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Understanding 5G Wireless Cellular Network: Challenges, Emerging Research Directions and Enabling Technologies

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Abstract The increasing usage of smart devices and the penetration of mobile phones in the low-end markets have outpaced the average growth of this wireless mobile communications industry due to which the world is witnessing the demands of burgeoning data traffic, proliferating bandwidth and energy efficient wireless communication technologies. Realizing these increased demands, the research on the Fifth Generation (5G) mobile communication technology has already been initiated by research institutes and industries worldwide. This paper gives a brief overview of some 5G technologies along with their possible challenges and the applications.

Keywords 5G · 5G requirements · 5G challenges · 5G technologies · Wireless cellular technologies

1 Introduction

Wireless communication is the transference of data between two or more points without any aid of wired material between them. The immense growth and rapid advancements in the wireless mobile communication technologies over the last few years have already transformed our society in many ways. We are no longer dependent on our landline phones

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for communication. Every three out of four people have access to mobile communications nowadays. However, the introduction of communication devices like tablets and smart phones in the society and the expected Internet of Things (IoT), where everything and everyone will be connected, have increased the data traffic demands. This calls for the need of a new generation of wireless communication system which could not just provide an efficient bandwidth and energy system but also provide solutions for the limitations of the previous wireless communication technologies.

4G is still being deployed in various parts of the world, and is sufficient for now to handle the obstructed data traffic caused by the escalating usage of devices. But due to the forecast of more than 50 billion devices interconnected by the year 2020, 4G is likely to hit the limit of data traffic and the storage capacities. Researchers are already on to develop the next generation technology i.e. 5G. Fifth Generation (5G) is not likely to replace the existing technologies but rather a combination of all. This integration of technologies like 1G, 2G, 3G and 4G will provide better connectivity at a higher speed to the so-called network of inter-connected devices, IoT. 5G is expected to upgrade the current wireless network worldwide by the year 2020.

The rest of the paper is organized as follows. Section 2 provides a brief overview of this emerging 5G technology. Section 3 reviews a number of enabling technologies for 5G and discusses the related challenges and issues. And Sect. 4 finally concludes the paper.

2 Fifth Generation (5G) Wireless Cellular Network

2.1 Introduction to 5G

While researchers are already looking forward to a future wireless 5G technology, the industries in various parts of the world are still working on the advanced LTE and WiMAX technologies. The attention of 5G networks is focused towards an inter-connected society which will enable the devices to communicate with each other in the future, called Device to Device (D2D) communication. In 2012, ITU Radiocommunication Sector (ITU-R) assigned the Working Party 5D (WP 5D) to initiate its work towards the future IMT-Advanced system, IMT for 2020 and beyond. ITU-R has already set a timeline that calls for the standards to be finalized by the year 2020. WP 5D is currently involved with the detailed investigation of different elements of 5G. In the time frame of 2016–2017, it will define the evaluation criteria and performance requirements for the new radio interfaces. In the early 2008, National Aeronautics and Space Administration signed an agreement with Machine-to Machine Intelligence to cooperate for the development of a fifth generation wireless system that will provide seamless data transfer. There already have been many achievements for this technology by many network giants that claim their speeds much faster than the speed of existing wired network of Google Fibre. In the mid-2014, Samsung Electronics performed various tests on their experimental 28 GHz 5G network and found that the technology was 30 times faster than the existing 4G LTE technologies. The speed they achieved was 7.5 Gbps (stationary) and 1.2 Gbps (moving). Ericsson has also tested its 5G trial and found the speed to be 5 Gbps in the 15 GHz spectrum. Similarly Japanese operator, NTT DoCoMo has hit a blazing fast speed of 10 Gbps in their so called 5G network test using Multiple-input multiple-output (MIMO) technology. The standards of the 5G network have not been decided yet and the networks have still around 5 years for commercial launches, but every month or so, impressive speed records from different cellular companies are witnessed.

2.2 The Need for 5G

In 2008, the number of devices connected to the internet exceeded the total number of human beings, and according to Cisco, this number will exceed 50 billion by the year 2020 [2]. This rapid growth of the connected devices is due to the introduction of smart phones, tablets and various other smart devices in the low-end markets on cheaper rates. With the concepts of Internet of Things, these devices will be able to communicate with each other, which will open up a wide range of applications in this expected inter-connected society. This calls for the need of a powerful network that allows more bandwidth and low latency for fast transfer of this gigantic data, because the existing wireless technologies like 4G cellular, Wi-Fi, LTE, LTE-Advanced, WiMAX, WiMAX 2, WLAN and WPAN are not able to provide the required latency and bandwidth to the powerful applications of the future. Not all the applications are going to have such high demands for the bandwidth and latency. Some will even work with low bandwidth and high latency and with minimum energy resources but still, there must be a network for the wide range of challenging applications. For example, the driver-less or autonomous cars will demand the packets to arrive fast so they can update their maps at a much faster rate i.e. low latency, which 5G promises to give. Similarly, this 5G network will also enable good end-to-end connectivity, with which better streaming of the video calls, TV, and Video on Demand services will be possible. It is not just the users who need the 5G technology, but refrigerator, television and many other such appliances which will be connected to Internet, are going to need it more than us. This 5G technology is not just about a blazing-fast speed but it will form a ubiquitous connected society which will ensure all the connected devices and the end-user a 24/7 internet connectivity with a reliable and improved network performance, also it will enable services for the expected applications. The signals will be strong enough for efficient data transmission, no matter what the weather conditions are or wherever the user is.

2.3 The Requirements for 5G

Although there are no 5G standards as yet, top IT vendors have already put out their white papers which discuss the requirements of the next generation cellular network with pragmatic approaches based on the end user perspective. This section highlights some of the requirements that must be met for a next generation cellular network.

2.3.1 Higher Network Capacity

Load of traffic on the networks is increasing at a faster speed than the technology itself, 5G must be able to able to provide a 1000 to 5000 fold increase in capacity than the previous LTE generation of the cellular network while maintaining the Quality of Service (QoS), to meet the demands of the unprecedented traffic increase on the cellular networks.

2.3.2 Higher Data Rates

5G must be able to offer users a perception of infinite capacity with a ultra-high 100-fold data transfer speed compared to the previous generation, to meet the demands of the whole new range of particular applications.

2.3.3 Lower Latency

Latency is the time taken by the device to obtain the results which must be very low for a real-time communication. By the year 2020, there will be a billion of devices with reduced latency requirements like almost zero latency so 5G must be able to provide a 5 to 10 fold lower latency limit than the previous generation, to support a whole new range of devices with faster response times.

2.3.4 Reduced Battery Consumption

There will be many upcoming challenges for the next generation infrastructure, incorporating different sensors and available or new technologies. 5G must be able to provide a system capable of ensuring a 100-fold energy efficiency with a reduced power consumption in mobile networks and an increased battery life of terminal devices and the sensor networks which transmit their device data at infrequent intervals so that their occasional unattended performance can be ensured for a longer time.

2.3.5 Cost Effective

For a ubiquitous adoption of this cellular technology, 5G must have some cost-effective benefits over the previous generation in the form of a low-cost infrastructure. So notable solutions for the cost reduction must be provided such that that an affordable connectivity for the billions of devices is ensured.

