Original Article

Development Of 5g And Beyond Technology: Challenges & Innovations

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Abstract

The fifth generation of broadband wireless telecommunications will increase the speeds of upload and download with decreasing the access network latency and enable bandwidth in excess of 100s of Megabits per second (Mb/s) with latency of less than 1 millisecond (ms), as well as provide access network to billions of subscribers. In this paper the innovations and challenges of 5G are described such as mm-waves, small cells, Massive MIMO, Beamforming, Full Duplex FD, Non-Orthogonal Multiple Access NOMA, and Mobile Edge Computing MEC. The results show that the millimeter waves development is the dominant innovation of 5G technology, which increases the data traffic 1000 times more data than 4G and offer manufacturing of products with cheaper prices. It is concluded that 5G, represents a big step forward in increasing the flexibility of the network infrastructure, and improve scalability and service. Also 5G is not limited to telecommunication services but it represents the Beyond technology in research, automotive, energy, e-business, e-government, vertical industry, security, e-Health, improving human being's life. 5G will be the future benchmark of smart city.

Keywords: Beamforming, Challenges, Cloud RAN, Full Duplex, Innovations, Massive- MIMO, MEC, mm-waves, NOMA, small cells.

1. Introduction

Millimeter waves (mm-waves) stand for radio waves with a carrier wave lengths between 1 mm and 1 cm, and they are planning to be applied in the fifth generation (5G) wireless communication. 5G provides communication services not only for end users, but also for different vertical markets, such as automotive, energy, city management, government, healthcare, manufacturing, and intelligent transport systems. Such heterogeneity creates demand for a level of service agility typical of a software environment, rather than an "ossified" hardware one [1].

A. What is 5G?

The 5G is the new fifth generation standard that allows obtaining superior performance both in terms of speed and latency compared to those obtainable today with 4G [20]. This is reflected in ITU-R's defined objective for IMT-2020: "Enabling a seamlessly connected society in the 2020 timeframe and beyond that brings together people along with things, data, applications, transport systems and cities in a smart networked communications environment" [2]. However, 5G is not only faster and less latent as it is the key technology to enable many value-added services that are not accessible today through 4G networks [3].

B. Why 5G?

The global society and the worldwide economy are becoming increasingly dependent on information and communication technologies (ICT), especially on wireless connectivity [4]. 5G will allow for new applications and unique service capabilities, not only for consumers but also for new industrial stakeholders, creating new business opportunities and allowing for novel Business to Business to Customers (B2B2C) business models.

1. **Literature survey**

1G First generation, started on 1980. 1G state-owned monopoly operators, very often obtaining the use of spectrum free of charge, to open-market starting with 3G, to 5G spectrum sharing. 2G Second generation global system for mobile communications (GSM) cellular networks started since 1990, initially provided digital voice service at bit rate 9.6 kbps. 3G Third Generation Universal Mobile Telecommunications System UMTS began on 2000 and offered up to 2 Mbps bit rate (often 364 kbps) initially, and then several tens of Mbps in downlink with High Speed Packet Access (HSPA). While since 2000, 4G Fourth-generation LTE features up to 300 Mbps in downlink, with a target of 1 Gbps, and up to 50 Mbps in uplink [21]. Starting from the end of 2002, 5G Fifth generation cellular networks started as the first trail under research and it is expected to increase the bit rate significantly, up to 20 Gbps. Figure 1, shows the historical literature survey. Since, 2014, NOMA and Massive MIMO with MEC are new technologies obtained due to the 5G mm-wave deployments which offer softwarization.

