Key Technologies in 5G: Air Interface

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***Abstract*—Due to the influence of Internet and mobile service in every part of our lives in addition to pervasive demand for them, next generation wireless networks should be able to address different kind of objectives or demands. New generation of cellular networks must achieve high user quality of experience (QoE) in order to satisfy the user demands and survive in market. To meet this demands, drastic revision need to be made in previous network architecture. This paper reviews some of the key technologies which are emerged to improve future network architecture and meet the demands of users, especially in Fifth generation (5G) cellular network. In this paper, the prime focus is on the air interface of 5G which includes millimeter wave communication, multiple access technologies, carrier aggregation (CA), and massive Multiple-Input Multiple-Output (MIMO).**

***Index Terms*—5G, air interface, carrier aggregation, massive-MIMO, millimeter wave communication, OFDM, PD-NOMA, SCMA.**

I. INTRODUCTION

The huge data demand and also the growing demand from the subscribers are encouraging the operators to look ahead at how the networks can be ready to meet future extreme capacity and performance demands. Fifth generation (5G) cellular networks have attracted much attention and triggered intensive research in the communications society. 5G will provide mobile connectivity for everybody and everything. 5G will also provide accessibility for a wide range of new applications and use cases such as smart homes, traffic safety/control, critical infrastructure, and industry applications.

The generations of wireless cellular communications are classified into five categories which is shown in Fig. 1:

- First generation: this generation uses analogue transmission channels for only voice application.
- Secondgeneration: with growing the demand from users for voice application and evolving the digital communication, this generation appeared. This generation includes new services such as text messaging and circuit switched data access.
- Thirdgeneration: The data rate of second generation (2G) could not satisfy the users. Hence, third generation (3G) emerged to provide fast data services and more capacity for voice.
- Fourth generation: This generation of mobile communications system was developed to provide high capacity and services with higher data rate for cellular communication and mobile multimedia.

5G systems will be used for human interactions as well as for connecting machines together. A huge growth in machine type communications, referred to as the Internet of Things, has been made. The devices will be controlled with other machines remotely. Hence, this kind of communications needs more reliability and lower transmission latencies. The benefit of these kind of connections is that machines can simply process information much faster than people. On the other hand, the tactile interaction is another application which will be used more in 5G and stands for the use of touch interfaces. In this kind of applications, delay requirement can be some times as low as one millisecond. The overall demand growth in both user data rates and network capacity is still the main driver for the technological evolution. Gigabit experience means data rate of gigabits per second available to users and machines. However, it is most likely that the gigabits per second experience deployment takes place in the centers of big cities where the demand for a high data rate will be felt. However, it must be accepted that a virtual zero latency gigabit connectivity will only become available where it matters [1]. A part of the demands for capacity and delay can be met with the existing systems, but around 2020, limits will be reached and 5G technology will be needed. In addition, all 5G requirements including high throughput and low latency must be achieved at an affordable cost to enable

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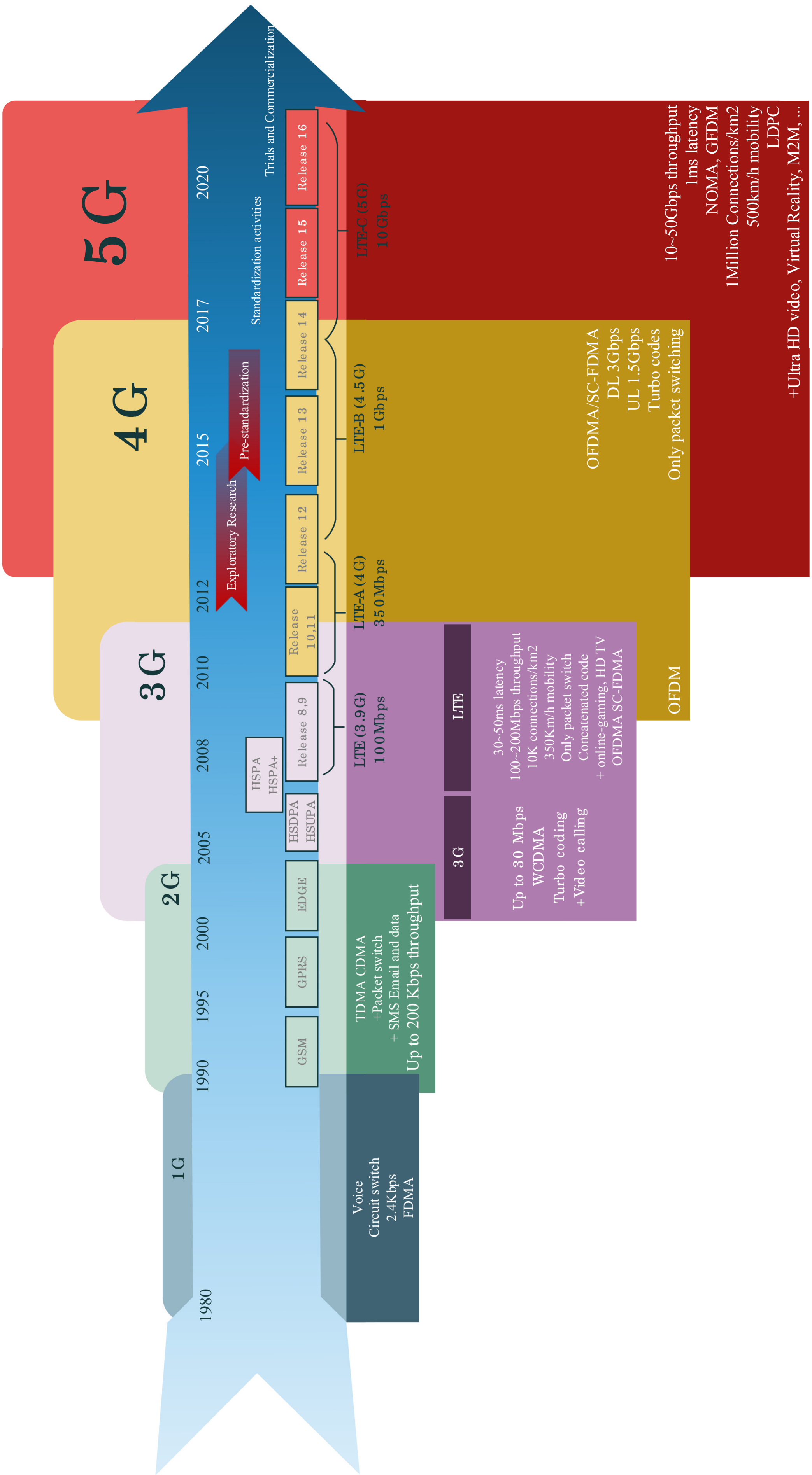


