forward their deployment plans. 5G device manufacturers should come up with new devices at affordable cost levels. Moreover, small scale 5G deployments such as local 5G networks should be encouraged to use in hospitals, factories, universities to cater specific and local demands by promoting local spectrum licensing [46].

D. Societal Issues

Incidents such as destroying the cellular base stations due to conspiracy theories linking new 5G mobile networks and the COVID-19 pandemic, disrupts connectivity affecting the applications [47]. The 5G solutions may require the user to possess sophisticated level of technical literacy [48]. However, many people lack such level of technical literacy. Furthermore, 5G user devices are significantly more expensive, leading to a cost burden.

Possible Solutions: Experts in 5G domain and media have responsibility to clear out these inaccurate social beliefs with the support of civil society and governments. The applications can be made easier to use and to run on average hardware and devices so that everyone can afford it and use the services.

E. Legal Issues

Contact tracing after the period for which the patient has provided the consent to trace contacts is a legal issue. Collection of unauthorized data through the applications or wearable devices, automatically guided UAVs taking the flight paths over flight restricted areas will also have legal implications [49]. Rapid deployment of third party services may not follow the exact guidelines defined by standard bodies and governments, which can lead to legal issues.

Possible Solutions: Standard bodies should define the guidelines at the early stages so that the solution developers can synchronize and follow, such as the EU policy on COVID-19 contact tracing applications [50]. Awareness programs by the government, standard bodies via media will also minimize legal implications.

IV. Conclusion

This paper presents how 5G, IoT and related technologies can be used in the fight against the COVID-19 pandemic. Use cases in the areas of telehealth, contact tracing and self isolation, online education, retail and supply chains, smart manufacturing and factory automation, e-government and media, and e-tourism and entertainment have been discussed while elaborating how different elements in 5G and IoT technologies can be used to develop innovative solutions suitable for a post COVID-19 era.

Implementing the proposed solutions requires addressing several potential challenges in the areas of security and privacy, scalability, limited connectivity, societal issues, and legal aspects. The paper also presents how each of these challenges can be addressed. However, providing efficient solutions to each of the challenges, especially in the area of security and privacy, opens up new research directions.

It is firmly believed that involved parties including engineers, technology managers, healthcare workers, government authorities, researchers and the general public at large will be able to fulfil their usual duties and functionalities by banking on the proposed innovative 5G and IoT based solutions. However, presently, the lack of widely available 5G communication networks imposes a limitation for the rapid adaption of proposed technologies. Yet, it should be noted that 5G networks are rapidly being deployed around the world. In addition, some of the solutions such as full-time online education, e-tourism and e-government services require users to change their regular habits, work patterns, tools, etc., and adapt to new ways of thinking and functioning. This is an interesting future research direction.

It is envisaged that this paper will also pave the path for future research and development work that would not only be pivotal in the battle against pandemics such as COVID-19 but also be instrumental for a new lifestyle in the 5G and beyond communication era.

References

[1] C.-C. Lai, T.-P. Shih, W.-C. Ko, H.-J. Tang, and P.-R. Hsueh, "Severe Acute Respiratory Syndrome Coronavirus 2 (SARS-CoV-2) and Corona Virus Disease-2019 (COVID-19): The Epidemic and the Challenges," *International journal of antimicrobial agents*, p. 105924, 2020.

[2] A. Spinelli and G. Pellino, "COVID-19 Pandemic: Perspectives on an Unfolding Crisis," *The British Journal of Surgery*, 2020.

[3] J. Willan, A. J. King, K. Jeffery, and N. Bienz, "Challenges for NHS Hospitals during COVID-19 Epidemic," 2020.

[4] M. Chinazzi, J. T. Davis, M. Ajelli, C. Gioannini, M. Litvinova, S. Merler, A. P. y Piontti, K. Mu, L. Rossi, K. Sun *et al.*, "The Effect of Travel Restrictions on the Spread of the 2019 Novel Coronavirus (COVID-19) Outbreak," *Science*, vol. 368, no. 6489, pp. 395–400, 2020.

[5] P. Walker, C. Whittaker, O. Watson, M. Baguelin, K. Ainslie, S. Bhatia, S. Bhatt, A. Boonyasiri, O. Boyd, L. Cattarino *et al.*, "Report 12: The Global Impact of COVID-19 and Strategies for Mitigation and Suppression," 2020.

[6] W. J. McKibbin and R. Fernando, "The Global Macroeconomic Impacts of COVID-19: Seven Scenarios," 2020.

