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5G roadmap: 10 key enabling technologies

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ABSTRACT

The fifth generation (5G) mobile communication networks will require a major paradigm shift to satisfy the increasing demand for higher data rates, lower network latencies, better energy efficiency, and reliable ubiquitous connectivity. With prediction of the advent of 5G systems in the near future, many efforts and revolutionary ideas have been proposed and explored around the world. The major technological breakthroughs that will bring renaissance to wireless communication networks include (1) a wireless software-defined network, (2) network function virtualization, (3) millimeter wave spectrum, (4) massive MIMO, (5) network ultra-densification, (6) big data and mobile cloud computing, (7) scalable Internet of Things, (8) device-to-device connectivity with high mobility, (9) green communications, and (10) new radio access techniques. In this paper, the state-of-the-art and the potentials of these ten enabling technologies are extensively surveyed. Furthermore, the challenges and limitations for each technology are treated in depth, while the possible solutions are highlighted.

1. Introduction

1.1. Motivation towards 5G

Over the past decades, the demand for higher data rates has been continuously growing to satisfy consumers' desire for a faster, safer, and smarter wireless network. The industry of wireless communications has experienced a great evolution in efforts of boosting system performance on data rates, from analog to digital system, from circuit-switched to packet-switched network, from a bulky handheld cellular phone to a smartwatch on wrist [1,2]. However, a significant paradigm shift is required to further strengthen the wireless communication networks, since current wireless systems are facing a bottleneck in spectrum resources which makes it difficult to enhance performance in the limited available bandwidth. The industry has predicted that in order to reach the network-level capability of serving more users with higher data rates, more spectrum resources are required to be allocated for the next generation of wireless communication networks, and current spectrum needs to be utilized more efficiently [3]. Moreover, small cells and ultra-dense network will be deployed to make the network more flexible, and to provide more users with network connectivity at anywhere, anytime. Additionally, new wireless access technologies should be backward-compatible with the existing solutions to obtain the optimal network performance with faster data rates, which ultimately lead to the driving forces toward the fifth generation (5G) wireless communication networks [4]. In this paper, we investigate 10 enabling technologies, namely, wireless software-defined networking, network function virtualization, millimeter wave communications, massive MIMO, ultra-densification, mobile cloud computing, Internet of Things, device-to-device communications, green communications, and radio access techniques, as shown in Fig. 1. Although some of the key technologies have been researched for LTE-Advanced networks, the exponential increase in data rates is propelling a major wireless network architecture paradigm shift toward the wireless software-defining networking (WSDN) and network function virtualization (NFV), which will fundamentally help reconfigure and solve the open problems in the 5G networks. Note that there is no particular priority order for the technologies in this paper.

1.2. Organization of this paper

As the research process of 5G communication system will remain active and keep growing in the coming years, this paper

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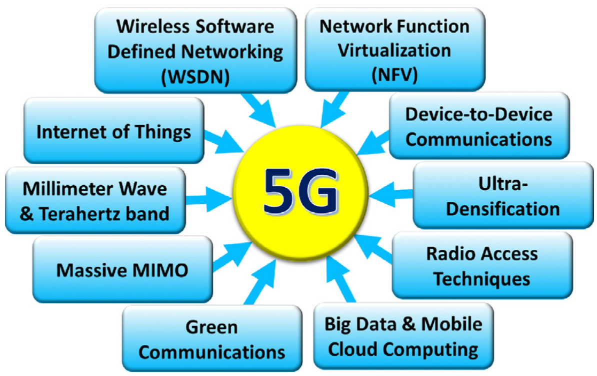

Fig. 1. The 10 key enabling technologies for 5G.

aims to motivate readers to foresee the revolutionary techniques that will shape the next generation wireless communication network. The paper is organized in the following structure. The requirements for 5G are elaborated in Section 2, which covers the demands of high data rates, low latency, cost-efficient energy consumption, high scalability, improved connectivity, and high network security. Based on the system requirements and user demands that the 5G wireless networks are expected to satisfy, the 10 key enabling solutions are explained in detail in Sections 3–12, where we cover their strengths and challenges, as well as the open problems needed to be resolved before deployed in the next generation wireless networks. The global research activities on 5G are summarized in Section 13. In Section 14, we conclude this paper.

