Statistical Channel Modelling of Millimetre Waves at 28 GHz and 73 GHz Frequency Signals Using MIMO Antennas

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Abstract. To meet the demand of high spectrum requirement and high-speed wireless communication in future, millimetre waves (mm-Wave) can play a very important role for it. Millimetre waves starting from 30 GHz and ending at 300 GHz can solve the problems like high throughput, faster data rates and capacity. Millimetre waves can help to achieve higher gain by using high dimensional antenna array technology. Beamforming and spatial multiplexing are very famous techniques that can help to increase the gain when antenna arrays are used. Channel modelling plays a very important role in determining the possibility of deploying the wireless communication system. In this research paper, the major challenges regarding the mm-Wave channel modelling are identified and the statistical behaviour of mm-Wave channel at 28GHz and 73 GHz is explained with the help of NYUSIM software. The power loss, power delay profile and path loss, angle of arrival and departure are simulated in this work. These simulations are performed using multiple antennas configuration along with considering the effect of atmospheric impairments like rain, humidity and temperature.

1. Introduction

The trend of consuming high data rate applications has increased the demand of high throughput, fast data rates and increased capacity. It is because of the way the users consumes information in this generation. There are many applications used in wireless communication system for machine communications, internet of things and smart sensors. These applications in the wireless communication system has caused the increase in demand of high data rate and required capacity. It has been predicted by UMTS that by 2020, daily mobile traffic will increase up to 130 Exabyte (1018) of data per year for some operators [1]. To meet the demand of increasing high data rates, new technologies are required that can also fulfil the demand of increased cellular capacity.

This challenge can be overcome by millimetre waves (mm-Wave) technology that have a frequency band of 3 GHz to 300 GHz. This frequency band can help in achieving the wider bandwidth and higher data rates than cellular networks used in today’s era [2]. The millimetre waves enables increased spectrum up to 200 times greater than today’s cellular networks [3]. The smaller wavelength of mm-Wave also help in designing high gain multiple miniaturized antenna system. Because of their small size, these antennas can easily be implemented in the cell phone and are quite feasible to fabricate. For the successful deployment and assessing the performance of wireless system channel modelling play a very important role in it. It is also helpful for designing the wireless system. Millimetre waves is considered as a leading contender in the wireless system that can meet the demand.
of high data rates and spectrum availability. Therefore, it is necessary to determine the propagation characteristics at millimetre waves. The effects of weather are very harsh to mm-wave because of their smaller wavelength and can easily be attenuated by atmospheric impairments. Free space path loss, which is an important factor for wireless channel modelling is significant at mm-wave frequencies along with penetration losses. Nevertheless, in order to increase the bandwidth higher frequency bands is required to be exploited and in this regards, high gain antennas can play a very important role in executing this work.

This research work encloses the results of channel modelling simulated by NYUSIM software for 28 GHz and 73 GHz frequency signals. These results are simulated according to urban microcell scenario and weather effects are taken into consideration during the simulations. Moreover, this work is organized in the following sections: Section II is illuminated with the background study of the channel modelling of mm-Wave, Section III states the different mm-Wave channel Modelling approaches and simulators used over the years, Section IV is enclosed with the simulation results and its elaboration, whereas in last section V, conclusion is described.

2. Background Study

The increase in the demand of high data rate and the required capacity have increased because of the applications like device-to-device communication and internet of things applications. To address the above-mentioned requirements, the fifth-generation (5G), the true revolution of technologies, is expected to support 100 – 1000 times higher system capacity over current cellular networks. There are many candidates under consideration for the realization of 5G mobile communication but mm-Wave is more suitable technology for realization of 5G. Millimetre waves along with massive MIMO antennas can be remarkable. It can solve the problems of higher bandwidth and mitigates the atmospheric impairments that cause the signals to be degraded. Different frequency bands in millimetre waves like 28 GHz, 38 GHz and 60 GHz are exploited and wireless channel modelling is performed [4-6]. Whereas, the millimetre waves in the range of 71 GHz to 81 GHz frequencies are also under consideration for wireless channel modelling. It is quite tedious and difficult to perform channel modelling at mm-wave because of their vulnerability in the atmosphere [7]. For outdoor communication, the frequency bands at 28 GHz and 73 GHz can be eye-catching. The attenuation at these frequencies is not too much high which is approximately around 0.1 dB [8] [9].

