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Characteristics of UHF Propagation Channels Due to the Impact of Vegetation on WSN in the Tropical Forests

Karakteristik Kanal Propagasi UHF Akibat Pengaruh Vegetasi Pada WSN di Area Hutan Tropis

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Abstract

The use of wireless communication in a wireless sensor network, especially in smart gardens, requires information about the amount of attenuation caused by vegetation. Therefore, measurements were made of the Received Signal Strength Indicator (RSSI) received by the XBee S2C device in the Bamboo Forest area, Surabaya, for several different lengths of vegetation depth and antenna height. From the measurement results, it is known that there is no significant difference between RSSI for antenna heights of 1 m and 2 m, while better RSSI is obtained for antennas with a height of 3 m. The antenna used is a vertical monopole antenna for the 2.4 GHz frequency. This is because, at an antenna height of 3 m, the number of vegetation that becomes obstacles is less than that of antennas of 1 m and 2 m. From the measurement results, it is also known that with this antenna height, data packets can be received up to a vegetation depth of 80 m. Then, the attenuation resulting from the calculation shows that the resulting trend is in accordance with the attenuation trend with the Weissberger, ITU-R, and FITU-R models but with higher values. Differences in measurement methods, locations, obstacles, and different climates and weather can cause this. To predict attenuation at a certain vegetation depth distance, based on the results of the attenuation calculation, a linear equation for calculating attenuation as a function of distance is created of the attenuation calculation, a linear equation for calculating attenuation as a function of distance is created.

Keywords: Attenuation, RSSI, S2C, Vegetation, XBee

Abstrak

Penggunaan komunikasi nirkabel dalam *Wireless Sensor Network* pada *smart garden* memerlukan informasi tentang besar redaman yang disebabkan oleh tumbuhan. Oleh karena itu, dilakukan pengukuran *Received Signal Strength Indicator (RSSI)* yang diterima oleh perangkat XBee S2C di area Hutan Bambu, Surabaya, untuk beberapa panjang *vegetation depth* dan tinggi antena yang berbeda. Dari hasil pengukuran diketahui bahwa tidak terdapat perbedaan yang signifikan antara RSSI untuk tinggi antena 1 m dan 2 m, sedangkan RSSI yang lebih baik diperoleh pada antena dengan tinggi 3 m. Antena yang dipergunakan adalah antena monopole vertikal untuk frekuensi 2,4

GHz. Hal ini disebabkan bahwa pada tinggi antena 3 m jumlah tumbuhan yang menjadi penghalang lebih sedikit daripada pada antena 1 m dan 2 m. Dari hasil pengukuran juga diketahui bahwa dengan tinggi antena tersebut paket data dapat diterima hingga panjang *vegetation depth* 80 m. Kemudian redaman yang dihasilkan dari perhitungan menyebutkan bahwa *trend* yang dihasilkan sesuai dengan *trend* redaman dengan Model Weissberger, ITU-R, dan FITU-R, tetapi dengan nilai yang lebih tinggi. Hal ini bisa disebabkan karena perbedaan metode pengukuran, lokasi, halangan, dan iklim serta cuaca yang berbeda. Sementara itu untuk memprediksikan redaman pada jarak kedalaman vegetasi tertentu, maka berdasarkan hasil perhitungan redaman dibuatlah suatu persamaan linear perhitungan redaman sebagai fungsi jarak.

