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Design aspects of 5G: Frequency allocation, services and MIMO antennas

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Abstract

The 5th Generation of mobile communication is the next big technological leap that will fulfill the needs of the information society in the coming decade. Researchers, academicians and stakeholders have come together to identify the scope and formulate the policies to be implemented for easy roll-out of 5G services around the globe. This paper reviews the work of numerous researchers and telecom standard developing organizations, with an aim of better understanding of the important design aspects of 5G-like allocation of the frequency spectrum, identified 5G services, methods of distribution of network resource with aim to attain defined Key Performance Indicators, User Equipment MIMO antenna design challenges and Base Station massive MIMO antenna requirements.

Keywords: 5G antenna, 5G spectrum, 5G services, Key performance indicators, Network slicing

1. Introduction

The introduction of new technologies and services has resulted in an exponential growth of the mobile communication industry. The 5th Generation of mobile communication will fulfil the needs of our information society in the coming decade. With major aims of providing greater data-bandwidth at significantly reduced latency, this communication system is bound to be the largest and most complex communication system ever. Expected to be commercially rolled out in the latter half of 2019 around the globe, 5G communication technology will break through the limitations of space and time to result in an all-dimensional interconnection between people and things [1]. During its initial proposal in 2017, 3GPP proposed Non-Stand-Alone (NSA) New Radio (NR) specification for 5G that required integration with the previous 4G systems based on Long Term Evolution (LTE) communication technology [2]. However throughout 2018, 3GPP focused on standardization of the first full set of standards of standalone 5G. These set of standardization measures were collectively grouped under 5G NR release 15 and release 16 versions [3]. The main focus of these release versions was performance evaluation of the three generic services supported by 5G as per ITU, enhanced Mobile Broadband (eMBB), massive Machine Type Communication (mMTC) and Ultra Reliable Low Latency (URLLC) [4-6].

In the following sections, certain prime design aspects of 5G communication networks will be discussed, including the frequency spectrum proposal for 5G New Radio, supported 5G services, 5G service deployment scenarios, Key Performance Indicators (KPIs) defined for these services, techniques of resource allocation, restrictions and challenges faced by antenna designers and a few Multiple-Input Multiple-Output (MIMO) antenna prototypes proposed by various researchers. A comparison of current 4th with the future 5th Generation of mobile communication is also discussed in terms of network features and KPIs.

2. 5G Frequency spectrum

In release 15 of 3GPP RAN4 activities, two broad frequency ranges were allocated that can be used for 5G NR services. The first range, FR1, corresponds to frequency spectrum between 450 MHz and 6000 MHz, while the second range, FR2,refers to the frequency spectrum between 24250 MHz and 52600 MHz [7-8]. The FR1 band is commonly referred to as the sub-6 GHz band, while the FR2 band is known as the mmWave band. Table 1 lists the 5G NR bands defined under FR1. These 27 bands are comprised of 12 bands working on Frequency Division Duplexing (FDD), 7 bands working on Time Division Duplexing (TDD), 2 bands working as Supplementary Downlinks (SDL) and 6 bands working as Supplementary Uplinks (SUL).

The bands defined in the FR1 range, however, could not achieve the throughput target set for the 5G services, hence a new higher frequency band needed to be considered [2]. The higher frequency bands identified by 3GPP are listed in Table 2. The International Telecommunication Union (ITU) organises a World Radio communication Conference (WRC) in every 3 to 4 years to review and revise radio-frequency

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spectrum. The upcoming WRC is scheduled to be held in October and November 2019 [9]. Some of the higher frequencies falling in FR2 range stand a chance of being discussed in the WRC-2019 Agenda Item 1.13. These frequencies are listed in Table 3. Figure 1 illustrates the range of frequencies from both FR1 and FR2 bands that are allotted or are under consideration for 5G roll out around the globe.

The use of a multi-spectrum approach in 5G is required to maintain the quality of service, to ensure proper deployment and to meet growing demands. The spectrum below 2 GHz can be used for providing services requiring wide-area coverage. The spectrum above 6 GHz can be used for services requiring extremely high data speeds, while the spectrum in between 2 GHz and 6 GHz can be allotted for providing services that require a balance between coverage and capacity [10].

