Air-Ground Channel Modeling Method Using Digital Elevation Data

Kibeom Son, Youngeun Kang, Young-Ho Jung

School of Electronics and Information Engineering

Korea Aerospace University, Goyang-si, Korea

rlqja56@kau.kr, yhjung@kau.ac.kr

Hee Wook Kim

Aerospace ICT Research Department

Electronics and Telecommunications Research Institute, Daejon, Korea

prince304@etri.re.kr

January 3, 2018

ACKNOWLEDGMENT

This work was supported by the ICT R&D program of MSIP/IITP. [R0126-18-1005, Development of High Reliable Communications and Security SW for Various Unmanned Vehicles]

***Abstract*— In this paper, we propose an air-ground channel modeling method using digital elevation model data for unmanned aircraft system (UAS) communication systems. Until now, the air-ground channel models for the UAS communication system were derived based on the measurements from urban, suburban, mountainous, hilly, and over-water environments in the USA. However, they are disadvantageous when it comes to predicting the accurate channel attenuation considering the real terrain environments. In this study, the path loss value is estimated by extracting the altitude information of the cross-section between a transmitter and receiver and applying an appropriate channel attenuation model. The proposed method is validated by comparing the estimated results with actual flight test results.**

Keywords*— *UAS; UAV; CNPC; DEM; air-ground channel model;

1. Introduction

The usage of unmanned aerial vehicle (UAV) and unmanned aircraft system (UAS) is rapidly increasing in industrial and military applications. Research is being actively conducted to utilize the UAS in various services, such as surveillance and communication relay. However, to ensure safety, UAS must be controlled securely like a manned aircraft. Nowadays, various organizations are carrying out studies to improve the safety of unmanned aircraft (UA) by harmonizing it with the conventional aviation systems [1, 2].

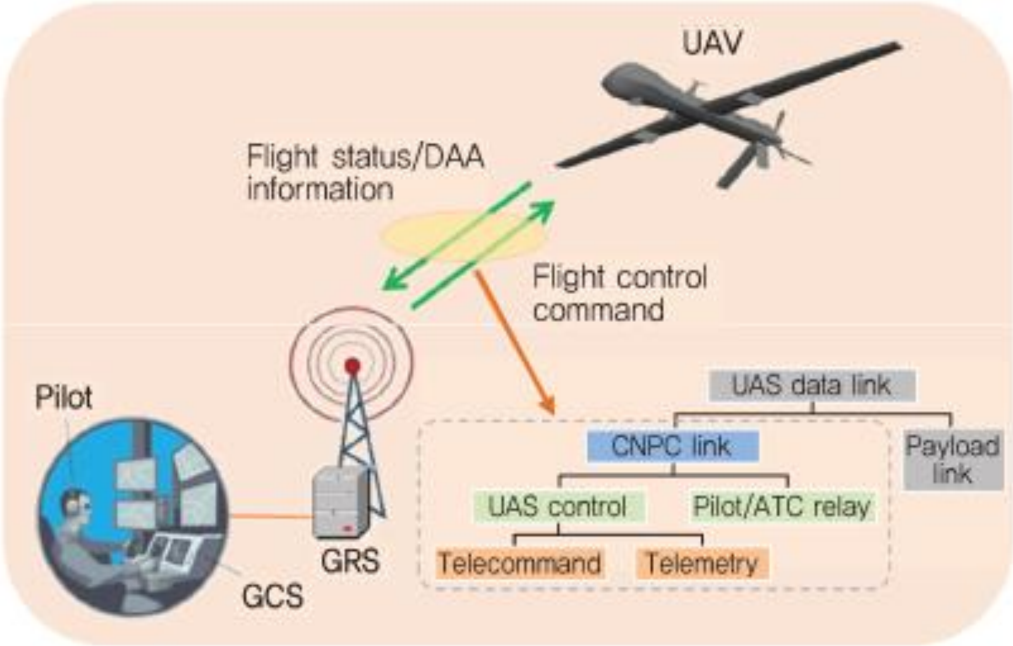


Figure. 1. UAV System [3]

The Radio Technical Commission for Aeronautics (RTCA) has developed a concept of control and non-payload communication (CNPC) system and minimum operational performance standards (MOPS) in cooperation with Federal Aviation Administration (FAA) and National Aeronautics and Space Administration (NASA) [3]. As is the case for other wireless communication standardizations, it is essential here to develop a good set of air-ground channel models that can reasonably replicate the actual channel conditions in the CNPC standard development process and performance evaluation. Supported by NASA, the L and C band air-ground channel characteristics have been measured for various terrain environments in the ground site (GS) including hilly, mountainous, suburban, urban, and over-water environments. Based on these data, a number of air-ground channel models have been developed [4-7].

