

The Studies of Millimeter Waves at different Frequencies in different Environmental conditions for 5G Applications – A State of Art

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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 essential to obtain vital information regarding mm-wave propagation characteristics and its behavior in various environmental conditions. This paper describes the various aspects of 5G technologies and various studies carried out earlier in the field of radio wave propagation at millimeter wave technologies in different environments.

Index Terms— Millimeter waves, Wireless Propagation, 5 G, outdoor propagation, indoor propagation.

1 INTRODUCTION

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1. INTRODUCTION

Recent advancements in wireless technology has driven the demand for more radio spectrum bandwidths from every sector of the wireless applications. It is further accelerating day by day, and we are heading towards greater mobility with ever-increasing demand of higher data rates. The growth of internet has further fueled the demand for wireless services, due to which the available a scare radio spectrum is becoming and congested. Various studies have shown that the increasing demand for spectrum is due to the regulatory schemes introduced by authorities to protect rapid increase of spectrum users [1]. Various researchers are working hard in 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 powered 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 bands, situation would be just reversed, i.e. it provide less coverage, complexity in hardware and less mobility. Currently, no vacant spectrum especially below 3 GHz is available for newer wireless technologies. Radio spectrum, being natural resource, cannot be created. Therefore, its efficient use is inevitable [1].

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

2. THE EVOLUTION OF 5G NETWORKS

The first generation cellular network was introduced and operated in 1983, which was designed for using basic analog systems for voice communications [2]. During the year 1991, 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 consists of two protocols namely high speed downlink packet access (HSDPA) and high speed uplink packet access (HSUPA). The 4G of mobile communication was introduced by ITU in 2011 [1]. 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 di-

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vision 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) [1,2].

With the tremendous increase of demand for capacity in mobile broadband communications every year, wireless carriers must be prepared for the thousand fold mobile traffic increase in 2020. It forces researchers to find new wireless spectrum which has capabilities to support high data rate demand. The future of mobile communication is 5G technology [1]. The issues which need to be addressed by these technologies are greater spectrum allocation in millimeter wave frequencies bands, installations of highly directional beam forming antennas, longer battery life, and high bit rates with lower outage probability, lower infrastructure cost and increased capacity for many simultaneous users [1].

3. 5G PROSPECTIVE FROM DIFFERENT DOMAINS OF TELECOM SECTOR

As 5G is emerging as the budding candidate for mobile communication. Various telecom industries are working toward it.

HUAWEI [3] has discussed about the 5G in their white paper. They briefly discussed that how telecom industry is changing and what are their requirements, they discussed about how 5G will revolutionize internet by introducing ubiquitous ultra-broadband network and mass scale cloud architecture. They had also discussed about fundamental requirements of 5G. the key areas they has proposed for development of 5G are: Development of new algorithms for coding and modulation in order to improve spectral efficiency; development of new baseband and RF architecture are required to meet the requirements of advance solutions like mass scale MIMO; enhancement of single frequency full duplex radio technologies for spectral efficiency improvements; development of integrated access nodes and backhaul design for the deployment of radio network and development of new design for mobile device which can support low energy sensor, ultra-fast mobile instruments and long battery life. In the end they had discuss about how globally they can collaborate in order to design and develop 5G.

DOCOMO [4] has also briefly explained about need and want of 5G technologies in their white paper. They had then discussed about 5G requirements. They have proposed 5G architecture. The key concepts of that architecture are phantom cell, Flexible Duplex, waveform reuse, massive MIMO and non-orthogonal multiple access (NOMA). Then they had discussed about the experimentation and simulation studies done by them for the design and development of 5G networks. In the end they had done brief discussion of standardization process.

In this white paper Fraunhofer Fokus [5] provide novel concept of 5G from its extensive 20 years of research experience.

They explain about 5G and its market prospective, what are the RAN requirements etc. they also explained about how LTE-A and Wi-Fi will co-exist in indoor environments. The impact of fixed and satellite communications has also discussed. The concept of Network Function Virtualization and its implications are also discussed. They also discussed that what type of complexities should come while deployment of future network and their remedy followed by security issues. They have formed a group in which different Fraunhofer partners. In that group they design and test 5G technologies under a tool kit Open5GCore.