3. 5G Services and network slicing

3GPP began a project named 'Study on New Services and Markets Technology Enablers (SMARTER)' in 2015. The project aimed at building high level use cases and recognizing the features and functionality that would be required by 5G networks to deliver them. At the beginning

Table 1 Bands and corresponding frequency spectrum of the 5G FR1 range [2]

5G NR Band	*Uplink Frequency*	*Downlink frequency*	*Duplex mode*
n1	1920-1980 MHz	2210-2710 MHz	FDD
n2	1850-1910 MHz	1930-1990 MHz	FDD
n3	1710-1785 MHz	1805-1880 MHz	FDD
n5	824-849 MHz	869-894 MHz	FDD
n7	2500-2570 MHz	2620-2690 MHz	FDD
n8	880-915 MHz	925-960 MHz	FDD
n20	832-862 MHz	791-821 MHz	FDD
n28	703-748 MHz	758-803 MHz	FDD
n38	2570-2620 MHz	2570-2620 MHz	TDD
n41	2496-2690 MHz	2496-1690 MHz	TDD
n50	1432-1517 MHz	1432-1517 MHz	TDD
n51	1427-1432 MHz	1427-1432 MHz	TDD
n66	1710-1780 MHz	2210-2200 MHz	FDD
n70	1695-1710 MHz	1995-2020 MHz	FDD
n71	663-698 MHz	617-652 MHz	FDD
n74	1427-1470 MHz	1475-1518 MHz	FDD
n75	N/A	1432-1517 MHz	SDL
n76	N/A	1427-1432 MHz	SDL
n77	3.3-4.2 GHz	3.3-4.2 GHz	TDD
n78	3.3-3.8 GHz	3.3-3.8 GHz	TDD
n79	4.4-5.0 GHz	4.4-5.0 GHz	TDD
n80	1710-1785 MHz	N/A	SUL
n81	880-915 MHz	N/A	SUL
n82	832-862 MHz	N/A	SUL
n83	703-748 MHz	N/A	SUL
n84	1920-1980 MHz	N/A	SUL
n85	2496-2690 MHz	N/A	SUL

Table 2 Bands and corresponding frequency spectrum of the 5G FR2 range [8]

5G NR Band	*Frequency range*	*Duplex mode*
n257	26.5 – 29.5 GHz	TDD
n258	24.25 – 27.5 GHz	TDD
n260	37 – 40 GHz	TDD
n261	27.5 – 28.35 GHz	TDD

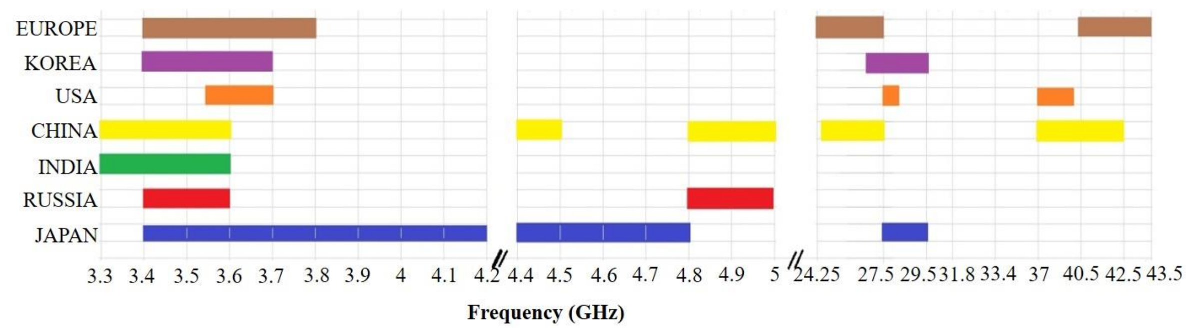

Figure1 Frequency spectrum already allotted or under consideration by regulators around the globe **[**10]

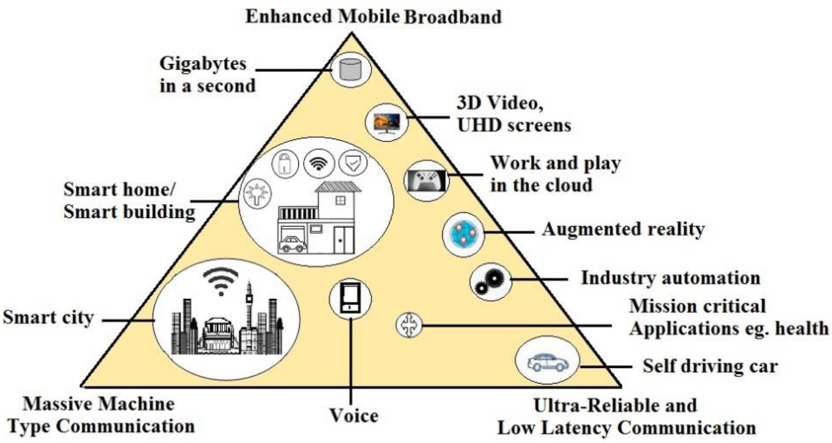

Figure 2 5G New Radio use cases [10]

