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Performance Analysis of Millimeter-wave Based 5G Backhaul Links in City Environment

Congzheng Han*, Juan Huo
LAGEO, Institute of Atmospheric Physics, Chinese Academy of Sciences, Beijing, China

Abstract

Millimeter-wave technology is the key technology for 5G wireless networks, for transmission links and also backhaul solutions. In this paper, trial measurements were conducted to investigate the performance of millimeter-wave backhaul deployments in city environment. Backhaul links at various millimeter-wave frequencies in line-of-sight (LOS) path conditions were monitored over a period of 10 days, including 38 GHz, 72 GHz and 82 GHz. The performance of the backhaul link transmission and received signal level are analyzed over the test period. We also study the variations of signal propagation due to rain and compare the backhaul link performance in sunny and rainy days.

1 Introduction

With the introduction of 5G, the interest in using millimeter-waves for backhaul solutions is high. Traditional microwave backhaul links use frequencies from 2 GHz to around 20 GHz. Lower frequencies allow signals to transmit over longer distances and penetrate buildings better. Frequencies from 30 GHz to 300 GHz are often referred to as millimeter-waves. At millimeter-wave frequencies, with much wider bandwidth, they can achieve high capacity. Recently, the E-bands at 71-76, 81-86 have become popular. E-band can provide twice 5 GHz bandwidth, offering 10 GHz aggregate spectrum (71-76 GHz and 81-86 GHz) and enable Gbps data rates [1].

However, practical use of millimeter-wave also faces challenges, e.g. electromagnetic signals at millimeter frequency band experience large path loss and atmospheric loss [2], [3]. E-band backhaul can be rapidly deployed, including street lamps, rooftops, and the sides of buildings, is expected to facilitate dense millimeter-wave 5G deployments on street-level sites. However, in order to meet the 10 Gbps capacity requirement, the transmission range of E-band links are typically within 7 km. Traditional bands from 26-42 GHz can be deployed over a much longer distance and cover much broader areas with lower capacity. Recently, a new backhaul technique is proposed to combine a higher frequency band with a lower frequency band to ensure both coverage and capacity [1]. This enables both increase in performance and flexibility and provide higher capacities over much longer distances compared to a single frequency microwave link.

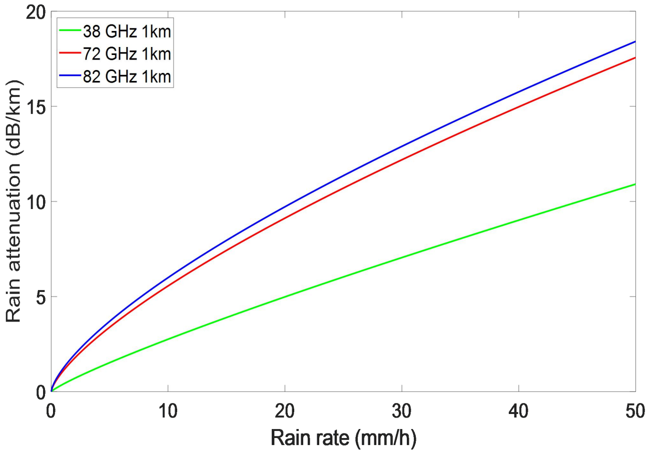
In this paper, we will present performance analysis based on real measurement from one 7 km long 38 GHz, one 3km long 72 GHz and one 3 km 82 GHz backhaul test link in Gothenburg, Sweden. We will present the main observations of the received signal variation, and additional attenuation in rainy weather.

2 Millimeter-wave Signal Attenuation in Rain

Atmospheric attenuation and weather effects are important for millimeter-wave propagation. A power law empirical model is often used in the calculation of rain induced attenuation Ar and the rain rate R [4]:

$$A_r = aR^bL \text{ (dB)} \quad (1)$$

where the constants a and b are related to frequency, rain temperature, the rain drop size distribution, and polarization depending on rain attenuation model. L (km) is the length of the microwave link, and Ar is the overall signal attenuation induced by rain between the transmitter and receiver. Vertical polarization were deployed in our test measurements, and the power-law coefficients (a, b) are calculated to be (0.3844,0.8552) for 38 GHz link, (1.0711, 0.7150) for 72 GHz link, and (1.2034, 0.6973) for 82 GHz link using the equations given in ITU-R P. 838-3 [4].



