ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

5G MOBILE SYSTEMS, CHALLENGES AND TECHNOLOGIES: A SURVEY

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ABSTRACT

The huge increase of the data traffic was exited the borne of 5th Generation (5G) mobile communication system looking at 10 Gbps data rate and around 1ms latency. As the cellular data demand increasing, the actual 3 GHz spectrum band becoming so crowded. This leads to look for a new allocated mobile communication frequency bands that can offer a broadband amount of spectrum. In 5G mobile system the ultra-wide millimeter wave (mmWave) spectrum will be adopted. mmWave frequency band starting from 30 GHz to 300 GHz, constitutes a substantial portion of the unused frequency spectrum, which is an important resource for future wireless communication systems in order to fulfill the exponential demand of capacity. In this paper, we provide a survey on the mm-Wave frequency band general characteristics and its main challenges; we also state the required technologies that were necessary for making 5G system as a real and efficient solution.

Keywords: *5G, Millimeter Wave Communications, Path Loss, Beamforming, Small Cells, Massive-MIMO, FBMC, Device-To-Device (D2D) Communication*

1. INTRODUCTION

The phenomenal success of mobile communications system is mirrored by a rapid pace of technology innovation. From the second generation (2G) mobile communication system debuted in 1992 to the 3G system first launched in 2001, the wireless mobile network has transformed from a pure telephony system to a network that can transport rich multimedia contents. 4G system or Long-Term Evolution–Advanced (LTE-A) introduced in 2011, which established a broadband mobile system (1Gbps) through utilizing multi input multi output (MIMO) and orthogonal frequency division multiplexing (OFDM) technologies [1].

Nonetheless, existing wireless systems will not be able to deal with the thousand-fold increase in total mobile broadband data and with the Societal development which lead to changes in the way mobile and wireless communication systems are used. In this context, the fifth generation (5G) wireless communication technologies are expected to attain 1000 times higher mobile data volume per unit area, 10-100 times higher number of connecting devices and user data rate, 10 times longer battery life and very reduced latency. While for 4G networks the single-user average data rate is expected to be 1 Gb/s, it is postulated that a cell data rate of the order of 10 Gb/s will be a key attribute of network [2-4]. The actual Cellular system frequencies bands below 6 GHz have been used heavily, making it difficult for operators to acquire more broad band data [5, 6]. In addition, the next-generation 5G mobile wireless system is expected to accommodate considerably larger number of wireless connections to better support existing and emerging applications including machine-to- machine (M2M) applications many of which require more stringent quality-of-service (QoS) including better delay, reliability, and higher spectral and energy efficiency. For example, wireless communications supporting smart connected cars for road safety, remote monitoring, and real-time control must satisfy very stringent delay and reliability constraints. Furthermore, the vision of the hyperconnected world with billions of wireless connections where all the world of human and things can be inter-connected wirelessly in the so-called Internet of Things (IoT) [4, 7]. Millimeter-wave (mm-W) communication is a promising technology for future 5G mobile systems, which can provide multi-GbPS data rates in a wide frequency bandwidth of 30GHz to 300GHz, therefore it has much smaller wavelengths, starting from 1 mm to 100 mm, while 4G frequencies have wavelengths that are tens of centimeters.

Journal of Theoretical and Applied Information Technology
15th June 2019. Vol.97. No 11

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

Path loss for mm-Wave is fundamental and could restrict the propagation. In wireless engineering society, common myth is that atmosphere and rain make mm-Wave spectrum unusable. Even more, measurements characterizing the scattering in mm-Wave channels show that non-line-of-sight (NLOS) communication is achievable if enough array antenna gain is established via beamforming [8].

On July 14, 2016, the Federal Communications Commission (FCC) voted to adopt a new mm Wave licensed bands, namely 28 GHz (27.5-28.35 GHz), 37 GHz (37-38.6 GHz), 39 GHz (38.6-40 GHz) for supporting the 5G project [9, 10].

2. TECHNICAL REQUIREMENTS FOR THE 5G SYSTEM

The academia and industries agree on the following technical requirements for the 5G wireless network [11].

- *Coverage and Data Rate:* 5G should preserve online connectivity anytime and anywhere with a minimum subscriber experience data rate of 1 Gbps up to 10 Gbps.
- *Latency*: The end-to-end latency requirement for 5G is expected to be in the order of 1–5ms.
- *Connected Devices*: The 5G network will have the capability to integrate many connected devices, the density of these devices will be increased by 100 times, while the traffic density will increase by 1000 times compared with 4G wireless network.
- *Multiple Radio Access Technologies*: The 5G network is not considered to replace the existing wireless networks. It will be built upon the current wireless technologies such that: GSM, 3G, HSPA, 4G (LTE-A), and wireless fidelity (Wi-Fi).
- *Energy and Cost Efficiency*: 5G wireless networks should be created to fulfill the needs of data consuming applications but at a lower cost and higher energy efficiency, when compared to the current wireless network.

3. MM-WAVE PROPAGATION CHALLENGES

The most important challenges that effect the exploitation of mm-Waves band for 5G mobile communication system was showed by Figure 1 and can be summarized as follows:

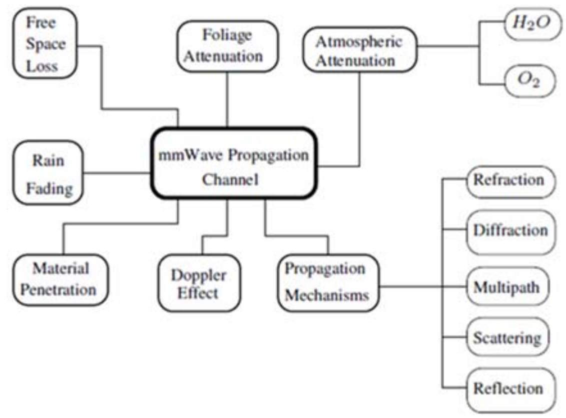

Figure1: Major Propagation Challenges in mmWaves

3.1 Pathloss Challenge

Path loss for mm-Waves is significant and may limit the propagation. Three types of pathloss models were illustrated in this section; the first one is the free space path loss model, rural macrocell (RMa) path loss model and the urban microcell (UMi) large scale path loss model.