Table 3 Frequency range considered in Agenda Item 1.13 of WRC-2019 [10]

Group	*Frequency Band*
Group 30	24.25 - 27.5 GHz, 31.8 – 33.4 GHz
Group 40	37 – 40.5 GHz, 40.5 – 42.5 GHz 42.5 – 43.5 GHz
Group 50	45.5 – 47 GHz 47 – 47.2 GHz 47.2 – 50.2 GHz 50.4 – 52.6 GHz

of the project, around 70 use cases were identified and grouped into four categories: FS-SMARTER massive internet of things, FS-SMARTER critical communication, FS-SMARTER enhanced mobile broadband and FS-SMARTER network operations [11]. With time, these categories got trimmed on the basis of performance attributes to result in the three primary 5G New Radio use cases- eMBB, mMTC and URLLC, as illustrated in Figure 2.

eMBB can be considered a direct evolution of existing 4G services. It will be designed to support steady connections with extremely high data rates and will be among the first 5G services to be made commercially available. MTC is also broadly understood as Internet of Things (IoT). It refers to automated data communication among devices without any kind of human intervention. mMTC in 5G will provide scalability to handle massive numbers of such devices. These devices will have optimal power use. They will be periodically active and transmit small data payloads [12]. URLLC will be designed to provide multiple enhanced services for extremely low latency-sensitive devices, for example robotic surgeries, large scale factory automation, self-driving cars and other such technologies. Owing to its characteristics of handling large amounts of data with minimal delay, URLLC is the most promising yet the hardest achievable of the 5G capabilities. 3GPP has defined certain targets as KPIs for 5G services, as listed in Table 4.

Various scenarios are considered to study 5G service deployment for all the three use cases. These are indoor hotspots, dense urban, rural, urban macro, high speed, extreme long distance coverage in low density areas, urban coverage for massive connection, a highway scenario, an

Table 4 KPIs of 5G use cases [13]

KPI (theoretical)	Target value considering error-free conditions
Peak data rate for eMBB	20 Gbps for downlink, 10 Gbps for uplink
Peak spectral efficiency for eMBB	30 bps/Hz for downlink, 15 bps/Hz for uplink
Control plane latency	10 ms
User plane latency for URLLC	0.5 ms for both downlink and uplink
User plane latency for eMBB	4 ms for both downlink and uplink
Reliability	10^{-5} packet error rate for 32 byte within 1 ms user-plane latency
Mobility	500 km/hr
Connection density for mMTC	1 million devices/km^2
User experienced data rate in dense urban area for eMBB	100 Mbps for downlink and 50 Mbps for uplink
Mobility interruption time for eMBB and URLLC	0 ms

urban grid for connected cars, commercial air to ground scenarios, light aircraft scenarios and satellite extension to terrestrial applications. Each of these deployment scenarios has certain proposed attributes defined in terms of carrier frequency, aggregated system bandwidth, number of Base Station (BS) antenna elements and User Equipment (UE) antenna elements, Inter-Site Distance (ISD) and service profiles [13]. Network slicing has been proposed to allow multiple 5G services with different Quality of Service (QoS) values to co-exist within the same shared physical infrastructure in various deployment scenarios [12-14]. It will play a fundamental role in supporting a wide range of customised reliable services using limited resources [14-15]. By slicing the physical network into multiple logical networks, resources can be dynamically mapped to individual logical slices on the basis of QoS demands to guarantee bandwidth, privacy, reliability and latency [16].

Several network slicing strategies have been proposed by researchers. Guan et al. proposed a mathematical model to form network slice requests and map them into the

Table 5 Value of BS and UE antenna elements defined by 3GPP for varied deployment scenarios [13]

