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Analysis of Drone Propagation With Ray Tracing From Sub-6 GHz Upto Terahertz Frequencies in a Real World Urban Environment

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Abstract

- Unmanned aerial communication platforms have been recently considered as an effective solution to provide homogeneous and extended network coverage to terrestrial users.
- The first target of this paper is to analyze the propagation characteristics of drone transmission at different frequencies i.e., **3.5 GHz, 28 GHz, 60 GHz, and up to 180GHz with 20 GHz step**.
- In simulation setup, drone is at different heights i.e., **from 50m up to 250m** altitude, and we carry out 3D ray tracing simulations assuming a propagation environment that is defined by the real building data from Helsinki city.
- We study the validity of a previously proposed geometrical Line of Sight (LOS) probability model between ground user and drone, and based on simulations we propose new modeling parameters.
- In the second part of the paper, the ray tracing results are compared with the analytical reference model.

Analytical Model for UAV Propagation

The Line of Sight (LOS) probability for a link between a UAV and the terrestrial UE is approximated

$$\mathrm{PR}_{LOS}(\theta) \approx \frac{1}{1 + a\exp\left(-b(\theta - a)\right)}$$

$$\mathrm{PR}_{NLOS}(\theta) = 1 - \mathrm{PR}_{LOS}(\theta)$$

In a typical urban area, we have **a = 9.61 and b = 0.16** [14].

The mean path loss in dB scale is given as:

$$L = 20\log_{10}\left(4\pi\frac{d}{\lambda}\right) + \mathrm{PR}_{LOS}\eta_{LOS} + (1 - \mathrm{PR}_{LOS})\eta_{NLOS}$$

η_{LOS} and η_{NLOS} are the average additional losses due to obstacles

In urban case, we have $\eta_{LOS} = 1$ dB and $\eta_{NLOS} = 20$ dB

Simulation Environment

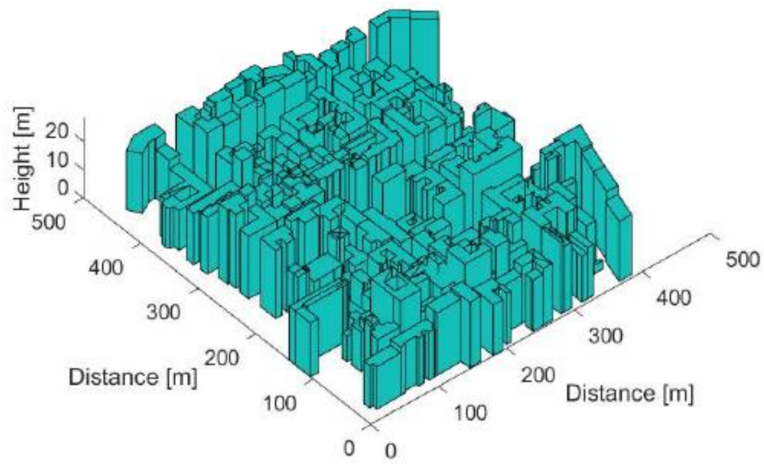
➢ 3D ray tracing simulations using a MATLAB based tool developed by the authors of this paper.

➢ The **Image Theory (IT)** method is used for finding the propagation paths with reflections and diffractions.

➢ The grid of red dots in shows the positions of the terrestrial outdoor users with 5m mutual separation at the ground level, whereas the blue mark in the middle represents the ground projection of the UAV position.

➢ All the receiver locations are considered at 1.5m height. An omni directional antenna is assumed at both the user and UAV end.

➢ Maximum transmission power in the downlink direction is set to **30 dBm (1 watt)**.