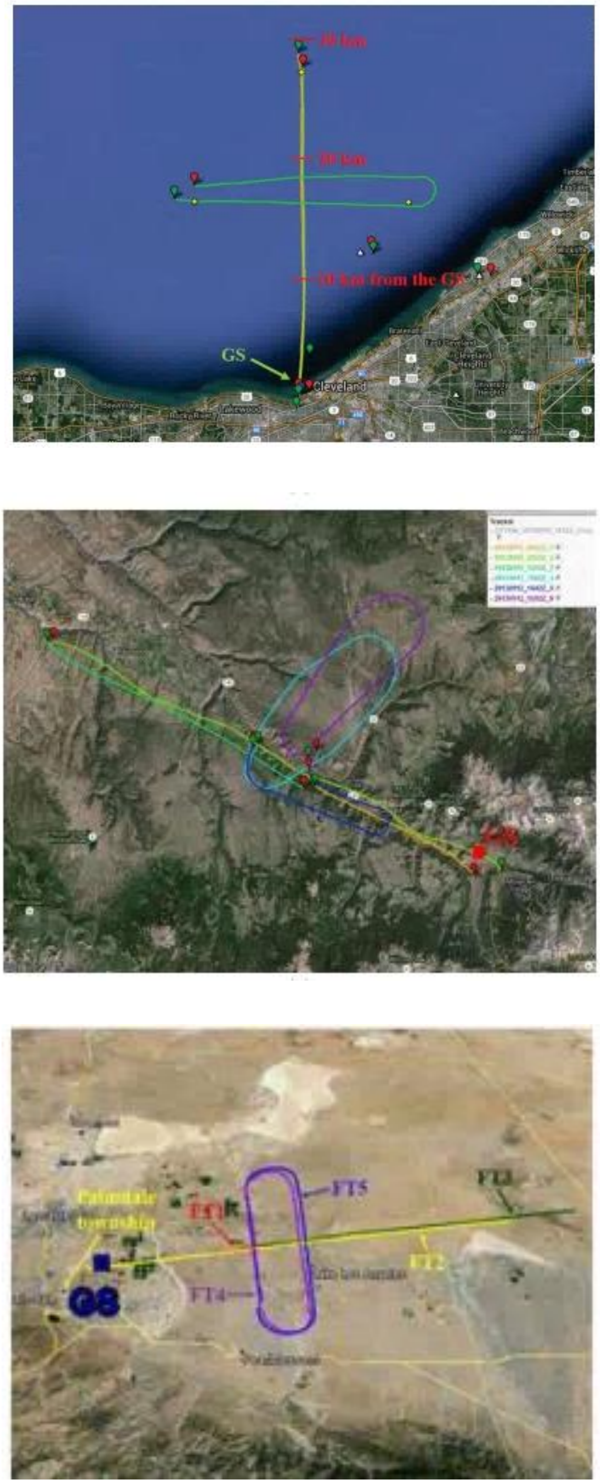


Figure. 2. flight paths for Air-Ground channel measurments [4-7]

To simulate the performance of UAS communication systems, it is required to select a specific channel model from the existing air-ground channel models for the given simulation region. For example, to verify the CNPC channel allocation capacity of a particular country, it is required to consider its terrain condition and find a suitable model for that terrestrial environment between the GS and each UA. A channel model can be intuitively selected from the available preliminary information of each region. However, since the models are based on the data from United States alone and the geographical conditions are different in each country, it is not possible to find an accurate model. For mountainous terrain, there are many mountains over 3000 m in the United States, but most of the mountains in Korea are about 1000 m high. Hence, it is difficult to predict the air-ground channel of the mountainous terrain with a single channel model.

To solve this problem, this study proposes a deterministic channel modeling method using the digital elevation model (DEM) data. Here, the altitude information of the cross-section between the transmitter and receiver is extracted. After reflecting the effect of the spherical earth's surface, an appropriate channel prediction model is selected according to whether there is a line of sight between the transmitter and receiver and whether there is water. Thereafter, the path loss value is estimated by using the appropriate path loss model corresponding to that particular environment. The process is similar to the commercial channel emulation software, e.g., Terrain Integrated Rough Earth Model (TIREM) included in OPNET software [8].

To verify the proposed method, we compared the path loss results with one of the actual flight test results obtained by NASA [4]. We also developed a software for predicting the UAV communication performance in 3-dimensional space by applying the proposed channel modeling method. Because the proposed method requires only DEM data, it is expected to predict the performance of UAV communication channels effectively for different geographical environments in each country.