GSMA [6] as an organization plays a significant role in deployment of strategic, commercial and regulatory arrangements for 5G ecosystems. They describe in their white paper about definition of 5G, one is based on hyper connected vision and another is based on next generation radio access technology. They through some light on the implications of 5G technologies on mobile operators. What is current scenario and how will it going to change.

IMT 2020 5G research group [7] also discussed about 5g Technologies. According to them the two main drivers of 5G are Internet of Things (IoT) and mobile internet. These two technologies will drive the market in 2020 and beyond. They had also discussed about the current market trends and possible trends after 2020 which is estimated that mobile traffic will increase 1000 times. They had explained the possible challenges face by 5G technologies on the bases of scenarios, services and performance. This group is willing to contribute globally in order to develop future technologies.

The European expert working group has briefly described about the 5G challenges, and priorities [8]. They describe about different KPIs (Key Performance Indicators) like throughput, Latency, energy efficiency, battery lifetime, coverage etc. for the designing and development of 5G. Then they has discussed about different research priorities required for 5G. These priorities are 5G ecosystem, stakeholders, 5G requirements, coverage connectivity, wireless subsystems, and network virtualization. After detailed descriptions of priorities they had given recommendations for the implementation of 5G ecosystem.

SK Telecom [9] has also given their view on 5G. They have also described about key requirements of 5G. They suggest user experience, intelligence, connectivity, reliability, and efficiency as a 5 basic values required for 5G. Then they describe the 5G architecture which is divided into three different parts, innovative service, enabling platform, and Hyper connected infrastructure. Then they describe about 5G enabling technologies by mapping with 5G architecture and 5G values. Then in the end they had discuss about possible spectrum band for 5G networks.

Intel [10] has also presented brief overview of 5G and its challenges and its requirements. The more emphasis is on Software Driven Network (SDN) and Network Virtual Function (NVF). Intel offer building blocks to enable transformation of

networks from device to data center. They are also keen to form standards for designing 5G.

5GPPP [11] has given its concern about the future plans of European manufacturers and industries over 5G technology. They had explained what socio economic factors affecting the European industries. How the need for setting of global standards for 5G devices are increasing. How 5G technology can act as a catalyst for future industry. How 5G will revolutionaries manufacturing sector. In the end they had given brief description of business and policy aspect of 5G in manufacturing sector.

ERICSSON [12] has given a white paper on security aspects of 5G. the main points of their discussions are ; what are basic security requirements for 5G and how are they identified, can 5G security is carbon copy of 4G security and security approach followed previously are still valid for future technologies and for what extent. They also discussed about security challenges of 5G like, new trust model, security for service delivery model, threat issues, ad privacy concerns. Then they propose main key topics for 5G security those are security assurance, identity management, security for 5G radio, security architecture ad cloud security.

ETSI [13] has introduce new technology for 5G network that is mobile edge computing. This technology provides IT service platform and cloud computing environments for mobile networks. They had discussed about market drivers of 5G and how their technology are mapped with those drivers. They also discussed about business values followed by business scenarios. In the end they had given their Industry specification group on mobile edge technology.

Mobile Future [14] has given 5G plans for the USA. They have discussed about the 5G and its requirements. How different part of the world is doing in the area of future technology for mobile computing. Ten they describe the strategy of US for deployment of 5G technology. Then they discussed about the challenges they face while achieving bandwidth gains. Then they give 5 step plans for implementation of 5G infrastructure.

NGMN [15] has given a detailed description of 5G implementation. They have discussed about 5G vision and what are their business models in order to implement 5G. then they have discussed about 5G requirements in details. Some of the broad categories of requirements which they have classified are user requirement, system performance, device requirements, enhanced services, new business model, and network deployment operations and management. They have also proposed 5G architecture. They have also discussed about spectrum issues of future technologies. What are spectrum needs and what are possible solutions. They had also discussed about IPR issues need to be handle when they will design future technology. Then they had discussed about their entire and clear roadmap of how they will go further in the directions of implementations of 5G Technology.

