Available online at www.sciencedirect.com

ScienceDirect

Procedia Computer Science 194 (2021) 149–155

Procedia Computer Science

www.elsevier.com/locate/procedia

The 18th International Learning and Technology Conference

Factors that affect LoRa Propagation in Foliage Medium

Rabeya Anzum

Department of Electrical and Computer Engineering

International Islamic University Malaysia

53100 Kuala Lumpur, Malaysia

rabeyaanzum@gmail.com

Abstract— **Long Range (LoRa) is a popular communication technology which has been used recently for many of the internet of things (IoT) applications. LoRa technology is being used for various smart city operations as well as in the field of smart agriculture. Some of the smart agricultural applications need LoRa propagation in vegetation medium. To model a wireless channel, several factors should be considered as those have significant impact on the performance of LoRa propagation through foliage medium. In this paper some of the possible factors are highlighted as those are responsible for the degradationof LoRa channel quality. Aslo an experimental study was undergone in the foliage medium (a line of five date palm trees) to investigate the LoRa physical layer performance utilizing different spread factors (SF7-SF12). The RSSIvalues were measured for the propagation through a line oftrees and compared with the expected RSSI values. The result shows that the measured RSSI values are higher thanthe expected values for LoRa propagation in foliage medium. The result obtained in this paper may help LoRa propagation Channel modelling in foliage medium in futurestudies.**

Keywords— **LoRa, Foliage propagation, channel modelling, internet of things (IoT).**

1. Introduction

The Long Range (LoRa) is a low power wide area (LPWAN) technology that have been recently developed for the internet of things (IoT) applications in various fields. LoRa technology provides huge connectivity and usability with other end node devices with extended battery life. To fulfil the need of a technology which can serve with limited energy resource accompanied with end devices, the low-power wide-area networks (LPWANs) technologies are designed to ensure long battery lifetime with the speciality of transmitting small amount of data over long geographical distances.

Some of the popular LPWAN-based technology solutions are narrow-band IoT (NB-IoT), Sigfox,and LoRa. [1]; among these technologies, LoRa (Long-Range) is used mostly for IoT applications due to its high potential and low deployment and maintenance cost. The term LoRa is commonly used for the physical layer of the communication link while LoRaWAN [2],[3] defines the communication protocol of this LPWAN technology. LoRaWAN enables a larger range of machine-to-machine(M2M) communications and cable to tackle both thepower consumption issue and infrastructure maintenance costs. Thus LoRa is chosen as a feasiblesolution for interconnecting a very large number of end-devices and operates through Internet.

The LoRaWAN technology solution was introduced by a French company Cycleo (later purchased by Semtech [4]. The LoRa RF platform (SX127X) provides a M2M cellular infrastructure to sever its user with a cost-efficient way. LoRa physical layer protocol operates using a spread-spectrum technique operational in the sub-GHz frequency spectrum. The most usable frequencies are 433MHz, 868MHz, and 915MHz, which poses less interference with other frequency bands such as 2.4GHz used by WiFi and Bluetooth [3]. In principle in these frequency bands, signal propagation is more robust for noise sensitivity resulting the relatively low energy consumption. This characteristic has

10.1016/j.procs.2021.10.068

made LoRa an ideal technology for many IoT applications.

The performance of LoRa indoor and outdoor propagation has been studied in several researches, while there exists a very few research on LoRa foliage propagation. The effect of foliage propagation for wireless channel modelling can be expressed in terms of path-loss calculation where, shadowing effects and multipath dispersion effects are greatly considered in the articles [5], [6]. An empirical research was undergone by Iova et al. [7] commented that there is a significant decrease in range and channel quality for a non-line of sight (NLOS) foliage propagation. Another experiment was conducted considering a foliage environment (rubber plantation) in tropical region using the 433 MHz band [8] shows degradation in RSSI with the increasing distance between transmitter and receiver. However, further studies are needed to investigate the factors impacting the LoRa propagation in different foliage environments.

