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Channel Characterization at 2.4 GHz for Aerial Base Station

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Abstract

The paradigm shift towards high data rate demands of mobile users in IMT-2020 commonly known as 5G, led to the possibility of using Aerial Base Stations (ABS) to fulfill such requirements. However, for implementation of ABS, an appropriate air-to-ground channel model is needed. It is an important factor to incorporate the understanding of the channel fading behavior before designing the system. In this article, we present novel channel propagation results obtained from ray tracing simulations for different environments, such as Suburban, Urban and Urban-High-Rise, according to ITU Radio-communication parameters. The details of different channel characteristics such as Spatial Correlation and Cumulative Distribution Function for Small Scale Parameters as Delay Spread and Angle-of-Arrival are presented for different ABS heights. We also focus on various channel modeling approaches and frameworks for 3D channel models.

Keywords: Air-to-Ground; Low Altitude Aerial Base Station; Ray Tracing; Spatial Correlation; Cumulative Distribution Function; Statistical Parameters.

1. Introduction

With the rapid growth of communication traffic in 5G with high data rate requirements, drone assisted cellular networks [1] has become a topic of interest in academia and industry. However, earlier drones, also known as Unmanned Aerial Vehicles (UAVs), were developed for military purposes such as surveillance and reconnaissance. Now, drones are being successfully implemented in many civil operations [2] such as remote sensing, weather detection, precision agriculture, wildlife monitoring, film making, search and rescue etc. Due to the flexibility of drones with on-demand deployment, they have gained enormous attention in telecommunication industry as Aerial Base Stations (ABS) to support data demands of flash crowds [3] such as concerts, public rallies, sport events or cultural festivals,

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where large mass of people are present in a small area. However, for a system level design of mixed analog-digital front-ends for ABS, an appropriate channel model is needed, with full channel characterization. A survey on Air-to-Ground (A2G) channel modeling for UAVs has been provided in [4, 5]. Most of the literature focuses on the portion of two spectral bands, L-band (960-977 MHz) and C-band (5030-5091 MHz), allocated for reliable control and non-payload communication (CNPC) data links for drones, over near urban, hilly suburban, sea surface, mountains etc, with transmitter (Tx) and receiver (Rx) link distance in the range of 1-19 km, approximately. It is not clear if these site specific measurement campaigns can be extended to other environments or used as general models. Apart from these, several other measurements have been performed to propose new propagation models for A2G links. In [6], authors perform statistical analysis with multiple sets of measurements to provide received power and quality of service measurements, such as round-trip time and jitter, between a Rx mounted UAV and base station (BS) at a building rooftop of height 11 m with link distance ranging up to 3 km, for different cellular technologies such as EDGE, HSPA+ and LTE. Morever, another statistical analysis of narrowband UAV fading channel in urban area to develop a time-series generator is shown in [7], where an airship transmits over Prague city at an altitude of 100-170 m under low elevation angles w.r.t. the receiver, between 1-6 deg. In [8], authors' model the uplink and downlink channel via field measurements for an open field and campus scenario. They provide Path Loss Exponents (PLE), received signal strength and throughput performance for different drone yaw angles and heights. Some studies have also been performed over A2G Multiple-Input-Multiple-Output (MIMO) channel in [9], where authors' propose UAVs as a broadcast node and viable relay for high capacity communications. The measurements were carried out at 915 MHz with drone altitude at 200 m approximately for obtaining time varying channel characteristics, affected not only by the velocity of the drone but also by its elevation and roll. Also, measurements have been performed in open fields for low altitudes of drones up to 16 m to obtain stochastic Path Loss (PL) and multipath channel model [10]. All these major experimental studies have focused on developing appropriate A2G channel models to integrate UAVs into cellular networks. However, most of them are site-specific (mainly suburban or near urban scenarios) with low altitudes of ABS. However, concerning the high data rate demands of flash crowds [3] and on-demand UAV deployment, more investigation is required to come up with channel models. Also, different altitudes of the ABS should be considered to find channel variation with respect to the height of ABS, which is a crucial parameter of the system. In our previous work [11], we have overcome the aforementioned limitations and addressed ABS height and elevation angle with respect to receivers as one of the fundamental design parameter. We calculated the PLE, the standard deviation (SD) of shadowing and the Ricean factor in generalized environments. Moreover, Line of Sight (LoS) and Non-Line of Sight (NLoS) links were investigated with respect to their probability of occurrence. As seen from the preceding literature survey, the A2G channel for low altitude aerial platforms (LAPs) is different from the well developed terrestrial and satellite communication channels.

