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Original Article

Low-Flying Drone to Collect Path Loss Data: An Improvement on Longley-Rice Model

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Abstract - *The continuous evolution in wireless communication has led to smaller cell sizes, smart antennas, higher frequencies, and frequency reuse to increase the quality of service. The varying terrain profiles across the globe are causing losses in wireless communication. Path loss is one of the major causes of these losses. A good understanding of it helps in effective radio network planning to avoid poor network interconnectivity and congestion. In this paper, a system of a low-flying drone to collect path loss data is proposed. The path loss data collected using the proposed system in different terrain profiles are then compared to the results simulated on MATLAB using the Longley-Rice propagation model at varying antenna heights.*

Keywords - *Antenna, Longley-rice, Low-flying, Path loss, Propagation model.*

1. Introduction

Wireless communication has developed in recent years and is integral to communications. In wireless communication systems, when waves travel from transmitter to receiver through space, their power density decreases, termed path loss [1]. Path loss is one of the vital radio propagation attributes of an environment. It decreases the received signal power level several orders below the transmitted signal power level. The degree of attenuation depends on the transmission medium, distance, and frequency. Several propagation factors, such as absorption, deflection, diffraction, reflection, scattering, and air particles, impact the transmission of signals [2, 3]. Path loss significantly affects signals with high frequencies as there is a greater chance for them to be absorbed and diffused.

Following are some of the critical propagation issues faced by a signal.

- Attenuation
- Noise
- Dispersion
- Distortion
- Multipath propagation
- Delay spread
- Doppler spread

An experimental mathematical formula known as the path loss prediction model can be used to describe how Radio Frequency (RF) waves travel with respect to the distance between transmitter and receiver antennas. These models were created using a considerable dataset gathered from particular environments. Determining the propagation model is crucial to network planning and interference studies before implementation [4]. These models typically predict the effective coverage area of the transmitter or path loss along an antenna link. Figure 1 shows signal propagation through a commercial area.

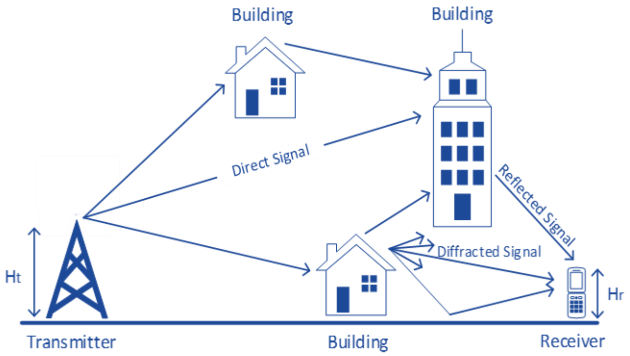

Fig. 1 Outdoor signal propagation

Two subdivisions of propagation models are made based on the environment: Outdoor and indoor propagation. This paper includes the outdoor propagation model. Outdoor propagation models differ from indoor propagation models in accuracy and complexity. Okumura [6], HATA [7], Durkin's, and Longley-Rice are some of the globally recognized propagation models being used to predict path loss over irregular terrain [9]. These models are different in terms of the frequencies they are valid in. Okumura Model works for frequencies between 150 and 1920 MHz [11]. Similarly, HATA and Durkin's models are used in the frequency ranges of 150-1500 MHz and 900-1800 MHz, respectively [12]. Longley-Rice applies point-to-point communication systems over different terrain in frequencies ranging from 40 MHz to 100 GHz [14].

The characteristics of outdoor propagation for near-ground scenarios were measured by Sangodoyin et al. [15]. It was found that the path loss shows crucial dependence on antenna heights and operating frequency. Other studies [16, 17] confirmed that the terrain type could significantly impact radio propagation near the ground and proposed empirical path loss models for such outdoor environments. The signal-to-noise ratio is an important factor in the literature that must be noticed while working with path loss. It is the ratio between desired power of a signal and the undesired signal or the power of the background noise.

