Millimeter Wave Mobile Communication for 5G Cellular

Lujain Dabouba and Ali Ganoun

University of Tripoli– Faculty of Engineering - Electrical and Electronic Engineering Department

1. Introduction

During the last few decades, mobile communication have significantly contributed to the economic and social developments of both developed and developing countries. Today, mobile communication form an indispensable part of the daily lives of millions of people in the world; a situation which is expected to continue and become even more undeniable in the future. Currently, many researchers and operators worldwide are deploying new technologies to offer faster access with lower latency and higher efficiency that its predecessors in the one before such as 3G, 3.5G, 4G and LTE-Advanced. As expected for such a situation challenges of the future are so huge that there is vastly increased need for new communication system with even further enhanced capabilities [1].

It is expected that the 5G (Fifth Generation) system will address the communication needs for humans and devices far beyond 2020 and enable the all-communicating world. Different from earlier generation changes, 5G will not only considerably improve the telecommunication services currently offered to the end users, but it will enable the support of evolved services tailored for other industries and humankind as such, for instance vehicular safety and transport system efficiency, industrial control, eHealth applications etc. Also 5G came to provide all the need for mobile broadband networks to support ever-growing consumer data rate demands and the need to tackle the exponential increase in the predicted traffic volumes [2].

One of the most important features for 5G technology is mm-waves which came as solution for the problem of the available frequency spectrum in the exciting technologies plus the huge bandwidth that can offer to the users. The main objectives of this paper is to study how mm waves can be a better choice for the next generation network. Other objective is to use the NYU simulator to explore the effect of environmental variations related to Tripoli city for different frequency bands.

This paper organized as follows: The first section presents a brief introduction. The second section outlines the 5G technology and it's most important features. The third section presents a brief introduction of the NYU simulator. Section 4 summarizes the simulation results of mm waves for Line Of Sight (LOS) and Non Line Of Sight (NLOS) and the effect of the environment for both cases. The last section concludes the study with some recommendations for future work.

2. The 5th generation (5G) wireless Network

The fifth generation refers to the next and the newest mobile wireless standard based on the IEEE 802.11ac standard of broadband technology. 5G is to be a new technology that will provide all the possible applications, by using only one universal device, and interconnecting most of the already existing communication infrastructures. The 5G terminals will be a reconfigurable multimode and cognitive radio-enabled. It will have software defined radio modulation schemes. The 5G mobile networks will focus on the development of the user terminals where the terminals will have access to different wireless technologies at the same time and will combine different flows from different technologies. Besides, the terminal will make the final choice among different wireless/mobile access network providers for a given service. The 5G core is to be a Re-configurable, Multi-Technology Core. The most important components that 5G offers can be summarized as follows:

1. **Phantom cell**

Network densification using small cells with low power nodes is considered a promising solution to overcome mobile traffic explosion, especially in hot spot areas. The major benefits of the Phantom cell architecture includes enhanced capacity by small cells, easy deployment of higher frequency bands and small cell deployment without impact on mobility management [1].

2. **Massive Multi Input Multi Output (MIMO)**

MIMO deployment uses multiple antennas that are located at the source (transmitter) and the destination (receiver). Those antennas are linked in order to minimize error and increase efficiency of a network. This method's ability to multiply the capacity of the antenna links has made it an essential element of wireless standards. Massive MIMO takes MIMO technology and scales it up to hundreds or even thousands of antennas and terminals.

3. **Flexible duplex**

A frequency separated network deployment, where different frequency bands are individually assigned to different cell layers, may use different duplex schemes such as FDD and TDD for lower and higher frequency bands. Therefore, it is desirable to support the Phantom cell solution irrespective of whichever duplex scheme is used in either the lower or higher frequency bands [1].

4. **Millimeter-Waves**

It is being related to the use of mm-waves by allocating more bandwidth to deliver faster, higher-quality video, and multimedia content and services.

