InComTech: Jurnal Telekomunikasi dan Komputer
vol.12, no.2, Agustus 2022, 119-128
http://publikasi.mercubuana.ac.id/index.php/Incomtech
P-ISSN: 2085-4811 E-ISSN: 2579-6089

Comparison of 920 MHz and 2.4 GHz Near Ground Electromagnetic Wave Pathloss Propagation Model for Wireless Sensor Network in Forest Environment Application

Galang P. N. Hakim[1*], Rachmat Muwardi[2], Mirna Yunita[3], Diah Septiyana[4]

[1,2]*Department of Electrical Engineering, Universitas Mercu Buana Jakarta, Indonesia*
[3]*School of Computer Science and Technology, Beijing Institute of Technology Beijing, China*
[4]*Industrial Engineering Departement, Universitas Muhamadiyah Tangerang, Indonesia*
*Corresponding Email: galang.persada@mercubuaan.ac.id

Abstract:
A Wireless Sensor Network (WSN) system that uses wireless communication technologies occasionally experiences data loss when undertaking wireless data communication. This problem happens because of the WSN system being placed on top of the ground and surrounded by vegetation that adds more loss to the transmission. In order to avoid this problem, the wireless system design must meet its best performance. To build the best performing WSN system, electromagnetic wave behavior in the forest environment needs to be studied well. This paper investigates the electromagnetic wave behavior transmitted and propagated by a WSN node at less than 30 cm from the ground using a 920 MHz frequency. We have analyzed that low height (30 cm) and vegetation environments can also add more loss at about 30.96 dB to the free space pathloss model. The new 920 MHz (that adds 30.96 dB loss) model shows identical behavior to 2.4 GHz with an average difference of 12.24 dB. However, the 920 MHz model performs better, achieving an average RMSE of 1.06 compared with the 2.4 GHz model, which can only achieve an average RMSE of 4.92 compared with the 920 MHz measurement.

Key Words:
Near Ground;
Electromagnetic Wave;
Propagation;
Wireless sensor Network;
Wireless Data Communication;
Pathloss;
Forest;
920 MHz;
2.4 GHz

Article history:
Received January 3rd, 2022
Revised April 15th, 2022
Accepted May 24th, 2022
Published August 18th, 2022

DOI:
10.22441/incomtech.v12i2.14186

1. INTRODUCTION

ITU-T classified the Wireless Sensor Network (WSN) system in 2010 as a next-generation network [1]. WSN is a concept to connect sensor nodes using wireless technologies. The WSN network can exchange and communicate between its nodes using multiple wireless technologies such as WiFi, LoRa, zigbee, and others [2]. There are some advantages to WSN technological concepts. There are some advantages to WSN technological concepts. First of all, it can monitor its environment using sensors. Its data will be sent to the sink node and finally to the server to be processed automatically [3]. Second, it can reduce deployment costs by using existing infrastructure and low sensor node costs [4]. The third one can extend coverage by using ad-hoc wireless communication methods [5]. Furthermore, the fourth one can be deployed universally from forest to cities environment [6], [7].

Even though WSN technologies have many advantages, they also have disadvantages. One of the WSN disadvantages, such as small energy capacity [8] and data transmission problems (interference [9], delay [10], packet loss [11], and others [12]). Several researchers are working to solve WSN power issues by developing additional power sources (energy harvesting) such as soil energy harvesting [13], solar energy harvesting [14], and many others [14–16]. Meanwhile, for data transmission problems, some researchers try to use routing concepts such as LEACH [17], MUSTER [18], PDORP [19], and many others [20], [21].

In a forest environment, this data transmission problem occurs mainly because of terrain and distance. Therefore, to solve this problem, the wireless system in the WSN network must be designed with its best performance, including its environmental analysis. This paper proposes to study the behavior of electromagnetic waves in a forest environment. Because the WSN node is usually placed on the top of the soil [22], this behavior was studied, especially in near-ground electromagnetic wave propagation. Figure 1 shows the wireless sensor network nodal before crop grows bigger. Because in Indonesia there are regulation for LPWAN (A low power wide area network) and ISM frequency band that use for LPWAN device transmission such as WSN node, therefore we only do measurement for 920 MHz [23] and for 2.4 GHz was using our previous model [24]. The novelty of this study would be an electromagnetic wave near-ground path loss propagation model that can be used for 920 MHz and 2.4 GHz for WSN systems in forest applications.