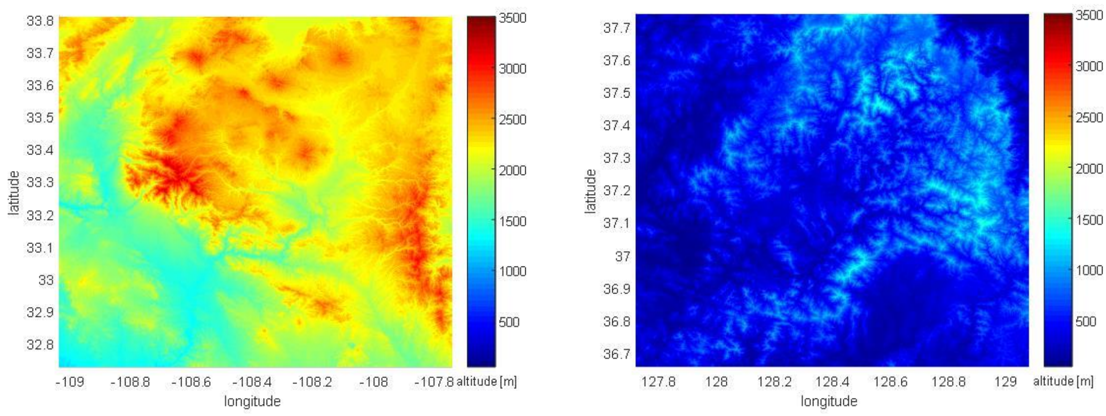
2. Background

1) Air-Ground Channel Models Based on Measurement for UAS Communications

The channel characteristics including path loss, shadowing, and small-scale fading between UA and GS depend on the terrain environments. With the support of NASA, researchers at University of South Carolina measured the channel characteristics of L and C bands in various environments including hilly, mountainous, suburban, urban, and over-water environments to develop air-ground channel models for UAS communications corresponding to each geographic test environment. Based on these data, the air-ground channel models have been developed [4-7]. The channel measurement environments and corresponding references are summarized in Table1.

Setting	Location	Environmental Details
Oversea [4]	Oxnard, CA	Open salt water with few stationary structures & watercraft
Urban [5]	Cleveland, OH	Cityscape view with many tall buildings on flat terrain, adjoining open freshwater
Hilly Suburban [5]	Latrobe, PA	Mix of rural terrain & urban structures in valley, viewed from airport
Hilly terrain [6]	Latrobe, PA	GS antenna beam to mountain ridge w/natural cover. Ridge extends into line-of-sight between UA & GS
Mountainous [6]	Telluride, CO	Very mountainous terrain
Hilly [6]	Palmdale, CA	Dry, hilly terrain with natural cover
Hilly Suburban [5]	Palmdale, CA	Open, flat desert & agricultural terrain
Fresh Water [7]	Cleveland, OH	Open fresh water
Suburban [5]	Cleveland, OH	Suburban, some over-water, flat terrain

Table1. List of Air-Ground Channel Measurement Environments and Corresponding References



(a) (b)

Fig. 3. Example of DEM data in specific areas for simulation (a) Bearwallow Mountain in NM, USA and (b) Sobaek Mountain in Korea

2) DEM data

DEM is a digital model of a terrain's surface, which includes digital surface model (DSM) and digital terrain model (DTM). DSM represents the earth's surface and includes all the objects on it. DTM represents the bare ground surface without any object like plant and building [9]. The DEM data is publicly available worldwide. For example, the SRTM digital elevation data can be obtained with a precision of 90m for the global area [10]. Figure 3 shows examples of the DEM data in mountain areas in the USA and Korea; although both are for mountainous terrain, there is a big difference in the altitude distribution between the two areas.