Kata kunci: RSSI, Redaman, S2C, Tumbuhan, XBee

I. INTRODUCTION

Recently, wireless communication has been widely used by people throughout the world. This wireless communication requires accurate wave propagation models in various environments, including environments filled with vegetation. One of them is if this wireless communication is implemented in a Wireless Sensor Network (WSN) to support monitoring of the volcanic conditions of a volcano [1]. For remote mountainous or forest areas where there is no telecommunications infrastructure, radio waves can be used to transmit measurement data to the receiving server [2]. Wireless communications that work in the UHF frequency band require great interest if WSN is applied in areas that are susceptible to scattering, reflection and refraction in plants [3]. So that this WSN can work well in areas that are susceptible to vegetation attenuation, it is necessary to create a model of radio channel characteristics in the UHF band. The channel characteristics model indicates the amount of attenuation and signal reception power that occurs in the communication system on a WSN which is influenced by the environmental conditions where the network is implemented [4]. Therefore, together with other network parameters, such as signal-to-noise ratio (SNR), delay, throughput, packet loss, etc., Received Signal Strength Indicator (RSSI) is a necessary factor in planning a WSN and optimizing it [5]. RSSI measurements have been carried out in various environments using the ZigBee protocol and the XBee Pro S2 and XBee Series 2 communication modules but in limited space scenarios [6], [7].

To determine the characteristics of WSN channels that are influenced by vegetation, in this research RSSI measurements and analysis were carried out on the distance and height of the antennas. RSSI is generated from the XBee S2C device which works at the 2.4 GHz frequency which functions as a transmitter and receiver. The collected RSSI data is then calculated as attenuation in dBm. These attenuation values need to be obtained to calculate the link budget before designing a smart garden or other sensor network that uses the XBee S2C device under the influence of vegetation attenuation. The trend of attenuation values based on distance is then compared with models of signal attenuation caused by vegetation, such as the Weissberger Model, ITU-R Model and FITU-R Model. After that, an attenuation equation is created as a function of vegetation depth to determine the amount of attenuation produced for the measurement location.

II. LITERATURE REVIEW

WSNs that function to monitor natural conditions, for example, volcano monitoring networks, smart farming, smart gardens, and so on, require channel modeling to determine the amount of attenuation needed to find the transmit power required by the communication network on the WSN [8]. The design of communication networks that work on WSN is influenced by environmental conditions. For WSN used in poultry farming areas, pathloss is influenced by poultry cages and concrete floor dividers [9]. Signal intensity and power loss variations in vineyards and oil palms have also been studied using ZigBee sensor nodes [10], [11], [12]. Likewise, the power received in several conditions of rice plants was also studied using the XBee 2SC sensor node, which states that the modified two slope log distance model is suitable for modeling the power received on wireless channels from WSN which is influenced by the height and shape of the rice plants observed [13]. However, not many have carried out observations of the power received of channels which are influenced by the diversity of vegetation in tropical forests, except for a few measurements in Nigeria [14]. Therefore, in this research, the power received of a communication system used by WSN was measured which is influenced by the diverse vegetation conditions in tropical Indonesia.

This WSN is implemented in Indonesia where the forest that influences attenuation, scattering, and multiple path effects in the WSN is the tropical rain forest. Tropical rain forests have high humidity due to high rainfall, at a temperature of 20º - 30º C with a rich diversity of vegetation types which include low plants near the ground surface to tall trees that appear above the canopy due to high levels of sunlight [15]. The signals that propagate between the transmitter-end and receiver-end on a WSN via a wireless channel are influenced by the ground surface, vegetation height, vegetation depth, and node layout in the WSN environment [16]. These various forms of propagation cause multipath fading which affects the resulting pathloss. So, the amount of pathloss must be measured before designing the WSN communication system.

III. RESEARCH METHOD

In WSN, the node that functions as a transmitter is a sensor, while the node that functions as a receiver is a sink node. However, in this measurement, the transmitter does not send data packets resulting from sensor measurements, but instead sends data packets that are generated randomly. Meanwhile, the functions of the sink node is receiving and collecting data packets to be stored on the Personal Computer (PC).

A. Measuring Device

The XBee S2C embedded module from Digi International Inc is used as a Zigbee wireless transmission module for the sink node. This XBee module has also been used as a sink node for processing humidity sensors in agriculture and for transmission networks [17], [18]. The main characteristics of the Zigbee module used are a working frequency of 2.4 GHz with IEEE 802.15.4 standard protocol, 5 dBm transmit power, 9600 bps baud rate, -100 dBm receiver sensitivity, and Direct Sequence Spread Spectrum (DSSS) modulation technique. In the DSSS technique, the original signal data bits are represented by multiple bits known as spreading code which is generated by pseudonoise. An omnidirectional antenna with vertical polarization is used on both the transmitter (Tx) and receiver (Rx). The gain of the Tx and Rx antennas is 3.2 dBi and the length is 18 cm. Figure 1 is an embedded XBee S2C with an omnidirectional antenna. A computer connected to a serial port and XCTU software is used to obtain control parameters and data acquisition sent by the transmitter and store the Received Signal Strength Indication (RSSI) received by the receiver. RSSI is used to determine the quality of the communication link [19].

