UAV wireless communications performance in urban environments

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ABSTRACT

As the adoption of UAVs grows steadily, more and more applications are being devised. In the scope of urban environments, initiatives like U-Space in Europe seek to standardize and regulate the different operations that can be undertaken by these aircraft. However, we find that accurate communication models are lacking that accurately represent urban environments in detail. In particular, the obstacles created by tall buildings are prone to interfere with communications, no matter whether these are UAV-to-UAV communications, UAV-to-GCS communications, or even communications between UAVs and ground vehicles (mobile). Hence, in this project we seek to study the impact of communications and obstacle models on UAV transmissions in urban environments by using the OMNeT++ simulator, importing detailed obstacle models from OpenStreetMap. This study aims to offer a better understanding of the expectable performance for applications in such scenarios, and the impact of flight altitude and building height.

CCS CONCEPTS

• **Applied computing → Avionics**; • **Networks → Cyber-physical networks**.

KEYWORDS

UAV; wireless performance; ArduSim; urban environments

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1 INTRODUCTION

The remainder of this paper is organized as follows: Section 2 will discuss other related works. Section 3 will provide an overview of the problem, and the main challenges involved. Next, section 4 will describe the methods used, and the experiments performed to validate the solution. Afterwards, the results of these experiments will be discussed in section 5. This paper will be concluded in section 6 with some future works.

2 RELATED WORKS

While there have been numerous studies on the impact of propagation models on the communication performance of ad hoc networks, such as VANETs and MANETs, there is a lack of research on the impact of these models on the performance of FANETs, which include both aerial and ground communication.

The study presented in [6] evaluates routing protocols and propagation models in VANETs to enhance communication reliability and efficiency. The authors use a realistic scenario from OSM and conduct simulations using SUMO and NS-3. The results show that the Two-Ray Ground and FRIIS propagation models outperform other models tested. However, one limitation of this study is that the movement of nodes was random, which may not accurately reflect real-world conditions.

The study presented in [11] investigates the performance of three radio propagation models (RPMs) - Free Space propagation, Two Ray Ground propagation, and Nakagami propagation - in Vehicular Ad-hoc Networks (VANETs). The primary objective of the study is to evaluate packet loss, throughput, and average end-to-end delay between vehicles by implementing different RPMs. To conduct the research, the authors utilize several software tools, including Java OpenStreetMap (JOSM), Simulator of Urban Mobility (SUMO), Mobility Model Generator for VANET (MOVE), and Network Simulator Version 2 (NS2), to obtain a detailed performance analysis of RPMs in VANETs. The study finds that the performance of RPMs can vary depending on the targeted traffic area and environmental conditions.

The study in [7] investigates how three different radio propagation models and mobility affect the performance of the Optimized Link State Routing (OLSR) protocol in Sparse and Dense scenarios in Mobile Ad-hoc Networks (MANETs). The research uses performance metrics such as packet drop, latency, and throughput to evaluate the impact of propagation models and mobility on OLSR. The simulations are conducted in NS-2, and the results demonstrate that the choice of propagation model and mobility significantly affect the performance of OLSR in the considered scenarios. The study concludes that selecting an appropriate propagation model and considering mobility is critical to achieving optimal performance in MANETs, particularly in Dense scenarios.

The study in [8] evaluates the performance of three radio propagation models used in Mobile Ad hoc Networks (MANETs) by analyzing their performance under varying mobility and traffic

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parameters. The research focuses on the impact of these models on the Destination-Sequenced Distance Vector (DSDV) routing protocol and uses Network Simulator-2 to simulate performance metrics such as average network delay, delivery ratio, throughput, and packet drop ratio over the mobility parameter speed. The results demonstrate that the three models exhibit different performance characteristics under the same traffic and mobility conditions, with the Shadowing model showing a higher data sending ratio at higher mobility speeds than other models. However, the Shadowing model also exhibits longer and more consistent average delay and drops more data packets than other models at high mobility speeds.

The study presented in [2] compares the performance of four ad hoc routing protocols - Ad hoc On-demand Distance Vector (AODV), Dynamic Source Routing (DSR), Dynamic MANET On-demand (DYMO), and Optimized Link State Routing (OLSR) - under different radio propagation models in a real urban map for Intelligent Transportation System (ITS) applications. The authors note that previous studies on this topic have not been realistic for vehicular networks or urban environments, which limits their accuracy. The evaluated metrics were the Packet Delivery Rate and End-to-End Delay, which were measured using the Omnet++ and SUMO simulators.

