

# Millimeter Wave (MMW) Communications for Fifth Generation (5G) Mobile Networks



Umar Farooq and Ghulam Mohammad Rather

**Abstract** Millimeter wave (MMW) communication is envisioned to satisfy the need of high data rate wireless links for next generation 5G networks in addition of addressing the spectrum scarcity and capacity limitations of current wireless systems and enable a plethora of applications in near future. However the field of MMW communication is still in its infancy because of the various technical challenges faced in its practical implementation due to the fundamentally different propagation characteristics in this frequency band. The treatment of these challenges has initiated a lot of research activities. In this paper the MMW propagation characteristics have been studied in the context of free space loss, atmospheric loss and foliage loss and the effect of these losses on the performance of the MMW communication channel has been examined through simulation studies. Further in this paper the performance evaluation of the MMW communication link for different data rates for various Line of Sight (LOS) and Non-Line of Sight (NLOS) cases in a highly dense communication network scenario and the impact of various parameters on the performance of the communication channel are analyzed.

**Keywords** Millimeter wave communication • 5G • SNR • MIMO  
LOS • NLOS

## 1 Introduction

The ever-increasing demand for multi-gigabit wireless applications has posed enormous challenges for next generation wireless technologies. In particular, the unbalanced temporal and geographical variations of spectrum usage along with the rapid proliferation of bandwidth-hungry mobile applications have inspired a new promising technology to alleviate the pressure of scarce spectrum resources for 5G

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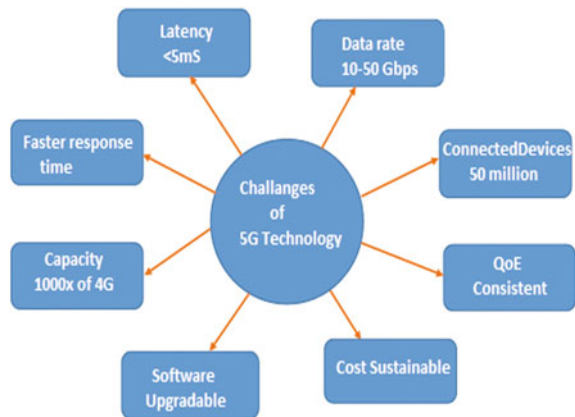
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mobile broadband applications. This technology is known as millimeter wave (MMW) communication technology [1]. It is envisioned as a key technology for fulfilling the high data rate requirements of the 5G wireless networks. Figure 1 shows the broad overview of next generation 5G system challenges that have initiated the different research activities by industries, academia, and research organizations [2]. The idea behind MMW communication is to exploit the huge unexploited spectrum from 30 to 300 GHz spectrum with the corresponding wavelength ranging between 10 and 1 mm [3] as it provides number of benefits like [4, 5]

- Availability of huge unexploited bandwidth that can provide high-speed links with throughput of ~10 Gbps.
- Higher degree of spectrum sharing as compared with lower frequencies.
- Smaller antenna size which can facilitate the fabrication of large antenna arrays over a small area like postage stamp.
- Better spatial resolution as the small wavelength allows modest size antennas to have a small beam width.
- Processors, memories along with other devices can be incorporated on a Monolithic Microwave Integrated Circuit (MMIC) chip and the received data can be quickly processed and stored.

However despite these attractive advantages, these high frequency bands have not been fully explored because at higher frequencies the signal generation, reception and propagation gets highly complex due to free space and atmospheric loss factors [6]. The distinguishing traits of MMW communications have a direct impact on the selection of antenna technologies, modulation, besides other technical issues like user dynamics and coexistence with other communication standards like Wi-Fi, LTE. Multiple approaches have been provided so far to overcome these technical difficulties so as to make MMW technology deployable in near future and enable a plethora of applications.