Fig. 1. Evolution and generation of Cellular network.

operators to maintain and improve their profitability. For more capacity, the new 5G system should be designed in a way that enables deployments in new frequency bands. More likely, 5G will be a combination of the existing radio access technologies (RATs) in both the licensed and unlicensed bands plus one or more novel RATs optimized for specific deployments, scenarios, and use cases [1].

5G will be built around two key design principles that guide all the requirements and technical solutions. We can classify these principles as follows [2]:

- Flexibility: 5G consists of various kind of services. Each of these services has distinct characteristics and requirements. Massive data transmissions require large packet sizes. Non-stationary sensors may need only small packets, reliable links, and efficient usage of the battery. Cloud gaming or remote machine control requires low end-to-end latency. 5G will need to be flexible enough to accommodate all the requirements without increasing the complexity of the management.
- Reliability: Reliability relates to the perception of infinite capacity and coverage that future mobile networks need to deliver and to equipment up-time. This in principle means that for different use cases and the vast majority of the users, the required data should be received in the required time and should not be dependent on the adopted technologies. Moreover, reliability is more crucial for control and safety applications. A reliable connection can be indicated by the value of the probability that a certain data package is decoded correctly within a certain time frame.

The remainder of the paper is organized as follows. In Section II, we describe millimeter Wave (mmWave) communications. Section III gives the detailed description of Generalized Frequency Devision Multiplexing (GFDM), Sparse Code Multiple Access (SCMA), and Power-Domain Non-Orthogonal Multiple Access (PD-NOMA). In Section V, Carrier Aggregation (CA) is presented. Section VI discusses about massive Multiple-Input Multiple-Output (massive-MIMO). Finally, we conclude our paper in Section VII.

II. Millimeter Wave Communications

There are some new technologies which are introduced in fourth generation (4G) to deliver the additional capacity needed to sustain the traffic surge for the next few years. However, none of these solutions are seen as a viable solution to support the hundreds of times more traffic demands as foreseen in 2020 and beyond. From the data rate perspective, we expect 5G systems to offer a minimum of 1 Gb/s data rate anywhere to provide a uniform gigabits per second experience to all users. Most mobile cellular systems are deployed in the sub-3 GHz spectrum. One of the most innovative and effective solutions to 5G requirements is the use of large chunks of under-utilized spectrum in the very high frequencies such as the mmWave bands (3 to 300 GHz). Within the mmWave, up to 252 GHz can potentially be used for mobile broadband communication as depicted in Fig. 2 [3] and [4].

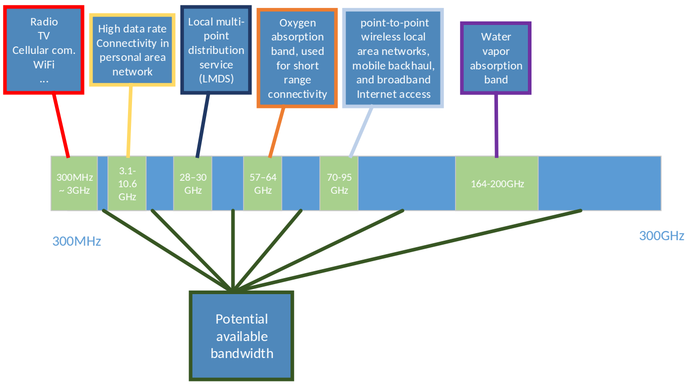


Fig. 2. Potential available bandwidth for mmWave.

In order to use mmWave in outdoor cellular applications, two key hurdles must be solved: large geographical coverage and mobility issue even in Non-Line-of-Sight (NLoS) environments [5]. Two main features of the mmWave bands are large amounts of bandwidth enabling very high broadband communication and very small wavelengths enabling a large number of massive-MIMO antennas deployment in a given device area [6]. Antenna array is a key feature in mmWave systems. Large arrays can be used to keep the antenna aperture constant, eliminate the frequency dependence of path loss. Moreover, adaptive arrays with narrow beams reduce the impact of interference. mmWave systems could more often operate in noise-limited rather than interference-limited conditions [4].

mmWave cellular networks are different from conventional networks in several ways [7], [8] and [5]

- Large path loss (especially with NLoS propagation).
- Signal blocking/absorption by various objects in the environment.
- Large number of antennas.
- Hardware constraints.

While signals in the sub-3 GHz spectrum can travel many miles and easily penetrate buildings, mmWave signals can only propagate a few miles and do not generally penetrate solid materials. However, this is not a disadvantage. These fundamental characteristics of low-interference mmWave communications will certainly promote:

- Densely packed communication links for more efficient spectrum reuse,
- Privacy and security of communication transmissions.