Millimeter-Waves for 5G technology

The vision for 5G is expansive, but one aspect of it is fiber-like connections providing multi-gigabit per second data rates to mobile devices. This connectivity will make many applications and services like 3D telepresence and virtual reality available, but these ultra-high-capacity applications will require mastery of millimeter wave spectrum in the frequency bands above 24 GHz for mobile applications.

Currently the available frequency below 4GHz are being totally used by cellular communications systems, and by the very nature, these frequencies could only offer a maximum bandwidth of 4 GHz, even if they were all clear for use which is obviously not possible. By having a 5G millimeter-wave interface, much wider bandwidths are possible, and there are several candidate millimeter bands that are being considered for allocation to this type of service.

Millimeter wave spectrum is the band of spectrum between 30 GHz and 300 GHz. Wedged between microwave and infrared waves. This spectrum can be used for high-speed wireless communications with the latest 802.11ad Wi-Fi standard (operating at 60 GHz).

Propagation effects of mm-Waves

High frequency means narrow wavelengths, and for mm-waves that sits in the range of 1 millimeter to 10 millimeters. Its strength can be reduced due to vulnerabilities against gases, rain and humidity absorption. Also as known in microwave systems, transmission loss is accounted for principally by the free space loss. However, in the millimeter wave bands additional loss factors come into play, such as gaseous losses, rain in the transmission medium, Humidity, Foliage Losses and Scattering Diffraction Communication systems operating at millimeter wave frequencies can take advantage of the propagation effects. System designers can take advantage of the propagation properties manifested at millimeter wave frequencies to develop radio service applications.
The windows in the spectrum are particularly applicable for systems requiring all weather/night operation, such as vehicular radar systems; or for short range point-to-point systems such as local area networks. The absorption bands (e.g., 60 GHz) would be applicable for high data rate systems where secure communications with low probability of intercept is desirable; for services with a potentially high density of transmitters operating in proximity; or for applications where unlicensed operations are desirable [3].

3. Channel Simulator

New York University (NYU) announced in 2016 that its channel model simulator and measurement data are free and open to all. The **NYU WIRELESS** simulator provides the first open access to statistical spatial channel models. The simulator is based on previous experiments that showed that mm-Wave frequencies would work for 5^{th} generation of mobile communication [4]. There are 20 input parameters to the channel simulator, which are grouped into two main categories: Channel Parameters and Antenna Properties.

The Channel Parameters set contains eight fundamental input parameters about the propagation channel, the most important parameters are Frequency (GHz), RF Bandwidth (MHz), Environment: Line-Of-Sight (LOS) or Non-Line-Of-Sight (NLOS). The Transmitted power (TX).

The Antenna Properties panel contains 12 input parameters related to the TX and RX antenna arrays, the main parameters are the antenna array type (TX/RX), Number of TX and RX Antenna Elements, The spacing between adjacent TX/RX antennas in the array in terms of the carrier wavelength, Number of TX/RX Antenna Elements Per Row, The azimuth half power beam-width (HPBW) of the TX/RX antenna (array) in degrees and The elevation HPBW of the TX/RX antenna (array) in degrees [4].

The main Output Data

1. Path Loss Model & Attenuation

The close-in free space reference distance (CI) path loss model with a 1 m anchor point, with an extra attenuation term due to various atmospheric attenuation factors is employed in NYUSIM, which is expressed as:

$$\mathrm{PL}^{\mathrm{CI}}(f,d)[\mathrm{dB}] = \mathrm{FSPL}(f, 1\ \mathrm{m})[\mathrm{dB}] + 10n\log_{10}(d) + \mathrm{AT}[\mathrm{dB}] + \chi_{\sigma}^{\mathrm{CI}}, \quad \text{where } d \geq 1\ \mathrm{m} \tag{2}$$

where f denotes the carrier frequency in GHz, d is the 3D T-R separation distance, n represents the Path Loss Exponent (PLE). AT is the attenuation term induced by the atmosphere, $\chi_{\sigma}^{\mathrm{CI}}$ is a zero-mean Gaussian random variable with a standard deviation, σ in dB.