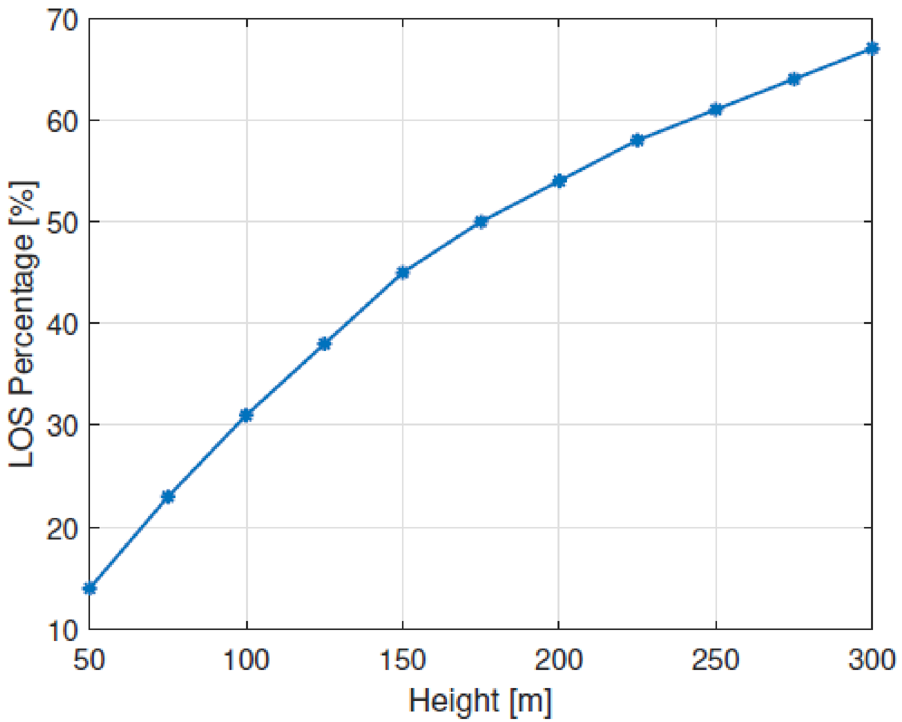


Results: LOS percentage

Height of the UAV has an impact on the LOS condition and the propagation environment between the terrestrial UE and UAV.

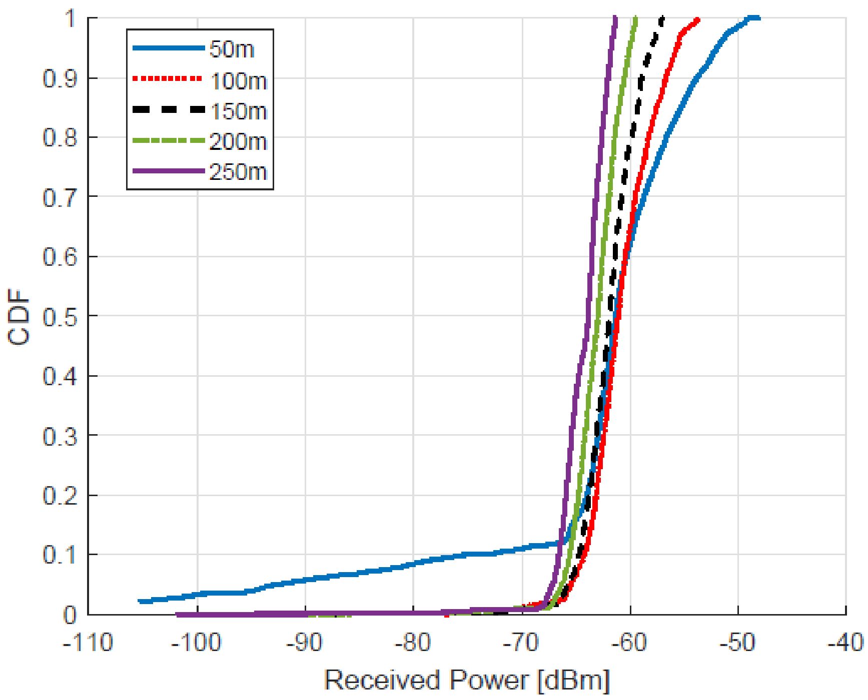
At **50m** height, there are only **14%** users in LOS, but when UAV is at **200m** height the percentage increases to **54%,** and the growth of LOS connections continues with the increasing height of the UAV.

Several countries have restrictions on flying the drones above **250m** height, we have limited our focus on the UAV heights up to 250m.



Results: CDF of Received Power at 3.5 GHz

At **50m** altitude around **2%** of the users were in outage as no signal path was found by ray tracing simulations with given number of reflections and diffraction.



At 3.5 GHz, the received power levels with UAV at 50m height are still acceptable, as generally the minimum power requirement is **-120 dBm**.

