Modeling of Propagation Channels at Different frequencies of Millimeter Waves in Indoor and Outdoor Environments for Designing of 5G Networks

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***Abstract*-With the tremendous growth of commercial mobile communication networks world over, the radio frequency becomes more valuable natural resources. The Radio spectrum is an essential tool for economic and social growth of a country.The shortage of bandwidth forces researchers for the exploration of the underutilized millimeter wave spectrum for designing the communication broadband networks. Very little research has been done in the areas of cellular mm-wave propagation in densely populated indoor and outdoor environments. For the design of future 5G network it is very necessary to obtain vital information regarding mm-wave propagation characteristics and its behavior in various environmental conditions. This paper describes the various studies carried out earlier in the field of radio wave propagation at 60 GHz in outdoor and indoor environment. A simulation is also performed for the comparison of 2 GHz and 60 GHz.**

Key Words: Millimeter waves; Wireless Propagation, 5 G, 60 GHz

I. INTRODUCTION

With the tremendous growth of commercial mobile communication networks world over, the radio frequency becomes more valuable natural resources. Nowadays, Radio spectrum is considered as an essential tool for economic and social growth of a country. Advancement in wireless technology has driven the demand for more radio spectrum bandwidth from every quarter of the society. It is further accelerating day by day, and we are heading towards greater mobility with ever-increasing data rates. The growth of internet has further fueled the demand for wireless services, due to which the available radio spectrum is become congested. The reserve radio resources pool is also depleting. Various studies have shown that the increasing demand for spectrum is due to the tight regulatory schemes introduced by authorities to protect rapid increase of spectrum users. Various researchers are working hard on devising a methodology for resolving forthcoming spectrum crisis. Recently various regulators have shown interest in sponsoring free radio channels to allow access for unlicensed devices. For example Industrial, Scientific and Medical (ISM) radio band in 2.4 GHz frequency are allocated freely for public usage. This was very successful in short range low power radio communications in wireless local area network.

Most of the terrestrial commercial applications are below 3GHz and have already been assigned to different radio communications services which are working with non-spectrum efficient technologies. Lower spectrum bands provide better coverage, simpler hardware and good mobility. If we go to higher spectrum regions, situation would be just reversed, provide less coverage, complexity in hardware and less mobility. Currently, no vacant spectrum especially below 3 GHz is available for new wireless technologies. Radio spectrum, being natural resource, cannot be created. Therefore, its efficient use is inevitable.

The 5th generation wireless systems denote the next major phase of mobile telecommunications standards beyond the current 3G/4G/IMT-Advanced standards.

The shortage of bandwidth forces researchers for the exploration of the underutilized millimeter wave spectrum for designing the communication broadband networks. Very little research has been done in the area of cellular mm-wave propagation in densely populated indoor and outdoor environments. For the design of future 5G network it is very necessary to obtain vital information regarding mm-wave propagation characteristics and its behavior in various environmental conditions [1].

A. THE EVOLUTION OF 5G NETWORKS

The first generation cellular network was introduced in 1981. It was designed for using basic analog systems for voice communications. During the year 1992, 2G was introduced for providing voice and data services with improved spectrum utilization. It was using digital modulation and time division or code division multiple access. During the period of 2001, 3G was introduced with high speed internal access and improved audio and video streaming capabilities. It uses technologies like wideband code division multiple access (W-CDMA) and high speed packet access (HSPA). HSPA is consist of two protocols namely high speed downlink packet access (HSDPA) and high speed uplink packet access (HSUPA) [2]. The 4G of mobile communication was introduced by ITU in 2011. The technology used in it was the International Mobile Telecommunication – Advanced (IMT- Advanced).

Although LTE radio access technology was also used in 4G networks. LTE is an orthogonal frequency division multiplexing (ODFDM) based radio technology which supports up to 20MHz bandwidth. For enabling high spectrum efficiencies, linked quality improvements and radio pattern adaptation new technology was introduced called multiple Input Multiple Output (MIMO) [3].