2.3.6 More Reliability

5G must provide a secure encrypted infrastructure against intrusion detection such that there's no unauthorized access to the sensitive data and protection of the network against its vulnerabilities like security attacks including Denial-of-Service, so that an uninterrupted resources and services operation can be ensured. Also it must be capable of self-healing as a result of various network attacks.

2.3.7 Energy Harvesting

5G must also provide a combination of different energy harvesting technologies which could power the network elements by scavenging wasted energy resources, to maximize the lifetime of the wireless networks.

2.3.8 Seamless Roaming

5G must provide a seamless roaming by ensuring a rapid switching between different Radio access technologies of a Radio Access Network (RAN). It must also provide support for both high and low mobility use cases by ensuring a seamless handover which enables the user to transfer one Base station (BS) to another.

2.3.9 Spectrum Efficient

5G must maximize the higher frequency bands potential for licensed spectrum to boost the capacity and speed to a novel level as well as it must be able to utilize the unlicensed spectrum efficiently for smart traffic overloading. Also, coverage of the network highly depends on the spectral bands and its deployment so 5G must introduce new frequencies in centimetre or millimetre spectrum to support ultra dense deployments.

2.3.10 Flexibility and Intelligence

It must provide a flexible infrastructure that can provide software driven personalized services on demand and as well as intelligent services to a massive number of applications by fast and robust analyzing of real-time data. Also, it must provide Plug and Play feature to give an ability to use a new radio access technology in the network without extra modifications as soon as plugged in.

2.3.11 Scalability

Scalability is a very important feature that ensures the expansion of network elements with the increasing traffic demands. 5G cellular generation must be easily scalable to handle the traffic growth. Not all devices will have high requirements for the improved data rate and latency, so it must be provided as per devices' demands so 5G cellular generation must be able to support the devices having either of the low data rate/high latency and high data rate/low latency cases. Similarly, not all devices are stationary with no mobility requirements, some will have such requirements too which must be provided on-demand.

3 Enabling Technologies for 5G

Driven by a number of newly posed requirements for the future wireless network, an existing LTE-Advanced network is not an adequate solution to address these growing needs. Wireless service providers therefore are not just leveraging the existing technologies towards a better cellular generation, but also exploring new solutions to address the challenges of increasing traffic, higher data rate, higher bandwidth and various other challenges. In this section we discuss a number of enabling technologies that could be used to form a robust and effective cellular 5G network which is able to meet these demands.

3.1 Carrier Aggregation (CA)

Carrier Aggregation and acquisition of more frequency bands are the key element for an increased mobile spectrum in 5G. Carrier Aggregation, a cost effective technique specified by the third Generation Partnership Project (3GPP), allows the amalgamation of different radio channels within the same or different frequency bands to address the capacity challenges, and to provide higher data rates and considerable low latency. It allows the mobile operators to utilize the fragmented spectrum resources acquired through auctions or through amalgamation or alliance of other mobile operators, for achieving greater capacity. In addition to that, CA enables the load balancing technique with which wireless traffic is efficaciously distributed between different access points and the spectrum, which prevents overloading on the network [3]. It also maximizes the throughput and minimizes the response time and gives improved network utilization.

Spectrum is mainly of two types, Licensed Spectrum and Unlicensed Spectrum. Licensed spectrum allocates a fixed frequency band to the operators and is highly prioritized for it provides better Quality of Service. While, unlicensed spectrum does not provide satisfactory quality of service, however it does not cost any money. But with the help of Carrier Aggregation technique, we can make use of this unlicensed spectrum as well to meet the increasing traffic demands of the network. The Licensed spectrum can be used to provide advanced services to the traffic that demand a better quality of service and experience. While, the services to the traffic having less demands can easily be provided with the unlicensed spectrum. This way, operators can make a combined network of both spectrum which could not just provide the efficient spectrum but also reduced cost and better Quality of Service and Experience. 3GPP RAN is already working on the future LTE in the unlicensed spectrum known as Licensed Assisted Access, which was first introduced in 2013 and is generating a lot of interest recently. The current study item focuses on the LTE enhancements in the unlicensed spectrum and its coexistence with the Wi-Fi technology. There are two scenarios for exploiting unlicensed spectrum in deployment which is depicted in Fig. 1.

3.2 Shared Spectrum

3.2.1 Cognitive Radio (CR)

Cognitive Radio (CR) is a remarkable software-defined technology in the context of 5G, which improves the spectral efficiency by utilization of the congested or unused spectrum resources that results in more bits transmission per second (bps) and increased throughput. The fact that most of the time, the spectrum is not being utilized to its maximum leads to the need of a technology that could effectively make use of those unused portion of spectrum and hence Cognitive Radio was introduced. Cognitive Radio dynamically leases

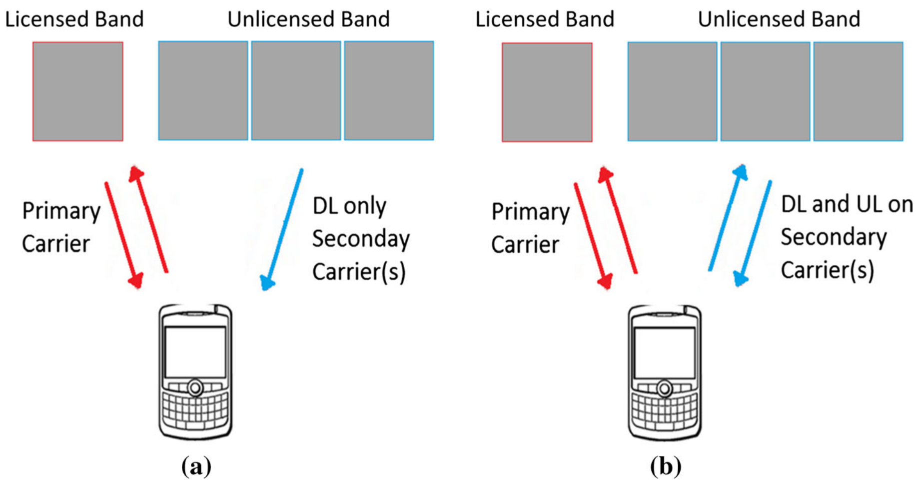


Fig. 1 (**a**) Primary carrier configured as both UL and DL, while Secondary carrier configured as DL only. (**b**) Primary carrier and Secondary carrier both configured as UL and DL

the spectrum to a cognitive radio network when the primary network (E-UTRAN Node B, abbreviated as eNB) is not utilizing its spectrum efficiently, on a significantly lower cost as compared to purchasing the licensed spectrum, which prevents overloading of the network in peak hours [4]. CR enables the access of unlicensed spectrum users to the licensed spectrum with the minimum interference.

3.2.2 Licensed Spectrum Access (LSA)

Cognitive radio provides solution for the wasted spectrum resources utilization; however, it has few concerns related to the interference of unlicensed spectrum with the licensed spectrum. So, to address the growing traffic challenges and high demand of more spectrums without making use of the CR, band sharing is achieved by Licensed Spectrum Access (LSA). LSA allows the sharing of the frequency band with other authorized users without the need of a license but based on some particular conditions imposed by the license holder, which produce more spectrum resources by utilizing the underutilized spectrum band and also provide solutions for the concerns in CR [5].

