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# Channel Modelling for UAV Air-to-Ground Communication

Valencia Lala  
*Electronic Information and  
Communications  
HUST*  
Wuhan, China  
lalasoavalencia@gmail.com

Feno Heriniaina R.  
Studio A,  
Antananarivo, Madagascar  
fenoheriniaina@studio.mg

Andrea F. Ndreveloarisoa  
*National Engineering School of Tunis*  
Tunis, Tunisia  
andrea.ndreveloarisoa@gmail.com

Nour Mohammad Murad  
*PIMENT, IUT*  
*University of La Réunion*  
Saint Pierre, La Reunion  
nour.murad@univ-reunion.fr

Wang Desheng  
*Electronic Information and  
Communications  
HUST*  
Wuhan, China  
dswang@hust.edu.cn

Glauco Fontgalland  
*School of Engineering  
University of Mount Union  
Alliance, USA*  
fontgagl@mountunion.edu

Blaise Ravelo  
*NUIST*  
Nanjing, China  
ORCID: 0000-0001-7334-5016

**Abstract**— After a brief literature review, this paper presents the main advantages and drawbacks of UAV and IoT cellular network communication. Nowadays, UAVs are increasingly exploited in urban environments. However, optimizing the performance of UAV-BS cellular networks for coverage remains a significant challenge for communication system design engineers. For this reason, the air-to-ground (A2G) and ground-to-air (G2A) wireless propagation channels are analytically modeled by identifying the optimal geometrical position. This paper investigates channel communication modeling in urban environments. Different cases parameterized by the coverage zone radius, assumed as the A2G channel for two different scenarios, are simulated by assessing the line-of-sight (LOS) probability (PLOS) and path loss. The obtained results enable the identification of the optimal elevation angle corresponding to the expected PLOS and the optimal altitude for minimal path loss. UAV-BS cellular network performance is illustrated, emphasizing that the UAV cellular network is potentially useful for monitoring and remote control.

**Keywords**— *Wireless communication system, Cellular network, UAV deployment planning, 5G network, Path loss, UAV base station, Air-to-ground (A2G) channel modeling*

## I. INTRODUCTION

In recent years, the use of UAVs in wireless communications has garnered widespread attention [1-4]. Urban social events, often attended by large crowds, demand reliable mobile device connectivity. Ground-based base station (BS) deployments are often unsuitable for these scenarios due to potential underutilization when events are not occurring. As a solution, deploying UAVs as base stations (UAV-BSs) offers a flexible and efficient alternative to meet the fluctuating connectivity needs.

### A. Brief State of the Art on UAV-to-Infrastructure Communication Network

A concept of multi-layer operation of UAV-BS cellular network as illustrated by Fig. 1 was proposed [5]. It acts as an intelligent deployment of UAVs in 5G heterogeneous communication environment for the improved coverage [6].

A survey and various protocols for classification and associated architectures of UAV-assisted 5G and beyond wireless networks are illustrated in Fig. 2 and Fig. 3, respectively, as proposed in [7]. An overview on reinforcement learning algorithms [8] and planning wireless cellular networks [9] can be found. During an emergency or disaster situation, a drone can be used as a BS if the ground installation is destroyed or if the required services are not available.

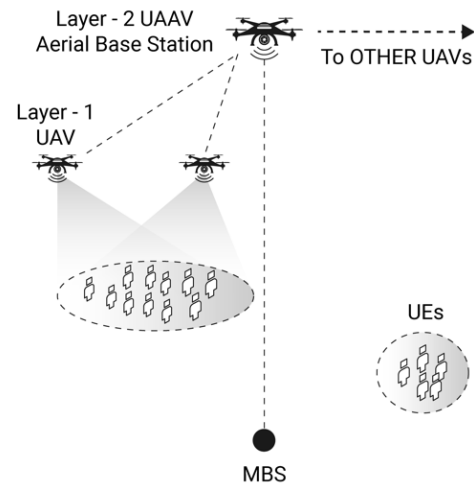


Fig. 1. Illustration of the multi-layered network formation with UAVs [24].

