Evaluation of Antenna Dependent Wireless Communication Based on LoRa For Clear Line of Sight (CLOS) And Non-Clear Line of Sight (NC-CLOS) Applications

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Abstract. The emerging field of the internet of things (IoT) requires a low-power-low-range solution in remote and inaccessible places where connectivity in any form is not possible. There are many IoT devices like Zigbee, LoRa WAN, Sigfox, which operate within 5m to 5kms, with a change in bandwidth and power consumption. The difficulties in installing these types of IoT devices are critical because of connectivity issues and external hindrances like a non-clear line of sight (NC-LOS), frequency, bandwidth, time on Air (ToA), and power availability. The long-range (LoRa) is a portable, low-power wireless communication device that works on the principle of chirp spread spectrum (CSS) modulation. Its performance concerning frequency, power consumption, ToA, clear line of sight (CLOS), and NC-LOS depends on the type of antenna used for unknown distances. Therefore, in this paper, the 868MHz frequency is used to communicate between LoRa - end-transmitter node to LoRa-end receiver node with a fixed bandwidth of 125 kHz in the premises of Symbiosis. The constant data size, also known as the data-packet of 11-bytes, is sent wirelessly through transmitter-node receiver-node at different locations and altitudes. The contribution of this paper is to investigate the distance required to transmit the data-packet and give a choice of the antenna in CLOS & NC-LOS. A practical demonstration of different low-cost available antennas with variation in the distance with different LoRa devices like SX1276/SX1278 is proposed. It shows that the low-cost helical type antenna is more-favorable horizontally and vertically up to a certain range in CLOS and NC-LOS conditions.

Keywords: LoRa; frequency; bandwidth; antenna; CLOS; NC - LOS

1. Introduction

Wireless data transmission and communication have become an essential aspect of today's global plan [1]. The transmission of the signal depends upon the connectivity and susceptibility of each wireless devices. The global system for mobile (GSM) communication works on higher frequency and bandwidth ranges [2]. This builds the system very costly without flexible bandwidth availability. The industrial, scientific, and medical bands (ISM-B) are unlicensed, and it concerns devices that can be installed as per desired location [3]. The data transmission interval and separation space are much more than the available wireless networks like ZigBee, Sigfox, and Bluetooth. The antenna's selection criteria are followed by choosing the appropriate wireless devices mounted outdoors or indoors with the arrangement of enclosures like IP-65, IP-67, or IP-68. The limitations in design layout, antenna integration, and surrounding interference become challenging to overcome the signal noise. The
availability of electrical and mechanical specifications for the selected antenna module, shape, dimension, and location-based on wireless transceiver node is important for measuring the desired frequency range and location [4,5]. The antenna's mounting is mag-mounted, adhesive mounted, screw-mounted, off-board type, or one-ended soldered cable mounted and printed circuit board mounted. The connector's specification to microcontroller module and length of cable as an antenna is required with gauge and variable design [6]. This makes the antenna an important aspect of wireless communication.

The extensive simulations are carried out with different algorithms on the low-powered wide area network (LPWANs) devices [7]. But energy consumption with quality in signal strength and network coverage has become an issue. The range testing of communication between LoRa end-node to LoRa gateway is carried out with a change in technical differences between the chirp spread spectrum (CSS) and ultra-narrowband network [8]. The CSS type modulation can send six-times more data-packets than Sigfox or Zigbee, with the range of about 10kms [9]. The geo-location changes like low & high terrains and an inaccuracy concerning its physical setup are described in brief [10]. The data-latency with the transfer of data-packets and power consumption is focused[11], but no antenna specialization is briefed. The advantages of star-type and mesh-type topologies are described [11,12], but the IP-67 based waterproof antenna cable with a cap is used for a single frequency of 868 MHz. Various applications with the same type of antenna, its deployment, and communication methods are described [13,14]. The network topologies and their algorithms are discussed [15]. The norms, limitations, methodologies, and site survey required for indoor and outdoor data transmission are elucidated [16]. The applications based on the conventional IP-67 based antenna are applied practically [17], where the substrate type of antenna is used in 868 MHz. But, other frequencies like 433 MHz and 915 MHz are not applied practically. The ranges verified on the directly embedded printed PCBs have very little distance from 1m to 3m depending on the CLOS and NC – LOS. The miniature type antenna is also tested on a 433 MHz frequency band. But, its range and testing on ISM frequency ranges are not demonstrated [18,19]. Testing of LoRa links is carried out to measure data transmission indoors, outdoors, and subsequently in the individual-building and multiple-buildings in the urban and suburban environment [20]. The filtering characteristics of the antenna are proposed, but in this case, the frequencies are different. The indoor antenna checking of integrated type waveguide antenna is demonstrated for specific frequencies in the urban, forest, and coastal experimental observations on 915 MHz is proposed with the same substrate type antenna [21,22].

