SUMMARY For many countries in the world, 5G is of strategic significance. In the 5G era, telecom operators are expected to enable and provide multiple services with different communication characteristics like enhanced broadband, ultra-reliable and extreme real-time communications at the same time. To meet the requirements, the 5G network essentially will be more complex compared with traditional 3G/4G networks. The unique characteristics of 5G resulted from new technologies bring a lot of opportunities as well as significant challenges. In this paper we first introduce 5G vision and check the global status. And then we illustrate the 5G technical essentials and point out the new opportunities that 5G will bring to us. We also highlight the coming challenges and share our 5G experience and solutions toward 5G vision in many aspects, including network, management and business.

key words: 5G, communication service, network management, operations support system.

1. Introduction

According to the 5G vision [1] put forward by NGMN (Next Generation Mobile Networks Alliance), it is suggested that 5G is an end-to-end ecosystem and it is not only to provide connected network facilities, but also to create value for customers and partners, to support existing and emerging use cases as well as sustainable business models. 5G is expected to be applied in various situations, serving all works of life. Therefore, many countries around the world believe that 5G has strategic importance. 5G not only opens a new generation of wireless systems, but also plays an important role in smart life evolution.

For 5G standards, the NSA (Non-Stand-Alone) 5G NR (New Radio) specifications were first delivered in late 2017. The NSA specifications aim to leverage 4G LTE core networks so that operators can rapidly deploy NR base stations without the need of introducing a new 5G core network. Later, the scope of Release 15 [2] NR specifications expands to cover SA (Stand-Alone) 5G that requires a next-generation core network. While Release 15 NR specifications are mainly designed for eMBB (enhanced Mobile Broadband) applications, the second (Release 16) and third (Release 17) phases of 5G are developed to better support mMTC (massive Machine Type Communications) and URLLC (Ultra Reliable Low Latency Communications) services. Currently the Release 16 [3] specifications were completed in June 2020 and the Release 17 specifications are scheduled to be published by March 2022.

In addition to the 5G standardization, we introduce the global 5G network status as follows. According to the GSA (Global mobile Supplier Association) report [4] in October 2021, a total of 180 operators in 72 countries have launched 5G commercial services. The superiority of 5G has also been demonstrated by real-world measurements. The Opensignal report [5] in September 2021 shows that the global average download speed of 5G compared to 4G has achieved a remarkable improvement of 438.2%. The improvement of 5G global average uplink speed compared to 4G has also reached 116.9%. Consequently, the significantly improved user experience has stimulated more mobile data consumption. As shown in [6], 5G consumes up to 2.7 times more data than 4G (globally). Taking Taiwan as an example, the average monthly 5G data consumption per user reached 47.3 GB, far exceeding the 4G data usage of 26.9 GB.

The 5G networks lay the solid foundation for nourishing innovative 5G applications towards customers and enterprises.

2. Technical Essentials of 5G

Many key technologies are introduced in all aspects of 5G, including the radio access network, the core network, the transport network, and the management. In general, 5G network basically is softwarized and cloudified so it can benefit from IT (Information Technology) and cloud features like the agility and flexibility in deployment, configuration, intelligent operations and recovery. The overall 5G technical essentials are illustrated in Fig. 1 and will be elaborated as follows.

2.1 5G Radio

From the specification perspective, 5G radio introduces several new elements that were not used in 4G, including higher frequency and the use of massive MIMO (Multiple-Input and Multiple-Output). Before 5G, the operating frequencies used by mobile networks were almost below 3 GHz. 5G extends the operating frequencies to the higher band above 3 GHz (e.g., 3.5 GHz) and even to the mmWave band (e.g., 28 GHz). Higher frequencies bring the benefit of wider bandwidth. For example, the bandwidth of a single 5G
carrier is 100 MHz, which is 5 times the bandwidth of a single 4G carrier. Wider bandwidth implies higher data rate. In addition, 5G introduces the massive MIMO technology. Massive MIMO can concentrate the transmit power of a base station towards the desired target user, so that the user’s received signal quality can be improved. And unlike D-RAN (Distributed Radio Access Network) architecture that dominates 4G, both C-RAN (Cloud Radio Access Network or Centralized Radio Access Network) and D-RAN architectures are considered for cellular network in 5G.