In this research we revisit the factors that affect the foliage propagation and also carry out some results based on RSSI measurements utilizing different spreading factors. The contributions of this paper can be concluded as (1) Review of factors that impact of LoRa propagation in foliage medium (2) performance analysis of LoRa utilizing SF7-SF12 at 868 MHz frequency.

The organisation of this paper is as follows. The performances of LoRa with several impacts are discussed on Section II. The foliage experimental set-up for RSSI measurements are in Section IV, followed by result and discussion in Section V. Finally, Section VI concludes the contribution of the paper.

II. LORA PROPAGATION PERFORMANCE

In this part, several factors that impact the LoRa performance in foliage medium are going to be discussed. These factors include Fresnel zone and some of the environmental factors such as temperature, foliage, and rainfall as well as LoRa physical parameter settings.

1) Fresnel zone: LoRa offers huge coverage up to 10Km in rural areas with the presence of lager concentration of foliage compared to the buildings. Generally propagation loss due to the foliage obstructions happens for the cases: a tree, a line of trees and dense plantation in forest area. Signal obstruction in foliage medium experience diffractions for the tree edges, scattering for the leaves and brunches as well as reflection from the ground or reflective nearby objects. The foliage effect on LoRa propagation can be understood considering Fresnel zones. The amount signal loss caused by reflection and diffraction between the propagation channels can be measured using the Fresnel zone [9].Fresnel zone can be understood assuming an elliptical shape between the transmitter and receiver. The radius of the Fresnel zone (assuming the earth is flat) can be calculated as:

$$R_{Freznel}(m) = 8.657 \times \sqrt{\frac{0.6 \times \mathrm{D}}{\mathrm{f}}}$$

In this equation, D is the distance measured in km between Transmitter and receiver antenna, f is the frequency used for foliage propagation. The flowing picture depicts two Fresnel zones for 433 MHz and 868 MHz frequency in foliage medium.

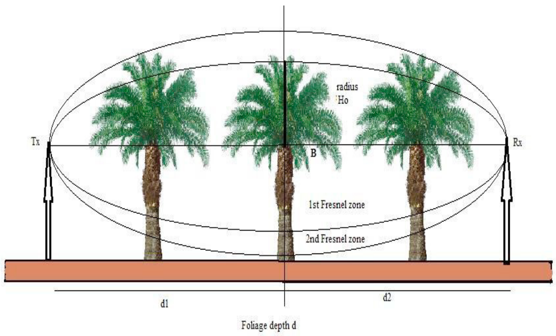


Figure1: Fresnel zone in foliage

Since signal energy transmission is concentrated between the propagation channel in the first Fresnel zone, this zone is considered to affect the performance of wireless network mostly The radius of this zone is r which is the greatest distance is at the center (B) of line-of-sight (LOS) as depicted in Figure 1. For optimal radio propagation performance approximately 60% of the first Fresnel zone should be kept clear .Tuner et. al. in their research conducted in 2019 also commented that lesser the blocked part will lessen the interference caused by diffraction loss.[12] Therefore, Fresnel zone is an important factor for Tx and Rx antenna height set up. The following expression is used for computing the size of 1st Fresnel zone [13]:

$$H_0 = \frac{1}{2}\sqrt{\lambda d}$$

Where, H_0 is the semi-minor axis of the ellipse which forms the first Fresnel zone and d is the foliage depth (distance between Tx and Rx) which is blocked. The wavelength is λ , which calculated for λ=c/f, where c is the speed of light.

2) Environmental Factors: Vegetation is very prone to environmental effects such as wind can cause the foliage movement and responsible for poor channel quality. It has been found that signal travelling through moving vegetation shows rapid variation in received signal amplitude. Moreover tropical regions are very prone to rainfall that can cause humidity variation in dense leaves, stems and tree branches. In a gross, permittivity and conductivity of foliage changes those may result into propagation loss. Therefore the existing foliage path loss models might not be accurate because of foliage and environmental diversity. Several factors in the forest environment as well as some other weather induced factors like temperature, humidity, rain fall are reasonable for channel performance degradation [11]–[14].