The sensitivity to blockages is the main difference between microwave and mmWave frequencies [5]. One of the big misconception among wireless engineers is about free-space propagation loss dependency of it to frequency. In other words, the reason for this misconception is the underlying assumption that the path loss is calculated at a specific frequency between two isotropic antennas whose effective aperture area increases with the wavelength. An antenna with a larger aperture has larger gain and it captures more energy from a passing radio wave. However, with shorter wavelengths, the massive-MIMO technology can be used and more antennas can be packeted into the same area. Hence, for the same antenna aperture areas, shorter wavelengths should not have any inherent disadvantage compared to longer wavelengths in terms of free space loss [3]. In addition, the small wavelengths of mmWave frequencies facilitate the use of a massive-MIMO in a compact form factor to synthesize highly directional beams corresponding to large array gains [5]. Appropriate beamforming schemes for focusing the transmitted and/or received signal in a desired direction in order to overcome the unfavorable path loss are the key enablers for cellular communications at mmWave frequency bands. mmWave signals will have weaker diffractions due to the small wavelength. Therefore, Line-of-Sight (LoS) signals will propagate as in free space [8]. However, the best NLoS signals produced by reflections are shown to be much weaker than LoS signals. The emergence of mmWave communications has created the need for new signal processing, circuit, antenna, and communication technologies. The convergence of these technologies is almost surely inevitable to cope with the stringent constraints imposed by the high propagation loss.

We can categorize other mmWave losses as follows [7], [8] and [5]:

- The loss due to reflection and diffraction depends greatly on the materials and the surface. Although reflection and diffraction reducees the range of mmWave, it also facilitates NLoS communications.
- It can experience significant attenuations in the presence of heavy rain.
- Foliage losses for mmWave are significant and can be a limiting impairment for propagation in some cases. In this case, a mechanism such as supporting emergency communications over cellular bands when mmWave communications are disrupted by heavy rains should be considered as a part of the mmWave system design.

However, when one considers the fact that today's cell sizes in urban environments are on the order of 200 m, it becomes clear that mm-wave cellular can overcome these issues [8].

In the view of doppler shift, in the case of mmWave, the narrow beams at the transmitter and receiver will significantly reduce the angular spread of the incoming waves which in turn reduces the doppler spread. In addition, as the incoming waves in mmWave are concentrated in a certain direction, there will be a non-zero bias in the doppler spectrum which will be largely improved by the automatic frequency control loop in the receiver side. Therefore, the time-domain variation of an mmWave channel is likely to be much less than that observed other traditional system by omnidirectional antennas in a rich scattering environment [3].

III. Multiple Access Technologies

There are different types of radio access technologies which are used in previous generations such as Frequency Division Multiple Access (FDMA), Time Division Multiple Access (TDMA), Code Division Multiple Access (CDMA), and Orthogonal Frequency Division Multiple Access (OFDMA) which provide the means for multiple users to access the system resources, simultaneously. However, in 3GPP Long Term Evolution (LTE) and LTE Advanced, orthogonal multiple access schemes based on OFDMA or single carrier (SC)-FDMA are adopted. Orthogonal multiple access is a reasonable choice for achieving sufficient throughput with simple receivers for applications in those generations.

A. Generalized Frequency Division Multiplexing

In 4G, Orthogonal Frequency Division Multiplexing (OFDM) is a widely adopted solution mainly due to its ability to control multipath channels and easy implementation based on Fast Fourier Transform (FFT) algorithms. However, 5G needs low latency and high throughput. It is means that OFDM signals with one Cyclic Prefix (CP) per symbol would present a prohibitive low spectral efficiency. Moreover, the high Out-of-Band (OOB) emission of OFDM makes the opportunistic and dynamic spectrum access a challenging tasks. We can classify all challenges of OFDM in 5G as follows [9]:

- Unsuitable for applications with low data rate,
- Spectral inefficiency for short bursts of data,

- High OOB emission,

Therefore, this shortcomings make OFDM unsuitable solution for 5G networks.

For 5G networks, a flexible multicarrier waveform scheme which is called GFDM has been proposed in [9] and [10]. GFDM is a recent physical layer scheme designed to satisfy the demands and challenges of 5G systems. GFDM is based on the modulation of independent blocks. GFDM's flexibility can address the different requirements. GFDM is flexible in a block structure and is confined in a block frame composed of M time slots with K sub-carriers. When there is a restriction for latency, the signal length can be reduced to fulfill certain requirements. This pliable sample structure helps to match the time constraints of low latency applications. Moreover, a single CP protects the information contained in M time slots and results in higher spectral efficiency compared to OFDM. In the low latency applications such as tactile internet scenario, a GFDM frame can be designed to fit the 100 μSec time budget [10]. When there is a need for the high throughput, non-continuous sub-carrier allocation or non-proportional sub-carrier spacing can be used to accommodate the extra data rate. Using this scheme retains all the main benefits of OFDM at the cost of some additional implementation complexity. Hence GFDM aims at combining the flexibility and simplicity of OFDM with stronger interference reduction mechanisms. Furthermore, all the major synchronization algorithms developed for OFDM can be adapted for GFDM. Therefore, the advantages of GFDM are low OOB radiation, robustness against time and frequency offsets, and flexibility to accommodate a variety of channels and applications. We can classify the benefits of GFDM for 5G physical layer as follows [9] and [11]:

- For real-time and latency restriction applications, the signal length can be reduced.
- For improving symbol error rate and OOB emission, different filter impulse responses can be used to filter the sub-carriers.
- For improving the spectral efficiency of the system, the overhead is kept small by adding a single CP for the entire block.

Therefore, GFDM can be assumed to be the best candidate for the physical layer of 5G which is also capable of addressing all types of communications foreseen for the future networks.