3.3 Virtualization

3.3.1 Software Defined Networks (SDN)

Software defined Networks (SDN) is an emerging software defined approach towards designing and managing networks, which is very different from the traditional networks which rely on the nodal architecture and smart machinery. In the traditional networks, control plane that controls the behavioural elements of a network and forwarding plane (sometimes called data plane) that manages the network packets on arrival is done on the same machine. However, SDN separates the control plane and forwarding plane which makes them able to be configured separately through software instead of having to configure through physical switches and routers, making it significantly flexible for providing the best path on request for any certain type of traffic to meet the changing demands. SDN ushers in a completely virtual network platform that allows rapid, portable, scalable and flexible backward compatible deployment of new services on the changing demands, with reduced CAPEX and OPEX and improved user experience with better QoS and security infrastructure.

3.3.2 Network Function Virtualization (NFV)

Network Function Virtualization (NFV), also known as Virtual Network Functions, emerged in late 2012 by an Industry Specific Group, working under European Telecommunications Standards Institute (ETSI), for the purpose of accelerating the progress towards a cost efficient and a flexible virtual network infrastructure. NFV is the virtualization of the core network functions applicable to both data and control planes, previously done by hardware dedication. Once the network functions are operational on the firmware running virtual machines like a Virtual Machine Monitor (also known as Hypervisor) and are no longer dependent on the specific hardware, the mobile carriers can easily deploy and manage their services on virtual platforms. The adoption of NFV will provide the scalability to cater the increasing demands; also it will ensure mobile carriers a reduction in deployment costs (CAPEX), as well as in network operations (OPEX). Moreover, the carriers will not have to dispatch their technicians and engineers to the site for installing the new network functions; instead they will be able to install or configure the network functions virtually, which will effectively reduce the expensive Truck Rolls. A number of network functions that could be virtualized by NFV include Network Address Translation (NAT), Intrusion Detection, Domain Name Service (DNS), Switching, Firewalling and the Load balancers. The virtualized network functions can then be easily managed through software based routers on x86 servers or even replicated on any other hardware.

3.3.3 SDN Versus NFV

Software defined networks and network function virtualization are two closely related hot research topics in the context of 5G because of their virtualization purposes. Both the techniques have common goals including reduction of CAPEX, OPEX and complexity of the network by virtualization of the network infrastructure, however both have different domains and hence not exactly the same. The focus of NFV is on virtualization of the specific network functions while SDN focuses on the decoupling of control plane and data plane. So, both SDN and NFV can efficiently function as a standalone technology, but a combination of both can usher the carriers to reap great many benefits from it. This combination can enable the carriers to provide a better quality of service with a level of agility and increased network resources. The basic infrastructure of both NFV and SDN is already being used by the IT key vendors; however they further need to be taken on the next level of robustness and flexibility considering the increasing demands of high data rates and latency requirements.

3.4 Spectral Efficiency

3.4.1 Advanced Interference Mitigation

Spectral efficiency is the transmission rate measured in bps per Hz (bit/s/Hz). The improvement in spectral efficiency increases the amount of data transmission within a given bandwidth. One of the hurdles that stand in the way of progressing towards higher data rate and spectral efficiency is the interference between the cells, and to counter this problem, mobile carriers have constructed more towers and even used filters to reduce or cut out interference from the network. But the increase in traffic causes increase in spectrum usage which makes it too hard for the carriers to deal with the interference. Interference happens because of two reasons, Frequency Reuse Factor and Heterogeneous Deployment [6]. Frequency Reusing Factor is an important factor to consider when there are limited spectrum resources, but this leads to the interference between the cells having the same frequencies, as shown in Fig. 2. The interference considerations are tackled by the following relation:

$$S_t = S_0 K \tag{1}$$

where S_t is the available RF channels, S_0 is the channels per cell, which defines the capacity of a system and K is the Reuse Factor, which is the total number of the repetitive cells.

The lowest Reuse factor is $K = 1$ which provides less distance between the neighbouring Evolved Node B having the same frequency channels and hence causing interference, however a higher Reuse factor results in a low interference because of more

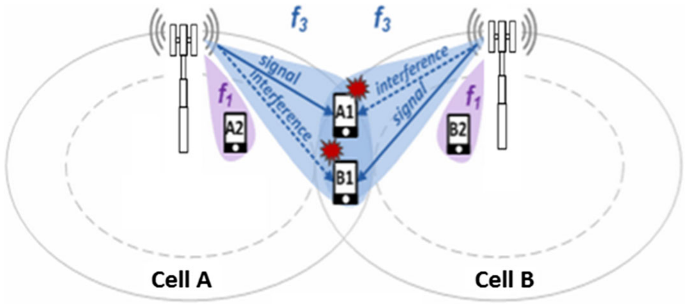


Fig. 2 No Interference in central regions (which has A2 and B2 operating on same frequency, f1), because of less power consumption in communication between the cells. While A1 and B1, operating on the same frequency f3, consume more communication power being at cell edge and hence cause interference

distance. Similarly, the random and irregular deployment of the Base stations results in more interference for cell edge users.

Inter-Cell Interference Coordination (ICIC) method, introduced in 3GPP Release 8, deals with the interference issues at the cell-edge, while mitigating only the traffic channels interference using power and frequency domains. It coordinates cell-edge scheduling such that none of the users in different cells have the same frequency, time resources as shown in Fig. 3. The Base station exchanges the information with other base stations via X2 interface through which the other base stations learn about the interference statuses of the other neighbouring base stations on the basis of which frequency and power is allocated to avoid the interference. Other than the interference information, X2 Interfaces are also capable of exchanging information related to handover and resource status etc.

Inter-cell interference coordination is way effective in reduction of interference between the cells in the network, but ICIC does not reduce the interference between the control channels which caused the need of an enhanced version of ICIC which could deal with the limitations of ICIC. So, an upgradation of ICIC to support Heterogeneous Networks (Het-Nets), Enhanced Inter-Cell Interference Coordination (eICIC) method was introduced in 3GPP Release 10 which mitigates interference on both control and traffic channels and hence makes the system robust. eICIC comes with two main technologies, Almost Blank Subframe (ABS) and Cell Range Expansion (CRE), introduced in 3GPP Release 10. ABS makes the cell-edge UEs in small cells to use different time span (or sub frames), as shown in Fig. 4. Despite of having same resources, prevention of interference between the cell-edge UEs and the neighbouring macro cells is ensured. While, CRE increases the coverage area of small cells to make their wide-range availability possible for the in-range cell-edge UEs.