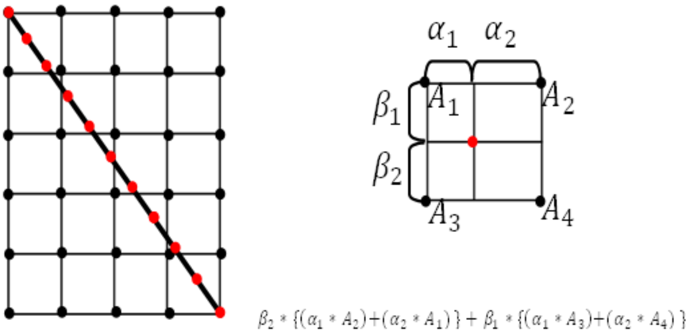


Fig. 4. Interpolation method of DEM

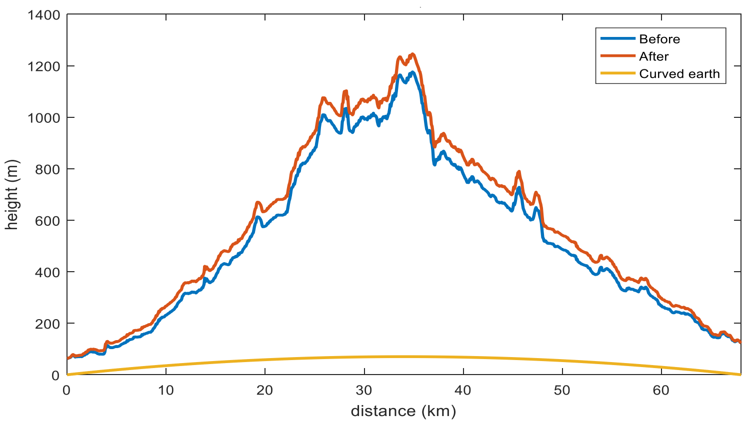


Fig. 5. Altitude information of the cross-section

3. Proposed Channel Model Method Using Digital Elevation DATA

There are nine different CNPC channel models corresponding to different measurement environments as shown in Table I. To effectively estimate the performance of a CNPC communication link in a specific area through simulation, it is necessary to select a specific channel model among multiple channel models [11]. However, the channel model selected for the type of terrestrial environment is applicable only for the line-of-sight environment, and there is a reliability problem depending on the distance [3]. Therefore, we want to provide more general results by analyzing the altitude information of the cross-section between CNPC propagation paths. Here, DEM is used to obtain the altitude information. Because the DEM has a resolution of 90 m, we use the interpolation method shown in Figure 4 to estimate the altitude at locations where no information exists. In addition, the effect of the earth's curvature is shown in Figure 5. The final elevation cross-section (red line) is obtained by combining the altitude information extracted from DEM (blue) and earth's curvature effect (yellow).

The channel model is identified using the algorithm shown in Figure 6 based on the altitude information of the cross-section between the transmitter and re ceiver. The importance of this algorithm lies in the obstacle determination. The obstacle identified in this algorithm exists in the propagation path and influen ces the diffraction as a Knife edge shown in Figure. 6. In the case of a single knife edge, there is one valid obstacle in the propagation path. In the case of multi knife edges, there are two or more obstacles. If no obstacle is present, it can either be the two-ray model or free space model depending on whether there is water in the propagation paths or an ordinary land.