The previous studies did not examine how propagation models affect communication performance in FANETs, specifically in UAV-to-UAV and UAV-to-GND scenarios. Therefore, this study seeks to address this gap by exploring how different propagation models impact FANET performance in both aerial and ground communication scenarios.

3 PROBLEM OVERVIEW

4 EXPERIMENTAL SETUP

4.1 Propagation Models

This section describes the propagation models used in this work.

A. *Free Space*

Free space propagation mode refers to the way in which electromagnetic waves propagate through space in the absence of any obstacles or obstructions. In this mode of propagation, the electromagnetic waves travel in straight lines and do not interact with any physical medium. This is also sometimes referred to as "line-of-sight" propagation, as the waves travel directly from the transmitting antenna to the receiving antenna without any obstructions in their path. The model characterizing the free-space electromagnetic wave propagation goes back to the work done by Harold T. Friis [5] and The power at the receiver is represented by the following formula:

$$P_r(d) = \frac{P_t G_t G_r \lambda^2}{(4\pi)^2 d^\alpha L} \tag{1}$$

In (1), P_t is the power at TX, the gains of the antennas in TX and RX are G_t and G_r respectively and λ is the wavelength. Last, α is the exponent of the path loss according to the environment. For Free Space the value is 2, which represents a quadratic loss as distance increments. This means that the intensity of the wave decreases exponentially as much as d.

B. *Two Ray Ground*

The two-ray ground reflection model is a simple propagation model used to estimate the path loss of a radio signal propagating between a transmitting antenna and a receiving antenna over a flat Earth surface. In this model, the radio signal travels along two paths: one direct path from the transmitting antenna to the receiving antenna, and another path that reflects off the Earth's surface before reaching the receiving antenna. The two paths combine at the receiving antenna, and the signal power is the sum of the powers of the two paths. This model computes interference in the far-field only and is the same as free space path loss up until a certain crossover distance d_c which can be computed using (3). Equation (2) shows the TRG math, which estimates the signal strength at the receiver when d » ht, hr as read in [10]:

$$P_{rTRG}(d) = \frac{P_t G_t G_r h_t^2 h_r^2}{d^4} \tag{2}$$

$$d_c = \frac{4\pi h_t h_r}{\lambda} \tag{3}$$

In (2), the height of TX and RX are h_t and h_r respectively.

C. *Log-normal Shadowing*

In addition to deterministic models, listed above, is possible to use a probabilistic model like the Log-Normal Shadowing, as found in [10]. In log-normal shadowing, the signal strength at a particular location is modeled as a log-normal random variable. The log-normal distribution is used because it provides a good fit to the observed variations in signal strength over long distances and in different types of environments. The log-normal shadowing model assumes that the signal strength at a particular location is the sum of two components: a deterministic component that represents the signal strength in the absence of obstructions and a stochastic component that represents the variations in signal strength due to obstructions in the environment. The stochastic component is modeled as a normal distribution with a mean of zero and a standard deviation that depends on the distance between the transmitting and receiving antennas and the environment. Equation (4) describes the LNS model.

$$P_{rLNS}(d) = P_r(d_0) - 10\gamma \log_{10}(\frac{d}{d_0}) + X_\sigma \tag{4}$$

The last parameter X_σ is a random variable normally distributed, which represents the randomness of the environment, with zero mean and σ as the standard deviation. To obtain real values of a given environment, empirical experiments must be done, to determine the values of γ and σ.

D. *Rician Fading*

The Ricean fading model is a statistical model used in wireless communication systems to describe the variations in signal strength due to multipath propagation. The Ricean fading model assumes that the received signal is the sum of a strong, line-of-sight (LOS) component and a weaker, scattered component. The LOS component is typically stronger than the scattered component in outdoor environments, while the opposite may be true in indoor environments.

The Ricean fading model is characterized by a parameter called the K-factor, which represents the ratio of the power in the LOS component to the power in the scattered component. If the K-factor is large, then the received signal is dominated by the LOS component, and the fading is said to be Ricean. If the K-factor is small, then the received signal is dominated by the scattered component, and the fading is said to be Rayleigh.