Figure 1. Embedded XBee S2C equipped with omnidirectional antenna

B. Design and Measurement Methods

To analyze the pathloss characteristics of wireless channels which are influenced by attenuation of vegetation, an experiment was carried out in a flat garden during the day with no rain. The experimental location for this attenuation measurement is located at Bamboo Forest, Surabaya (729º S, 112.80º E) on June 10 – 15, 2023. The Bamboo Forest is located in Keputih Village, Surabaya City with an area of 40 hectares, consisting of a Bamboo Forest, Harmoni Park and Public Space. The measurement location is located in the Harmoni Park section which contains various types of plants, from tall trees, shrubs, bushes and grass. Apart from tall trees such as Tabebuya (Tabebuia rosea), African Tulip (Spathodea campanulata), Trembesi (Samanea saman), and Pule (Alstonia scholaris) on the site also grow shrub trees such as Pucuk Merah (Syzygium myrtifolium), Javanese Soka (Ixora javanica), and Peacock Flower (Caesalpinia pulcherrima). Shrubs are plants that have a height of less than 6 meters, while bushes have a maximum height of 1.5 meters.

Figure 2. Experimental location consisting of various types of tropical vegetations

Figure 2 shows the vegetations that grow at the measurement site, which is an urban forest that grows in tropical areas with various types of plants. To recognize the characteristics of various plants regarding attenuation, 3 (three) antennas with different heights are used, namely 1 (one) meter, 2 (two) meters, and 3 (three) meters high.

WSN in this research is represented as a PC that generates data packets connected to Arduino Uno, XBee Shield, and XBee S2C on the transmitter side. Then, the XBee S2C and XBee adapter are connected to the PC to process and store data as shown in Figure 3. In this measurement, there are 2 types of communication modes, namely serial communication between Arduino and XBee S2C, and wireless communication between XBee S2C as transmitter and XBee S2C as receiver. XBee S2C which functions as Tx is fixed, while Rx is mobile following a predetermined distance. The distance between Tx and Rx varies between 10 meters to 200 meters. This distance between the Tx and Rx, which lies among the trees, where the signal will pass through that distance when transmitted, is referred to as the vegetation depth. The vegetation depth is also called foliage depth [20] and tree depth [21]. The vegetation depth in Figure 3 is noted as d. The measurement scenarios are as follows:

a. Tx and Rx are placed at a predetermined vegetation depth (d), namely 10 meters, and the antenna is set at the first height (h), namely 1 meter.
b. Tx sends data packets at the first vegetation depth (d) and antenna height (h).
c. The data packet is confirmed to be sent, and the RSSI value can be obtained.
d. RSSI data are stored.
e. Tx and Rx are at the same vegetation depth (d), but the antenna height (h) is changed by 2 meters.
f. And so on, until RSSI values are obtained at the longest vegetation depth and an antenna height of 3 meters.

