BOOSTING SMARTER DIGITAL HEALTH CARE WITH 5G AND BEYOND NETWORKS

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Abstract – *With 5G and beyond on the horizon, ultra-fast and low latency data transmission on the cloud and via the Internet will enable more intelligent and interactive medical and health-care applications. This paper presents a review of 5G technologies and their related applications in the health-care sector. The introduction to 5G technology includes software defined network, 5G architecture and edge computing. The second part of the paper then presents the opportunities provided by 5G to the health-care sector and employs medical imaging applications as central examples to demonstrate the impacts of 5G and the cloud. Finally, this paper summarize the benefits brought by 5G and cloud computing to the health-care sector.*

Keywords – 5G, health care, medical imaging, VR/AR

1. INTRODUCTION TO 5G

Being actively researched and worked on by the WGs and TSGs from different standardization bodies, 5G promises to provide more than just high-speed Internet. Release 16 in 2020 by 3GPP addresses the standardization of 5G [1]. Three types of network slices have been specified by 3GPP, namely enhanced Mobile Broadband (eMBB), Ultra-Reliable Low Latency Communications (URLLC), massive Machine-Type Communications (mMTC)[2, 3] while up to 256 such slice types can be allocated in the current 3GPP Release 16 specification [2, 3, 4]. The proliferation of connected objects and devices will pave the way for a wide range of new services and business models enabling automation in various industry sectors and vertical markets (e.g. energy, e-health, smart city, connected cars, industrial manufacturing, etc.). To more pervasive human-centric applications, e.g., virtual and augmented reality (VR/AR), 4k and 8k video streaming, etc., 5G and beyond networks will support the required communication of machine-to-machine and machine-to-human type applications far better. The mobile communication created by autonomous devices will bear significantly different traffic patterns than the dominant human-to-human traffic today. The coexistence of human-centric and machine type applications will impose very diverse functional and KPI/performance requirements that 5G networks are expected to support.

Among the significantly impacted industries by the telecommunication technology, the health-care sector, with its closeness to people's lives and public welfare, is under the spotlight. 5G technology, featured by its high data transmission rate and low latency, may bring more critical health-care applications demanding real time data communication, such as remote surgery and smart ambulance services, into reality. In remote surgery, real and virtual environments are combined to provide realistic human-machine interactions where robots obtain and handle information on behalf of humans. Smart ambulance services, while caring for a patient, may benefit from a 5G network to send the video inside the ambulance and the patient data in real time to hospitals to receive specialized remote support in real-time via high-definition video. 5G also brings the health-care sector seamless integration with the cloud infrastructure. Access to huge medical data such as medical images can be achieved on-the-fly. Reliable low latency mobile communications have added extra mobility to health-care applications. The high bandwidth and low latency brought by 5G ensures that KPIs for such applications can be guaranteed.

As illustrated in Fig. 1, the network slice is a composition of adequately configured network functions, network applications, and the underlying cloud infrastructure (physical, virtual or even emulated resources, Radio Access Network (RAN) resources etc.), that are bundled together to meet the requirements of a specific use case, e.g., bandwidth, latency, processing, and resiliency, coupled with a business purpose. The details of three types of network slices, i.e. eMBB, URLLC and mMTC, are listed as follows.

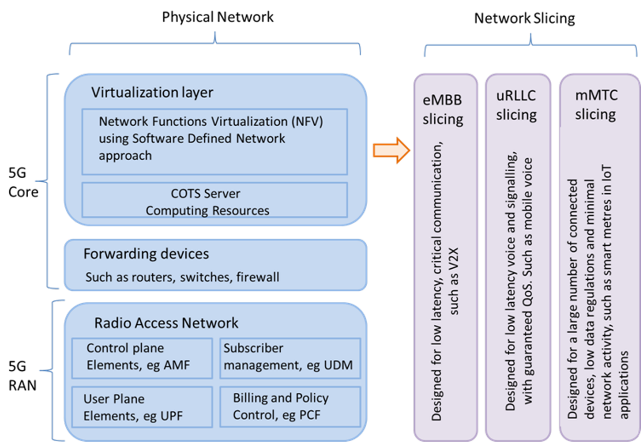

Fig. 1 – 5G architecture concepts (adapted from [1])

