Near Earth Propagation Loss Model in Forest for Low Power Wireless Sensor Network

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Abstract—Radio wave propagation in the forest environment of cellular systems is an important theme, and many propagation models have been proposed. In recent years, forest applications of low power wireless sensor network are also demanded from the viewpoint of environmental protection using a compact ultra-low power sensor nodes.

In this paper, we measured the distance dependency of RSSI (Received Signal Strength Indicator) in the forest environment at low antenna height 105cm using wireless sensor modules with small pattern-antenna 2.4 GHz (3mW) and 920 MHz (20mW). As a result, at 2.4 GHz, TWDP (Two-Wave Diffuse Power) fading is significant factor influenced by ground reflection at short distance, and Rayleigh fading becomes dominant as distance becomes longer. On the other hand, in the 920MHz, scattering occurred even at a close distance with a prospect, the influence of ground reflection was relatively small, and it became clear that fading occurred at any distance. In consideration of these phenomena, we propose a new radio wave propagation model near the ground surface that can be applied 920MHz-2.4 GHz.

Keywords—WSN, radio wave propagation model, forest environment, pattern antenna, TWDP, fading

I. INTRODUCTION

Several model equations have already been proposed in radio wave propagation studies in forest environments. The fundamental model is expressed as equations (1)-(3) as in [1] described in insertion of Fig.1 Among the conventional forest models, Weissberger[2], ITU-R model [3], COST235 model [4], etc. are representative models. These models are based on the cellular system. On the other hand, Kurnaz and Helhel proposed a model for device-to-device communication where the tree trunks are considered in areas characterized by tree species [5]. Smith *et al.* show that the influence of ground reflection is affected at antenna positions of 2 m or less by analyzing Ricean Fading's K-factor in detail [6]. However, since the measurement is done in the Forest Trail, they have not reached the model construction. In this paper, we use a radio module with an antenna height of 105 cm and an omnidirectional small pattern antenna in the forest, and make detailed measurements of radio wave propagation at 2.4 GHz and 920 MHz. From the results, we propose a new model considering the effects of ground reflection and tree scattering.

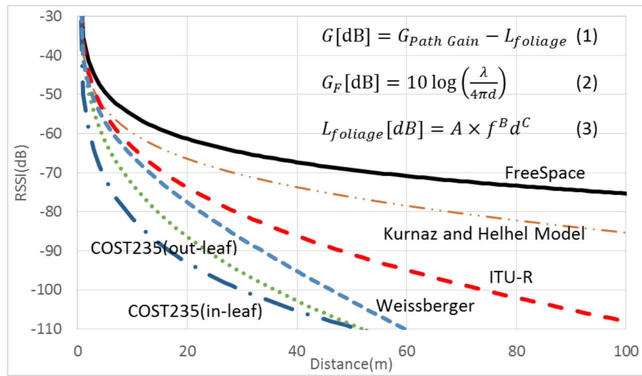


Fig. 1. Comparison of forest propagation models of RSSI vs. distance.

II. EXPERIMENTAL FIELD AND CONDITION

The equipment used is NEC ZB24TM-E2036 (2.4GHz) and TYSS92-E2730 (920MHz) module designed specifically for application of low power WSN. The module is constructed with a small pattern antenna. Therefore, the directional characteristics (horizontal/vertical) of the antenna were measured in an anechoic chamber and appropriate directions of both RX and TX were determined so as not to have influence of antenna fading. The value of RSSI can be acquired as the average value of 100 times of communication. First, in order to obtain the reliability of equipment setup and measurement method, we confirmed that RSSI-distance curve can be reproduced accurately by the 2-Ray model considering the ground reflection on a flat soil ground for every 10cm to 100 m-distance in the university campus with a 2.4 GHz and 920MHz device. Figure 2 shows photographs of two-kinds of forests. Forest 1 location is 33.99N and 131.88E, and Forest 2 location is 33.95N and 131.96E in Yamaguchi prefecture Japan.

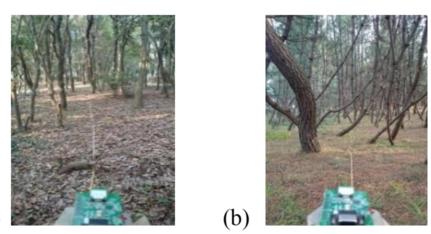
(a) (b)


Fig. 2. Measurement environments (a) Forest1 Deciduous broad-leaved forest: Sawtooth Oak, the ground is covered with fallen leaves. (b) Forest2 Coniferous forest: Japanese Red Pine, The height of the antenna is set at 105 cm

III. EXPERIMENTAL RESULT AND DISCUSSION

A. 0-25m Measurement Result

From Fig. 3 for 2.4GHz, notches can be also confirmed in the Forest 2. In the case of open ground, the two-ray model and the position of the notch match, but in the case of the Forest 2, the notch spacing widens and the notch cannot be seen far from 20m. From this, it is obvious that there is an influence of ground reflection at 2.4 GHz. Here, the $Model_{25m}$ in Fig. 3 is a new model with parameters of A 0.01, B 0.31, and C is 1. In Fig. 3 for 920 MHz, clear notches are not seen compared to the free space radio wave propagation model, scattering occurs due to the influence of the trees around the transmitter and receiver space, and its influence is higher than the ground reflection. In any case, it is considered to be TWDP (Two-Wave Diffuse Power) fading, although there is a difference in the degree of influence of the two-rays. Here, $Model_{25m}$ is the same model as the 2.4 GHz. Here, the difference in the initial value around several 10 cm for 920MHz is caused by the difference in the antenna gain of the device.