Omnidirectional path loss at mm-Wave frequencies is higher than current cellular frequencies because of smaller wavelength but this flaw can be mitigated by using MIMO antennas and beamforming techniques. MIMO antennas with the help of beamforming techniques results in increasing the gain of antenna with same physical antenna size. The path loss may get lessened because of the locations which are not in outage [10]. There is also a multipath effect because of multiple copies of signals received from different reflections and scattering. Because of the multipath effects, the concepts of spatial multiplexing and diversity gains can be utilized [11].

It is essential to understand the propagation effects of the millimetre wave channel for the deployment of wireless communication system. The propagation channels are characterized through the path loss model on a large scale that represents the attenuation of the signal according to the distance. There are also other factors like dry air, vapour, haze, rain etc. that attenuates the transmitted signal. These can be very helpful in making the communication system more efficient [12]. The presence of massive MIMO antennas has made it feasible for the implementation of 5G mobile and wireless communication system. Massive MIMO is a special type of MIMO system in which several antennas are installed on the base station [13]. It provides the communication between the base station controller and multiple mobile stations simultaneously. It also diminish the small scale fading of the system providing higher data rates and reliable link. Spectral efficiency and energy efficiency are two important factors of the wireless communication system and by installing the number of antennas at transmitter and receiver, better performance of these two factors can be achieved [14].
2.1. Path loss (PL) Model
Path loss (PL) is an important factor to model the wireless communication channel. It helps in estimating the link budget along with outage. The equation of free space path loss having a reference distance of 1m and attenuations because of atmospheric impairments \[15\][16][17] is given in the following equation:

\[ PL[dB] = FSPL[dB] + 10n\log_{10}(d) + \psi[dB] + \xi_{d} \]  

(1)

In the above equation, \(d\) is the distance and \(\psi\) is atmospheric attenuation. Whereas, \(n\) and \(\xi\) are path loss exponent and Gaussian random variable respectively. From the above equation, it can be analyzed that this model is dependent on the distance and carrier frequency. Moreover, free space path loss (FSPL) and \(\psi\) attenuation are described as follows:

\[ FSPL[dB] = 10\log_{10}\left(\frac{4\pi f}{c}\right)^{2} \]  

(2)

\[ \psi[dB] = \alpha[dB/m] \times d[m] \]  

(3)

In the above equations, \(c\) and \(f\) is the speed of light and carrier frequency respectively, whereas \(\alpha\) is the attenuation factor in dB/meter.

At millimetre waves, there is significant growth in PL because of the higher frequencies. This is a key technical challenge that must be addressed to realize the communication at mm-Waves. Nowadays, this challenge is overcome by two methods i.e. increasing the antenna array gain and decreasing the propagation distance.

2.2. Power Delay Profile and Delay Spread
Power delay profile (PDP) is an important factor of channel modelling that predicts the strength of a received signal when there is a multipath environment. PDP is a function of time delay and it has a shape of spectrums that diminish exponentially. Delay spread is also a key factor for describing the time dispersion of the multipath channel. It is considered as a collection of the multipath containing significant energy that spread over the PDP and can be derived from PDP. Besides, the DS of the channel is an important metric to understand the required system overhead to facilitate communication [18].

Delay spread is quantified through the root mean square and it is determined by taking the square root of the second central moment of power delay profile and is given as follows:

\[ \sigma_t = \sqrt{\frac{\sum_{n} P(t_n)\tau_n^{2}}{\sum_{n} P(t_n)}} \]  

Here:

\[ \bar{t} = \frac{\sum_{n} P(t_n)\tau_n}{\sum_{n} P(t_n)} \]  

(4)

(5)

Here, \(\bar{t}\) is the mean delay that has exceeded; it is the first central moment and \(\bar{t}^{2}\) is the second central moment of power delay profile. \(P(t_n)\) is power in milliwatt of the delay bin corresponding to the delay bin \(t_n\).