1. Enhanced Mobile Broadband (eMBB) slicing has high-level requirements for the bandwidth to deploy cache in the mobile cloud engine of a local Data Center (DC), which provides high-speed services located in close proximity to users, reducing bandwidth requirements of backbone networks. The examples of services include: augmented reality, high quality video, and real-time video services.
2. Ultra-Reliable Low Latency Communications (URLLC) slicing has strict latency requirements in application scenarios of self-driving, assisted driving, and remote management. RAN real time and non-real time processing function units must be deployed on site to provide a beneficial location which is preferably based in close proximity to users. The examples of services include: automatic vehicle services and remote surgery.
3. Massive Machine-Type Communications (mMTC) slicing involves a small amount of network data interaction and a low frequency of signalling interaction in most MTC scenarios. The examples of services include: Internet of Things (IoT) applications, such as smart meters.

2. 5G ARCHITECTURE

With the standization of 5G still in progress and the deployment of 5G at the outset, it is not surprising that the related vertical applications are also in their early stages of development. Regarded as one of the most critical vertical applications, the health-care sector may potentially benefit significantly from 5G technologies despite the actual functions and scenarios not yet being defined.

End-to-End (E2E) connect-and-compute infrastructures are application and service-aware, as well as time, location and context aware. They represent an evolution of native flexibility and programmability conversion in all radio and non-radio 5G network segments. Network softwarization and enablers aim to provide networking and communication functionality through programmable software that is separable from hardware. In reality, a research challenge is to identify and design a set of elementary functions or blocks to compose network functions, which currently are implemented as monolithic. More generally, it includes any networking and communication technology that features open programmable interfaces accessible to third parties, extensibility through software, software development kits, and separation of data forwarding, control, and management planes.

In addition, programmability in networks and enablers allow the functionality of some of their network elements to be dynamically altered. These networks aim to provide easy introduction of new network services by injecting dynamic programmability to network devices such as routers, switches, and application servers. Network programmability empowers the fast, flexible, and dynamic deployment of new network and management services executed as groups of virtual machines in the data plane, control plane, management plane and service plane in all segments of the network.

2.1 Logical structure of 5G

Fig. 2 illustrates 5G network functions from the perspective of the logical and physical network softwarization and programmability.

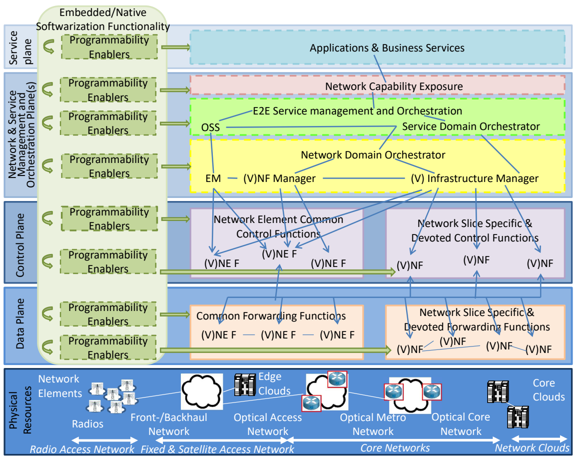

Fig. 2 – 5G logical and physical network softwarization and programmability viewpoint (adapted from [5])

The physical layer consists of the underlying hardware facilities. The multi-domain network operating system facilities include different adaptors and network abstractions above the networks and clouds of heterogeneous fabrics. Its responsibilities include the allocation of (virtual) network resources and maintaining the network state to ensure network reliability in a multi-domain environment.

The data layer comprises the Virtual Network Functions (VNFs) and Physical Network Functions (PNFs) needed to carry and process the user data traffic.

The control layer accommodates the two main controllers, Software Defined for Mobile Network Coordination (SDM-X) and Software Defined for Mobile Network Control (SDM-C), as well as other control applications. Following the SDN principles, SDM-X and SDM-C translate decisions of the control applications into commands to VNFs and PNFs. SDM-X and SDM-C, as well as other control applications can be executed as VNFs or PNFs by themselves.