**Fig. 1** General overview of next generation 5G system challenges



In the present study capacity of a MMW communication link is carried out for LOS and NLOS scenarios for different link parameters in a dense network scenario. The work is reported as technical paper and has been organized into number of sections. Section 1 gives the Introduction, Sect. 2 briefly summarizes the MMW propagation characteristics. Performance evaluation and mathematical analysis of the MMW communication link is carried out in Sect. 3. Section 4 concludes the paper.

## 2 MMW Propagation Characteristics

Attenuations and environmental losses in the MMW bands are much higher as compared to microwave frequencies, thus making 5G cellular network operations over these frequencies a much more challenging task. MMW link use LOS communication and these LOS communication links suffer from free space path loss which is given as [7]:

$$L_p, dB = 20 \log_{10} \left( \frac{4\pi d}{\lambda} \right), \quad (1)$$

where ‘ $\lambda$ ’ is the wavelength of signal and ‘ $d$ ’ is the distance between transmitter and receiver.

This loss is quite high for longer distances. However these links can be utilized for short distance communication. The loss can be further mitigated by the use of highly directional antenna system, relay and multipath routing [8–10]

### 2.1 Atmospheric Loss Factors

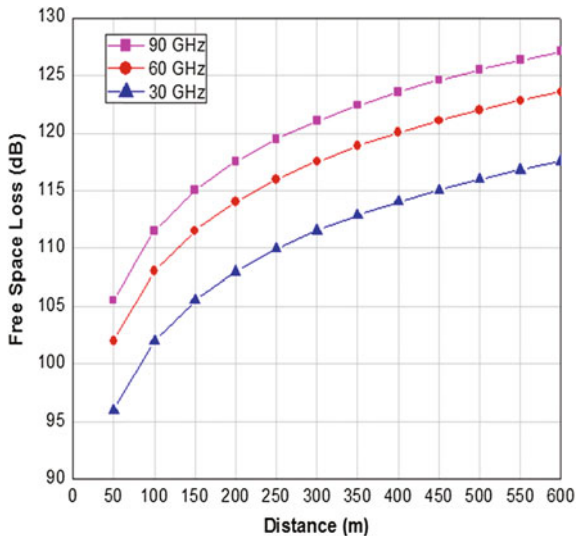
In atmosphere millimeter waves are absorbed/scattered by molecules of oxygen, water vapor, and other atmospheric constituents including the rain, fog and clouds. These losses are greater at certain frequencies, coinciding with the mechanical resonant frequencies of the gas molecules. This atmospheric loss dB is given by [11]:

$$L_{atm} = -\alpha_{atm}(f) \cdot d, \quad (2)$$

where  $\alpha_{atm}(f)$  is the measured value of atmospheric attenuation as the function of frequency operation ‘ $f$ ’ and ‘ $d$ ’ as the separation between transmitter and receiver.

Figure 2 shows the free space path loss and Fig. 3 shows the atmospheric loss for dry atmospheric conditions. Of all atmospheric conditions, rain causes the most significant signal loss depending on the intensity of the rainfall. Oxygen, humidity and fog also incur losses but they can be neglected to certain limits of the millimeter

**Fig. 2** Free space path loss w.r.t. distance



**Table 1** Signal losses due to atmospheric conditions [12]

Factor	Description	Signal loss (dB/km)
Oxygen	Sea level	0.22
Humidity	100% @30°	1.8
Fog	1gm/m <sup>3</sup> , 10 °C (50 m visibility)	3.2
Cloud burst	25 mm/hr rain	10.7
Light rain	1 mm/hr rain	0.9
Moderate rain	4 mm/hr rain	2.6
Heavy rain	25 mm/hr rain	10.7
Intense rain	50 mm/hr rain	18.4

wave link. The description of different atmospheric conditions and the losses incurred in dB/km are given in Table 1.