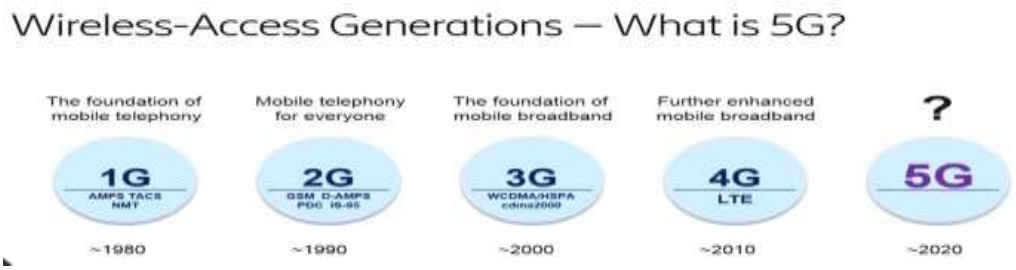


Figure 1: 5G literature survey

2. Theoretical Principles

A. Millimeter Waves

The portion of spectrum carrying signals with wavelength between 1 mm and 1 cm named mm-waves, is denoted by ITU and spans frequencies from 30 to 300 GHz [22–29]. However, even frequencies below 30 GHz, the performance of the fifth generation (5G) of cellular communication systems is modified in order to fulfill broadband applications (e.g., remote control, monitoring, intelligent transport systems, and tactile interaction), with user experienced data rates up to 1 Gbps (500 Mbps) in downlink (uplink) and latency as low as 0.5 ms. IMT-2020 will be defined by third generation partnership project (3GPP) as a release, finally commercialized as 5G system to the end user [30-37]. Conference (WRC) in 2015, has identified various spectrum portions between 24 to 86 GHz for mobile communications [6]. On the other hand, mm-waves also pose technical channels to overcome strong attenuations, provide a good channel estimate, and discover new users entering cells, as described in the following. Millimeter wave(mm-waves) signals provides large bandwidth and high throughput, which can be particularly in the following applications, V2V communications between very close vehicles and V2I communications for bulk data transfer. Figure 2, shows the mm-waves frequency spectrum.

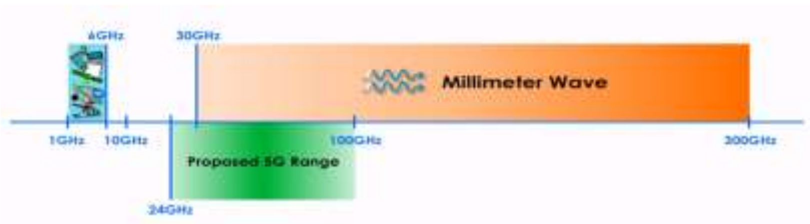


Figure 2: mm-waves frequency spectrum.

A. Coverage issues

Recent studies have shown that, under a business-as-usual model, in UK 90% of the population will be covered with 5G not before 2027 and that 100% coverage will be extremely hard to reach due to prohibitively increasing deployment costs in less populated areas [5]. Similar expectations have been reported for other countries during discussions at the 2018 IEEE 5G World Forum.

B. Full duplex FD

Compared to others like NB-IoT, LTE-M is optimized for higher bandwidth and mobile (in the sense of moving nodes) connections [38-48]. As a consequence, it reaches up to 1 Mbps of data rate and well supports nodes mobility. One clue advantage of LTE-M included in the standard, is the possible choice for operation in either full duplex FDD, half duplex FDD or time division duplex (TDD). Its modulation is still OFDMA, following LTE numerology. One other peculiarity of LTE-M is the support of voice over LTE. See Figure (3).

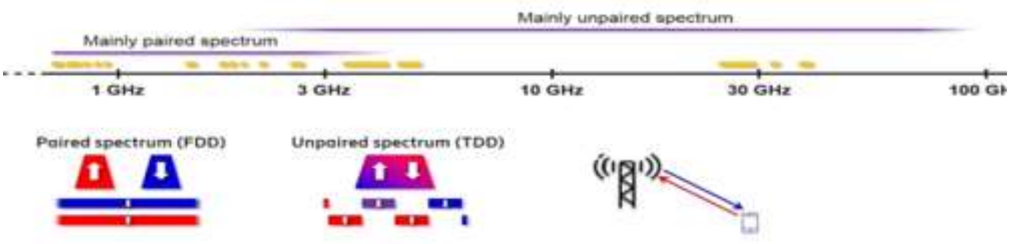


Figure 3: Duplex with TDD than FDD.

C. 5G Spectrum and Enabling Technologies

5G New Radio NR will operate in the frequency range from below 1 GHz to 100 GHz with different deployments [7,8]. There will typically be more coverage per base station (macro sites) at lower carrier frequencies, and a limited coverage area per base station (micro and Pico sites) at higher carrier frequencies [49-58]. This is one of the major reasons why NR needs to exploit also frequencies in the mm-wave range, as well as aggregation of multiple wideband carriers.

3. 5G Challenges & Innovations

In 3GPP NR 5G cellular systems, communication at mm-waves introduces new challenges for the whole protocol stack, which may have a significant impact on the overall end-to-end system performance [10]. First, signals propagating in the mm-waves spectrum suffer from severe path loss and susceptibility to shadowing, thereby preventing long-range omnidirectional transmissions[59-68]. Second, mm-waves links are highly sensitive to blockage and have ever more stringent requirements on electronic components, size, and power consumption [69-70]. Third, directionality requires precise beam alignment at the transmitter and the receiver and implies increased control overhead. In order to overcome these limitations, the NR specifications include new Physical (PHY) and Medium Access Control (MAC) layer operations to support directional communications, which are collectively referred to as beam management according to the 3GPP terminology [11,12]. In particular, NR networks must provide a mechanism by which User Equipment’s (UEs) and Next Generation Node Base Stations, see Figure (4).