With the tremendous increase of demand for capacity in mobile broadband communications every year, wireless carriers must be prepare for the thousand fold mobile traffic increase in 2020. It forces researchers to find new wireless spectrum which has capabilities beyond 4G [4]. The future of mobile communication is 5G technology. The issues which are addressed by this technologies are greater spectrum allocation at millimeter wave frequencies bands, installations of highly directional beam forming antennas, longer battery life, high bit rates with lower outage probability, lower infrastructure cost and increased capacity for many simultaneous users.

B. WHY MILLIMETER WAVES?

Various researches have shown that mm-wave frequency band 30GHz – 300GHz can be used to overcome currently saturated 700MHz to 2.6GHz band for mobile communications [1]. Now CMOS technologies are also operate on mm-wave frequency band provide larger bandwidth allocations and high data transfer rate [5,6]. Millimeter wave has smaller wavelength. This characteristic is used to exploit polarization techniques such as MIMO and adaptive beam forming [7]. These significant characteristics of mm-wave will provide more capacity than today's 4G network in highly populated areas. Operators are continuously reducing cell coverage areas in order to exploit spatial reuse, and implement new architecture (Cooperative MIMO), interference issues and relays between base stations. The cost per base station will become cheaper as they become more plentiful and more densely distributed in urban areas. The millimeter wave spectrum allocation is relatively much closer which makes radio wave propagation characteristics more comparable and homogenous.

C. ISSUES IN INDOOR MILLIMETER WAVE PROPAGATION

The study of mm-wave indoor propagation characteristics is significant because mm-wave communication is mostly used in indoor environments like laboratory, offices, colleges, malls etc. [8]. Indoor propagation model can be classified into two broad categories empirical and deterministic models [9].

The empirical model consists of simple mathematical formulas. It requires simple inputs only and its operations are very fast. This model requires precise equipment for study. The limitations of this model is that some useful propagation parameters are not obtained while using this model such as direction of arrival, distribution of direction of arrival and angular speed [10].

On the other hand the deterministic model is based on the theory of electromagnetic wave propagation. The deterministic model is further divided into ray tracing method and finite difference time domain method. Out of these two methods ray tracing method is most popular. Ray tracing method is further divided into image method, minimum optical path method, test ray method, shooting and bounding ray tracing method, deterministic ray tube method and shooting and bounding ray tracing image method.

The image method [11] is a simple ray tracing method which does not need intersection test and only applied to simple structure of environment. The minimum optical path method [12] use minimum optical path to determine the location of the reflection point of wall. The test ray method [13] needs receiving ball. This method can be applied to complex environment, but the prediction accuracy is depends on the radius of the ball. The shooting and bounding ray tracing method [14] requires lot of computer resources. The deterministic ray tracing method [15] needs to create a ray tree based on actual environment. The shooting and bounding ray tracing image method [16] can be used for complex environmental conditions and can find all the radio wave propagation path from transmitter to receiver with high computational efficiency and accuracy.

D. ISSUES IN OUTDOOR MILLIMETER WAVE PROPAGATION

There are various issues related to mm-wave propagation which has to be considered in order to design and develop any system [17]. These effects are due to earth's atmosphere, geographical conditions and their impact on the communication system. These are as follows:

- Gaseous Absorption: during the clear sky conditions the attenuation mechanism at mm-wave frequency band is due to the gases like oxygen and water vapor present in the atmosphere which contribute to the total path loss in band [18].
- Cloud Attenuation: presence of cloud in the sky contribute significant loss (greater then 10dB) for total path attenuation.
- Rain Attenuation: as rain s variable in nature i.e. it depends on geographical conditions but still has significant role in total path loss in mm-wave band. [19]
- Scintillation: this is the effect cause by rapid fluctuations in the refractive index of the atmosphere causes rapid variations in the attenuation of the propagation signals at the time interval of 0.5 seconds.
- Depolarization: for frequency reuse systems it is important to identify signal leakage between polarization of the same signal via simultaneous co-polarization and cross polarization measurements.
- Group Delay: group delay across the bandwidth will naturally limit the full usage of the spectrum [20].