Recently, the industry is also exploring Open Radio Access Network called Open RAN or O-RAN, which intends to open the interfaces of base station functions and leverage cloud and AI technologies [7] to increase the flexibility of 5G radio network deployments and reduce CAPEX (Capital Expenditure) and OPEX (Operating Expense).

2.2 5G Core

5G core network has several key features. First, it introduces CUPS (Control and User Plane Separation) and MEC (Mobile Edge Computing), which bring the data processing capability closer to the client side and provide great improvement on latency and security. Second, SBA (Service-Based Architecture) is introduced in the 5G SA (Standalone) core network. Core network elements are deconstructed into various NFs (Network Functions). Each NF service is connected to each other through an SBI (Service Based Interface). And using virtualization and cloud technologies, core networks can be established in the way of deploying VNF (Virtualized Network Function) or CNF (Cloud-native Network Function) on-demand. In this way, network and hardware resources can be configured and used more flexibly and efficiently. In addition, network slicing and service chaining for specific service can be achieved by using SDN (Software Defined Networking) and NFV (Network Functions Virtualization) technologies.

2.3 5G Transport Network

To satisfy diverse transmission requirements associated with 5G networks, the transport network should support the corresponding functionalities. Due to smaller coverage of the gNB (or gNodeB), the number of 5G base stations is several times than that of 4G base stations. Thus, in general, more fibers are needed for 5G network deployment. In addition, to frequency synchronization, due to 5G’s TDD transmission characteristics, 5G transport networks should also support time synchronization protocols. In the past, 4G network traffic were generally P2P (Point-to-Point) from eNB (evolved Node B) to core network, but 5G network traffic includes local breakout for MEC, local switching between gNBs, and gNB to core network, etc. Therefore, 5G transport networks should support A2A (Any-to-Any) transmission capability. Additionally, the 5G transport networks should be able to support both services of 5G mobile and fixed networks to improve the overall network resource utilization efficiency and reduce network operation costs. Then, to flexibly utilize network resources and support more efficient transmission of diverse services, 5G transport networks should make use of SDN to strengthen network intelligence, support provision flexibility and enhance traffic engineering.

2.4 5G Management and Orchestration

The virtualization and containerization technologies have been applied to 5G cloud network components to support fast-customized network services. Currently, 5G network components are most likely to be container-based (i.e., CNF) or VM-based (i.e., VNF) to support 5G cloud networks. Generally, 5G cloud management and control include the onboarding and flexible remote deployment of VNFs/CNFs and virtual applications. In addition, operators need to support lifecycle management of 5G network components as well as the service operations.

Compared to previous generation networks, E2E MANO is one of the essential changes to 5G. E2E MANO aims to optimize Quality of User Experience (QoE). Working with heterogeneous resource orchestrators, it is needed to manage network slicing for various services with different communication characteristics in one physical 5G network. E2E MANO also plays a key role for intelligent network management and operations. It leverages a variety of AI/big data analysis techniques, including machine learning, deep learning, and data mining on a large amount of run-time data. For example, MANO can utilize the run-time data to predict the possible cause of service outage or degradation. The target is to enable largely autonomous networks, which will be capable of self-configuration, self-monitoring, self-healing and self-optimization without further human intervention.
3. New Opportunities

Every generation of wireless systems has its own representative industries and companies. Network equipment vendors and operators were at the center stage in the 1G era. The feature phones and the corresponding supply chain like Qualcomm and Nokia became dominant in the 2G era. The smartphones and their suppliers like Apple start to rise in the 3G era. And the OTT riding the mobile network reaped most benefit in the 4G era. Currently in the 5G era, there are also numerous opportunities open for new players.

3.1 New Industry Opportunities

In general, 5G introduces many IT technologies, and that helps openness and network disaggregation for preventing vendor lock-in (i.e., locking in one vendor’s proprietary solutions). In this way, more players can join the supply chain to increase the flexibility and diversification.