In this article, we focus on fading channel characteristics such as Angle-of-Arrival (AoA) and Delay Spread (DS) with their cumulative distribution functions (CDFs) and spatial correlation properties at different ABS altitudes and environments from ray tracing simulations. AoAs are the azimuth and elevation angles at which a ray in multipath signal is incident and DS is the time interval between first and last ray of that multipath signal. Here the elevation angle, is the angle made by LoS ray at ground Rx to the perpendicular at ABS towards the ground. This is important in computing fading channel coefficient for further transceiver design. The ray tracing provides accurate and efficient predictions [12] of electromagnetic propagation and fading channel characteristics with broader simulation parameters and environment options, which may not be feasible with realistic channel measurements through channel sounding. Also, drone flight permission are not easily granted by aviation administration authorities in dense city scenarios or near airports, hospitals etc, for public safety [13]. However, UAV flight standardization are being renewed, due to outset of drone usage in civil applications. Therefore, ray tracing is presently one of the best options for channel parameterization of LAPs. This article is organized as follows. First we describe the generation of simulation environment, performed on a commercial design and ray tracing software. Then we address the different channel modeling approaches developed during various channel modeling campaigns. Also, we describe the three-dimensional channel model, considerably used for current scenarios. Later, we present results for different channel parameters with concluding discussion. To the best of our knowledge, this is the first article addressing channel fading characteristics for low altitude ABS in generalized environments.

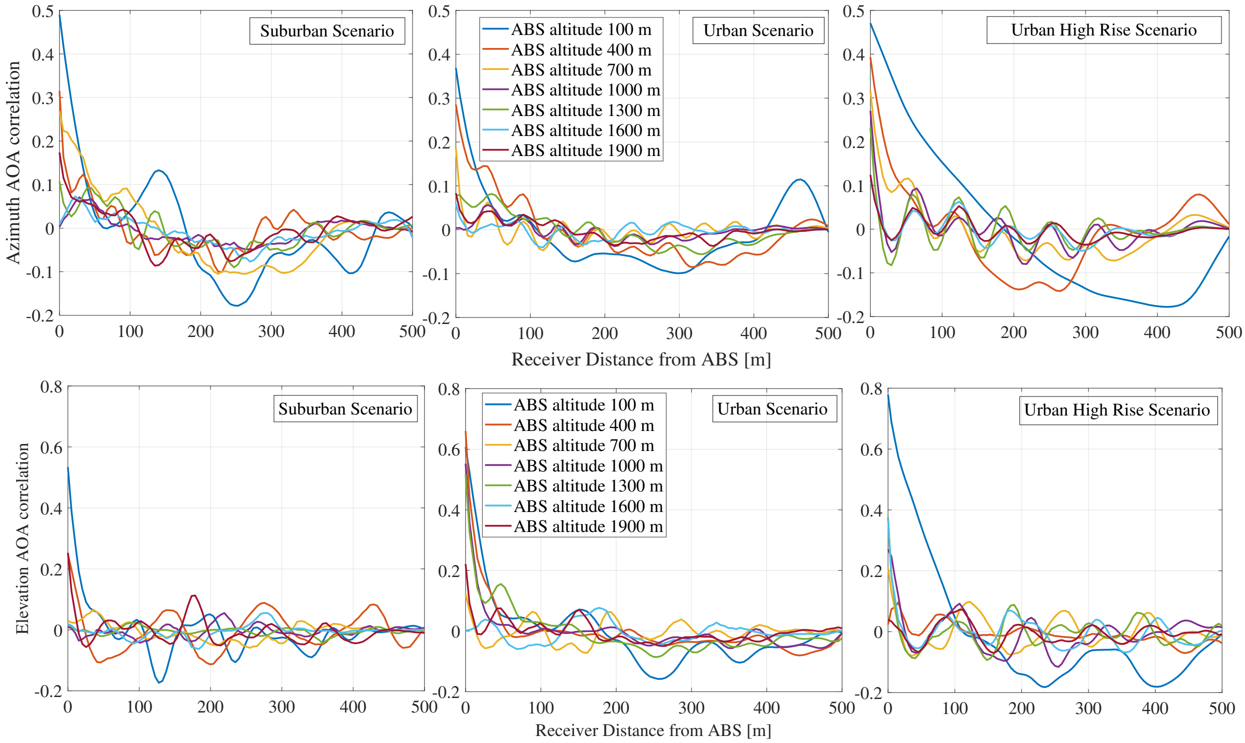

Fig. 1. Spatial Correlations of (top) Azimuth and (bottom) Elevation AoA with receiver distance.