Generally in OFDM, the CP is used for simplification of signal equalization, but at the cost of high peak-to-average power ratio. However, in the uplink of LTE, when using a CP in conventional single carrier systems, a lower peak-to-average power ratio as well as a simple equalization is achieved. On the other hand, each sub-carrier represents an independent single carrier with CP link which can be modulated individually having its own bandwidth and pulse shaping. Indeed, GFDM uses the simple equalization of OFDM and single carriers with the ability of flexible use of the small available spectrum

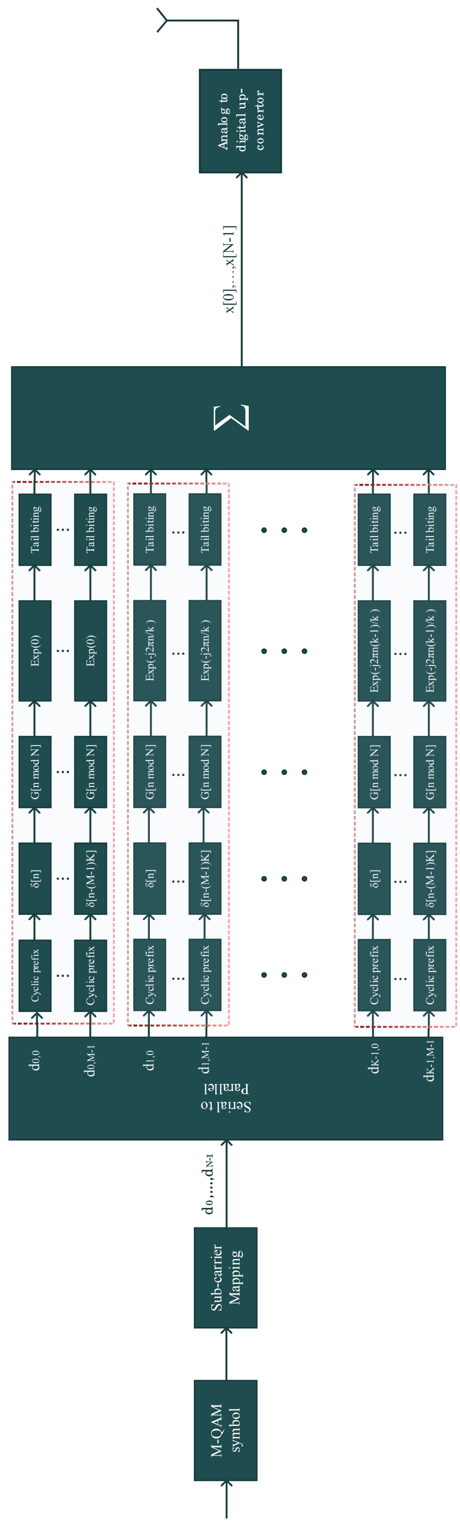


Fig. 3. Block diagram of the transmitter [9].

and controllable OOB radiation.

In order to enhance the spectral efficiency, avoid long filter tails, and keep the GFDM frame contained within MK samples, a tail biting technique is used to shorten CP. This means that GFDM uses circular convolution in the filtering process instead of the linear convolution. The length of CP in OFDM technology depends on the filter length of the digital pulse shaping, the filter length of the digital receive filter, and the length of the mobile channel impulse response. In GFDM, every sub-carrier is modulated individually using some form of M-QAM signalling [12] and [9]. To yield low OOB radiation, the M data symbols on the kth sub-carrier are up-sampled by factor K. The up-sampled signal is then circularly convolved with the transmitter filter block as follows:

$$t_k[n] = s_k[n] \circledast g_{Tx}[n], \tag{1}$$

where $t_k[n]$ is the transmit signal before up-converting to the frequency of the k^{th} sub-carrier, $s_k[n]$ is up-sampled signal of the k^{th} sub-carrier, $g_{Tx}[n]$ is the transmitter filter, and $\circledast$ denoted the circular convolution. Sharp filter edges are required which in turn necessitate high Tx-filter orders. Large filter orders are generally problematic due to CP which has to be matched to the aggregate filter lengths of all the system filters involved. However, with tail-biting technique, the length of CP header can be reduced. After that, each carrier is digitally shifted to its carrier frequency as follow:

$$T_k[n] = t_k[n]e^{j2\pi\frac{kn}{K}}. \tag{2}$$

Obtained signal is converted from digital to analog, mixed to the carrier frequency, amplified, and transmitted [9], [11] and [12]. The block diagram of a GFDM transceiver is shown in Fig. 3.

IV. Non-Orthogonal Multiple Access

Considering future radio access in the 2020s, further enhancement to achieve significant gains in capacity and system throughput performance is a high priority requirement in view of the recent exponential increase in the volume of the mobile traffic. In order to continue the sustainability of 3GPP radio access technologies over the coming decade, new solutions must be identified and provided that can respond to future challenges. To accommodate such demands, a combination of multiple approaches would be required. In this sense, innovative radio access technologies to enhance significantly the spectrum efficiency in the 3GPP is very important. On OFDMA based techniques, the spectrum is allocated to user orthogonally. However, sharing the spectrum among users by using appropriate techniques would improve the spectral efficiency. In this way, non-orthogonal multiple access (NOMA) techniques are introduces which allow multiple users to send their information over the same spectrum with low interference which leads to increase in spectral efficiency of the networks compared to orthogonal allocation methods. Here, we introduce two important and widely considered schemes for NOMA transmission.

1) Power Domain NOMA (PD-NOMA): In cellular mobile communications, the design of radio access technology is one of the most important and difficult aspects in improving system throughput. In order to boost further the spectrum efficiency and improve the total rate of system in the future, PD-NOMA is considered as a very promising technology for further cellular enhancements toward 5G in both the uplink and downlink. In PD-NOMA, multiple users are encouraged to transmit at the same time, code, and frequency, but with different power levels. In PD-NOMA, multiple users are multiplexed in the power-domain on the transmitter side and multi-user signal separation on the receiver side is conducted based on Successive Interference Cancellation (SIC) [13]–[16]. In fact, the receiver demultiplexing is ensured via the allocation of large power difference between paired receivers and the application of SIC in power-domain. In general, three dimensions of radio resources (frequency, time and space) are exploited to multiplex the signals. The comparison of multiple access schemes is shown in Fig. 4.

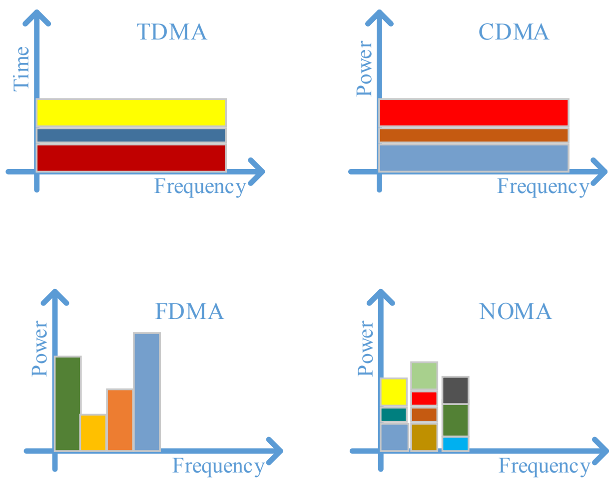


Fig. 4. Comparison the multiple access technologies, TDMA, CDMA, FDMA, and PD-NOMA.