Figure 1. Wireless Sensor Network Nodal Before Crop Grows Bigger

2. ENVIRONMENT, INSTRUMENT, METHOD, AND PREVIOUS MODEL

This section will discuss forest environmental conditions, measurement methods, measurement instruments, and electromagnetic wave propagation in a free space environment.

2.1 Measurement Environment

The experiment was conducted in Indonesia near East Jakarta, with the exact location at the Jamboree Cibubur, which has forest sites as its characteristic. There is no difference in land elevation in this forest environment, only flat land. This forest site also has trees taller than 4 m. It is also more than 30 cm tall and thick with bushes and grass. Figure 2 depicts the location of Observed Forest Environments.

Figure 2. Forest Like condition site

2.2 Walk Test Measurement Methods

The measurement method would be to do a walk test along with the site. The Walk test is a signal quality test performance that is usually performed on a cellular network [25]. Therefore, the same method was used in this study. The main objective would be to capture a Received Signal Strength Indicator (RSSI) signal every 3 meters with a straight line.

2.3 Measurement Instrument

In this study, we are using a couple of radios. Both use transmitters to generate electromagnetic waves and receivers to capture electromagnetic waves. Figure 3 shows the measurement methods, equipment, and the results, while Figure 4 shows walk test measurement using the Arduino IDE serial monitor.

2.3.1 Transmitter

For the 920 MHz transmitter, we are using the microcontroller ESP32 combined with the Semtech chipset LoRa radio. The LoRa radio transceiver, according to its manufacture datasheet, has been calibrated before, therefore this measurement was accurate [26]. The LoRa transmitter antenna used in this study would be omnidirectional. This transmitter is then powered using a rechargeable battery. This transmitter is also placed on the top of the soil with an antenna height of less than

30 cm. Then, the electromagnetic waves are generated every 500 milliseconds. Meanwhile, the power transmitter will be set at 0 dBm.

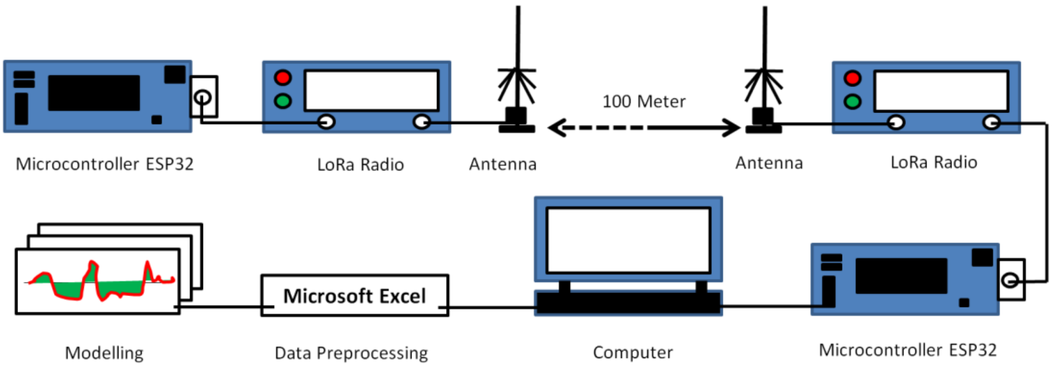

Figure 3. Measurement methods, environment, and tools

2.3.2 Receiver

For the 920 MHz receiver, we are also using the microcontroller ESP32 combined with the Semtech chipset LoRa radio [26]. The LoRa receiver antenna used in this study would be omnidirectional. This receiver is also placed on the top of the soil with an antenna height of less than 40 cm. The captured signal will then be sent to the computer via the Arduino IDE serial monitor, as shown in Figure 4, for easy monitoring. After it is easy to see, we process the electromagnetic wave signal using Microsoft Excel for data processing.