A Rician fading channel can be described by two parameters [1]. The first one, K, is the ratio between the power in the direct path and the power in the other, scattered paths which can be calculated as $K = \frac{v^2}{2\sigma^2}$ and The second one, Omega , is the total power from both paths, and acts as a scaling factor to the distribution: $\Omega = v^2 + 2\sigma^2$.
The resulting Probability density function is

$$f(x) = \frac{2(K+1)x}{\Omega} \exp(-K - \frac{(K+1)x^2}{\Omega}) I_0(2\sqrt{\frac{K(K+1)}{\Omega}}x) \quad (5)$$

where $I_0(.)$ is the 0th order modified Bessel function of the first kind.

E. *Nakagami*
The Nakagami (NAK) model is a continuous probability distribution that provides a good fit to empirical fading measures in various environments. This model relates to the gamma distribution and its name comes from the statistical Minoru Nakagami [9]. The probability density of the amplitude of the envelope is:

$$f(x) = \frac{2m^m}{\Gamma(m)\Omega^m} x^{2m-1} e^{-\frac{m}{\Omega}x^2} \quad (6)$$

where loss of signal intensity is represented by m, known as shape factor, and Ω is the factor that controls the spread of the signal. Furthermore, NAK distribution can graph a Ricean distribution, and a Rayleigh distribution can be defined as a specific case of NAK [2].

To achieve the goal of realistic simulations, empirical studies were sought to obtain the values of the parameters of propagation models and they are depicted in the following table.

Table 1: Simulation Parameters for Propagation Models

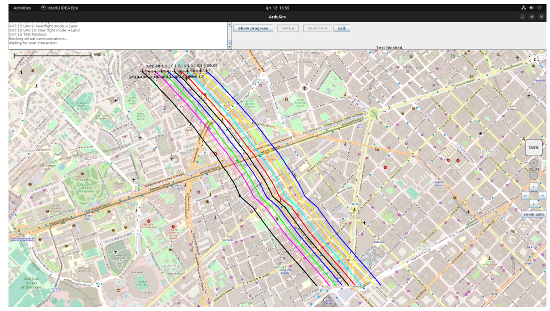
FSP	TRG	LNS	RF	NF
default	default	σ = 6.31 or 8dB[3]	K = 7.6[3]	m = 1.56

Next, we will provide a brief overview of our experimental setup.

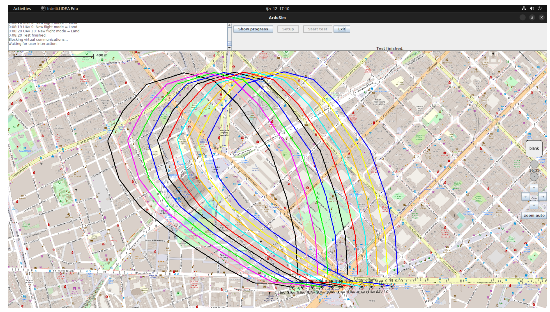
4.2 General Setup

We evaluated propagation models using two simulators: Ardusim [4], a free and open-source multi-UAV simulator that accurately simulates UAV behavior, and OMNeT++, an open-source simulation environment for academic use that includes the framework Inet, which offers various implementations of propagation models, both deterministic and stochastic.

To achieve realistic UAV flight, we used Ardusim to simulate UAV behavior accurately by providing a desired .kml file containing the geographical coordinates of each UAV in a specific location. We obtained this data easily from Google Earth or OpenStreetMap. In the figure below , we can observe UAVs moving in straight and



(a) Staright Path



(b) Curved Path

Figure 1: UAV movement in Ardusim

curved paths, which we will use later for LOS and NLOS scenarios. In this work, we simulated the movement of UAVs at altitudes of 20m, 60m, and 120m.

To create an urban environment, we built a city covering an area of 800m by 800m and including buildings ranging from 50m to 150m in height. The city was created using a .xml file, which allowed us to place basic shapes like cuboids, spheres, and prisms at specific locations and with properties of a specific material, such as concrete. The obstacle file was loaded at the start of the simulation, ensuring that the obstacles remained stationary. A top-down and isometric view of our city is depicted in Fig 4.

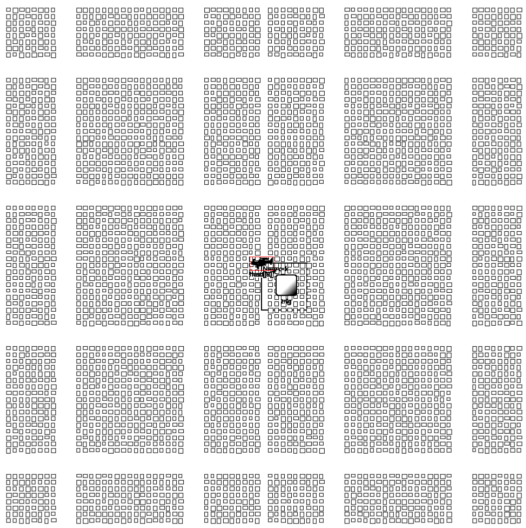
For all experiments, the UAVs move in accordance with the information received from Ardusim, except for the ground (static) nodes. Next, we will provide a brief overview of each scenario.