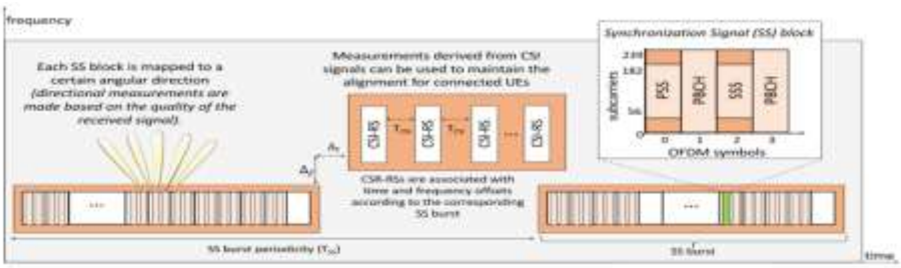


Figure 4: Beam management structure in NR systems. SS blocks and CSI-RSs are used for beam measurements in idle and connected modes [11,12].

A. Multipath Propagation of mm-waves signals

Figure (4), shows one BS antenna is used and in this case the transmitting signals are blocked and attenuated due to the reflection from different buildings and the signal is attenuated due to the multipath reflection effect as shown in Figure (5), While Figure (6), shows the attenuation of mm-waves due to atmospheric attenuation which absorbs the radio signal.

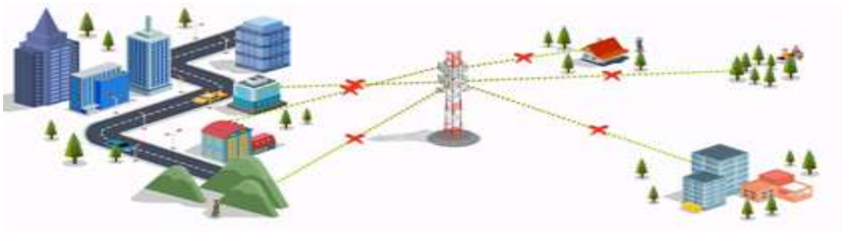


Figure: 5 Millimeter waves Wave Reflections Building obstacles

Figure 6: Atmospheric attenuation produce wave absorption.

B. Small Cell Technology

To avoid the problems mentioned before, many small cells are used instead of one large macro cell by distributing many small cell BS stations are used between buildings to fill in the coverage gaps and decreasing the transmitting distance between the BS transmitter and users, then decreasing the transmitting power per cell [14], see, Figure (7).

Figure 7: Macro cell for 4G technology.

Figures 8 (a) and (b), will offer denser deployment of access points with shorter distance and will reduce the power consumption.

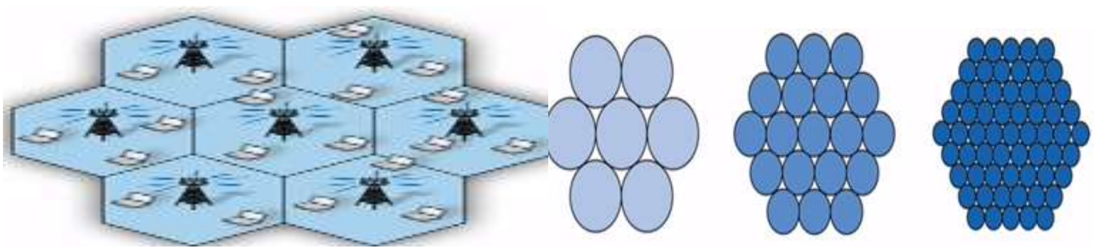


Figure 8: (a) Higher cell density (b) Higher denser cell density

Figure (9), shows the introducing of small cells in the coverage gaps avoiding the obstacles from building and the reflection and multipath attenuation.

Figure (9): The distance between the small cells depend on the population at each location.

Figure (10), shows the distance between difference small cells tower is decreased to 300m closer than the distance of 70km which is shown in Figure (7).

Figure (10): shows the distance between different small cells.