A. *Geological Location of foliage*: In tropical area temperature is generally warm and remains relatively constant throughout the year. Tropical vegetation locates near the equator gets intense sunlight and contains broad leaves [15] On the other hand, temperate regions vegetation locates far from equator, gets less sunlight and because of the cooler temperature the leaves are generally needle like. Therefore tropical plantation areas are more reasonable for signal attenuation than temperate regions [16].

B. *Temperature:* The change in the temperature affects network performance concluded in the works [4], [13]. The rise of temperature is responsible for degrading link quality resulting packet loss due to reduction of signal strength [17], [18], [19]. Other researchers also noticed increased packet lost, corrupted packet and weak signal at the receiver because of the gradual rise in ambient temperature [3], [4].

C. *Humidity:* An outdoor experiment was undergone where researcher found correlation between received signal strength and change in humidity [3]. Another study [21] has found that the humidity and precipitation effects are significant where received signal strength is not varied for the temperature change only. Moreover the channel quality is also differed for the different dielectric parameters of foliage type. Also, wind can cause some temporal variations of in propagation medium. Therefore wind and humidity are two important factors that may cause shadowing effects in foliage propagation. [22]. some of recent studies observed that foliage medium dramatically degrade channel quality and also decrease the range of LoRa [23].

D. *Rain Attenuation:* Rainfall is one the reason behind channel degradation where precipitation rate, density, rain drop size matters for the quality of a propagation link. Some tropical regions like Malaysia, heavy rainfall with large rain drops could result in signal attenuation [24]. Moreover, rain attenuation seems to be critical for the higher frequency bands propagation. However no recent studies has undergone considering the rainfall effects on LoRa communication in tropical region.

3) The impact of LoRa Physical Layer Parameters:

The physical layer parameter setting is very crucial to get better performance because these parameters impact the performance of the radio link. These three physical layer parameters are Spreading factor (SF), Bandwidth (BW),and Coding Rate (CR). These parameters influence the effective bit rate during modulation result in noise and signal interference in communication channel. The following table shows a summary of the expected receiver sensitivity with respect to several BW and SF for the LoRa transceiver SX1276 data sheet [25].

BW \ SF	7	8	9	10	11	12
125kHz	-123	-126	-129	-132	-133	-136
250kHz	-120	-123	-125	-128	-130	-133
500kHz	-116	-119	-122	-125	-128	-130

LoRa radio channel bandwidth determines the noise floor and thereby the receiver sensitivity. It is expected that an increase in channel bandwidth results in decrease of the receiver sensitivity, and the higher spreading factor the higher the receiver's sensitivity. Furthermore, an increase in coding rate improves the packet delivery ratio.
The expected impacts of the LoRa physical layer parameters can be summarized according to the theoretical findings are as follows:

Spreading Factor (SF): The ratio between the symbol rate and chip rate is the spreading factor. Setting a high level of spreading factor results in increasing the Signal to Noise Ratio (SNR) which affects the sensitivity and range on the other hand it increases the airtime of the packet. SF= number of chips per symbol which is calculated as 2SF.A high SF should be easily decodable and provides the longer communication range with lower PER and lesser RSSI. On the other hand, a lower SF therefore should result in a higher PER and a higher minimum RSSI. Again, higher SF values are more prone to Doppler Effect due to Ts becomes double when the SF increases with a constant BW remains constant. The effect of SF for various velocities has been experimented in [26].

Coding Rate (CR): LoRa modem that offers protection against bursts of interference and usually CR can be set to either 4/5, 4/6, 4/7 or 4/8. With higher CR the system is more protective but it increases the time on air. A bigger CR transmits more redundant data bits resulting the increase of protection against decoding errors but it longer the packet delivery rate.