Samsung Electronics [16] in their white paper briefly describe about 5G technologies. They have briefly describe 5G services

like IoT, Immersive Multimedia, cloud computing, and Intuitive Remote Access, then followed by 5G requirements, its technical specifications. They had also discussed about key 5G technologies like mm-wave technology, multi - RAT, advanced network, advanced MIMO, adaptive coding modulation (ACM), advanced D2D and advanced small cell. Then in the last they have discussed about 5G deployment strategies followed by standardization policies.

Tech UK [17] has also given a detailed description of 5G technologies which they had developed, their testbeds and their trials. Initially they also explained about 5G innovation use case. They has briefly discussed about frequency greater then 6GHz. Then they has discussed about non frequency specification like power amplifier architecture, massive MIMO, filter technology etc. they have describe about software defined network. Some security aspects have also being discussed. They have given frequency related requirements for 5G innovations. At the end they has discussed about standard bodies working for 5G technologies.

EPRS (European Parliamentary Research Service) [18] has given a brief overview of 5G technologies implementation scenarios in whole Europe. They has discussed about different 5G applications scenarios followed by technical requirements. Then they has briefly describe about key 5G technologies. Then they explain about kind of support provided by EU and other parts of the world.

ITIF [19] has given a brief description of 5G environments. The goal of 5G is describe by them. The 5G triangle include massive IoT, enhanced broadband, and critical communications. Then they have discussed about technology concerns of 5G like High band Spectrum, Antenna Technology, and Software Networking. They also tell about standardization process of 5G. The different worldwide corporation formed, challenges and competition facing within organizations for 5G are also discussed. In the end they have given recommendations of 5G policy.

3.1 INITIAL CONCLUSION FROM 5G SURVEY

From the above survey we can conclude some common key requirements for the 5G technologies are:

- Greater than 10 Gbps speed
- 1 millisecond latency
- 1000x bandwidth per unit area
- 10 to 100x number of connected device
- 99.999% availability
- 100% coverage
- 90% reduction in energy usage
- Increased battery life

3.2 CANDIDATE BANDS FOR 5G APPLICATIONS

For achieving these promising requirements for 5G we need higher frequency bands. For that mm-wave bands are good choice as discussed in above papers. In World Radio Conference 2015 Korea has proposed frequency band:

1452-1492MHz
1452-1492MHz
1980-2010MHz
2170-2200MHz
3.6-4.2GHz
4.4-5.0GHz

And after thorough study bands 1.5GHz and 3.6-4.2GHz appear strongest band for 5G applications.

Super High Frequency bands are in early stage for finalization. It is expected to be finalizing in WRC-19. For higher frequency Korea has proposed bands for 5G are:

13.25-14GHz
18.1-18.6GHz
24.25-29.5GHz
38-39.5GHz

Out of these bands more suitable bands for 5G applications are 27-29GHz and 70-80GHz which are already a candidate bands for METIS and FCC.

Based on the forecast of ITU-R for 2020 and on the basis of researches done by RATG (Radio Access Technique Group) [1] for IMT-2000 and RATG 2 for IMT-Advance the possible spectrum 1340 and 1960MHz are suitable for future technology [9].

4. 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 [20]. Now CMOS technologies are also operate on mm-wave frequency band provide larger bandwidth allocations and high data transfer rate [21]. Millimeter wave has smaller wavelength. This characteristic is used to exploit polarization techniques such as MIMO and adaptive beam forming [22]. 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.

5. STUDIES DONE SO FAR IN OUTDOOR ENVIRONMENT

Various researches have carried out studies in the areas of millimeter wave propagation in outdoor environment, but are

limited especially for 60GHz. 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. There are various types of outdoor environments and have different effects on propagation of radio waves. Different types of environments are:

URBAN ENVIRONMENTS

Less Dense

Highly Dense

RAINY ENVIRONMENTS

VEGETATION ENVIRONMENTS

The less dense areas consist of city streets with less population, road tunnels, empty parking area, grass fields etc. where as in highly dense urban areas consist of pedestrian walkway in densely populated city, multistoried buildings etc. in the rainy conditions various factors affects the propagation like drop size, rain intensity etc. vegetation also plays an important role as size and types of trees, shape of leaves, trunk size etc. affect the radio wave propagation.