Section II of this paper gives MATLAB simulations for path loss prediction using the Longley-Rice model. The use of low-flying UAVs for path loss prediction is discussed in section III. The experimental setup comprising a low-flying UAV and RF communication system and results gathered from the experimental setup are discussed in section IV. Section V summarizes the findings.

2. Longley-Rice Model

When building a propagation model for a novel situation, the initial concern is if the propagation properties of this scenario can be measured. Terrain and environmental conditions can significantly affect the propagation model. Therefore, only the estimated model is correct. In some circumstances, it is risky or challenging to take precise measurements. Therefore, one should seek an empirical model with terrain and antenna height comparable to the case to achieve more accurate predictions of the propagation characteristics.

The irregular Terrain Model or Longley Rice Model is used to predict the signal strength of a radio signal at a given point on the earth's surface based on the transmitter and receiver's location and various terrain characteristics. The Longley-Rice model is based on a combination of statistical data and a physical model. It considers several factors that can affect the propagation of radio signals, such as the height of the transmitter and receiver, the distance between them, the curvature of the earth, and the type and height of terrain in the area. It also considers radio frequency and weather conditions as input.

The mathematical model is trained using data from measurements taken in the area of interest. The data is used to adjust the model's parameters to accurately predict radio wave transmission characteristics in that area. Though it is more complex than HATA, ECC, and COST231-HATA models, it is used because of its accuracy in predicting the signal strength for a specific area.

In the following sub-section, the Longley rice model measures signal coverage and path loss at varying antenna heights in different terrains. The terrains selected are mountainous regions and residential areas from Islamabad (the Capital of Pakistan).

2.1. Residential Area

Using MATLAB, the simulations for estimating antenna coverage and path loss prediction were first done in residential area B17 of Islamabad Capital Territory, Pakistan. The transmitter was placed at Longitude 72.819 and latitude 33.681. After that, using the Longley-Rice model, antenna coverage was simulated. The receiver was then placed at Longitude 72.8220 and latitude 33.671. The antenna height of 5m was selected. The surface elevation was selected to be 502m. Environment and variability parameters are summarized in Table 1. The path loss was then calculated for this scenario using MATLAB.

The path loss measured for the transmitter and receiver placed at the mentioned coordinates and antenna height of 5m using the Longley-Rice propagation model was 121.109dB. At an antenna height of 10m, the path loss of 110.48dB was calculated. Similarly, at an antenna height of 15m, a path loss of 107.223dB was observed. The coordinates of the transmitter and receiver were kept the same in all three scenarios to observe the effect of changing antenna height on path loss. The value of path loss decreased with the increase in antenna height. The antenna coverage for the antenna height of 5m is shown in Figure 2.

Table 1. Environment and variability parameters for simulations

Parameter	Value
Antenna Polarization	Horizontal
Atmospheric Refractivity	301
Ground Permittivity	15
Ground Conductivity	0.005
Situation Variability Tolerance	0.5
Time Variability Tolerance	0.7
Climate Zone	Continental Temperature