4.3 UAV to UAV

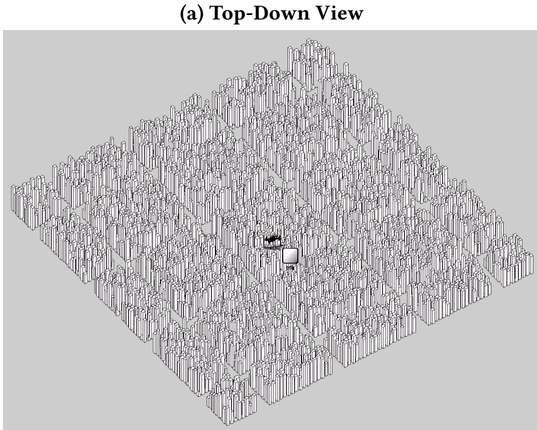
For the UAV-to-UAV experiment, all UAVs move in OMNeT++ along the curved path shown earlier. In this scenario, one UAV acts as the broadcaster, while the others act as listeners. The setup is illustrated in the figure 3.

4.4 UAV to ground station

In this scenario, one UAV acts as the broadcaster, while the other five UAVs act as listeners on the ground. We have placed them with a 100m separation along the roadside. There are two conditions: line-of-sight (LOS) and non-line-of-sight (NLOS). The setup is illustrated in the figure below.



(a) Top-Down View



(b) Isometric View

Figure 2: Urban scenario used

4.5 UAV to vehicle

In this scenario, one UAV is broadcasting while the other five UAVs are acting as receivers while moving on the ground. The setup is illustrated in the figure below.

In this illustration, the red car represents a moving vehicle, while the black cars represent static ones. The three dots indicate that there are three other cars between. The black arrow indicates the direction of movement of the moving car.

5 RESULTS

In this section, we

6 CONCLUSION AND FUTURE WORK

In

As future work,

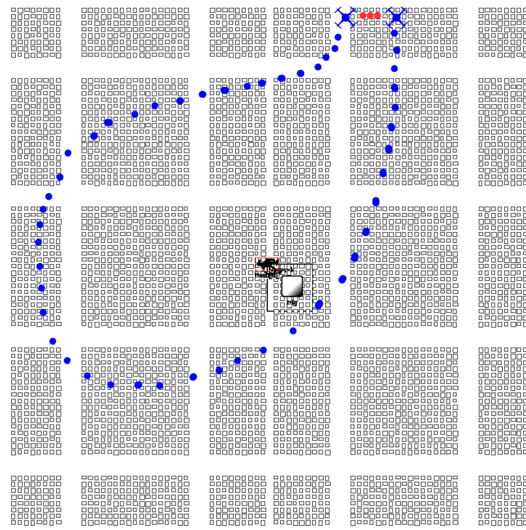


Figure 3: UAV-to-UAV movement

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REFERENCES

[1] A. Abdi, C. Tepedelenlioglu, M. Kaveh, and G. Giannakis. 2001. On the estimation of the K parameter for the Rice fading distribution. *IEEE Communications Letters* 5, 3 (2001), 92–94. https://doi.org/10.1109/4234.913150

[2] William Angeles, Vinicius Pozzobon Borin, Anelise Munaretto, and Mauro Fonseca. 2016. The Impact of Propagation Models in the Performance of Ad Hoc Routing Protocols for Urban VANET. In *2016 IEEE 84th Vehicular Technology Conference (VTC-Fall)*. 1–5. https://doi.org/10.1109/VTCFall.2016.7881251

[3] Zhuangzhuang Cui, Ke Guan, César Briso-Rodríguez, Bo Ai, Zhangdui Zhong, and Claude Oestges. 2021. Channel Modeling for UAV Communications: State of the Art, Case Studies, and Future Directions. arXiv:2012.06707 [eess.SP]