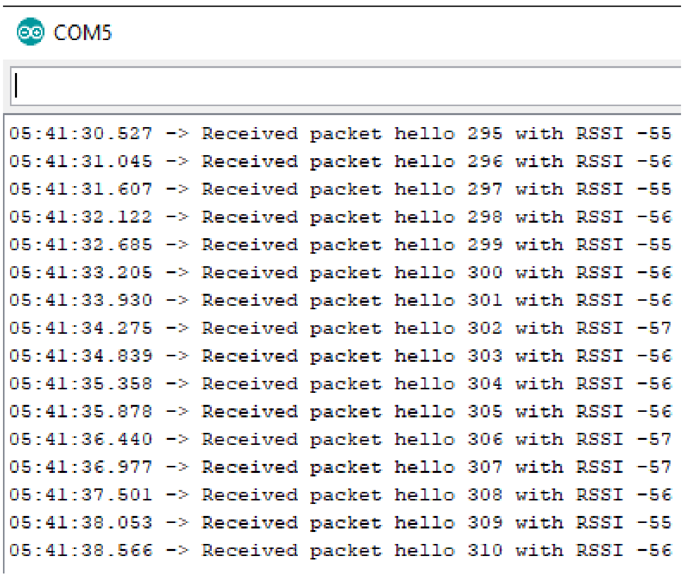

Figure 4. Walk Test Measurement using Arduino IDE Serial Monitor

2.4 Free Space Pathloss Model

According to Chrysikos, the electromagnetic wave loss is summed up by adding the two independent loss processes, which are free space loss and obstacle loss [27]. As a result, the rudimentary method can be used to model LoRa radio wave propagation loss, which is a free space path loss propagation model and an obstacle loss model caused by Fresnel zone and scattering (due to its surrounding vegetation). The FSPL (Free Space Path Loss) propagation model is a propagation model derived from the transmission derivative function of two transmitting and receiving antennas (Friss transmission). This function states that the relationship between the received power and the transmitted power between two antennas separated by a large enough distance d (Figure 5). The Friss transmission function is an application of the far-field antenna, with the limitation that the distance must be greater than the wavelength [28].

Figure 5. Illustration of the Friss transmission equation for a far-field antenna (2 antennas separated by a distance d)

The gain on the transmitting antenna can be written as:

$$S = \frac{P_{in} G_t}{4\pi d^2} \tag{1}$$

Therefore, the power to be received by the receiving antenna is:

$$P_r = \frac{P_{in} G_t}{4\pi d^2} . \frac{\lambda^2}{4\pi} D_r \tag{2}$$

Because the efficiency of the receiving antenna also affects the output power received by the receiving antenna [29], we can write:

$$P_{out} = P_r \eta_{er} = \frac{P_{in} G_t}{4\pi d^2} . \frac{\lambda^2}{4\pi} D_r \eta_{er} = \frac{P_{in} G_t}{4\pi d^2} . \frac{\lambda^2}{4\pi} G_r = \left(\frac{\lambda}{4\pi d}\right)^2 G_t G_r P_{in} \tag{3}$$

Therefore, the transmission function is the power received by the receiving antenna based on the power sent by the transmitting antenna, the distance traveled, and the function of electromagnetic waves on the surface of the transmitting and receiving antennas:

$$\frac{P_r}{P_t} = \left(\frac{\lambda}{4\pi d}\right)^2 G_t G_r \tag{4}$$

Being a function of electromagnetic waves in free air (FSPL Free Space Path Loss):

$$FSPL = \frac{P_t}{P_r} = \left(\frac{4\pi d}{\lambda}\right)^2 G_t G_r \qquad (5)$$