[7] R. Ohannessian, T. A. Duong, and A. Odone, "Global Telemedicine Implementation and Integration within Health Systems to Fight the COVID-19 Pandemic: A Call to Action," *JMIR public health and surveillance*, vol. 6, no. 2, p. e18810, 2020.

[8] ETSI, "5G," Technical Report, 2020. [Online]. Available: https://www.etsi.org/technologies/5g

[9] A. Osseiran, F. Boccardi, V. Braun, K. Kusume, P. Marsch, M. Maternia, O. Queseth, M. Schellmann, H. Schotten, H. Taoka *et al.*, "Scenarios for 5G Mobile and Wireless Communications: The Vision of the METIS Project," *IEEE communications magazine*, vol. 52, no. 5, pp. 26–35, 2014.

[10] ITU, "IMT Vision – Framework and Overall Objectives of the Future Development of IMT for 2020 and beyond," Rec. ITU-R M.2083, Sept. 2015.

[11] M. Shafi, A. F. Molisch, P. J. Smith, T. Haustein, P. Zhu, P. Silva, F. Tufvesson, A. Benjebbour, and G. Wunder, "5G: A Tutorial Overview of Standards, Trials, Challenges, Deployment, and Practice," *IEEE Journal on Selected Areas in Communications*, vol. 35, no. 6, pp. 1201–1221, 2017.

[12] M. Liyanage, A. Gurtov, and M. Ylianttila, *Software Defined Mobile Networks (SDMN): Beyond LTE Network Architecture*. John Wiley & Sons, 2015.

[13] A. A. Barakabitze, A. Ahmad, R. Mijumbi, and A. Hines, "5G Network Slicing using SDN and NFV: A Survey of Taxonomy, Architectures and Future Challenges," *Computer Networks*, vol. 167, p. 106984, 2020.

[14] A. Mahajan, G. Pottie, and W. Kaiser, "Transformation in Healthcare by Wearable Devices for Diagnostics and Guidance of Treatment," *ACM Transactions on Computing for Healthcare*, vol. 1, no. 1, pp. 1–12, 2020.

[15] 3GPP, "Study on Communication Services for Critical Medical Applications," Technical Report, November 2018. [Online]. Available: https://www.3gpp.org/ftp/Specs/archive/22_series/22.826/

[16] 3GPP, "Study on Communication for Automation in Vertical Domains," Technical Report, July 2018. [Online]. Available: https://portal.3gpp.org/desktopmodules/Specifications/SpecificationDetails.aspx?specificationId=3187/

[17] P. O'Neill, T. Ryan-Mosley, and B. Johnson, "A Flood of Coronavirus Apps are Tracking us. Now It's Time to keep Track of Them," 2020, mIT Technology Review.

[18] Y. Du, K. Wang, K. Yang, and G. Zhang, "Energy-efficient Resource Allocation in UAV based MEC System for IoT Devices," in *2018 IEEE Global Communications Conference (GLOBECOM)*. IEEE, 2018, pp. 1–6.

[19] M. Zikky, K. Fathoni, and M. Firdaus, "Interactive Distance Media Learning Collaborative based on Virtual Reality with Solar System Subject," in *2018 19th IEEE/ACIS International Conference on Software Engineering, Artificial Intelligence, Networking and Parallel/Distributed Computing (SNPD)*. IEEE, 2018, pp. 4–9.

[20] A. Baratè, G. Haus, L. A. Ludovico, E. Pagani, and N. Scarabottolo, "5G Technology for Augmented and Virtual Reality in Education," in *Proceedings of the International Conference on Education and New Developments 2019 (END 2019)*, 2019, pp. 512–516.

[21] S. Malik, V. Dedeoglu, S. S. Kanhere, and R. Jurdak, "TrustChain: Trust Management in Blockchain and IoT supported Supply Chains," in *2019 IEEE International Conference on Blockchain (Blockchain)*. IEEE, 2019, pp. 184–193.

[22] T. Hewa, G. Gür, A. Kalla, M. Ylianttila, A. Bracken, and M. Liyanage, "The Role of Blockchain in 6G: Challenges, Opportunities and Research Directions," in *2020 2nd 6G Wireless Summit (6G SUMMIT)*, 2020, pp. 1–5.

[23] N. Kato, Y. Kawamoto, A. Aneha, Y. Yaguchi, R. Miura, H. Nakamura, M. Kobayashi, T. Henmi, O. Akimoto, Y. Kamisawa *et al.*, "Location Awareness System for Drones Flying Beyond Visual Line of Sight Exploiting the 400 MHz Frequency Band," *IEEE Wireless Communications*, vol. 26, no. 6, pp. 149–155, 2019.