Both of these discusses technologies were somewhat effective but lacked an interference avoidance scheme against the interference due to dynamic scheduling that handles the priorities between the UEs, so Coordinated Multi-Point (CoMP) method was introduced in 3GPP Release 11 to deal with these limitations and provide some upgradations like support of both homogeneous and heterogeneous networks. Other than the Time and Frequency domains, CoMP makes use of the spatial domain as well and makes many cells to work together in cooperation to improve the cell-edge performance. It mitigates the interference between the cells and unlike the traditional networks, allows the serving cell as well as other cells in different locations to communicate with the UE through association with each other which results in a reduced interference and hence better throughput at cell-edge. In the case of downlink (DL), two exemplary ways of transmission are Joint Transmission

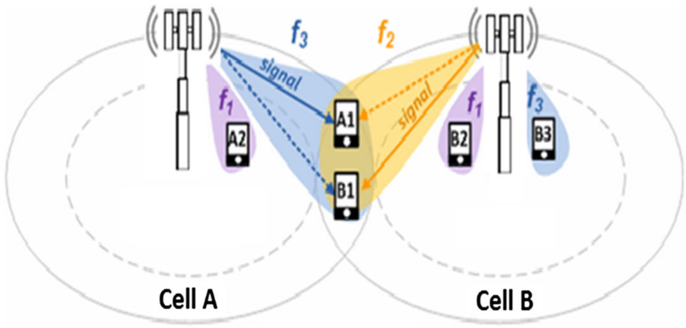


Fig. 3 Frequency resources for A1 and B1 at cell-edge are different because of ICIC method, causing no interference between them. While the same frequency is allocated to a less power consuming User Equipment (UE) because Cell A is already using that frequency for a UE at the cell-edge

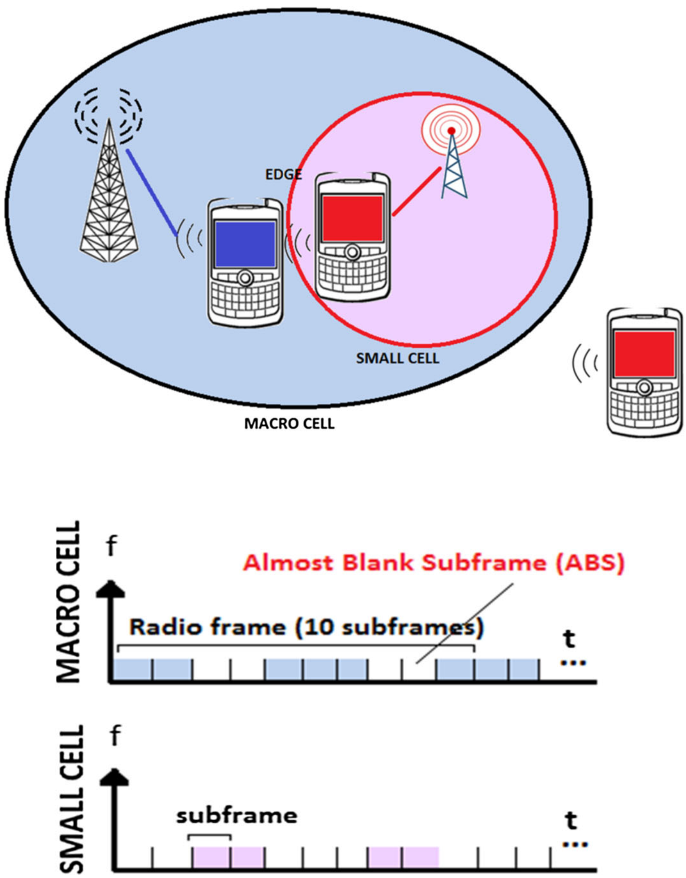


Fig. 4 eICIC scenario

Table 1 Small cells

	Picocells	Femtocells
No. of cells	Multiple small cells	One cell
Deployed by	Network operator	The customer
Power	High	Low
Coverage	Enterprises, malls	Houses or appartments

(JT) and Dynamic Point Selection (DPS). In JT, two or more transmitter (TX) points transmit on the same frequency, time and sub frame. While, in DPS, only one among the two or more TX points transmits in each sub frame at a time. In the case of uplink (UL), there is a Joint Reception in which the receiver (RX) points receive the data from the UE and then amalgamate for improvising the quality.

3.4.2 Network Densification and Offloading

Network Densification through small cells is another effective approach implied on previous many cellular generations as well having cell sizes in range of many square kilometers which nowadays are very small, to improve the spectral efficiency and the network capacity. Small cells are low power, operator controlled nodes, able to work in both licensed (LTE) and unlicensed band (e.g. Wi-Fi) and having a range of few meters to few kilometers as compared to the Macro Cells which provide service through a high power BS and have a range of few dozen kilometers. Having known the problems of increased requirements for coverage due to traffic growth, small cells provide an effective solution by increasing the number of small cell access points which decreases the distance between transmitters and the user-end and the number of resources-hungry users on each BS, resulting in offloading of the heavy users' traffic off the macro cell towards the small cells which frees up the network resources and hence increasing the quality of service and the coverage [7]. Additional benefits of having a small cell network include a lower latency and better cell-edge performance. Shrinking of the cell results in no different strength of the signal, but at the cost of a worse quality of service and increased Signal-to-Interference Ratio (SIR). However, the cells can be shrunk as much as required until the Base station start serving a sole or idle user which results in wastage of resources or in other words, until the power-law pathloss model is ensured, the cells can be shrunk as per the requirement with a better SIR [8]. Small cells can generally be classified into femtocells, picocells and microcells, with femtocells the smallest in size, used for residential deployment and microcells the largest, used for wider coverage deployment. Table 1 outlines the differences between the three types.

3.4.3 Massive and 3D MIMO

Multiple-Input Multiple-Output is the use of multiple antennas at the TX/RX points to fulfill the demands of high speed communication with link reliability in rough conditions at the cost of increased hardware complexity and more consumption of energy [9].

Massive MIMO, a promising technology for 5G cellular network, scales up the benefits of the traditional MIMO systems by allowing high-resolution beam-forming and using a lot more number of antennas at the existing Macro BS than the number of transmitted and received data streams in both DL and UL respectively using spatial multiplexing technique, that transmits energy to the user-end. It serves every active user-end using both time/frequency resources and provides a large degree of freedom in spatial domain of wireless channels to aid more information, which can even be exploited by beam-forming through the available information of the channel state. Massive MIMO depends on the spatial way of combining signals that actually counts on the condition that BS has good channel related information on both DL and UL (Fig. 4).

The increase in capacity and energy of the Massive MIMO results due to spatial multiplexing and the sharp focused energy into spatial small regions respectively [10]. The larger degree of freedom results in increased data rate because the increased number of antennas provide more paths which allows more data transmission at a time, and an increased Signal-to-Noise Ratio (SNR) along with reliability, energy efficiency and as well as exploitation of higher frequency spectrum benefits. Another technology under consideration is the special kind of a larger scale MIMO, known as 3D MIMO, which allows 3D beam-forming. The 3D beam-forming method is different from the normal beam-forming methods that allows formation of beam in two dimensions, while 3D beam-forming forms the beam in a three-dimensional array structure which allows more sectors in the cell range as shown in Fig. 5. 3D Beam-forming requires new 3D channel models, and the work on it has been completed in 3GPP Release 12. 3D Beam-forming and Massive MIMO are the key technologies to deal with the future requirements of higher capacity, so a detailed study on the higher MIMO technologies for higher frequencies is required.