3.1.1 Free Space Path Loss (FSPL) Model

For instance, the free space path loss ($FSPL$) between two communicating isotropic antennas separated by a distance d in kilometers (km) and operating at a frequency f in MHz is given by [12, 13].

$$FSPL_{dB} = 32.4 + 20\ log\ f_c + 20\ log\ d \qquad (1)$$

Equation (1) can be formulated as:

$$FSPL_{dB} = 92.4 + 20\ log\ f_c + 20\ log\ d \qquad (2)$$

where L_{FSL} is the free-space loss in dB, f_c is the carrier frequency in GHz; d is the LOS distance between the transmitter and receiver in Km. This means a high L_{FSL} as the carrier frequency enters the mm-Wave frequency band, in comparison with the sub-3 GHz band. The free-space path loss between a transmit and a receive antenna grows with the carrier frequency f_c.The omnidirectional path loss is approximately 20 dB higher in the mm-Wave frequencies relative to current mobile frequencies in distances relevant for small cells as illustrated here in Figure 2 using (2) for the case of 30GHz and 3GHz respectively. However, because of the reduced wavelength, this loss can be completely compensated by a proportional increase in antenna gain with no increase in physical antenna size which could be achieved by utilizing array antenna and beamforming technique [14, 15].

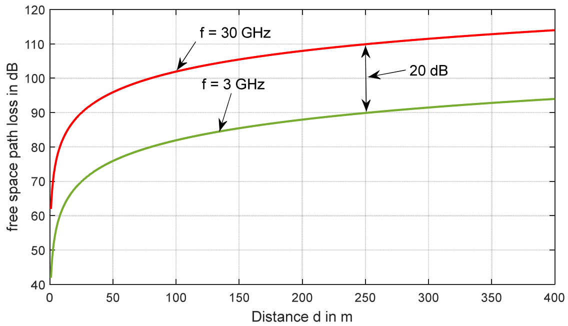

Figure 2: Free Space Path Loss

3.1.2 Rural Macrocell (RMa) path loss model

The general form of the close-in (CI) reference distance model pathloss is expressed as follows:

$$PL^{CI}(f_c, d)[dB] = FSPL(f_c, d_0)[dB] + 10n\log_{10}\left(\frac{d}{d_0}\right) + x_\sigma \quad (3)$$

Where $d \geq d_0$, PL is the path loss measured in dB that is a function of T-R separation distance d in m between the TX and RX,

FSPL is the free space path loss in dB at a distance d_0, f_c is the carrier frequency in GHz, and d_0 is the close-in free space reference distance in m. For distance *d* between the TX and RX, 2D or 3D distances may be used, n represents the path loss exponent (PLE), and x_σ denotes the shadow fading which is a zero-mean Gaussian random variable with standard deviation σ in dB [16-18].

The RMa CI path loss models for LOS and NLOS environments can be written as [16]:

$$PL^{CI}_{LOS}(f_c, d)[dB] = 32.4 + 21.6\log_{10}(d) + 20\log_{10}(f_c) + x_{\sigma LOS} \quad (4)$$

Where d ≥ 1m, and $\sigma_{LOS} = 1.7$ dB

$$PL^{CI}_{NLOS}(f_c, d)[dB] = 32.4 + 27.5\log_{10}(d) + 20\log_{10}(f_c) + x_{\sigma NLOS} \quad (5)$$

Where $d \geq 1m$, and $\sigma_{NLOS} = 6.7\ dB$

where the shadow fading standard deviations $\sigma_{LOS}$and $\sigma_{NLOS}$are 1.7 dB and 6.7 dB, respectively, according to the measured data [16]. RMa path loss (4), (5) are valid for distances from 1 m to 11 km and frequencies from 500 MHz to 100 GHz.

3.1.3 Urban Microcell (UMi) large scale path loss model

The general close-in (CI) UMi path loss model accounts for the frequency dependency of path loss by using a close-in reference distance based on Friis' law is given by [2, 7, 19-21].

$$PL^{CI}(f_c, d_{3D})[dB] = FSPL(f_c, 1m) + 10n\log_{10}(d_{3D}) + x_\sigma^{CI} \quad (6)$$

where $x_\sigma{}^{CI}$ is the shadow fading (SF) that is modeled as a zero mean Gaussian random variable with a standard deviation in dB, n is the path loss exponent (PLE) found by minimizing the error of the measured data to (2), d_{3D} > 1m, FSPL (f; 1 m) is the free space path loss (FSPL) at frequency fc in GHz at 1 m and is calculated by [2]:

$$FSPL(f_c, 1m) = 20\log_{10}\left(\frac{4\pi f_c \times 10^9}{c}\right) = 32.4 + 20\log_{10}(f_c)[dB] \quad (7)$$

where c is the speed of light, 3×10^8 m/s.

Using (7), it is clear that (6) can be represented as given in (8) and (9) below to represents the urban micro (UMi) path loss model for outdoor and street canyon for the LOS and NLOS scenarios respectively. These equations are valid for frequency range between 6GHz and 100GHz [19].

$$PL_{LOS} = 32.4 + 21\log_{10}(d_{3D}) + 20\log_{10}(f_c) + x_\sigma \quad (8)$$

$$PL_{NLOS} = 32.4 + 31.7\log_{10}(d_{3D}) + 20\log_{10}(f_c) + x_\sigma \quad (9)$$

where $f_c$is the carrier frequency in GHz (6 < f_c<100GHz), d_{3D} is the distance from the top of the UE to the top of the BS in meters, as shown in Figure 3. The shadowing factor is represented by x_σ and it is Gaussian variable with mean zero and standard deviation σ= 3.76 and σ= 8 for LOS and NLOS, respectively.