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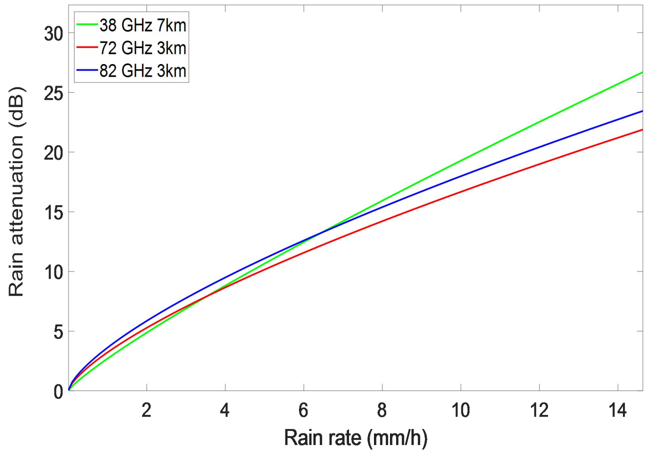


(b)

Figure 1. The theoretical rain induced signal attenuation for various rain rates at different frequencies (a) per kilometer (b) for a 7 km long 38 GHz, a 3 km long 72 GHz and a 3 km long 82 GHz test links using our measurement scenario.

The expected rain induced signal attenuation per kilometer based on (1) for our considered millimeter frequencies is presented in Fig. 1(a). Rain affects link at millimeter-frequency ranges, especially for higher frequencies. For increasing rain rate, the rain attenuation experienced by E-band link becomes more severe compared to the 38 GHz link. For a heavy rain event, the rain induced signal attenuation can be up to 9.7 dB for the 82 GHz link at rain intensity of 20 mm/h, compared to 5 dB for the 38 GHz link. For our considered measurement setup, a 7 km long 38 GHz link experiences similar or less signal attenuation compared to a 3 km E-band link for rain intensity lower than 7 mm/h.

3 Outdoor Measurement

In this section, we present a summary of the measurements from three outdoor millimeter-wave backhaul test links at 38 GHz, 72 GHz and 82 GHz.

A 3 km E-band test link was deployed between Lindholmen and Älvsborgsbron in Gothenburg, Sweden, and the geographic location information of the link is listed in Table I. One end of the backhaul radio equipment was installed on the roof of Ericsson building in Lindholmen. The transmission from site A to site B is operated at 72.625 GHz. The transmission from site B to site A is operated at 82.625 GHz. The received signal level is sampled at an interval of 30 seconds.

A 7 km 38 GHz test link was also deployed in Gothenburg, Sweden, and the geographic location information of the link is listed in Table 1. One end of the backhaul radio equipment was installed close to the E-band link radio equipment, also on the roof of Ericsson building in Lindholmen. The received signal level is sampled at an interval of 30 seconds.

During the measurement period, weather statistics including rain, humidity, temperature, air pressure and wind information were recorded by a weather station installed at the rooftop of Ericsson building.

TABLE I. E-BAND MEASUREMENT PARAMETERS

Frequency	72.625 GHz, 82.625 GHz
Transmit power	7 dBm
Antenna type	Cassegrain antenna
Antenna size	0.6 m
Tx / Rx antenna gain	50.5 dBi / 50.5 dBi
VSWR / Return loss	1.5:1 / 14 dB
Tx / Rx HPBW	0.5 ° / 0.5 °
Tx / Rx polarization	V / V
Sampling interval	30 seconds
Link length	3 km
Site A location	57°42′18.97″N, 11°56′29.67″E
Site B location	57°41′20.04″N, 11°54′10.76″E
Modulation	BPSK, 4QAM, 16QAM, 32QAM, 64QAM, 128QAM, 256QAM