[24] R. Masoni, F. Ferrise, M. Bordegoni, M. Gattullo, A. E. Uva, M. Fiorentino, E. Carrabba, and M. Di Donato, "Supporting Remote Maintenance in Industry 4.0 through Augmented Reality," *Procedia Manufacturing*, vol. 11, pp. 1296–1302, 2017.

[25] M. Matinmikko, M. Latva-Aho, P. Ahokangas, S. Yrjölä, and T. Koivumäki, "Micro Operators to boost Local Service Delivery in 5G," *Wireless Personal Communications*, vol. 95, no. 1, pp. 69–82, 2017.

[26] Y. Siriwardhana, P. Porambage, M. Liyanage, J. S. Walia, M. Matinmikko-Blue, and M. Ylianttila, "Micro-operator driven Local 5G Network Architecture for Industrial Internet," in *2019 IEEE Wireless Communications and Networking Conference (WCNC)*. IEEE, 2019, pp. 1–8.

[27] I. Sarrigiannis, K. Ramantas, E. Kartsakli, P.-V. Mekikis, A. Antonopoulos, and C. Verikoukis, "Online VNF Lifecycle Management in a MEC-enabled 5G IoT Architecture," *IEEE Internet of Things Journal*, 2019.

[28] S. Ortiz, C. T. Calafate, J.-C. Cano, P. Manzoni, and C. K. Toh, "A UAV-based Content Delivery Architecture for Rural Areas and Future Smart Cities," *IEEE Internet Computing*, vol. 23, no. 1, pp. 29–36, 2018.

[29] Y. Hu, A. Manzoor, P. Ekparinya, M. Liyanage, K. Thilakarathna, G. Jourjon, and A. Seneviratne, "A Delay-tolerant Payment Scheme based on the Ethereum Blockchain," *IEEE Access*, vol. 7, pp. 33 159–33 172, 2019.

[30] A. Nayyar, B. Mahapatra, D. Le, and G. Suseendran, "Virtual Reality (VR) & Augmented Reality (AR) Technologies for Tourism and Hospitality Industry," *International Journal of Engineering & Technology*, vol. 7, no. 2.21, pp. 156–160, 2018.

[31] A. El Rhammad, P. Gioia, A. Gilles, and M. Cagnazzo, "Towards Practical Hologram Streaming using Progressive Coding," in *Applications of Digital Image Processing XLII*, vol. 11137. International Society for Optics and Photonics, 2019, p. 111371E.

[32] D. Soldani, F. Fadini, H. Rasanen, J. Duran, T. Niemela, D. Chandramouli, T. Hoglund, K. Doppler, T. Himanen, J. Laiho, and N. Nanavaty, "5G Mobile Systems for Healthcare," in *2017 IEEE 85th Vehicular Technology Conference (VTC Spring)*, 2017, pp. 1–5.

[33] R. Gupta, S. Tanwar, S. Tyagi, and N. Kumar, "Tactile-Internet-Based Telesurgery System for Healthcare 4.0: An Architecture, Research Challenges, and Future Directions," *IEEE Network*, vol. 33, no. 6, pp. 22–29, 2019.

[34] P. Porambage, J. Okwuibe, M. Liyanage, M. Ylianttila, and T. Taleb, "Survey on Multi-Access Edge Computing for Internet of Things Realization," *IEEE Communications Surveys Tutorials*, vol. 20, no. 4, pp. 2961–2991, 2018.

[35] A. Osseiran, J. F. Monserrat, and P. Marsch, *5G Mobile and Wireless Communications Technology*, 1st ed. USA: Cambridge University Press, 2016.

[36] M. J. Keeling, T. D. Hollingsworth, and J. M. Read, "The Efficacy of Contact Tracing for the Containment of the 2019 Novel Coronavirus (COVID-19)," *medRxiv*, 2020.

[37] J. L. Hall and D. McGraw, "For Telehealth to Succeed, Privacy and Security Risks must be Identified and Addressed," *Health Affairs*, vol. 33, no. 2, pp. 216–221, 2014.

[38] R. Khan, P. Kumar, D. N. K. Jayakody, and M. Liyanage, "A Survey on Security and Privacy of 5G Technologies: Potential Solutions, Recent Advancements, and Future Directions," *IEEE Communications Surveys & Tutorials*, vol. 22, no. 1, pp. 196–248, 2019.

[39] M. Liyanage, A. Braeken, P. Kumar, and M. Ylianttila, *IoT Security: Advances in Authentication*. John Wiley & Sons, 2020.