The above CI model ties path loss at any frequency to the physical free space path loss at 1 m according to Friis' free space equation, and has been shown to be robust and accurate in various scenarios [2, 22, 23].

Journal of Theoretical and Applied Information Technology
15th June 2019. Vol.97. No 11

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

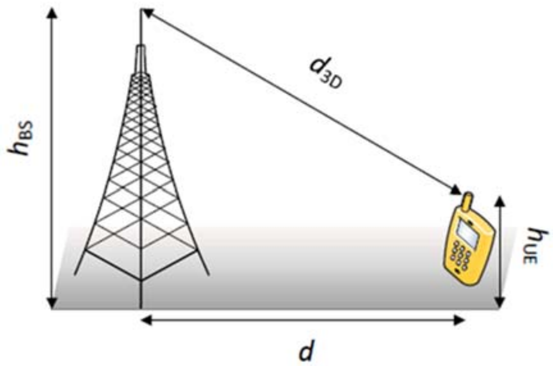

Figure 3: Reference for the Distances for the UMi Propagation Model.

3.2 Rain Attenuation

In heavy rain, mm-Wave transmissions can suffer serious attenuation because the raindrops are close to the size of the radio wavelengths (millimeters) and hence leads to scattering.

For a very heavy rainfall of 25 mm/hr, the rain attenuation at 28 GHz has an attenuation of 6 dB/km as shown in Figure 4 [15, 23].

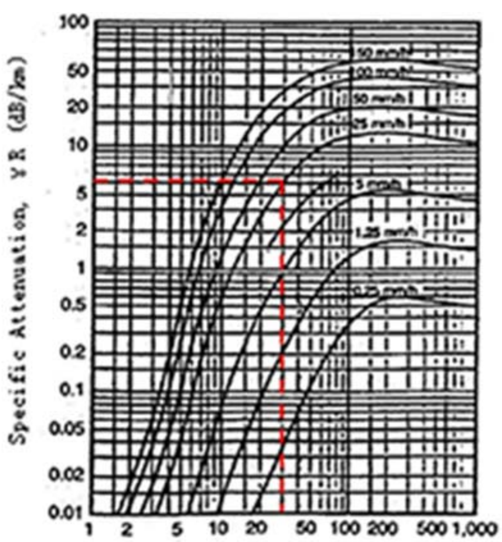

Figure 4: The Rain Attenuation Characteristics of mm-Wave Propagation in dB/km

However, the rain attenuation will decrease to about (6/1000) x 200 = 1.2 dB if cell coverage areas are 200m in radius. Obviously, rain attenuation can have a minor impact on the propagation of mm-waves at 28 GHz to 38 GHz for small cells.

3.3 Atmospheric Absorption

It is well-known that the oxygen and water vapor (H2O) have an impact to the atmosphere. Figure 5 presents atmospheric absorption characteristics across frequency for the mm-wave propagation in dB/km. The attenuation related to atmospheric absorption is 0.012 dB, over 200 m at 28 GHz and 0.016 dB, over 200 m at 38 GHz. The 70 to 100 GHz and 125 to 160 GHz have also small loss [15, 19].

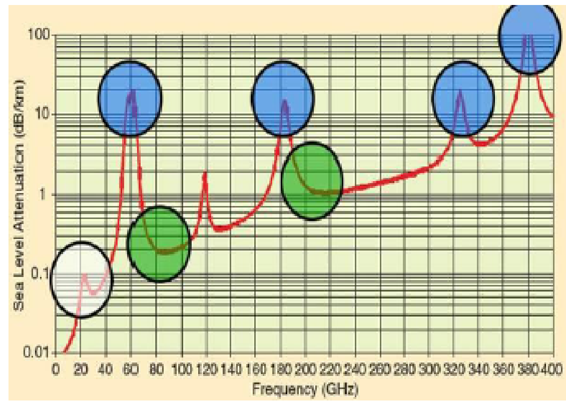

Figure 5: Atmospheric Absorption of Electromagnetic Waves at Sea Level.

Because of significant atmospheric attenuation (20 dB/km), the 60-GHz band agreement to be assigned for short-range (several meter) indoor application. The most important allocated frequencies in the mm-Wave frequency band have been summarized in Table 1.

Table.1. 5G Frequency Allocation

Frequency (GHz)	Band type	Applications
28, 38 and 73	Licensed	Mobile cellular system
60, 120, 183, 325, and 380,	Unlicensed	Shor rang (indoor)
77 and 240	Unlicensed	Industrial, scientific, and medical (ISM)

3.4 Foliage Attenuation

Vegetation presence between the transmitter and receiver creates a further attenuation to the signal may it may severely influence the Quality of Service (QoS) of a mobile communication system.

Figure 6 shows the foliage attenuation made by the presence of several trees, where the thickness of the lines shown represent the signal power [12].

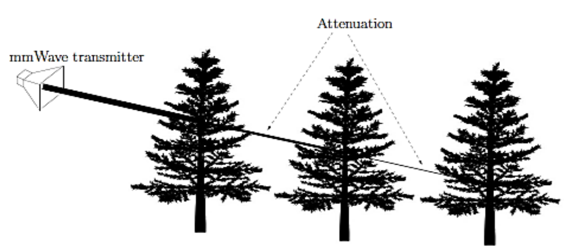

Figure 6: An Illustration of Foliage Attenuation.