Fig. 2 Antenna coverage for transmitter placed in the residential area

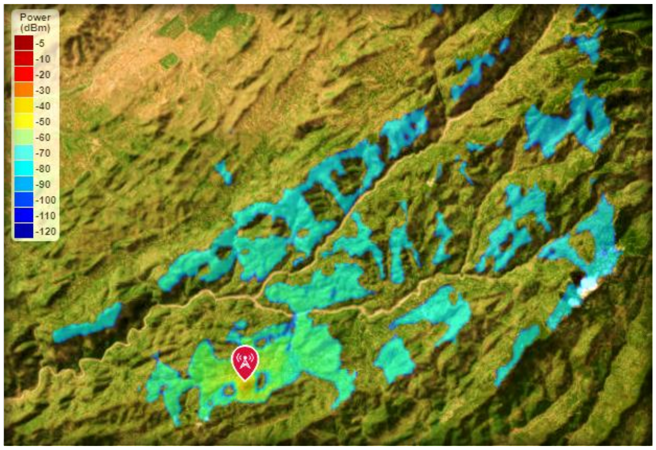

Fig. 3 Antenna coverage for transmitter placed in the mountainous area

2.2. Mountainous Region

In this case, the transmitter was placed at a longitude of 73.173 and a latitude of 33.8517 (a mountainous region of Islamabad Capital Territory, Pakistan). The antenna coverage for this scenario is shown in Figure 3. In this case, the environment and variability parameters were the same as in Table 1. To calculate path loss, the receiver was placed at a longitude of 73.173 and a latitude of 33.8517 (1km from the transmitter). The antenna height was 5m, and the surface elevation was 1184m. A path loss of 149.95dB was calculated using the Longley-Rice model. Varying the antenna heights from 5m to 20m and 35m, respectively, while keeping the coordinates of the transmitter and receiver the same, yielded a path loss of 147.96dB and 143.69dB, respectively. Inverse change in path loss was observed by varying antenna height.

3. Low-Flying UAVs and Signal Propagation

Multiple investigations and theoretical models have been used to characterize and model the Access Gateway (AG) channel. It has been a widespread practice to consider the AG channel as either a free-space or two-way channel, where the direct or Line-of-Sight (LoS) component is supplemented by a reflected signal from the earth's surface. Traditionally, big aircraft like fixed-wing planes, balloons, or airships were flown at high altitudes to take measurements and model AG channels. However, the data gathered at different altitudes and with varying flight dynamics are insufficient to characterize the impact of the terrestrial environment on the propagation channel at low altitudes. The literature has just a handful of measurements taken at low altitudes, although even those are at elevations greater than 200 m [18].

So, it is essential to consider and estimate the propagation channel for tiny UAVs between ground level and 100 metres in the air. In this altitude range, the surroundings and the heights of the adjacent obstructions have a significant impact on the propagation. As a result of deep rapid fading, average route losses tend to rise. Some studies on this phenomenon at low altitudes have been provided in the literature [11, 12]. Ray tracing technique simulations can provide light on the impact of reflection, diffraction, and scattering from the surrounding environment on AG channels operating at those altitudes.

4. Experimental Setup and Results

4.1. Mathematics of the Path Loss

The Path Loss (PL) measured between an antenna link is expressed mathematically as:

$$PL = 20\log_{10}(4\pi d/\lambda) \tag{1}$$

Here, 'd' is the distance between the transmitter and the receiver. Similarly, λ is the wavelength of the signal. Friis' transmission equation is used to measure power received from the transmitter at a distance 'd' between transmitter and receiver:

$$P_r = P_tG_tG_r(\lambda/4\pi d)^2 \tag{2}$$

From the above Equation 2,

$$P_r/P_t = G_tGr(\lambda/4\pi d)^2 \tag{3}$$

The relation between transmitted power and received power in terms of path loss can be expressed as:

$$PL = P_t - P_r \tag{4}$$

4.2. Low-flying UAV

Two prototypes of quadcopter were manufactured—one for testing and the other as a spare in case of an emergency or sudden crash. The quadcopter UAV used in the experimental setup consists of the following components.

- DJI F450 Frame
- BLDC Motor
- Propellers
- Electronic Speed Controller
- LiPo Battery
- Telemetry Radio
- Flight controller
- RF harvester
- GPS module

Fig. 4 Experimental setup used for path loss prediction

The in-depth details and datasheets of the components used for the quadcopter are not disclosed here. The measurement system for path loss prediction using a low-flying drone consisted of two wireless sensor nodes, one acting as a receiver and the other as a transmitter. The receiver and transmitter nodes being used work at the 470MHz band with a data transfer rate of 9.6kbps. The height of the transmitter was varied to observe the effect of changing antenna height on path loss. The drone was flown at a height of 500m from the ground. The RF receiver was attached to the low-flying UAV. Figure 4 shows the low-flying drone setup used for testing.

4.3. RF Harvester

The drone's flight to various locations was monitored using a GPS module attached to the drone. After the drone takes its flight, the power transmitted by the antenna is received by the receiver front end attached to the RF harvester of the quadcopter. The RF harvester processes the received signal according to the system shown in Figure 5. The received signal strength is measured by the Received Signal Strength Indicator (RSSI), and the value of received power at various locations is stored in the cloud. The transmitted power Pt was fixed at +50 dBm in the experimental setup.