The Management and Orchestration (MANO) layer manages the virtual resources based on the QoS requirements of each application. The management is also responsible for slice orchestration and reclaim of slices no longer needed by the allocated services. In the ETSI Network Functions Virtualization (NFV) MANO functions, this layer includes the Virtualised Infrastructure Manager (VIM), the VNF manager and the NFV Orchestrator (NFVO). An inter-slice broker handles cross-slice resource allocation and interacts with the service management function. Further, the MANO layer accommodates domain-specific application management functions, such as Element Manager (EM) and Network Management (NM) functions, including Network (Sub-)Slice Management Function (N(S)SMF). Those functions would also implement ETSI NFV MANO interfaces to the VNF mannager and the NFVO. As an intermediary function between the service layer and the inter-slice broker, the service management transforms consumer-facing service descriptions into resource-facing service descriptions and vice versa.

The service layer comprises Business Support Systems (BSSs) and business-level policy and decision functions, as well as applications and services operated by the tenant. This includes the end-to-end orchestration system.

2.2 Slicing and integrating with broadband

In order to handle diverse vertical requirements, network slicing is applied at different parts of the network, as shown in Fig. 3 where the slices are also mapped to the core network, transport network and access network, respectively. In 5G networks, a Radio Access Network (RAN) implements radio access technology and connects a wireless device (such as a phone) to a core network via a transport network.

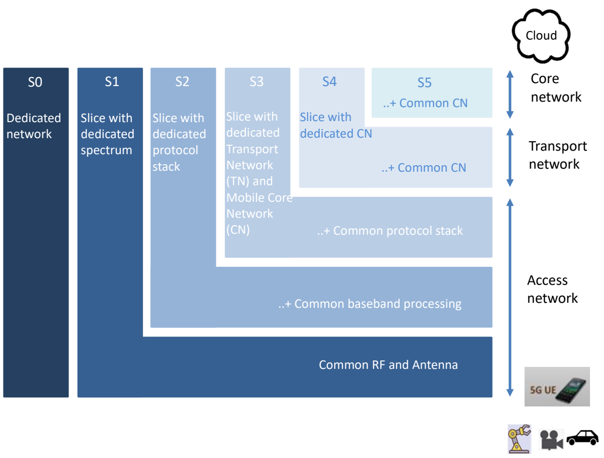

Fig. 3 – Three different types of slicing [6]

In addition to the slice type, each network slice can be further categorized via a slice differentiator, which significantly widens the support for different verticals. These network slices are essentially logical networks operating on top of the same physical infrastructure. Network slices may operate in total isolation among them or they may share resources and network functions. A vertical service may require the use of one or more network slices controlled or operated by more than one stakeholder, e.g., a mobile network operator and the vertical itself. The deployment and management of the network slices are performed in a standardized, as well as implementation-specific, way. It is worth noting that network slicing is an end-to-end concept; therefore, slicing support for different verticals may require modifications and extensions in the access, transport and core network domains.

When considering transport network slicing management from an end-to-end perspective, it needs to be integrated with broadband network services. Transport network slicing is considered a fundamental enabler in order to migrate the Multi-Service Broadband Network (MSBN architecture) from ”one architecture fits all” to the logical ”network per service”. The transport network slicing is clarified into three types: network service as a service focusing on fixed networks, supporting 5G-related 3GPP use cases, and slicing across fixed-mobile converged networks. As shown in Fig. 4, the processes and operations of service management and network slice control supported by MSBN require a continuous process capable of analyzing the service requirements and assuring the desired performance even when the conditions of the network change or the requirements from the customer perspective evolve with time. Combining the network slice management with the service management as transport management domain provides capabilities such as service abstraction, service negotiation, service operations, service adjustment, and service template to verticals, application/service providers and 3rd parties for end-to-end service management.

