Network Slicing in Software DefinedNetworking for 5G

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Abstract

Network slicing stands out as a crucial feature of software-defined networks (SDN), playing a pivotal role in the deployment of 5G networks amid the current era of technological advancement. This capability empowers operators to manage multiple virtual networks atop a shared physical infrastructure. Service providers can thereby segment their network resources into distinct logical networks, each tailored to meet the specific requirements of diverse users or services. As 5G deployment progresses, network function virtualization (NFV) and software-defined networking (SDN) are poised to steer the implementation of network slicing. In this review, I provide an overview of SDN in the context of 5G, exploring the role, motivation, and recent advancements in network slicing. The review further delves into the application scenarios of SDN within network slicing for 5G. The proposed architecture for network slicing in software-defined networking (SDN) for 5G networks encompasses three key usage scenarios: enhanced mobile broadband (eMBB), ultra-reliable low-latency communications (URLLC), and massive machine-type communications (mMTC). Conclusively, this report outlines challenges and suggests future research directions focused on network slicing in the context of 5G.

Introduction

The evolution of mobile communication technologies has undergone a significant transformation, particularly with the transition to 5G, leading to a paradigm shift in network architectures. This evolution has been marked by the integration of Software Defined Networking (SDN) with 5G, resulting in the emergence of the innovative concept of Network Slicing. Network Slicing, a critical development in this landscape, entails the creation of virtual networks customized for specific applications or services, providing a flexible and efficient means to address diverse connectivity needs. According to the Third-Generation Partnership Project (3GPP) and the IEEE Computer Society, key technologies crucial for realizing the goals of 5G, including network slicing, SDN, NFV, IoT, Cloud, ML, and Big Data, have been identified. These technologies aim to meet the escalating demands from end-users while reducing capital and operational expenditures. The deployment of 5G networks is deemed crucial to accommodating diverse industrial use cases and enhancing overall network performance, surpassing the limitations of existing mobile networks in delivering varying levels of quality of service (QoS) to customers.

In recent decades, pivotal technologies like software-defined networking (SDN) and network function virtualization (NFV) have been introduced, becoming core elements for software development, virtualization technologies, and the implementation of network slicing in 5G networks. Network slicing plays a pivotal role in the 5G network by enabling developers to construct segregated logical networks on a physical infrastructure to cater to diverse user needs with different service specifications. The evolution of generations for network slicing in 5G, illustrated in Fig. 1, showcases its progressive development.

The journey began with the first generation of mobile communication technology, 1G, in 1980, relying on analog technology primarily for voice calls. Subsequent generations introduced digital technology, supporting text messaging and basic data services (2G), high-speed data capabilities enabling mobile internet and multimedia services (3G), and even higher speeds and lower latencies facilitating advanced applications like video streaming and online gaming (4G). As we enter the 2020s, the fifth generation, 5G, aims to provide higher speeds, lower latencies, improved capacity, and coverage, supporting a wide range of applications and use cases.

The primary objective of software-defined networking (SDN) in 5G networks is to enhance the flexibility, agility, and scalability of the network. By separating the control plane and data plane, SDN allows centralized and more easily programmable control, enabling service providers to create and manage virtual networks effortlessly. In the context of 5G networks, SDN is instrumental in implementing network slicing, facilitating the creation of virtual networks tailored to meet the specific requirements of different user types or services. This approach optimizes network performance for each service type, contributing to an enhanced overall user experience. The evolution of mobile communication technologies has thus reached a crucial juncture with the advent of 5G, wherein the integration of SDN and the innovative concept of Network Slicing is poised to redefine the landscape. Recent progress in standardization, orchestration frameworks, and tangible implementations reflects the industry's commitment to unlocking the full potential of Network Slicing in the dynamic 5G environment.

Contribution of the Report

The main contributions of the report are as follows:

• **Objective of the Report**: The primary goal of this report is to introduce the concept of network slicing, enhance comprehension of its current state, and identify issues within the 5G framework using Software-Defined Networking (SDN).