The received power level stored in the cloud can be used to calculate path loss at different distances from the transmitter using Equation 4 since the transmitted power level is already known. The microcontroller processes the readings of received power to make a database of path loss in different terrains by comparing power transmitted by the transmitter (fixed value of 50dBm) and power received by the RF receiver (which varies at different locations because of varying terrain profiles).

4.4. Path loss measured using the experimental setup

The received power values stored in the cloud were used to calculate path loss. The path loss values in the current experimentation were noted successively after a 0.25km distance between the transmitter and receiver. Path loss values were plotted against distance at varying antenna heights to observe trends. The plot of path loss in the residential area is shown in Figure 6. The path loss in the mountainous region is shown in Figure 7.

It was observed that increasing the distance between the transmitter and receiver increased path loss. This trend is due to the high scattering, distortion, and dispersion chances. The path loss value decreased with an increase in antenna height because of low chances of attenuation in signal due to interference and other propagation issues.

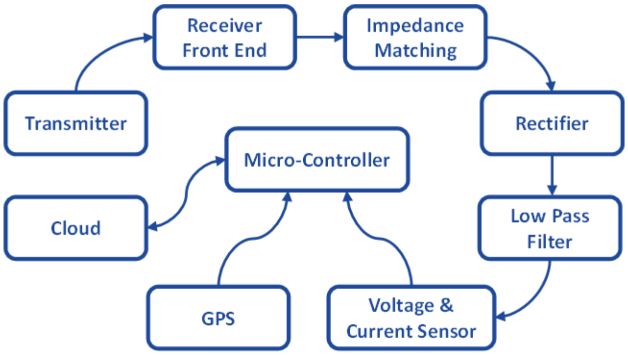

Fig. 5 RF harvester used in the experimental setup

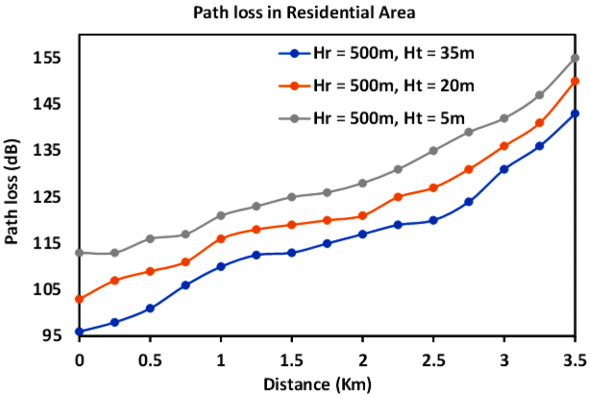

Fig. 6 Path loss in the Residential Area

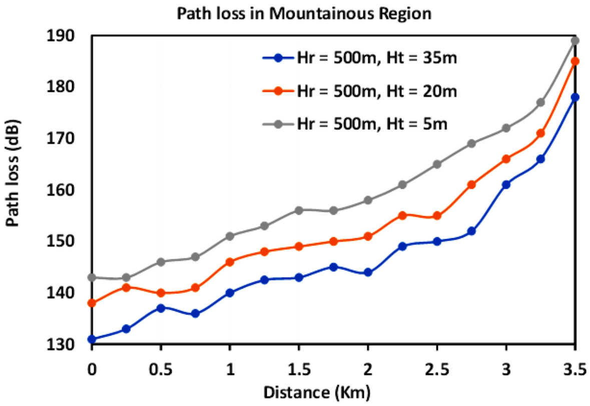

Fig. 7 Path loss in the mountainous region

5. Conclusion

An experimental setup was designed to calculate path loss in different terrain profiles. This setup was intended to improve the existing Longley-Rice propagation model to predict path loss. MATLAB simulations using the Longley-Rice model were run in different terrains, and results were gathered. Then, the low-flying drone calculated path loss in the same terrains. The path loss calculated experimentally was more accurate than the path loss simulated using the Longley-Rice model since real-life constraints and limitations were catered to in experimentations.

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