2. Simulation Setup

The customized simulation setup was developed to address wide range of scenarios with different ABS altitudes and transmitting power, to find channel characteristics of a generic A2G channel model for LAPs, using one-type-fits-all design philosophy. We develop three environments [11] - Suburban, Urban and Urban High Rise, on a Computer-Aided-Design (CAD) software, 3DS MAX according to ITU-R parameters [14]:

- α = Ratio of land area covered by the buildings out the total area (*dimensionless*).
- β = Mean number of buildings per unit area ($building/km^2$).
- γ = Variable determining the building height distribution.

The CAD environments had an area equal to 2000×2000 m^2, out of which simulations was conducted over 1000×1000 m^2 at different locations. The ABS was placed at the center, with approximately 32.500 receivers uniformly spread over the entire environment surface with 5 m spacing from each other. The building density and Rayleigh distributed heights were set according to the environment type (Suburban, Urban, Urban High Rise). Also, standard concrete and earth materials were used for buildings and terrain, respectively. Other properties such as street width and building spacing are given in [11]. The ray tracing simulation was performed in a commercial radio wave propagation software, Wireless InSite 3.0.1. The accuracy of the software with respect to practical measurements is well defined in [12]. The simulations were conducted at 2.4 GHz carrier frequency and 20 MHz bandwidth of the ABS with its altitude ranging from 100 to 2000 m, at each 100 m interval and transmitting power between 18 and 46 dBm, at intervals of 2 dBm. The LTE unlicensed spectrum was preferred since there is not a standard allocated spectrum for such a system, till now. The results from different snapshots were averaged at each ABS altitude. The receivers inside the buildings were not considered for the simulation. The antenna mounted on ABS was isotropic with 2 dB gain, in order to remove the effects of antenna directivity on the channel measurements.

3. Channel Modeling Approach

There have been several channel modeling projects such as those from 3rd Generation Partnership Project (3GPP/3GPP2), International Telecommunications Union (ITU), Wireless World Initiative New Radio (WINNER I, WINNER II and WINNER+), Mobile and Wireless Communications Enablers for the Twenty-Twenty Information Society (METIS I and on-going METIS II in collaboration with 5G Infrastructure Public Private Partnership). Apart from these, there have been also several Millimeter-Wave channel modeling campaigns for 5G. METIS I addresses three different channel modeling approaches [15], which are currently followed by researchers and industries: Map-based, Stochastic and Hybrid. The map-based model is based on ray tracing simulation in a propagation environment that inherently accounts for propagation mechanisms such as specular reflection, scattering, diffraction and geometrical description of the environment such as building and terrain material with roughness. This model provides realistic channel characteristics. The stochastic model is based on parameter distributions extracted from the measurements. The hybrid model provides scalable and flexible framework between map-based and stochastic approach. In hybrid model, large scale parameters (LSPs) such as PL and shadowing are obtained via map-based approach and small scale parameters (SSPs) via stochastic approach. Currently recognized channel models such as 3GPP/3GPP2 spatial channel model, WINNER geometry based stochastic channel model, COST-259, 273, 2100 and ITU-R IMT-Advanced model, are based on stochastic approach and not sufficient to fulfill upcoming 5G requirements. Also, these models are focused on 2D channel modeling where only azimuth angular characteristics are considered, since the Txs and Rxs are at comparable altitudes. However, for an ABS, the elevation angle becomes an important parameter due to high altitude difference between ABS and Rxs. Therefore, in this article, we focus on map-based channel modeling approach instead of stochastic and hybrid, since previous experimental measurements do not cover a wide range of environments and ABS altitudes. The development and evaluation of ABS downlink and uplink is based on the 3D Channel Model (3CM) developed by 3GPP, where significant importance was given to the elevation angle of the antenna and height of terrestrial base stations. The initial 2D Channel Models (2CM) from 3GPP spatial channel model, ITU and WINNER II, assumes a 2D plane for location of transmitters, receivers, reflectors and scatterers, which is not valid for ABSs. Being an extension of 2CM, 3CMs also extracts LSPs and SSPs using the stochastic approach. However, to further develop from 3GPP 3CM, LSPs such as PL, Shadowing and LoS and SSPs such as AoA, Angle-of-Departure (AoD) and DS, are based on ray-tracing or map-based approach, as done in METIS channel model [15].