The function FSPL (f, 1 m) denotes the Free Space Path Loss in dB at a T-R separation distance of 1 m at the carrier frequency f and is given as:

$$\mathrm{FSPL}(f, 1\ \mathrm{m})[\mathrm{dB}] = 20\log_{10}\left(\frac{4\pi f \times 10^{9}}{c}\right) = 32.4\ \mathrm{dB} + 20\log_{10}(f) \tag{3}$$

where c is the speed of light, and f is in GHz. The term AT is characterized by:

$$\mathrm{AT}[\mathrm{dB}] = \alpha[\mathrm{dB/m}] \times d[\mathrm{m}] \tag{4}$$

where α is the attenuation factor in dB/m for the frequency range of 1 GHz to 100 GHz, which includes the collective attenuation effects of dry air (including oxygen), water vapor, rain, and haze. d is the 3D T-R separation distance as in (2).

2. Received Power

The received power obtained at a Transmitter (TX) – Receiver (RX) unique pointing angle combination was obtained by summing the power of each individual multipath component in time for mm-Wave communication channel [3]. The relation between the transmitted and received power is given by Friis free space equations:

$$P_r = P_t G_t G_r \frac{\lambda^2}{(4\pi d)^2} \tag{5}$$

Where the dimensionless quantities G_t and G_r represents the transmitted and received antenna gains, λ is the wavelength, d is the T-R separation, P_t is the transmitted power and P_r is the received power.

2. RMS Delay Spread

It's one of the most important measurable value in any wireless environment. In telecommunications, the **delay spread** is a measure of the multipath richness of a communications channel. In general, it can be interpreted as the difference between the time of arrival of the earliest significant multipath component and the time of arrival of the latest multipath components.

4. Performance Analysis

This section presents the simulation results and the performance analysis of mm-Waves propagation in Tripoli city environment for different frequency bands. It has been divided into two scenarios Line of sight (LOS) and Non line of sight (NLOS) as indoor or outdoor propagation measurements using the NYUWIRELESS 5G channel simulator. The basic input parameters and their assumptions during the simulation are listed in Table (1).

Table (1): Simulation Input Parameters [5]

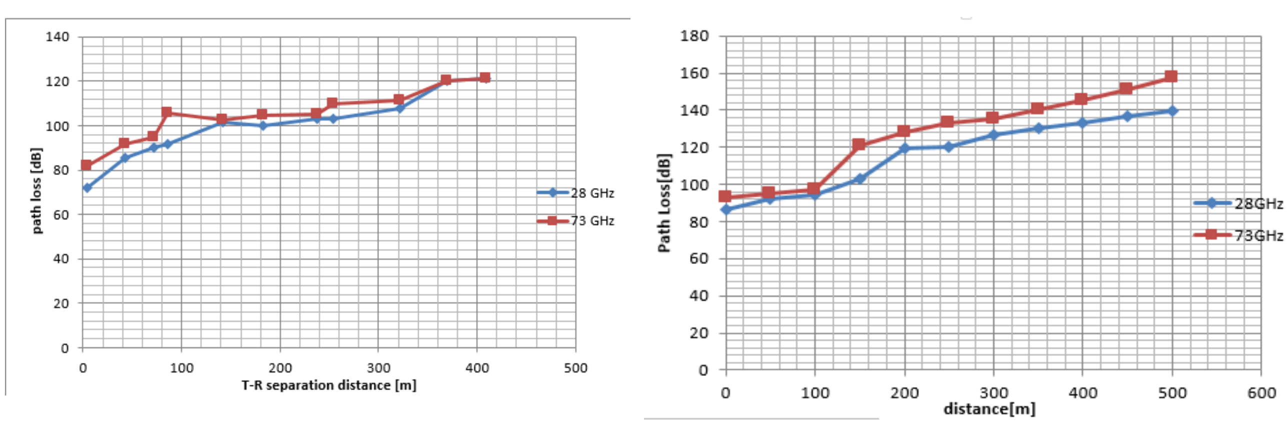
Parameter	Selected value	Parameter	Selected value
Transmitted Power (Pt)	**30.1dBm**	RX antenna elevation HPBW	**8.6°**
Polarization	**Co-Polarization**	Barometric Pressure	**1029 bar**
Scenario	**UMi**	Temperature	**14 - 40°C**
Number of RX locations	**1**	Humidity	**10 - 100%**
TX array type	**ULA**	Rain rate	**0-10 mm/hr**
TX antenna azimuth HPBW	**10.9°**	Environment	**LOS - NLOS**
RX antenna azimuth HPBW	**10.9°**	Bandwidth	**800 MHz**
TX antenna elevation HPBW	**8.6°**		