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

3.5 Human blockage

Millimeter wave (mmWave) communication systems can provide high data rates of the order of a few Gbps Compared to UHF, communications in mmWave networks are expected to operate over shorter distances and in crowded urban environments. Rapidly fading channels caused by pedestrians in dense urban environments will have a significant impact on millimeter-wave (mmWave) communications systems that employ electrically-steerable and narrow beamwidth antenna arrays [21].

Since the height of the 5G base station transmitter could be much lower than that of traditional base stations (BS), humans surrounding the receiver can act as blockers to signal propagation. Furthermore, human presence between the transmitter and the receiver severely attenuates the received signal (Figure 7). Human body can reduce the signal strength by the order of 20 dB [12, 24].

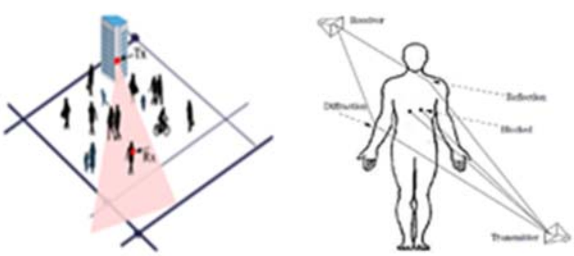

Figure 7: The Human Blocking Scenario.

4. ENABLING TECHNOLOGIES FOR MAKING 5G A REALITY

The principle supporting that are essential for the realization of the 5G mobile communication system was shown in Figure 8 and will be summarized as follows:

4.1 Suitable mm-Wave Broadband

Within the mm-Wave band, up to 252 GHz spectrum could be easily exploited by the cellular mobile communications system as shown in Figure 9 [25].

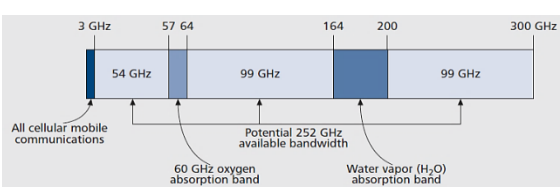

Figure 9: Millimeter-Wave Spectrum.

4.2 Silicon Phased Arrays Antenna in mm-Wave Bands

The core of 5G is dependent on nanotechnology, where the process controlled in nanometer scale; between 0.1 and 100nm. Moreover, the very small wavelengths of mm-W signals along with advances in low-power CMOS RF circuits enable large number of miniaturized array antennas to be integrated in small area, producing a very high gain, electrically steerable arrays, as well as easy to fabricate at the base station and in the skin of a cell phone, or even inside a chip [26]. A structure diagram of a millimeter-wave wafer-scale phased array with on-chip antennas is shown in Figure 10 using SiGe HBT and CMOS FET technology [27].

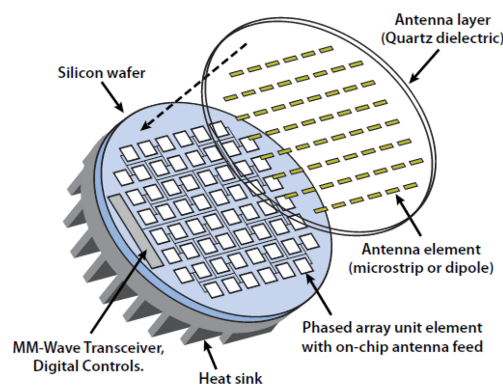

Figure 10: A Millimeter-Wave Wafer-Scale Phased Array with On-Chip Antennas.

Figure 11 illustrates the Chip photograph of the wafer-scale 4x4 (6.5x6.0 mm^2) dipole array is fabricated on a 100 µm-thick quartz wafer and is placed on top of the 4x4 phased array IC.

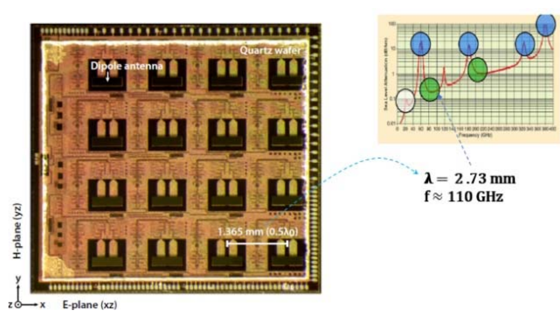

Figure 11: Chip Photograph of the Wafer-Scale 44 Phased Array. (6.5x6.0 mm2)

A comparison between a single element dipole antenna and 4x4 array antenna from the view point of gain and directivity is shown in Figure 12. A noticeable difference in the gain was around 15 dB when adopting array technique.

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

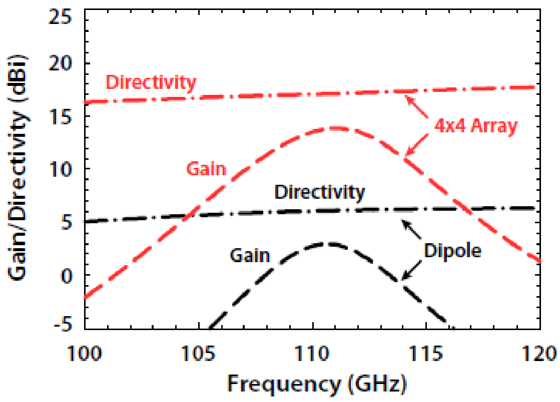

Figure 12: Simulated Directivity and Gain of a Single Dipole Antenna and the 4 x 4 Array Antenna.

One of the main limitations in 5G system is the Silicon wafer technology capability. For the moment been we cannot guess how rapidly this technology will be able to follow the society need in term of capacity and data rate, especially when the internet of things (IoT) will immerged in the 5G domain.