Fig. 5 illustrates the basic PD-NOMA scheme which uses SIC for receivers in the cellular network. In the transmitter side, the transmitted signals can be formu-

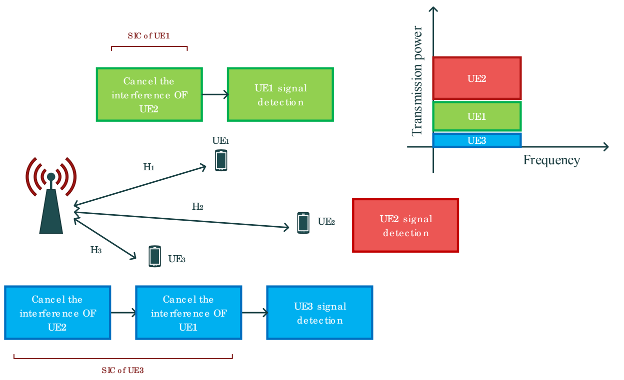


Fig. 5. Basic PD-NOMA scheme.

lated as follows:

$$x_{Tx}^n = \sum_{i \in k_n} \sqrt{P_i} x_i, \tag{3}$$

where x_{Tx}^n is the transmitted signal on the sub-carrier n, P_i is the transmitted power of transmitter i, x_i is the signal of transmitter i, and k_n is the number of signals which are transmitted on sub-carrier n.

The received signal at the receiver i is represented as:

$$y_i^n = h_i^n x_{Tx}^n + N_0^i, \tag{4}$$

where h_i^n is the channel coefficient between transmitter and receiver i on sub-carrier n, and N_0^i contains the Additive White Gaussian Noise (AWGN) and the inter-cell interference at receiver i [17].

On the other hand, the SIC process is implemented in the receiver. In the receiver side, the receiver needs to cancel the signals intended to other receivers. Therefore, the optimal order for canceling the other receivers' signals is in the order of decreasing channel gain normalized by noise and inter-cell interference power. In other words, any receiver can correctly decode the signals of other receivers whose decoding order comes before that receiver. For example, receiver i can cancel the interference from receiver j (signal of receiver j) if $\frac{h_i^n}{N_0^i} > \frac{h_j^n}{N_0^j}$. The receiver j does not perform interference cancellation since it comes first in the decoding order. The receiver i first decodes x_j and subtracts this component from the received signal y_i. Next, it decodes x_i without any interference from x_j. Hence, the throughputs of the receivers i and j can be formulated as follows:

$$R_i^n = \log_2(1 + \frac{P_i |h_i^n|^2}{N_0^i}), \tag{5}$$

$$R_j^n = \log_2(1 + \frac{P_j |h_j^n|^2}{P_i |h_j^n|^2 + N_0^i}). \tag{6}$$

From (5), the overall cell throughput, the cell-edge throughput, and the user fairness are closely related to the power allocation scheme adopted. This means that, any change in the value of the transmit power of each receiver affects the throughput of other receivers in that sub-carrier, and therefore, affects the Modulation and Coding Scheme (MCS) used for data transmission of each receiver. The receiver with the high channel gain is allocated less power and the receiver with the low channel gain is allocated more power. Such a large power difference facilitates the successful decoding and thus the successful cancellation of the annoying signal (other receivers signal) at the intended receiver. In addition, at the receiver with low channel gain, the signal is decoded directly by treating the interference from other receivers as noise [17].

We can classify the motivations and benefits of PD-NOMA as follows [13] and [17]:

- All the receivers are in win-win condition; in PD-NOMA scheme, the receivers with high channel gain lose a little by being allocated less power, but gain much more by being allocated more bandwidth.
- Robustness against Channel State Information (CSI) feedback latency and error; in PD-NOMA schemes, multiplexing does not more rely on the knowledge of the transmitter about the instantaneous fading channels. In PD-NOMA, CSI is used at the receiver for demultiplexing and at the transmitter mainly to decide on receiver pairing and multi-receiver power allocation.

2) Sparse Code Multiple Access: SCMA is a new multiple access scheme which is defined in [18]–[21] as a multi-dimension codebook-based non-orthogonal spreading technique to address the tighter requirements of 5G networks and to allow the massive connectivity. Generally, SCMA works such that the set of incoming bits are directly mapped to a complex sparse vector called a codeword which is selected from a code book set. Due to the sparseness of codewords in this multiple access technique, the Message Passing Algorithm (MPA) detection is applicable with a moderate complexity. SCMA encoder maps $\log_2(M)$ bits to a K-dimension complex codebook of size M. K-dimensional complex codewords are sparse vectors with N non-zero elements where $N < K$. There exist J separate layers in an SCMA encoder corresponding to different users [20].

We can summarize the property and advantage of SCMA as follows [18]

- By using a predefined codebook set, binary domain data will encoded to multi-dimensional complex domain codewords.
- By generating various codebooks for each layer or

user, multiple access is achieved in system.

- Due to the sparseness of the codewords, the iterative message passing (MPA) multi-user detection algorithm with moderate complexity is applicable.
- The overloading feature of SCMA can provide massive connectivity with a limited complexity of detection.

[21] addresses the contention based data transmission for uplink user. The contention based transmission mechanism is a solution for some future applications with tight latency requirement. This mechanism allows nodes to forward immediately the arrived packets without the need to wait for a transmission grant assigned from BS. In this condition, several specified time-frequency regions are defined as a contention region. By using the sparsity of SCMA codewords, the overloading feature of SCMA can provide massive connectivity with a limited complexity of detection.

