# Research on the Effect of Meteorological Factors on Non-terrestrial Channel Characteristics

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***Abstract*—The integration of non-terrestrial and terrestrial communication systems plays a vital role in the fifth-generation mobile communication system (5G) for the ubiquitous coverage, reliable service, and flexible networking. Millimeter wave communication technology with ultra-high transmission rate and ultra-wideband is the key enabler for 5G intelligent urban transportation. However, millimeter wave will be affected by various meteorological factors in the process of propagation, the attenuation caused by meteorological factors should be considered and included in the design of millimeter wave communication link. According to the 3GPP model and ITU-R Recommendation, the calculation methods of various meteorological attenuation of non-terrestrial link are described in detail. The typical urban scenario is simulated through a high-performance Cloud-computing Ray-Tracing platform (CloudRT). Based on the output of the simulator, the effect of meteorological attenuation on the channel characterization is calculated and analyzed. The results can provide theoretical and data support for the evaluation of non-terrestrial channel characterization, and will help for the design of the non-terrestrial communication system enabling future intelligent urban transportation.**

***Index Terms*—Meteorological attenuation, Millimeter wave channel, Non-terrestrial link, Ray tracing simulation.**

## I. INTRODUCTION

Non-terrestrial communication systems have the advantages of wide coverage and high data transmission rates. They can supplement and expand dense terrestrial cells by providing a wide coverage area, thereby alleviating the problems of overload and congestion. They have achieved significant development in fields such as broadcasting, navigation, rescue, and disaster relief. While communication problems such as spectrum resource shortage and limited data transmission have been solved, the problem of signal fading caused by various meteorological factors has gradually become prominent, bringing new challenges to the design of reliable and stable wireless communication systems, especially millimeter wave satellite communication systems. The changes in atmospheric conditions have a significant impact on the performance of the earth-space channel, especially at frequencies above 10 GHz [1]–[3]. Therefore, it is necessary to accurately predict the attenuation caused by meteorological factors and analyze their impact on channel characteristics.

The researchers in [4] investigate the dynamic property of a tropical forested channel due to the weather effect on very high frequency (VHF) and ultrahigh frequency (UHF) radio-wave propagation. The authors in [5] present a joint multipath-shadow-weather fading channel modeling approach, which investigates the influences of various weather conditions as well as multipath and shadow fading by utilizing the overall least squares method for stochastic processes. The researchers in [6] use NS-3 as a simulator to study the effect of harsh weather of dust or sand on the propagating loss of 5G mm-Wave and 4G LTE signal. A Ka-band land mobile satellite (LMS) channel model which is able to take into account weather impairments is proposed in [7]. Similarly, a tropical weather-aware LMS channel model is presented in [8], which can be applied at areas with diverse atmospheric (rain, clouds, and tropospheric scintillation) and mobility impairments. The proposed tropical-LMS channel model is designed based on actual experimental measurements conducted in a tropical area. The researchers in [9] presents a reliable channel model of satellite-to-land mobile terminals that consider dynamic cloudy weather impairments. The cloud's dynamic parameters and their effect on the Rician factor are modeled.

However, current research lacks analysis of non-terrestrial channel characteristics that considers multipath and shadow fading under different weather conditions. Additionally, our work investigates the difference between the weather impacts on three different transmitter height. In this paper, the attenuation caused by meteorological factors on the signal propagation of non-terrestrial links in an urban scenario is included in ray tracing simulations. The meteorological attenuation that significantly affects the signal propagation of non-terrestrial network includes atmospheric gases attenuation, rain attenuation, cloud and fog attenuation, and tropospheric scintillation attenuation. The current channel research lacks prediction of attenuation caused by meteorological factors and analysis of their impact on channel characteristics. Thus, the channel of non-terrestrial network in a typical urban scenario is simulated. Based on ray tracing simulation results and accurate calculation, the impact of meteorological attenuation on channel characteristics is predicted and analyzed, which helps to improve the accuracy of coverage prediction during base station deployment.