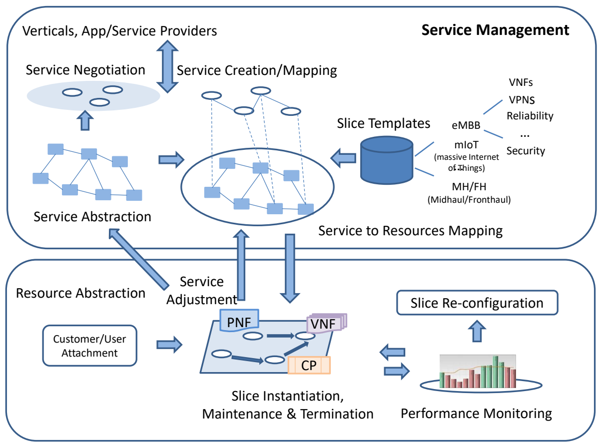

Fig. 4 – Service management (adapted from [7])

3. EDGE COMPUTING

By bringing content and computing resources closer to the users, edge computing reduces latency and load on the backhaul [8]. In edge computing, a small data center is placed at the edge of the Internet, in close proximity to mobile devices, sensors, and end users. Moreover, 5G's increased networking capabilities are pivotal in strengthening the connections between edge devices and cloud computing centers, which play significant roles in today's applications where data is the key driven factor.

In the case of a smart ambulance, the edge computer within each car will need to handle the real-time operation of the vehicle, such as safely navigating intersections and avoiding accidents on the road. However, some decisions will require peripheral, cloud-based information, navigation decisions and route planning will likely originate from the cloud. It is necessary to carefully allocate computations to the edge and cloud and efficiently communicate between the edge and cloud.

In the home application, smart apps, or connected apps, are the future of applications both for business and consumer. Such applications often require instant communication and connection with data analytic mechanisms for real-time decision-making. When critical actions are being completed by these smart apps, latency needs to be as low as possible to minimize machine errors. For 5G, industry experts are predicting a jump to 10x less latency than with the 4G infrastructure currently in use. By using edge computing, processing can be placed extremely close to the user (or device) , which will enable quick connections and communications with apps.

Though many developers are still using traditional data centers and cloud-based hosting for their applications, there has been a significant pivot to hosting code on the cloud edge. This is happening because as edge computing grows, developers are seeing a distinct latency and reliability difference when deploying their code and apps. Typically, when apps are deployed in the cloud or in traditional data centers, the latency for users is greater than 60ms. However, when supported by localized edge data centers and micro-services, apps that require critical connection time receive super low latency typically less than 15ms. That is a huge advantage for connected apps such as remote surgery, autonomous vehicles, and IoT, which require almost instant server communication.

Due to limitation on the computing resources of terminals, even in the case of robotics when intensive training is needed, a common practice is to offload tasks of various applications to computing systems with sufficient computing resources, i.e. data centers in the cloud. However, the drawbacks of the offloading method are high latency and network congestion in the IoT infrastructures. With regard to this issue, the paradigm of edge computing, with the idea to support the devices with a cloud closer to the edge of the network appears as an appealing solution.

Fig. 5 shows a description of video stream analysis. The use of a Multi-access Edge Computing (MEC) server is highly advantageous in allowing flexibility on the analysis performed on video streams, especially compared with video processing at source (at the camera site). Additionally, it saves the transmission of potentially massive amounts of video streams through the core network to cloud-based services.

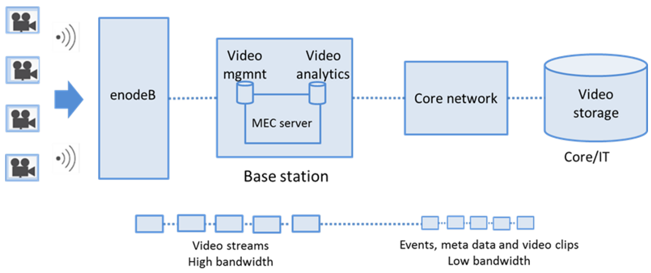

Fig. 5 – Example of video stream analysis

4. 5G IN E-HEALTH CARE

4.1 Opportunities

As an enabling technology for the sharing of data and computing power, the wireless Internet has brought unprecedented changes to many traditional industries including the health-care sector. With 5G on the horizon, ultra-fast and low latency data transmission on the cloud and via the Internet will enable more medical and health applications, which might formerly have been constrained by data volume, computing power, transmission latency or location, become reality. The opportunities brought by 5G to the health-care sector may include, but are not be limited to, the following:

- Data sharing

High bandwidth and low latency data sharing on the cloud enables more pervasive sharing of larger volume of medical data across much wider geographical domains from edge to medical data centers. Data sharing can promote the use of wearable devices, remote monitoring devices, various IoT devices, remote diagnosis and surgery, empowering physicians as well as patients to store, acquire, share and utilize medical data to a much larger extent.