V. Carrier Aggregation

One key feature in order to meet the growing demand for high-speed and diverse wireless broadband services is the support of wider bandwidths. However, the candidate frequency bands are non-continuous and some of them are less than 100 MHz [22].

One key enhancement feature is bandwidth extension via CA. CA is a technique that allowing multiple carriers or bands to be aggregated together to provide larger system bandwidth. In this technique users can be scheduled on continuous or non-continuous Component Carriers (CCs) and users are able to transmit and receive on several CCs simultaneously. CA has been introduced as a key feature in LTE Release 10 (known as LTE-A). A bandwidth up to 100 MHz and peak downlink data rates up to 1 Gb/s can be achieved by CA technique [23]. Moreover, CA will allow peak target data rates of 500 Mbps in the uplink to be achieved [24]. In CA, up to five CCs can be aggregated to each other to support higher bandwidth. The benefit of CA is significant flexibility for efficient spectrum utilization, and gradual reframing of frequencies previously used by other radio access systems. Generally, main purpose of deployment of CA systems is to improve user data rates rather than spectral efficiency. CA technology can aggregate across different spectrum bands such as licensed, unlicensed, and shared access (such as TV white spaces) bands [25].

There are three possible aggregation scenarios [24] and [22]. These possible scenarios are shown in Fig. 6:

- Contiguous aggregation of CCs in a single band: in this case, the several contiguous CCs are used and all CCs are placed in same band. The spacing

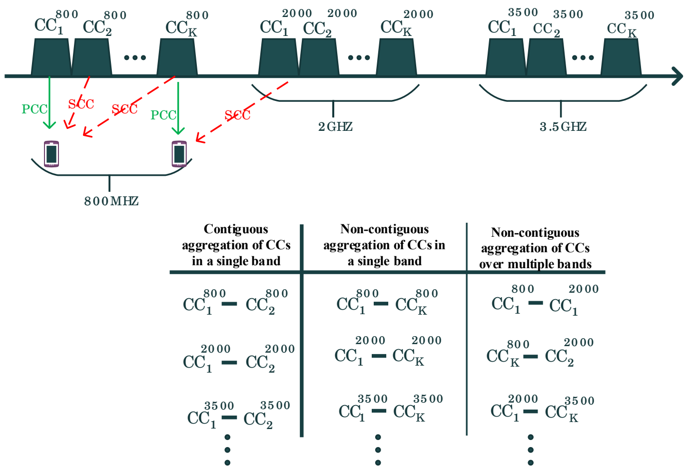


Fig. 6. Possible aggregation scenarios for CA.

space between center frequencies of contiguously aggregated CCs should be a multiple of 300 kHz. However, this scenario may be impossible in given frequency allocation today, but it can be applied to broadband allocation in wider frequency band such as 3.5 GHz band.
- Non-contiguous aggregation of CCs in a single band: in this scenario the contiguous CCs are not available, hence, multiple non-contiguous CCs belonging to the same band are used.
- Non-contiguous aggregation of CCs over multiple bands: In this scenario, different frequency bands are performed for wireless communication, such as the 2 GHz band, 3.5 GHz and the 800 MHz band. The advantage of this scenario is robustness against mobility by exploiting different radio propagation characteristics of different bands.

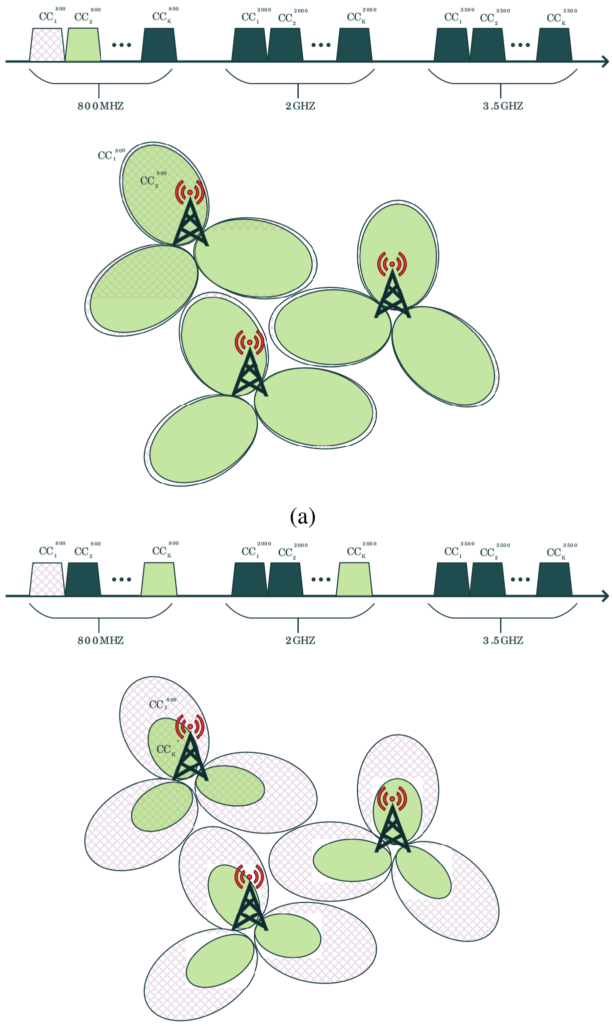
For aggregation of non-contiguous CCs, there are some requirements that each carrier should meet such as emission mask, adjacent channel leakage, and spurious emission. These requirements provide backward compatibility and ensure minimal interference to adjacent carriers. Hence, each CC has guard band to restrict undesirable emissions into adjacent bands [24]. In case of contiguous CA large guard band is not necessary and hence, a more efficient use of the available spectrum is possible. In the view of the architecture, in order to achieve contiguous CA, it is possible to use a single FFT module and a single RF unit. In the case of the non-contiguous CA, in most cases, multiple RF chains and FFT modules will be required [22]. From the perspective of resource allocation and management, contiguous CA is also easier to implement.

