The impact of rainfall on E-band millimeter-wave links in East China

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Abstract

Millimeter-wave has a larger available bandwidth, which can meet the 5G transmission requirements for large capacity and high speed. The E-band millimeter-wave can bring richer channel resources and higher data rates. This paper introduces the field experiment of E-band millimeter-wave link in Nanjing, China. The link operates at 71 GHz and 81 GHz. The experiment evaluated the accuracy of the ITU-R model in estimating rainfall-induced attenuation along long-distance, high-frequency links in 5G networks.

1 Introduction

With the rapid development of fifth-generation wireless communication technology (5G), more spectrum and wider bandwidth are required. However, the global bandwidth shortage has prompted the exploration of the underutilized millimeter-wave frequency band. Among them, E-band millimeter-waves have attracted attention recently.

Studies have shown that millimeter-waves are affected by many factors such as scattering, reflection, and atmospheric absorption in the process of space propagation. Among them, the influence of rainfall is the most obvious. The attenuation of the millimeter-wave signal becomes greater with increasing frequencies [1]. Therefore, it is important to study the atmospheric effects that affect the E-band millimeter-wave links, especially the characteristics of rainfall-induced attenuation.

The study presented in this paper is based on real practical measurement of E-band millimeter-wave link built in Nanjing, located in east of China.

2 Experimental Data and Methods

2.1 Measurement setup

The E-band millimeter-wave link is deployed in Nanjing area (N 31°14′-32°36′, E 118°22′-119°14′). The link is approximately 2.6 km long and operates at 71 GHz and 81 GHz. We collected the received power data from December 2019 to March 2020, sampling every 1 minute with a resolution of 0.1 dB. Due to the interruption of the data acquisition system, the original data shows missing values (Nan), and we will exclude the data with missing values. This link is a dual-polarization link, and only vertical polarization is used in this article. The description of the microwave link and system operating parameters are detailed in Table 1.

Table 1. System Parameters of the E-band Link

Parameter	71 GHz / 81 GHz
Transmit power	+ 7 dBm
Tx and Rx antenna gain	50 dBi
Antenna polarization	vertical
Antenna size	0.65 m
Bandwidth	250 MHz
Throughput	1 Gbps full duplex
Link budget (BER=10^{-6})	196 dB (including 2ft antennas' gain)
Modulation	QPSK-1/QPSK-2/QPSK-3/QAM16/QAM64

2.2 Methods

Rainfall-induced attenuation A_r (dB) and equivalent path-averaged rainfall rate R (mm/h) follows a power-law relationship. We can calculate rainfall-induced attenuation through the formula provided in ITU-R P.838-3 [2]. The model is as follows:

$$A_r^{ITU-R} = \gamma_r^{ITU-R} l = kR^{\alpha} l(dB) \tag{1}$$

In the formula, γ_r^{ITU-R} (dB/km) is the rainfall induced attenuation per kilometer, l (km) is the link length, and k and α are the frequency compliance coefficients, which are related to the millimeter-wave operating frequency, rainfall temperature, polarization mode and raindrop size distribution.

On a rainy day, the transmitted wireless signal is attenuated by raindrops due to scattering and absorption, which causes the signal level at the receiver to attenuate [3]. The total attenuation value on the link path is obtained by subtracting the transmit power from the received power. The attenuation baseline is dynamically changing. Therefore, the attenuation value during the dry period cannot be directly used as the baseline. We use the method proposed by Schleiss and Berne in [4] to determine the attenuation baseline $A_b(t)$ (dB).

Assuming that $A_T(t)$ (dB) is the total attenuation of the link over time. Rainfall-induced attenuation is expressed here as:

$$A_r(t) = A_T(t) - A_b(t) \qquad (2)$$

3 Result and Discussion

Fig. 1(a) shows a rainfall event on March 10, 2020. A_T1 and A_T2 represent the total attenuation of 71 GHz and 81 GHz received signals, and A_b1 (71 GHz) and A_b2 (81 GHz) represent the attenuation baseline. Fig. 1(b) shows the rainfall rate R output by the raindrop spectrometer set up at the experimental site. It can be seen that during a rainfall event, the received signal level is attenuated accordingly, and the rainfall rate is positively correlated with the signal attenuation.

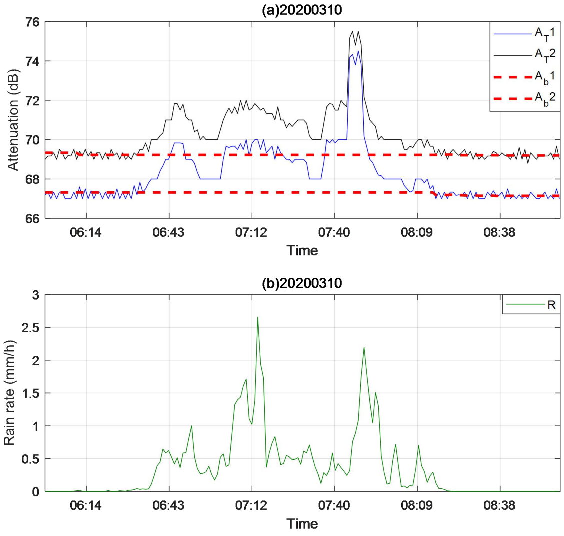


Figure 1. (a) The total attenuation and baseline on March 10, 2020; (b) The rainfall rate measured by the raindrop spectrum instrument.