Usage Scenarios in 5G Network Slicing

This report elaborates on three usage scenarios and their applications for network slicing in 5G, encompassing end-to-end capabilities that necessitate slicing the 5G Radio Access Network (RAN), core, and management systems. These scenarios include:

•**Enhanced Mobile Broadband (eMBB)**: Supporting various types of services.

•**Ultra-Reliable Low-Latency Communications (URLLC)**: Catering to specific classes of applications.

•**Massive Machine Type Communications (mMTC)**: Addressing services connecting a large number of devices.

Challenges in Network Slicing

The report delves into the various challenges confronted by network slicing, primarily attributed to the inadequate transformation of the future 5G network infrastructure. These challenges encompass interoperability, resource allocation, security, management and orchestration, virtual private networks, firewall implementation, mobility support, and ensuring fairness among different slices. Additionally, the report presents use cases that demonstrate the applicability of the proposed architecture.

The key characteristics of network slicing in 5G are:

Network Slicing in 5G is characterized by several key features and attributes that make it a transformative concept in the realm of mobile communication. Here are the details on the characteristics of Network Slicing in 5G:

Virtualization:

• **Description**: Network Slicing involves the virtualization of the network infrastructure.

• **Significance**: This virtualization allows the creation of multiple logical networks on a shared physical infrastructure, providing isolation and customization for different services or applications.

Isolation and Segmentation:

• **Description**: Each network slice is isolated and segmented from others.
•**Significance**: This characteristic ensures that the performance and resources of one slice do not impact others, providing dedicated and independent network resources for each slice.

Customization:

• **Description**: Network Slicing enables the customization of virtual networks.
• **Significance**: Service providers can tailor each slice to meet the specific requirements of diverse applications, user types, or industries, offering a flexible and efficient solution.

Service-Specific Characteristics:

• **Description**: Each network slice can have service-specific characteristics.

Significance: This allows for the optimization of network parameters such as latency, bandwidth, and reliability based on the particular needs of the services or applications supported by the slice.

Dynamic Allocation of Resources:

• **Description**: Resources are dynamically allocated based on the requirements of each network slice.

• **Significance**: This dynamic allocation ensures that slices receive the necessary resources on-demand, optimizing resource utilization and enhancing overall network efficiency.

End-to-End Network Slicing:

• **Description**: Network Slicing spans the entire network infrastructure, from radio access to core networks.

• **Significance**: This end-to-end approach ensures that the benefits of slicing, such as low latency or high bandwidth, are consistently maintained across the entire network, offering a seamless experience.

Orchestration and Management:

• **Description**: Network Slicing involves orchestration and management frameworks.

• **Significance**: These frameworks automate the creation, configuration, and management of network slices, providing an efficient and scalable solution for deploying and maintaining slices.

Slicing for Diverse Use Cases:

• **Description**: Network Slicing is applied to accommodate diverse use cases.

• **Significance**: Different slices can be created to support various applications, including enhanced mobile broadband (eMBB), ultra-reliable low-latency communication (URLLC), and massive machine-type communication (mMTC), ensuring versatility in meeting specific use case requirements.

Standardization Efforts:

• **Description**: There are ongoing standardization efforts related to Network Slicing.

• **Significance**: Standardization ensures interoperability and compatibility among different network slices, allowing for a cohesive and standardized implementation across the industry.

Security and Isolation:

•**Description**: Network Slicing incorporates security measures to ensure isolation and protection.

• **Significance**: Security features are integral to each slice, preventing unauthorized access and maintaining the integrity of the virtual networks.

Monetization:

Virtualization provides a means for service providers to monetize their network resources. Offering diverse network slices with varied pricing plans creates additional effectively revenue streams, enhancing competitiveness in the market.