Deployment scenario	Base Station Antenna Elements			User Equipment Antenna Elements		
	Around 30 GHz/ 70GHz	Around 4GHz	Around 700MHz	Around 30 GHz/ 70GHz	Around 4 GHz	Around 700MHz
Indoor hotspot	256	256	-	32	8	-
Dense urban	256	256	-	32	8	-
Rural	-	256	64	-	8	4
Urban macro	256	256	-	32	8	-
High speed	256	256	-	32	8	-

network. The proposed technique enables service-oriented end-to-end network slicing that can be used to create eMBB, mMTC and URLLC slices [17]. Costanzo et al. proposed a prototype for managing network slices in a Cloud-Radio Access Network based on a Software Defined Network (SDN). The prototype employs an Open Air Interface (OAI) platform and a SDN controller named FlexRAN to deal with spectrum slicing and efficient bandwidth sharing [18]. Addad et al. proposed a cost-optimized cross domain network slicing model, allowing a mobile network operator to efficiently allocate the underlying layer resources in accordance to its subscribers' requirements [19]. Li et al. introduced OAI-based end-to-end network slicing to increase eMBB slice downlink rates and lessen delays for URLLC slices [20]. Rigorous research is on-going in this field to find the optimum solution for efficient allocation of resources to achieve the KPIs for 5G use cases.

4. 5G antenna systems

Designing antenna systems has becoming extremely challenging over the past few years. The allocation of new spectrum resources with the introduction of every new mobile communication generation, the ever-increasing growth in subscriber demands and the significant changes mobile terminals have undergone in terms of size and functionality have been three major driving forces behind the growing complexities of antenna systems. The 5th Generation of mobile communication can be designed over both the FR1 and FR2 spectrum ranges as discussed above. This requires that the transmitting and the receiving antennas work efficiently over multiple frequency bands. In 5G, the user data rate is expected to increase 100 times compared to that offered by the 4G system. In order to achieve this enormous increase in data rate with reduced latency, MIMO antennas form the basic pre-requisite for 5G [21]. In MIMO antenna systems, multiple antennas are required at transmitting and receiving ends. The deployment of multiple antennas can increase the channel capacity. However placement of multiple antennas in close proximity leads to high mutual coupling. A well performing MIMO antenna system requires a design with low correlation between the elements [22]. 3GPP has defined a limit on the number of antenna elements that can be incorporated for both BS and UE antenna system [13]. Table 5 lists the attributes for individual deployment scenarios defined by 3GPP.

4.1 5G User equipment antenna

Antenna designers need to address the challenges while designing modern MIMO antenna systems for handheld terminals. Prerequisites include:

- Designed antenna must be compact and must easily integrate inside handheld devices.
- Modern mobile networks are heterogeneous in nature, simultaneously supporting multiple technologies of different communication standards. Designed antennas must have multi-band characteristics, supporting bands of multiple mobile generations to support seamless global roaming using the same handheld device [23].
- An antenna have a Specific Absorption Rate (SAR) value, which measures the maximum RF energy absorbed by unit mass of the human body. It must be lower than the safe value of 1.6 Watt/kg defined in FCC guidelines [24].
- The designed MIMO antenna must have mutual coupling that is lower than the threshold value. Mutual coupling is inevitable between closely spaced antenna elements. It may arise between the identical antenna elements due to a huge flow of surface current from the ports or due to space radiation. It is extremely important to design ways to mitigate mutual coupling and enhance the efficiency of MIMO antenna systems. Various techniques have been reported by researchers to improve the isolation between closely spaced antenna elements in MIMO setups. These are:
  - i Introduction of protruded ground planes between the antenna elements to increase the length of surface current [21, 25].
  - ii Introduction of a neutralization line to pass the electromagnetic waves from one antenna element to another, resulting in opposite coupling to enhance isolation over certain frequencies [26-27].
  - iii Introduction of defected ground structures to reduce the surface current and alter its direction [28-29].
  - iv Introduction of ground slot structures [30].
  - v Introduction of parasitic elements [31].
  - vi Introduction of electromagnetic band gap structures [32].
  - vii Using pattern diversity [33-34].
- The envelop correlation coefficient (ECC) value between the antenna elements of designed MIMO system must be lower than industrial standard limit of 0.5 [35]. ECC is a reflection of diversity performance of MIMO antenna system that measures the correlation between the radiation patterns of identical antennas. When two antennas are perfectly un-correlated, their ECC value is zero.

Antennas for handheld device have undergone major transformations in terms of shape, size and functionalities. Extensive research is on-going for designing MIMO antennas to most efficiently cover 5G frequencies. Several configurations comprising dual-elements, four-elements, eight-elements and higher order elements have been investigated. In the following section, some recent work on terminal antennas for 5G applications is discussed.

