The Study on Characteristics of Rain Attenuation Along 28 GHz and 38 GHz Line-of-Sight Millimeter-Wave Links

Congzheng Han*, Shu Duan
Institute of Atmospheric Physics, Chinese Academy of Sciences, Beijing, China

Abstract

Millimeter-wave channel modeling is an important topic for 5G research. As atmospheric changes are complicated, many of the existing studies are based on millimeter-wave measurements in sunny weather, and not many address the atmospheric loss in millimeter wave transmission in addition to propagation loss. In this study, we carried out line-of-sight signal transmission measurements at 28 GHz and 28 GHz, We monitored the variation of received signal during rain, and compared the theoretical rain-induced attenuation with the practically monitored attenuation.

1. Introduction

Millimeter waves have been recognized as carriers for future 5G cellular networks. The advantage of millimeter waves in communications, is the greater capacity to carry information, due to the higher frequency. Data rates in microwave frequencies and below are limited to about 1 Gbit/s, and it can reach 10 Gbits/s and more in the millimeter-wave range. Spectrum between 24.25 GHz and 86 GHz will be considered for IMT under WRC-19 Agenda, including 24.25-27.5 GHz, 31.8-33.4 GHz, 37-43.5 GHz, 45.5-50.2 GHz, 50.4-52.6 GHz, 66-71 GHz, 71-76 GHz, 81-86 GHz. In addition, 28 GHz band will be used for millimeter-wave 5G in some countries, such as the US, South Korea, Japan, India and Canada [1]. However, millimeter-wave technology has also been considered as challenging. The main limitation of millimeter-wave is range. Electromagnetic signals at millimeter frequency band experience large path loss, atmospheric loss due to dry air, water vapor, rain, fog, snow, etc.

The current 3GPP TR 38.801 provides the details of channel model for frequencies from 0.5 to 100 GHz, and suggests that the channel model is expected to support advanced simulations, such as simulations with very large arrays and large bandwidth, simulations affected by oxygen absorption, simulations in which spatial consistency is important, simulations of mobility, and simulations of blockage effects [2]. In this paper, we will study the impact of rain for the received signal quality at 28 GHz and 38 GHz band. We have built a 28 GHz and 38 GHz measurement link at and will present some findings from our trial measurements and compare the theoretical signal attenuation and measured signal attenuation. The results suggest that the it is important to consider the atmospheric parameters for millimeter-wave channel modeling, and the received signal level can be degraded further by wet antenna effect as a consequence of rainfall [3], [4].

2. Measurements

Weather conditions and atmospheric phenomena have a dramatic impact on the millimeter-wave signals and cause attenuations. The atmospheric loss is generally defined in terms of decibels (dB) loss per kilometer of propagation. Since the fraction of the signal lost is a strong function of the distance traveled, the actual signal loss experienced by a specific millimeter wave link due to atmospheric effects depends directly on the length of the link. If it is a rainy day, an additional attenuation caused by rain further increases the path loss as shown in Fig. 1.

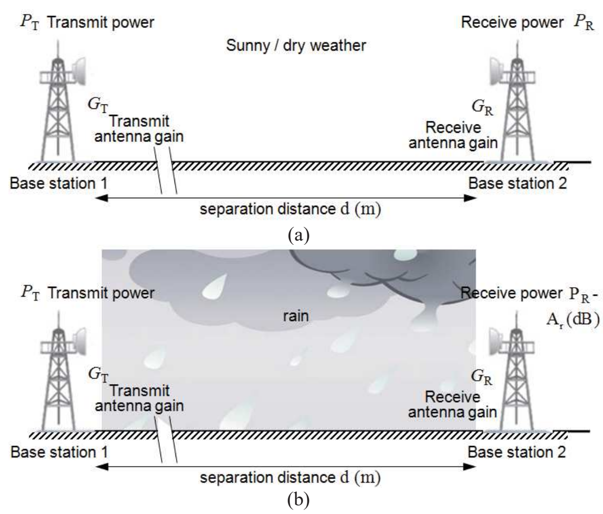

Figure 1. Illustration of the wireless transmission from one base station to another (a) in a sunny/dry day (b) in a rainy day and the received signal is attenuated due to rainfall

A power law equation for modeling the rain induced attenuation is stated in [5]:

$$A = aR^b \text{ (dB/m)} \quad (1)$$

Where R is the rain rate and a and b are functions of frequency and polarization. The constants a and b are related to frequency, polarization, and the rain drop size distribution.