- Computing resource sharing

Low latency and high bandwidth data transmission implies that applications supported by 5G tend to be more distributed and decentralized. Powerful computing resources can be further shared among different entities, making deep mining and processing of medical data possible.

- Intelligence sharing

5G connections not only provide sharing of human expertise via high definition video-based remote diagnosis, but also gather and share machine and human intelligence via machine learning, AI and robotics, exposing best expertise and knowledge to a wide range of institutions.

4.2 Examples

Examples of e-health care applications include remote diagnosis/intervention, long-term monitoring for chronic diseases, remote surgery, and home care with robots. The driving technologies include monitoring devices and systems, robotics, virtual/augmented reality, AI technologies, and data analytics. Here we list a few applications which demand intensive computations, where the high data rate and low latency ensured by 5G may contribute significantly. In addition, the flexibility brought by 5G also enriches the possibilities and coverage of the services.

1. Robotics: Robots have huge potential applications in health care, in particular, home care and surgery. In [9], authors proposed an approach allowing offloading of time-critical, computational-exhaustive operations onto a distributed node architecture, such as the cloud server. The communication between the robot and the cloud server is achieved via a URLLC 5G communication system.

2. Remote surgery: Based on the tele-exchange of medical information, such as image, video, audio via telecommunication networks, remote surgery is a critical application demanding real-time data intensive services. The delay and instability of the network have been the main obstacles of remote surgery. 5G with its fast data transmission rate and low latency communication provides potential for more practical, safer and higher quality remote surgery applications. Lacy et al. [10] presented two proof-of-concept cases of 5G-assisted telementored laparoscopic surgery, where low latency and high quality transmission of videos and voices are demanded. The integration of the surgical robot and 5G enables telerobotic surgery. Zheng et al. [11] treated 12 patients with 5G telerobotic spinal surgery and confirms its efficacy and feasibility.

3. Home care: With the evolution of telecommunication technologies, future health-care services tend to be more distributed, reachable and personalized. Home care and monitoring, traditionally often impeded by a lack of nurses and the guidance of medical professionals, may benefit from 5G. In [12], the authors aim to provide e-health care support to medical emergency first responders by adopting machine learning algorithms to detect the demeanour of a patient on the scene of an incident using Intel RealSense camera system. The implementation and evaluation were carried out in a lab setting. The authors stated the patient condition could be captured and detected at the patient location with 5G mobile edge computing.

5. MEDICAL IMAGING

Medical services such as medical imaging can be substantially enhanced and transformed by 5G technologies [13, 14]. Collaboration between clinical services and hospitals can be promoted by the sharing of medical data and images. Patient empowerment may be achieved by enabling patient access to their health data via cloud services. Experts from different medical branches can cooperate in remote diagnosis and surgery with the support of the cloud and 5G.

Medical images, as one of the most central medical data type, due to its data, storage and computation intensive nature, is an ideal example to demonstrate the importance of 5G and cloud in the medical and health-care sector. In the following subsections, the role of 5G and cloud in medical imaging will be introduced as examples.

5.1 Medical image storage

The storage requirements of modern medical tomography such as Computer Tomography (CT), Magnetic Resonance (MR) and Positron Emission Tomography (PET) images are demanding as many slices representing part of the 3D body are scanned in one study. Moreover, with the rapid renovation of medical imaging techniques and devices, the spatial and temporal resolution of medical images are being constantly improved, leading to the considerable increase of image size and the surge of storage demands. In addition, multi-modal tomography study and processing is a common practice today [15], implying that more storage is needed for a single study.

5G-based cloud will provide faster, more pervasive and reliable means for storage and the sharing of huge medical image datasets, satisfying the massive data storage demand. It also provides distributed services to query and access this data remotely.

