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Technically speaking

RADIO ACCESS TECHNOLOGIES IN 5G COMMUNICATION NETWORKS

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1. INTRODUCTION

The fifth-generation (5G) network has been designed to support highly reliable and fast communication technologies to satisfy the increasing demands for higher values of data rates, device density, user mobility, spectrum, and energy efficiency [1]. In these networks, a service-oriented architecture is developed to support a wide range of emerging applications and services with a demanding requirement of quality of user experience (QoE). 5G systems are designed as flexible, customizable, scalable and deployable networks where new paradigms as network function virtualization (NFV), software-defined networking (SDN), artificial intelligence (AI) and network slicing have emerged [2]. Besides, new radio access network (RAN) schemes have been developed by several standard development organizations (SDO) to meet the demanding key performance indicators (KPIs) of 5G communication systems. This technically speaking is addressed to illustrate the new use-cases in 5G networks and the required KPIs to achieve these emerging applications. Main insights regarding the RAN technologies are also described focusing on millimeter wave (mmWave) communication, massive multiple inputs multiple outputs (mMIMO), small cells (SCs), interference management (IM), and energy harvesting (EH).

2. NEW USE-CASES AND KEY PERFORMANCE INDICATORS IN 5G NETWORKS

According to the International Mobile Telecommunications (IMT) 2020 initiative, 5G technologies are addressed to provide enhanced mobile broadband (eMBB), ultra-reliable low latency communications (URLLC), and massive machine-type communications (mMTCs) as depicted in Fig. 1. In this scenario, new use-cases emerge in areas such as industrial automation, manufacturing, intelligent transportation, entertainment, tourism, and public safety [3].

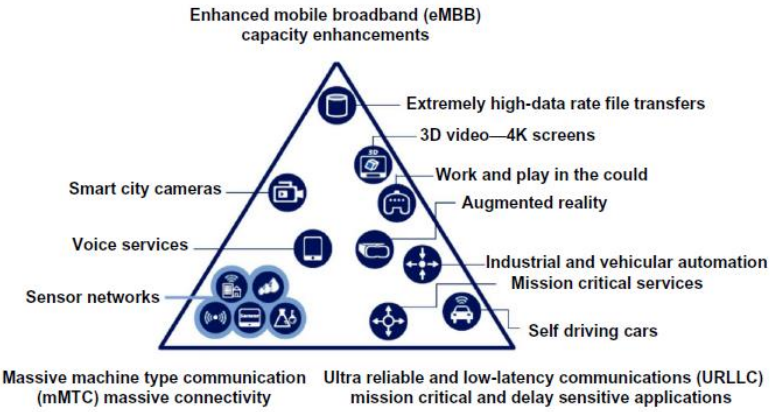

Fig.1 New use-cases in 5G communication networks [2].

The enhancements of mobile broadband enable new applications as: ultra-high-resolution video streaming, interactive gaming, immersive video conference, augmented/virtual reality (AR/VR) with a huge impact in society not only in entertainment area but also in medical treatment, safety, and security. For example, emergency drones are a specific use-case that combines live video streaming and 5G communication in drones to provide connective to a catastrophe area and to improve the effectiveness of the health authorities' response. On the other hand, URLLC supports new applications as autonomous vehicles, real-time traffic control optimization, remote medical surgery, industrial manufacturing, and public safety. Also, the Internet of Things (IoT) and Industry 4.0 arise as the most promising features of 5G focused on connecting a very large number of devices in heterogeneous networks based on the mMTCs principle. In this scenario, different devices as smartphones, sensors, actuators, cameras, and vehicles will be connected to flexible and scalable networks to support additional use-cases as predictive maintenance manufacturing, smart cities, agriculture, healthcare, location-based service applications that provide improved emergency rescue services, vehicle-to-vehicle, and vehicle-to-road infrastructure communication [2] [3].

These use-cases demand high capacity and highly reliable 5G services in outdoor and indoor scenarios. The International Telecommunication Union (ITU) has developed several studies since 2012 to define the KPIs that must be achieved in each 5G networks [1] [4]. These KPIs are described in the IMT-2020 standard and they are illustrated in Fig.2 [1] [3]. In comparison to IMT-Advanced (4G), IMT-2020 requires 1000 times network capacity, 100 times data rate, and 3 times spectral efficiency in high mobility scenarios with only 1 ms of latency and lower energy consumption.