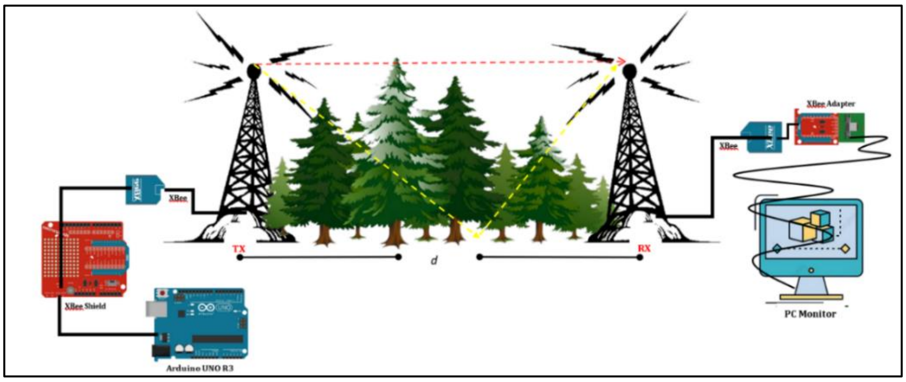

Figure 3. Measurement System Design

Pathloss measurements which are influenced by vegetation attenuation were carried out with an XBee S2C device. This XBee S2C device measures the amount of RSSI received by the device. RSSI measures the amount of power in a radio signal and is the strength of the signal received by the antenna, expressed in dBm units [22]. The RSSI value is displayed in negative dBm. These RSSI values are obtained from pin 6 on the XBee module in the form of Pulse-Width Modulation (PWM) signals. XCTU displays RSSI values in hexadecimal form, which are converted to decimal form for further processing. Then the RSSI is used as the received power to calculate attenuation and pathloss, and the results are compared with the existing attenuation model. Pathloss on channel (L) is calculated based on the resulting RSSI and expressed in dBm. Pathloss is calculated using Eq. (1) as follows [23]:

$$L = P_t + G_T + G_R - P_r, \tag{1}$$

where P_t is the XBee S2C transmit power, while P_r is the resulting RSSI which has been converted in dBm scale. G_t and G_r are the Tx and Rx antenna gains gain in dBi respectively. These L values are calculated for each specific vegetation depth distance, then plotted based on each antenna height.

The pathloss models used as comparisons for this experiment are the Weissberger, ITU-R, and FITU-R models. The Weissberger model is based on measuring additional attenuation in signal propagation working in the UHF frequency band which is expressed by Exponential Decay (EXD) [24]. Using the same operational frequency data, vegetation depth distance, gain, and antenna height, the path loss is then calculated using Eq. (2) as follows:

$$L = 0{,}26F^{0{,}77}d_f, \tag{2}$$

where L is the loss due to vegetation in dB, F is the frequency in GHz, and d_f is the vegetation depth in meters. Then for frequencies between 230 MHz to 95 MHz, a better prediction of attenuation is to use the improved EXD model to become the Modified Exponential Decay (MED) Model [25], resulting in the Eq. (3) as follows:

$$L = 1{,}33F^{0{,}24}{d_f}^{0{,}588} \text{ for } 14 \le d_f \le 400 \tag{3}$$
$$= 0{,}45F^{0{,}284}d_f \text{ for } 0 \le d_f \le 14. \tag{4}$$

The MED model can be applied to signal transmission that is obstructed by dense vegetation with complete leaf condition in dry air conditions in areas where the temperature follows the conditions of mid-latitude areas [26]. The ITU-R recommendation for calculating vegetation attenuation ($A_{ITU-R-foliage}$) in dB is built on measurements in the UHF band [27] which produces Eq. (5) as follows:

$$A_{ITU-R-foliage} = 0{,}2f^{0{,}3}d^{0{,}2}, \tag{5}$$

where f is the frequency in MHz, and d is the propagation distance affected by vegetation, in meters.

The Fitted-ITU-R Model (FITU-R) is a model adapted from the ITU-R Model to be suitable for use by electromagnetic waves that work in the Very High Frequency (VHF) band that propagate through relatively short vegetation depths, which are less than 400 m [28]. The FITU-R model is also derived from two vegetation conditions, namely in-leaf and out-leaf as follows:

$$L = 26{,}6f^{-0{,}2}d^{0{,}5} \ out - of - leaf, \tag{6}$$
$$L = 15{,}6f^{-0{,}009}d^{0{,}26} \ in - leaf, \tag{7}$$

where f is the frequency in MHz, and d is the vegetation depth in meters.

By using data on the same working frequency, distance, gain and antenna height, the resulting pathloss is also calculated based on the Weissberger Model using Eq. (2), the ITU-R Model using Eq. (5) and FITU-R using Eq. (6) and (7).