More specifically, 5G involves the combination of CT (Communication Technology), IT (Information Technology) and OT (Operation Technology) technologies. Therefore, in addition to the communication network itself, plus all possible new applications, it brings many new industry opportunities as illustrated in Fig. 2. For example, network virtualization and openness have paved the way for new equipment vendors such as Altiostar and Affirmed. Network cloudification brings hardware and software cloud vendors into the network equipment supply chains. Hyperscalers such as MS, Google and AWS have entered the telecommunications industry to provide core and edge cloud solutions. Moreover, the 5G private network policy allows enterprises such as Bosch (German private operator) to build their own 5G networks and become private operators. System integrators such as Cisco have emerged to offer total turn-key solutions to enterprises. New-type terminals such as electric vehicles (e.g., Tesla), VR glasses (e.g., Oculus), and robots (e.g., Pepper) are also likely to become 5G killer devices.

3.2 New Service Opportunities

5G’s features such as high data rate, low latency and massive connections and other characteristics, coupled with its open, cloud-native and dynamic network-slicing characteristics, make it easier to integrate with emerging technologies. For example, 5G can integrate with microservices, edge computing, artificial intelligence, big data, internet of things, augmented and virtual reality, etc., to create new applications and services. Based on the development schedule of the 5G standard, we expect that there will be three waves of 5G applications and services.

- For the first wave, eMBB takes the lead. The eMBB services focus on consumer entertainments which need high bandwidth, such as high-quality streaming, multi-angle-view video services, virtual concerts and cloud gaming.
- The second wave is for mMTC applications. A large scale of various sensors, meters and cameras can be widely deployed to collect information (or images) for different kinds of vertical domains. The vertical applications include smart city, smart metering, smart agriculture, smart security, etc.
- The third wave is about URLLC. The URLLC applications are brand-new in specific domains which need ultra-low latency. The URLLC applications often integrate with new types of devices, e.g., drones, self-driving cars and specific medical equipment.

In general, 5G enables cross-domain integration and provides unlimited space for innovation.

4. 5G Challenges and Solutions

4.1 5G Radio Challenges and Solutions

The high operating frequency of 5G creates challenges for base station deployment. Due to the radio propagation characteristics, the coverage area of 5G base stations becomes smaller than that of 4G base stations. The coverage radius would be even smaller when 5G uses mmWave frequencies. One possible solution for operators is to use parts of their legacy 3G/4G spectrum for 5G. In this way, 5G can use frequencies above or below 3GHz, and thus can take the advantage of high throughput without reducing the coverage too much.

The second challenge is about the power efficiency. Compared to 4G networks, 5G base stations usually consume more power (due to the use of massive MIMO technology). The antenna of massive MIMO is an active component that needs to consume much power. More antenna elements, e.g., 128 TR antennas, can achieve better performance while having higher power consumption. To overcome the problem, our solution is to carefully choose the appropriate size of antenna elements that can provide good enough performance without consuming too much power.

4.2 5G Edge Computing and Core Challenges and Solutions

As mentioned in Section 2.2, MEC is a key feature of the 5G core networks. As the foundation of 5G, MEC provides computing and storage resources close to end users,
and realizes high-bandwidth and low-latency services. It is expected to bring many new business opportunities and vertical applications, such as IoT, smart factory, AR/VR, facial recognition, self-driving cars, etc. Normally MEC is located between the BS and the mobile core network, and the generic architecture of MEC is illustrated in Fig. 3. The “Data Plane Function” in MEC provides a “local breakout” service. Customers can use this kind of service to access the applications deployed in MEC. MEC is generally utilized to provide 5G private network services. Different from other single-service approaches, 5G private network is an end-to-end multi-service solution, including cloud platform, data plane function and diverse applications. Specifically, a cloud platform can provide remote on-demand deployment and lifecycle management of virtualized services, e.g., VNFs, CNFs and vAPPs. A data plane function can connect to a mobile network and provide the local breakout function. The diverse applications can be provided by telecom operators, cloud service providers, third party vendors or the customers themselves.