The rest of this paper is organized as follows: Section II describes the methods of calculating meteorological attenuation which has a significant effect on the earth-space channel. Section III introduces the urban scenario and the simulation setup. The channel parameters are compared and characterized in Section IV. At last, Section V describes the conclusions.

## II. Attenuation Calculation Due to Different Meteorological Factors

The meteorological attenuation which have a significant impact on earth-space wave propagation includes atmospheric gases attenuation, rainfall attenuation, clouds attenuation, fog attenuation and tropospheric scintillation attenuation. Referring to the definition of 3GPP and ITU-R recommendation, the theoretical calculation of various types of meteorological attenuation are described briefly in this paper [10]–[17].

### *A. Attenuation due to atmospheric gases*

Atmospheric absorption attenuation refers to the attenuation of radio waves when passing through the earths atmosphere, which is caused by the absorption of EM wave energy by atmospheric molecules. In millimeter-wave (mmWave) and terahertz (THz) bands, oxygen and water vapor are the main components of atmospheric gas absorption. Oxygen molecule has a magnetic dipole moment and water molecule has a residual electric dipole moment. Under the action of the electromagnetic field, when the frequency of the electromagnetic wave is consistent with the transition frequency of the molecular rotational energy level, the molecule absorbs the energy of the electromagnetic wave, and its rotational energy level transits from low to high, forming resonance absorption.

Attenuation by atmospheric gases which is entirely caused by absorption depends mainly on frequency, elevation angle, altitude above sea level, and water vapor density (absolute humidity). At frequencies below 10 GHz, it may normally be neglected. However, for elevation angles below 10 degrees, it is recommended that the calculation is performed for any frequency above 1 GHz. The technical report of ITU-R P.676 details the method for calculating the atmospheric gases attenuation [10].

### *B. Attenuation due to rain*

Rain attenuation refers to the attenuation of radio waves when passing through the rainy area. The higher the frequency of radio waves, the shorter the wavelength. The wavelengths of Ku-band and Ka-band microwaves with frequencies above 10 GHz are only 10 to 30 mm, which are comparable to raindrops of several millimeters in diameter. Therefore, dense raindrops will cause serious transmission loss for high-frequency radio waves above Ku-band when passing through the rainy area.

Due to the uncertainty of the occurrence time and region of rainfall, it is impossible to calculate the attenuation by rain accurately. After decades of observation and research, ITU-R and its predecessor have summarized the methods of estimating the maximum rain attenuation statistics for different time probabilities. The calculation of long-term rain attenuation statistics from point rainfall rate is given in Recommendation ITU-R P.618 [11]–[15].

### *C. Attenuation due to clouds and fog*

Clouds and fog are important condensates of water vapor in nature. The attenuation due to clouds and fog has a great influence on the millimeter-wave transmission that the influence on radio wave of the satellite communication link cannot be ignored. In general, when the frequency of the electromagnetic wave is higher than 10 GHz, it is necessary to consider the attenuation by clouds and fog, but only when the frequency is higher than 50 GHz, the attenuation is important.

Clouds and fog have smaller particles, which are suspended in the air. The number of particles per cubic centimeter ranges from 100 to 500 and the size of particles is much smaller than the wavelength of millimeter-wave. The density of particles is not uniform, and the types of clouds and fog are diverse, which makes it difficult to calculate the attenuation accurately. The attenuation due to clouds and fog can be calculated by the total columnar content of cloud liquid water in Recommendation ITU R P.840 [16]. A mathematical model based on Rayleigh scattering, which uses a double-Debye model for the dielectric permittivity of water, can be used to approximately calculate the attenuation for frequencies up to 200 GHz.