4. Channel Measurement Results and Analysis

Spatial Correlation (SC) is the correlation among the values of a variable with respect to the distance between the points at which the measures are obtained. It has been a significant parameter for channel characterization, generally for performance of Multiple-Input-Multiple-Output (MIMO) systems in terms of Rx and Tx antennas spacing to achieve maximum space and time diversity of multipath channels. Here, we address SC with an analogous perspective for a single isotropic antenna mounted on the ABS and closely spaced multiple mobile users on the ground. A lower correlation factor is likely to increase independent reflected and scattered rays, thereby reducing the interference at the Rxs. Also, it governs the minimum spatial separation required at Rxs to achieve Independent and Identically Distributed (IID) signals. Also, CDFs of SSPs have been presented in this article, which gives an insight about the likelihood of the SSPs lower than a given threshold. Figs. 1 (a) and (b) represent the SC of Azimuth-AoA (A-AoA) and Elevation-AoA (E-AoA) with respect to Rx distance from ABS, respectively. The correlation of each Rx is plotted with respect to its neighboring Rx, 5m apart from each other. The correlation is plotted in one direction, radially away from the ABS, since correlation along different directions from ABS were found to have nearly homogeneous behavior. The variation in SC at different ABS altitudes and environments is also shown. As can be clearly observed from Fig. 1 (a), Suburban environment has a lower A-AoA correlation than Urban environment, which in turn is again lower than Urban High Rise. However, such prominent pattern cannot be clearly distinguished for E-AOA in Fig. 1 (b). This is due to the fact that correlation are found along one radial direction in the snapshots. Therefore, likelihood of A-AoA arriving from one particular direction is high but E-AoA along that direction would be different as the Rx distance increases. Also, SC for both A-AoA and E-AoA are higher for the Rxs near the ABS and decreases as the Rx distance increases. Also, AoA correlations were found higher for lower ABS heights and decreases as the ABS altitude increases. This means that, Suburban environments exhibit higher probability of IID channels than Urban and

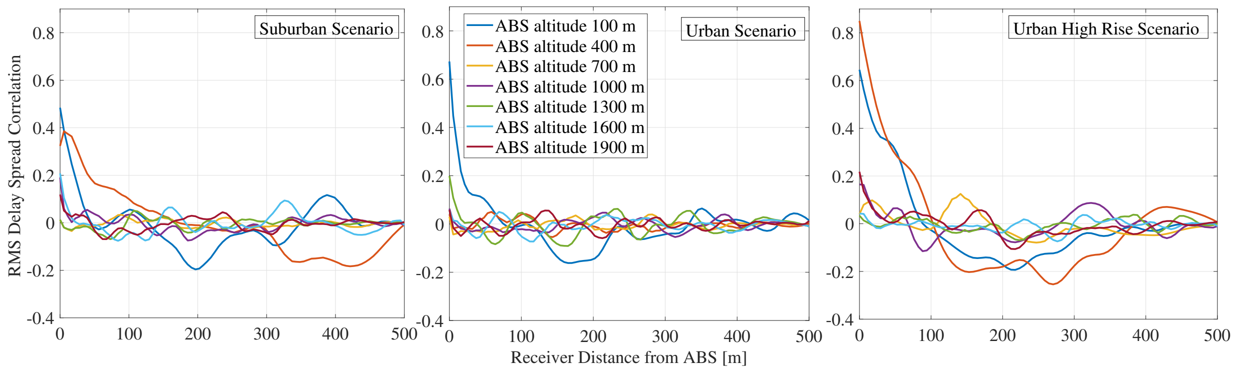

Fig. 2. Spatial Correlations of RMS delay spread vs receiver distance.

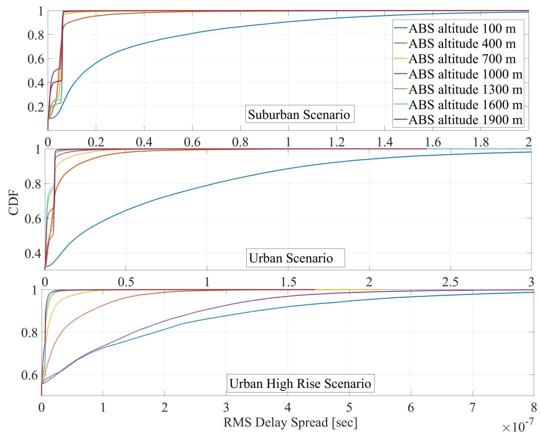

Fig. 3. Cumulative Distribution function of RMS delay spread.

