

# The Studies of Millimeter Waves at 60 GHz in Outdoor Environments for IMT Applications: A State of Art

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**Abstract** As the growth of mobile technology network increasing exponentially due to which radio frequency becomes more valuable natural resources. Shortage of bandwidth creates an enormous opportunities for researchers and engineers for exploration of underutilize millimeter wave spectrum in order to design and develop future technologies. It is a need of an hour to do extensive studies on the impact of millimeter wave technologies as both indoor and outdoor environments. This paper describes the various studies carried out earlier in the field of radio wave propagation at 60 GHz in different outdoor environments.

**Keywords** Millimeter waves · Wireless propagation · 5G · 60 GHz

## 1 Introduction

Recent advancements in mobile technologies has increased the demand for more radio spectrum bandwidth exponentially. With this accelerating demand we are heading toward greater mobility with higher data rate demands. The growth of internet and enabled technologies like internet of things (IoT) fueled the demand for higher frequencies which leads to more congested spectrum.

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Most of the applications for terrestrial communications are below 3 GHz, which have been already assigned a different communication services. Lower spectrum bands provide greater coverage area with good mobility as compare to higher spectrum bands. In case of propagation higher bands have higher complexities. They are more sensitive to outdoor environmental conditions like rain, gas, dust, vegetation etc. but are good candidate bands for supporting next generation technologies which require greater speed and capacity.

## 2 The Evolution of 5G Networks

The first generation (1G) mobile technology was based on analog base systems. In 1978 first cellular system was installed by Nippon Telephone and Telegraph, Japan. Some of the examples of mobile cellular systems of that time are Advanced Mobile Phone System, Nordic Mobile Telephone and Total Access Communication Systems. The Second Generation Technology (2G) was introduced around 1991, which was based on Global system for mobile communications. It was introduced for providing data and voice services with better utilization of spectrum. As 2G has very less speed of 9.6kbps for the internet service so General Packet Radio Service (GPRS) was introduced. It was also termed as 2.5G system. Services like short messaging services (SMS), multimedia message service (MMS), wireless application protocol (WAP) etc. are supported by 2.5G technology. 3G technology was introduced in 2001 in order to provide high internet speed of about 384 kbps. This technology provide improved audio and video streaming capabilities. The technology used by 3G systems are wideband code division multiple access (WCDMA) and high speed packet access (HSPA). HSPA consist of two protocols namely high speed uplink packet access (HSUPA) and high speed downlink packet access (HSDPA). In 2011 a new technology was introduced by ITU called 4G. it offers very high speed up to 100 Mbps. The technologies used by 4G are worldwide interoperability for microwave access (WiMax) and Long Term Evaluation (LTE) [1].

The future technology for wireless communication is 5G of fifth generation which is expected to be implemented worldwide up to 2020.

## 3 Concept of WISDOM

Today presence of various devices incorporates productivity and quality of life of human beings, in all technological domains. In most cases these devices work in isolation or with very little cooperation among each other, and serve a well-defined single purpose for which they have been designed [5]. The recent innovation of device manufacturing and communication technologies have enabled personalized and mobile connectivity of various devices, making them smart and their penetration is expected to grow exponentially in the next years such a huge growth is already creating an unprecedented opportunity for novel applications and services that grow far beyond the mere purpose of each user, but are based on interconnectivity and interworking. Users are benefiting from services in the public or private sphere, while more and more personalized digital content is being generated. This novel concept of connectivity and mobility is called WISDOM [1]. The Wireless Innovative System for Dynamically Operating Mega Communications, which is proposed to provide ubiquitous terabit wireless connectivity enabling human-centric mega-communication applications over a dynamic, interoperable and secure network.

WISDOM is developed to enable the growth of an interconnected society, bridge the physical and virtual worlds by offering a seamless personalized rich digital experience for the end users, while creating the optimal conditions for capitalizing on future internet innovations [4].

The three founding pillars of WISDOM are:

- An information theoretic performance/capacity estimation of different types of networking paradigms.
- Design of protocols based on end-to-end, cross-network-domain performance optimization.
- Cognitive radio network based self-organizing networks for management of possible usage scenarios and to minimize the spectrum and energy requirements [1, 6].

WISDOM aims to design and develop technologies, system that could globally integrate, interconnect and communicate into a flexible and dynamic system for the human centric and machine centric communications in 2020 and beyond [1, 11].