[40] M. Liyanage, J. Salo, A. Braeken, T. Kumar, S. Seneviratne, and M. Ylianttila, "5G privacy: Scenarios and Solutions," in *2018 IEEE 5G World Forum (5GWF)*. IEEE, 2018, pp. 197–203.

[41] F. Kemmer, C. Reich, M. Knahl, and N. Clarke, "Software Defined Privacy," in *2016 IEEE International Conference on Cloud Engineering Workshop (IC2EW)*. IEEE, 2016, pp. 25–29.

[42] T. Li, Y. Liu, N. N. Xiong, A. Liu, Z. Cai, and H. Song, "Privacy-preserving Protocol for Sink Node Location in Telemedicine Networks," *IEEE Access*, vol. 6, pp. 42 886–42 903, 2018.

[43] J. Ortiz, R. Sanchez-Iborra, J. Bernal, A. S. Gomez, C. Benzaid, T. Taleb, P. Alemany, R. Muñoz, R. Vilalta, C. Gaber, J.-P. Wary, D. Ayed, P. Bisson, M. Christopoulou, G. Xilouris, E. Montes de Oca, G. Gür, G. Santinelli, V. Lefebvre, A. Pastor, and D. Lopez, "INSPIRE-5Gplus: Intelligent Security and Pervasive Trust for 5G and Beyond Networks," in *ARES 2020 - 5G-NS Workshop*, August 2020, pp. 1–5.

[44] A. S. Yeole and D. Kalbande, "Use of Internet of Things (IoT) in Healthcare: A Survey," in *Proceedings of the ACM Symposium on Women in Research 2016*, 2016, pp. 71–76.

[45] P. Jones and D. Comfort, "A Commentary on the Rollout of 5G Mobile in the UK," *Journal of Public Affairs*, vol. 20, no. 1, p. e1993, 2020.

[46] A. Basaure and B. Finley, "Urban 5G Regulation: Local Licensing versus Coopetition," 2019.

[47] W. Ahmed, J. Vidal-Alaball, J. Downing, and F. L. Seguí, "COVID-19 and the 5G Conspiracy Theory: Social Network Analysis of Twitter Data," *Journal of Medical Internet Research*, vol. 22, no. 5, p. e19458, 2020.

[48] O. Adelakun and R. Garcia, "Technical Factors in Telemedicine Adoption in Extreme Resource-Poor Countries," in *Global Health and Volunteering Beyond Borders*. Springer, 2019, pp. 83–101.

[49] C. Stöcker, R. Bennett, F. Nex, M. Gerke, and J. Zevenbergen, "Review of the Current State of UAV Regulations," *Remote sensing*, vol. 9, no. 5, p. 459, 2017.

[50] Europe Technology Policy Committee, "Statement On Essential Principles and Practices for Covid-19 Contact Tracing Applications," May 2020. [Online]. Available: https://www.acm.org/binaries/content/assets/public-policy/europe-tpc-contact-tracing-statement.pdf

Yushan Siriwardhana (Student Member, IEEE) is currently a Doctoral degree student in the Centre for Wireless Communications, University of Oulu, Finland. He received the bachelor's degree in electronics and telecommunication engineering from the University of Moratuwa, Sri Lanka, in 2009 and the master's degree in wireless communication engineering from the University of Oulu, Finland, in 2019.

Chamitha de Alwis (Member, IEEE) is a senior lecturer in Electronic and Telecommunication Engineering in University of Sri Jayewardenepura, Sri Lanka. He received his Ph.D. degree in Electronic Engineering in 2014 from Univerity of Surrey, United Kingdom. His research interests include next-generation networks, IoT, Information Security and Coding.

Gürkan Gür (Senior Member, IEEE) is a senior researcher at Zurich University of Applied Sciences (ZHAW), Switzerland. Turkey. He received his B.S. degree in electrical engineering in 2001 and Ph.D. degree in computer engineering in 2013 from Bogazici University. His research interests include Future Internet, information security, next-generation wireless networks and ICN.

Mika Ylianttila (Senior Member, IEEE) is a full-time associate professor (tenure track) at the Centre for Wireless Communications (CWC), University of Oulu, Finland. His research interests include edge computing, network security, network virtualization and software-defined networking.

Madhusanka Liyanage (Senior Member, IEEE) is an Assistant Professor/Ad Astra Fellow at School of Computer Science, University College Dublin, Ireland. He is also an adjunct professor/docent at the University of Oulu, Finland. His research interests are SDN, IoT, Blockchains, MEC, mobile and network security.