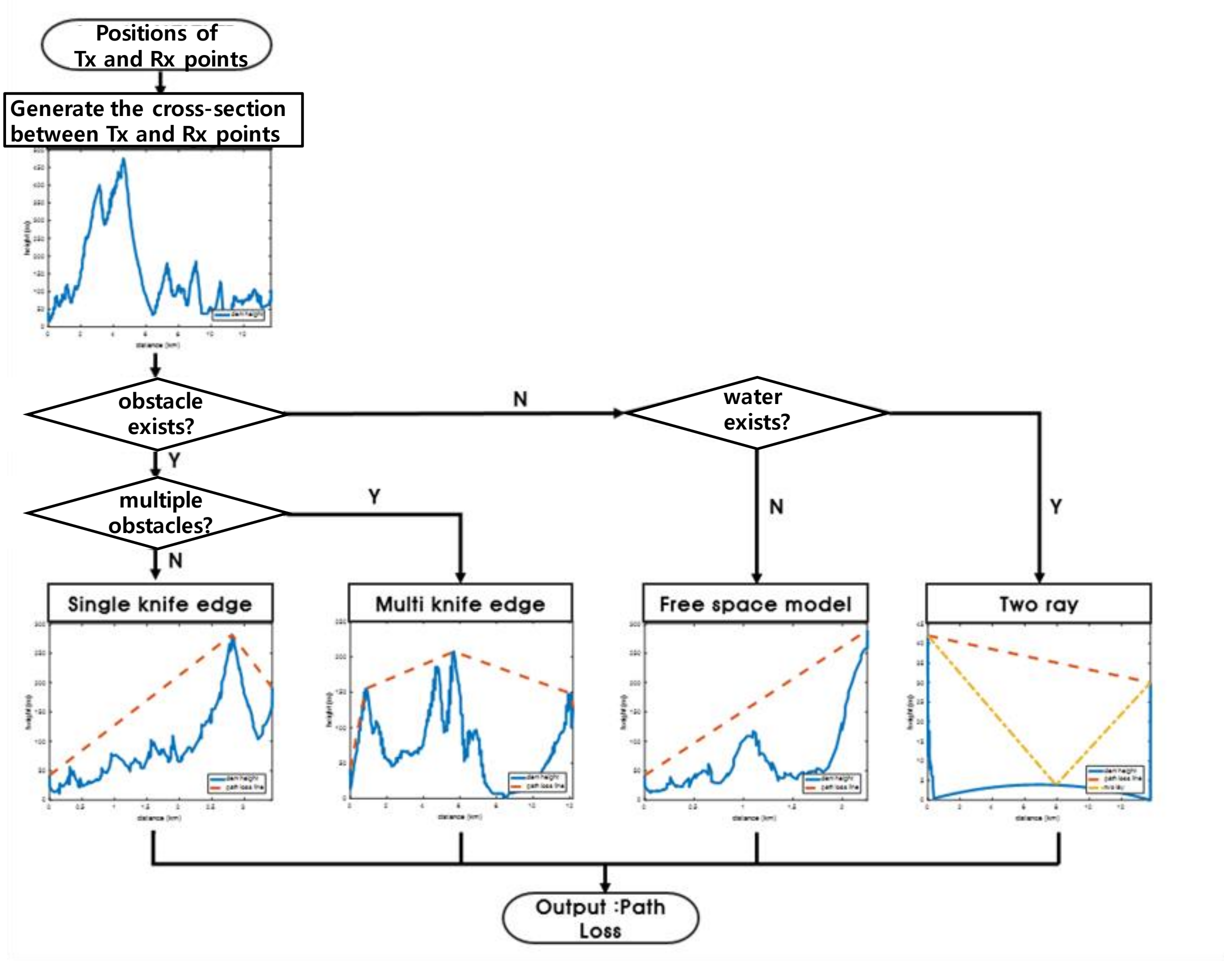


Fig. 6. Channel model selection algorithm

4. Test Results of the Proposed Channel Model Selection Method

Figure 7 compares the actual measurements of the NASA experiment [4] with the simulation results obtained in this study. NASA conducted the experiment at Erie Lake in Cleveland to measure the path loss in a freshwater environment. The experimental flight was a straight path above the fresh water with the altitude and antenna height of GS fixed at 580 m and 20 m respectively. The same flight path, flight altitude, ground station location, and antenna height were used in the simulation. Figure 7 shows that there is no significant difference between the NASA experiment and free space path loss results. Figure 8 shows the channel model prediction simulator between the transmitter and receiver using the proposed channel selection method. The simulator shows the altitude cross-section and propagation path between the transmitter and receiver, and the expected path loss. The upper and lower panels of Figure 8 respectively show the two-ray model selected for UAV communication over the islands and ocean and the knife-edge model selected by the obstacle in UAV communication at the mountains. Thus, the results of the simulator are consistent with the expected results from the altitude cross-section. Therefore, the channel modeling method utilizing DEM has sufficient reliability.