## 4 Importance of 60 GHz

With the increase in the demand of higher frequencies various researchers have shown their interest in millimeter wave mainly in 60 GHz. The 60 GHz frequency band has many advantages over lower frequency bands. One of the reasons for increasing craze in the availability of huge bandwidth is that it provides continuous and less restricted bandwidth in terms of power limit. With the huge potentials of capacity and flexibility 60 GHz bandwidth became a good candidate for high transmission rate future communication systems [13].

The regulations allows high transmission power for 60 GHz as compared to other less frequency bands in order to overcome high power losses due to oxygen and rain. As due to limited range of network in 60 GHz, it is confined to very limited areas which in turn provide higher frequency reuse which allows high throughput network. The form factor of 60 GHz systems is 140 times smaller than the systems which use lower frequencies.

With various advantages provided by 60 GHz bands it also has some of the limitations which need to be resolved. The IEEE 802.15.3c has provided various applications in the millimeter wave technology with various data rates and ranges. It is very challenging task for 60 GHz systems to provide sufficient power margins for reliable and efficient communication link. Another challenge for 60 GHz is the delay spread of the channel. Larger delay spread increases the complexity of the system which makes its practical implementation difficult.

## 5 World Wide Band Allocations for 60 GHz

Some of the world's radio regulations body has allocated frequency bands around 60 GHz in various parts of the world [13].

International Telecommunication Union (ITU)

The millimeter wave bands allocated by ITU Radio regulations are:

$$\left. \begin{array}{l} 55.78-66 \text{ GHz} \\ 71-76 \text{ GHz} \\ 81-86 \text{ GHz} \\ 92-94 \text{ GHz} \\ 94.1-100 \text{ GHz} \end{array} \right\} \text{for fixed and mobile services}$$

64-66 GHz}for mobile except aeronautical Mobile

## EUROPE

The European Conference of Postal and Telecommunication Administration (CEPT) has 46 European spectrum regulators. The bands allocated by CEPT are as follows:

59-66 GHz——For Mobile Services  
59-62 GHz——For Radio Local Area Network

$$\left. \begin{array}{l} 62-63 \text{ GHz} \\ 63-64 \text{ GHz} \end{array} \right\} \text{for Broadband Mobile Systems and Road Transport Informatics}$$

$$\left. \begin{array}{l} 58.2-59 \text{ GHz} \\ 64-65 \text{ GHz} \end{array} \right\} \text{for Radio Astronomy Observation}$$

## UNITED STATES OF AMERICA

All the regulatory arrangements in USA are done by The Federal Communications Commission (FCC). The frequency bands allocated by FCC for millimeter wave technology are as follows:

$$\left. \begin{array}{l} 57-59 \text{ GHz} \\ 59-64 \text{ GHz} \end{array} \right\} \text{Unlicensed Band}$$

$$\left. \begin{array}{l} 71-76 \text{ GHz} \\ 81-86 \text{ GHz} \end{array} \right\} \text{Licensed Band on Non-Exclusive basis}$$

92-95 GHz

## CANADA

The Spectrum Management and Telecommunications Sector of Industry Canada is responsible for Spectrum regulations in Canada. The frequencies bands allocated by it are:

### 57–59 GHz}Unlicensed Band

59–64 GHz}For low power license exempt Devices on non-interferences, Non protection basis.

#### JAPAN

The Ministry of Public Management, Home Affairs, Posts and Telecommunications (MPHPT) of Japan is regularity body. The bands allocated by it are:

59–66 GHz—Unlicensed Band

54.25–59 GHz—Licensed Band

#### AUSTRALIA

The regulatory body in Australia is Australian Communications and Media Authority (ACMA) which allocated a band for millimeter wave communications is 59.4–62.9 GHz for unlicensed use.

#### INDIA

In India the band allocations according to National Frequency Allocation Plan 2011 are [11]:

59.3–64 GHz

FIXED

INTER-SATELLITE

MOBILE

RADIO LOCATION

64–65 GHz

FIXED

INTER-Satellite

MOBILE except aeronautical mobile

65–66 GHz

EARTH EXPLORATION SATELLITE

INTER-Satellite

MOBILE except aeronautical mobile

SPACE RESEARCH

## 6 Studies Done So Far in Outdoor Environment

Lot of research has been done in the field of millimeter wave at outdoor environmental conditions, but very few for 60 GHz frequency bands. The 60 GHz frequency bands are very sensitive for various environmental factors like gas, water droplets of rain, fog etc. it is very interested to see its effect on other outdoor factors like buildings, etc.