4.1. Propagation Simulation Tests

The simulation consider two main propagation characteristics of mm-Waves communications in different bands under LOS and NLOS channels. The simulation consider two frequency bands 28 GHz and 73GHz.

I. Path loss

Figure (1) shows the path loss for two frequency bands under LOS (a) and NLOS (b). From the simulation results we noted that generally the Path loss increases with the increase in the separation distance between the transmitter and receiver**,** also in most cases the frequency band 73 GHz has a higher Path loss compared to 28 GHz. As expected the path loss in the NLOS case is higher than the LOS situation.

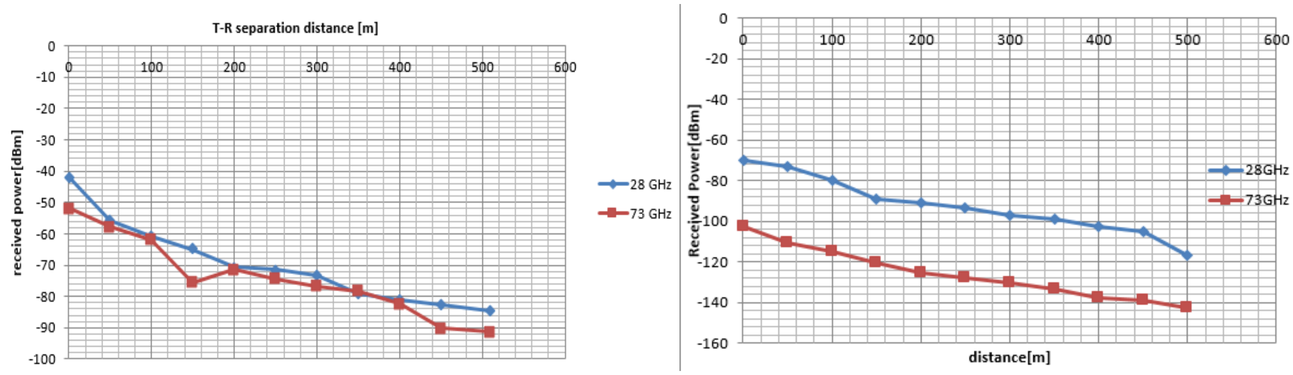


(a) (b)

Figure 1: The path loss measurements of LOS (a) and NLOS (b)

II. Received Power

Figure (2) shows the simulation results for the two frequency bands with the received power at the receiver end. **F**rom the shown figures we notice that the received power at the receiver location for different frequency bands decreases as the separation distance between the transmitter and receiver location increases. The simulation results show that for NLOS the values of received power smaller than the case in LOS scenario. It's also can be noticed that the received power using 73GHz is smaller than the received power with 28GHz and the difference between the received power for the two frequencies is more higher in the NLOS case is higher compared to the LOS case.