4.3 Beamforming

For improving the base station antenna gain and focusing antennas energy in a preferred direction, beamforming technique will be deployed. Additionally, narrow beams and directional transmissions for a cellular application are useful to reduce interference introduced by spatial reuse which leads to increase the signal to interference ratio (SINR) as shown in Figure 13 [28]. An advantage of millimeters waves is smaller antennas requirements due to shorter radio wavelengths (e.g., λ = 3.75 mm for 80GHz carrier frequency).

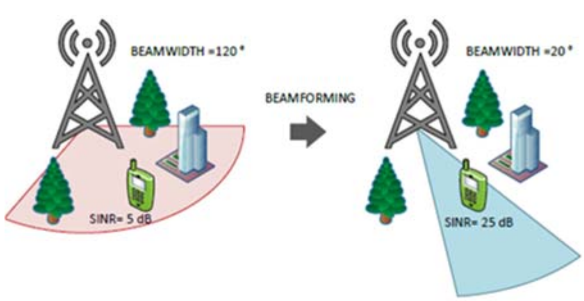

Figure 13: SINR Increase Due to the Beamforming Gain.

Nevertheless, a smaller antenna also leads to smaller effective antenna aperture sizes, thus smaller antenna gains. For instance, according to free-space equation (1), a mm-Wave signal at 30 GHz will suffer 20 dB larger path loss compared to a signal at 3 GHz. Therefore, an antenna at mm-W frequencies at 30 GHz captures 100 times less energy compared to a similar antenna at 3 GHz. In order to overcome the small antenna gains along with other losses at millimeter waves, multi-antenna array beamforming can be used which is also known as smart antenna [29].

Along with small antenna size (λ/2 dipole or patch), antenna separation (d) can be reduced to a very short distance (around λ/2) for beamforming purpose. The small size and separation of millimeter wave antennas make it possible for putting a plenty of antennas in a small dimension, which gives a high gain antenna implementation in a relatively small area (e.g., tens of antennas per cm^2 area at 80GHz carrier frequency). The well-known two types of smart antennas, shown in Figure 14, are the switched beam systems and the adaptive array systems [30, 31].

The switched beam systems provide a predetermined group of beams which can be chosen as appropriate. The defect of this method is that the user of interest may not be in the center of the main beam. Simultaneously, interferers are not situated in a radiation nulls. Adaptive arrays enable the antenna to steer the beam to any direction of interest, by setting the user of interest in the center of the main beam while at the same time nulling interfering signals.

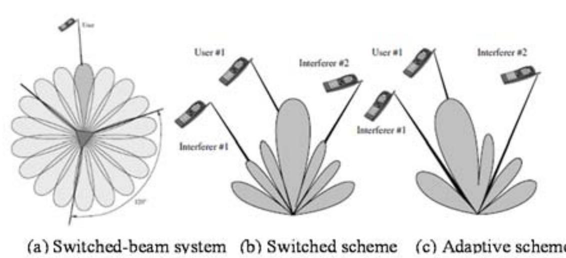

Figure 14: Comparisons Between Switched-Beam Scheme And Adaptive Scheme

Beam direction can be determined using the so-called direction-of-arrival (DOA) estimation techniques.

Beamforming techniques is another limitation factor related to the fact that 5G puts a very high priority on almost-zero latency, which implies the need to rely more on silicon technology for complex processing and less on software. That could mean you have to move processing of beamforming and all that stuff out of software and put it into the PHY layer but this is going to make the PHY layer more complicated.

4.4 Massive Multi Input Multi Output (MMIMO)

In radio, multiple-input and multiple-output, or MIMO, is the usage of multiple antennas at both the transmitter and receiver to enhance the mobile system performance. MIMO systems have gained increased attention due to their ability to enhanced the spectral efficiency and improve the network capacity. Generally, the more antennas the transmitter/receiver comes with, the more signal paths and the better the reliability of the link and the data rate [28, 32]. MIMO techniques were previously presented in the current 4G mobile systems [28].

The next thing with MIMO is to maintain increasing antenna arrays with an order of magnitude, more elements than in systems being built presently, for instance 100 antennas or more; this was popularly known as massive MIMO [5].

Massive MIMO also called large-scale antenna systems, very large MIMO, hyper MIMO, and full-dimension (FD) MIMO and it will be going to lead the way to 5G cellular system [33]. Figure 15.a shows a FD-MIMO depends on 3D beamforming in order to control the beam in a 3D space and Figure 15.b show a Massive MIMO antenna array setup designed for measurement purposes and it includes a compact circular massive MIMO array with 128 antenna ports. This array arranged in a circle, with 4 circles stacked on top of each other [28].

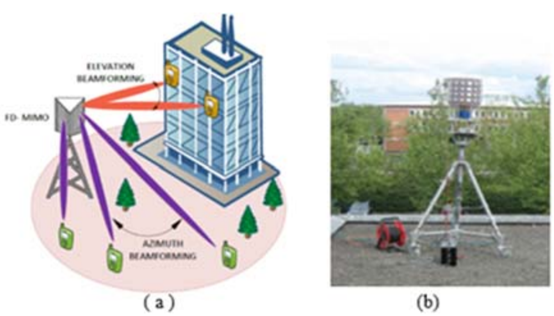

Figure 15. (a) FD-MIMO, (b) mmWave Massive MIMO Antenna Arrays Used for Measurements Setup.