### *D. Attenuation due to tropospheric scintillation*

Tropospheric scintillation is a phenomenon that causes rapid fluctuation of signal amplitude and phase in the satellite communication system. Unlike ionospheric scintillation, the effect of tropospheric scintillation on signal increases with the increase of carrier frequency, especially above 10 GHz. In this case, the sudden change of the refractive index caused by the change of temperature, vapor content, and air pressure results in the fluctuation of the signal.

A general technique for predicting the cumulative distribution of tropospheric scintillation at elevation angles greater than or equal to 5 degrees is given in Recommendation ITU-R P.618 [11]. It is based on monthly or longer averages of temperature and relative humidity and reflects the specific climatic conditions of the site. Since the average surface temperature and average surface relative humidity vary with season, the scintillation fade depth distribution varies with season. The seasonal variation may be predicted by using seasonal average surface temperature and seasonal average surface relative humidity. While the procedure has been tested at frequencies between 7 and 14 GHz, it is recommended for applications up to at least 20 GHz [17].

## III. Parameter Configurations for Ray-Tracing Simulations

### *A. Simulation Scenario*

The three-dimensional (3D) model of the urban scenario is reconstructed by SketchUp tool as shown in Fig. 1. In the urban scenario, the geometry of objects are taken into account and corresponding materials are allocated to the surfaces of each object. In order to reconstruct the real urban street scenario, roadside trees, bus stations, and other common small-scale objects (i.e., traffic lights/signs) are all considered in the modelling.

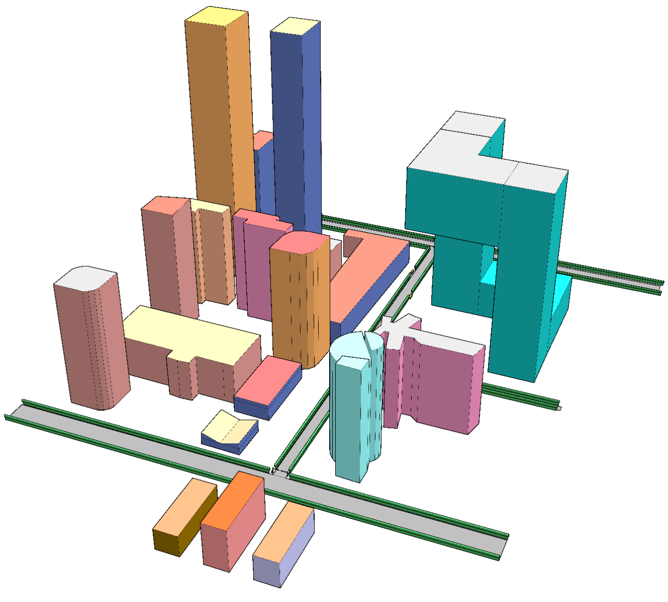


Fig. 1. 3D model of the constructed urban scenario

TABLE I
CONFIGURATION OF UPLINK/DOWNLINK FOR FIVE SIMULATION DEPLOYMENTS

| | Link | Center frequency | Transmitted power | Transmitter position | Transmitter height |
|---|---|---|---|---|---|
| D1 | Downlink | 20 GHz | 41.5 dBm | GEO | 35786 km |
| | Uplink | 30 GHz | 33 dBm | | |
| D2 | Downlink | 2 GHz | 58 dBm | | |
| | Uplink | 2 GHz | 23 dBm | | |
| D3 | Downlink | 2 GHz | 58 dBm | LEO | 1000 km |
| | Uplink | 2 GHz | 23 dBm | | |
| D4 | Downlink | 20 GHz | 41.5 dBm | | |
| | Uplink | 30 GHz | 33 dBm | | |
| D5 | Downlink | 20 GHz | 41.5 dBm | HAPS | 10 km |
| | Uplink | 30 GHz | 33 dBm | | |
| | Downlink | 2 GHz | 58 dBm | | |
| | Uplink | 2 GHz | 23 dBm | | |

### *B. Simulation Configuration*

Ray tracing (RT) simulation can build accurate channel models by tracking the rays for various propagation mechanisms and providing full information of multipath effects. The RT simulator used in the paper is CloudRT [18]. The official website of the CloudRT platform is *http://www.raytracer.cloud/*. As shown in Table I, five different non-terrestrial network simulation scenarios are considered based on 3GPP TR 38.811 [19]. Three different transmitter height are considered, including the geosynchronous orbit satellite (GEO), the low earth orbit satellite (LEO) and the high altitude platform station (HAPS).