The outdoor environments are broadly divided into three areas, urban environments, rain and vegetation. The urban environments consists of various man made constructions like buildings, lamppost, wires, roads, footpath, tunnels, vehicles, human beings etc. it is very interested to study the effect of these conditions on 60 GHz propagation.

In case of rain lot f research has been done for satellite links but very few for terrestrial links and especially for 60 GHz. As rain has complex structure as it is variable in nature.

For the terrestrial communication links vegetation plays an important role. Different types of trees, shrubs will effects the radio wave propagation in the fields of 60 GHz communication.

## 6.1 Urban Outdoor Environments

Matic et al. has performed a measurement at 60 GHz n outdoor environments of Delft University, Netherlands [7]. They had performed an experiment on empty parking area and grass fields of university campus.

The measurements are carried out outside building in open grassland. The receiver antenna was moved away in a straight line from 27 m distance apart from the receiver. The receiver was moved away from the TX and measurements were taken at the intervals of every one minutes. Hence, 27 different measurements were obtained. The height of antenna was 1.59 m.

Another measurement was done in an open empty parking area which includes some trees. The antenna height was kept at 1.59 m, the experiment was conducted with both type of antennas with a distance of 3–25 m and 25 points of observations in a straight line and 12 on the side of the parking.

The standard deviation of rice factor and average value of  $k$  was calculated from all experimentation performed.

Narrowband and wideband measurements are performed by Simulder et al. for the frequency of 60 GHz [12]. The results obtained by them are compared by their own proposed deterministic model. They have conducted experiments on different locations like urban streets, city tunnels, and airport fields.

They had used a channel sounder which was based on correlation. The RF frequency was centered around 59.0 GHz with bandwidth of 200 MHz, corresponding to a resolution of 5 ns. For transmitter  $90^\circ$  horn antenna was used and  $20^\circ$  bi-conical horn used as a receiver. The height of TX was kept at 4 m and RX was at 2.2 m.

The different parameters considered during measurements were mean delay (MD), RMS delay spread (RDS), delay interval (DI), delay window (DW) and sliding delay window (SDW).

A bad multipath situation was observed in city streets and parking garage. It is because of larger dimensions and relatively smooth surface leads to strong reflections. The values of RDS and SDW were observed 20 and 50 ns. In case of city streets SDW was 150 ns or more.

Wideband propagation measurements have been done by Esher Ben Dor team at 60 GHz for outdoor environments [14]. They have developed 750 mega chips per second spread spectrum sliding correlator channel sounder for 38 and 60 GHz. This has a 1.5 GHz null to null bandwidth and uses a 1.9 GHz RF pass band centered at 59.4 GHz carrier frequency in order to provide 1.3 ns multipath time resolution.

The experiment was performed in outdoor courtyard with pedestrian in University of Texas campus. The campus is consisting of various buildings and some trees. Another experiment was conducted for the investigation effect of vehicular communications. It was conducted in a parking area, which included various vehicles, several lampposts and surrounded by tall multistoried buildings with few vegetation. The TX and RX were placed 1.5 m above ground.

It was observed by the experiment performed at courtyard that path loss exponents are higher then free space path loss for LOS. In case of NLOS links for particular antenna orientation produce 15–40 dB weaker links then LOS. 36.6 ns of RMS delay spread was

observed for NLOS scenarios. In case of courtyard 6.02 ns of RMS delay spread was observed for both LOS and NLOS. For parking area RMS delay spread was 2.73 ns for both scenarios where TX was fixed and RX was moving.

Outdoor propagation measurements at frequencies 38 and 60 GHz have been carried out by Rappaport et al. [15]. They shows path loss delay spread as a function of antenna pointing and separation.

They use channel sounder which has variable rate PN sequence generator. For 38 GHz they had 400 Mcps and for 60 GHz they had 750 Mcps. The millimeter wave up down convertor get the input of IF frequency of 5.4 GHz. These convertors contain mixer and LO frequency multipliers which give output of 37.625 and 59.4 GHz. The 38 GHz Tx and Rx used vertically polarized horn antennas with gain of 25 dB and half power beam width of 7°. The 60 GHz Tx and Rx used vertically polarized antenna whose gain is 25 dB and contain beam width of 7.3°.