5G also encourages the sharing of medical images between different entities such as hospitals, physicians and even with patients is possible. With reuse and distributed access of medical images boosted, unnecessary imaging studies can be avoided, leading to further savings of time, labour and cost, as well as a reduction of radiation dosage for patients.

To summarize, 5G-enabled medical imaging solutions are more cost effective and convenient for data storage and have better accessibility to physicians and patients. 5G-based fast data acquisition will further improve the efficiency and user experience of cloud-based storage.

5.2 Medical image analysis and AI

Medical image analysis, including segmentation, registration, classification, reconstruction, and visualization are heavily dependent on machine learning and AI algorithms. More intelligent medical image processing and analysis is the future as it complements human expertise with machine intelligence. The wide application of AI together with 5G and cloud computing may significantly change the future of medicine and health care [16].

The training of AI algorithms are typically data and computing intensive. In the past decade, deep learning has been proven to have better performance over most traditional machine learning algorithms on a variety of tasks such as image segmentation, classification, and synthesis, image and voice recognition, text analysis, text-to-image conversion, etc. The wide application of deep neural networks especially deep Convolutional Neural Networks (CNN) on medical image processing has been studied by many researchers [17]. As most medical image data are essentially 3D, the widely employed deep learning models for medical image segmentation, registration and classification are more data and computing intensive. Deep learning needs to leverage massive datasets to infer a convincing model, which makes them very suitable for cloud storage platforms. Moreover, deep learning requires high-end GPU computing powers which makes them suitable for GPU clouds. With faster access to and reduced costs of cloud storage and computing resources via 5G-powered clouds available, it has become more accessible to analyze medical images using deep learning mod- els with the cloud. In addition, with the support of 5G, integrated data analysis of medical image data, Electronic Health Record (EHR) data and even data from wearable monitoring devices are made possible, which may produce better mining results and new insights.

5.3 Visualization and Virtual Reality (VR) / Augmented Reality (AR)

The result of medical image analysis often needs to be presented by visualization. Medical image analysis and visualization inherently are analysis and visualization of human or other biological tissues and structures. Medical images represents 3D spatial structures by a series of 2D slices with which radiologists traditionally reconstruct the 3D anatomies in their mind. However, with the advancement of VR and AR technologies as well as the revolutionary advances in graphic hardware, 3D volume data can be visualized at interactive rates, benefiting 3D medical applications, remote visualization and diagnosis.

5G plays a critical role in medical VR/AR applications to provide fast access and processing of data. On one hand, the reconstruction and visualization time can be reduced or even achieved in real time. On the other hand, the data can be stored closer to the end user via edge computing and transmitted much more quickly, making interactive or even real-time analysis, reconstruction and visualization possible. The empowerment of 5G will move more medical image visualization capabilities to the user end, even to portable devices, freeing them from location and computing power constraints.

5.4 An example application

[18] presents a hybrid operating room, equipped with advanced imaging systems, such as fixed C-arms (X-ray generator and intensifiers), CT scanners and MR scanners. Key requirements of the operating room are listed as follows:

1. Ultra-high resolution video: generated by endoscopes which produce up to 8K uncompressed (or compressed without quality loss) video. It supports High Dynamic Range (HDR) for larger colour gamut management (up to 10 bits per channel), as well as HFR High Frame Rate (HFR), i.e., up to 120 frames per second. The graphics allow surgeons to distinguish small details like thin vessels and avoid any artefacts that could potentially induce surgeons to make wrong decisions.

2. 2D ultrasound images: 2D ultrasound requires a data rate of 160 Mbit/s up to 500 Mbit/s. The data stream includes uncompressed images of 512x512 pixels with 32 bits per pixel at 20 fps (up to 60 fps in the fastest cases).

3. 3D ultrasound volumes: Dedicated 3D probes require higher data rates, i.e. above 1 Gbit/s of raw data, and are expected to reach multi-gigabit data rates in the future. That is 3D Cartesian volumes of 256 x 256 x 256 voxels each encoded with 24 bits at 10 volumes per second.