Because this form is in watt units, calculating gain or loss in power transmission is difficult. Therefore, to simplify calculations, all power transmission, both at the transmitter and receiver, is converted to decibels. So, the equation can be written:

$$FSPL = \frac{P_t}{P_r} = 10\log_{10}\left(\left(\frac{4\pi d}{\lambda}\right)^2\right) + G_t + G_r \qquad (6)$$

If we use an isotropic antenna, the gain on the transmitting and receiving antennas is 0, so we can write:

$$FSPL = 20\log_{10}\left(\frac{4\pi d f}{c}\right) \qquad (7)$$

or

$$FSPL = 20\log_{10}(d) + 20\log_{10}(f) - 147.55 \qquad (8)$$

Where:

For d in meters and f in kHz, the constant becomes -87.55.
For d in meters and f in MHz, the constant becomes -27.55.
For d in kilometers and f in MHz, the constant becomes 32.44

2.5 Previous or Existing Model

In 2016, we also conducted 2.4 GHz measurements for the Wireless Sensor Network near-ground forest application. Furthermore, we also built a model based on its measurement [24] and based on free-space path loss. This model has been tested to be accurate against the free-space path loss, greenhouse model [30], and Green-Obaidat models [29]. This model was measured in high grass-bushes for more than 30 cm and in the forest environment. The antenna for transmitter and receiver was also less than 40 cm in height. Therefore, the model would be:

$$F_{FSPL} = 20log_{10}d + 20log_{10}f + 32.45 + FS \qquad (9)$$

Where:

f = frequency in Hertz (MHz)
d = overall distance in meter (km)
FS = scattering loss for 2.4 GHz, which is 35.2 dB in average.

3. RESULTS AND DISCUSSION

The measurements were carried out in a forest with thick bushes and grass at noon. The result is shown in Table 1. From Table 1, we can see how near-ground wireless data communication using frequency at 920 MHz can reach a distance of about 57 meters. We also try to use the 2.4 GHz near-ground path loss propagation model built in 2016. We try to validate if we can use a 2.4 GHz near-ground path loss propagation model even though we use different frequency measurements such as 920 MHz. Table 1 shows a 2.4 GHz near-ground path loss propagation model versus a 920 MHz near-ground measurement.

Table 1. 920 MHz RSSI Measurement vs 2.4 GHz Model

Distance (in Meter)	920 MHz Measurement in (dBm)	2.4 GHz Model in (dBm)
3	-64,27	-84,28
6	-77,29	-90,30
9	-86,31	-93,82
12	-86,44	-96,32
15	-84,97	-98,26
18	-92,32	-99,84
21	-93,89	-101,18
24	-94,07	-102,34
27	-90,72	-103,36
30	-94,40	-104,28
33	-97,93	-105,10
36	-94,86	-105,86
39	-93,41	-106,56
42	-94,00	-107,20
45	-92,94	-107,80
48	-91,68	-108,36
51	-94,82	-108,89
54	-94,40	-109,38
57	-95,40	-109,85

Based on Table 1, we can see that the 920 MHz near ground path loss measurements are fit in behavior with the 2.4 GHz model. The average difference between the 920 MHz measurement and the 920 MHz free space model was 30.96 dB. Therefore, we can write a new model for 920 as below:

$$F_{FSPL} = 20log_{10}d + 20log_{10}f + 32.45 + FS \quad (10)$$

Where:

f = frequency in Hertz (Hz)

d = overall distance in meter (m)

FS = average scattering loss or 920 MHz was 30.96 dB

Figure 6 shows the results of 920 MHz measurement versus 2.4 GHz and 920 MHz pathloss model. The average difference between the 920 MHz model and the 2.4 GHz model was 12.24 dB, while the average difference between the 920 MHz measurement and the 920 MHz model was 0.2 dB. To validate our measurement, we would like to apply RMSE as shown in Table 2 below.Based on Table 2, we can see that our new 920 MHz model performed well for Near Ground Electromagnetic Wave Pathloss Propagation Model for Wireless Sensor Networks in Forest Environments that use the 920 MHz frequency band better compared with the 2.4 GHz model. The 920 MHz model can achieve an average RMSE of 1.06 compared with the 2.4 GHz model that can only achieve an average RMSE of 4.92.