Band Width (BW): A higher BW gives a higher data rate(thus shorter time on air), but a lower sensitivity (because of integration of additional noise). A lower BW gives a higher sensitivity, buta lower data rate. A typical LoRa network operatesat either500 kHz, 250 kHz or 125 kHz bandwidth. However, increasing the bandwidth decreases the communication range and sensitivity.

II. Experiment Set Up

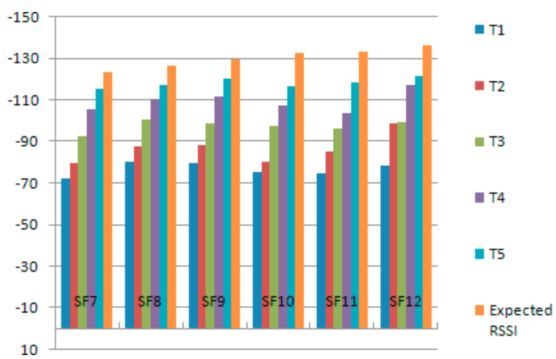
The measurement took place for a line of date palm trees located in ISTAC-IIUM campus. For this experiment five date palm trees were examined as foliage medium. The LoRa module (RF1276) attached with a wire whip antenna (transceiver) was used in this test. Two set of LoRa module were used and each of the modules was plugged into a PC using USB adapter (PL2303). This adapter was used as a bridge between USB and UART port converter. For the RSSI measurements on all spreading factors(SF7-SF12) supported by the LoRa end device utilizing 868MHz frequency band for center frequency and 125KHz bandwidth. The system parameter details are noted in the table below:

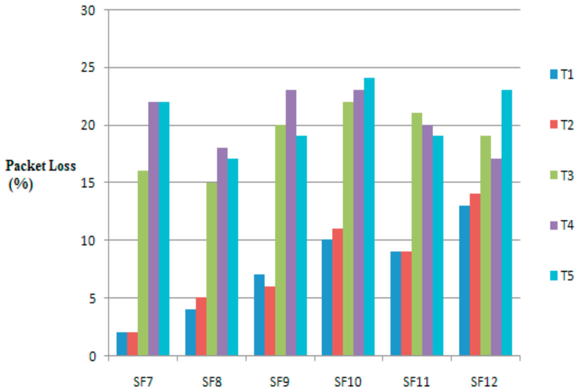
LoRa Settings	
Parameter	**Value**
Frequency	868MHz
Bandwidth (BW)	125Hz
Spreading Factor	SF7-SF10
Antenna Gain	2dBi
Tx- power	14dbm

For the simulation, the two LoRa modules communicate via two computers and the date was extracted using SSCOM tool which is provided by the manufacturer.

IV. Results and Discussion

The RSSI values were measured at five locations (a date palm tree apart) and those are noted as T1-T5.Utilizing different SF (7-10), the measured RSSI values are presented in the graph below and compare with the expected RSSI values.





The graph shows the measured RSSI values and RSSI values for Semtech SX1276 LoRa receiver theoretical sensitivity which is specified for 125KHz BWs with all the SFs [4].In this experiment the transmitter sends 25 data packets, each with 25 bytes of payload, at every test location(T1-T5), utilizing (SF7-SF12). The graph shows the value of measured RSSI at locations T1, T2, T3, T4 and T5. As the number of tress (non line- of-sight) and distance between the Tx and Rx increases, the RSSI values decreases. This trend is observed for all SF values. By observing the result for (SF7-SF12); SF8 and SF9, SF9 performs better than expected, and SF8 performs even much better. In other words, SF7 and SF8 are performing as expected, while SF9 up to SF12 perform worse than expected. Change in variables can effect on propagation quality can be further understood by looking at packet error rate (PER). Therefore we also measure the packet error rate and analyze it. The following figure illustrates the packet error rate (PER) versus LoRa transmitter locations (T1-T5) for spreading factors SF7 to SF12. The transmitter sends 50 data packet with 20s duration for 5 minutes in each location. From the figure we can see that in general the packet loss has an increasing trend when the transmitter is farther from the receiver's location. Although based on theoretical analysis we can expect that a higher SF should result in a lower PER. However it was not observed
at any one of the five locations.