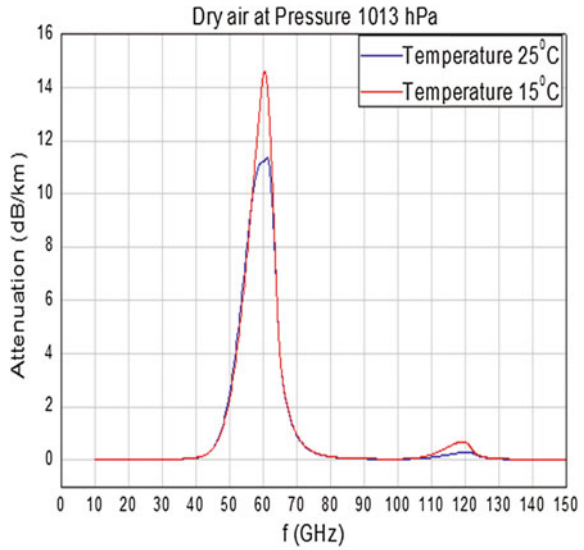
### 2.2 Foliage Losses

At millimeter wave frequencies these losses become a critical propagation impairment and are non negligible. If  $f$  is the frequency of signal in MHz,  $R$  is the foliage depth then Foliage losses are given as [13]

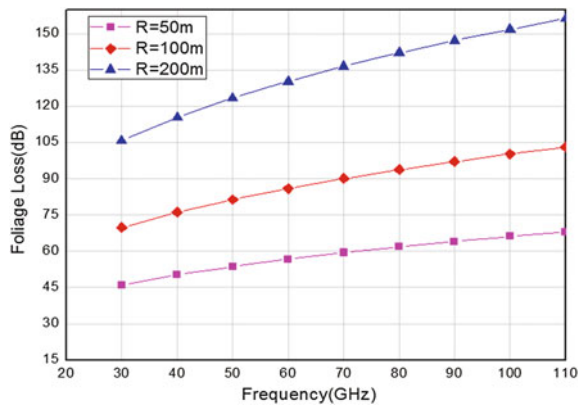
$$L_{\text{foliage}} = \frac{1}{5} f^{0.3} R^{0.6} \tag{3}$$

Equation 3 applies for the scenarios where  $R < 400$  m.  $L_{\text{foliage}}$  is measured in dB. The Foliage losses of the millimeter wave signals for different Foliage depths are plotted in Fig. 4.

**Fig. 3** Atmospheric losses for dry air



**Fig. 4** Foliage loss as function of frequency



### 3 Performance Evaluation of MMW Link

The use of high gain directional antennas is an option to compensate the high path loss of millimeter waves however this method may be feasible only for clear LOS conditions. In scenarios where clear LOS is not guaranteed the antenna arrays, multipath routing, use of repeaters become highly desirable [14, 15].

In this section performance evaluation of the MMW communication channel for specific data rates is carried out for both LOS and NLOS case scenarios.

#### 3.1 Mathematical Analysis

Consider a MMW link scenario as shown in Fig. 5. If 'f' is the frequency of operation and 'd' be the range of communication link. Then SNR at output of the receiver is

$$\text{SNR} = P_{\text{Tx}} + G_{\text{Tx}} + G_{\text{Rx}} + G_{\text{LNA}} + G_{\text{BPF}} + G_{\text{TFN}} + G_{\text{RFN}} + G_{\text{amp}} + G_{\text{CSF}} - \text{PL}_0 - \text{PL}(d) - N_{\text{Rx}} - M_{\text{SHAD}}, \quad (5)$$

where

$P_{\text{Tx}}$  = Transmitted Power (dBm)

$$\text{PL}_0 (\text{Path loss at 1 m}) = 20 \log_{10} \left( \frac{4\pi d}{\lambda} \right)$$

$G_{\text{Tx}}$  = Transmit antenna gain (dBi)

$M_{\text{SHAD}}$  = Shadowing link margin (dB)

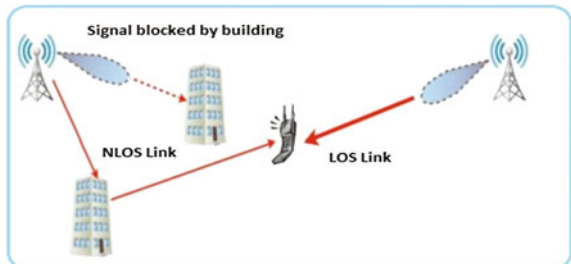
$G_{\text{Rx}}$  = Receiver antenna gain (dBi)

$N_{\text{Rx}}$  = Input noise level at receiver.