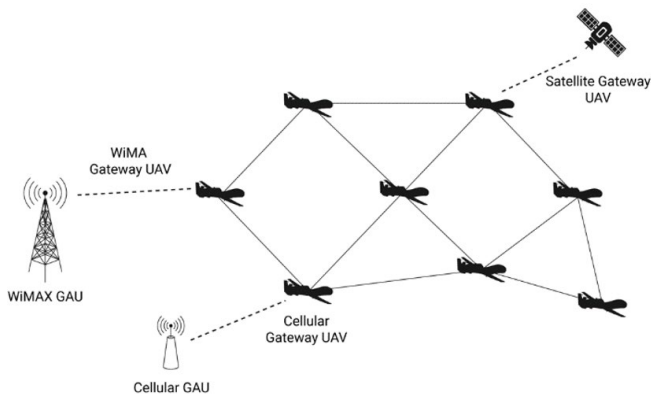


Fig. 2. Network of UAV-to-UAV (U2U) and UAV-to-Infrastructure (U2I) communication [7].

The UAVs can also be used as trunks where some improvements are required for the performance of existing networks. Using a drone as a wireless communication node as a relay or BS can reduce operating costs.

Besides, deploying UAV-BS is simpler and more flexible than traditional BS. Nowadays, research work enabling to plan the deployment of UAV-BSs in 5G cellular networks are still required.

The performance of UAVs as BSs is affected by undesirable effects such as loss and delay [10]. Further research work is expected to improve the communication quality.

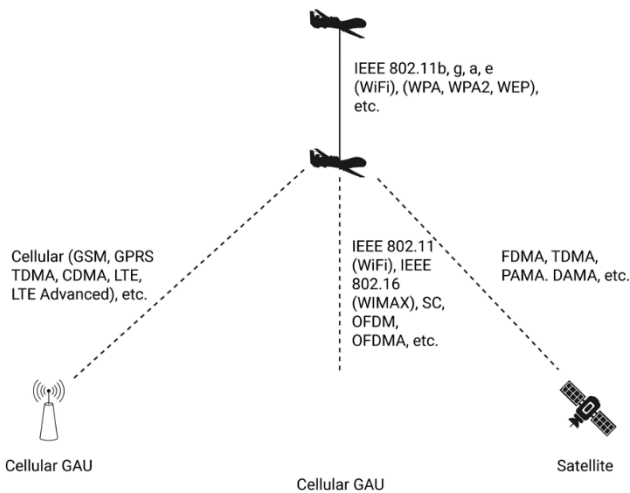


Fig. 3. Various protocols at different links of the UAV communication system hierarchy [7].

Therefore, should be evaluated as briefly reviewed in the next subsection.

### B. Brief Review on Channel Modelling with UAV Based Communication Network

The characteristics of the A2G are different from ground communication channels and can determine the performance of UAV aerial BS in terms of coverage and capacity [10].

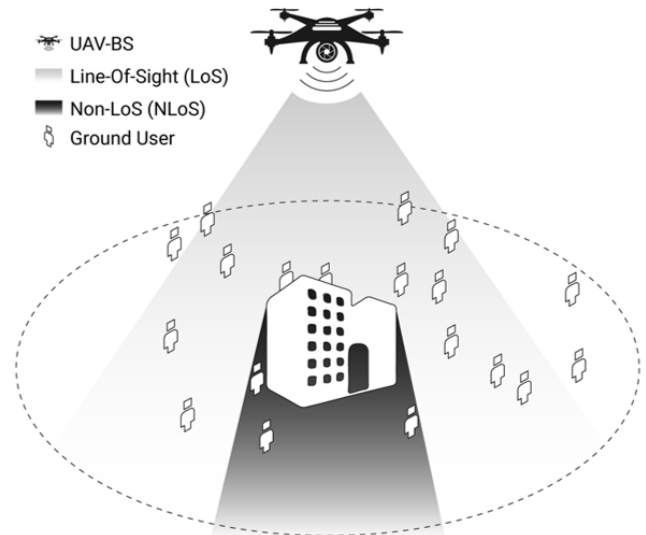


Fig. 4. Scenarios illustrating LOS and NLOS of A2G channel [11].