VI. CONCLUSION

In this paper, some possible factors that may affect the performance of LoRa communication technology are highlighted. Factors identified include the LoRa Physical parameter factors and other factors like Fresnel zone and environmental effects are discussed. Also an experiment was setup using LoRa Module test the performance in terms of RSSI measurements of LoRa communication in foliage medium. The impact SF settings at different locations were investigated while comparing the measure RSSI values with the expected theoretical receiver sensitivity RSSI values. The test concludes that the SF settings with the Tx and Rx positioning should be varied to get better performance. Moreover, all the measurements were taken in the moderate temperature while the environment was not humid and windy. Change in the environment results in different RSSI output. Further studies will investigate LoRa propagation in foliage medium in tropical regions of Malaysia in order to achieve optimal coverage considering the propagation factors.

References

[1] H. Zhang et al., "Fronthauling for 5G LTE-U Ultra Dense

Cloud Small Cell Networks," IEEE Wireless Commun., vol. 23, no. 6, Dec. 2016, pp. 48–53.

[2] X. Ge et al., "5G Ultra-Dense Cellular Networks," IEEE Wireless Commun., vol. 23, no. 1, Feb. 2016, pp. 72–79.

[3] H. Zhang et al., "Energy Efficient User Association and Power Allocation in Millimeter-Wave-Based Ultra Dense Networks with Energy Harvesting Base Stations," IEEE JSAC, vol. 35, no. 9, Sept. 2017, pp. 1936–47.

[4] Y. Saito et al., "Non-Orthogonal Multiple Access (NOMA) for Cellular Future Radio Access," IEEE VTC-Spring '13, Dresden, Germany, June 2013, pp. 1–5.

[5] L. Dai et al., "Non-Orthogonal Multiple Access for 5G: Solutions, Challenges, Opportunities, and Future Research Trends," IEEE Commun. Mag., vol. 53, no. 9, Sept. 2015, pp. 74–81.

[6] Z. Ding et al., "Application of Non-Orthogonal Multiple Access in LTE and 5G Networks," IEEE Commun. Mag., vol. 55, no. 2, Feb. 2017, pp. 185–91.

[7] Y. Cai et al., "Modulation and Multiple Access for 5G Networks," IEEE Commun. Surveys & Tutorials, vol. 20, no. 1,2018, pp. 629–46.

[8] Y. Sun et al., "Optimal Joint Power and Subcarrier Allocation for Full-Duplex Multicarrier Non-Orthogonal Multiple Access Systems," IEEE Trans. Commun., vol. 65, no. 3, Mar. 2017, pp. 1077–91.

[9] Mohamed Aref and Axel Sikora. Free space range measurements with semtech LoRaTM technology. In Wireless Systems within the Conferences on Intelligent Data Acquisition and Advanced Computing Systems: Technology and Applications (IDAACS-SWS), 2014 2nd International Symposium on, pages 19–23. IEEE, 2014.

[10] Turner, J. S. C., A. B. Shahriman, A. Harun, M. S. M. Hashim, Z. M. Razlan, W. K. Wan, Z. Ibrahim et al. "Effect of Roadways Plantation on Signal Propagation Analysis in Connected Autonomous Vehicle Communication." In IOP Conference Series: Materials Science and Engineering, vol. 557, no. 1, p. 012056. IOP Publishing, 2019.

[11] Marco Centenaro, Lorenzo Vangelista, Andrea Zanella, and Michele Zorzi. Long-range communications in unlicensed bands: The rising starsin the IoT and smart city scenarios. IEEE Wireless Communications,23(5):60–67, 2016.