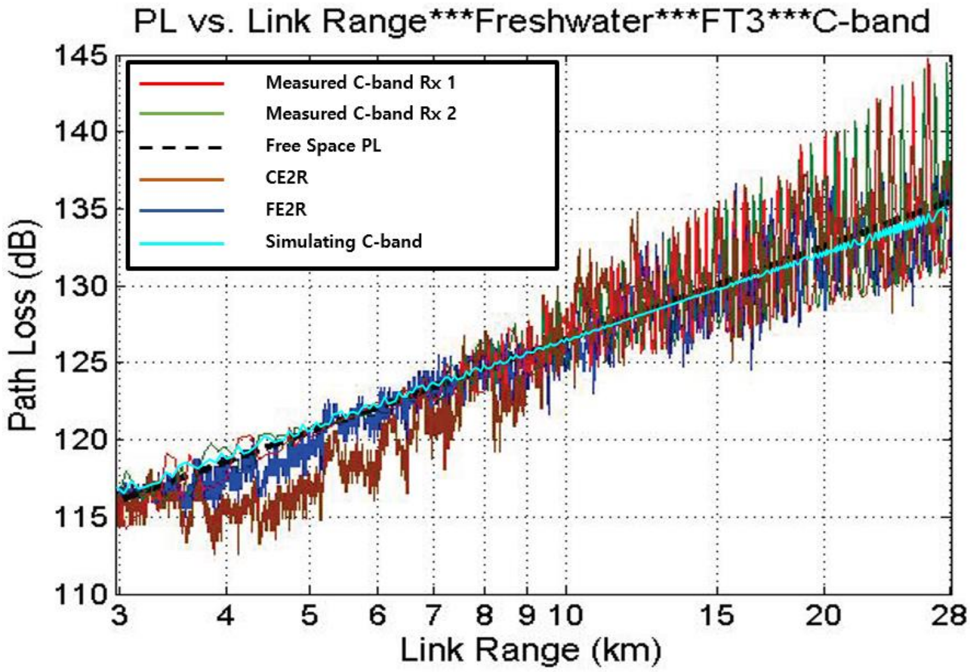


Fig. 7. Comparison between measurement results and simulation results

The simulator in Figure 9 and Figure 10 are an extended version of that in Figure 8 (point-to-point situation) as it analyzes the point-to-multipoint situation. The simulator sets the input values of communication parameter, such as the transmission power, noise intensity, and bandwidth. Thereafter, it selects the channel model between the GS and the neighboring location by the proposed method to calculate the signal-to-noise ratio (SNR). As a result, the SNR distribution of the peripheral region can be obtained. It can also analyze the maximum, minimum, and average SNR of the surrounding area as well as the cumulative distribution function (CDF) and probability distribution function (PDF) of SNR. As a result, it provides the SNR distribution in the surrounding area as well as at the desired altitude. Furthermore, if the required SNR threshold is set, the simulator shows the shadowing areas that are lower than the SNR threshold for the area around the selected GS position. In this way, the SNR distribution around the GS location can be obtained, and communication efficiency can be simulated according to the GS location. This result can be used as a basis for selecting the GS location for CNPC communication.

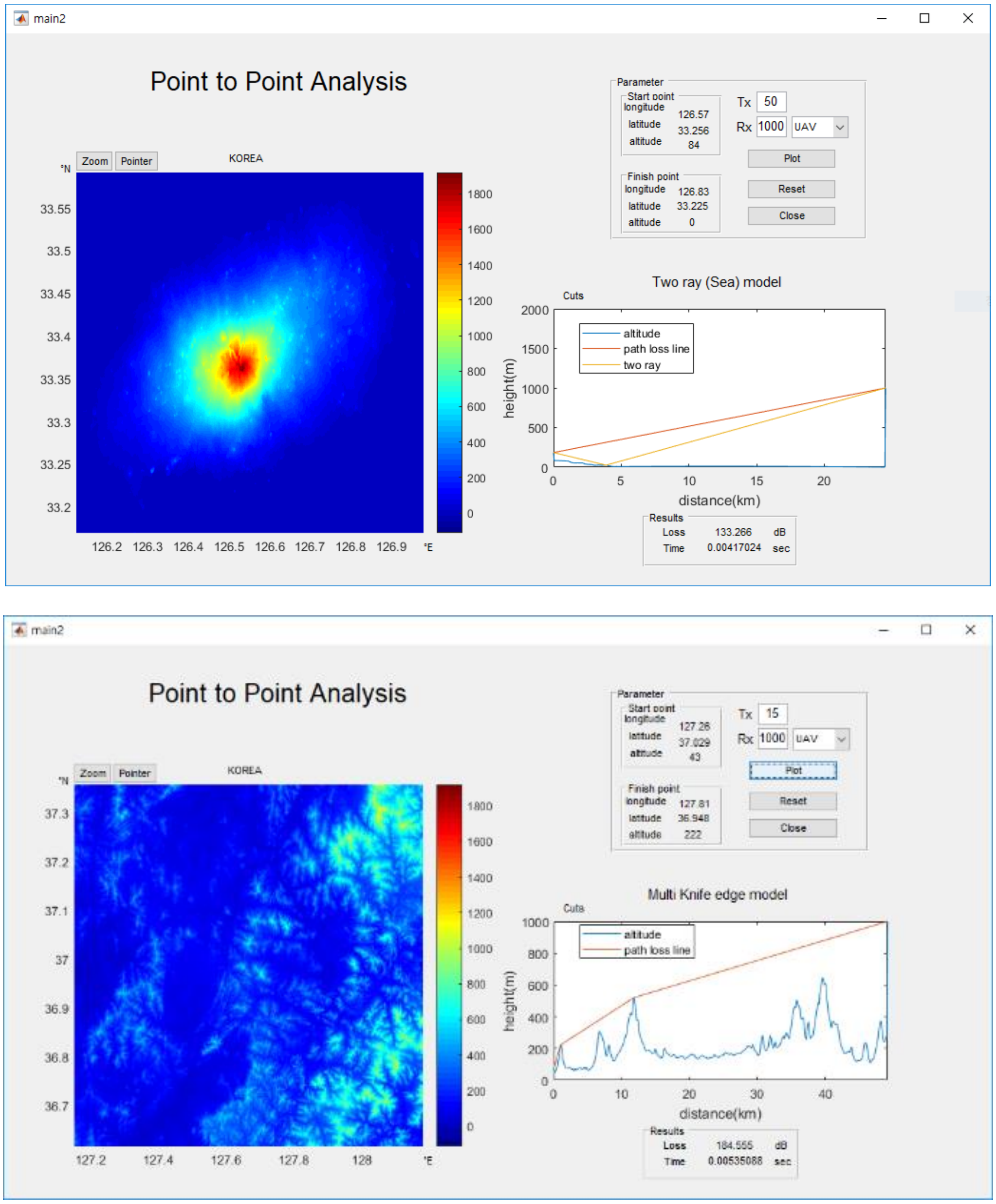


Fig. 8. Simulator 1: Checking the channel model between the transmitter and receiver (upper: under water, lower: mountainous)