## IV. CHANNEL CHARACTERISTIC ANALYSIS

Based on the RT simulation results, the non-terrestrial channel characteristics are further analyzed by extracting following channel parameters: received power, **root-mean-square (RMS)** delay spread and Rician K-factor. The meteorological attenuation is added to the path loss of each ray, the effect of meteorological attenuation on the channel characteristics is calculated and analyzed.

### *A. Received Power*

Fig. 2 shows the received power of the uplink/downlink for five simulation configurations without considering meteorological factors or considering meteorological factors. Among them, **'UL'** represents the uplink, **'DL'** represents the downlink, and **'MF'** represents meteorological factors.

The red dashed line indicates considering meteorological attenuation, while the blue dashed line indicates not considering meteorological attenuation. For Deployment1 and Deployment2, the satellite is in the geostationary orbit and remain relatively stationary from the ground, so the received power is almost unaffected by the motion of the receiver. The obstruction of traffic signs and traffic lights cause a sharp decrease in the power of the direct path component, resulting in deep fading of the received power at certain times.

The antenna beam used for non-terrestrial communication is narrow, and the distance between the transmitter and receiver is too far, resulting in minimal impact of multipath components on the received signal, compared to the direct path. This makes the received power almost constant during the receiver's motion. The received power of Fig. 2(a)-Fig. 2(d) is represented as a constant value.

For Deployment3 and Deployment4, the satellite is located in a lower orbit and moves rapidly. As the satellite gradually approaches the receiver, there is a significant change in received power. As for the case of 2 GHz, compared to 30 GHz, the frequency is lower and the attenuation caused by meteorological factors is very small. Therefore, in all 2 GHz cases, the red lines and blue lines almost overlap.

### *B. RMS delay spread*

RMS delay spread is an important measure that quantifies the dispersion effect due to propagation in the time delay domain, to which the communication systems might be sensitive. RMS delay spread is defined as the square root of the second central moment of the power delay profile (PDP) as in:

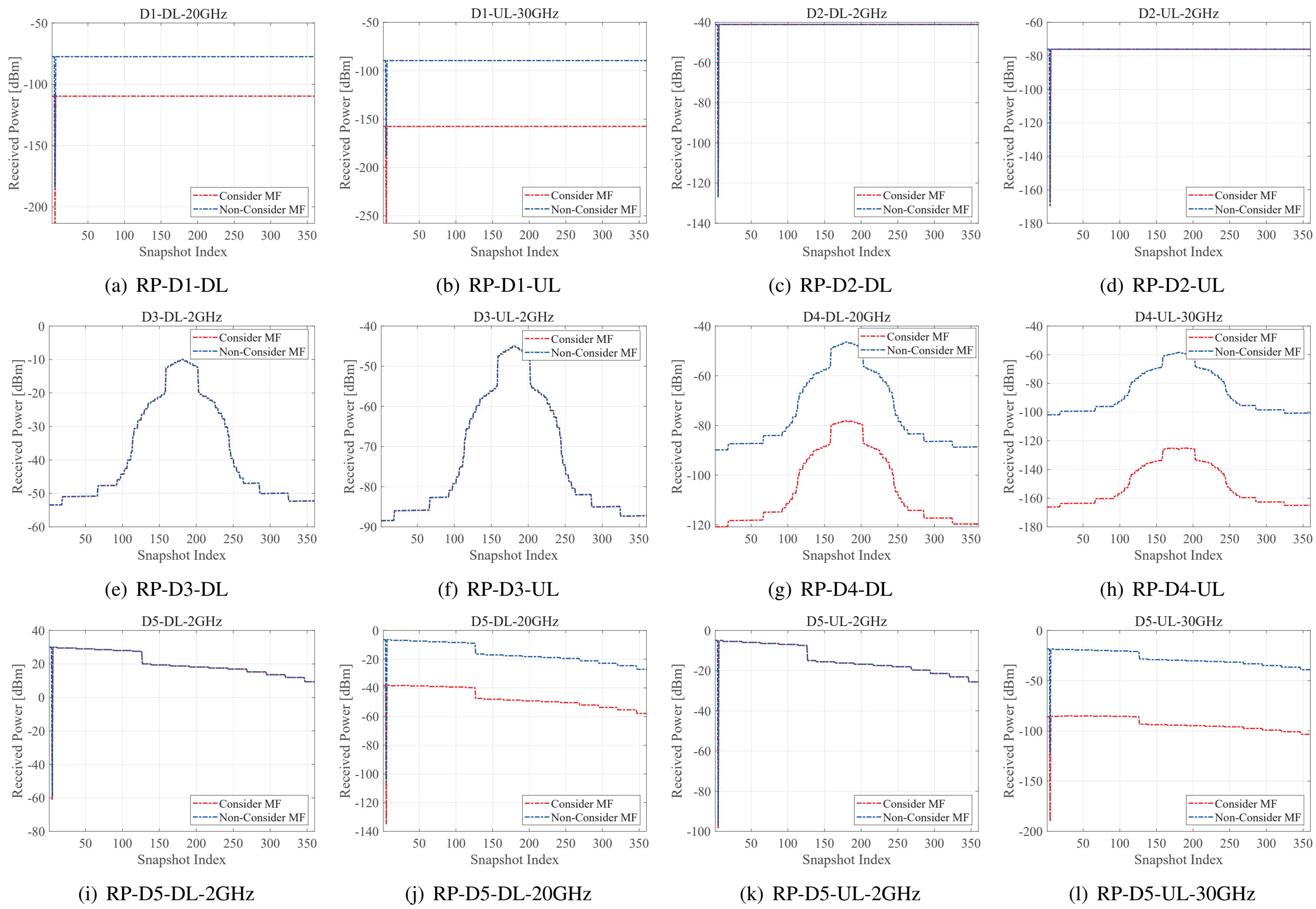
$$\sigma_\tau = \sqrt{\frac{\sum_{n=1}^{N} {\tau_n}^2 \cdot P_n}{\sum_{n=1}^{N} P_n} - \left( \frac{\sum_{n=1}^{N} \tau_n \cdot P_n}{\sum_{n=1}^{N} P_n} \right)^2} \quad (1)$$

where $\sigma_\tau$ is the RMS delay spread, $P_n$ and $\tau_n$ are the power and the excess delay of the $n^{th}$ multipath, respectively.

In order to quantify the RMS delay spread, the obtained results are fitted by normal distribution of mean value $\mu$ and standard deviation $\sigma$, as depicted in Table II.

### *C. Rician K-factor*

The Rician $K$-factor is a significant parameter to quantify the channel fading severity, which is defined as the ratio of




