A Stochastic Ray-Based Model for UAV-to-Ground Radio Channels in Built-Up Environments

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Abstract

A stochastic ray-based model is applied to model the UAV-to-ground radio channel in urban areas. The modeling method relies on simple input data, such as input distribution parameters (e.g. mean building height, building height variance). The physical part of the model being based on ray-tracing, it is also applicable over very wide parameter ranges at a very low computation time thanks to a pre-calculation procedure.

1. Introduction

Unmanned Aerial Vehicle (UAV) communications have attracted a significant interest over the past years [1], as UAVs can be used as surrogate base stations or flying mobile terminals. Yet, important challenges still need to be investigated. In particular, radio channel models have mostly focused on the Air-to-Ground (A2G) path loss [2], with very results dealing with large- and small-scale fading. In this paper, a fading model is presented that tackles the fading model while linking the geometrical parameters with the fading statistics in a physical way, as detailed in Section 2. Experimental validations are outlined in Section 3.

2. UAV-to-Ground Fading Model

2.1. Generic Modeling Setup

In most cases [3], stochastic geometrical predictions can be analytically formulated. In this paper, the narrowband fading s is modelled by means of the following distribution:

$$p(s) = \int_{\Psi} p(s|\psi) p(\psi) d\psi \qquad (1)$$

where ψ is a vector of input geometrical parameters, Ψ representing the whole set of possible parameters (building height and spacing, street width, link elevation angle, etc.). The conditional distribution $p(s|\psi)$ represents the (Ricean) fading distribution for a given realization of ψ. Such given realization of ψ generates a simulation area, described in Figure 1.

The geometrical parameters are defined as follows:

- w [m] is the street width at the terminal location (the width of other streets is taken as the average street width and denoted as w_0),

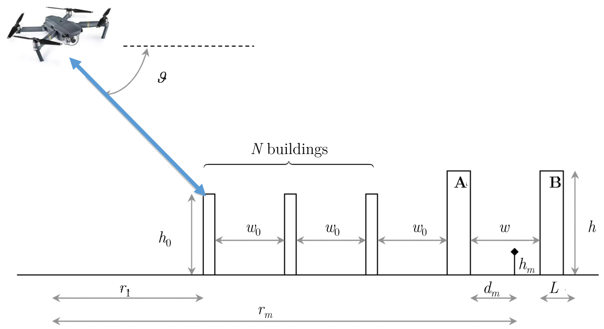

Figure 1: Simulation setup.

- d_m [m] is the perpendicular distance from the terminal to the nearest building,
- h [m] is the nearest building height (the height of remote buildings is taken as the average building height h_0),
- h_m [m] is the height of the terminal antenna,
- r_m [m] is the UAV-to-terminal distance,
- r_1 [m] is the distance between the UAV and the first building,
- ϕ is the link azimuth angle relative to the street axis (this angle is not represented in Figure 1, which corresponds to $\phi = 0$),
- L [m] is the width of the nearest buildings (which can be fixed without loss of generality, e.g. $L = 5$ m), while the N other buildings are assumed to have a null width.

2.2. From an Electromagnetic Ray-Based Model to Ricean Fading

The conditional relationship $p(s|\psi)$ is evaluated from the application of a physical ray-based model. Four propagation mechanisms are included: (1) line-of-sight (LOS) transmission, (2) rooftop to street single wedge diffraction by rooftop wedge **A**, (3) rooftop to street single wedge diffraction by rooftop wedge **B**, (4) multiple diffraction caused by successive building knife-edges, and (5) contributions arising from single and double reflections from the ground and/or the nearest building walls, which might also possibly include diffuse components.

The radio signal transmitted from the UAV is assumed to be a plane wave with a given polarization to be specified. The above-listed field contributions can then be estimated by means of geometrical optics as well as the Uniform Theory of Diffraction. Regarding multiple diffraction, it is recommended to use $N = 10$ and 15, respectively in suburban and urban areas [3]. From the electromagnetic simulations, which can be pre-processed and tabulated for every set of parameters $\psi \in \Psi$, a Ricean fading model is considered, i.e. $p(s|\psi)$ is Ricean, with a dominant path amplitude equal to contribution (1) or (2) (the latter being considered when the LOS transmission is blocked), whereas the scattered multipath power is obtained as the non-coherent addition of all other power contributions (i.e. (2) to (5) or (3) to (5), in LOS and non-LOS respectively).

2.3. Geometrical Parameter Distributions

Street width or building height can be associated with known analytical probability density functions. As an example, building height has been found to be lognormally-distributed [3],

$$p(h) = \frac{1}{\sqrt{2\pi}\sigma h} \exp\left[-\frac{\log^2(h/\mu)}{2\sigma^2}\right] \qquad (2)$$

with parameters outlined in Table 1.

Table 1: Building height lognormal fitting parameters.

Environment	μ [m]	σ
Suburban	7.1	0.25
Urban (London)	20.6	0.44
Urban (Athens)	15.0	0.30
Urban (Brussels)	17.6	0.31

3. Experimental Validation

First-order fade statistics provided by the model are compared with measurements from an airborne campaign carried out by the European Space Agency [4] at 1.6 GHz. In the experiment, the mobile platform moved parallel to the measurement vehicle, at various elevation angles, in a suburban residential area with detached two/three-storeyed houses, 10-20 meters distant from the road. Hence, a suburban building height profile and constant values for $w = w_0 = 30$ m and $\phi = 0$ (ϑ depends on the experiment) are chosen as input parameters (note that the building height data are not taken directly from the measurement site). The receiver is assumed to be located in the middle of the street (so that $d_m = w/2$) at a height $h_m = 2$ m.

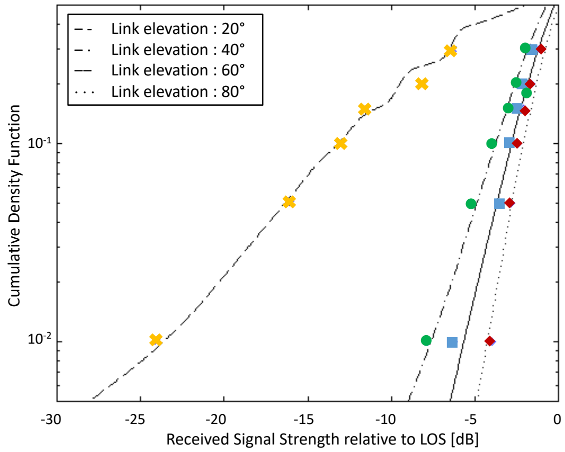

Figure 2: Comparison between simulation (dashed, dot-dashed, solid and dot lines) and experimental (crosses, circles, squares and diamonds) results at various elevation angles.

In Figure 2 , an excellent agreement between the measured statistics and the model can be observed, and that the model is quite robust to small deviations in the input data (as the chosen building height is a generic suburban profile).

4. Conclusions

A physical-statistical model of the UAV-to-Ground channel has been described and experimentally validated. The fading model relies on the combination of ray-based pre-processed simulations and stochastic input data corresponding to the (sub)urban setup. The model is able to represent the variation of fading statistics with the link elevation angle and is robust with respect to the exact distribution of physical parameters.

References

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