Mathematical modeling is conducted to find an equation that represents the measurement results. This equation involves one independent variable, which is path length between the transmitter (Tx) and receiver (Rx), referred to as vegetation depth and measured in meters, and one dependent variable, which is the attenuation expressed in dBm. Since this modeling involves only one independent and one dependent variable, a simple linear regression analysis that fits the data is chosen. The resulting equation has the following form:

$$y = p_1 x + p_2, \quad (8)$$

where p_1 is the constant representing the intersection with the x-axis, p_2 is the regression constant, and y is the response variable. In this case, the values of y are the attenuation in dBm, furthermore the x represents the vegetation depth in meter. The p_1 and p_2 values are obtained using linear regression technique.

IV. RESULTS AND DISCUSSION

The measurements were carried out over six days. In one measurement session, 120 RSSI samples were obtained for each vegetation depth and each antenna height. Because they were carried out over 6 sessions, 6×120 samples were produced which were used to determine the RSSI value for each antenna height and each vegetation depths. The RSSI measurements that have been carried out produce figures as can be seen in Table 1. The values shown in Table 1 are the mode of the values obtained from the measurements. The mode value is taken because, at the time of measurement, there is an incidental disturbance. Therefore, the mode is the value that frequently appears during measurement when there is no such incidental disturbance.

Table 1. RSSI Based on Vegetarian Depth

Vegetation depth (m)	**RSSI (dBm) for each antenna height (m)**		
	1	**2**	**3**
10	-79	-87	-75
20	-84	-86	-89
30	-90	-87	-79
40	-93	-90	-90
50	-89	-85	-85
60	-93	-92	-85
70	-94	-94	-90
80	-94	-94	-89
90	-94	-94	-94
100	-94	-94	-94
110	-94	-94	-94
120	-94	-94	-94
130	-94	-94	-94
140	-94	-94	-94

The measurements were planned to be conducted at vegetation depths ranging from 10 to 200 meters. However, beyond 140 meters, no RSSI indication appeared on the PC screen. This indicates that the communication link was lost, resulting in no data packets being received. At all three antenna heights—1 meter, 2 meters, and 3 meters—the communication link was interrupted at vegetation depths greater than 140 meters. In the RSSI measurements for antenna heights of 1 meter and 2 meters, there was no significant difference; both heights had approximately the same RSSI values. Assuming no data was lost at an RSSI of -94 dBm, data could be transmitted at antenna heights of 1 meter and 2 meters before reaching a vegetation depth of 60 meters, as the RSSI level had not yet reached -94 dBm. In contrast, the antenna at a height of 3 meters could transmit data up to a vegetation depth of 80 meters. This is because at antenna heights of 1 meter and 2 meters, the transmitted signal was subject to fading, resulting in multipath fading. This multipath fading occurs because the signal propagating as a radio wave experiences scattering, diffraction, refraction, and ducting when encountering obstacles, in this case, tree trunks and leaves. The fading experience causes a phase angle change between the line-of-sight (LoS) and non-line-of-sight (NLoS) waves, making it prone to weakening when the phase angle of the direct wave opposes the phase angle of the indirect wave. Additionally, there is energy absorption of the radio wave when passing through obstacles like trees, trunks, and leaves, causing attenuation of the received power.

The attenuation received by the 1-meter and 2-meter antennas is greater than that of the 3-meter antenna because the attenuation factors for the 1-meter and 2-meter antennas include more obstacles such as shrubs, small leaves, and tree trunks. In contrast, the attenuation factor for the 3-meter antenna is only three trunks. Measures that can be taken to improve the RSSI value include increasing the antenna height to reach LoS position, changing the antenna type from omnidirectional to sectoral, and choosing devices with higher transmission power.

The proposed method, obtained using regression as described by Eq. (8), can be used to predict the attenuation value (L) as a function of vegetation depth distance (d). By this method, the following equation is obtained:

$$y = 0.2x + 86.05, \tag{9}$$

where y is attenuation in dBm and x is vegetation depth in meters.