Integrating technologies from different fields into one system is a challenge. We achieved this goal through our different-domain R&D teams working together. We have self-developed cloud platform, the software-defined 5G data plane functions [8] as well as the corresponding MANO. We continuously conduct the integration and accumulate the experience. We also have a variety of our own applications and keep cooperating with various application providers to provide suitable application services according to customers’ requirements. In addition, to help customers build on-premises private network services and maintain stable operation is also a challenge. We take advantage of our rich experience in service construction and maintenance to assist customers properly design the deployment including the equipment, the network and the environment. Then, the services in accordance with the planned content were built. A centralized management system for the whole was also built and it was capable to maintain and operate multiple private networks through a single portal. Besides, there was a dedicated team to perform maintenance tasks to ensure the normal operation of the services.

The POS (Proof of Service) were conducted in our 4G/5G NSA commercial network in Taiwan. In addition, some of the functions and applications were also presented at MWC (Mobile World Congress) 2018 and 2019.

4.3 5G Transport Network Challenges and Solutions

The challenges faced by the 5G transport networks, and the corresponding solutions are described as follows. The first challenge is the massive fiber requirements. Because the signal coverage of a 5G base station is much smaller than that of a 4G base station, the number of 5G base stations is several times than that of 4G base stations. Accordingly, the demand for fiber cores (connecting the base stations) will increase. Also, 5G usually adopts the C-RAN architecture. The number of C-RAN fiber cores grows with the number of active antenna units. Compared with the traditional D-RAN architecture, the demand for fiber cores will increase by about 10 times. Taking a 5G base station with 18 active antenna units as an example, each antenna needs 2 fiber cores (for transmitting and receiving), and it will require 36 fiber cores. To tackle this challenge (for massive fiber-core requirements), our solution is to design a passive optical component called EC (External single fiber bi-directional wavelength Conversion module) and integrate it with CWDM (Coarse Wavelength Division Multiplexing) to greatly reduce the number of fibers required. For the example given above, 2 fiber cores are enough for the 18 antenna units. In addition, after we applied the self-developed EC component, it only needs 1 fiber core. In this example, the 36 fiber cores become 1 fiber core, and the reduction rate can be more than 90%.

The second challenge is the any-to-any transmission. 4G networks use peer-to-peer transmission, i.e., the UE traffic must be directed to the 4G core networks to access application services. In contrast, with diverse applications associated with 5G, the any-to-any connectivity is inevitable. For example, a private 5G network can adopt MEC architecture to access the services nearby. Also, V2X (Vehicle-to-Everything) applications can be interconnected with each other to meet the low-latency requirements. Therefore, the 5G transport network must be able to provide any-to-any transmission. For this challenge, we introduce IP-based technologies with SDN features to attain the objectives. Specifically, the 5G transport networks can support time synchronization protocols and meet stringent transmission delay needs. Moreover, to simplify network architecture, the transport networks carry both the 5G applications and fixed-network-broadband services. For the any-to-any connections, our solution can support the provision of flexible paths, and thus can effectively enhance the utilization efficiency of overall network resources.

4.4 5G Management Challenges and Solutions

4.4.1 5G Cloud MANO

5G brings new radio and core technologies to meet the needs of large bandwidth, massive connections, and low latency. However, 5G has also accelerated the challenges of network management, and there are still many challenges in 5G management with cloud MANO.
The first challenge is about the vendor-lock-in issues of the cloud MANO modules and VNFs/CNFs. It causes the problem of efficient allocation of cloud resources. Also, it increases the cost of automation for the 5G cloud MANO. In addition, it limits the flexibility of VNFs/CNFs deployment, and increases the overheads of the multi-vendor VNFs/CNFs integration for telco operators. To tackle this challenge, we proposed the 5G E2E MANO to realize the flexible deployment and efficient resource allocation of VNFs/CNFs, as shown in Fig. 4. We use NUMA (Non-Uniform Memory Access)-aware resource allocation to provide advanced resource management in the 5G edge cloud. It improves the efficiency of resource allocation and greatly accelerates the utilization of cloud environment deployment and management. 5G E2E MANO can also manage and configure CNFs/VNFs in the 5G core cloud to achieve the automation of 5G Cloud MANO management. By using 5G E2E MANO, we can offer different levels of automation and support the multi-vendor VNFs/CNFs integration.