3.5 Spatial Modulation (SM)

The use of multiple antennas at the transmitter and receiver ends is an effective solution for a significant improvement in the spectral efficiency without any hardware complexity. However, dealing with the inter-cell interference makes the implementation complex for it since it requires a great amount of energy to perform processing at the BS. Instead of a simultaneous multiple transmissions of digital encoded signals through the antennas, Spatial Modulation (SM), one of the efficient ways to lessen the complexity of a MIMO network, considers the antenna arrays as a spatial constellation diagram where each antenna in the system carries a sequence of information bits. This technique enables the transmission from just one antenna off the antenna array at a time on a successful match of the incoming symbol with the existing symbol on the antenna, whose spatial position is encoded with the data needed to be transmitted, while others remain inactive. SM maps the

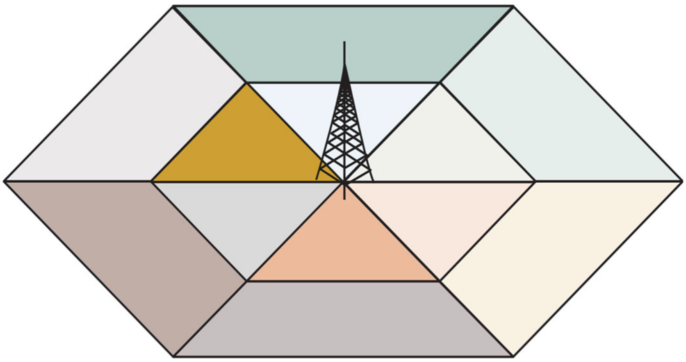


Fig. 5 Sectorization scenario in 3D MIMO

information bits block to two further units of base-2 logarithm, among which one is the Quadrature Phase Shift Keying modulation scheme that transmits two bits at a time, $\log_2(M)$ and the other is the number of antennas selected for transmission off the antenna array, $\log_2(N)$.

Spatial modulation significantly improves the communication network performance and exploits immense MIMO gains for energy efficiency in communications. But, SM sacrifices the spatial degree of freedom because of the logarithmic increase of the multiplexing gain (which causes a gain in capacity with no additional bandwidth requirements, as a result of transmission of different data streams using the same resources in a spatial domain) with the increasing number of antennas at constant energy dissipation. With the number of benefits, SM is considered to be a strong enabling technology for fulfilling the demands of futuristic data-hungry devices.

3.6 Full Duplex Communication (FDC)

The transmission and reception of the information in the existing wireless networks occur alternately i.e. half-duplex way of communication; however two separate frequencies are used for simultaneous communication in both the directions. The Full-duplex technology, one of the core technologies of the futuristic wireless cellular network 5G, enables the simultaneous flow of information using the same spectrum resources, time slots and the frequency bands [11]. This bi-directional communication doubles the whole capacity of the wireless network and increases the spectral efficiency by utilization of the same frequency and time, without any new requirements for the hardware and additional towers. The main challenge in achieving the full-duplex communication in a network is the Self-Interference which is caused by the leaked energy of the transmit antenna into the transceiver path which then exhibits itself as a noise signal, much stronger than that of the original signal. Particularly, in a MIMO system, the self-interference is very much stronger due to a big number of transmitters and receivers in the field. As shown in Fig. 6, The Radio-1 and Radio-2 are simultaneously carrying out the communication with the similar frequencies, But the signal that Radio-1 receives from the Radio-2 is not that strong as compared to the signal generated from the self-transmission of the TX at the RX i.e. self-interference, so it makes difficult for the Radio-1 receiver to interpret the incoming information from the Radio-2 [12]. This interference must be reduced to the equal level as the noise floor, which is a measure of the sum of the noise signals, to interpret the actual signal on the receiver by making it almost negligible, else the noise signal can cause a huge reduction in the Signal-to-Noise ratio and accordingly the throughput in both DL and UL. As an example, the self-interference of the Wi-Fi signals that transmit at an average power of 20 dBm (or 100 mW) with the noise floor approximately around 90 dBm (or 1×10^{-9} mW), is to be

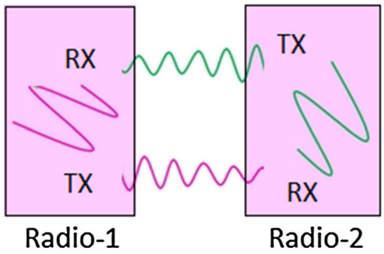


Fig. 6 Self interference in a full-duplex single channel communication

cancelled by 110 dBm [20 dBm − (−90 dBm)] for the reduction to the same level as the noise floor [13].

Achieving full-duplex communication could help getting over many limitations in the wireless networks including the bandwidth limitations. Many recent developments in the interference-cancellation methods make full-duplex a practical solution for dealing with spectral and many other constraints for the 5G cellular networks.

3.7 Mobile Femtocell (MFemtocell)

The MFemtocell concept incorporating the moving network (or mobile relays) is a promising technology for the improvement in spectral efficiency of the next generation network. MFemtocell is a kind of small cell that can be easily deployed in the moving buses, trains and cars, enabling the BS to perform transmission and reception of the data with the users on-board. The deployed femtocells continuously change their positions so they repeatedly move into the regions where the eNB signal strength is relatively poor due to which they perform nonstop handovers with the nearby base stations, and which must be really quick enough to provide a seamless wireless connectivity to the user-end as they move around. MFemtocells make the whole handover process very complex due to frequent connection changing requests and the need to fulfill the requests in a fixed time which causes signaling load and the frequent connection drop on the network if proper actions to deal with these issues are not taken. The MFemtocell concept is of enormous benefits to the wireless cellular network as it provides a significant increase in the spectral efficiency of the network and the average throughput. MFemtocell treats its traffic as a single UE (or a transceiver), with some additional features.

Since the MFemtocells can handover on behalf of all their linked users so it reduces the frequent change of networks which ensures a reduction in the signaling load and as a result lower energy consumption. It provides a better quality of service by a setup with antennas located on the outside and the femtocells inside the conveyance. The Fig. 7 shows a PF and

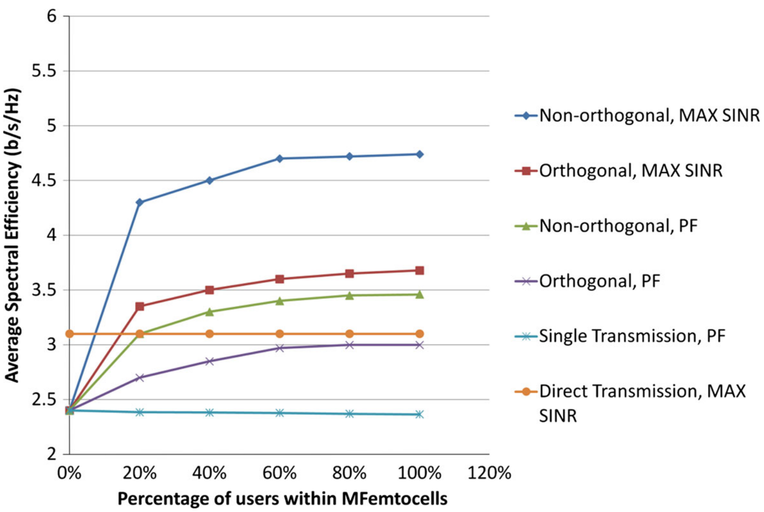


Fig. 7 Increase in percentage of users within the MFemtocells leads to more spectral efficiency in the case of the MFemtocells instead of the traditional direct scheme