A2G channels are more vulnerable to interference than air-to-air communication links that have a dominant line-of-sight (LOS) and non-LOS (NLOS) as presented in Fig. 4 [11]. The path loss between a UAV and a ground user depends on the UAV and the ground device locations as well as the type of propagation environment such as rural, suburban, urban, and dense urban [10]. Generally, channel model for UAV could be classified as ground to UAV (G2A) model, UAV to UAV (A2A) model and UAV to Ground (A2G) model [1-4,12]. The A2G models play a fundamental role during the design of UAV-BS cellular network communication by optimizing the coverage area [13-14].

Different wireless propagation models were developed, and they can be categorized by [13-21] as:

- Statistical first or second order model,
- Theoretical or analytical model,
- And empirical model, and so on.

To deploy and design UAV-based communication systems, the use of a specific A2G channel model is required. The work [22] provided an overview of the research related to A2G channel modeling.

In [23], the authors presented simulation and measurement results for path loss, delay spread, and fading in A2G communications. In [24], the probability of LOS links for A2G communication was calculated based on the elevation angle and average height of buildings in urban areas. Besides, some studies based on UAV-to-ground channel modeling measurements have identified some key features of the channel characteristics [25]. The overall cellular network system model can be improved with UL and DL radio link optimization techniques [26-27].

### C. Main Aim of the Present Study

The present research work is focused on the investigation on UAV and BS wireless communication modelling under LOS link. The originality of the study lies on the UAV-BS wireless communication context of urban environment scenarios. The main aspects treated in the paper are:

- The modelling considers a simplex case enabling to understand how the communication quality depends on the channel loss probability.

- As a proof-of-concept illustrating the modelling feasibility study, different cases of A2G downlink communication channel modelling results are discussed by means of MATLAB® programming.

## II. ANALYTICAL DESCRIPTION OF A2G COMMUNICATION CHANNEL MODELLING

The basic analytical approach on the A2G communication channel is elaborated in this section.

### A. A2G Channel Modelling Parameters Definition

The analytical modelling of A2G channel requires a consideration of (Oxyz) cartesian system.

The UAV 3-D positioning enables the placement of each drone unit within the space. It acts as a geometrical 3-D problem and can be considered a cartesian system, as shown in Fig. 5. The considered parameters constituting the A2G channel model are listed in Table I. As presented earlier, the channel model for aerial BS differs from the A2G channel model. In this work, the path loss model of the A2G channel will consider the LOS and NLOS channels.

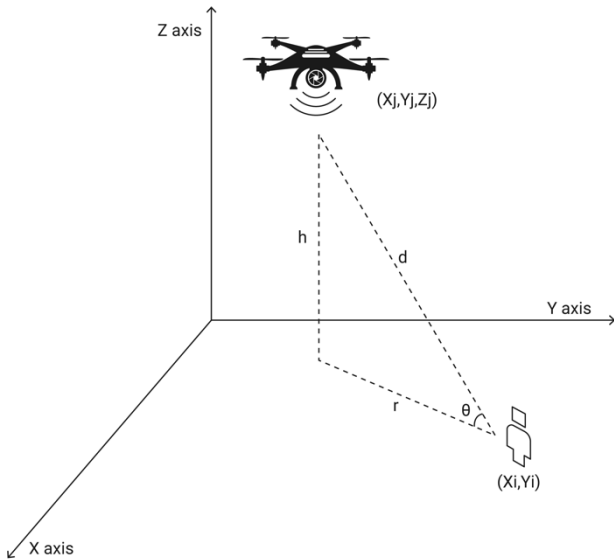


Fig. 5. Geometric representation of A2G channel with UAV and ground mobile communication device user.

TABLE I. LIST OF CONSIDERED PARAMETER NOTATIONS FOR THE A2G CHANNEL MODELLING

Notation	Description
$a, b$	Constant values depending on the environment
$\theta$	Elevation angle between user and UAV-BS
$h$	Altitude of the UAV-BS
$r$	Horizontal distance between UAV-BS and user
$f_c$	Carrier frequency
$c$	Light speed
$\eta_{LOS}$	Average additional loss of free space propagation for LOS link
$\eta_{NLOS}$	Average additional loss of free space propagation for NLOS link

The approach constitutes the suitable way to model the channel for UAV-based communication. The probability of LOS can be formulated as follows [29,30]:

$$P(LoS, \theta) = \frac{1}{1 + a \exp\left[b\left(a - \frac{180}{\pi}\theta\right)\right]}$$

(1)

Equation (1) shows that the probability of LOS depends on the elevation angle  $\theta$  and the environment (rural, suburban, urban, dense urban, etc ...) parameters  $a$  and  $b$ .  $a$  and  $b$  are called the S-curve parameters. The value of  $\theta$  is given by  $\arctan(h/r)$  and it ranges from 0 to 90° angle.