The second challenge of 5G cloud MANO is the remote deployment and management of VNFs/CNFs and virtual applications for different edge clouds. More specifically, to meet the requirements of remote fast deployment in the cloud, the remote VNFs/CNFs and VM (Virtual Machine) images deployment (and the extension of the VNFs/CNFs onboarding) in the 5G cloud MANO environment need to be considered. In response to this challenge, we proposed the VNFs/CNFs and virtual applications onboarding management to effectively manage and dynamically deploy the virtual applications. Our solution can provide on-demand service deployment of virtual applications, and support 5G User Plane Functions (UPFs) deployed near the client sites and connected to the operator’s core network to implement low-latency applications.

4.4.2 5G Cross-Domain E2E Orchestration

Before elaborating on 5G cross-domain E2E orchestration challenges and solutions, we first provide a blueprint for E2E orchestration. Specifically, the E2E orchestration includes three end-to-end operation processes, and they are “Operations Support & Readiness”, “Fulfillment” and “Assurance”. Each operation process involves at least two aspects, e.g., customer relationship management, service management (SM), and resource management (RM). The challenges of 5G cross-domain E2E orchestration mainly lie in how to optimize performance by designing appropriate processes of readiness, fulfillment and assurance. We will discuss the corresponding challenges and our solutions as follows.

The first challenge for 5G E2E orchestration is the design of operations support and readiness processes. The processes are in charge of the management of service and resource infrastructure. More specifically, the processes have to ensure that proper services and resources (i.e., the computing and networking resources) are available to support the fulfillment and assurance processes. Using manual operation to assign resources is inefficient (i.e., time-consuming) and also prone to errors due to the messy resource configuration. To tackle the above challenge, we implemented the corresponding solutions in the network resources provisioning and management system. In order to successfully complete large-scale processes, it is essential to introduce automated allocation operations. In addition, to reduce the cost of resources (such as cables), the distribution path should be as short as possible. Accordingly, our implementation methods leverage graph theory [9] to automatically find the shortest available path in 4G/5G mobile networks. Considering the network architecture, we have designed a DFS-based (Depth-First-Search-based) [10][11] solution for path allocation (i.e., resource allocation). In our solution, for each part of the path, it needs to refer to the neighbor-relationship data (from the inventory) between network devices. The path-searching method keeps searching for available devices until the available path is complete or no available path is found. From the experience of our implementation, the key is to strike a balance between efficiency (of the operations support and readiness processes) and complexity (of the path-searching algorithm).

The second challenge for 5G E2E orchestration is the issue of the fulfillment processes. The fulfillment operation processes are responsible for “order handling”, “service configuration & activation” and “resource provisioning”. As mentioned in Section 2.3, 5G networks need to support any-to-any transmission. Hence, the service requirements and the corresponding technical requirements of 5G networks are higher than those of 4G networks. To deliver services, telecom operators must finish provisioning of network elements in a short time, and this is exactly the challenge. To deal with this challenge, we implemented an automatic provisioning solution in Taiwan’s pre-commercial 5G network (Q3 2020 [12]). The automatic provisioning system consists of three parts. First, the service provisioning management system provides northbound APIs (Application Programming Interfaces) for other OSSs (Operations Support Systems) to connect. It is responsible for receiving service provision data (of customers), including service type, service priority, device type, IP address, VLAN ID, port...
number, etc. Then, the provisioning job dispatch subsystem transforms the data into objects (based on object-oriented structures). These objects are dispatched to the provisioning configuration subsystems. Eventually, the provisioning configuration subsystems would connect to network elements and set the configuration (to the network elements).

At the end of 2021, our provisioning solution supported approximately 25,000 5G circuits, 4,500 5G base stations, and 600,000 5G users in Taiwan. It is worth mentioning that in the past, it took about 5 minutes to manually set the provisioning commands; currently, it only takes about 10 seconds by using our automatic provisioning system.