Here we built a LOS millimeter-wave signal link of 700 m at 28 GHz and 38 GHz that in central Beijing and the measurement setup is presented in Table 1. The rainfall intensities were monitored using a nearby rain disdrometer and a rain gauge.

TABLE I MEASUREMENTS SETUP

Parameter	Value
Centre frequency	28 /38 GHz
Transmit power	7 dBm
Tx-Rx distance	700 m
Tx antenna gain	24.4 dBi (28 GHz) 25.6 dBi (38 GHz)
Rx antenna gain	24.4 dBi (28 GHz) 25.6 dBi (38 GHz)
Polarization	Transmit antenna and receive antenna are vertically polarized
Cable loss	2 m (-2.23 dB), 3 m (-4.95 dB)

3. Results

We monitored the instantaneous received signal level and recorded the data every 15 s. A total of 17280 signal measurements recordings were noted, and 4800 recordings were taken during rain. The measurements are summarized in Table II.

TABLE II MEASUREMENTS RECORD

Date	Rainy period	Peak rain rate (mm/h)	Average rain rate (mm/h)	Link Freq (GHz)	Link length (km)
17.08.19	2:43-07:00	7.2	0.7	28	0.70
17.10.09	5:22-24:00	11.0	2.2	38	0.70
18.04.04	15:08-24:00	60.0	11.4	38	0.70

For LOS link, the channel is expected to follow Rician fading distribution, which can be expressed as:

$$f_x(x)=\frac{x}{\sigma^2}\exp\left(-\frac{\left(x^2+A^2\right)}{2\sigma^2}\right)I_0\left(\frac{Ax}{\sigma^2}\right),\ K=\frac{A^2}{2\sigma^2} \qquad (2)$$

where $I_0(\cdot)$ is the modified Bessel function of the first kind and zero order, A is the amplitude of the dominant signal, and σ is the standard deviation of all other weak signals. The parameter K is the Rician factor and specifies the Rician distribution. To better understand our measurement environment and channel characteristics, we examined our measurement results during dry time before rain. The cumulative distribution function (CDF) functions for the received signal level relative to its mean value for the LOS measurements for the 28 GHz and 28 GHz links are plotted in Fig. 2 and 3. For comparison, the CDF of a Rayleigh distribution, and Rician distribution with various K-factors in increments of 5 dB are also plotted. The empirical results show that for our measurements, the Rician distribution gives the best fit to the data.

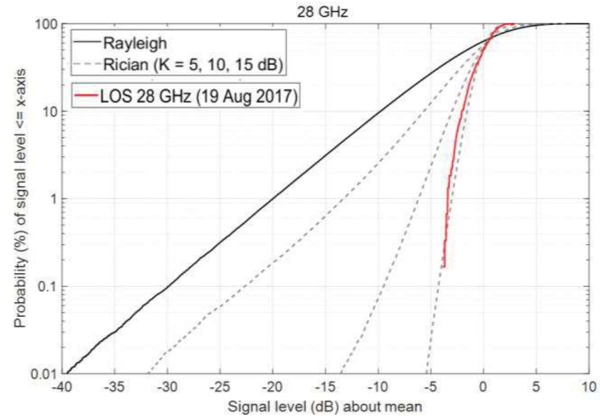

Figure 2. CDF plot of the received signal power relative to the mean value for the 28 GHz LOS millimeter-wave link measurement on 19 August 2017. Rayleigh and Rician distributions (K factors range from 5 dB to 15 dB) are also plotted for comparison.

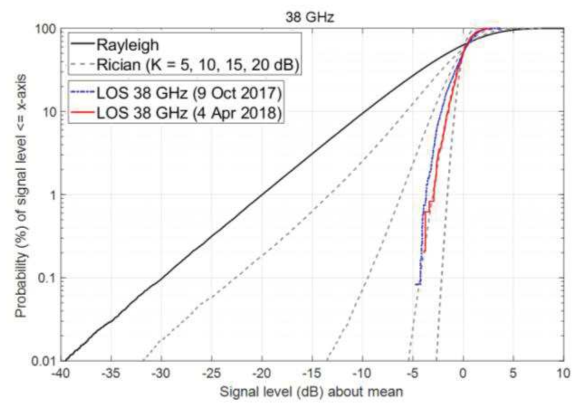

Figure 3. CDF plot of the received signal power relative to the mean value for the 38 GHz LOS millimeter-wave link measurement on 9 August 2017 and 4 April 2018. Rayleigh and Rician distributions (K factors range from 5 dB to 20 dB) are also plotted for comparison