4.1.1 Dual-element MIMO antenna

Biswas et al. proposed a dual element MIMO antenna for a handheld device that resonates over five ranges of frequencies – 700 to 750 MHz, 1.47 to 1.9 GHz, 2.04 to 2.26 GHz, 2.7 to 2.89 GHz and 3.2 to 3.8 GHz supporting GPS, 2G, 3G, LTE FDD & TDD and 5G standards. The designed unit antenna elements are of a non-uniform width monopole. T-shaped ground extensions have been proposed to improve the isolation between the radiating elements. The ECC value for all the five bands is below 0.07 for the final prototype [21]. Chen and Chang proposed an L-shaped dual antenna-element MIMO that can be integrated with laptop computers and work over three frequency ranges – 3.4 to 3.6 GHz, 4.8 to 5 GHz and 5.15 to 5.85 GHz [25]. Baharom et al. proposed a dual-element PIFA antenna that can work over super-high frequencies centered at 15 GHz. Air is used as the substrate to deal with the issue of loss arising at higher operating frequencies [36].

4.1.2 Four-element MIMO antenna

Saxena et al. proposed a four-element MIMO antenna that can be used for sub-6 GHz 5G applications. This work proposes a novel technique of introduction of a circular metallic disc between the unit antenna elements, which in turn acts as a pool of current with a phase difference of 180º causing high isolation in the MIMO system [37]. Abdullah et al. proposed a four-element MIMO antenna consisting of an L-shaped monopole radiating element, each with a parasitic shorted strip to radiate over a frequency band 3.4 GHz to 3.6 GHz. Neutralization line techniques have been adopted to minimize the mutual coupling between the unit elements [38]. Dioum et al. proposed a four-element MIMO antenna with unit elements in a combination of U-shaped metallic structures and meandering monopoles. The resonating structures work efficiently over two frequency bands ranging from 2.5-2.7 GHz and 3.4-3.8 GHz [39]. Abdullah et al. proposed a compact four-element MIMO antenna that can work over frequencies ranging between 3.4 GHz to 3.6 GHz. The significance of this work is that pattern and polarization diversity is used for improving isolation [40].

4.1.3 Eight-element MIMO antenna

Parchin et al. proposed novel eight port dual-polarized square ring slot radiators that can work over frequencies ranging between 3.4 GHz and 3.8 GHz with a total efficiency of more than 60%. The mutual coupling between the antenna elements is less than -15dB using a pair of open-ended circular ring parasitic structures [41]. Zhao et al. proposed a self-isolated eight-element MIMO antenna that can work efficiently between 3.4 GHz and 3.6 GHz. Each of the eight unit antenna elements contains an inverted-U shaped element, two vertical stubs and a T-shaped feeding element. Without the use of any isolation improvement technique, isolation of better than 19.6 dB is achieved [42]. Li et al. proposed a balanced open slot antenna element that enhances isolation between the adjacent input ports. The final prototype is an eight–element MIMO antenna that can work between 3.4 GHz and 3.6 GHz with a total efficiency that is higher than 65%, isolation better than 17.5 dB and an ECC value less than 0.05 over the entire range [43]. Jiang et al. proposed an eight-element antenna that resonates efficiently over the frequency range of 3.3 GHz – 3.6 GHz with isolation better than 15 dB obtained by introduction of a neutralization line. The unit antenna elements were comprised of U-shaped and L-shaped coupled-feed loops. The effect of a user's hand position on the MIMO antenna's performance was explained by the authors [44].

4.1.4 Ten-elements or higher-order MIMO antenna

Li et al. proposed a ten-element MIMO antenna system that can resonate over two frequency bands ranging from 3.4 GHz to 3.8 GHz and 5.15 GHz to 5.925 GHz. Unit T-shaped coupled-fed slot antennas are designed to obtain the bands. Spatial and polarization diversity techniques are used to obtain isolation better than 11 dB. The final prototype exhibited antenna efficiencies higher than 42% and 62% with ECC values lower than 0.15 and 0.05 in the first and second bands, respectively [45]. Deng et al. proposed a ten-element MIMO antenna that comprised of six monopoles and four slots with a coupled feed to resonate over frequencies between 3.3 GHz and 3.6 GHz. In the final prototype, mutual coupling that was less than -11 dB was obtained without the use of any decoupling structure. The results indicate an ECC value lower than 0.15 and an antenna efficiency better than 50% is obtained over the entire frequency range [46]. Li et al. proposed a twelve element MIMO that comprised of an inverted π-shaped antenna, longer and shorter inverted L-shaped open slot antennas. The designed prototype covers frequencies ranging from 3.4 GHz to 3.8 GHz and 5.15 GHz to 5.925 GHz with isolation better than 12 dB between unit antenna elements [47].