The performance of four types of measurements, viz., clear horizontal line of sight (HC - LOS), clear vertical line of sight (VC – LOS), horizontal non-clear line of sight (HNC - LOS), and vertical non-clear line of sight (VNC - LOS) keeping the same frequency of 868 MHz throughout to acquire coverage in a vast diversity of environment is carried-out. Various measurements are conducted with actual LoRa end-node transceiver with ANT-CW-RAH with SMA connector type antenna, helical type antenna, and thin-copper film-type antenna at 868 MHz frequency each in a pair of transmitter and receiver, respectively [23]. The contribution of this paper is based on the data recorded under indoor and outdoor environments. Initially, theLoRa sensor-node is setup with a thin-copper film-type antenna on both the LoRa modules, which is then programmed separately as transmitter node and receiver node using Arduino UNO microcontroller board [24]. The two individual batteries are connected after programming to provide a continuous power supply to both nodes. The distances and other performance-based parameters are measured under two main broad conditions, viz., measurement of CLOS and NC – LOS vertically and horizontally to test the range of LoRa node-to-node communication. The classification of the frequency with fixed values of spreading factor (SF), bandwidth (B), and coding rate (CR) with a change in the type of antenna, altitude (m), distance (m), received signal strength index (RSSI) and signal to noise ratio (SNR) can become a catalog which will give guidance for choosing the suitable antenna for the specific distances as per application [25].
2. Mesh Topology of LoRa Wireless Communication

![Figure 1: Fundamental mesh-topology of LoRa based on end-to-end node communication. It consists of sensors connected to the LoRa end-nodes with various varieties of low-cost antennas. The data-packets are sent using chirp-spread-spectrum technology. The highlighted area between LoRa end-node sender and LoRa end-node receiver annotates the CLOS or NC – LOS, which corresponds to distance (m), altitude (m), RSSI (dBm), and SNR (DB) values.](image)

The mesh-topology of LoRa based end transceiver node-to-node wireless communication is as shown in Figure 1. The chirp spread spectrum (CSS) is the frequency modulation to encode the data; it uses chirp pulses with wide-band linear frequency. The conventional bandwidth in which this modulation is carried out is 125 kHz, 250 kHz, and 500 kHz. Mostly, 125 kHz bandwidth is used for more linear propagation of frequency rather than its counterparts. The spreading factor (SF), ranging from 7 to 12, is how the data is transferred through an air medium. The SF value of 7 takes the least time in air-medium data transmission, and SF = 12 takes the most. The LoRa end-nodes comprised of LoRa-IC of RF95X/SX1276/SX1278 with micro-controller and the combination of sensors. The ATMEGA-328P-PU based Arduino UNO microcontroller board is used as a low-cost solution, and an easy serial peripheral interface (SPI) between the RF sensor and the microcontroller can be achieved. The data transmission and storage of LoRa sensor data are stored in the Arduino UNO module. Either of the LoRa end-node can be programmed as a transmitter or receiver, and they can be communicated with each other with the help of two same antennas simultaneously at a time. To be more precise, the 11-bytes of data packet is transferred through 868 MHz frequency with respect to variations in altitude and distances so as to start communication between LoRa transmitter and receiver end-nodes.