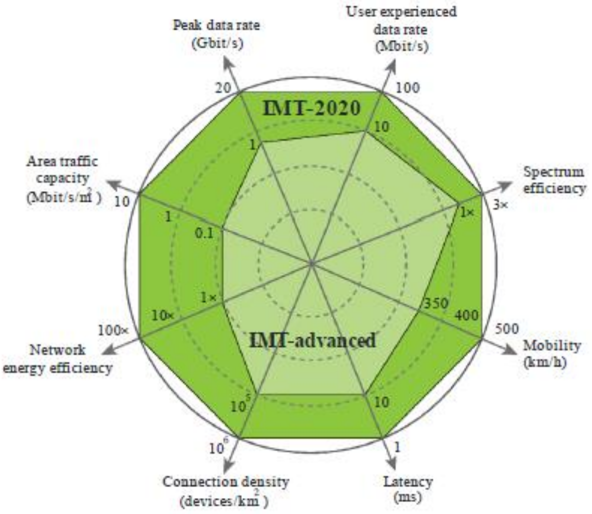

Fig.2 KPIs of IMT-Advanced and IMT-2020 [3].

3. THE 5G RADIO ACCESS TECHNOLGIES

The Institute of Electrical and Electronics Engineers Standards Association (IEEE SA), the 3rd Generation Partnership Project (3GPP), and other SDOs are developing new RAN 5G technologies to meet the KPIs requirements above. IEEE has several working groups (WGs) developing standards for 5G and Beyond 5G. On the other hand, 3GPP project covers cellular telecommunications technologies, including radio access, core network, and service capabilities. 3GPP works on several Releases in parallel, starting future work well in advance of the completion of the current Release. Releases 15, 16, and 17 are addressed to standardization in 5G communication systems.

The mmWave

mmWave communication is one of the most promising technologies capable of providing a huge bandwidth to support the required peak data rates of 20 Gbps and experienced user data rates of 100 Mbps to a very large number of users [5]. However, mmWave communication has several disadvantages as a severe propagation loss, atmospheric absorption, penetration losses, and high sensitivity to blockage. Besides, small mmWave components are more affected by phase noise, limited gain amplifiers, and higher power consumption. Therefore, the manufacturing cost of mmWave electronic components is higher because they require more precision and more complex design [6].

Massive MIMO

To overcome the propagation loss challenge in mmWave scenario, new adaptative beamforming techniques are designed by using a high number of antennas in the mMIMO case. Adaptative beamforming steers the main beam pattern toward the desired direction, while the nulls are steered toward the undesired angular direction to avoid interference [7]. As the number of antennas increases, the beamforming becomes more directive. Therefore, mMIMO systems allow obtaining very narrow high directive beams that increase the coverage in mmWave networks without requiring additional transmit power. The mMIMO systems compound by large antenna arrays could be obtained in small physical dimensions as a consequence of the short wavelength of mmWave [6].

On the other hand, the mMIMO is also utilized in sub-6 GHz base stations to multiplex several data streams to different users in the spatial domain by using digital precoding techniques as zero forcing (ZF). The spatial multiplexing idea is depicted in Fig. 3. As the same time/frequency resource is utilized, the spectrum efficiency of the network is increased. However, the implementation of fully-digital precoding algorithms for mMIMO at mmWave frequencies becomes almost inviable because it requires a radio frequency (RF) chain per antenna. This design demands very complex and expensive hardware solutions in mmWave with high power consumption. In this scenario, hybrid beamforming reduces the number of RF chains by splitting the fully-digital processing in a cascade system compound by digital beamforming (DBF) and analog beamforming (ABF). The ABF stage only utilized programable phase shifters and it is designed to achieve larger beamforming gains. Then, DBF applies digital precoding at baseband with a lower matrix dimension to cancel the Inter User Interference (IUI) and enhance the performance of multiple data streams [8][9].

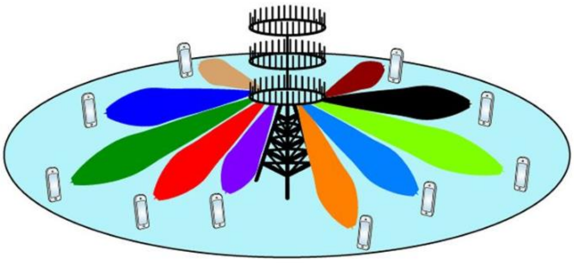

Fig.3 Spatial multiplexing in mMIMO systems.