Urban High Rise scenarios, which leads to better performance in Suburban zones. Similarly, the Rxs far from ABSs with higher ABS altitudes should expect better performance. However, expectation of IID fading channel has to be optimized with the transmission power of ABS for best system performance, since for longer link distances between ABS and Rxs, transmission power will be less. A different result was observed in shadowing correlations with respect to ABS altitudes and environments in [11]. However, certain anomalies can be seen at ABS altitude equal to 1000 m in Suburban scenario in Fig. 1 (a), ABS altitude at 400 m and 1700 m in Urban and Urban High Rise scenarios, respectively in Fig. 1 (b). These are due to the stochastic nature of channel modeling, with certain constructive or destructive interference in multipath channels for a randomly generated city scenario, even following a map-based approach. Also, a smooth behavior can be observed in Urban High Rise and Urban environments, as compared to Suburban, particularly for lower ABS altitudes with high correlation and anti-correlation values. This is probably due to different fading in A2G links as seen in [11]. The Suburban scenarios tend to follow Rayleigh fading due to higher scattering losses while Urban and Urban High Rise follows a Rician fading due to better LoS probability in A2G, which is different from terrestrial networks.

Similarly, Fig. 2 shows the SC of Root Mean Square (RMS) of DS w.r.t. Rx distance from ABS at different ABS altitudes and environments. The RMS DS is an important factor for transceiver design as it addresses the nature of the fading channel, i.e. flat or frequency-selective fading channel, causing inter-symbol interference. The pattern of the results are similar to Fig. 1. However, the value of correlation is much lower at higher altitudes of ABS, except for Urban High Rise scenario where DS correlation is lower for ABS altitude equal to 100 m. This is due to the lower ABS altitude than the building heights in the scenario, which leads to higher scattering and multipath effects, thereby creating bigger differences in mean DS values for far and near Rxs to ABS.

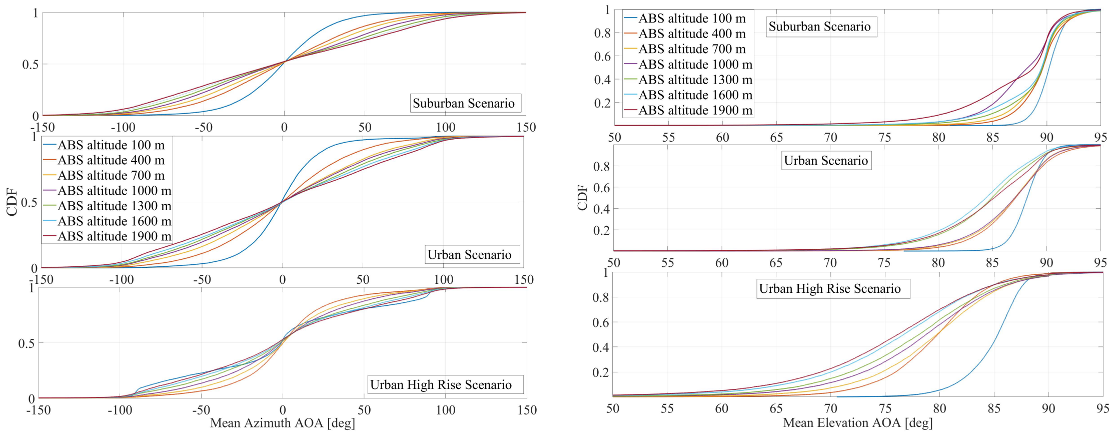

Fig. 4. CDFs of Azimuth AoA (left) and Elevation AoA (right) vs ABS altitude.

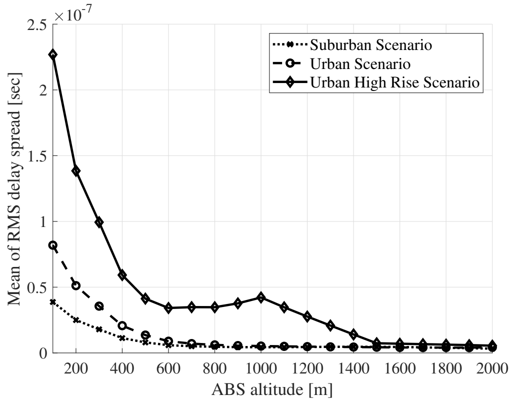

Fig. 5. Variation of the exponential probability distribution parameter of RMS DS vs ABS altitude.

