2.4GHz and 920MHz RF Propagation in the Grain Filling Stage of Paddy Field

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Abstract This paper describes the detailed RF propagation measurements and modeling in a Japonica paddy field of grain filling stage. From the viewpoint of practicality, a commercially available wireless communication module equipped with a small pattern antenna was used for the experimental apparatus. Detailed measurements of RSSI were made considering the various clutter effects such as vegetation, reflection, and scattering. The antenna height was chosen as 55, 105, and 155cm against to rice plant height of about 90 - 100cm. The measurement results are discussed based on the propagation phenomena associated with three kinds of propagation models. As a result, these models fit well depending on the antenna height respectively, where two of them are conventional and the other is newly developed in this study.

Keyword wireless sensor network, low power, propagation, communication reliability

1. INTRODUCTION

Nowadays, IoT continues to grow, and is expanding not only to the secondary industry field of manufacturing factories, but also to the primary industries such as agriculture, forestry and fisheries. In this trend, wireless sensor devices with a multi-hop mesh network is attracted as a low cost and simple implementation of system. In order to construct a reliable network, propagation distance between terminals is one of key parameters as well as antenna height. This paper describes RF propagation of 2.4GHz and 920MHz in a paddy field of grain-filling stage. The RSSI (Received Signal Strength Indication) measurement results of RSSI-distance curves for various antenna heights are discussed based on the propagation models.

2. EXPERIMENTAL DEVICES

In recent years, with the aim of reducing the size of equipment, pattern antennas built directly on chip antennas or circuit board have been used. The experimental equipment used here is also equipped with the pattern antenna shown in Table 1. The communication frequencies are 2.4GHz and 920MHz. In addition, the directivity of each antenna is omnidirectional.

Table 1. Specifications of wireless sensor devices.

Model Number	ZB24TM-E2036	TY92SS-E2730
Frequency Band	2.4GHz	920MHz
Output Power	3mW	20mW
Distance Max	200m	250m

3. PADDY FIELD CONDITIONS

The measurement was made on October 16, 2018. The plants became the filling stage after the flowering season and the top of plants formed a waving plane due to the well aligned 20x20cm square matrix formation as shown by a photograph in Fig,1. The height was 80-90cm. A transmitter TX position was fixed on the side walk of paddy field at 3meter from the corner, while a receiver RX was moved from the corner 1meter step by step from 4 to 56meters. The paddy filed was open space so that no reflection was influenced.

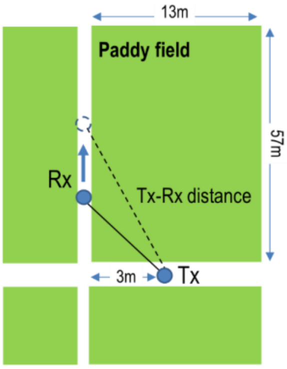

Fig.1. Photograph of grain-filling stage of Japonica paddy field. The top of plants surface becomes dense and its height is about 80-90cm. The left-side figure schematically shows position of a transmitter TX and a receiver RX.

4. RF PROPAGATION MODEL

A total of three RF propagation models were used in this study. Firstly, the EXD model (Exponential Decay Model) shows attenuation characteristics depending on distance in a range of forest density, and is shown as Eq. (1, 2) as its model equation[1].

$$\mathbf{G_{EXD}[dB] = G_{Path\ Gain} - L_{foliage}} \quad (1)$$

$$L_{foliage} = A \times f^B d^C \quad (2)$$

Here, A, B, and C in Eq. (2) are parameters obtained empirically, f is the frequency, and d is the communication distance. The first term in eq.(1) is the path gain in an open space.

Secondly, the RET (Radiative Energy Transfer) model is a physical model to predict the leaf loss of various vegetation terrains[2]. The fundamental concept of the model is to manage the boundary between open space and the foliage space. However, this model requires precise physical parameters of plants, such as dielectric constant, reflectivity, and so on. Therefore, simplified RET model was proposed recently, conceptually implementing the open and foliage space condition [3] as shown in Eq. (3).

$$\mathbf{P_{trans}} = \begin{cases} \mathbf{e^{-\gamma_1 d}} & \mathbf{d < d1} \\ \mathbf{e^{-\gamma_2 d}} & \mathbf{d \geq d1} \end{cases} \quad (3)$$

Here, γ_1 and γ_2 represent different forest attenuation parameters, and they switch at the breakpoint d1.

Final one is the two-ray paddy field model. When the rice plant has a certain density or more, it is considered that the paddy field can be a virtual ground. This means that the reflected wave is generated at a position higher than the reflected wave that occurs in the conventional two-ray ground reflection model[4], and the attenuation by rice plant is also performed simultaneously. Therefore, the antenna height at this time is a model that assumes communication at the effective antenna height obtained by subtracting the height of rice plant from the actual antenna height. Thus, we developed a new model named the two-ray paddy field model, as shown in Eq. (4).

$$\mathbf{G_{PaddyField}} = \left(\frac{\boldsymbol{\lambda}}{\mathbf{4\pi}}\right)^2 \times \left(\frac{\mathbf{1}}{\mathbf{d'}} + \frac{\boldsymbol{\Gamma(\theta)}}{\mathbf{d''^{\alpha}}}\frac{\mathbf{e^{-j\Delta\Phi}}}{\mathbf{d''}}\right)^2 \quad (4)$$

Here, λ is the wavelength, α is the attenuation parameter of the reflected wave, and $\Delta\varphi$ is the phase difference.