The gain due to the various components at the transmitter and the receiver of the link are mentioned in Table 2 [16].

In the study the other path loss parameters have also been considered which as per IEEE 802.15.3c standard [17] are given below

**Fig. 5** MMW link in LOS and NLOS scenario



**Table 2** Gain of various transmitter and receiver components

Component	Gain (dB)
Tx feeding network ( $G_{TFN}$ )	-5
Rx feeding network ( $G_{RFN}$ )	-5
Amplifier at receiver ( $G_{amp}$ )	30
BPF at receiver ( $G_{BPF}$ )	-1
LNA at receiver ( $G_{LNA}$ )	20
Channel selector filter ( $G_{CSF}$ )	-5

$$\text{Path loss exponent: } n = \begin{cases} 2 & \text{LOS Case.} \\ 2.5 & \text{NLOS Case.} \end{cases}$$

$$\text{Shadowing Link Margin: } M_{SHAD} = \begin{cases} 1 \text{ dB} & \text{LOS Case.} \\ 5 \text{ dB} & \text{NLOS Case.} \end{cases}$$

Assuming the noise to be AWGN and using Eq. 5 the data carrying capacity of the MMW link can be easily calculated by Shannon’s Capacity formulae given by:

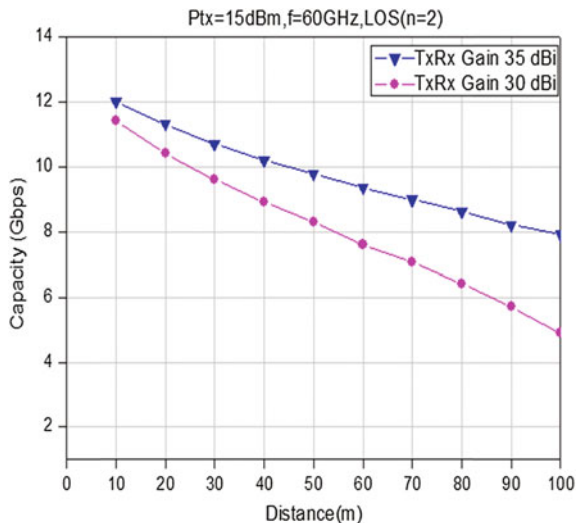
$$C = B \log_2(1 + SNR), \text{ where } B \text{ is the bandwidth of the communication link.}$$

### 3.2 Simulation Results

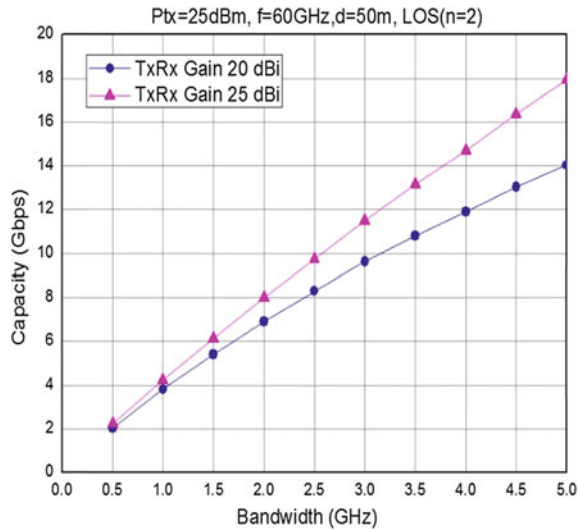
The MMW link is simulated and analyzed for data carrying capacity. The parameters taken into account for the performance analysis of such system are: Range of the communication link (d), data rate, frequency of operation (f) and the bandwidth of the link (B). Figures 6 and 7 show the simulation results for LOS path scenario.