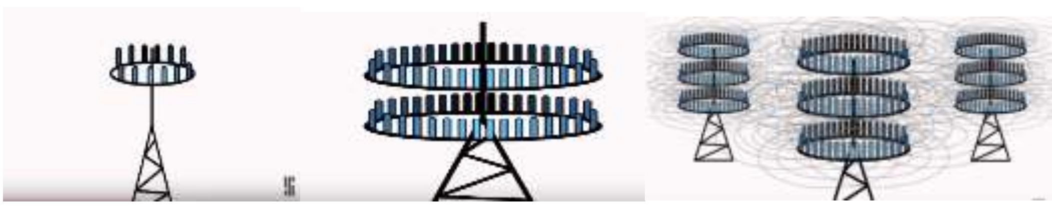
C. Integrated Circuits Advancements

Only in ’10s of the third millennium the industry has been ready to mass-produce transistors with a minimum feature down to 28 nm and below, providing a reliable platform for applications operating above 10 GHz. Indeed, the advance of this technology has pushed the use of mm-waves in many fields, including communications (devices for HD transmission from digital set top boxes, Wi-Fi standards, satellite communications), sensors (road radars for cars, body scanners), and medical applications) [15,16,17].

4. Massive MIMO and Beamforming

A. Massive MIMO

Massive MIMO is a core component of NR systems, while the combination of extreme cell densification, increased system bandwidth, and more flexible spectrum usage (e.g., by resource sharing) represents a feasible and sustainable solution to meet 5G performance requirements[31-35]. Massive MIMO technology is suggested to enhance the coverage and avoid multipath propagation and increasing spectral efficiency and capacity. The second advantageous of using mm-waves is the Massive MIMO antenna which produces massive beam forming critical for coverage at higher frequencies. Figure 11 (a) shows the MIMO antenna and Figure 11(b), shows 2 Massive MIMO and Figure 11(c), shows the 3 Massive MIMO with small cells technology, which enhance the coverage and avoid multipath propagation, then offer higher power spectral efficiency. See Figure (13).



(a) MIMO Antenna (b) Massive MIMO (c) Massive MIMO with small cells

Figure 11: Massive MIMO Technology

Figure 12, shows example of the MIMO antenna with 128 antenna elements at 28GHz.

Figure 12: MIMO antenna with 128 antenna elements at 28GH

Figure (13): 5G Beamforming with mm-waves technology.

Figure (14), shows the comparison between the beam forming MIMO antenna and standard antenna In practice, experimental results have provided reduction of the attenuation by 40 dB with the transmitter and the receiver equipped with uniform planar array antennas with 64 elements [18].

(a) 4G Beamforming (b) 5G Beamforming

Figure 14: Comparison between 4G Beamforming & 5G Beamforming with mm-waves

B. Mobile Edge Computing MEC

Flexibility and performance, lead to the design of two options for the 5G architecture: one, which represents an evolution of 4G LTE standard IP architecture, and the other where the core network functions interact with each other using a Service Based Architecture (SBA). Those services can be classified as URLLC (Ultra-Reliable Low Latency Communication) services, Vehicular communications and remote control of robots or machinery belong to such class of services, and they are well-known 5G application scenarios [19]. It is foreseen that moving computing, storage, and networking resources to the edge of the radio access network (RAN) will be a key ingredient to alleviate backhaul and core network and to allow executing delay-sensitive and context-aware applications in the proximity of end users[36-37]. This paradigm, referred to as mobile edge computing (MEC), poses however concerns [10]. A MEC platform follows the trend towards cloud-based architecture, but exploits the advantage of being located in close proximity to the end users, see Figure (15). In the case of 5G, this means in the RAN.

Figure 15: MEC Architecture

C. Non-Orthogonal Multiple Access NOMA

Motivated by recent theoretical challenges for 5G and beyond 5G systems, this research aims to position relevant results in the literature on code-domain non-orthogonal multiple access (NOMA) from an information theoretic perspective, given that most of the recent intuition of NOMA relies on another domain, that is, the power domain [23]. This scenario may be easily envisioned in 5G, for example in the internet-of-things (IoT), in which a huge number of terminals are required to transmit simultaneously. In order to enable detection at the receiver side, different users are detected based on the difference of power or spreading codes, leading to two main corresponding approaches: power-domain NOMA vs. code-domain NOMA [23]. This NOMA approach is currently known as code-domain NOMA [25], see Figure (16).

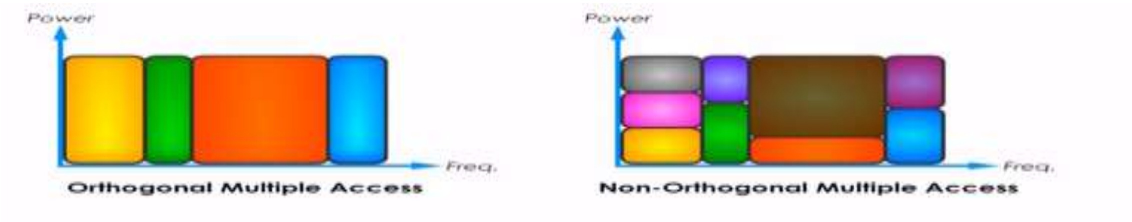


Figure 16: OMA & NOMA techniques.