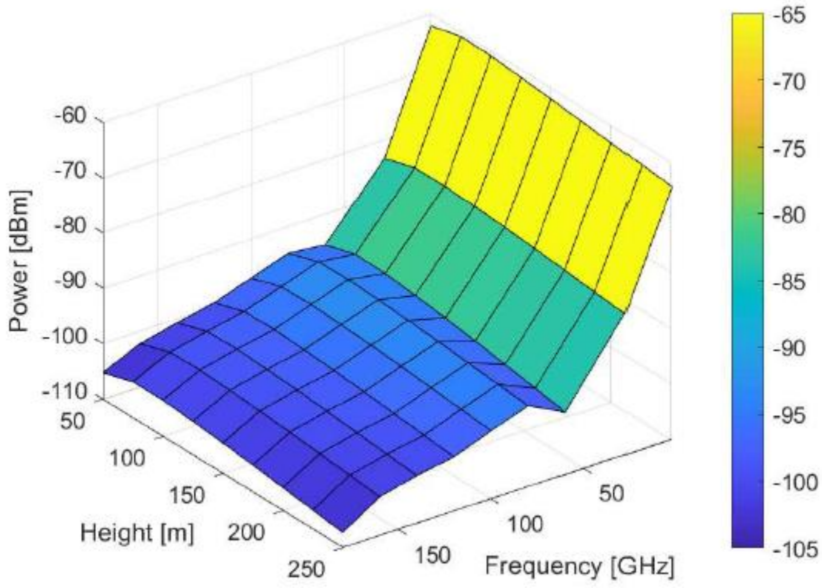
However, at higher carrier frequencies these CDF curves will be shift in the left direction, and the outage probability increases.

Results: Mean Received Power

➢ With the increase in UAV height from 50m to 75m, although the distance between the terrestrial user and the UAV is increased, the additional height also improves the LOS probability between the UAV and the user, and increased height improves the coverage within the cell.

➢ For a given scenario and user grid, the UAV altitude of 75m is found as an optimal height in terms of received power.

➢ Mean received power level drops by almost **20.5 dB** and **33.5 dB** while migrating from **3.5 GHz** to **28 GHz** and **60 GHz**, respectively.

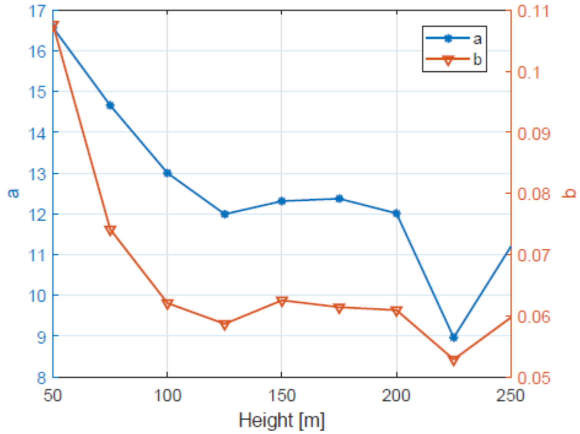


➢ Due to significantly high atmospheric absorption at **60 GHz** compared to **80 GHz**, despite of higher frequency of operation the mean received power is found slightly better at 80 GHz compared to 60 GHz.