The third challenge is the assurance part, and is about how to be as cost-effective as possible. In the 5G era, the network architecture is composed of many heterogeneous devices. The complex infrastructure means that the telecom operators would need to pay a high cost to solve network problems. To trace the root cause of network faults, network maintenance staffs have to spend much time. In order to solve the above problem, we proposed an intelligent fault-location solution in 2021 [13]. Our solution can assist network maintenance staffs in decision-making, increase automation, and reduce the costs. In our solution, multiple intelligent algorithms are utilized, e.g., the Ant Colony Optimization (ACO) and fuzzy logic methods. We apply ACO to derive network devices’ pheromone concentrations, which represent the health statuses of the devices. For instance, if a large number of users report faults about certain network circuits, the pheromone concentrations of the related devices will increase abnormally. In addition, to diagnose the network faults in a short period of time, we apply the fuzzy logic methods [14][15]. These methods can calculate the probabilities of fault locations within a short time period. The intelligent fault-location solution has been applied to manage many kinds of devices and services where the number of customers are more than 3,000,000. The solution can also effectively reduce OPEX for more than 530,000 person-hours per year.

Our E2E MANO solution suite is developed on the basis of the international open API standards [16]. The cross-functional collaboration is based on the TM Forum Open Digital Architecture (ODA) [17], which makes it highly interoperable. To demonstrate the E2E orchestrator, we take an open 5G private network R&D (Research and Development) project as the implementation example, as shown in Fig. 5. We initiate this project in 2021. For an E2E 5G service, we need to consider many cross-domain issues. Therefore, to achieve the end-to-end goal, our domain experts from different laboratories work together and collaborate with each other. As to be open, to establish the E2E solution, there are many possible combinations, as illustrated in Fig. 5. Taking these combinations into account, we establish an Open Lab for the interoperability testing of different vendors’ products. This R&D achievement will be used in the National Asia Silicon Valley Development Agency Project (ASVDA). In addition, combined with different applications, we will deploy open private 5G networks in at least three cities for filed verification and demonstration.

5. 5G Applications

5.1 5G Business Challenges

In the 5G era, in addition to the technical challenges as described in Section 4, sustainable business operations also bring significant challenges. First, for the diverse 5G applications in different vertical fields, the establishment of an end-to-end ecosystem is always not easy. The main reason is that it involves in-depth conversation, trust and collaboration in several completely different fields. Second, due to the introduction of a large number of software features/functions in 5G, hyperscalers such as MS, Google and AWS also intent to enter the telecom field and may become strong competitors. Third, since many 5G vertical applications are new, the monetization and business models are still open issues.

To cope with these challenges, we are committed to supporting always broadband-connected communications, and have begun a network-transformation journey for softwareization and cloudification. In terms of ICT (Information/Communications Technology) infrastructure, several platforms which have build-in capability of IoT communications, big data processing, AI, AR/VR, cloud scalability and cybersecurity were built to become the enablers for 5G business innovations. More specifically, the platforms include video platform, AI platform, IoT platform, AIoT edge platform and AR/VR platform and can be used in combination. They accelerate the delivery of new applications and are widely used in various vertical domains.

As shown in Fig. 6, we adhere to the customer-centric starting point, and integrate 5G with AI, AIoT, big data, AR/VR, cloud, security and other technologies to assist enterprises in digital transformation. We also cooperate with various industries to promote diverse vertical applications, such as smart entertainment, smart manufacturing, smart
transportation, smart healthcare, etc. These 5G applications can be classified into at least three categories: B2C (Business to Customer), B2B (Business to Business) and B2B2C (Business to Business to Customer) applications. We will provide the corresponding information of the applications in the following subsections.

5.2 5G B2C Applications

We have been actively building ecosystems in various fields and launching a variety of new services, including many 5G B2C applications. For example, based on our video platform, and cooperating with content operators and AR/VR terminal companies, in July 2021, for the first time, we launched 4K VR live-video services for Tokyo 2020 Olympic Games. The VR services can offer immersive experiences through 5G networks and VR terminals.

As shown in Fig. 7 (a), cloud gaming is another example of 5G B2C applications. We cooperate with gaming platform and game content creators to launch 5G cloud gaming services. Currently, there are hundreds of games on our cloud, and customers can play a game remotely by using their own computers and mobile phones (with Android/iOS). Besides, lossless Hi-Fi (High Fidelity) music with FLAC (Free Lossless Audio Codec) format are supported. These applications take full advantage of 5G high-bandwidth and low-latency characteristics.