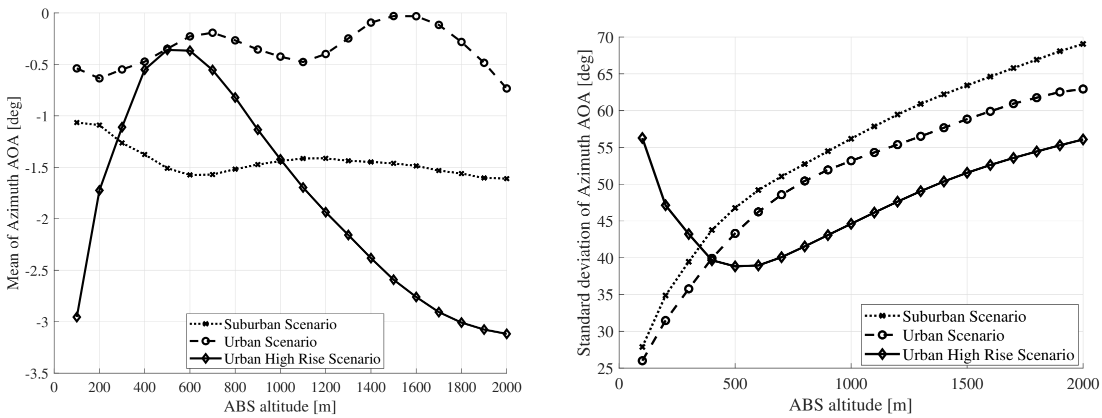

Fig. 6. Mean and Standard Deviation of Azimuth AoA vs ABS altitude.

Figs. 3 and 4 display the CDFs of DS and AoA, respectively for different ABS altitudes and scenarios. Here, unlike SC, the results obtained for CDF are not along one direction but for the Rxs in a complete snapshot. Also, the figures have been scaled for a clear interpretation of the curves, w.r.t. ABS height. In Fig. 3, a significant difference for CDF

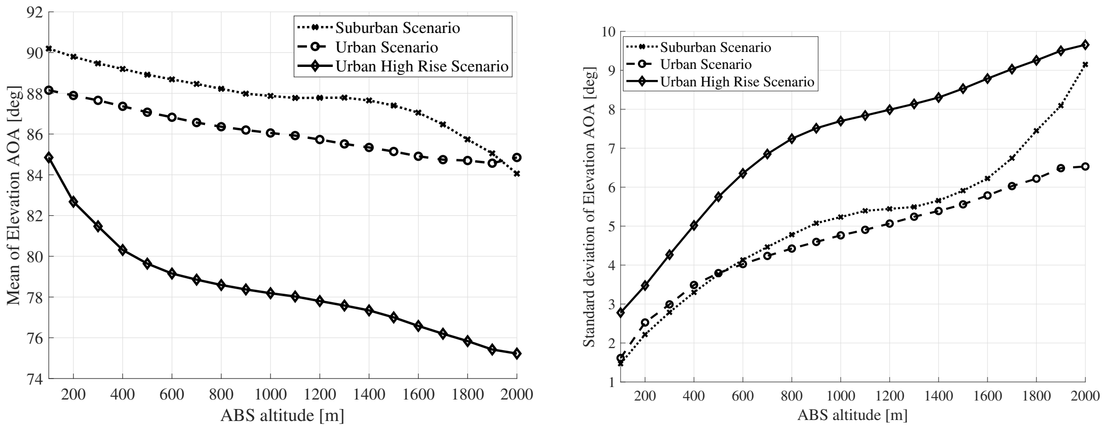

Fig. 7. Mean and Standard Deviation of Elevation AoA vs ABS altitude.