In summary, the fundamental characteristics of network slicing in 5G comprise virtualization, customization, resource utilization, and monetization. These attributes empower service providers to establish virtual networks on a shared physical infrastructure and customize the network for different user types and services, leading to efficient resource utilization and monetization opportunities. These characteristics collectively contribute to the transformative nature of Network Slicing in 5G, providing a versatile and efficient solution to address the diverse requirements of modern mobile communication services and applications.

Results and contributions

Network Slicing in Software Defined Networking (SDN) for 5G has brought about several significant results and contributions, revolutionizing the landscape of mobile communication. Here are the main results and contributions of Network Slicing in the context of 5G:

Customization and Flexibility:

Result: Network Slicing allows the creation of virtual networks customized for specific applications or services.

Contribution: This customization provides a flexible and efficient means to address diverse connectivity needs, catering to the specific requirements of different user types or services.

Enhanced Network Performance:

• **Result**: The implementation of Network Slicing, facilitated by SDN, enhances the overall performance of the 5G network.

• **Contribution**: By optimizing network performance for each service type, Network Slicing contributes to an improved user experience, ensuring the efficient delivery of diverse applications.

Resource Optimization:

•**Result**: Network Slicing optimizes the utilization of network resources by allowing the creation of segregated logical networks on shared physical infrastructure.

• **Contribution**: This contributes to resource efficiency and enables service providers to manage and allocate resources more effectively based on the specific demands of each virtual network.

Support for Diverse Use Cases:

• **Result**: Network Slicing facilitates the accommodation of diverse industrial use cases.

• **Contribution**: By tailoring virtual networks to meet the distinct requirements of different applications, Network Slicing ensures that the 5G network can support a wide range of use cases, including enhanced mobile broadband (eMBB), ultra-reliable low-latency communication (URLLC), and massive machine-type communication (mMTC).

Evolutionary Progress:

• **Result**: The progression of Network Slicing in 5G is evident in its standardization efforts, orchestration frameworks, and tangible implementations.

• **Contribution**: These advancements reflect the industry's commitment to unlocking the full potential of Network Slicing, making it an integral part of the dynamic 5G environment.

Efficient Network Management:

• **Result**: SDN, as a key enabler of Network Slicing, enhances the flexibility, agility, and scalability of the network.

• **Contribution**: The separation of the control plane and data plane allows centralized and programmable control, enabling service providers to manage virtual networks effortlessly, leading to efficient network management.

Revolutionizing Network Architectures:

• **Result**: Network Slicing, driven by SDN, has played a pivotal role in redefining network architectures.

• **Contribution**: By introducing the concept of virtual networks tailored for specific purposes, Network Slicing has set the stage for a paradigm shift, offering a revolutionary approach to network design and operation. In summary, Network Slicing in SDN for 5G has not only delivered tangible improvements in network performance, resource utilization, and customization but has also contributed to the evolution of mobile communication technologies, making them more adaptable to the diverse and demanding requirements of the digital era.

Motivation and Network Slicing in 5G

The currently prevalent wireless network technology is 4G LTE, surpassing the capabilities of its predecessors 3G and 2G by providing higher data rates. Primarily focused on IP networks, it facilitates activities such as internet access, web browsing, and streaming, including the provision of social media services. Users connected via the LTE core and transport share the same resources through resource allocation, presenting a one-size-fits-all scenario where contention for resources occurs among users. This network optimization is particularly tailored for internet-type browsing.

The advent of 5G holds promise for several reasons:

• **Increased Demand for High-Bandwidth Applications**: The growing demand for high-bandwidth applications like video streaming and online gaming is expected to be more effectively supported by 5G networks than their 4G counterparts. Network slicing, a key feature of 5G, enables service providers to create virtual networks optimized for high-bandwidth applications, enhancing the user experience and meeting rising demand.

• **Emergence of New Types of Applications**: 5G networks are anticipated to support new applications requiring low latency and high reliability, such as autonomous vehicles and remote surgery. Network slicing facilitates the creation of virtual networks tailored for these applications, contributing to improved user experiences and the emergence of innovative services.