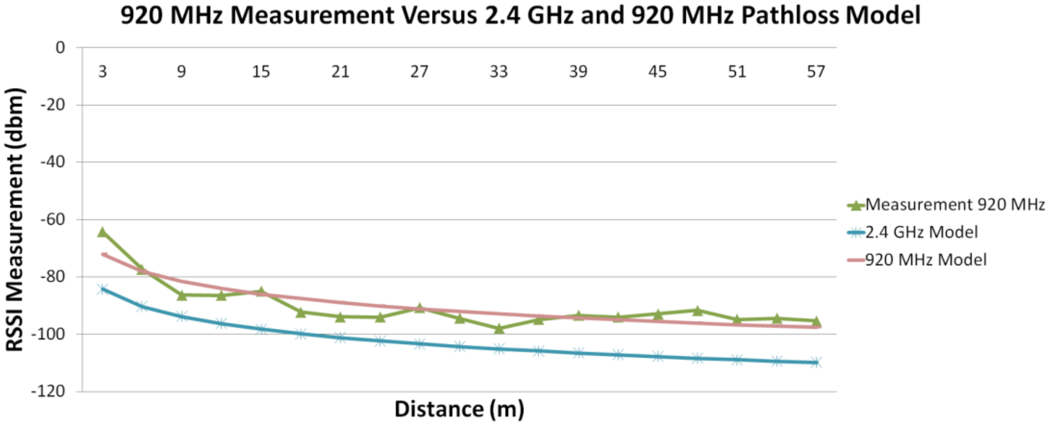

Figure 6. 920 MHz Measurement versus 2.4 GHz and 920 MHz Pathloss Model

Table 2. 920 MHz and 2.4 GHz Pathloss Model Validation using RMSE

Measurement 920 MHz	2.4 GHz Model	RMSE 2.4 GHz Model	920 MHz Model	RMSE 920 MHz Model
-64,27	-84,28	4,59	-72,04	1,78
-77,29	-90,30	3,07	-78,06	0,18
-86,31	-93,82	1,82	-81,58	1,15
-86,44	-96,32	2,47	-84,08	0,59
-84,97	-98,26	3,43	-86,02	0,27
-92,32	-99,84	2,01	-87,60	1,26
-93,89	-101,18	2,02	-88,94	1,37
-94,07	-102,34	2,39	-90,10	1,15
-90,72	-103,36	3,81	-91,12	0,12
-94,40	-104,28	3,12	-92,04	0,75
-97,93	-105,10	2,39	-92,87	1,69
-94,86	-105,86	3,89	-93,62	0,44
-93,41	-106,56	4,97	-94,32	0,34
-94,00	-107,20	5,39	-94,96	0,39
-92,94	-107,80	6,64	-95,56	1,17
-91,68	-108,36	8,34	-96,12	2,22
-94,82	-108,89	8,12	-96,65	1,06
-94,40	-109,38	10,59	-97,14	1,94
-95,40	-109,85	14,45	-97,61	2,21

4. CONCLUSION

This paper investigates the electromagnetic wave behavior transmitted and propagated by the WSN node at less than 30 cm from the ground in the forest environment. Although the free space model has shown identical behavior with 920

MHz measurement, we can conclude that this low 30 cm height and vegetation environment can also add more loss (fresnel zone and obstacle loss) at about 30.96 dB to the free space model. Therefore, we built a new model with a free space path loss model and added 30.96 dB, and this model performed well with 920 MHz measurement with an average difference of only 0.2 dB. The 920 MHz model and also the 2.4 GHz model in Table 2 show that the near-ground electromagnetic wave path loss propagation models were not so different either. Those models only have 12.24 dB differences on average. However, the 920 MHz model can achieve an average RMSE of 1.06 compared with the 2.4 GHz model that can only achieve an average RMSE of 4.92 compared with the 920 MHz measurement.