The LoRa mesh topology becomes an important part of the system where any signal from transmitter to receiver can be transferred with accounted hindrances like CLOS and NC-LOS. The CLOS consists of the clear or open space horizontal or vertical altitudes and straight visibility of both the transmitter and receiver in indoors and outdoors, respectively. The NC-LOS consists of natural or manmade hindrances, like trees, hills, plateaus, mountains, buildings, castles, mansions. Many factors associated with LOS and NC-LOS are dependent on the antenna, altitude (m), distance (m), RSSI values, SNR values and SF values to incorporate transmission of data from sending end LoRa-node to receiving end LoRa-node. Factors like, trees, plants, houses, and moving people along becomes a static or dynamic hindrance. Factors affecting environments like lighting, storms and cyclones is acknowledged as the dynamic and vulnerable conditions for this system. Therefore, the deployment of this LoRa end-node-to-node system can be carried out depending upon the terrain to be chosen and depending upon the data to be transmitted.
Figure 2: The phenomenon of data transmission of LoRa communication in CLOS. Here, the line-of-sight is supposed to have the plane ground surface consisting of grass and shrubs in which the data can be transferred from LoRa transmitter end-node to the LoRa receiver end-node without any obstacle.

As described in Figure 2, it is observed that, LoRa end-node-to-node communication can be carried out without any interruption with CLOS. The garden consists of grass, plants and shrubs, which does not affect the transmission of data from LoRa end-node-to-node wireless communication. The Fresnel zone of the visibility is maximum in between LoRa node-to-node communication when in clear line-of-sight.

Figure 3: Phenomenon of data transmission in (a) NC - LOS with tall plants and trees, where LoRa communication can be observed, when both the LoRa end-nodes are placed approximately 1 m to 2 m above the height of ground and (b) NC-LOS with tall building where the LoRa communication can be observed is carried-out and placed at either side of the building. The dotted line represents the CSS wireless communication spectrum.

As described in Figure 3, it is observed that the NC-LOS has variations in the types of obstacles. Here, obstacles are buildings, trees, vehicles and people moving around. If only trees are considered in between LoRa end – node-to-node communication then, the distance observed is least as compared to...
CLOS. The CSS-based modulation signal passes through trees and takes more SF value (towards SF = 12) and more delay on time as compared to CLOS. The LoRa end-nodes as a transmitter and receiver is placed on the altitude of ground level at both the ends of trees and building in the Symbiosis premises, which is as described in Figure 3 (a). This makes the situation invisible and a strong NC-LOS can be achieved. The CSS-based modulation penetrates the signal through the building and transfers data with higher SF value (≥ 7) and high delay in time on-air (ToA) as compared to NC-LOS with only trees as an obstacle. Considering the level of NC-LOS, the obstacle becomes more complex when huge buildings or trees occur together in between the LoRa end node-to-node transceiver, which is as shown in the Figure. 3 (b). Moreover, the highest value of SF can be observed as 12 and the delay time in the air is maximum and some data-packets are lost while traveling through the obstacles. The battery consumption is also more as compared to the CLOS\textsuperscript{21}. This makes the IoT researcher think about variations in the location and finalizing the setup arrangements by considering the altitudes and the structure of natural landscapes accordingly.

3. Types of Antennas
The LoRa end-node devices consist of three main types of antennas. They are thin-film copper type antenna, helical type antenna and ANT – CW - RAH with sub-miniature of version – A (SMA) antenna which has a semi-precision RF coaxial connector type port, respectively. The JEM type thin-film copper type antenna is compatible to 433 MHz\textsuperscript{24}. Its dimension is 30 mm × 24 mm (l × b) and has the typical range of 1m to 25m in CLOS and 1m to 15m in NC-LOS (considering both at horizontal and vertical distances), respectively.

The ANT – CW-RAH with SMA connector compliant type antenna is compatible to 433 MHz and 868 MHz\textsuperscript{24}. It is a right-angle shaped antenna with an aesthetically pleasant appearance and is able to withstand punishing environments due to the presence of IP – 67 cover on the antenna with SMA connector. It is a low - cost, ultra-compact, rugged, and damage resistant antenna with omni directional pattern. Its dimension is 47 mm × 8 mm (l × w) and has the typical range of 1m to 150m in CLOS and 1m to 95m in NC-LOS (considering both at horizontal and vertical ranges), respectively.