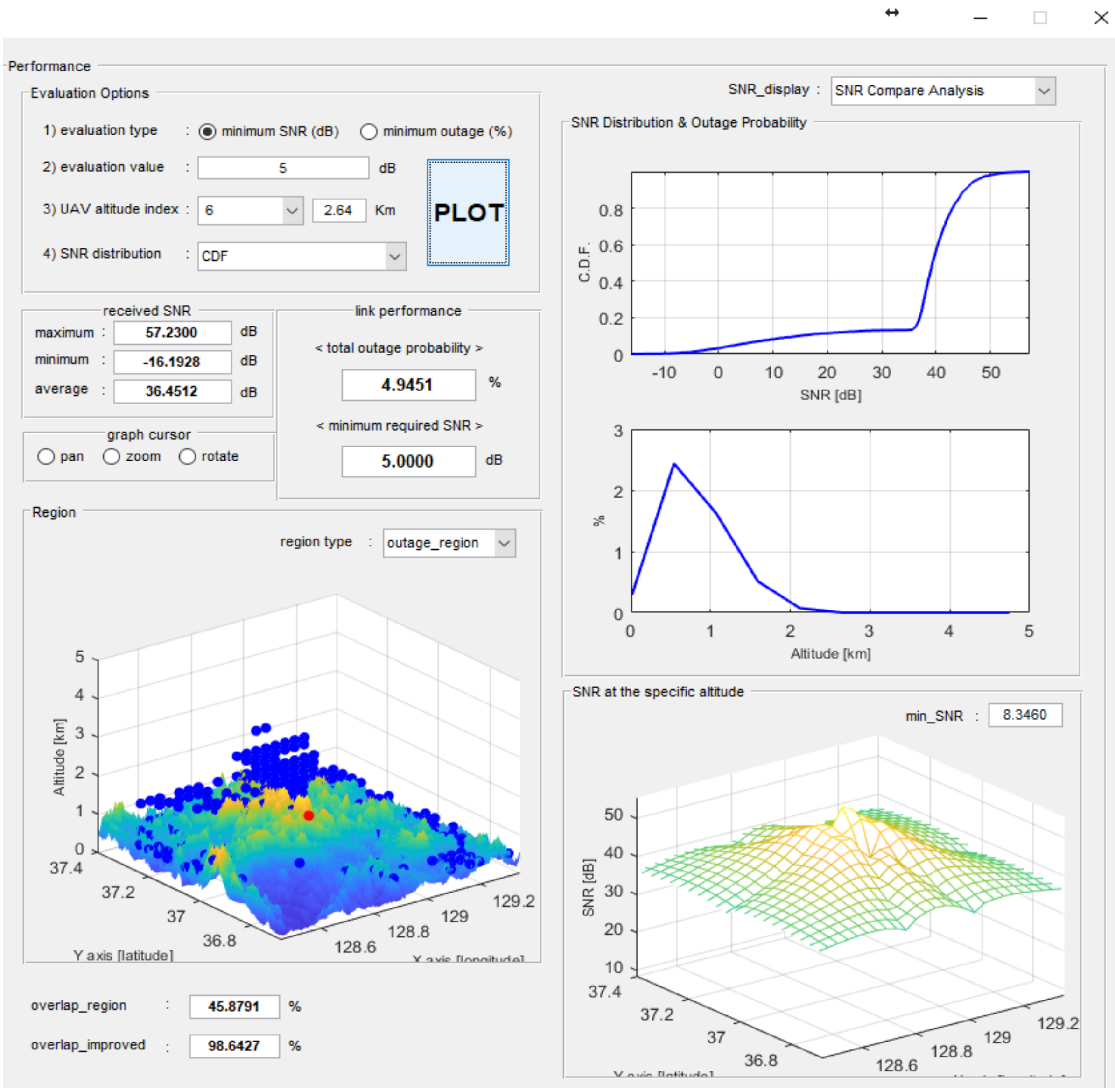


Fig. 9. Simulator 2: SNR analysis simulator for selecting a GS location

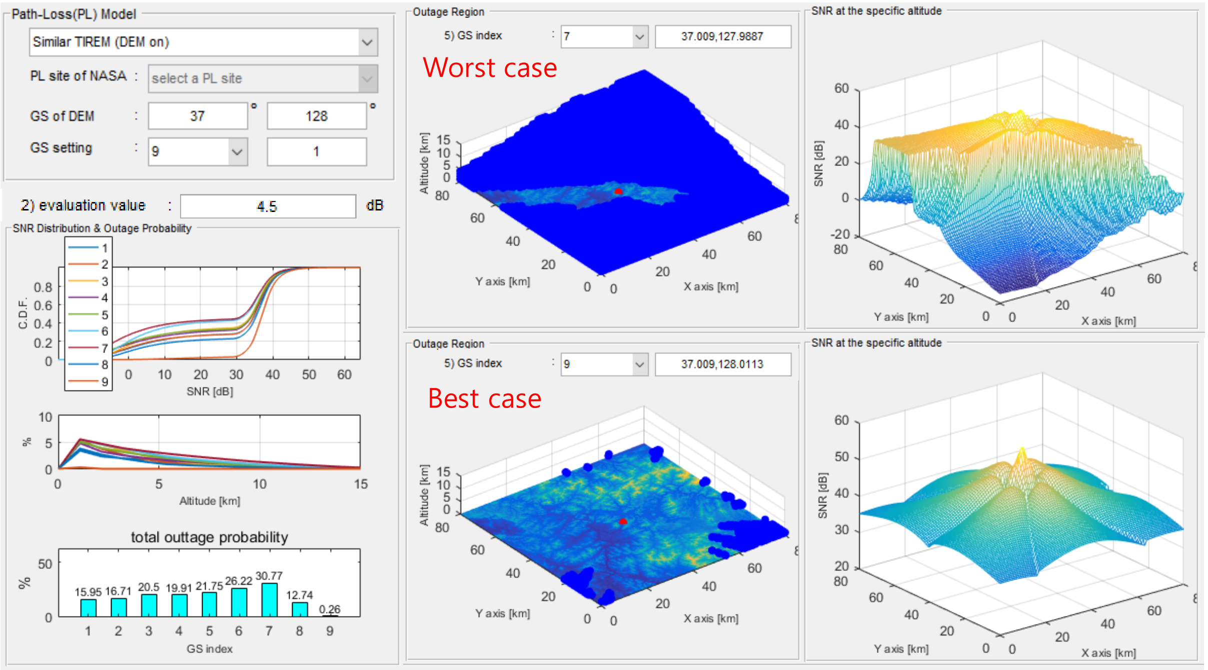


Fig. 10. Simulator 2: SNR analysis simulator for comparing various GS locations

5. Conclusion

In this paper, we propose an air-ground channel modeling method using DEM data. The proposed method selects an appropriate channel model based on the analysis of altitude information of the cross-section between a transmitter and receiver. Because the DEM data can be obtained easily for any place in the world, the proposed channel modeling method can easily be applied for any country in the world to predict the performance of UAS communication systems.

REFERENCES

[1] International Telecommunications Union (ITU), “Characteristics of unmanned aircraft systems and spectrum requirements to support their safe operation in non-segregated airspace,” Report ITU-R M.2171, December 2009.

[2] Congressional Research Service (CRS), “Unmanned aircraft systems (UAS): commercial outlook for a new industry,” CRS report R44192, September 2015.

[3] RTCA, “Command and control (C2) data link minimum operational performance standards (MOPS) (terrestrial),” RTCA-DO-362, Sep. 2016.