[12]Mohamed Aref and Axel Sikora. Free space range measurements with semtech LoRaTM technology. In Wireless Systems within the Conferences on Intelligent Data Acquisition and Advanced Computing Systems: Technology and Applications (IDAACS-SWS), 2014 2nd International Symposium on, pages 19–23. IEEE, 2014.

[13] Oana Iova, Amy Murphy, Gian Pietro Picco, Lorenzo Ghiro, Davide Molteni, Federico Ossi, and Francesca Cagnacci. LoRa from the city to the mountains: Exploration of hardware and environmental factors. In Proceedings of the 2017 International Conference on Embedded Wireless Systems and Networks, 2017.

[14] C. A. Boano, M. Zúñiga, J. Brown, U. Roedig, C. Keppitiyagama, and K. Römer. TempLab: A testbed infrastructure to study the impact of temperature on wireless sensor networks. In IPSN-14 Proceedings of the 13th International Symposium on Information Processing in Sensor Networks, pages 95–106, April 2014.

[15] Tng, David YP, Greg J. Jordan, and David MJS Bowman. "Plant traits demonstrate that temperate and tropical giant eucalypt forests are ecologically convergent with rainforest not savanna." PLoS One 8, no. 12 (2013).

[16] Souza Bezerra,Níbia, Christer Åhlund, Saguna Saguna, and Vicente A. de Sousa. "Temperature Impact in LoRaWAN—A Case Study in Northern Sweden." Sensors 19, no. 20 (2019): 4414.

[17] Carlo Alberto Boano, Hjalmar Wennerstrom, Marco Zuniga, JamesBrown, Chamath Keppitiyagama, Felix Oppermann, Utz Roedig, Lars-Ake Norden, Thiemo Voigt, and Kay RoÌ´Lmer. Hot packets: Asystematic evaluation of the effect of temperature on low power wireless transceivers. 2013.

[18] C. A. Boano, N. Tsiftes, T. Voigt, J. Brown, and U. Roedig. The impact of temperature on outdoor industrial sensornet applications. IEEE Transactions on Industrial Informatics, 6(3):451–459, Aug 2010.

[19] Petcharat Suriyachai, James Brown, and Utz Roedig. Time-critical data delivery in wireless sensor networks. In International Conference on Distributed Computing in Sensor Systems, pages 216–229. Springer,2010.

[21] Hjalmar Wennerström, Frederik Hermans, Olof Rensfelt, Christian Rohner, and Lars-Åke Nordén. A long-term study of correlations between meteorological conditions and 802.15. 4 link performance. In 2013 IEEE International Conference on Sensing, Communications and Networking (SECON), pages 221–229. IEEE, 2013.

[22] Yu Song Meng and Yee Hui Lee. Investigations of foliage effect on modern wireless communication systems: A review. Progress In Electromagnetics Research, 105:313–332, 2010.

[23] Khairol Amali Ahmad, Mohd Sharil Salleh, Jivitraa Devi Segaran, and Fakroul Ridzuan Hashim. Impact of foliage on LoRa 433 MHz propagation in tropical environment. In AIP

Conference Proceedings, volume 1930, page 020009. AIP Publishing, 2018.

[24] I. Shayea, T. Abd. Rahman, M. Hadri Azmi, and M. R. Islam. Real measurement study for rain rate and rain attenuation conducted over 26 GHz microwave 5G link system in malaysia. IEEE Access, 6:19044–19064, 2018.

[25] Lora alliance–wide area networks for iot. [Online]. Available: https://www. lora-alliance. org/[Accessed: 06 February 2016], 2016.

[26] Juha Petäjäjärvi, Konstantin Mikhaylov, Marko Pettissalo, Janne Janhunen,and Jari Iinatti. Performance of a low-power wide-area network based on LoRa technology: Doppler robustness, scalability,and coverage. International Journal of Distributed Sensor Networks, 13(3):1550147717699412, 2017.