5. MEASUREMENT RESULT AND DISCUSSION

The measurement results of the paddy field during grain filling period and the results of fitting the model will be described in order of antenna height 55 cm, 105 cm and 155 cm.

First, Fig. 2 shows a graph of the fitting result at a TX and RX antenna height of 55 cm. When the antenna height was 55 cm, the line of sight between the RX and TX antennas was completely blocked by the rice plant, so the EXD model could be fitted well.

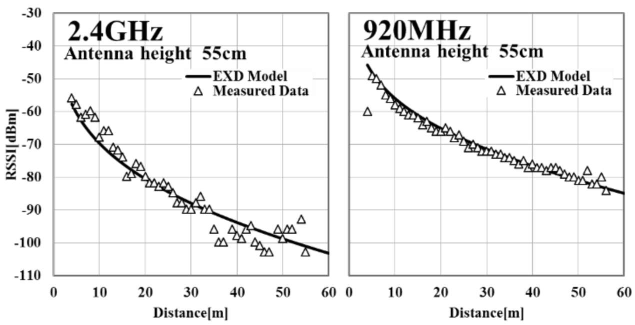

Fig.2. RSSI-distance dependence of RF propagation characteristics in Japonica paddy fields at an antenna height of 55 cm. Measured value and EXD model curve. 2.4 GHz(left) and 920 MHz(Right).

Second, Fig. 3 shows a graph of the fitting result at a TX and RX antenna height of 105 cm. Unlike the antenna height of 55 cm when the antenna height is 105 cm, both the TX and RX can be checked visually, but the line of sight between the TX and RX has not been sufficiently secured. The influence of the reflected wave was not seen. However, unlike the case of 55 cm, a clearer inflection point could be confirmed at 105 cm, and the RET model became a model curve closer to the measured value.

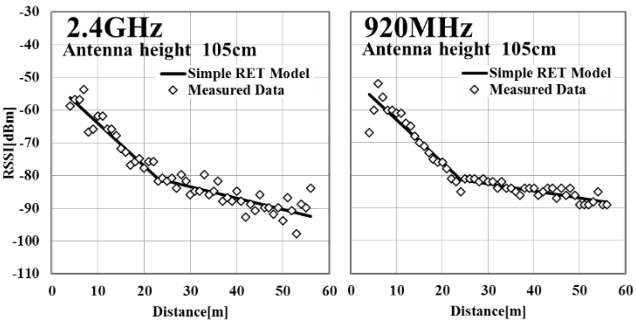

Fig.3. RSSI-distance dependence of RF propagation characteristics in Japonica paddy fields at an antenna height of 105 cm. Measured value and RET model curve.

Finally, Fig. 4 shows a graph of the fitting result at a TX and RX antenna height of 155 cm. The notches are observed in the measured values due to the influence of the reflected wave, unlike the cases of 55 cm and 105 cm. At 2.4 GHz, the measured value and the position of the notch on the model curve coincide with modified two-ray model, but at 920 MHz the position of the notch does not match. This is considered to be due to the fact that, at 920 MHz, the reflection path was increased by the diffraction of radio waves by plants, and the scattering occurred as well.

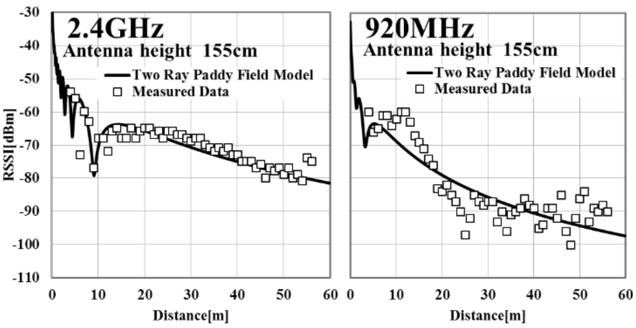

Fig.4. RSSI-distance dependence propagation in Japonica paddy fields at an antenna height of 155 cm. Measured value and two-ray paddy field model curve.

6. SUMMARY

RF propagation measurements and modeling were made in a Japonica paddy field of grain filling stage. According to the space conditions for antenna, above/under top of plants, it is clarified that three kinds of model should be considered. When the antenna height was 55 cm of no line-of-sight, the EXD model could be fitted well. The RET model became a model curve closer to the measured value for 105cm. When the antenna height is 155 cm, modified two-ray model fit well for 2.4GHz, while at 920 MHz the reflection path was increased by the scattering.

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