4.5 Filterbank Multicarrier (FBMC)

Orthogonal Frequency Division Multiplexing (OFDM) is a multiplexing technique that subdivides the available bandwidth into multiple orthogonal frequency sub-carriers. The input data stream is divided into several parallel sub-streams of reduced data rate (thus increased symbol duration) and each sub-stream is transmitted on a separate orthogonal sub-carrier as shown in Figure 16. The increased symbol duration improves the robustness of OFDM to channel delay spread. Furthermore, the introduction of the cyclic prefix (CP) can completely eliminate ISI as long as the CP duration is longer than the channel delay spread. The CP is typically a repetition of the last samples of data portion of the block that is appended to the beginning of the data payload. The CP prevents inter-block interference and makes the channel appear circular and permits low-complexity frequency domain equalization. The idea behind OFDM is to convert a frequency selective channel into a collection of frequency-flat subchannels with partially overlapping spectra. OFDM modulation can be realized with efficient Inverse Fast Fourier Transform (IFFT), which enables a large number of sub-carriers with low complexity [34].

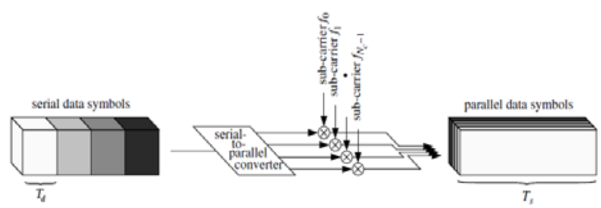

Figure 16: OFDM Basic Configuration

Filterbank Multicarrier (FBMC) is one kind of modulation techniques proposed for the 5G cellular system [35]. FBMC promises very low out-of-band energy of each subcarrier signal when compared to OFDM. It uses the multicarrier techniques that are immune to fading caused by transmission of more than one path at a time and also immune to intersymbol interference besides able to function effectively compared to OFDM which is used in Fourth Generation (4G) mobile communications technology [36]. Multicarrier communication systems like FBMC and OFDM simultaneously transmit signals across several subcarriers. In each subcarrier, the information bits are encoded and transmitted as a series of pulses of different amplitudes and phases. For Multicarrier system the main source of jittering comes from the intersymbole interference (ISI). FBMC system will reduce this jittering, by separating signals on different subcarriers from one another. FBMC uses special transmitter and receiver filters that are based on the square root Nyquist pulse shapes.These filters can be designed from the transformation of a square root raised cosine pulse to minimize a cost function that strikes a balance between stopband attenuation, the residual intersymbol interference, robust sensitivity to timing jitter, and/or reduced peak-to-average power ratio. Figure 17 shows the square root Nyquist pulse shape that is used in FBMC and, as a reference, the rectangular pulse shape of OFDM [37, 38].

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

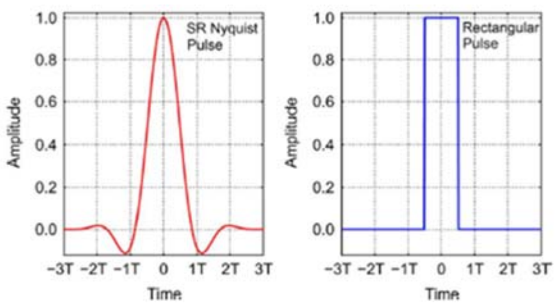

Figure 17: Square-Root Nyquist (FBMC), And Rectangular (OFDM) Pulse Shapes (Symbol Duration).

Figure 18 shows that the energy was concentrated within the frequency range of a single subcarrier for the FBMC systems, in the same time the OFDM system create a strong sidelobes because of rectangular windowing.

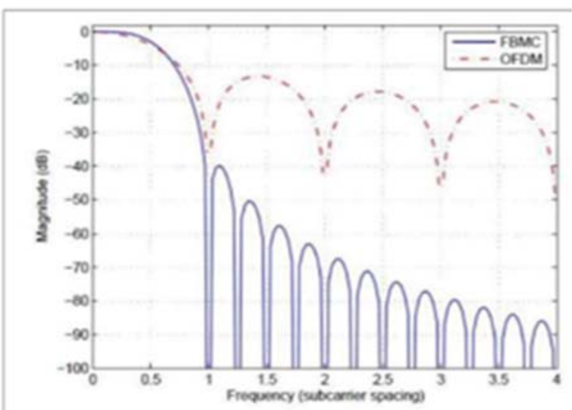

Figure 18: Frequency Responses for OFDM and FBMC for a Single Subcarrier.

FBMC represents a potential replacement for OFDM to facilitate the asynchronous transmissions known by Orthogonal Frequency Division Multiplexing Access (OFDMA) and efficient use of available spectrum in the next 5G cellular systems.

Filter bank multicarrier with offset quadrature amplitude modulation (FBMC/QAM) is one of the promising candidates which provide very low out of band radiation, as well as immunity against synchronization errors [39]. Figure 19 presents signal constellations for FBMC /16QAM at the output of the matched filter at the receiver for the timing phases of 0, 5, 10 and 15% of a symbol period. As expected, the proposed Nyquist (M) design is less sensitive to timing offset. For instance, at the timing offset of 15%, in the raised-cosine design the received symbols begin to overlap and errors can occur, even in the absence of channel noise. On the other hand, for the same timing offset, in the Nyquist (M) design, the constellation clusters remain separated [40].