Figure 7 shows the data carrying capacity of the MMW communication link of 50 m as the function of bandwidth and it is observed from the figure that high gain

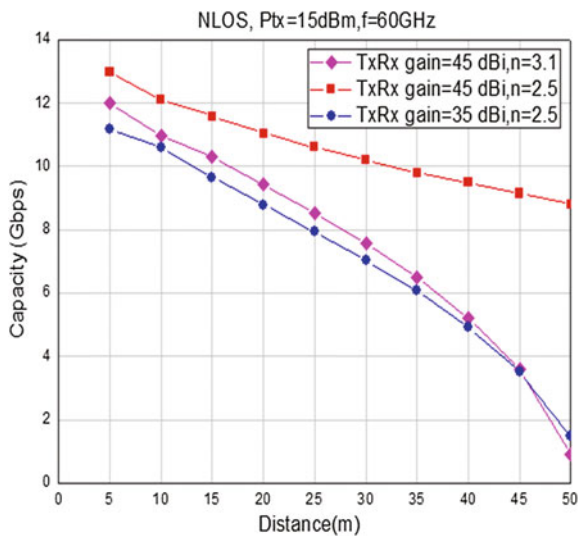
**Fig. 6** Capacity as function of range of link



**Fig. 7** Capacity as function of link band width



**Fig. 8** Capacity for different antenna gain (NLOS Case)



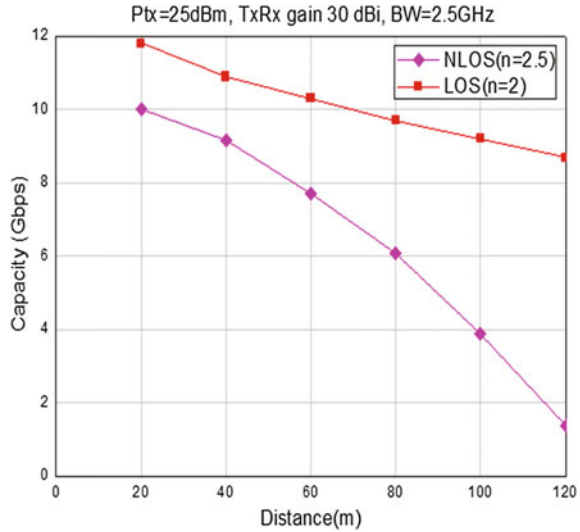
antennas at the transmitter and the receiver are required to achieve the data rate of the order of Gbps for long distance communication applications even for LOS cases.

Similarly Figs. 8 and 9 show the simulation results in case NLOS Scenario. In either case the performance of the MMW channel is limited due to the system noise as well as the losses due to various atmospheric factors.

As can be seen from the figures, in both LOS and NLOS Scenarios, the impact of noise as well as the losses due to various atmospheric factors limit the performance



**Fig. 9** Capacity for LOS and NLOS links



the MMW link however the antennas play a critical role in the enhancement of efficiency of such systems. It can also be observed that increase in the operating distance drastically decreases the capacity of the MMW link and this situation worsens in case of NLOS cases. Also it can be observed that Capacity increases as a function of the SNR or Bandwidth (B) or both; however as the operational distance of the link increases the SNR degrades due to the various atmospheric losses. Under such circumstances the capacity is improved with help of high gain directional antennas and hence highlighting the importance of such antenna configurations for very high data rate applications for next generation networks.