[4] Francisco Fabra, Carlos T. Calafate, Juan Carlos Cano, and Pietro Manzoni. 2018. ArduSim: Accurate and real-time multicopter simulation. *Simulation Modelling Practice and Theory* 87 (2018), 170–190. https://doi.org/10.1016/j.simpat.2018.06.009

[5] H.T. Friis. 1946. A Note on a Simple Transmission Formula. *Proceedings of the IRE* 34, 5 (1946), 254–256. https://doi.org/10.1109/JRPROC.1946.234568

[6] Lopamudra Hota, Biraja Prasad Nayak, Arun Kumar, Bibhudatta Sahoo, and G. G. Md. Nawaz Ali. 2022. A Performance Analysis of VANETs Propagation Models and Routing Protocols. *Sustainability* 14, 3 (2022). https://doi.org/10.3390/su14031379

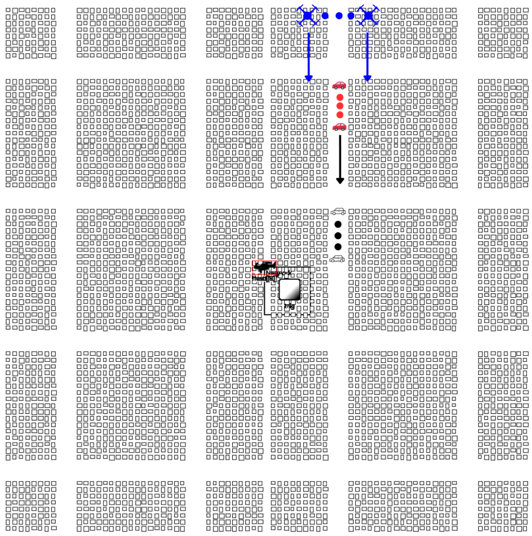
[7] Altaf Hussain, Tariq Hussain, Iqtidar Ali, Muhammad Rafiq Khan, et al. 2020. Impact of sparse and dense deployment of nodes under different propagation models in manets. (2020).

[8] Mahmood Khan, Muhammad Faran Majeed, Amjad Mehmood, Khalid Saeed, and Jaime Lloret. 2020. The Impact of Mobility Speed over Varying Radio Propagation Models Using Routing Protocol in MANET. In *Advanced Intelligent Systems for Sustainable Development (AI2SD'2019)*, Mostafa Ezziyyani (Ed.). Springer International Publishing, Cham, 277–288.

[9] MINORU NAKAGAMI. 1960. The m-Distribution—A General Formula of Intensity Distribution of Rapid Fading. In *Statistical Methods in Radio Wave Propagation*, W.C. HOFFMAN (Ed.). Pergamon, 3–36. https://doi.org/10.1016/B978-0-08-009306-2.50005-4

[10] Theodore S Rappaport. 2002. Wireless Communications–Principles and Practice, (The Book End). *Microwave Journal* 45, 12 (2002), 128–129.

[11] Nurain Izzati Shuhaimi, Nur Liyana Ashmadi, Ezmin Abdullah, Roslina Mohamad, and Sarah Yasmin Mohamad. 2021. Performance Analysis of Radio Propagation


(a) LOS scenario

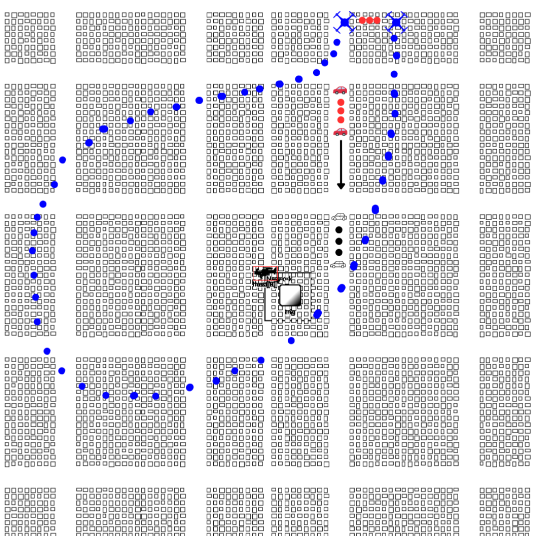

(b) NLOS scenario

Figure 4: UAV-to-GND and UAV-to-VEH Setup

Models in VANET Application. In *2021 IEEE 11th IEEE Symposium on Computer Applications & Industrial Electronics (ISCAIE)*. 372–377. https://doi.org/10.1109/ISCAIE51753.2021.9431810