SNR algorithm based comparative graphical analysis between the percentage of users within the MFemtocells and their average spectral efficiency by making use of the MFemtocell transmission with orthogonal and non-orthogonal resources partition schemes and the direct transmission [14]. Since the femtocells can be easily deployed by users themselves so to prevent interference and the resulting decrease in capacity of the network due to deployment, the network parameters must be self-adjusting to the situation. The estimations of Signal-to-Interference plus Noise Ratio (SINR) through the path loss model are as followed [15]. The path losses between UE and Macro BS can be known by the following equations with Eq. 2 representing the path loss when UE is inside and Eq. 3 when UE is outside:

$$PL_{db} = 15.3 + 37.6\log_{10} R + L_{ow} \tag{2}$$

$$PL_{db} = 15.3 + 37.6\log_{10} R \tag{3}$$

where R is the distance between RX and TX with the units of length and L_{ow} is the outdoor wall penetration loss i.e. 20 dB. Similarly, the path loss between a UE and Femto BS when UE is inside and when UE is outside is represented by Eqs. 4 and 5 respectively:

$$PL_{db} = 38.46 + 20\log_{10} R + 0.7d_{2D,indoor} + 18.3n^{\left(\frac{n+2}{n+1}-0.46\right)} + qL_{iw} \tag{4}$$

$$\begin{aligned} PL_{db} = {} & \max(15.3 + 37.6\log_{10} R, 38.46 + 20\log_{10} R) + 0.7d_{2D,indoor} \\ & + 18.3n^{\left(\frac{n+2}{n+1}-0.46\right)} + qL_{iw} + L_{ow} \end{aligned} \tag{5}$$

where $0.7d_{2D,indoor}$ is the penetration loss due to the walls inside an apartment and is measured in units of length, n is the number of penetrated floors, q is the total walls separating apartments between Femto BS and UE and L_{iw} is the penetration loss of the wall separating apartments i.e. 5 dB.

The SINR of the macro user m and a femto user f on a sub-carrier k when interfered with the nearby Macro and Femto cells can be estimated with Eqs. 6 and 7 respectively:

$$\mathrm{SINR}_{m,k} = \frac{P_{M,k}G_{m,M,k}}{N_0\Delta f + \sum_{M'} P_{M',k}G_{m,M',k} + \sum_{F} P_{F,k}G_{m,F,k}} \tag{6}$$

$$\mathrm{SINR}_{f,k} = \frac{P_{F,k}G_{f,F,k}}{N_0\Delta f + \sum_{M} P_{M,k}G_{f,M,k} + \sum_{F'} P_{F',k}G_{f,F',k}} \tag{7}$$

where $P_{M,k}$, $P_{M',k}$ and $P_{F,k}$ are the transmit powers of the Macro cell M and the nearby Macro cell M′ and Femto cell F′ respectively on the sub-carrier k, N0 is the white noise with a constant power spectral density, $\triangle f$ is the sub-carrier spacing and $G_{m,M,k}$, $G_{m,M',k}$ and $G_{m,F,k}$ are the channel gains between macro user and Macro cell M, nearby Macro cell M’ and Femto cell F respectively on sub-carrier k. The path loss affected channel gain G can be expressed as: $G = 10^{-PL/10}$.

3.8 Millimeter Wave (mmWave)

Millimeter Wave (mmWave) is a promising enabling technology for the future cellular networks which can support higher data rates of Gigabits per second (Gbps) by making the network to operate in the frequency range 30–300 GHz so as to make use of the large chunk of raw and unused bandwidth in this range which can effectively provide more number of channels to the users and greater data rates to meet the growing traffic demands [16]. ITU has designated this frequency range as an Extremely high frequency (EHF) that is found between microwaves (1–30 GHz) and IR waves and represents a section of electromagnetic spectrum where the electromagnetic radiation frequencies become too low. mmWave is the next band above the microwave. Since the band has a wavelength in the range 1–10 mm, it is called mmWave. Besides relieving of pressure on the lower frequencies, the mmWave can be exploited to reap great many advantages like it can be used to introduce new polarization techniques which have an important role in wireless communication networks, and as well as major improvements in the beam-forming techniques for high directional transmission and reception of the signal. Moreover, the huge spectrum due to mmWave can be used to ensure the communication between different Base stations as well and it further allows the mobile carriers to increase the channel bandwidths for radio frequencies without notable attenuation which eventually increases the channel capacity and supports the extreme latency-sensitive applications by reducing the latency [17]. Besides the enhancement of cellular communications to deal with the limitations of radio technologies and a great many benefits, the usage of this high frequency band poses few challenges that needs to be addressed through substantial researches. mmWave do not penetrate into the solid substances as the lower radio frequency technologies in the existing cellular networks do and other than the common path losses, the radio waves even suffer from propagation losses (or penetration losses) like loss of energies over larger distances due to absorption of water vapors, scattering by different gases and attenuation due to fog or snow. The free-space path loss (FSPL) between the transmitter and receiver can be known by the following equation:

$$\begin{aligned} FPSL &= \left(\frac{4\pi d}{\lambda}\right)^2 \\ &= \left(\frac{4\pi df}{c}\right)^2 \end{aligned} \tag{8}$$

where 'λ' is the wavelength in meters, 'd' is the distance between the transmitter and receiver with the similar unit to the wavelength, 'f' is the frequency in hertz and 'c' is the speed of light in vacuum. In terms of dB, it can be expressed as:

$$\begin{aligned} FPSL_{(db)} &= 10\log_{10}\left(\left(\frac{4\pi df}{c}\right)^2\right) \\ &= 20\log_{10}\left(\frac{4\pi df}{c}\right) \\ &= 20\log_{10}(d) + 20\log_{10}(f) + 20\log_{10}\left(\frac{4\pi df}{c}\right) \\ &= 20\log_{10}(d) + 20\log_{10}(f) - 147.55 \end{aligned} \tag{9}$$

For example, the loss at 30 m distance with 60 GHz frequency is:

$$FPSL_{(db)} = 20\log_{10}(30) + 20\log_{10}\left(60 \times 10^9\right) - 147.55 = 97.55\,\text{dB}$$

This 97.55 dB loss can be easily overcome by using higher antenna gains and transmit power. Also, the lower radio waves frequencies in the mmWave band below 10 GHz have a foreseeable attenuation, but the higher frequencies are highly affected by oxygen (O_2)

and water vapors (H_2O) in the atmosphere, due to which the communication range becomes limited. The total attenuation due to these atmospheric conditions is the sum of attenuation caused by the free-space path loss, oxygen and water vapors absorption and the rain:

$$A_{tot} = A_{FPSL} + A_{O_2} + A_{H_2O} + A_{Rain} \tag{10}$$

The Fig. 8 shows the attenuation versus frequency graph due to absorption of O_2 and H_2O at the sea level.

All the losses discussed above limit the communication through mmWave to a very short range of around a kilometre to a very few kilometres, if not dealt efficiently, but this is not literally a disadvantage because they perform very good in different applications of short-range communication like the expensive last mile technology that forms a direct connection between carrier and the user over a shorter distance. And obviously the re-using of frequencies in wireless communications is common too which can benefit from the short range characteristic of the mmWave. The narrow beam width achieved from the small antennas can also help with re-using of the spectrum. With the high directional beams nature, deployment of many radios in the same path and area is also possible using the same frequencies without any interference. Considering the high frequencies of mmWave, the wavelength which is the distance a radio wave covers in a cycle and is relative to the size of antenna, the wavelength decrease which in turn reduces the size of the antenna and the carriers can therefore make much lighter and smaller antennas, which can be expressed by the relation:

$$\lambda = {}^{c}\!/_{f} \tag{11}$$

where 'λ' is the wavelength in meters, 'c' is the speed of light i.e. 3×10^8 m/s and 'f' is the frequency in Hertz. For example, the wavelength at 30 GHz is:

$$\lambda = \frac{3 \times 10^8}{30 \times 10^9} = 0.01\,\text{m}$$

Similarly, not being able to penetrate into the solid substances can be advantageous in the sense that it provides security against the miscreant users as they will need to put the malicious instruments in the path of transmission and reception so it can be a mean of providing protection against the possible attacks. Also, the absorption of oxygen causes