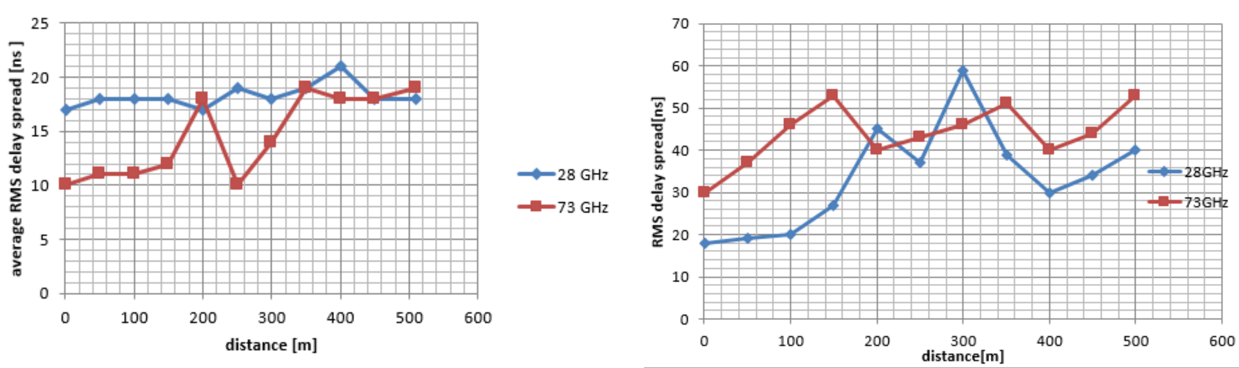


(a) (b)

Figure 2: The received Power in dBm for LOS (a) and NLOS (b) channel scenarios

III. RMS Delay Spread

Figure (3) presents the RMS delay spread related to the separation distance for both frequency bands. **F**rom the simulation we notice for the LOS case that at 28GHz the RMS delay spread has a stable condition until separation distance of 200m then the values fluctuate randomly and a maximum value at 400m. In the other hand at 73GHz the maximum value at 350m. For the NLOS scenario it's more unstable in both frequency bands. The 73 GHz band has a maximum value of 51ns at 150m spacing while the 28GHz frequency has its maximum at 300m spacing.

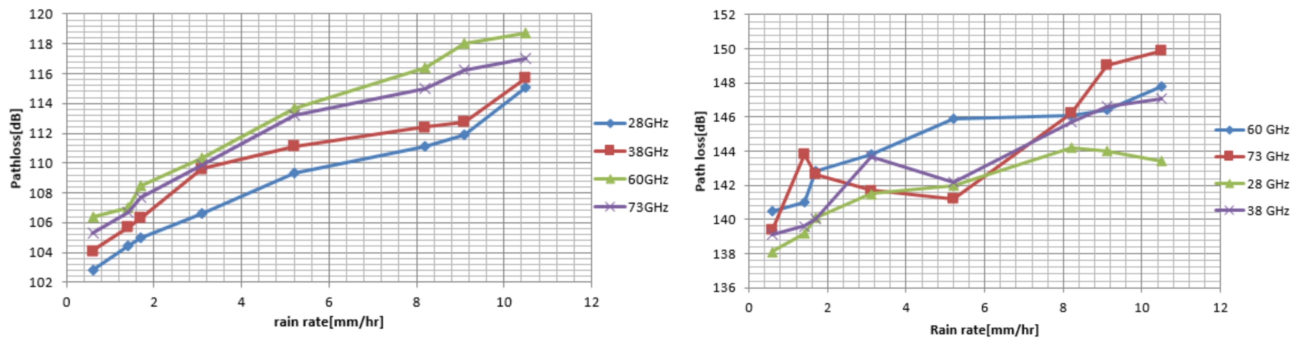


(a) (b)