5.1 URBAN OUTDOOR ENVIRONMENTS

The urban environments consist of a city which, contain buildings, streets, lamp posts, vehicles and people. There are also variations in urban environments which includes less dense and highly dense urban environments. Researchers had done various studies in these types of environments. Less dense urban environments consist of cities which are moderately populated. Their streets are not over crowded. Few high rise buildings are there with considerable distance between them. Roads are broader and lots of open spaces are available. Highly dense urban area consists of overcrowded cities. Their streets are full of traffic and lots of people are moving in pedestrian walkways. Considerable amount of high rise buildings are also present.

5.2 LESS DENSE URBAN ENVIRONMENTS

Various researchers have done propagation studies in this type of environments. Which mostly include university campus, grasslands, empty parking area etc.

The outdoor 60 GHz frequency measurements done by Duncan M. Matic, Ramjee Prasad et. al. [23] in the outdoor environments of Delft University, Netherlands. They had chosen grass fields outside the building and empty parking area. Here there were no obstacles. They present the results of frequency fading over 100 MHz bandwidth centered around 59.9 GHz. from the experimental results they obtained the 'K' factor of the Rice distribution and path loss coefficients. By fixing the position of TX and moving the RX different spatially distributed locations throughout the test area was used. The experiment setup used in [23] consists of synthesizes signal generator named Marconi 2024, 60 GHz TX and RX and spectrum analyzer named Anritsu MS2651A. From spectrum analyzer to PC, data was transferred by general purpose information bus.

The frequency response consists of 500 amplitudes samples at a frequency sampling of 0.2MHz. [23]. The TX consists of 120 degrees flat omnidirectional antenna and RX consists of 120 degree omnidirectional and 15 degree patch directional antenna was used.

From all the experimental results the average value of 'k' and standard deviation 'o' of rice factor 'k' are calculated. For experiment done on grass field the value of k was 84.25 and o was 87.94. For parking area value of k was 80.71 for omnidirectional antenna and 423.85 for directional antenna. The value of 'o' was 79.87 for omnidirectional antenna and 165.35 for directional antenna.

Smulders. et.al. [24] has performed both narrowband and wideband measurements at outdoor environments for 60 GHz. The experimental results which they obtained are compared with deterministic model developed by them. They had conducted different experiments in different outdoor environments like airport fields, urban streets and city tunnels.

The observation made in city streets do not represent multipath situation. Values of RDS and 90% SDW was lower than 20ns and 50ns respectively. In the case of city square, the 90% SDW may be 150 ns or more. A tunnel had many similarities to the city streets environments. A bad multipath situation was observed by parking garage because of the large dimensions and the relatively smooth surfaces creating strong reflections.

For the simulation purpose, a ray tracing tool was developed [24]. It includes the features like direct and reflected rays which are up to the third order and diffuse reflections and diffractions are neglected. Rays are interpreted by non-reflected objects such as foliage. A dielectric canyon having a rough surface type of scenario was described. For both transmitter and receiver antennas polarization and radiation patterns are taken into account. This simulation tool was developed [24] in order to understand the behavior of outdoor environments more specifically in urban streets, and allow the estimation of both narrowband and wideband channel characteristics. The results obtained were good except 90% SDW. This is because sensitivity of this parameter toward reflected rays with low amplitude, therefore yielding large differences between simulation and real results.

5.3 HIGHLY DENSE URBAN ENVIRONMENTS

Eshar Ben Dor. et. al. in [25] described 60 GHz wideband propagation measurements in cellular peer to peer outdoor environments. They presented a channel sounder operating at 38 and 60 GHz with a pass band bandwidth of 1.9 GHz. The channel sounder provides RMS delay spread measurements resolutions and angle-of-arrival (AoA) [25].