The probability of NLOS is given by:

$$P(NLoS) = 1 - P(LoS) \quad (2)$$

The path loss modelling using the introductory parameters is proposed in the next subsection.

### B. Path Loss Model

In addition to the probability of LOS and NLOS, the path loss depends on various parameters such as the distance between the UAV-BS and the users:

$$z = \sqrt{h^2 + r^2} \quad (3)$$

free space propagation loss:

$$L_{dB, free} = 20 \log\left(\frac{4\pi f_c \sqrt{h^2 + r^2}}{c}\right) \quad (4)$$

and the additional loss ( $\eta_{LOS}, \eta_{NLOS}$ ) which depends on the environment. After knowing how to increase the probability of LOS, the path loss model appropriate to the model is given as follows:

$$L_{dB} = \left[ 20 \log\left(\frac{4\pi f_c}{c}\right) + 10 \log(h^2 + r^2) + \eta_{LOS} P(LoS) + \eta_{NLOS} P(NLoS) \right] \quad (5)$$

In cellular communication systems, the UAV-BS representation can be deemed as new access node layers. There is no need to change the transmission power to create different coverage areas because the coverage can be adjusted by changing the height of the UAV-BS. To illustrate the effectiveness of the analytical model, an application case will be presented in the next paragraph.

## III. STUDY CASE OF A2G CHANNEL MODELLING IN URBAN ENVIRONMENT

An example of an urban environment study case is presented in this subsection.

### A. Specifications of the Urban Environment Scenario

The overall objective of this work is to model the communication channel in an urban environment using aerial BSs. The A2G channel model is useful to find the minimum number of the UAV-BSs needed to serve the users based on their traffic requirements. It considers the capacity and coverage constraints, UAVs battery life, and the average spectral efficiency. The urban environment simulations were performed using MATLAB® software to evaluate the A2G channel modelling performance. Table II indicates the parameters considered for different categories of urban environments.

TABLE II. CONSIDERED PARAMETERS OF DIFFERENT URBAN ENVIRONMENT SCENARIOS

Environment	$a$	$b$	$\eta_{LOS}$	$\eta_{NLOS}$
-------------	-----	-----	--------------	---------------

Suburban	4.88	0.43	0.1	21
Urban	9.61	0.16	1	20
Dense urban	12.08	0.11	1.6	23
High-rise urban	27.23	0.08	2.3	34

By taking that range as the elevation angle value  $\theta$ , Fig. 6 shows the variation of the probability of LOS. The obtained result demonstrates that for any environment, the probability of having the LOS link depends on the elevation angle  $\theta$ .

When the value of  $\theta$  increases, the probability of LOS increases too which also means that if the horizontal distance ( $r$ ) between UAV-BS and users is fixed by increasing the UAV-BS altitude ( $h$ ), the probability of LOS will increase.

In addition to the UAV-BS wireless communication probability of LOS, the path loss modelling was also investigated. The computed results are discussed in the next subsection.

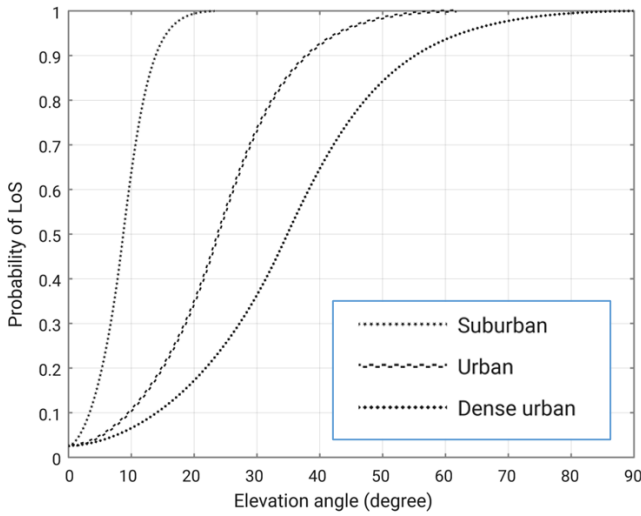


Fig. 6. Probability of LOS versus elevation angle.