## 4 Conclusion

Millimeter wave (MMW) communication is a promising technology to cope up with the ever increasing demand for multi-gigabit wireless applications and in particular alleviate the problems of spectrum scarcity for 5G mobile communication applications. In this paper we broadly explore the MMW propagation characteristics and examine the effect of free space loss, atmospheric loss and foliage loss on the MMW communication channel. Performance evaluation of the MMW communication link is carried out for different data rates for both LOS and NLOS cases in a highly dense communication network scenario. In either case the performance of the MMW channel is limited due to the system noise as well as the losses due to various atmospheric factors. Since it is observed that the data carrying capacity is affected as a function of operational distance of the link, the use of high gain directional antennas becomes the first choice to overcome this issue. Hence the

antennas play a critical role for improving the performance of such systems and therefore highlight the importance of such antenna configurations for very high data rate applications for next generation mobile networks.

## References

1. Pi, Z., & Khan, F.: An introduction to millimeter-wave mobile broadband systems. *IEEE Communications Magazine*, 49(6), (2011).
2. Gupta, A., & Jha, R. K.: A survey of 5G network: Architecture and emerging technologies. *IEEE access*, 3, 1206–1232, (2015).
3. Pietraski, P., Britz, D., Roy, A., Pragada, R., & Charlton, G.: Millimeter wave and terahertz communications: Feasibility and challenges. *ZTE Communications*, 10(4), 3–12, (2012).
4. Niu, Y., Li, Y., Jin, D., Su, L., & Vasilakos, A. V.: A survey of millimeter wave communications (mmWave) for 5G: opportunities and challenges. *Wireless Networks*, 21(8), 2657–2676, (2015).
5. Saponara, S., & Neri, B.: mm-wave integrated wireless transceiver: enabling technology for high bandwidth short-range networking in cyber physical systems. *Microsystem Technologies*, 22(7), 1893–1903, (2016).
6. Baldemair, R. et. al.: Evolving wireless communications: Addressing the challenges and expectations of the future. *IEEE Vehicular Technology Magazine*, 8(1), 24–30, (2013).
7. Friis, H. T.: A note on a simple transmission formula. *Proceedings of the IRE*, 34(5), (1946).
8. Singh, S., Ziliotto, F., Madhow, U., Belding, E., & Rodwell, M.: Blockage and directivity in 60 GHz wireless personal area networks: From cross-layer model to multihop MAC design. *IEEE Journal on Selected Areas in Communications*, 27(8), (2009).
9. Wang, J., Prasad, R. V., and Niemegeers, I. G.: Exploring multipath capacity for indoor 60 GHz radio networks. In *Communications (ICC), 2010 IEEE International Conference*, IEEE, (2010).
10. Rusek, F., Persson, D., Lau, B. K., Larsson, E. G., Marzetta, T. L., Edfors, O., & Tufvesson, F.: Scaling up MIMO: Opportunities and challenges with very large arrays. *IEEE Signal Processing Magazine*, 30(1), 40–60, (2013).
11. am Atmospheric Model. Available Online <https://www.cfa.harvard.edu/~spaine/am/>.
12. Adhikari, P.: Understanding millimeter wave wireless communication. *Loea Corporation*, (2008).
13. Meng, Y. S., & Lee, Y. H.: Investigations of foliage effect on modern wireless communication systems: A review. *Progress In Electromagnetics Research*, 105, 313–332, (2010).
14. Zhang, X., Zhou, S., Wang, X., Niu, Z., Lin, X., Zhu, D., & Lei, M.: Improving network throughput in 60 GHz WLANs via multi-AP diversity. In *Communications (ICC), IEEE International Conference*, pp. 4803–4807, (2012).
15. Lan, Z., Sum, C. S., Wang, J., Baykas, T., Gao, J., Nakase, H & Kato, S.: Deflect routing for throughput improvement in multi-hop millimeter-wave WPAN system. In *Wireless Communications and Networking Conference*, pp. 1–6, (2009).
16. Huang, K. C., & Edwards, D. J.: *Millimetre wave antennas for gigabit wireless communications: a practical guide to design and analysis in a system context*. John Wiley & Sons, (2008).
17. IEEE 802.15-05-0493-27-003c, “TG3c selection criteria.” Jan. 2007.