The experiment done in the courtyard showed that the path loss exponents are slightly higher than free space for LOS

paths. For NLOS paths when exited for particular antenna orientation they produce a link which was 15 – 40 dB weaker than LOS. It was also observed that for all outdoor locations some of NLOS antenna pointing scenarios could make a link. For NLOS scenarios, the RMS delay spread was observed as 36.6 ns. In courtyard, the mean RMS delay for both LOS and NLOS scenarios was 6.02 ns. For the experiments done in parking area, where transmitter was fixed on a ground and receiver was fixed inside a car and moving in a confined parking area. The mean RMS delay was observed as 2.73 ns and maximum of 12.3 ns for 17 measured LOS and NLOS scenarios in parking area. It was observed that in a free space path loss LOS pointing scenarios offered less than 1 ns RMS delay spread. On the other hand NLOS antenna pointing scenarios produce much higher multipath delay spread and path loss.

Rappaport, et. al. [26] has carried out propagation measurements at 38 GHz and 60GHz frequencies in various outdoor environments. Their measurements show time delay spread and path loss as a function of separation distance and antenna pointing angles.

The experimental results obtained for LOS link was free path loss with no RMS delay spread. In NLOS there was higher RMS delay spread of 122 ns for first experiment and 107 ns for second experiment. It was also observed that as if the azimuth pointing angles increased from the bore sight the RMS delay spread is also increases in NLOS.

In [27] Jonathan S. Lu. et. al. has performed experimentation on diffraction and scattering on 60 GHz radio wave. Diffraction was measured at building corners whereas scattering was observed at car, lamppost and buildings. Human obstruction was also measured.

It was observed that scattering measurements done from cars and lampposts was higher near the specular direction. The diffraction results suggest that the scattering from lamppost and cars are higher than diffraction from corners of buildings. It was observed from scattering measurements of buildings that received power was higher when TX and RX were placed in horizontal plane and in specular direction. In case of non-specular direction best results were found in case of ridges and columns.

The results of human blockings suggests that the absorbing screen models used in the work was quite accurate with the actual results obtained with standard deviation of prediction error not more than 5 dB.

5.4 RURAL ENVIRONMENTS

The authors in [28] have done propagation experimentations in rural environments at 60 GHz. They had done statistical analysis of received signals and calculated RMS delay spread and cumulative distribution function (CDF). The complete details of measurements setup can be found in [28].

It was observed through experimentation that from the 83% of recorded channel transfer function the value of cumulative distribution function fits the long normal Rayleigh distribution, which in turn represents the effects of scattering caused by various obstructions in the environments. Another observation made for 87 % of recorded signals, the fade margins was less than 20 dB. So the author concluded that there was possibility of establishing a 60 GHz communications in rural areas despite of availability of scattering.

5.5 RAINY ENVIRONMENTS

Lots of studies had been performed in order to find attenuation in rain at various frequencies. Very little work had been done for higher frequencies. It has been observed that frequencies greater than 10 GHz will have higher attenuation rate. In case of rainy environment various parameters comes into play like rain intensities, type of rain, rain drop velocities, rain drop size etc. some of the work done in rain attenuation in 60GHz range are as follows.

Walther Asen and Chris J. Gibbins [29] had done experimentation for rain attenuation and drop size distribution (DSD) at two different sites i.e. Chilbolton, U.K. and Singapore. They focused on special data sets, data processing and various ways of viewing DSDs which helped them in quantifying some parameters. For this experiment data was obtained from a "millimeter wave propagation experiment in southern England" [29] which was operated by Rutherford Appleton Laboratory (RAL) for number of years. In this radio wave propagation measurements are carried out at various frequencies ranges over a shorter path length. The different parameters used in these experiments were rainfall rate, which was obtained by using rapid response rain gauge. Another parameter used was rain drop size distribution which was obtained by impact type drop size disdrometer, RD-69.