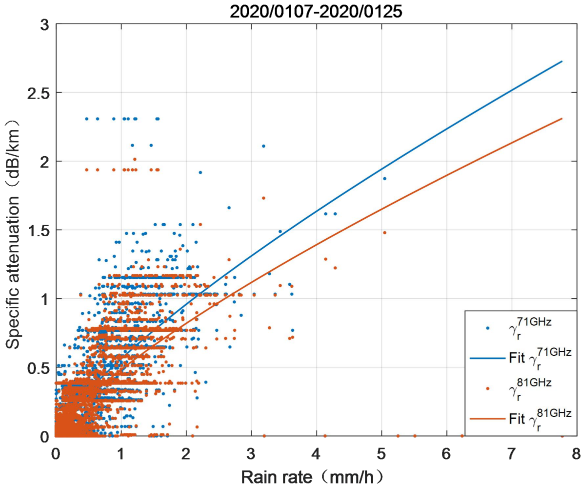


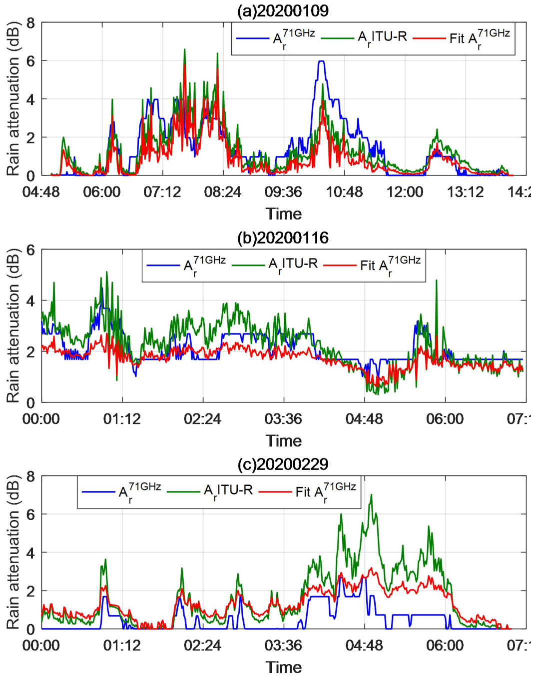
Figure 2. Fitting using specific attenuation (γ_r^{71GHz} and γ_r^{81GHz}) and rainfall rate. Only stratiform events considered: January 2020.

Fig. 2 shows the fitting using specific attenuation and rainfall rate at 71GHz and 81GHz. The fitted power coefficients k and α and the coefficients provided by ITU-R are shown in Table 2.

Table 2. The power law coefficient $\gamma_r = kR^{\alpha}$ is derived from link data and recommendation ITU-R P.838-3.

Frequency	ITU-R P.838-3		Link fitting data	
	k	α	k	α
71GHz	1.0409	0.7193	0.4738	0.7698
81GHz	1.1793	0.7004	0.3857	0.7629

Fig. 3 shows the rain-induced attenuation on different days. The A_r^{71GHz} represents the measured rainfall induced attenuation. The A_r^{ITU-R} (green line) represents the attenuation estimation using the method recommended by ITU-R P.838-3 based on the rainfall rate given by the disdrometer. The red line is the rain-induced attenuation calculated using the coefficients fitted to the link data. It can be seen from Fig. 3 that the trends of the two curves are similar. However, the ITU-R model does not accurately predict the actual rainfall-induced attenuation, especially at the peak of rainfall-induced attenuation (as shown in Fig. 3(c) and Fig. 3(e)). Most of them overestimated the actual rainfall-induced attenuation. There are two possible reasons for this. On the one hand, during periods of rainfall, the rainfall rate is not homogeneous along the path [5]. The power law parameters k and α provided by the ITU-R model are generalized values and are not suitable for this situation. On the other hand, the link adaptive feature of the wireless transceiver can increase the transmission power, and can also use a most robust modulation scheme to maintain the link when the channel quality is poor.



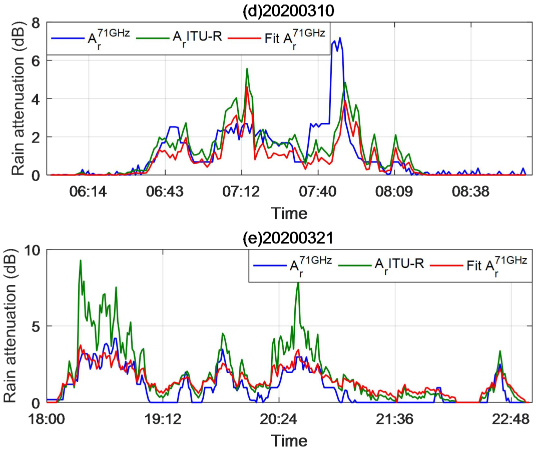


Figure 3. The rainfall-induced attenuation on different days. The link measured attenuation (blue line and black line), estimated from *R* using recommendation ITU-R P.838-3 (green line) and calculated using power rate coefficients fitted to link data (red line).

We evaluate the result by calculating the mean relative error. The formula is as follows:

$$MRE_k = \frac{100\%}{\mathrm{N}} \times \sum_{i=1}^{N} \left| \frac{X_i - Y_{i,k}}{X_i} \right| \tag{3}$$

Table 3 lists the rain-induced attenuation mean relative error value. MRE_1 represents the average relative error of A_r^{71GHz} and A_r^{ITU-R} , and MRE_2 represents the average relative error of A_r^{71GHz} and fit A_r^{71GHz} .It can be seen from Table 3 that the average relative error between the rain-induced attenuation calculated using the fitted power rate coefficient and the link measurement result is smaller.

Table 3. Mean relative error of the estimated rain-induced attenuation (based on the 71 GHz).

Date	MRE_1	MRE_2
2020/01/09	1.98	1.21
2020/01/16	1.86	1.43
2020/02/29	1.97	1.63
2020/03/10	0.84	0.57
2020/03/21	0.98	0.89

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