Small cells

Ultra-dense networks (UDN) compound by SCs is also a promising technology to overcome many issues in mmWave systems such as blockage and short-range coverage. SCs are compounded by low power consumption devices that operate in licensed spectrum in a limited range of few meters' coverages. Several measurement campaigns have proved that mmWave communication can achieve satisfactory performance in SCs with 100 m of radio [5]. Also, SCs improve the spectrum efficiency to meet the high data rate of 5G networks since they increase the spectrum spatial reuse.

However, the densification of the network faces many technical challenges as interference, difficulties in mobility management, and backhauling [2]. Besides, as 5G network are typically heterogeneous enabling the integration of multiple technologies in the same SC, new protocol and resource allocation algorithm has to be improved. Fig.4 illustrates a heterogeneous 5G network compound by three small cells where cellular links coexist with device-to-device (D2D) communications. In this scenario, novel IM and resource allocation algorithms must be implemented.

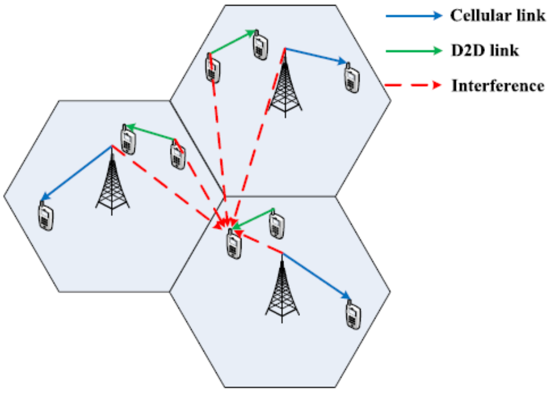

Fig.4. Small cells heterogeneous network with cellular and D2D links [10].

Interference management

IM schemes in mmWave are based on physical (PHY)/medium access control (MAC) cross-layer optimization. Several orthogonal methods have been implemented to cancel interference such as Frequency-division multiple access (FDMA), Time-division multiple access (TDMA), and code-division multiple access (CDMA). However, orthogonalizing the channel only guarantees that each user access to a fraction of all time/frequency dimensions. Therefore, these techniques do not achieve an optimal value of degrees of freedom (DoFs). In this scenario, Interference Alignment (IA) based on the proper design of the precoding/decoding matrices is a promising solution in the PHY layer that can reach the Shannon capacity of interference networks at a high signal-to-noise ratio (SNR) value [11]. Different IM algorithms have been designed with great interference suppression capacity in SCs networks working at mmWave frequencies [9], [12]–[14].

Energy harvesting

The increased data rates and computing capacities at base stations and mobile user equipment (UE) demand higher power consumption. However, green communications parading imposes to meet the 5G requirements with low energy consumption. Therefore, energy-efficient algorithms have been designed to deliver the same information [15] or to process the same data [16] with less energy. On the other hand, EH has gained a lot of attention to implement self-sustainable communication systems. EH has great applicability in IoT guaranteeing a continuous operation of wireless sensor networks (WSN). A recent assumption in the scientific community proposes to harvest energy from interference signals by using a simultaneous wireless information and power transfer (SWIPT) scheme [17]. SWIPT is based on the principle that RF signals carry information and energy simultaneously. The main idea is to divide the received signal into two terminals: information decoder (ID) and energy harvester (EH). Interference is eliminated by IM techniques in the ID terminal while all received signal, comprised by interference plus desired information, is converted to electrical energy in the EH terminal. To this implementation, several solutions have been proposed to jointly optimize wireless energy harvesting (WEH) and IM based on power splitting optimization (PSO) algorithms [18], power allocation policies (PA) [19], user selection scheme [18], [20], [21], and angle switching (AS) schemes [22].

4. CONCLUSIONS

5G networks require very stringent KPIs to support the new use-cases with high QoE. This can be only achieved by the implementation of new RAN technologies. Several SDOs are working on the development of new techniques and different revolutionaries' ideas have emerged. In this scenario, SDN, NFV, AI, mmWave, mMIMO, SCs, UDN, IM, EH, and SWIPT are the most innovative idea to develop 5G communications.

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