6. Results

Depending on the following formula the data traffic in cellular network is calculated in bits/s/km2,

$$\underbrace{\text{Capacity}}_{\text{bit/s per km}^2} = \underbrace{\text{Cell density}}_{\text{cells/km}^2} \cdot \underbrace{\text{Spectral efficiency}}_{\text{bit/s/Hz/cell}} \cdot \underbrace{\text{Available spectrum}}_{\text{in Hz}}$$ ……… (1)

A. Higher Cell density cells/km2

Figure (8), shows increasing data traffic [bit/s/km2] which handle 10 times more traffic per area (e.g., 1 km2) and the results of using higher cell density which increases the performance of 5G network capacity.

B. Higher Spectral efficiency bit/Hz/cell

Figure (17), shows the comparison between Omni-directional antenna and the multi-beams forming MIMO antenna. This result will provide 20X higher spectral efficiency compared with 4G LTE, because the signals are directed and focused towards the users as shown in Figure 16(b) with better directivity and better capacity.

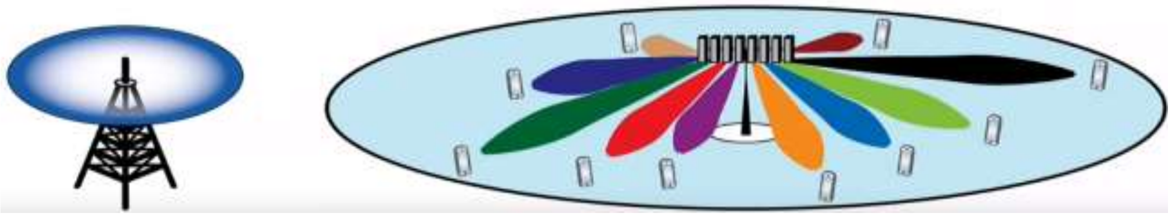


Figure 17: (a) Omni-directional antenna (b) Multi- simultaneous Beams with MIMO antenna

C. Higher Frequency Spectrum

Figure (18), shows the results of introducing the mm-waves frequency spectrum which shows that the frequency spectrum is increased by 5X and more transmission per second and using much higher frequencies compared to 4G LTE.

Figure 18: Introducing higher data rate by 5G mm-waves technology

Now by applying formula (1), the total capacity is calculated and we will obtain 1000times more data as shown in figure (19) which shows increasing data traffic [bit/s/km2] which handle 1000 times more traffic per area (e.g., 1 km2).

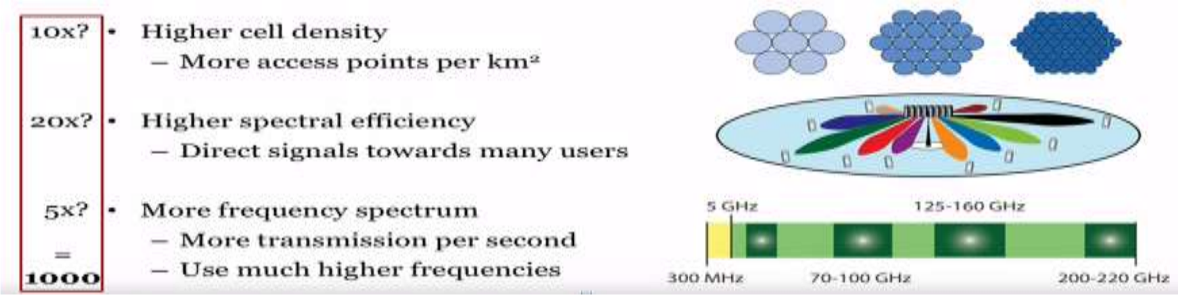


Figure 19: 5G technology handle 1000 times more data

Conclusions

Millimeter wave makes it possible to have a lot of transmitters and receivers installed on a small size cell or panel. Cloud RAN and MEC represent a big step forward in increasing the flexibility of the 5G network infrastructure, with the purpose to improve scalability and service support with virtualization and softwarization. It is concluded that that the millimeter waves development is the dominant innovation of 5G technology and 5G technology is not limited to telecommunication services but it represents the Beyond technology in research, automotive, energy, e-business, e-government, e-economy, vertical industry, security, experimentations, e-Health, sport, which improve human being's life and facilitates the challenges of technology services and save money and space and offer faster speeds for uploading and downloading services. This will be the future benchmark of smart city.

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