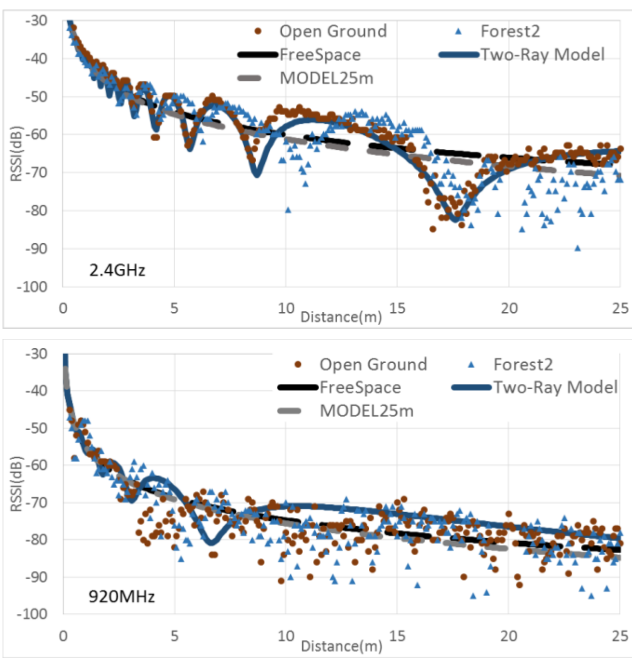


Fig. 3. Measurement and simulation results for propagetion distance 0-25m.

B. 0-100m Measuremetn Result

Top curves of Fig. 4 shows the measurement results (Forest 1 and 2) for 2.4 GHz at 0 to 100 m. Line-of-Sight cannot be secured at this distance. Therefore, measurements were carried out carefully at 1 m intervals (excluding the position where trees are growing), checking the linearity of distance by the 3 points method. First, the RMS error of $Model_{25m}$ was 8.03 dB compared with the measured value for Forest 2, and the error increased from 50m distance. This is thought to be due to the change to Rayleigh fading as it gets far from TWDP fading. Therefore, fitting was carried out to measured-data Forest 1 and 2 of 0 to 100 m. There was no dominant difference in the result. This is probably because the trunk densities of Forest 1 and 2 are almost equal, respectively. Therefore, $Model_{100m}$ was obtained by combining the measured data of Forest 1 and 2. Value A of $Model_{100m}$ is 0.01, B is 0.37, and C is 1. The error of the $Model_{100m}$ for 2.4 GHz was 5.25 dB. Similarly, the results actually measured for 920 MHz and the model were compared as shown in Fig.4. The error of the measured values at $Model_{100m}$ for 920 MHz is 5.52 dB.

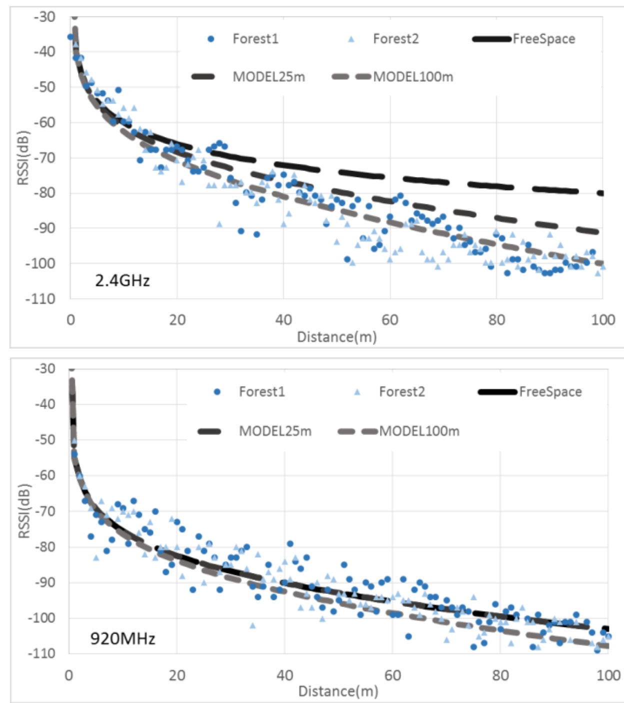


Fig. 4. Measurement and simulation results for propagation distance 0-100m.

IV. CONCLUSION

In this paper, RSSI vs. distance are measured comparing the frequency 2.4 GHz and 920 MHz in two-kinds of forest environments where the antenna height is set at 105 cm. At 2.4 GHz, TWDP (Two-Wave Diffuse Power) fading is strongly influenced by ground reflection at short distance, and Rayleigh Fading becomes dominant as distance becomes longer. Meanwhile, at 920 MHz, scattering occurred even at a close range with a clear line of sight. The new model is proposed and it fits well for both cases.

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