It was observed from the experiment that frequency independent parameter was derived from the measurements taken from the rain drop disdrometer in order to do modeling of rain attenuation. These parameters vary for different climatic conditions. The observation made from the results obtained from the experiment showed multi model behavior which was reported by earlier records. This behavior was disappeared when high calibration was applied. From this study it was proved that single model for rain attenuation is not sufficient for the entire globe as it differ from different climatic conditions. In this experimentation various parameters are calculated like drop size distribution to gamma, shifted long normal and Weibull distribution. It was observed that out of these parameters shifted long normal distribution fit best to the rain attenuation model. On the other hand gamma distribution does not perform effectively in this model.

Grey Timms et.al. [30] has conducted two studies of the outdoor propagation of 60 GHz, one at CSIRO, Sydney and

TESTCOM, Praha. They described the relationship between rainfall and measured attenuation of various frequencies. The results obtained from experimentation were compared with ITU-R recommendations.

The experimental data obtained was analyzed statistically. The author showed the cumulative distribution attenuation caused by rain for the period of one year at CSIRO. It was observed that the worst distribution was at the month of October, March and February. While cumulative distribution for TESTCOM showed that the worst distribution was at month of august, May and June. It was also observed that the cumulative distribution of attenuation for both the sites and for all rain intensities is higher than found in the ITU-R recommendations.

5.6 VEGETATION ENVIRONMENTS

Signal losses due to the presence of vegetation play a vital role in radio wave propagation. Various factors like tree height, leaf size, and shape, leaf movements due to wind and trunk size pay an important role in estimation of attenuation of signals.

Simon Perras et.al. [31] compared different temporal characteristics for various frequencies in different foliage and weather conditions. In this work the radio channels are analyzed statistically and calculated probability density function and cumulative density function are compared against different existing models. In this work second order statistics are also derived which include level crossing rate and average fade duration. They had done the experiments on different frequencies like 2.45, 5.25, 29 and 60 GHz. Transmission of frequencies was done with signal generator and up/down convertors are used for higher frequencies. Data was collected for 45 days. They had used spectrum analyzer, multimodal and a computer with GPIB interface. Spectrum analyzer was centered on carrier frequencies for lower frequencies and centered on down converted frequencies for higher frequencies. Both methods used 10 KHz resolution bandwidth for a sweep time of 1 microsecond for a span of 0Hz.

Michael Cheflena et.al. [32] has developed a simulation model for study radio wave attenuation due to vegetation by utilizing the experimental results obtained by [19]. Their model was developed for generating signal fading due to swaying vegetation by using a multiple mass spring systems to represent a tree and a turbulent wind model. Various parameters are used in this model like cumulative distribution function (CDF), auto correlation function (ACF), level crossing rate (LCR) and average fade duration (AFD). It was observed that there were the similarities between the simulated results and the actual experimental results. From the measurements Ricans k - factor for different wind speed was calculated.

Telmo R. Fernandes et. al. [33] presents a model for radio wave propagation in dense forest environments, which was based on Radiative Energy Transfer Theory (RET) model.

This simulation model shows the behavior of radio waves when they propagate in dense forest area. The results obtained from the model were compared with the actual measurements done in the same forest area at 20 GHz and 62.4 GHz. The forest is located at North East of Cardiff in South Wales. In the forest 6 different species of trees are taken into account and for exact characteristics of forest their exact location and canopy diameter were measured. For the exact measurement purposes the receiver antenna was placed at 5.5 m above the ground at different positions in the forest in order to measure the directional profile of a signal. The RX was rotated clock wise 360 degree with incremental steps of 1 degree. The TX was placed outside the forest area under experimentation at 13 m distance from the first boundary. For both TX and Rx lens horn antenna was used with 36 dBi and 2.8 degrees of HPBW. The measured RMS error value was 15 dB which was within the range of other published results. In some locations the value of RMS error was 18.7 dB. This deviation of results was due to the various possible reasons like localized blockages due to vegetation, inaccurately utilized parameter extraction method and wrong position of RX antenna.

6 CONCLUSION

This work had explored various studies done in radio wave propagation at mm wave. It had concluded that the higher frequencies specially 60 GHz are the very sensitive in nature for propagation in various outdoor environments. It was observed that results are different for different environmental conditions. It is also observed that rain attenuations are more complex in higher frequencies. In order to develop new technologies a thorough propagation studies are required in rainy conditions.

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