### B. Simulation Results Illustrating the Path loss versus UAV altitudes

In this study case, the MATLAB® simulation of path loss was performed based on equation (5). Accordingly, Fig. 7 displays the variation of the A2G channel path loss for urban environment by letting the area zone radius value indicated of  $r = \{100 \text{ m}, 300 \text{ m}, 500 \text{ m}\}$  and frequency carrier  $f_c = 2 \text{ GHz}$ .

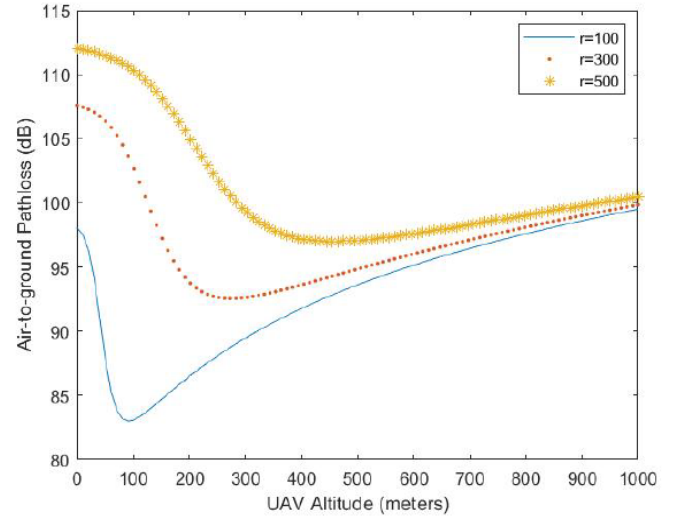


Fig. 7. Path loss versus UAV altitude.

The UAV-BS wireless communication results plotted in Fig. 7 provide valuable insights into the optimal altitude  $h_c$  in relation to the urban zone radius  $r$ . The behavior of the calculated results highlights on the following interesting remarks:

- Initially, the A2G channel path loss decreases as the UAV altitude increases, reaching an optimal altitude  $h_c$  where the path loss is minimal, as shown in Table III.
- Beyond this optimal altitude, further increases in UAV altitude lead to an increase in path loss.

TABLE III. OPTIMAL ALTITUDE AND MINIMAL PATH LOSS VERSUS COVERAGE AREA ZONE RADIUS

$r$ (m)	100	300	500
$h_c$ (m)	97	270	460
$L_{min}$ (m)	83	92	97

Additionally, the following observations can be made from the modelled results of UAV-BS A2D communication:

- At low altitudes, the probability of a NLOS connection is higher than a LOS link. It can be pointed out that this finding is essentially due to additional losses from NLOS links and other interfering objects.
- The path loss is minimized when the UAV-BS attains the optimal altitude.
- Beyond the optimal altitude, path loss gently increases, though not as significantly as at lower altitudes, due to the increasing distance between the transmitter and receiver.

## IV. CONCLUSION

Despite technological progress, many challenges in UAV base station design, especially regarding wireless communication coverage, must be overcome. Cellular network planning with UAVs is crucial for enhancing network efficiency and reliability. This study synthesizes the goals of 5G technology, drone UAV regulation, classification, and optimal deployment of UAV BS cellular networks. Key characteristics needing improvement for optimal UAV-based

cellular network performance include trajectory optimization, energy efficiency, and resource management.

This research proposes an applicative study of A2G wireless channel modeling for UAV-BS cellular networks. It provides a bibliographical summary on A2G channel modeling, highlighting issues related to UAV BS design in urban environments. Various urban environments using UAV-BS networks are analyzed through MATLAB® modeling and simulation of A2G wireless communication channels for sports events.

The present research opens promising avenues for the future generation of UAV-BS-based wireless network technology. The A2G channel modelling graphical analysis of high rise urban constitutes now our ongoing research work.

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