Figure 3: The RMS Delay Spread measurements for LOS (a) and NLOS (b) scenarios

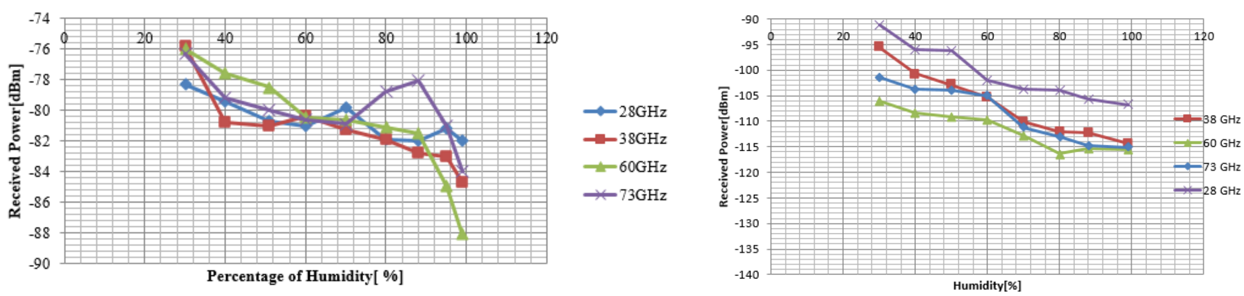
4.2. Atmospheric and Rain Absorption Effects

The following Figures shows the effect of the atmospheric and rain absorption on the propagation characteristics of mm-Waves communications at different frequency bands 28GHz, 38GHz, 60GHz and 73GHz. The simulation considers both LOS and NLOS channels. Figure (4) presents the effect of rain rate on the path loss. Figure (5) shows the effect of humidity on the propagation characteristics of mm-Waves communications at different bands. Figure (6) shows the effect of temperature variation on the propagation characteristics of mm-Waves communications at different frequency bands.



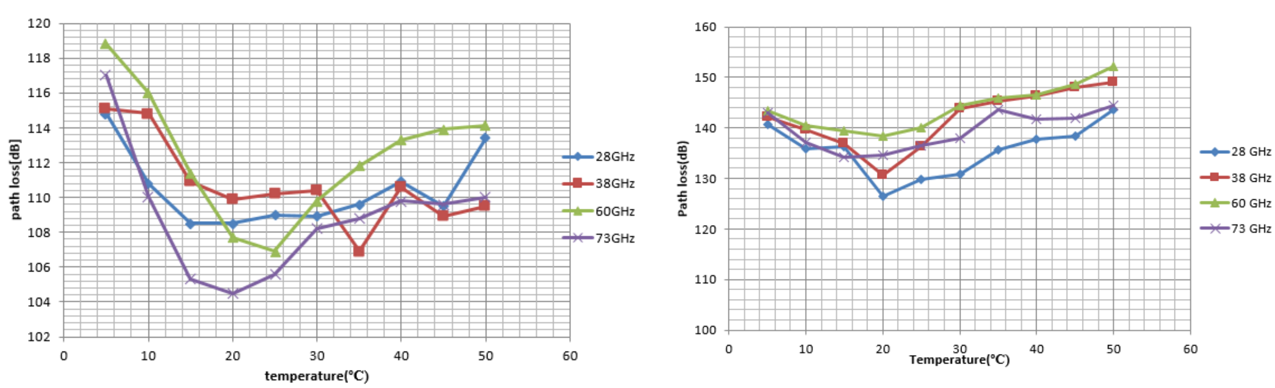
(a) (b)

Figure 4: The effect of rain on the propagation characteristics at different bands for LOS (a) and NLOS (b).



(a) (b)

Figure 5: The effect of propagation characteristics communications in different bands for LOS (a) and NLOS (b).



(a) (b)

Figure 6: The effect of temperature on the propagation of mm-Waves for the LOS (a) and NLOS (b)

From the simulation results, we can notice the following significant results:

- Increasing the rain rates increases the attenuation for each frequency. For example, the 28GHz band with LOS case has a 102.8 dB path loss at 0.6 mm/hr while at 10.5 mm/hr it has a 115.1 dB. Under NLOS channels, the rain attenuation for the 28 GHz band in most cases has a lower attenuation than other bands. It can be seen that the NLOS transmission has additional propagation loss compared with the LOS transmission for all four categories.
- The humidity effect for the LOS channel on the received power of mm-Wave channel propagation ranges as an average from -75.8dBm to -88.1dBm for different frequency bands as shown in Figure (5, a). Within the 60GHz band, the effect of humidity on the received power is notable especially for higher value of humidity, which has the lowest received power of -88.1dBm at 99%. For the NLOS channel the humidity range from 30% to 99% effects the received power of mm-Wave channel propagation, it ranges as an average from -91.2dBm to -115.5dBm at different frequency bands. The 60 GHz band has the lowest power received but it's the most stable during the variation of the humidity.
- Figure (6) summarizes the average temperature rates in Tripoli city and their effect on the path loss for the LOS channel. It can be noticed the values ranging from 15ºC to 30ºC has a stable values of path loss at different frequency values. Maximum path loss value was occurred at 60GHz frequency band and the minimum at 73GHz frequency band. The NLOS has higher path loss during the changes in the temperature than LOS scenario, also it can be noticed from Figure (6, b) that the lowest path loss is occurred at 20ºC for all frequency bands considered. The simulation results for the frequency band 60 GHz confirms to the simulation results mentioned in [6].

5. Conclusions and Future works

5.1. Conclusions

Given the worldwide need for cellular spectrum, and relatively limited amount of research done on mm-Wave mobile communications this paper presents an overview of the millimeter wave as a promising technology for the upcoming 5G cellular system. An extensive propagation simulations has been conducted at different frequency bands (28 GHz, 38 GHz, 60 GHz and 73 GHz) to gain insight on RMS delay spread, path loss, attenuation and received power for the design of future mm-Wave cellular system.

The simulation was divided into two main channel scenarios, the LOS channel propagation characteristics and the NLOS channel propagation characteristics. The presented simulation based on data considers an urban environments in Tripoli city.

The overall results can be summarized as follows:

- Path loss increases as the separation distance between the transmitter and receiver increased in both channel scenarios, it was larger in NLOS compared to LOS.
- The received power closest to the transmitter was significantly higher than other locations and the received power in case of NLOS channel scenario was lower, that is because there are reflection and diffraction paths apart from the direct path.

- The smaller the delay spread is, the greater related bandwidth will be. Therefore, 28 GHz has the minimum and the most stable values of RMS delay spread under LOS channel scenario which can suppress the inter-symbol interference.
- Attenuation path loss and received power were simulated with reference to separation distance. By comparing the simulation results, NLOS transmission has additional propagation loss compared with LOS transmission in all four different frequencies.
- The path loss is higher in 60GHz and 73 GHz than in other lower frequencies (28 GHz and 38 GHz), while 60 GHz has the highest path loss and the lowest received power in most cases also this frequency was the most stable frequency band during the atmospheric variations.

5.2. Future work

Millimeter waves is a new 5G technology that will be rolled by 2020, it needs more researches and studies to improve its performance and offer solutions to problems that may be facing this technology. In this paper the simulation is based on SISO systems, future directions suggests more depth study of the Massive MIMO system in which a number of issues must be addressed: hybrid (analogue and digital) beam-forming, hardware components design and fabrication, software defined architecture, control mechanism as well as heterogeneous networking.

References

[1] Takehiro nakamura, “5G Concept and Technologies” , NTT docomo, INC, 2014, White paper.

[2] T. Rappaport et al, “Millimeter Wave Mobile Communications for 5G Cellular: it will work!”, IEEE Access(Volume: 1) , (2013, May 10).

[3] Federal communications commission, “FCC definition of mm waves”, (1997, July).

[4] New York University and NYU WIRELESS, “NYUSIM User Manual”, (2016, July13).

[5] H. Yan et al, “5G Millimeter-Wave Channel Model Alliance Measurement Parameter, Scenario Parameter, and Measured Path Loss Data List”, (2016, Sep).

[6] S. Hosseini et al., “Analyzing Diurnal Variations of Millimeter Wave Channels”, IEEE INFOCOM 2016 - IEEE Conference on Computer Communications Workshops, (2016).