In this work two different types of experiments are done. In the first type TX and RX was placed at the same level. There was single TX and 10 RX was placed at different locations. The area was surrounded by various buildings which are of 1–10 stories long. The receiver moved away from the transmitter to about 19–129 m. There are various obstacles presented in the scenarios like automobiles, brick and aluminum sided buildings, foliage, lamppost, handrails and signs.

The second type of experiment was done in scenario where TX was placed on a roof top and receiver is placed at ground level. Rests of the situations were similar as described in first experiment.

The experiment results for LOS links shows that there is a path loss with no RMS delay spread. In case of NLOS there is a RMS delay spread of 122 and 107 ns for first and second experiments. Another observation was observed for NLOS that with the increase in azimuth pointing angle bore RMS delay spread is also increases.

Propagation studies for diffraction and scattering was performed at 60 GHz by Jonathan et al. [16]. Studies for diffraction were observed at building corner whereas scattering experiments was performed at lamppost, car, buildings. Propagation studies for obstruction due to human movements were also measured.

The TX used in this was consisted of SMF100A microwave signal generator of 10 GHz frequency which was attached to frequency multiplier SMZ90 which multiplies by 6. Then it was connected to V-Band horn antenna of 24dBi gain and 11° beam width. The RX system consisted of same antenna system used in TX. It was then connected to low noise amplifier NIZ-3387. The signal was then sent to harmonic mixer FS-Z90. Then signal was down converted and sent to vector signal analyzer FSQ26.

For the conduction of outdoor measurements on cars, lamppost and buildings the TX and RX are placed on a moving cart and then moved according to some fixed angles. The height of antennas was kept at 1.33 m.

The diffraction measurements were done for building corners. For this purpose two different sites were chosen one was the corner made up of concrete while another was made up of concrete and windows. In the first experiment TX cart was placed at a distance of 3.75 m from the corner and the angle inclination was 18°. The RX was placed at a distance of 2.8 m in the shadow region and moved in an arc. The movement was done on angles between 200° and 260° and recording was made at every 10° intervals. In the second experiment the TX was placed at a distance of 6.1 m from the corner with an inclination of 10°. The RX was placed at a distance of 4 m in a shadow region and again moves in an arc with an angle of 200°–260° with an interval of 15°.

The scattering measurements were done for a car in an empty parking area. The transmitter was placed at a distance of 23 m from car. The transmitter bore sight was centered on the side of car and normal to the surface of car. The receiver was moved in an arc of 23 m and scattering angles relative to the normal of car surface in ranges from  $14^\circ$  to  $75^\circ$ .

For the study of human blocking two scenarios was taken. In the first scenario it was assumed that the TX and RX were at same height, which was 1 m and moving from one place to another. The observation was made within the LOS distance of TX and RX of 7 m. In another scenario the TX was at roof top with height of 2.65 and RX at ground at the height of 0.9 m. They are moving within the radius of 7 m.

From the above experimentation it was observed that scattering from the objects like lamppost and still cars are higher than the diffraction observed from the buildings corners. When TX and RX are placed in horizontal plane and in specular direction the receiver power observed was higher, whereas for non-specular direction better results was observed in case of column and ridges. In the case of human blockings actual results are compared with the threshold model of absorbing screens proposed by them. It shows standard deviation of about 5 dB.

The propagation studies for rural environments at 60 GHz was done by Daniel et al. [22]. Statistical analysis of received signals was performed by them. The parameters used by them are cumulative distributive function (cdf) and root mean square delay spread.

The measurements are performed at two different sites. The first site consists of water canal, some trees, bushes and tall grasses. On the other hand another site consists of large grounds which include grass lands which consist of hillocks, pits and trenches.

From the experimentation results it was observed that CDF fits the long normal Rayleigh distribution, which reflects the effects of scattering due to different environmental condition for rural environments. The fade margins was around 20 dB.

## 6.2 Rainy Environments

For measuring the effect of rain of radio wave propagation especially at 60 GHz the studies are carried out by Walther et al [17] at two different sites namely UK and Singapore. They have obtained the data from the Rutherford Application Laboratory (RAL) located in southern part of England. Rain rate and drop size distribution was parameters used by them. Rain rate was observed from rain gauge and DSD was obtained from impact type drop size disdrometer, RD-69.

In RAL Singapore, rain drop size measurements were carried out from a collocated impact drop size disdrometer. The data obtained from this are studied in order to do comparisons between rains in different climatic conditions.