values between lower and higher ABS altitudes was observed for Suburban and Urban scenarios. This means that at lower ABS altitudes, the probability of DS lower than a specific value of DS is much less. Therefore, the DS is higher for lower altitudes of ABS due to heavy scattering and diffraction, leading to Rayleigh Fading A2G channel. As the height of ABS increases, with high probability of LoS, a Rician fading behavior is seen with lower DS values. However, at Urban High Rise scenario, along with low ABS altitudes, large DS values were seen and expected at high altitudes as well. This is probably due to higher building densities and heights, which further increase the multipath effects. Also, the CDFs are closely spaced in Suburban scenario rather than higher differences in Urban High Rise and intermediate difference in Urban scenarios. Figs. 4 show the CDF for A-AoA and E-AoA, respectively. These CDFs were obtained in the same way as DS CDFs, by using ray tracing simulation results for the entire snapshot. Also, here the result for Suburban and Urban scenario at low ABS altitude is different from Urban High Rise. In Fig. 4 (left), the values of CDFs are monotonically increasing with ABS altitudes for negative A-AoA, and monotonically decreasing for positive A-AoA, for all environments. However, such pattern cannot be observed for E-AoA in Fig. 4 (right). From E-AoA CDFs, the variation in elevation angles with ABS altitude can be interpreted: for the low altitudes of ABS, E-AoAs are higher, ranging from 80-95 degrees in Urban High Rise scenario and more than more than 85 degrees in Suburban and Urban scenarios. As the altitude of ABS increases, the elevation angle decreases. According to the simulation setup, the maximum elevation angle at the Rxs should be 90 degrees. However, due to several reflections and scattering effects in multipath fading environments, E-AoAs higher than 90 degrees were observed.

The SSPs discussed in this article, are considered to follow several probability distributions for different ABS altitudes and scenarios, which are not similar to the terrestrial communications. The statistical parameters such as mean (μ) and standard deviation (σ) have been provided in Figs. 5-7 for all ABS altitudes and environments, to re-create the results for transceiver design and clear understanding. Further, the probability distributions pertaining to these SSP parameters are provided in Table. 1. From Fig. 5, μ follows a decaying trend as the ABS altitude increases due to higher LoS probability [16] and lower multipath effect with A2G channel turning more Rician than Rayleigh. The RMS DS is larger in High Rise environments as well due to higher scattering effects. However, for A-AoA, μ follows rather a constant behavior, except in Urban High Rise environment in Fig. 6. This irregular trend is due to large buildings heights. When ABS is at lower altitudes, the cellular coverage is less [16] because of excess fading. However, increase in altitude reduces fading effects until an optimal altitude [16]. On the contrary, σ for Suburban and Urban scenarios follows an increasing trend with ABS altitude due to the increase in cell coverage and it follows an inverse trend than μ in Urban High Rise. This is mostly due to more adverse multipath effects in the environment. From Fig. 7, E-AoA follows a straightforward trend. Its μ decreases and σ increases due to decrease of link elevation angle between Rx and ABS with ABS altitude. Furthermore, as for higher multipath fading effects, μ is smaller and σ is larger for High Rise scenarios.

Since ABSs have become a significant targeted application in 5G, these parameters can be used by researchers for waveform, frame structure and numerology design for LTE, LTE-Advanced or LTE-Pro technology based transceivers.

However, validation of these parameters with experimental measures is necessary before implementation for ABSs, in order to remove any errors pertaining to software calculations.

Table 1. Probability Distributions.

Small Scale Parameter	Type of Distribution
RMS Delay Spread	Exponential
Mean Azimuth Angle-of-Arrival	Normal
Mean Elevation Angle-of-Arrival	Normal

5. Conclusion and Future Work

In this article, we have discussed fading channel characterization for Air-to-Ground channel for Low-Altitude-Aerial-Platforms, such as Unmanned Aerial Vehicles, equipped with base stations. Such Aerial Base Station (ABS) provide cellular network to ground users and this is one of the targeted application in 5G. Here, channel measurements have been performed in a commercial ray tracing simulator, on standard Suburban, Urban and Urban High Rise environments, developed in a computer-aided-design software according to ITU-R defined parameters. Experimental validations and drone movement addressing the Doppler effect is part of our future work. The details of small scale parameters such as delay spread and angle-of-arrival have been discussed, by providing spatial correlations at ground receivers and cumulative distribution functions of simulation snapshots, at different ABS heights and environments. Probability distribution parameters have been provided with mean and standard deviation for the considered SSPs, which can be utilized by researchers for transceiver design of ABSs. For fulfilling 5G requirements, multiple ABSs integrated with terrestrial network operating at millimeter-wave and sub-6 GHz frequency bands are needed, for which appropriate channel models need to be designed along with their validation in realistic environments.

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