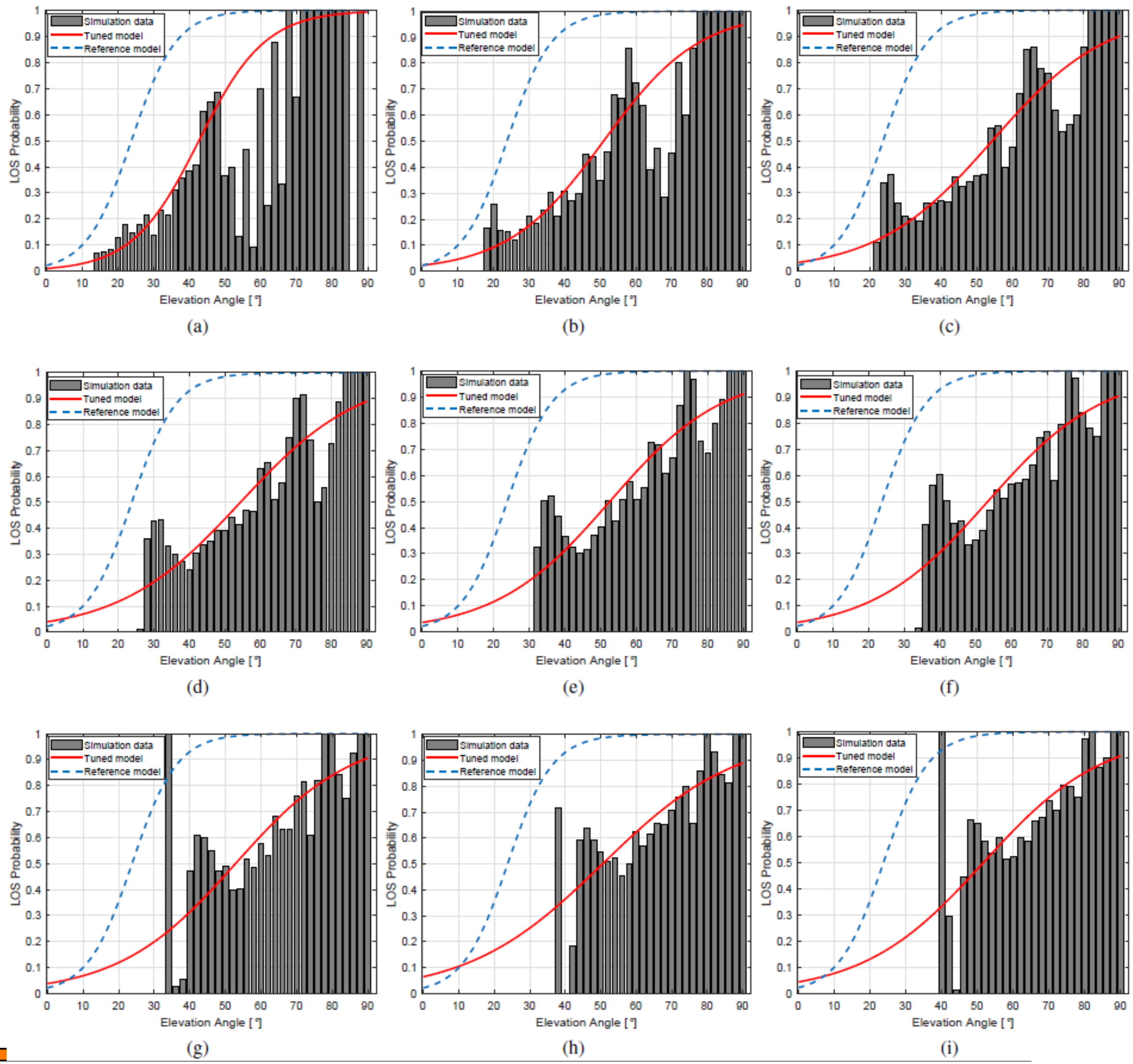
➢ After 80 GHz a gradual drop in mean received power level is witnessed up to 180 GHz.

LOS Probability

We recall that the tuned LOS probability model is obtained by adjusting parameters **‘a’** and **‘b’**, whereas the reference model assumes **a = 9.61 and b = 0.16**



Elevation angle has a wide spread at low UAV altitudes, and the spread of the elevation angle decreases with the increase in the height of the UAV.



(a) 50 m, (b) 75 m, (c) 100 m, (d) 125 m, (e) 150 m, (f) 175 m, (g) 200 m, (h) 225 m, and (i) 250m UAV height