This experiment was done in England for the frequencies of 57, 97, 135 and 210 GHz. The antenna was placed 4 m above the ground and distance between them is 500 m LOS. For the collection of raindrop data disdrometer was kept in a collecting area of  $5000 \text{ mm}^2$ . the sampling rate for data collection was 1 Hz with an integration time of 10 s the experiment done at Singapore at Nanyang Technological University similar experimental setup was used. The integration time for data collection was 30 s.

They have derived a frequency independent parameter from the results of above experimentation. These parameters vary for different climatic conditions. A multi model behavior was observed from experiment which was also reported from previous records. This behavior removed by applying high calibration. The conclusion made from this study

is that single model is not sufficient for making prediction for entire globe as different places has different climatic conditions.

Another study was conducted by CSIRO, Sydney and TESTCOM, Paraha by Timms et al. [18]. They describe the relationship between rain and attenuation for different frequencies and compared the results by ITU Rain model.

At CSIRO the 60 GHz link operating at 60.109 MHz on a bearing of 152° and at 61.845 MHz in the opposite direction at 133°. The operating distance between the links was 250 m and height was around 10 above ground level. These links was vertically polarized. Data transmission rate was 125 Mbps.

TESTCOM use 60 GHz link for rain attenuation measurements. They used siphon rain gauge and PWD for rain intensity measurements. They have modified the equipment with 60 cm diameter, and off-set antennas was manufactured at TESTCOM. The separation distance was 850 m and the frequencies used were 57,650 MHz with vertical polarization.

The author has done a statically analysis of experimental results. At CSIRO the worst cumulative distribution for attenuation was observed at the month of October, March and February. While for TESTCOM worst distribution for attenuation was at august, may, and June. The CDF for attenuation observed by experiment was higher as compared by ITU model.

### 6.3 Vegetation Environments

The studies done by Simon et al. [19] for calculating effects of vegetation on radio wave propagation at 60 GHz. The parameters used by them are cumulative density function and probability density function and compared them against different present models. The experimental setup was explained in [19].

The experiment was performed at various sites. The first site contains 3 foliated maple trees and one foliated flowering crab tree. The link distance was 63.9 m. Second site consists of several spruce and one pine tree in a row which resembles a wall. The link distance was 110 m. The third site consists of leafless maple tree and one leafless flowering crab tree. The link distance was 63.9 m. The result obtained from all the three experimental sites shows that the extreme value and lognormal model best fits the RF attenuation characteristics between trees. It was observed from experiment that propagation at 2 and 60 GHz was frequency and wind speed dependent. The attenuation observed through tree was larger when size of obstruction lies in the foliated path and wavelength are similar in size. The values of AFD and LCR were statistically modeled.

A simulation model was developed by Michael et al. [20] for studding effects of vegetation on radio wave propagation. In this model they have generated signal fading caused by swaying vegetation by using multiple mass spring model which represent tree and turbulent wind model. Different parameters used in this model are cumulative distribution function (CDF), level cross rate (LCR), auto correlation function (ACF) and average fade rate (AFR). Similarities between results obtained from this model and experiment results from [19] were observed.

Another simulation model was proposed by Telmo et al. [21]. The results obtained from there model are compared with the actual measurements taken in same forest at 20 and 62.4 GHz frequencies. This experiment was done on the forests of South Wales. Six different species of forest trees are considered and exact diameter, canopy and location are measured. The RX was placed at the height of 5.5 above ground at different positions. It was rotated 360° clock wise with the incremental step of 1°. TX was placed 13 m distance from the first boundary. The RMS error value obtained from experiment was 15 dB mostly,

which matches from other experimental results. Although in some area it was observed around 18.7 dB.

## 7 Conclusion

Different propagation studies has been conducted for different outdoor conditions at 60 GHz frequency bands. It was observed that for rural area multiple path effects and data rates limitations are predominant. Scattering and diffraction were the main propagation phenomenon giving rise to multipath in this area. It is also observed that reflection is rarely occur in this area. Vegetation loss is independent of polarization. Hilly terrain is less prone to multipath propagation. For urban environments the results shows that path loss exponents are slightly greater then free space in case of LOS path. It was also observed that by picking the best combinations of TX and RX pointing angles at any location, path loss and RMS delay spread can be reduced substantially. In case of rain the observed relation between attenuation and standard deviation is compared with the results from other sites. From the comparison it was found that the fade slop standard deviation s likely to depend on elevation angle and on climate, through its dependence on rain type. So 60 GHz is very sensitive for outdoor conditions but proves a best candidate bands for higher bit rate transmission technologies used in future.

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