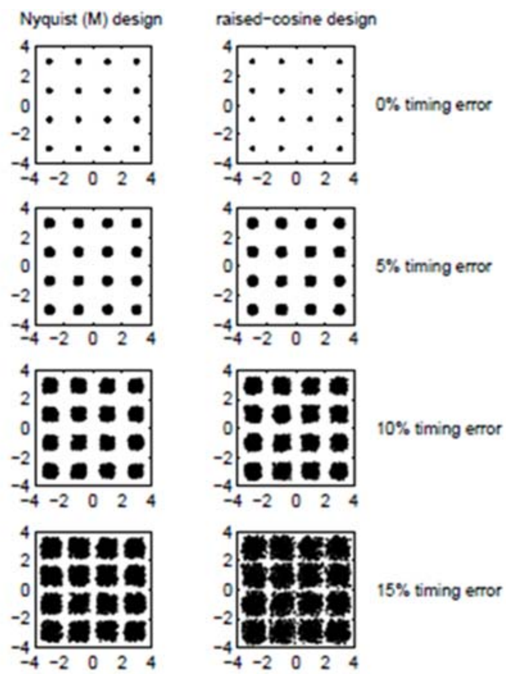

Figure 19: Demonstration of the robust behavior of a Nyquist (M)

4.6 Small Cell Deployment

Network densification is an approach to add more cell sites for supporting thigh traffic demand, especially in densely populated cities and hot spots like stadiums and shopping malls. Small cell sites, inside the coverage area of the already-deployed macro sites, resulting in what is called multi-layer or multi-tier network as shown in Figure 20 [28]. Through the deployment of small cell sites, the distance between the users and the base stations is reduced, which leads to lower propagation losses, energy efficiency and higher data rates.

High-speed user equipment (UEs) and those not covered by the small cells receive data and control from the macro cell. UEs covered by the small cells receive control from the macro cells and data from the small cells.

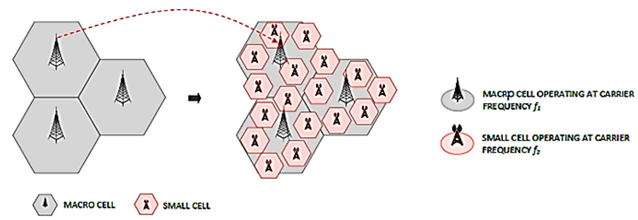

Figure 20: Deployment of Small Cell Sites on Top of Already Deployed Macro Cell Sites

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4.7 Device to Device

In the previous generations of mobile communication system, the use of device-to-device (D2D) communication did not take much consideration, but in 5G networks, it is expected to be an important factor for extending system capacity. D2D process allows communication between two devices, without the participation of the Base Station (BS) or core network, so it can undertake parts of the base station's transmitting loads, and thus relieve its heavy pressure. In wireless system it means bypassing the base station (BS) or access point (AP) and connecting on direct inter-device over either cellular resources or alternative over Wi-Fi/Bluetooth technologies. As an example, Bluetooth 5 supports a maximum data rate of 50 Mbps and a range close to 240 m, WiFi Direct allows up to 250 Mbps rate and 200 m range while LTE Direct provides rates up to 13.5 Mbps and a range of 500 m [41, 42]. Closet devices can make direct connection with each other by establishing direct links. Due to the short distance between D2D users, a power saving within the network was guaranteed, which is not the case in other conventional mobile system. One of its main benefits of D2D is offering the customers with an ultra-low latency due to a shorter signal path [43-46].

In term of spectrum adaptation D2D system can be classified either as licensed band, as for cellular communications (i.e., inband), or unlicensed bands such as Wi-Fi (i.e., outband) [45].

Figure 21 shows how mobile system and D2D communication function.

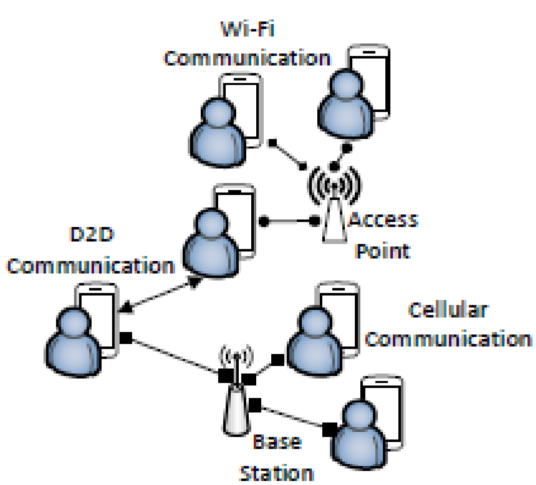

Figure 21: Cellular Communication Assisted D2D

4.8 Leveraging the Legacy 4G Network

In a mobile system, when the base stations, mobile stations, and relay stations if supported, communicate using both the cellular bands (<3GHz) as well as the millimeter wave bands (3-300GHz), we will deal with a hybrid (5G and 4G) system as shown in Figure 22. In comparison with millimeter waves, the radio wave frequencies lower than 3GHz can easier pass through obstacles and are much less sensitive to NLOS communication link or other impairments including absorption by foliage, rain, and various particles in the air. Consequently, it is useful to transmit particular important control channel signals using microwave (<3GHz) cellular radio frequencies, whilst employing the millimeter waves for high data rate communication via small-cells [11, 47].

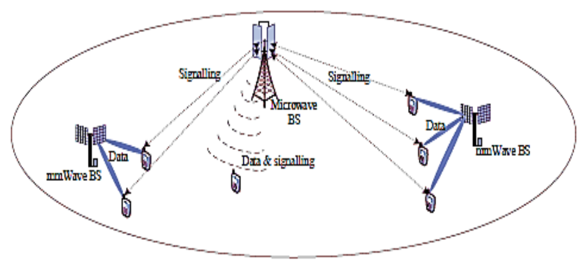

Figure 22: Hybrid System (5G & 4G) Configuration

5. BEAMFORMING AT BASE STATION

A base station is normally sectorized into a number of sectors. For a 6-sector configuration of the base station, which provide additional system throughput due to spatial multiplexing and minimized interference. The requirements for such system design are as follows [48]:

Provide high TX power (> 40 dBm), beam-steering in azimuth to > ±30° to cover sector with leakage less than -15 dBr to peak direction, beam-steering in elevation to > ±10° to account for distances up to 1 km, provide total antenna + beamforming gain of > 25 dB. An array of horn antennas at the base station was considered since horns have very high efficiency and gives relatively high antenna gain compared to other antenna types also horns are designed for transmitting very high-power output (in Watts) that is needed at the base station. The configuration of the base station array antenna is shown in Figure 23.