The resulting equation can be used to calculate the distance of vegetation (x) for attenuation above the threshold allowed for data transmission with the device. The method is knowing the receiver sensitivity of the receiving device, and the transmit power of the transmitter which is used to calculate attenuation (y). Receiver sensitivity is the minimum power in dBm that can be received by the device. Then, using the Eq. (9), the maximum vegetation depth (x) allowed for communication can be calculated.

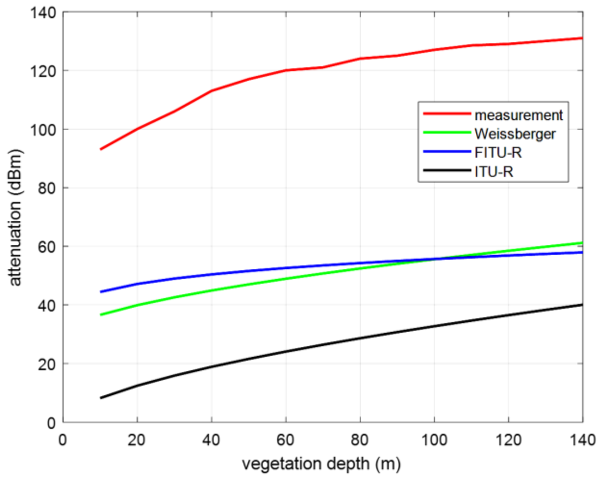

Figure 4. Comparison the attenuation of vegetation depth for an antenna height of 3 meters, significant differences between the proposed method (regression model based on measurement data) and the Weissberger, ITU-R, and FITU-R models

Figure 4 is a graph showing the relationship between attenuation (dBm) and vegetation depth (m), where the attenuation is obtained from Eq. (1). The comparative attenuation values are generated by Eq. (2), (3), and (5), which correspond to the Weissberger, ITU-R, and FITU-R models, respectively. The figure shows that the measured attenuation values exhibit the same trend as the predicted attenuation models due to vegetation, with attenuation increasing as vegetation depth increases. However, the measured attenuation values are higher than the predicted models. The ITU-R model underestimates vegetation attenuation, so it assumes low attenuation values, while the Weissberger model overestimates attenuation and assumes high attenuation values. Meanwhile, the FITU-R model is intermediate. However, the attenuation values predicted by Weissberger and FITU-R are still below the measurement results. This discrepancy may be due to different environmental conditions at the location. For example, Weissberger model is an empirical model based on attenuation measurements in areas with shrub trees, such as oak trees, while the FITU-R model is based on attenuation measurements with barriers of short trees with a height of less than 7 meters, like chestnut trees. While these measurements involve trees more than 10 meters high and bushes and shrubs as obstacles. Moreover, the climate and humidity in the tropical measurement area also cause differences with the predicted results, where the measurements made by these models are not in a tropical climate. Therefore, a proposed model as in Eq. (9) is needed to calculate vegetation attenuation in the Taman Harmoni area, Sukolilo, Surabaya.

V. CONCLUSION

To utilize XBee in a Wireless Sensor Network for a smart garden, it is essential to understand the network quality during packet transmission in an environment filled with vegetation. This network quality is measured using the Received Signal Strength Indicator (RSSI) received by the XBee S2C at different antenna heights. The measurement results show that antenna heights of 1 and 2 meters do not provide a significant difference, as neither height can receive data packets when the vegetation depth reaches 60 meters. With a 3-meter antenna height, the XBee S2C can receive data packets up to 80 meters. To improve the RSSI, the antenna height can be increased, the antenna type can be changed, and the device can be replaced with one having a higher transmission power. The attenuation values obtained from the measurements show the same trend as the attenuation results generated by the Weissberger, ITU-R, and FITU-R models, but with higher values. This discrepancy is due to differences in methods, equipment, environment, and weather conditions between the models. Linear equations can be used to formulate the attenuation equation as a function of vegetation depth distance, which is a method for predicting attenuation.

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AUTHOR CONTRIBUTION

IK led the determination of the contents of the paper. RA performed and analyzed the data. RB and MAS prepared the manuscript and revised the final version of the paper. IK and RA have read the final manuscript and approved the submission.

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