2.3. Atmospheric Effects
The most important atmospheric effects like oxygen, water vapour absorption, fog, and precipitation should be taken into consideration at mm-Wave frequencies. Millimetre waves have a smaller wavelength and it can easily be attenuated sharply because of path loss, depolarization, and multipath effects. When millimetre waves of 60 GHz to 73 GHz are transmitted into the atmosphere it is attenuated severely during a heavy rain [19]. In cellular communication, small cell having a radius of 200m the attenuation caused by rain and atmosphere can be ignored [20]. However, in those areas having heavy rainfall, it is necessary to take rain as an important factor when it comes to channel modelling of millimetre waves.
3. Channel Modelling Approach

Channel modelling is important for understanding the behaviour of the channel when the signals are propagated on it. It is categorized into deterministic and statistical channel modelling. To determine the channel behaviour in the deterministic approach solution of Maxwell equation with boundary condition is required. In this solution, walls and objects are considered through which the transmitted signal interacts. Thus, it makes deterministic models complex and require enormous computational efforts. On the other hand, statistical channel models are inherently random and the variables are assumed to be random and unknown. These models are easy to be determined and do not require complex calculations. In statistical channel modelling, path loss model is used to determine the received power of transmitted signals in a specific zone. In statistical channel modelling, PDP and angular spectrum can also be used to describe the channel. Although, there are many channel models that are discussed over a period of years but these models are not enough to fully describe the channel behaviour of mm-Waves. These models have shortcomings of inability to meet the particular requirements [21].

There are a number of channel model simulators that are being used to determine the channel behaviour of mm-Waves but currently, NYUSIM is leading among the mm-Wave channel simulators. Bit error rate simulator, Simulation of mobile radio channel impulse response, Simulation of indoor radio channel impulse response are few of the channel simulators that have been used previously for channel modelling of mm-Waves. NYUSIM is 5G mm-Wave channel simulator that helps in determining the channel behaviour of millimetre waves having a frequency range of 1 GHz to 100 GHz. This simulator is designed on the basis of statistical measurements of channel performed at mm-Wave frequency signals. It generates the simulation results of path loss profile, PDP and power spectrum of angle of arrival (AoA) and departure (AoD) signals. Time clusters and spatial lobes are the techniques that are used to generate the simulation results [22]. Time clusters are obtained from the multipath environment in which signals coming from alternative directions are received at a single point. NYUSIM software has a special feature of receiving multipath signals coming from different directions, which is not present in previous propagation models [23][24]. This is possible because of the availability of MIMO antennas feature in NYUSIM. NYUSIM is a powerful software to determine the channel behaviour of mm-Waves along with providing bit error rate (BER) simulations.

4. Simulation Results and Discussion

In this work, the results of mm-Wave channel are obtained at 28 GHz and 73 GHz frequency signals respectively. These simulations are performed to determine the behaviour of channel in urban microcell having a bandwidth of 800 MHz. The atmospheric effects as humidity, temperature, rain, and foliage are considered during simulations to determine the behaviour of the channel. These simulation results are obtained by using the NYUSIM channel model simulator that works from 2 GHz to 100 GHz. The results of Path loss, PDP and angular spectrum of signals departing and arriving at a point are simulated in this work. Whereas, the input channel and antenna parameters are given in the following table 1 and table 2.