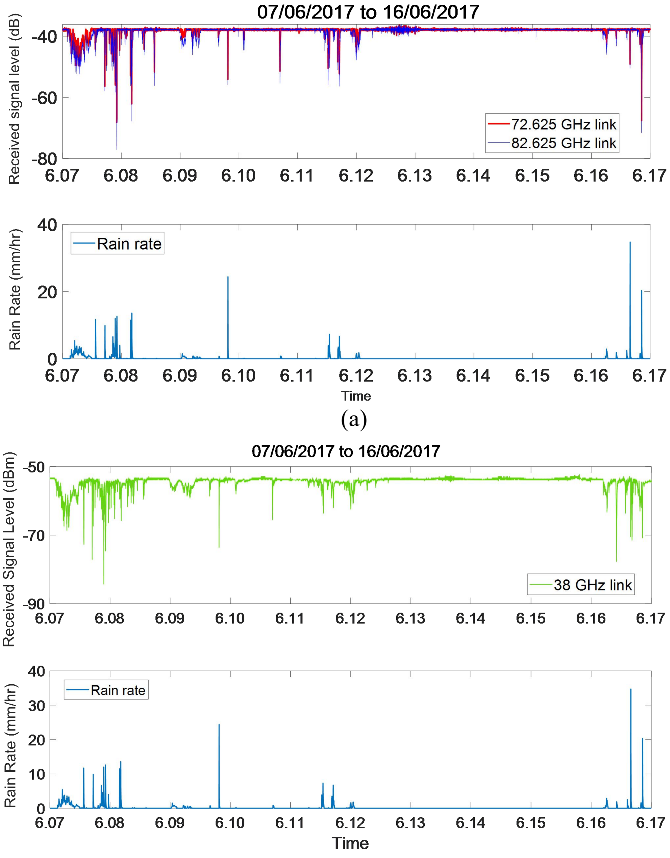
TABLE II. 38 GHZ TEST LINK MEASUREMENT PARAMETERS

Frequency	38 GHz
Transmit power	15 dBm
Antenna type	Cassegrain antenna
Antenna size	0.3 m
Tx / Rx antenna gain	40.3 dBi
Tx / Rx HPBW	0.5 ° / 0.5 °
Tx / Rx polarization	V / V
Sampling interval	30 seconds
Link length	7 km
Site A location	57°42′18.97″N, 11°56′29.67″E
Site B location	57°42′54.77″N, 12°1′26.46″E
Modulation	4QAM, 16QAM, 32QAM, 64QAM, 128QAM, 256QAM, 512QAM

4 Performance Analysis

The measurement lasted 10 days from 7 June 2017. The received signal level and path attenuation was measured in different weather conditions for the millimeter-wave links at 38 GHz, 72.625 GHz and 82.625 GHz with Gbps capacity. All three links were in operation at the same time.

During the measurement period, rain events occurred in 5 days. The variation of the receive signal level of three links are presented together with the rain intensity during the measurement period in Fig. 2. As an example, the received signal variation and the rain intensity on 7 June 2017 is given in Fig 3. Pearson correlation coefficient in the range of (-1,1) is computed, and a high correlation coefficient value shows strong relation between two data sets, millimeter-wave signal variation and measured true rain intensity. As expected, power attenuation is mainly due to rainfall, and they are highly correlated resulting in a correlation coefficient of approximately 0.8. Although the 38 GHz link was built over a much longer distance compared to the E-band links, the rain induced attenuation in the 38 GHz link is lower. This difference in rain induced attenuation between the lower frequency millimeter-wave link and higher frequency millimeter-wave link becomes more significant as the rain intensity gets higher. The largest rain attenuation in E-band links were found to be over 20 dB more than the 38 GHz link over the rain period. The attenuation of the E-band link is a lot more severe than expected. One possible reason is that the disdrometer provides a point measurement, while the measured signal attenuation is caused by the rain along the link. Although one end of the 38 GHz link and the E-band links located on top of the same building, but the links are built across different areas. The rain intensity that each link experienced along the path could be very different from the disdrometer measurement, and it could contribute to the difference in attenuation value. Overall, the received signal strength of the E-band link is shown to be heavily affected by the rain, and therefore the coverage is limited. In comparison, 38 GHz link is a lot more robust to bad weather conditions, even over long distance deployment.