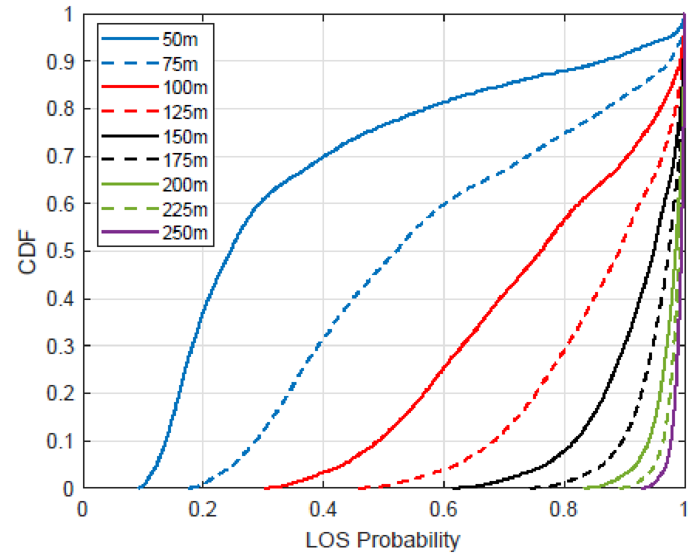
Results: CDF of LOS Prob.

It is critical to highlight here that the parameters of the reference LOS probability model given in the paper [11] was for low altitude platforms which fly at an altitude of upto few thousand meters.

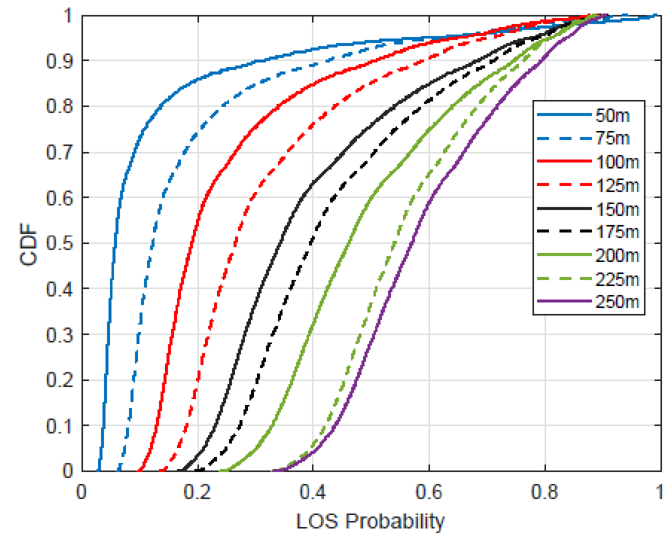
Whereas, in the study of this paper we are mainly targeting really low flying drones starting from 50m altitude to a maximum height of 250m.

10th percentile value of LOS probability CDF with reference model is **0.82, 0,94, and 0.98**, whereas with tuned model it is **0.23, 0.33, and 0.44** for **150m, 200m, and 250m**.

The behavior of reference model becomes close to identical above 175m, and clearly seems over optimistic as the LOS probability is exigently high. Whereas, the tuned model is giving realistic results and shows a fair approximate of LOS probability in a real world scenario.



(a) Reference LOS Probability model



(b) Tuned LOS probability model

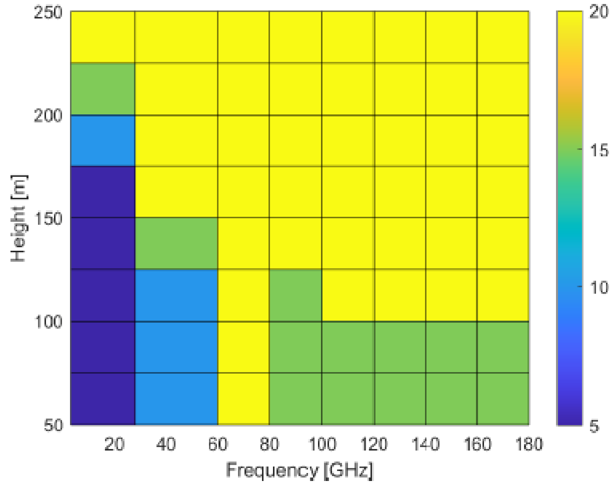
Results: NLOS parameter and RMSE

NLOS parameter

We have considered four different values of NLOS loss parameter i.e. 5, 10, 15 and 20 dB.