2. Requirements for 5G

In conventional cellular networks, mobile phones were practically the only type of device expected to be supported. With the proliferation of Internet and its numerous applications, there was the problem of handling several classes of traffic to meet the different QoS requirements of diverse applications like video streaming, data, VoIP calls, etc. A similar situation is arising now with the need to support several types of devices and applications with drastically varying QoS requirement to provide better experience to the user. Unlike previous generations of cellular networks, 5G cellular network is envisioned to support a multitude of devices and applications like smartwatches, autonomous vehicles, Internet of Things (IoT), and tactile Internet. In particular, according to the International Telecommunication Union (ITU), there are three types of service scenarios to be supported in 5G, which are mobile broadband services, massive machine type communications, and ultra-reliable and low latency communications, respectively [5]. The various types of devices and application scenarios need more sophisticated networks that not only can support high throughput, but also provide low latency in data delivery, efficient energy consumption scheme, high scalability to accommodate a large number of devices, and ubiquitous connectivity for users. In this section, we describe these requirements and explain how they can be met by potential solutions.

2.1. High data rates

The metric of data rate has been the most important evaluation factor over generations of wireless communication networks. With the advent of mobile Internet and services such as high-definition (HD) video streaming, pervasive video and video sharing, virtual reality available on mobile phones, as well as the proliferation of tablets and laptops which are accessible to wireless networks, increasing the data rate of cellular network is becoming an inevitable market driving force. Although the current maximum data rates can support HD video streaming which requires 8–15 Mbps, there are applications like ultra-HD 4K video streaming, high definition gaming, and 3D contents, which require even higher data rates at around 25 Mbps to provide a satisfactory experience to users.

With these emerging applications demanding higher data rates, 5G networks are expected to have the peak data rate of around 10 Gbps which is a 100-fold improvement over current 4G networks [6]. Besides increasing the maximum data rate, the cell-edge data rate, as the worst case data rate users experience, should also be improved to 100 Mbps, which is a 100 times improvement over 4G networks at cell edge. The maximum data rate is an optimum estimate that a user can experience. In fact, the affects of intercell interference and transmission loss make the maximum value hardly achievable. Therefore edge data rate level becomes more important from the perspective of network engineering, as this data rate must support around 95% of users connected to the network. Another metric based on data rate that characterizes the network is the area capacity, which specifies the total data rate the network can serve per unit area. According to its definition, the unit of area capacity is normally bits per second per unit area. This metric is expected to increase 100 times in 5G compared to 4G network. This demand for increase in data rate can be met by techniques such as millimeter wave communications, massive MIMO systems, and wireless software-defined networking, etc.

2.2. Low latency

The roundtrip latency of data plane in the LTE network is around 15 milliseconds (ms) [7]. However, for the recently emerging applications such as tactile Internet, virtual reality, and multi-player gaming that 5G networks are expected to support, the latency should be upgraded to an order of magnitude faster than current network, at around 1 ms [8]. For instance, tactile Internet is a recently developed application where the wireless network is used for real-time control applications [9]. The latency required for such applications is determined by the typical interaction for steering and control of real and virtual objects without creating cyber-sickness. The expected latency that would make these applications feasible is around 1 ms [9]. Although current smartphones have touch screens as the main interface, future devices will integrate various other interfaces like haptic, visual and auditory input and feedback, which will provide a new way of interacting with online environment for applications in virtual reality, healthcare, gaming, and sports, etc. These applications require real-time interactions with the user and any delay in the system will cause degradation to the user experience, thus latency is a crucial factor in 5G.

Another application that 5G networks are expected to support is the machine type communications (MTC) where the devices communicate with each other automatically [10]. This type of communication also requires extremely low latency for applications like vehicle-to-vehicle communication. The METIS project proposes that traffic efficiency and safety should be a typical application test case where the latency is critical in system evaluation. One typical scenario presented in METIS is intelligent traffic systems in which vehicles require timely exchange of data to avoid accidents [11]. The requirement of low latency will also improve the user experience for currently existing applications such as multi-user gaming. This demand in latency reduction requires technological innovation in waveform design as well as a flexible architecture in the higher layers of the network, which can be addressed by wireless software-defined networking.