(b)

Figure 2. Signal variation during the measurement period (a) 72.625 GHz and 82.625 GHz links (b) 38 GHz link.

Theoretical rain induced attenuation can be calculated using the rain rate measurement from the disdrometer and equation (1). For the experiment period, the measured statistics of rain attenuation versus calculated rain attenuation is plotted in Fig. 4. The rain rate varies from time to time, it is noticed that the measured attenuation is greater than the theoretical signal attenuation by 4 - 4.5 dB for 72 GHz and 82 GHz link, 2 dB for 38 GHz link, mainly due to humidity, wet antenna, hardware (radio, antenna) and alignment. For a rainfall event lasting for a long period of time, the wet antenna attenuation is expected to increase with increasing thickness of water film on the antenna. For high frequencies, wet antenna attenuation can be high even for low rain rates [5]. The bias due to the instability of the transmit power of commercial microwave backhaul equipment could be up to 1.6 dB [5], therefore causing more attenuation to the received signal level.

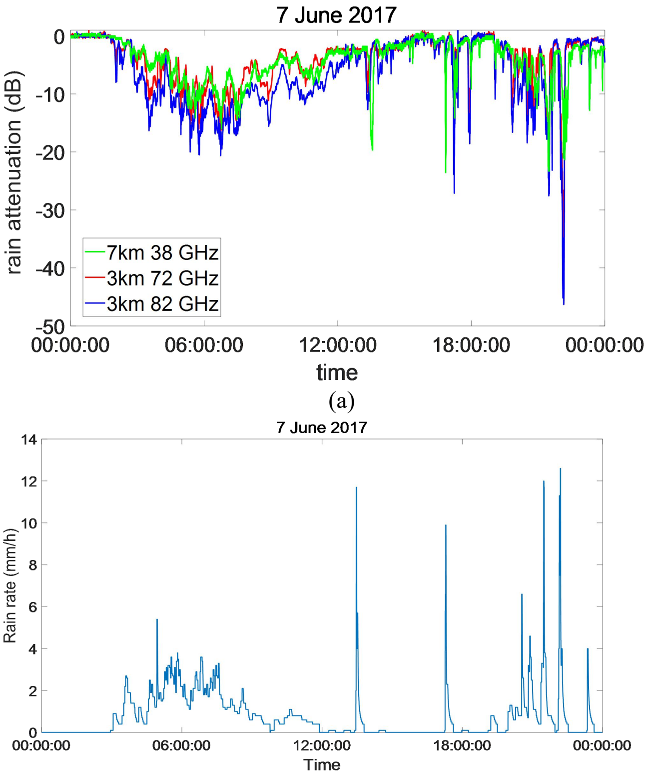


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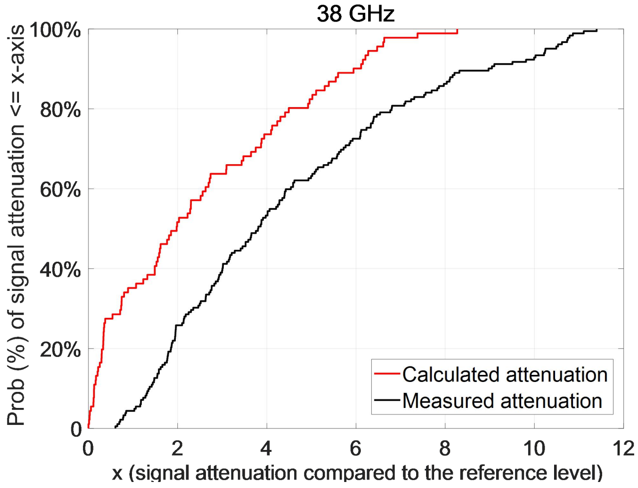
Fig. 3 (a) rain induced signal attenuation (b) rain rate on 7 June 2017

Figure 3. (a) rain induced signal attenuation (b) rain rate on 7 June 2017.