• **Increased Number of Devices**: With the deployment of 5G networks, there is an expected surge in the number of connected devices. Network slicing allows service providers to establish virtual networks for various device types, including IoT devices and sensors, enhancing network efficiency and performance.

• **Monetization Opportunities**: Network slicing empowers service providers to monetize their network resources more effectively by offering diverse network slices with varying pricing plans. This not only generates additional revenue streams but also enhances competitiveness in the market, providing a compelling incentive for implementing network slicing in 5G networks.

Role of SDN in Network Slicing

The role of Software Defined Networking (SDN) in implementing network slicing for 5G networks is to establish the essential infrastructure and control mechanisms necessary for creating virtual networks over a shared physical infrastructure. SDN achieves this by separating the control plane and data plane, enhancing network flexibility and agility. The control plane is responsible for making configuration decisions, while the data plane handles traffic forwarding. In the realm of network slicing, SDN empowers service providers to establish and oversee multiple virtual networks atop a common physical infrastructure through the control plane. These virtual networks, referred to as network slices, are adaptable to cater to the specific requirements of diverse user types or services. For instance, a service provider can craft a network slice tailored for high-bandwidth applications like video streaming and another slice optimized for low-latency applications such as gaming. This approach enables the service provider to fine-tune network performance for each service type, thereby delivering an enhanced user experience.

5G Usage Scenarios

A network slice ensures the provision of appropriate end-to-end Quality of Service (QoS) by optimizing resource allocation and providing dedicated resources. The 3rd Generation Partnership Project (3GPP) has standardized three types of slices: mobile broadband, low latency, and massive IoT. Each network slice encompasses end-to-end capabilities across the air network, the Radio Access Network (RAN) segment, the core and transport network segment, services, and effective life cycle management. Achieving end-to-end capability is a prerequisite for implementing network slicing in 5G. This necessitates the incorporation of both the 5G RAN and core network. Consequently, to integrate the slice into the network, it becomes imperative to segment the RAN, core, and management systems. Various scenarios present diverse performance requirements, as depicted in Fig. 2.

• Enhanced Mobile Broadband

Enhanced Mobile Broadband (eMBB) represents one of the three utilization scenarios within 5G networks, aiming to deliver high-bandwidth, low-latency connectivity for applications like video streaming, online gaming, and virtual reality. The objective is to support data rates reaching up to 20 Gbps with latencies of less than 1 ms. Utilizing network slicing enables the creation of virtual networks specifically optimized for eMBB, enhancing the user experience for these applications.

The initial usage scenario, eMBB, is designed to cater to services akin to those typically utilizing 4G for activities such as web browsing and video streaming. This encompasses traffic types like email applications, which often require very high peak data rates and may not be excessively sensitive to latency. The provision of support for these services underscores the significance of eMBB or eMVB as standardized network slices.

• Ultra-Reliable Low-Latency Communications

Ultra-Reliable Low-Latency Communications (URLLC) stands as the second usage scenario within 5G networks, aiming to deliver highly reliable and extremely low-latency connectivity. This is particularly targeted at applications requiring real-time communication and control, such as autonomous vehicles, virtual reality, augmented reality, smart grid, intelligent transport systems, and remote surgery, where strict time constraints are crucial for effective operation. URLLC is anticipated to support latencies of less than 1 ms and a reliability level of 99.999%. Utilizing network slicing allows for the creation of virtual networks optimized for URLLC, thereby enhancing the user experience for these applications, notably contributing to the automation of factory processes and energy systems.

• Massive Machine Type Communication

Massive Machine Type Communication (mMTC) constitutes the third usage scenario in 5G networks, designed to accommodate numerous devices, including sensors and IoT devices, communicating sporadically at low rates. This scenario is tailored to support a diverse array of applications like smart cities, smart agriculture, and industrial automation. An essential characteristic of mMTC is its capacity to handle a high device density, targeting up to 1 million devices per square kilometer. It is also expected to support data rates of up to 1 Mbps, sufficient for many IoT applications requiring low-rate communication. To facilitate mMTC, 5G networks are anticipated to leverage technologies like narrowband IoT (NB-IoT) and LTE-M, specifically crafted for low-rate and low-power communication. Network slicing, in this context, proves valuable by enabling the creation of virtual networks optimized for mMTC, enhancing the user experience for such applications.