- Atmospheric noise: the atmosphere has the black body temperature which ranges from 10K to 40K which has significant impact on mm-wave.
- Snow covered / Wet Antenna: wet or snow covered on antenna can cause signal loss.

Some reliable statistical methods are needed to predict above effects for smooth functioning of the system. Each effect mention above is the functions of frequency, location, path elevation angle and time.

II. LITERATURE SURVEY

A. OUTDOOR ENVIRONMENT

Various researches has been done in the areas of millimeter wave propagation in both outdoor and indoor environment, but are very few in numbers. As in outdoor environments these waves faces various challenges like rate of rain drop size, dust and snow particles causing attenuation, de-polarization and noise.

In [21] author had measured slant path attenuation and vertical path attenuation at 35GHz. Vertical height attenuation is done by radiometers and horizontal path attenuation is done by line of sight link.

On the other hand [22] author has done field study in the desert area for four years. It has been measured the signal attenuation caused by multipath fading at 40GHz. The author has measured various metrological parameters and analyzed it statistically.

The [23] had done his research in sub urban areas. It has been found a high probability of non – line of sight path due to presence of trees which in turn cause signal attenuation and signal variability when wind is present. The author had studied signal variability by using k factor and compared it with Rician cumulative distribution function. It has been also observed that the depolarization caused by vegetation is higher than caused by rain.

While on other hand [24] had presented a propagation model for prediction of millimeter wave power delay profile in urban site. They had worked in 54GHz frequency band. He map available in market had been used for prediction of delay characteristics.

In [25] author has studied effects of rain on millimeter wave propagation in two different sites in Australia at 60GHz frequency band. It has been observed that at rain intensity of 20 mm/h the diffraction is approximately 5dB/km at both site.

The [26] had demonstrated the effectiveness of ray tracing techniques for modeling the relatively space multipath for 60GHz channel. They had considered the propagation geometry which corresponds to lamppost style deployment. The result had shown that for the directivities considered, the channel is dominated by a relatively small number of paths, corresponding to the ground and wall reflections, but slight change in ranges and height can lead to severe fading.

[27] Described 60GHz wideband propagation measurement in outdoor environments. They present channel sounder that operates at38 and 60GHz with the pass band bandwidth of 1.9GHz. Measurements are done using rotating directional antenna in non-line of sight antenna pointing scenarios, which observes 36.6ns RMS delay spread and an average propagation path loss exponent of 2.23.

The [28] has presented study on38GHZ radio wave propagation in an outdoor, urban, cellular environment. They had provided path loss exponent and RMS delay spread distribution.

The work [29] describes experimental campaign for collecting V-band (50 – 75GHz) propagation data using a geosynchronous satellite.

The effects of dust storm on the propagation of electromagnetic wave at millimeter frequencies band of 10GHz, 50GHz and 85GHz are studied in [30]. The propagation of millimeter wave is affected by the dust particle by signal attenuation. The wave attenuation expression is proposed in terms of wavelength, visibility and complex permittivity.

The empirical measurements for 28GHz radio wave propagation in outdoor environments are carried out in [31]. They describe measured path loss as a function of the transmitter – receiver separate distance. The result shown that a large number of resolvable multipath component exist in both NLOS and LOS environment.

B. INDOOR ENVIRONMENTS

The [32] had done coherent wideband frequency- domain measurements of the complex frequency response of millimeter wave for indoor environments. They had worked in 58GHz band. The result had shown that 40dB dynamic range and 400 ns aliasing free range are sufficient for a correct estimation of the rms delay spread spectrum used for the measurement of data.