There are four deployment scenarios for CA which shown by two component carriers at frequencies of F1 and F2 [22]:

- Scenario1: this case is one of the most typical deployment scenarios. In this case the eNB antennas have the same beam directions/patterns for different CCs. The CCs are located at the same band or the frequency separation is small in this scenario which lead to nearly the same coverage for all CCs as shown in Fig. 7(a).
- Scenario2: there is large frequency separation between CCs. Hence this causes different coverage of CCs. In this scenario, CCs may be deployed at BSs with different transmit power levels even in the same band. This provides different coverage footprints for intercell interference management purposes. This case is shown in Fig. 7(b).
- Scenario3: This scenario is used to improve throughput at the cell edges. For different CCs difference beam directions or patterns are used to shift the beams across carriers. This case is shown in Fig. 8(a).
- Scenario4: In this case, usually there is one or several low frequency CC which provides macro coverage. Also there is one or several usually high frequency CC which is utilized to absorb traffic from hotspots by using Radio Remote Head (RRH) units. RRHs have connection with BS for allowing the aggregation of CCs between the macrocell and RRH cell. Such deployments is a good solution for improving the system throughput by using low-cost RRH equipment. This case is shown in Fig. 8(b).

In scenarios 1 and 2, CA allows higher user throughput at places where coverage of CCs overlaps. In CA, when initially UE wants to establish or reestablish connection with BS, only one CC for DL and UL is used which named the Primary CC (PCC) corresponding to the Primary Serving Cell (PCell). Next, one or more additional CCs are utilized depending on traffic load and quality of service (QoS) requirements that called Secondary CCs (SCCs) for Secondary Serving Cells (SCells). The PCC/SCCs configuration can be different for dissimilar UEs served by the same eNB. May be one CC for UE serve as PCC and for another user serve as SCC as shown in Fig. 6. The PCC can be changed for a user when UE moves within coverage area of BS for obtaining the best signal quality or can be change base on balancing the load between CCs. In the view of SCCs, the number of SCC can be changed base on the such elements as the buffered data amount, required QoS, and carrier loading.

In addition, CA can utilize unlicensed band beside licensed band which shown in Fig. 9, however, techniques designed for CA in the licensed bands cannot be much



(b)

Fig. 7. CA deployment scenarios (a) Scenario 1 (b) Scenario 2 [22].

useful to applied in the unlicensed and shared access bands due to the unpredictability of the interference of uncoordinated users in unlicensed bands [25].

VI. Massive-MIMO

Since MIMO technology [26]–[29] can significantly improve the capacity and reliability of wireless systems, it has been widely studied during the last two decades and applied to many wireless standards. The evolution of MIMO is shown in Fig. 10. Nowadays, new generation of MIMO technology has been emerged called Massive-MIMO [30]–[33]. The basic premise behind massive-MIMO is to reap all the benefits of conventional MIMO but on a much greater scale. This technology is also known as large-scale antennas systems, very large MIMO, hyper MIMO, and full-dimension MIMO. Massive-MIMO can focus signal into ever smaller regions of space which improvements in throughput and energy efficiency. We can consider the other benefits

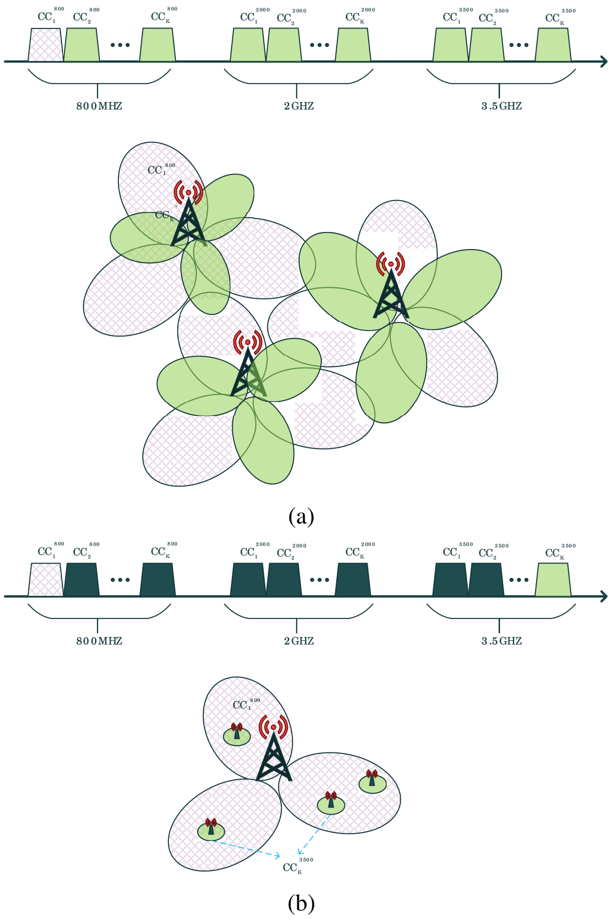


Fig. 8. CA deployment scenarios (a) Scenario 3 (b) Scenario 4 [22].

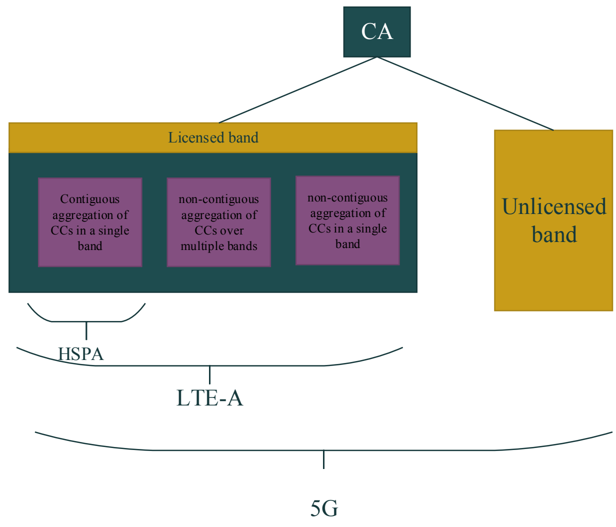


Fig. 9. CA taxonomy in different generations.