[4] D. W. Matolak, R. Sun, “Air–ground channel characterization for unmanned aircraft systems—part I: methods, measurements, and models for over-water settings,” IEEE Transactions on Vehicular Technology, vol. 66, no. 1, pp. 26-44, Jan. 2017.

[5] D. W. Matolak, R. Sun, “Air–ground channel characterization for unmanned aircraft systems—part III: the suburban and near-urban environments,” IEEE Trans. Veh. Tech, 26 January 2017

[6] R. Sun, D. W. Matolak, “Air–ground channel characterization for unmanned aircraft systems part II: hilly and mountainous settings,” vol. 66, no. 3, pp. 1913-1925, March 2017.

[7] D. W. Matolak, R. Sun, “Air-Ground Channel Characterization for Unmanned Aircraft Systems: The Over-Freshwater Setting,” Proc. IEEE Integrated Communications, Navigation, & Surveillance Conf., Herndon, VA, 8-10 April 2014.

[8] Terrain Integrated Rough Earth Model (TIREM)/ Spherical Earth Model (SEM) Handbook, Alion Science and Technology, 2007.

[9] https://en.wikipedia.org/wiki/Digital_elevation_model

[10] http://www.cgiar-csi.org/data/srtm-90m-digital-elevation-database-v4-1

[11] Y. H. Jung, Y. Kang, K. Son, H. W. Kim and K. Lim, “Air-ground channel model selection method for UAS communications using digital elevation data,” Ninth International Conference on Ubiquitous and Future Networks (ICUFN), Milan, pp. 115-118, 4 July 2017.