(a) RP-D1-DL (b) RP-D1-UL (c) RP-D2-DL (d) RP-D2-UL

(e) RP-D3-DL (f) RP-D3-UL (g) RP-D4-DL (h) RP-D4-UL

(i) RP-D5-DL-2GHz (j) RP-D5-DL-20GHz (k) RP-D5-UL-2GHz (l) RP-D5-UL-30GHz

Fig. 2. Received power with/without considering meteorological attenuation

TABLE II
NORMAL DISTRIBUTION FITTING VALUES FOR RMS DELAY SPREAD WITH/WITHOUT CONSIDERING METEOROLOGICAL ATTENUATION

| DS[ns] | | D1-DL | D1-UL | D2-DL | D2-UL | D3-DL | D3-UL | D4-DL | D4-UL | D5-DL | | D5-UL | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | 2 GHz | 20 GHz | 2 GHz | 30 GHz |
| $\mu_{DS}$ | MF | 9.79 | 7.76 | 3.60 | 7.18 | 0.21 | 0.36 | 0.23 | 0.26 | 5.90 | 2.08 | 2.69 | 2.55 |
| | No-MF | 6.75 | 8.16 | 4.72 | 6.82 | 0.21 | 0.36 | 0.21 | 0.25 | 5.91 | 2.32 | 2.69 | 2.60 |
| $\sigma_{DS}$ | MF | 19.14 | 46.74 | 20.32 | 46.16 | 0.13 | 0.40 | 0.10 | 0.15 | 39.81 | 39.35 | 48.06 | 47.15 |
| | No-MF | 21.52 | 46.70 | 20.26 | 46.18 | 0.13 | 0.40 | 0.09 | 0.15 | 39.85 | 43.87 | 48.06 | 48.25 |

TABLE III
NORMAL DISTRIBUTION FITTING VALUES FOR RICIAN $K$-FACTOR WITH/WITHOUT CONSIDERING METEOROLOGICAL ATTENUATION

| KF[dB] | | D1-DL | D1-UL | D2-DL | D2-UL | D3-DL | D3-UL | D4-DL | D4-UL | D5-DL | | D5-UL | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | 2 GHz | 20 GHz | 2 GHz | 30 GHz |
| mu | MF | 105.76 | 86.50 | 123.22 | 79.29 | 97.00 | 70.31 | 82.31 | 72.86 | 74.36 | 98.22 | 76.57 | 83.36 |
| | No-MF | 107.00 | 86.60 | 123.06 | 79.57 | 96.66 | 70.34 | 82.12 | 73.07 | 74.33 | 98.29 | 76.67 | 83.76 |
| sigma | MF | 12.64 | 9.63 | 22.54 | 8.17 | 22.74 | 9.11 | 16.44 | 11.83 | 7.98 | 11.03 | 9.77 | 10.80 |
| | No-MF | 13.15 | 10.08 | 22.14 | 8.12 | 22.66 | 9.34 | 16.08 | 11.50 | 7.67 | 11.30 | 10.17 | 11.15 |

the power of the strongest component to the total power of the remaining components in the received signal. Thus, the Rician $K$-factor can be calculated according to its definition:

$$KF\,(dB) = 10 \cdot \log_{10}\left(\frac{P_{\text{strongest}}}{\sum P_{\text{remaining}}}\right) \tag{2}$$

where $KF$ is the Rician $K$-factor, $P_{\text{strongest}}$ and $P_{\text{remaining}}$ are the power of the strongest component and each remaining component, respectively. **In order to quantify the Rician $K$-factor, the obtained results are fitted by normal distribution, as depicted in Table III.**

## V. Conclusion

In this paper, the channel at the center frequency of 2 GHz and 30 GHz in a realistic urban scenario is characterized. Aiming at the problem that the mmWave communication is affected by various meteorological factors, the meteorological attenuation is calculated according to 3GPP model and ITU-R Recommendation and the influence of that on channel characteristics is analyzed.

Considering the influence of meteorological factors, the received power suffers severe attenuation when the frequency is 30 GHz, while the signal level is almost unaffected by weather conditions at 2 GHz. The attenuation should be considered in the design and evaluation of the mmWave urban communication system, whether targeting GEO, LEO and HAPS. Besides the great impact on the path loss, the values of the RMS delay spread become slightly greater or slightly reduced for GEO scenario, while the values of the Rician $K$-factor are almost unchanged for all scenarios. The channel parameters and characterization provided in this paper can help to design the urban communication systems.

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