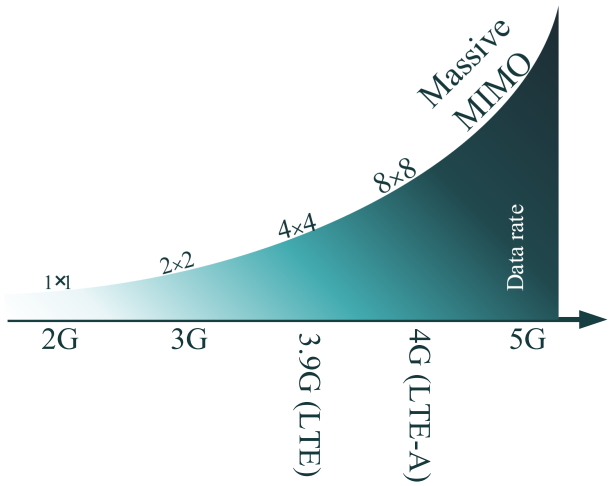


Fig. 10. The evolution of MIMO.

of massive-MIMO such as extensive use of inexpensive low-power components, reduced latency, simplification of the MAC layer, and robustness against intentional jamming [30].

With massive-MIMO, the systems that use antenna arrays with a few hundred antennas are able to simultaneously serve many tens of terminals in the same time-frequency resources. On the other hand, higher capacity can be achieved by very large MIMO arrays employed at the Base Station (BS). Some massive-MIMO configurations and deployment can be envisioned in Fig. 11. Each antenna unit fed via an optical or electric digital bus. Note that the transmit antennas can be co-located or distributed in different locations. Massive-MIMO antennas can be deployed in some many different places such as envision direct replacement of macro BSs with many antennas, conformal arrays on the facades of skyscrapers or arrays on the faces of water tanks in rural locations [4], [30], [34] and [35].

In massive-MIMO, a large number of terminals are served simultaneously in the same time-frequency resources, hence the overall spectral efficiency can be higher than the conventional MIMO systems. In massive-MIMO, in the must case, the number of antennas related to the BS is much larger than the number of devices which located in the cell per signaling resource. Change in architecture particularly in the design of macro BSs and new types of deployments may be appeared in massive-MIMO deployments [4].

Massive-MIMO systems under realistic propagation assumptions, bandwidth of 20 MHz, and for 40 users could achieve approximately a data rate of 17 Mb/s for each user in both the uplink and downlink directions [36]. A large number of degrees of freedom in massive-MIMO is available, since the number of antennas is typically assumed to be significantly larger than the number of users, which can be useful for shaping the transmitted signals or to null the interference [33].

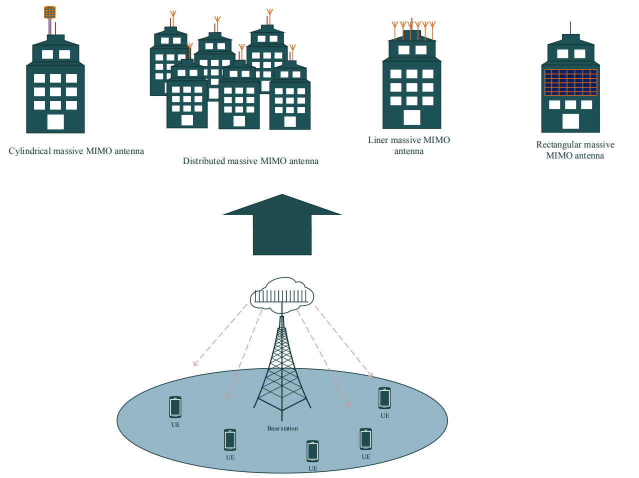


Fig. 11. Massive-MIMO and some possible deployments and configurations of antennas [30].

Use of more BS antennas than UE devices causes the channels to different devices quasi-orthogonal and very simple spatial multiplexing/ de-multiplexing procedure quasioptimal. The large excess of antennas at the BS makes it possible to design low-complexity linear signal processing strategies that are well matched to the propagation channel to maximize system capacity.

In massive-MIMO system, each single antenna user with respect to the number of antennas at the BS can scale down transmit power to achieve same performance as that of the Single Input Single Output (SISO) systems which leads to higher energy efficiency [33]. Each antenna can with use of very small peak-to-average ratio or even constant envelope transmit signals at a very modest penalty in terms of increased total radiated power. Such near-constant envelope signaling helps the use of cheap and power efficient RF amplifiers [30].

Some specific benefits of a massive-MIMO system are as follows [30]:

- It increases the capacity and improves the radiated energy efficiency.
- It builds with inexpensive and low-power components.
- It provides a significant reduction of latency on the air interface.
- It simplifies the multiple access layer.
- It increases the robustness against both the unintended man-made interference and the intentional jamming.

We can also classify the challenges of massive-MIMO as follow [30]:

- Channel Estimation/Feedback: Massive-MIMO will require a large amount of CSI, and this will be problematic especially for the downlink. Currently, only time division duplexing scenarios are considered for massive-MIMO due to the prohibitive cost of channel estimation and feedback.
- Fast Processing Algorithms: To deal with the massive amount of data from the RF chains, extremely fast algorithms to process the data will be required.
- Pilot Contamination: Reuse of pilot sequences causes pilot contamination and coherent interference. Ideally, every terminal in a massive-MIMO system is assigned an orthogonal uplink pilot sequence. However, there is limitation on the maximum number of orthogonal pilot sequences. If each cell is serving the maximum number of terminals, it will be possible that the available supply of pilot sequences exhaust.

VII. Conclusion

In this article, the air interface technologies of 5G have been discussed. The technologies such as millimeter wave communication, multiple access technologies, carrier aggregation and massive-MIMO which are proposed in this paper, have been some potential key technologies that can be deployed in 5G wireless systems to satisfy the expected performance requirements. These technologies can be seen as promising candidates to provide strict requirements of recently introduced services.

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