5.3 5G B2B/B2B2C Applications

In addition to B2C applications, many innovative 5G applications are B2B or B2B2C applications. For instance, we cooperate with Taiwan machine tool alliance (called TANGRAM) and leverages 5G technologies for smart manufacturing. Our AR/VR platform and IoT platform have been used to build applications for several use cases, such as machine tool display and sales, education and training, maintenance and repair, and remote collaboration.

As shown in Fig. 7 (b), smart transportation is another example. We cooperate with self-driving car companies to develop smart transportation applications, which provide public transportation services on several open fields. Specifically, there has been a self-driving bus shuttle service for public transportation in the 1.2-kilometer field in New Taipei City (Taiwan). A smart management system was built in the traffic control center to constantly monitor the driving statuses, including the real-time images of self-driving buses, intersections and intersection signs (i.e., the traffic lights). The Road-Side Units (RSUs) send information to the self-driving On-Board Units (OBUs) as a reference for self-driving decision-making to improve the traffic safety (of the intersections). Besides, we also cooperate with hospitals to build 5G ambulance systems and 5G private networks at emergency rooms to provide smart-health applications. Based on the examples of 5G applications, we realize that 5G services involve many cross-domain integrations.

6. Organization and Culture

We mentioned many technical and business challenges, but beyond that, there are still organizational and cultural challenges. End-to-end 5G services involve more cross-domain integrations which may be quite different from the past; therefore, it is necessary to overcome the silos of both the technical domains and the organizations. Telecom operators should shape the organizational culture to become customer centric, cross-domain collaborative, and agile. 5G continuously introduces many emerging IT technologies. To keep up with the pace, the digital literacy of the entire organization also needs to be improved. Accordingly, facing 5G era and aiming at business growth and better performance there are many actions for both organizational and cultural transformation need to be elaborated and taken.
7. Conclusions

In this paper, we provide useful information about the 5G: (1) opportunities, (2) challenges, and (3) solutions. Before realizing the 5G vision, there are still many issues and a lot of work to be done, e.g., transforming the network to an open, cloud-native, software-based, and autonomous network, seeking more innovative applications, making more vertical industries engaged, and exploring sustainable business models. In the 5G era, the authors adopt the 3C principle, namely, Change, Challenge, and Chance. More specifically, although many “changes” have taken place and new “challenges” are constantly emerging, we are still looking to the bright side and looking for new “chances”. We conclude that there is no single solution that can overcome all 5G challenges. Our solutions in this paper are practical, and are expected to help researchers explore more advanced solutions in the 5G era. In the future, we will continue to investigate the design of different network management solutions for 5G and beyond.

References


Chien-Chi Kao received the Ph.D. degree in Computer Science from National Tsing Hua University in 2014. From 2013 to 2014, he was a visiting student in Technische Universität Berlin, Germany. During 2015-2017, he was an Assistant Professor in National Taiwan Ocean University. Since 2018, he has been with Chunghwa Telecom, where he is now a researcher. His research interests include network management and algorithm design.

Hey-Chyi Young has joined Chunghwa Telecom for more than 30 years and is currently the Vice President of Telecommunication Laboratories (TL). She has extensive experiences in telecommunication management field. She previous led Network Management Lab as well as Cloud Computing Lab in TL. Under the lead, her team developed many important operations supporting systems providing auto-provisioning and quality assurance functions for Chunghwa Telecom’s broadband and public cloud services. She also played a key role in CHT NGOSS program which aimed at the consolidation and integration of many originally silo and function overlap OSS/BSS. This program successfully resulted operations automation and had a huge improvement on CAPEX/OPEX saving, operations efficiency and customer experience. She currently is mainly in charge of the R&D of ICT infrastructure and devotes herself to the integration of multi-domain technology for digital transformation of telco, including 5G network, software defined ICT infrastructure, end to end service and network orchestration, zero-touch intelligent operations, etc.