4.2 5G Base station antennas

In 5G communication system deployment, both lower and higher frequencies will be employed. As explained in Section 2,the portion of the spectrum below 2 GHz will be used for providing wide-area coverage. That above 6 GHz will be used to create hotspots for enabling high capacity while the spectrum between 2 and 6 GHz will be used to obtain the best compromise between coverage and capacity. Designing and deployment of suitable BS antennas will require addressing certain key requirements listed below:

- During the early phase of deployment of 5G systems, 3G and 4G systems will be in use in most countries around the globe. It will be necessary to integrate 3G and 4G services along with 5G services. Designing multi-system antennas for BSs will be extremely welcome.
- BS antennas will be required to serve multiple users in its coverage area. Designing massive MIMO antennas using large antenna arrays with highly directional transmissions will be essential [48]. Figure 3gives a pictorial representation of a BS with a massive MIMO antenna. mMIMO will aid in increasing the capacity by causing aggressive spatial multiplexing.
- BS antennas must have the capability of generating multiple concurrent yet independent directive beams.
- The EIRP emission limit of a BS is 1 mW/cm^2. Designing and deploying 5G BS antennas requires maintenance of this health and safety requirement [49].

The proposed massive MIMO system BS will employ spatial multiplexing and digital beam-forming with the aid of

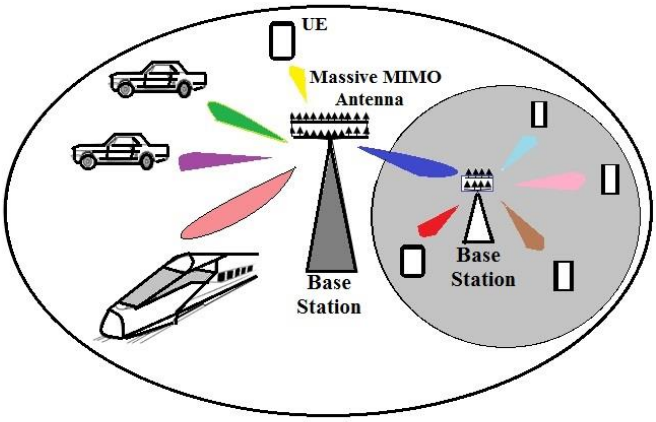

Figure 3 Base Station with massive MIMO antenna serving multiple UEs and automated vehicles

Table 6 Comparison of4G and 5G mobile communication

Parameter	***4G***	***5G***
Defined Use Case	MBB	eMBB, mMTC and URLLC
Frequency Spectrum	Three bands between 400 MHz to 960 MHz 1.4 GHz to 2.7 GHz and 3.3 GHz to 3.8 GHz	Two range of frequencies FR1:450 MHz to 6 GHz FR2: 24.25 GHz and 52.6 GHz
Switching	Packet (All IP)	Packet (All IP)
Service objects	People	People and thing
Peak data rate	100 Mbps	20 Gbps
Mobility	350 km/hr	500 km/hr
Connection density	10^5 devices/km^2	10^6 devices/km^2
Major Technologies	MIMO, carrier aggregation, OFDM	Massive MIMO, flexible frame, network slicing

numerous installed antennas. Traditional mm-wave systems are limited to short-range point-to-point indoor services however, massive MIMO BSs will open possibilities for multiple user transmissions over much longer ranges [50].

5. Comparison with earlier generation

The 5th Generation of mobile communication can be summarized as the Internet over Everything (IoE) oriented network. Table 6 compares the network features of the present human-oriented 4th Generation mobile communication standard with the future 5th Generation in terms of the frequency spectrum, switching techniques, defined use cases/services, proposed service objects and KPIs in terms of peak data rate, mobility, connection density.

6. Conclusions

The 5th Generation of mobile communication will open possibilities for innumerable services that registered subscribers will enjoy. The work of numerous researchers and telecom standard developing organizations has been reviewed with objective of understanding the core aspects of the future 5th Generation of mobile communications. The present and future allocation of the frequency spectrum has been discussed and 5G use cases identified, eMBB, mMTC and URLLC have been explained. Deployment scenarios to be considered for planning the 5G network have been addressed. Methods of distributing network resources with the aim to attain the defined KPIs for each 5G use case have been explained. Challenges faced by antenna designers are highlighted. Recently proposed MIMO antenna prototypes have been discussed and comparisons with existing 4G communication technology made to give proper insights into the next technological leap in the communications industry.

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