REFERENCES

[1] ITU-T, "Recommendation ITU-T Y.2221: Requirements for Support of Ubiquitous Sensor Network (USN) Applications and Services in the NGN Environment." p. 32, 2010.

[2] C. Del-Valle-Soto, C. Mex-Perera, J. A. Nolazco-Flores, R. Velázquez, and A. Rossa-Sierra, "Wireless sensor network energy model and its use in the optimization of routing protocols," *Energies*, vol. 13, no. 3, pp. 1–33, 2020, doi: 10.3390/en13030728.

[3] N. Sharmin, A. Karmaker, W. L. Lambert, M. S. Alam, and M. S. T. S. A. Shawkat, "Minimizing the energy hole problem in wireless sensor networks: A wedge merging approach," *Sensors (Switzerland)*, 2020, doi: 10.3390/s20010277.

[4] J. Lee, Z. Zhong, B. Du, S. Gutesa, and K. Kim, "Low-cost and energy-saving wireless sensor network for real-time urban mobility monitoring system," *J. Sensors*, 2015, doi: 10.1155/2015/685786.

[5] J. Chen, S. Li, S. H. G. Chan, and J. He, "WIANI: Wireless infrastructure and Ad-hoc network integration," *IEEE Int. Conf. Commun.*, 2005, doi: 10.1109/icc.2005.1495092.

[6] M. Hefeeda and M. Bagheri, "Wireless sensor networks for early detection of forest fires," in *2007 IEEE Internatonal Conference on Mobile Adhoc and Sensor Systems, MASS*, 2007, doi: 10.1109/MOBHOC.2007.4428702.

[7] M. S. Jamil, M. A. Jamil, A. Mazhar, A. Ikram, A. Ahmed, and U. Munawar, "Smart Environment Monitoring System by Employing Wireless Sensor Networks on Vehicles for Pollution Free Smart Cities," in *Procedia Engineering*, 2015, doi: 10.1016/j.proeng.2015.06.106.

[8] M. Sohail, S. Khan, R. Ahmad, D. Singh, and J. Lloret, "Game theoretic solution for power management in iot-based wireless sensor networks," *Sensors (Switzerland)*, vol. 19, no. 18, pp. 1–20, 2019, doi: 10.3390/s19183835.

[9] N. Azmi *et al.*, "Interference issues and mitigation method in WSN 2.4GHz ISM band: A survey," *2014 2nd Int. Conf. Electron. Des. ICED 2014*, 2011, doi: 10.1109/ICED.2014.7015839.

[10] Y. Yun and Y. Xia, "Maximizing the lifetime of wireless sensor networks with mobile sink in delay-tolerant applications," *IEEE Trans. Mob. Comput.*, vol. 9, no. 9, pp. 1308–1318, 2010, doi: 10.1109/TMC.2010.76.

[11] A. Akbas, H. U. Yildiz, B. Tavli, and S. Uludag, "Joint Optimization of Transmission Power Level and Packet Size for WSN Lifetime Maximization," *IEEE Sens. J.*, vol. 16, no. 12, pp. 5084–5094, 2016, doi: 10.1109/JSEN.2016.2548661.

[12] R. A. Uthra and S. V. K. Raja, "QoS routing in wireless sensor networks-A survey," *ACM Comput. Surv.*, vol. 45, no. 1, pp. 1–12, 2012, doi: 10.1145/2379776.2379785.

[13] Y. Huang, D. Xu, J. Kan, and W. Li, "Study on field experiments of forest soil thermoelectric power generation devices," *PLoS One*, 2019, doi: 10.1371/journal.pone.0221019.

[14] Mulyadi and R. W. Arsianti, "Low Power Electrical Generator from Soil Microbial Fuel Cell," *2018 Electr. Power, Electron. Commun. Control. Informatics Semin. EECCIS 2018*, 2018, doi: 10.1109/EECCIS.2018.8692948.

[15] Y. Y. Choo and J. Dayou, "A Method to Harvest Electrical Energy from Living Plants," *J. Sci. Technol.*, 2013, doi: 10.1109/19.387319.