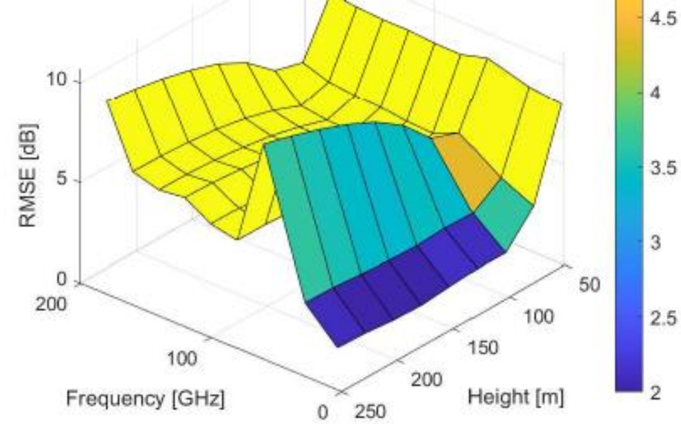
In reference model the surface plot is mainly dominated by NLOS = 20dB except at 3.5 GHz.

In tuned model there is a clear pattern showing that at 3.5 GHz and 28 GHz the recommended value for NLOS is 5 dB, at 60 GHz it is 15 dB, and at 80 GHz and above the minimum RMSE is achieved with NLOS equals to 10 dB. This way, we have found the link of NLOS with UAV height and frequency of operation.

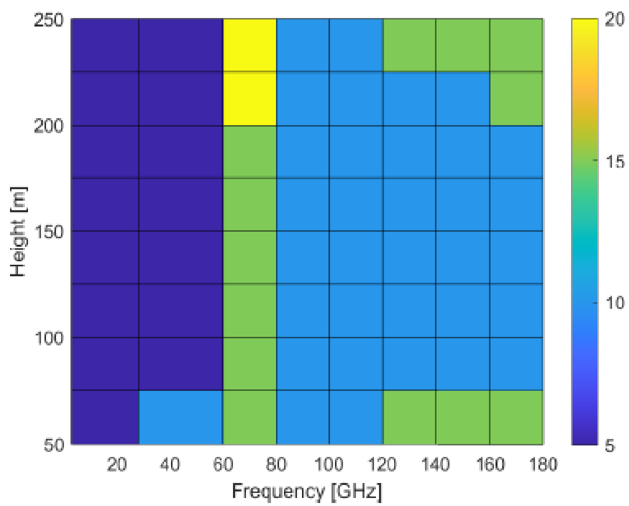


(a) Reference LOS Probability model

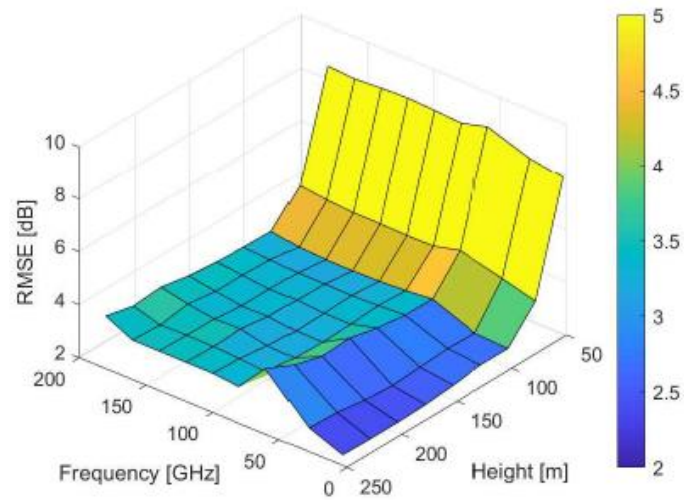
RMSE



(a) Reference LOS Probability model



(b) Tuned LOS probability model



(b) Tuned LOS probability model

Conclusion

- The radio propagation characteristics of UAV communication was studied using real building data from downtown Helsinki and 3D ray tracing simulations.

- The obtained simulation results clearly show the percentage of locations in LOS increases with the UAV height. Ray tracing simulation results revealed that at 50m UAV height the LOS percentage was **14%** and it grew up to **68%** when reaching the 300m height.

- The RT simulation data also indicates that the LOS probability function with the parameters given in the reference paper [14] gives highly optimistic and unrealistic LOS probability compared with the ray tracing data.

- We have proposed a new set of parameters which are acquired by using curve fitting based on ray tracing results.

- Furthermore, our recommended value for the NLOS loss parameter in the analytical path loss Model given for different operation frequencies and UAV heights helps in reducing the RMSE between the ray tracing simulation results and analytical results.

Thanks