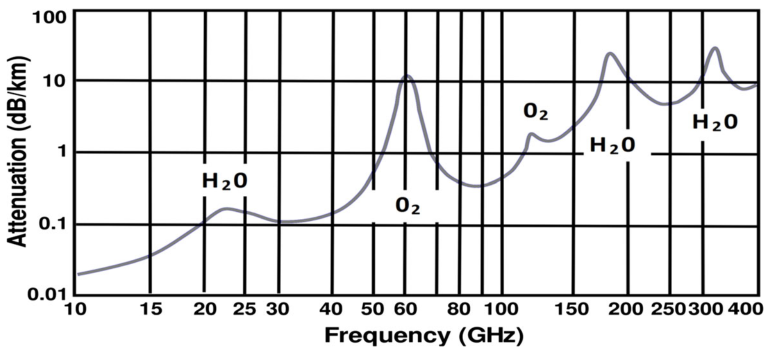


Fig. 8 The peak due to O_2 occurs at 60 GHz while the first peak due to H_2O occur at 22 GHz

propagation losses resulting in range limitation in mmWave but this has a huge advantage too in the form of a much lower interference particularly in the 60 GHz band which combined with the oxygen absorption and narrow beam width results in a much more re-using of the frequencies and lower interference, compared to that of the radios with low frequencies. There have been many researches in this field and it is now possible to create a cellular network operating at the mmWave frequencies with an inexpensive and a reliable infrastructure. However, the challenges of the existing mmWave based infrastructure and the expected challenges in the future need to be properly addressed to strengthen its roots in the 5G cellular network.

3.9 Visible Light Communication (VLC)

There has been a buzz about this new wireless technology for the last few years which has a significant potential to meet the demands of the growing traffic in the future cellular networks. Visible Light Communication, which is considered to be one of the potential enabling technology for access of 5G cellular communications, is a bi-directional, ultra-wideband, energy efficient, greener and high speed mean of wireless communications. It uses light which is a part of electromagnetic spectrum with the help of inexpensive Infrared, Near-ultraviolet, a range close to the visible spectrum or visible light between a very high frequency range of 400–800 THz from a fluorescent lamp or a light-emitting diode (LED) as a source of transmission instead of the RF waves which provide many great features as well as provide solutions for the bandwidth limitations of the Radio Frequency.

Visible light communication also known as Li-Fi, makes a perfect accompaniment to the RF communication, or can even be replaced with it which makes the future of Li-Fi bright as a cheaper and a reliable solution. It works by a continuous switching of the LED within a few nanoseconds which almost appears steady to the bare eye and provides a data rate up to 10 Gbps. The use of a high frequency limits the transmission range i.e. communication is done only on a shorter distance and is susceptible to the obstacles in the path of transmission, However, it has many advantages including zero electromagnetic interference which enables it to provide services where Wi-Fi is not allowed to, such as nuclear power plants and hospitals, because of the pollution caused by the RF waves that increases the risk of many diseases like DNA damage or cancer. The visible light spectrum of the Li-Fi technology is 10,000 times larger than that of the Radiowaves spectrum as shown in Fig. 9, which gives it a superiority over the radio-waves based wireless technologies that are already suffering from a capacity crunch. Since visible light is easily perceivable by the human eye so it limits the damages compared to the case of RF waves. Moreover, because the light cannot penetrate the walls so Li-Fi also provides security against the possible attacks on the systems.

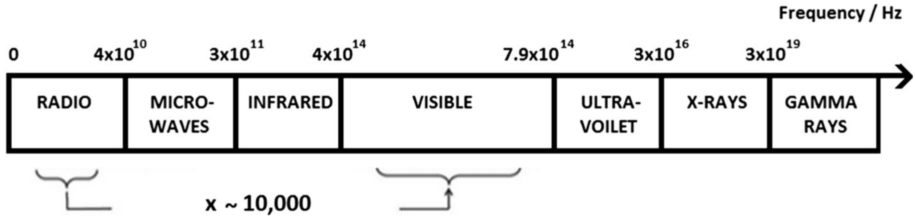


Fig. 9 The visible light spectrum is 10,000× larger than that of the radio waves spectrum

3.10 Device-to-Device (D2D) Networks

In a traditional network, Base Station is responsible for all the communications with the devices, in the licensed spectrum. But, in a D2D Network, two or more devices interconnect with the assistance of each other. However that does not mean that the communication with the BS is no more required, communication is still done through base stations

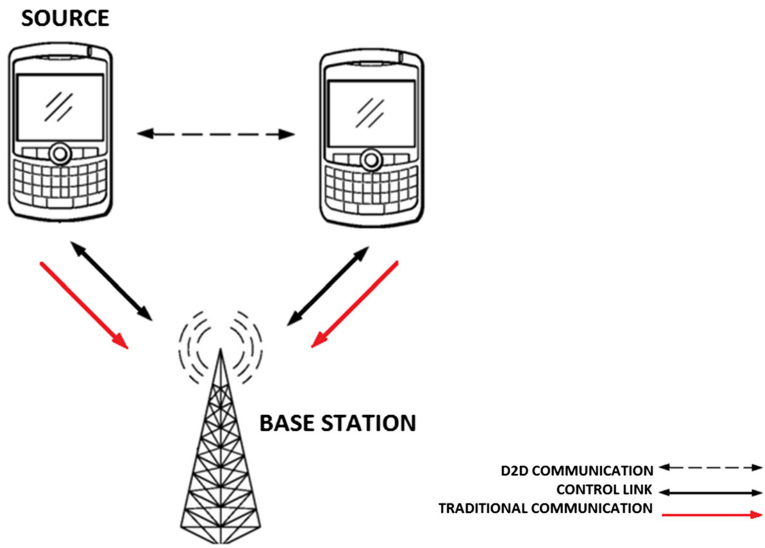
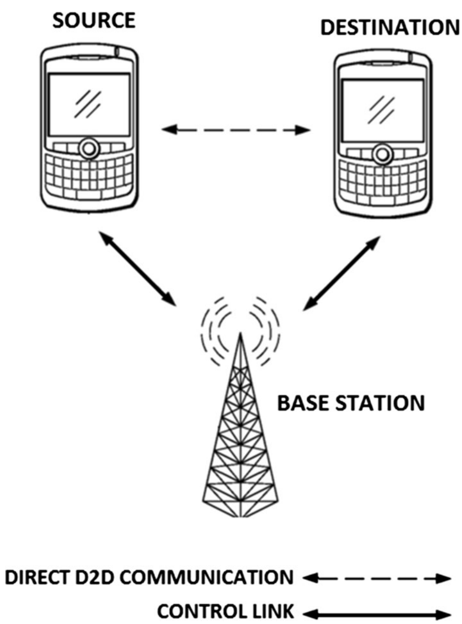