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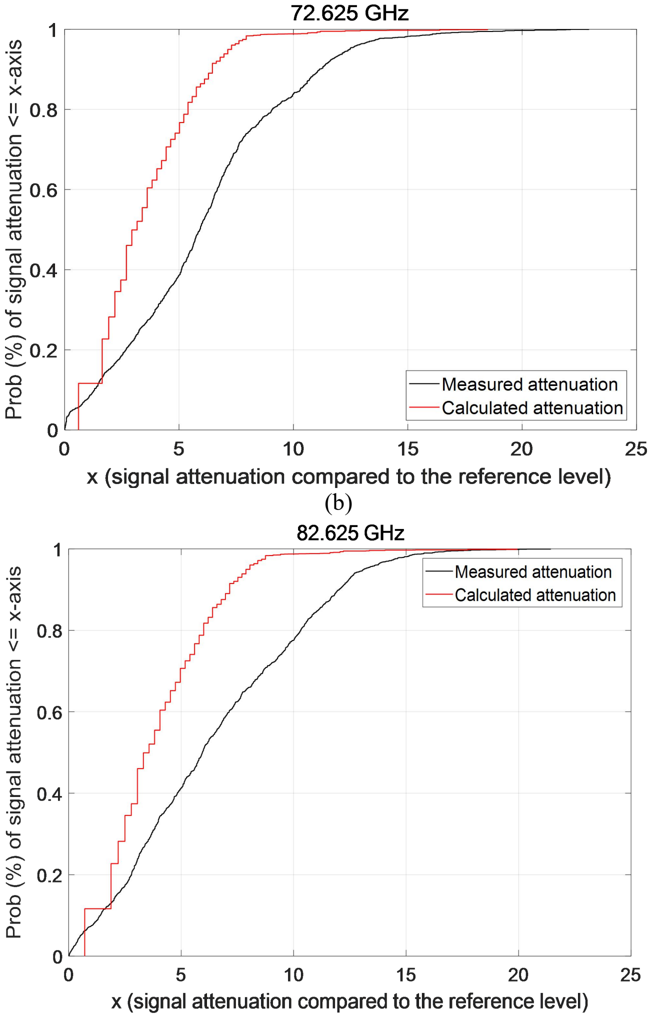

(b)

(c)

Figure 4. CDF plot of the calculated and measured signal attenuation due to rain for the (a) 38 GHz link (b)72.625 GHz link (c) 82.625 GHz link measurement

5 Conclusions

In this work, we have studied real outdoor measurements from three LOS millimeter-wave backhaul links at 38 GHz, 72 GHz, and 82 GHz. The focus of the measurement campaign is to evaluate the link performance over time and in changing weather conditions, especially due to the effects of rain. We have shown that the rain induced attenuation is strongly correlated with the rain intensity variation. As the link frequency becomes higher, the effect of rain on the signal level becomes more severe. In light rains, the difference in the signal attenuation observed in three links is less significant. As the rain intensity increases, over a relative short distance of 3 km, for the 82 GHz link, the rain attenuation can be greater than 40 dB for a heavy rain event with a peak rain rate of 12 mm/h. This limits the use of E-band link over longer distance. In comparison, the peak rain attenuation observed in the 7 km long 38 GHz link is less than 10 dB. In real deployment, the signal attenuation measured in rain period is found to be 2-4.5dB higher than calculated rain attenuation based on ITU model. The reasons include water film on the antennas, variation of humidity level, hardware (radio, antenna), alignment, type of precipitation, etc. While higher millimeter frequency links at E-band can achieve high throughput but the coverage is limited, the lower millimeter frequency link at 38 GHz is more robust to changing weather conditions and can be deployed over a much longer distance. If pairing the higher frequency link with the lower frequency link, the capacity and coverage requirement for the next generation microwave backhaul links can be met compared to a single frequency microwave link.

6 Acknowledgement

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