| Channel Parameter       | Value               |
|-------------------------|---------------------|
| Carrier Frequency       | 28GHz and 73 GHz    |
| Channel BW              | 800 MHz             |
| Current State           | Urban Microcell     |
| Transmitted power       | 30 dBm              |
| Polarization            | Cross Polarization  |
| Pressure                | 1013.25             |
| Humidity                | 50%                 |
| Average Temperature     | 20°C                |
| Average Rain Rate       | 50 mm/h             |
| Foliage Attenuation     | 0.4 dB/m            |

| Antenna Parameters      | Value               |
|-------------------------|---------------------|
| Transmitting Array type | Uniform Linear Array|
| Receiving Array type    | Uniform Linear Array|
| Number of Tx Antennas   | 3                   |
| Number of Rx Antennas   | 3                   |
| T_A Antenna Spacing     | 0.5 λ               |
| R_A Antenna Spacing     | 0.5 λ               |
| T_A Antenna Azimuth     | 10 degrees           |
| R_A Antenna Azimuth     | 10 degrees           |
| T_A Antenna Elevation   | 10 degrees           |
| R_A Antenna Elevation   | 10 degrees           |
In figure 1 and 2, the simulation results of directional and omnidirectional power delay profile are provided at 73 GHz. The value of path loss for directional PDP at 73 GHz is equal to 115.3 dB and for the omnidirectional PDP the value of path loss is equal to 111.1 dB. Whereas, the obtained path loss exponent for directional and omnidirectional profile at 73 GHz is equal to 2.2 and 2.0 respectively.

![Figure 1. Directional PDP at 73 GHz](image1)

![Figure 2. Omnidirectional PDP at 73 GHz](image2)

Path loss profile is simulated at 73 GHz in figure 3, showing the graph of path loss when configuration is omnidirectional and directional along with best-directed path loss. The simulation results of the small-scale power delay profile are also obtained in figure 4 depicting the strength of a received signal at 73 GHz when there is multipath propagation effect.

![Figure 3. Path loss profile at 73 GHz](image3)

![Figure 4. Small scale PDP at 73 GHz](image4)

Figure 5. and Figure 6. illustrate the angular spectrum of 73 GHz frequency signals arriving and departing at a point. It can be analysed from the above results that the power spectrum of AoA is more scattered that AoD but the power values are approximately the same in both spectrums.

![Figure 5. Power Spectrum of AoA at 73 GHz](image5)

![Figure 6. Power Spectrum of AoD at 73GHz](image6)
Simulation results of directional and omnidirectional PDP at 28 GHz are given in above figures 7 & 8. It depicts that the path loss of 113.7 dB and 107.1 dB respectively in each configuration. Whereas in the above results, the received path loss exponent (PLE) is 2.7 and 2.4 respectively when the configuration is directional and omnidirectional.

![Directional PDP at 28 GHz](image1)

**Figure 7.** Directional PDP at 28 GHz

![Omnidirectional PDP at 28 GHz](image2)

**Figure 8.** Omnidirectional PDP at 28 GHz

In figure 9 and figure 10, the simulations results of path loss profile and small-scale PDP are obtained at 28 GHz respectively. In path loss profile, the graph of path losses at directional, omnidirectional configuration are shown along with the best directional path loss in figure 9.

![Path Loss Profile at 28 GHz](image3)

**Figure 9.** Path Loss Profile at 28 GHz

![Small Scale PDP at 28 GHz](image4)

**Figure 10.** Small Scale PDP at 28 GHz

Simulation results of the angular power spectrum of angle of arrival and departure signals are provided in figures 11 & 12 respectively. It has been determined that the angular spectrum at 28 GHz is less scattered than that of the angular spectrum at 73 GHz.

![AoA Power Spectrum at 28 GHz](image5)

**Figure 11.** AoA Power Spectrum at 28 GHz

![AoD Power Spectrum at 28 GHz](image6)

**Figure 12.** AoD Power Spectrum at 28 GHz

5. Conclusions

In this research paper, the challenges occurring in mm-Wave channel modeling are identified, stating that there is always significant path loss when the frequency gets increased and this can be compensated with the help of using MIMO antennas and beamforming technique. In this paper,
Simulation results of channel modeling of millimeter waves for urban microcell at 28 GHz and 73 GHz are obtained using the MIMO configuration considering the effect of atmospheric impairments. Simulation results of Omnidirectional and directional PDP, small scale PDP, angle of arrival and departure power spectrum are provided and discussed at 28 GHz and 73 GHz. From the simulation results it has found that at higher frequency path loss and multipath propagation effect is significant than lower frequencies.

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