Fig. 10 Illustration of D2D communication with OC-DR

Fig. 11 Illustration of D2D communication with OC-IC



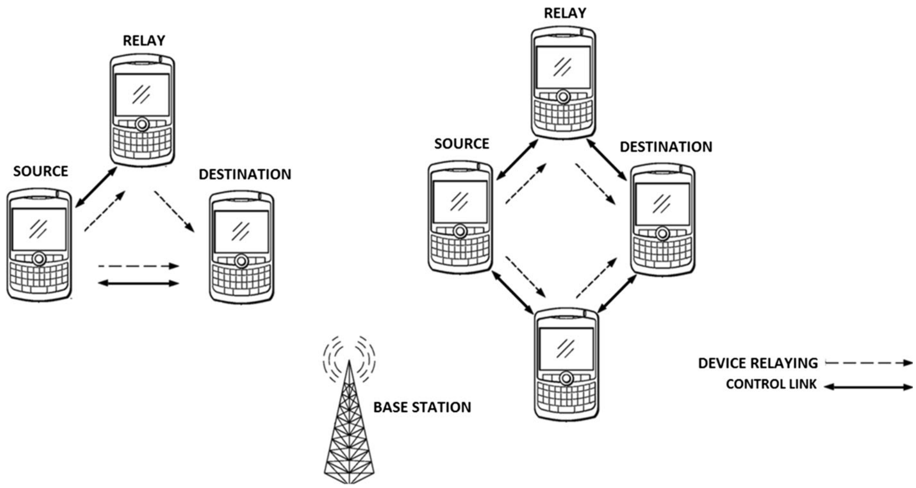


Fig. 12 Illustration of D2D communication with DC-DR

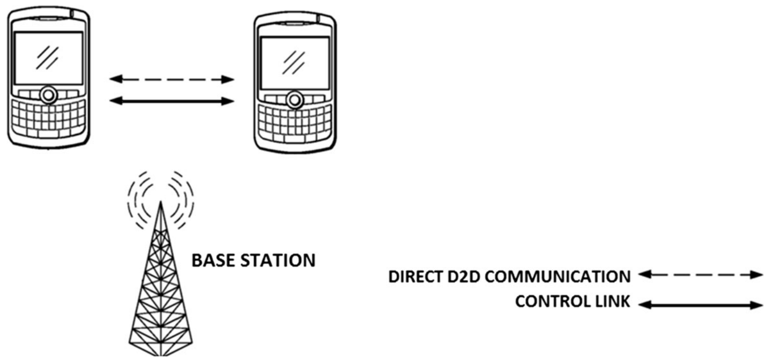


Fig. 13 Illustration of D2D communication with DC-IC

but D2D communication is helpful when there is a poor coverage for example, at the cell-edge. The four kinds of D2D communication, as shown in Figs. 10–13 are discussed below [18].

3.10.1 Operator Controlled Link Based Devices Relaying (OC-DR)

A device which is not in a range of the BS can perform transmission of the information with the BS by communicating through many other neighbouring devices which provides a better Quality of Service. BS has an operator controlled link with the devices through which spectrum allocation is managed for the reduction of interference. Through this control link, BS can even perform authentication methods to provide privacy for the data communication between the devices.

3.10.2 Operator Controlled Link Based Inter-devices Communication (OC-IC)

Two or more devices communicate with each other without having to depend on the BS, However, similar to the OC-DR type communication, the control link provides assistance to the devices by BS which provides authentication control of the access and manages the resources allocation between the devices.

3.10.3 Device Controlled Link Based Devices Relaying (DC-DR)

The devices communicate with the neighbouring devices for information transmission without having any control link between the BS and the devices. The only control link is between the interconnected devices themselves. Since the BS provides no solution for the resources allocation so the interference problems occur between the inter-connected devices and the devices affect the Macro cell users as well. However, approaches like Resource Pooling and Relay selection can reduce the interference problems.

3.10.4 Device Controlled Link Based Inter-devices Communication (DC-IC)

In this type of D2D communication, Devices communicate with each other independent of any control link either between the devices themselves or between the devices and the BS. It has no connection setup and resources management scheme, hence results in interference.

3.11 Ad Hoc Networks

An Ad Hoc Network is an unplanned network that allows a direct communication between the wireless nodes to forward the data between each other as they connect, instead of relying on the BS to flow the information around different nodes. However, the Ad Hoc network only allows connectivity between devices in a small region so it is better for a small network with not so many devices as it would not be easily manageable in that case. A common type of Ad Hoc network is a Mobile Ad Hoc Network (MANET). MANET is a peer-to-peer decentralized network, where either of the nodes in the network can establish communication with the other nodes. MANET configures itself and operates on the go without any infrastructure of interconnected nodes communicating on the wireless links with a relatively constrained bandwidth. These wireless nodes in the MANET are allowed to move freely due to which they may continually arrange with each other and change their locations over time. The nodes make use of the multi-hop radio relaying topology to relay the traffic between the BS and user-end. Similarly, the WiFi Direct standard also forms an Ad Hoc network over the WiFi between the devices in proximity.

The concept of Ad Hoc networks has already been practical for many years and is being used in military and many emergency operations due to its number of advantages. The independence from an infrastructure and therefore low costs is the biggest reason why Ad Hoc networks are highly preferred in the remote areas where there are no as such high requirements for infrastructure considering the minimal usage. Similarly, in the battle-grounds, building an infrastructure for communication purposes is pointless. Ad Hoc networks also provide reliability against loss of connectivity, like even with a fault in the node, it can still relay its information through other nodes by hopping on with them. However, Ad Hoc networks have a few disadvantages as well like there will be more interference in presence of many devices, it will require more system resources and the data flow would be a little slower than that of the traditional networks. For example, each node will have to directly connect with the other nodes instead of connecting through a common access source which will require additional resources, as well as more access time.

3.11.1 D2D Versus Ad Hoc Networks

The standards based on the Ad Hoc networks are being highly used because of their infrastructure-less network and therefore reduced costs. These standards provide a high data rate with a very low consumption of energy, but they are limited to a very short range which makes them ideal for a particular number of scenarios only. However, the D2D communications are performed in a licensed band which may have devices scheduled on the same time and frequency resourced with no interference between each other. D2D obviously has a proper security and some QoS rules set by the carrier and the carriers can even perform user authentication when needed, but this type of spectrum based communication becomes prone to different security issues when operating in assistance-less network.

4 Conclusion

The exponentially growing traffic brings new challenges and requirements for the mobile carriers including more network capacity, higher data rates and low latency with spectrum and cost efficiency which were discussed in this paper. Furthermore, the scenarios were presented in the paper from the end user perspective.

The 5G wireless communication network will provide solutions for all the needs of the growing traffic and provide services at any place and any time for anything and any one by making use of the existing and the new wireless technologies. However, a clear definition of 5G has still not been provided yet so there is no complete unanimity on what it will look like but it is more likely to be a combination of different wireless technologies. It is certainly a long road ahead to truly explore all the enabling technologies.

This paper provided an overview of such enabling technologies for the futuristic wireless cellular network like Massive MIMO, Moving networks and many others. The paper has explained the concepts for exploitation of the available spectrum. The integration of these new radio concepts and the exploitation of the spectrum will allow coping with all the expected traffic by the year 2020.

Besides all the existing and futuristic possible technologies of 5G discussed in the paper, there are some other technologies as well which are in the study phase like orbital angular momentum encoding and many more. We believe that all the technologies will have a great potential in the 5G development. In conclusion, the development of 5G will be a paradigm shift that will impact our societies and will progressively enrich the user experience in the 5G.

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