TABLE III MEASUREMENTS RECORD

Date	Calculated signal attenuation	Measured attenuation	Relevance	Wet antenna effect
28 GHz	⩽1dB	1-2.5 dB	0.72	1-1.5dB
38 GHz	⩽1.7	1.6-4.2	0.63	1.6-2.5dB

Based on the rain intensity measurement from the nearby disdrometer, we calculated the expected signal attenuation using equation (1). It is found that measured signal attenuation is well related to the changes of rain intensity over time. Their level of relevance is 0.72 for the 28 GHz link and 0.63 for the 38 GHz link measured using the cross-correlation function. The difference between the theoretically calculated signal attenuation and the signal attenuation monitored from the link measurement is illustrated in table III and Fig. 4. The measured signal attenuation is 1-1.5 dB higher than expected for the 28

GHz link, and 1.6-2.5 dB higher than expected for the 38 GHz, and this is mainly due to the wet antenna effect.

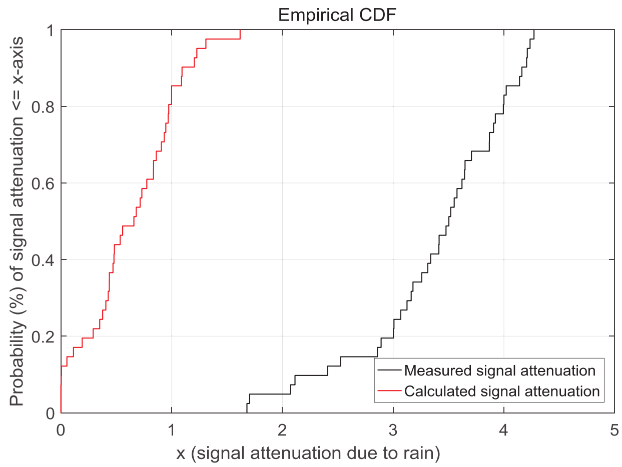

Figure 4. CDF plot of the calculated and measured signal attenuation due to rain for the 38 GHz LOS millimeter-wave link measurement

4. Conclusions

Atmospheric loss can be significant for wireless transmission especially at millimeter-frequency range. Exiting studies on millimeter-wave channel measurements and modeling rarely consider the impact of changing atmospheric conditions. In this paper, we studied the impact of rain on 28 GHz and 38 GHz LOS millimeter-wave transmission link. For a 700 m long link, the impact of rain and the wet antenna effect caused a signal loss up to 4.2 dB during our measurement period. We believe that it is important to consider the rain effects for millimeter-wave channel modeling and simulation, and we will continue our measurements at other frequencies and link lengths to verify this finding.

5. Acknowledgements

This work was supported by the National Natrual Science Foundation of China (Grant No. 41605122).

6. References

1. Agenda and Reference (Resolutions and Recommendations), ITU, August 2017. [Available]:https://www.itu.int/dms_pub/itu-r/oth/14/02/R14020000010001PDFE.pdf

2. 3GPP TR 38.901. "Study on channel model for frequencies from 0.5 to 100 GHz.," 3rd Generation Partnership Project; Technical Specification Group Radio Access Network, Release 14, Version 14.3.0, Dec 2017.

3. J. Ostrmetzky, R. Raich, L. Bao, J. Hansryd, H. Messer, “The Wet-Antenna Effect – a Factor to be Considered in Future Communication Networks,” IEEE Transactions on Antennas and Propagation, vol. 66, no. 1, Jan. 2018.

4. C. Moroder, U. Siart, C. Chwala, H. Kunstmann, "Fundamental Study of Wet Antenna Attenuation," 15th International Conference on Environmental Science and Technology, Rohdes, Greece, 31 Aug - 2 Sep 2017.

5. ITU-R P. 838-3 (International Telecommunication Union Radiocommunication Bureau Propagation Recommendation), Specific Attenuation Model for Rain for Use in Prediction Methods, 03/2005.