Massive Machine Type Communication

Massive Machine Type Communication (mMTC) constitutes the third usage scenario in 5G networks, focused on facilitating communication for numerous devices, including sensors and IoT devices, which operate sporadically and at low rates. The objective is to enable a diverse array of applications, including but not limited to smart cities, smart agriculture, and industrial automation. A distinctive feature of mMTC is its capability to accommodate a high density of devices, targeting up to 1 million devices per square kilometer. Additionally, it is expected to support data rates of up to 1 Mbps, meeting the requirements of many IoT applications relying on low-rate communication. To cater to mMTC, 5G networks are anticipated to leverage technologies like narrowband IoT (NB-IoT) and LTE-M, specifically tailored for low-rate and low-power communication. The implementation of network slicing proves beneficial in this context, allowing for the creation of virtual networks optimized for mMTC. This optimization contributes to an enhanced user experience for applications falling within the mMTC category.

Challenges and Future Research Plans

While the application of virtualization and network slicing techniques, utilizing SDN and NFV in 5G, offers advantages such as scalability, performance, usability, and reliability, several challenges must be addressed. This section outlines the challenges encountered in implementing network slicing in 5G and outlines future research plans:

• Interoperability:

One challenge associated with network slicing is achieving interoperability with diverse types of network infrastructure and equipment. This may restrict service providers' ability to implement network slicing and elevate the complexity and cost of deployment. Future research endeavors could concentrate on developing solutions to enhance the interoperability of network slicing with various network infrastructures.

• Resource Allocation:

Another challenge in network slicing pertains to the allocation of resources, including bandwidth, processing power, and storage, to different virtual networks. If the 5G network infrastructure is not suitably adapted to support this resource allocation, effective implementation of network slicing by service providers may be hindered. Subsequent research efforts could center on devising algorithms and mechanisms for efficient resource allocation within network slicing.

• Security:

Network slicing faces challenges in ensuring the security of virtual networks and shielding them from cyber threats. In the absence of a properly transformed 5G network infrastructure that supports robust security measures, the network may become susceptible to attacks, compromising its integrity. Future research initiatives could emphasize the development of security solutions tailored to safeguard virtual networks within network slicing from cyber threats.

Management and Orchestration:

Network slicing necessitates the management and orchestration of multiple virtual networks. In instances where the 5G network infrastructure lacks the requisite transformation to support such management and orchestration, deploying and operating network slicing effectively may prove challenging for service providers. Upcoming research endeavors might focus on crafting solutions for the management and orchestration of network slicing within 5G networks.

Conclusion

In conclusion, the exploration of Network Slicing in Software Defined Networking for 5G marks a paradigm shift in the way networks are conceived and utilized. The dynamic resource allocation, the introduction of network-as-a-service, and the potential for new business models underscore its transformative impact. However, challenges in interference, security, and orchestration complexity must be addressed to unlock its full potential. As the industry collectively tackles these challenges, the integration of Network Slicing with 5G holds the promise of ushering in a new era of flexible, efficient, and application-centric network architectures. Network slicing stands as a pivotal aspect of Software Defined Networking (SDN) within 5G networks, empowering service providers to segment their network resources into distinct logical networks. Each of these networks can be tailored to fulfill the specific requirements of diverse user types or services. This approach facilitates efficient resource utilization and opens avenues for monetization. However, challenges may arise in terms of interoperability, resource allocation, security, and management and orchestration. The proposed architecture for network slicing in SDN for 5G networks encompasses essential network elements, including Virtual Network Function (VNF) managers, VNFs, and network slices designed to support various usage scenarios. It becomes imperative for service providers to address the challenges associated with the implementation and operation of network slicing to harness its full potential, delivering customized services effectively to their users.