4. CT/MR scans: Images can range from a resolution of 1024x2024 to 3000x3000 pixels where higher resolutions are used for diagnosis purposes and lower ones are more suitable to fluoroscopy. The frame rate is typically at 5 to 30 frames per second. Higher rates are possible in order to monitor moving organs in real time.

6. SUMMARY OF 5G BENEFITS TO HEALTH CARE

[19] summarizes the benefits brought by 5G in various sectors, Table 1 lists benefits to the health-care sector.

Table 1 – Benefit examples drawn from verticals - the health-care sector

Benefit categories	Benefit examples drawn from verticals
Society critical	Enable fully and connected digitized emergency ambulance operations, ambulance teleguidance, ambulance routing; save lives through e.g. smart wearables; life-saving applications, e.g. wireless operating room calling on remote experts; Video application for health purposes.
Quality increase	Smart wearables for health monitoring, emergency localization, and secure access to patient records.

The indicative list in Table 2 is a compilation of key 5G features used in the specific projects. The number of 5G features depends on the number of projects that have been active in a specific vertical area. Although in principle all 5G features can be used to support a vertical sector, the list provides a snapshot of what the most important 5G features could be at this moment.

Table 2 – Demonstrated and planned 5G functionalities in verticals

5G Features	Health care
Network Slicing	Three types of network slices have been specified by 3GPP so far, namely eMBB, URLLC, mMTC. Up to 256 such slice types can be allocated in the current 3GPP Release 16 specification
Quality increase	Smart wearables for health monitoring, emergency localization, and secure access to patient records.
Mobile Edge Computing	High intensive computation demand for imaging process, AI, AR/VR, etc. will be processed at the edge that is close to the applications. It reduces the transmission time. In addition, edge node provides better computation and memory facilities.
Smart network management	Splitting of control plane and data plane ensures that the network resources can be better controlled at the control plane. In addition, intelligence can be applied to manage the network resources. With smart management, applications can be delivered based on Quality of Service (QoS) requirements. Automated mechanisms are provided to allow fast and easy deployment of network slices along with the necessary network and computing resources.
Location services & Context Awareness	Identifying exact location is one example for context awareness. This is essential for some health-care applications, for example, ambulance services or response to call from home care. High-accuracy localization not only fulfils the demanding QoS of 5G and beyond 5G, but also enhances the intelligence of user applications.
5G NR(New Radio) capabilities	With the new radio technologies, the access method of the 5G terminals for health care will be enhanced.
Softwarization	Softwarization enables flexible management of network resources. Decoupling the network functions from its hardware insulates applications from hardware changes and shortens the time needed for application deployment. It eases management of network resources.
Service chaining	The service chain concept composes and imposes the order in which service functions are invoked for a particular service. SDN and VNF support the dynamic creation and management of service function chaining. It enables efficient utilization of the network resources to meet requirements for health-care applications where heavy computations are involved, such as the processing of medical images.
Guaranteed QoS	Quality of service needs to be guaranteed for various application requirements, such as low latency, large data rate, or real time. Health care is no different from other applications, and therefore, QoS requirements need to be met.

7. CONCLUSION

As an enabling technology for the sharing of data and computing power, the wireless Internet has brought significant changes to many industries including the health-care sector. With 5G on the horizon, ultra-fast and low latency data transmission on the cloud and via the Internet will enable more intelligent and interactive e-health applications. This paper presents a summary of 5G technologies and their related applications in the health-care sector. 5G will transform traditional wireless computing to allow larger data volume to be accessed more quickly and easily for health-care applications. Employment of mobile devices and IoT devices will be encouraged by 5G technologies and interactive applications will become more prevalent. Furthermore, medical analytics based on data mining and deep learning will also benefit from 5G-powered techniques. For future health-care services 5G may not only mean faster data retrieval and storage of larger datasets, but it might also revolutionize the whole health-care industry by distributing more reliable services via 5G-powered clouds, decentralizing traditional roles of hospitals and physicians. Community-based and patient-oriented healthcare services might benefit from 5G-powered remote diagnosis and IoT sensors. More accurate analysis and diagnosis can be achieved with larger datasets and better computing power. To conclude, 5G technology will be one of the most critical driving forces for transforming the health-care industry in the coming years.

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