In [33] the effects of LOS obstructions as well as the influence of the access point antenna height are studied. Experiments are done in a small office like environments. The frequency used was 60GHz.

The work [34] presents various measurements results and models for 60GHZ frequency band in indoor environments. Multipath components were resolved in time by using a sliding correlation with 10ns resolution and in space by adjusting a directional antennas with 7^0 half power beam width in the azimuthal direction.

The [35] presents narrowband and wideband results derived by propagation modeling at 60 GHz band for indoor environments. With the help of simulation process multi ray model is proposed and verified.

The [36] introduced a model for the stochastic millimeter wave for 60 GHz channel. Yin this work the influence of randomness on the radio channel are studied. Various factors such as angle of departure, path length, amplitude, and spatial power density, average power of the direct path and k factor are investigated.

The influence of furniture in the room on 60 GHz radio wave was studied in [37]. Two rooms were selected out of which one was empty and another was full of furniture. The experimental results are compared.

The effect of polarization for indoor environments at 60 GHz is studied in [38]. They proposed a modified channel model based on IEEE 802.15.3c channel model for the study of polarization effect.

III. SIMULATIONS

In this a simulator is designed for simple ray tracing method. We have implemented simple two ray tracing method for frequencies of 2GHz and 60GHz. This model is basically used in highway microcells. In this simulation the receiver travels away from the transmitter. The comparison of two different frequencies has been done.2 GHz and 60 GHz. The transmitter power of 1 Watt is used with gain of 0 dBi. The Base antenna height was 10m and mobile antenna height was 1.5m. the sampling space of 1m was used. The distance from the transmitter and the receiver is d_0 and the distance from the ground image of the transmitter $-h_t$ to receiver is d1 + d2. The figure 1.1 shows

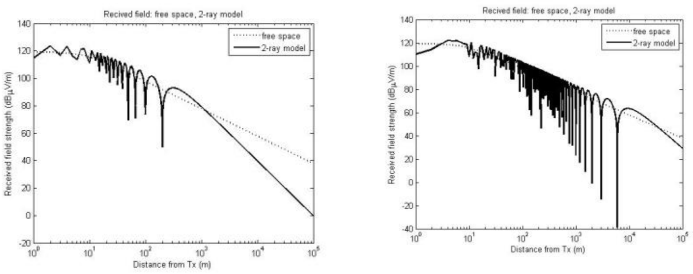

Figure 1.1: Received Field strength for 2 GHz and 60 GHz.

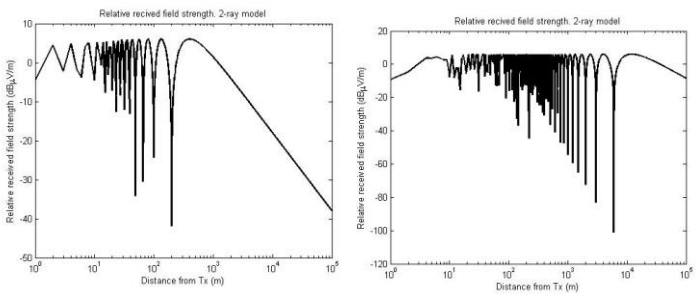

Fig 1.2: Normalized Field strength with respect to direct field strength for 2GHz and 60GHz.

the overall field strength in dBuV/m for two different frequencies. It has been observed that a strong oscillations about direct signal level has been observed near the transmitter, and it is more in case of 60 GHz. Figure 1.2 shows the field strength related to direct signal.

IV. CONCLUSION

In this work we have seen different aspect of radio wave propagation and its effect at different environments like indoor and outdoor. It has been observed that the challenges are higher in the case of outdoor environment as compare to indoor environments. More importantly it has also been observed that with the help of simulation that the challenges are higher for 60GHz at outdoor environments as compare to lower frequencies like 2 GHz. For the designing of new technologies it is the need of hour to do more experimentation for outdoor propagations.

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