Declarations

Author Contribution

The inspiration behind crafting the article on 5G, as detailed in the abstract, is rooted in the dynamic and rapidly evolving landscape of telecommunications technology. My motivation stems from the desire to contribute to the forefront of technological advancements, particularly within the realm of 5G networks. With network slicing emerging as a pivotal feature in the deployment of 5G networks, the author aims to provide a comprehensive overview, exploring its role, motivation, and recent advancements.The practical significance of 5G, especially its impact on service providers who can now manage multiple virtual networks, serves as a compelling area for exploration. The combination of 5G, network function virtualization (NFV), and software-defined networking (SDN) represents a transformative force in reshaping strategies within the telecommunications industry. The article explores into the diverse application scenarios of SDN within network slicing for 5G, ranging from enhanced mobile broadband (eMBB) to ultra-reliable low-latency communications (URLLC) and massive machine-type communications (mMTC).Beyond elucidating the current state of affairs, I am driven to outline the challenges associated with implementing network slicing in the context of 5G. Moreover, the article extends into the realm of future research directions, offering insights that could guide the industry towards overcoming hurdles and fostering further advancements. In essence, my motivation as the author lies in contributing valuable and timely insights to the academic and professional communities engaged in the transformative field of 5G telecommunications.

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Figures

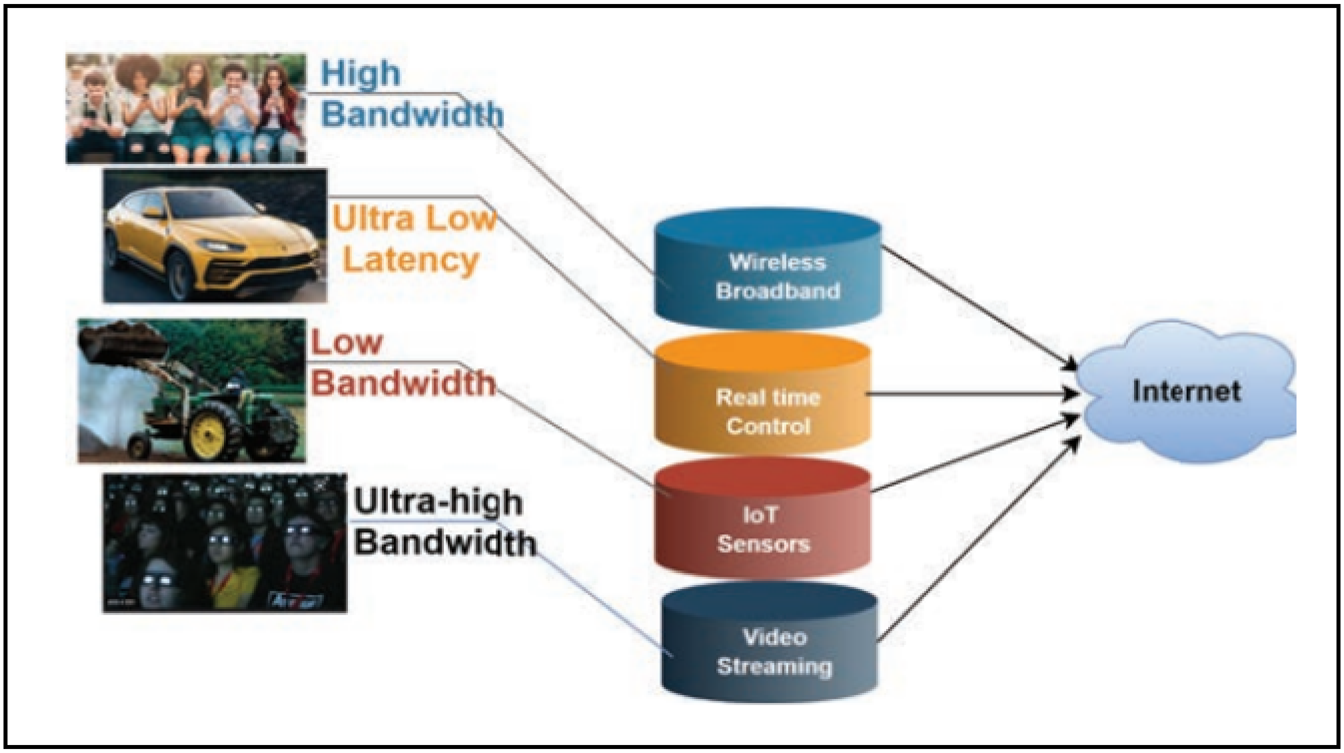

Figure 1

Network Slicing in 5G

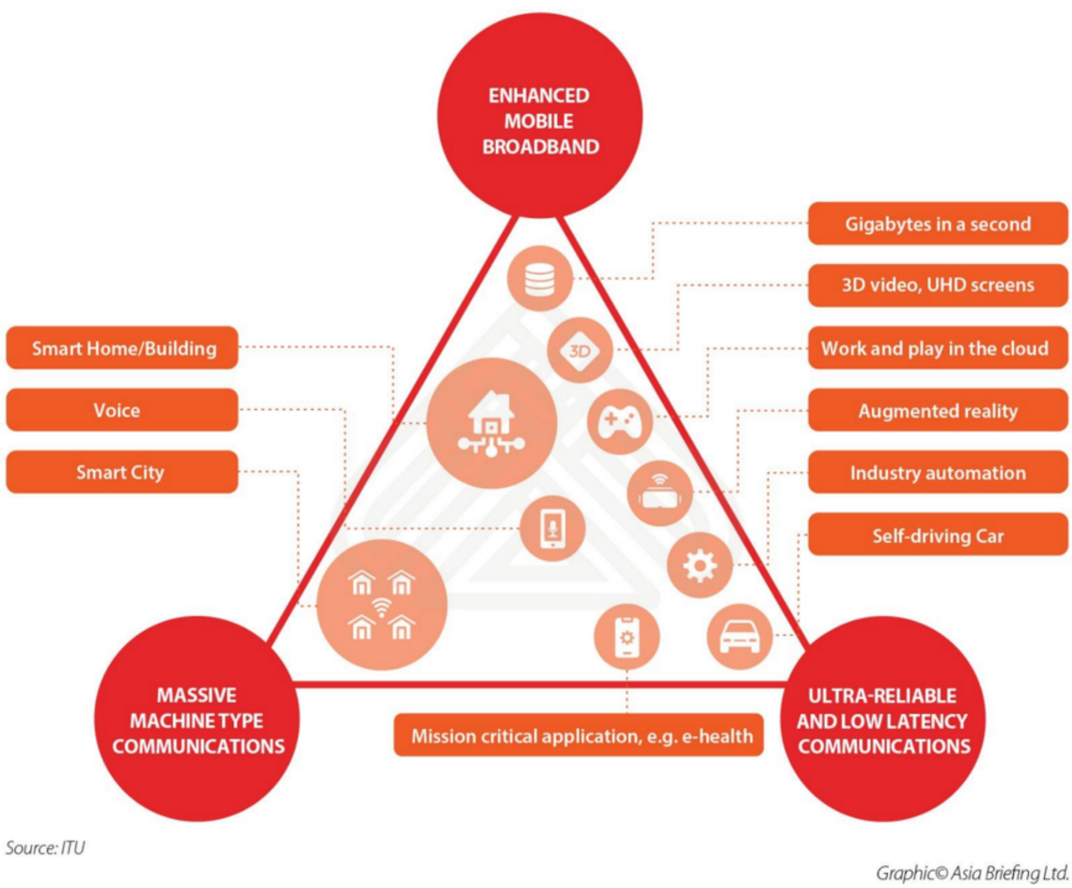

Figure 2

Scenarios in 5G-based network slicing