[16] X. Gao, W. H. Shih, and W. Y. Shih, "Flow energy harvesting using piezoelectric cantilevers with cylindrical extension," *IEEE Trans. Ind. Electron.*, 2013, doi: 10.1109/TIE.2012.2187413.

[17] A. Wahab, F. A. Mustika, R. B. Bahaweres, D. Setiawan, and M. Alaydrus, "Energy efficiency and loss of transmission data on Wireless Sensor Network with obstacle," *Proceeding 2016 10th Int. Conf. Telecommun. Syst. Serv. Appl. TSSA 2016 Spec. Issue Radar Technol.*, 2017, doi: 10.1109/TSSA.2016.7871084.

[18] L. Mottola and G. Pietro Picco, "MUSTER: Adaptive energy-aware multisink routing in wireless sensor networks," *IEEE Trans. Mob. Comput.*, 2011, doi: 10.1109/TMC.2010.250.

[19] G. S. Brar, S. Rani, V. Chopra, R. Malhotra, H. Song, and S. H. Ahmed, "Energy efficient direction-based PDORP routing protocol for WSN," *IEEE Access*, 2016, doi: 10.1109/ACCESS.2016.2576475.

[20] R. Bria, A. Wahab, and M. Alaydrus, "Energy Efficiency Analysis of TEEN Routing Protocol with Isolated Nodes," *Proc. 2019 4th Int. Conf. Informatics Comput. ICIC 2019*, 2019, doi: 10.1109/ICIC47613.2019.8985668.

[21] G. Lukachan and M. A. Labrador, "SELAR: Scalable Energy-efficient Location Aided Routing protocol for wireless sensor networks," *Proc. - Conf. Local Comput. Networks, LCN*, pp. 694–695, 2004, doi: 10.1109/LCN.2004.111.

[22] B. Majone *et al.*, "Wireless Sensor Network Deployment for Monitoring Soil Moisture Dynamics at the Field Scale," *Procedia Environ. Sci.*, 2013, doi: 10.1016/j.proenv.2013.06.049.

[23] Kementerian Komunikasi Dan Informatika Republik Indonesia, *Peraturan Menteri Komunikasi Dan Informatika Republik Indonesia Nomor 1 Tahun 2019 Tentang Penggunaan Spektrum Frekuensi Radio Berdasarkan Izin Kelas*. 2019.

[24] G. P. N. Hakim, M. Alaydrus, and R. B. Bahaweres, "Empirical approach of ad hoc path loss propagation model in realistic forest environments," *Proceeding - 2016 Int. Conf. Radar, Antenna, Microwave, Electron. Telecommun. ICRAMET 2016*, 2017, doi: 10.1109/ICRAMET.2016.7849600.

[25] N. N. N. B. Jefri, K. Anuar, and S. Arjunan, "Real time indoor measurement of 2G, 3G and LTE mobile networks in Malaysia," in *2016 IEEE 3rd International Symposium on Telecommunication Technologies, ISTT 2016*, 2017, doi: 10.1109/ISTT.2016.7918078.

[26] Semtech, "Datasheet SX1276/77/78/79 - 137 MHz to 1020 MHz Low Power Long Range Transceiver," 2020.

[27] T. Chrysikos, S. Kotsopoulos, and E. Babulak, "A Generic method for the reliable calculation of large-scale fading in an obstacle-dense propagation environment," in *Integrated Models for Information Communication Systems and Networks: Design and Development*, 2013.

[28] Y. Huang and K. Boyle, *Antennas: From Theory to Practice*. John Wiley & Sons Ltd, 2008.

[29] H. T. Friis, "A Note on a Simple Transmission Formula," *Proc. IRE*, vol. 34, no. 5, pp. 254–256, 1946, doi: 10.1109/JRPROC.1946.234568.

[30] Y. Peng, U. He, and J. Choi, "Wireless Sensing and Propagation Characterization for Smart Greenhouses," in *The 2012 International Workshop on Internet of Things (IOT Workshop 2012)*, 2012.