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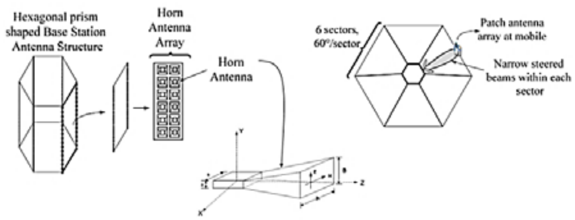

Figure 23: Base Station Antenna Configuration.

The requirement of 25 dBi gain from the base station horn antenna was decomposed into getting ≈10 dB from the inherent gain of each horn antenna element and ≈15 dB from the beamforming array factor. At 28 GHz, the size of the 12×4 horn array equates to 11.66 cm × 6.81 cm in area as shown in Figure 24.

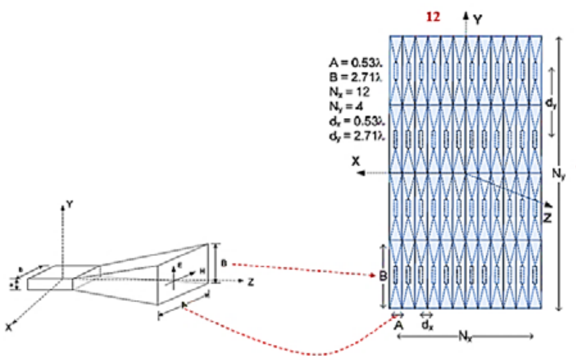

Figure 24: Base Station Horn Antenna Configuration Per Sector

6. FUTURE TREND

6.1 Design of Circular Patch Antenna Array for Mobil Station

Since the mobile station has area and power constraints, we cannot expect as large beamforming gains in the mobile station that we were able to provide for the base station. Further the size and shape of horn antennas are not feasible for easy integration on mobile phones. We considered only 12 dB as total gain to be attained on the mobile station. The requirement of 12 dB gain from the mobile station antenna was decomposed in getting ≈ 6 dB from the inherent gain of each patch antenna element and ≈6 dB from the beamforming array factor. A design and evaluation effort will be needed to achieve this goal.

6.2 Design of High Gain Wideband Log Periodic Dipole Array Antenna for Mobile Base Station

Beside using narrowband horn antenna at the base station in this work, it is useful to take the case of using wideband Log Periodic Dipole Array Antenna working over the range of (20 – 40) GHz. A design and evaluation effort will be needed to achieve this goal.

7. CONCLUSIONS

Millimeter-wave (mm-w) communication was adopted as a technology for the 5G mobile systems. This technology provides multi-Gbps data rates in a frequency range of 30GHz to 300GHz.

In this paper a concentrated survey was established on the millimeter wave band challenges and the main technologies needed to enable the 5G mobile system to exploit efficiently this band.

High path loss, atmospheric attenuation, rains attenuation, and limited device performance are probably major obstacles for establishing practical circuits and systems at mm-wave frequencies. On the other hand, huge available bandwidth, smaller antenna size, finer resolution and penetrating capability through thin materials are unique qualities that make mm-wave systems attractive.

Silicon phased arrays antenna in mm-wave bands have been an active research area in the past few years. The first wafer-scale silicon phased array antenna with attached on-chip antennas was already designed and fabricated at frequency of 110 GHz and was implemented in a 0.18 μm SiGe BiCMOS technology.

We conclude that, although mm-W systems have an omnidirectional path loss that is 20dB worse than the actual below 3GHz frequencies, the using of small cells sizes in urban environments on the order of 200m combined with array antenna beamforming technique are able to completely compensate for the loss, so 5G mobile system it will work.

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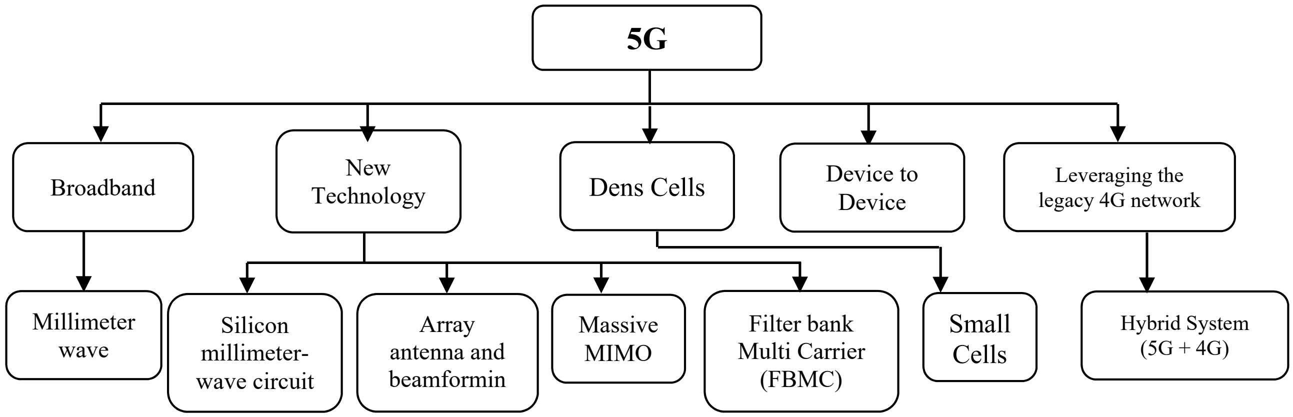

Figure 8: 5G Basic Technologies and Network Upgrading