Where in, the helical type antenna is compatible to 868 MHz and 915 MHz\textsuperscript{24}. It is soldered directly on the LoRa end-node printed circuit board (PCB). The power consumption and low-cost availability is compared with the above-mentioned antennas. Its dimension is 18 mm × 4 mm (l × b) and has the typical range of 1m to 500m in CLOS and 1m to 250m in NC-LOS (considering both at horizontal and vertical ranges), respectively.

4. Experimental Setup and Results
The pin connection is similar to all the experimental setups having distinct antennas for LoRa sensor node-to-node communication, which is as shown in the Table 1 [21].

| Lora SX1276 Module | Arduino UNO Board Pins |
|--------------------|------------------------|
| 3.3V               | 3.3V                   |
| GND                | GND                    |
| EN/NSS             | Digital Pin - 10       |
| G0 / DIO 0         | Digital Pin - 2        |
| SCK                | Digital Pin - 13       |
| MISO               | Digital Pin - 12       |
| MOSI               | Digital Pin - 11       |
| RST                | Digital Pin - 9        |
A. JEM type thin-film copper antenna setup with LoRa transmitter and Receiver end-node with Arduino Uno Board:

The thin-film copper antenna setup is connected to the LoRa SX1278, 868 MHz transmitter and an individual receiver end-node module. The antenna is directly connected to the adapter pin of the LoRa node module to check both the vertical and horizontal CLOS and NC-LOS conditions, respectively.

B. Helical type antenna setup with LoRa transmitter and Receiver end-node with Arduino Uno Board:

The helical type antenna setup is connected to the LoRa SX1276, 868 MHz transmitter and an individual receiver end-node module. The antenna is directly soldered on the PCB female port available, so as to consider it as a LoRa end-node transmitter and LoRa end-node receiver separately. The conditions on both the vertical and horizontal CLOS and NC-LOS distances are determined accordingly.

C. ANT-CW-RAH with SMA connector compliant antenna setup with LoRa transmitter and Receiver end-node with Arduino Uno Board:

ANT-CW-RAH with SMA connector compliant antenna setup is connected to the LoRa SX1278, 868 MHz transmitter and receiver end-node module. This antenna is connected using SMA connector separately so as to check LoRa node modules as transceiver and also to check both the vertical and horizontal CLOS and NC-LOS conditions, respectively.

As described in Figure. 4 (a), (b) & (c), the horizontal and vertical clear line of sight in the premises of the Symbiosis can be observed in CLOS. The yellow line represented in the image of google map of the Symbiosis Institute describes the total distance between LoRa end-node transmitter to the LoRa end-node receiver. The round yellow dot also represents that either of the end-node-to-node communication is carried out by swapping each time during experimentation. Similar observations were taken by changing the antennas after each iteration, and the distance was measured with change in altitude (m), distance (m), RSSI values, SNR values and SF values, respectively.
Figure 4: Practical experimentation in CLOS is performed in the premises of Symbiosis as 
(a) the distance between LoRa Node-to-Node sensor is **27.08 m** when used JEM type thin-film copper antenna; 
(b) the distance between LoRa Node-to-Node sensor is **102.99 m** when used Helical type antenna and 
(c) the distance between LoRa Node-to-Node sensor when used **53.99 m** of ANT-CW-RAH with SMA connector compliant antenna.
Figure 5: Practical experimentation in NC - CLOS is performed in the premises of Symbiosis as (a) the distance between LoRa Node-to-Node sensor is 5.64 m when used JEM type thin-film copper antenna; (b) the distance between LoRa Node-to-Node sensor is 81.78 m when used Helical type antenna and (c) the distance between LoRa Node-to-Node sensor is 36.11 m when used ANT-CW-RAH with SMA connector compliant antenna.

As described in Figure 5 (a), (b) & (c), the horizontal and vertical non-clear line of sight in the premises of the Symbiosis can be observed in NC – LOS conditions. The yellow line represented in the image of google map of the Symbiosis Institute describes the total distance between LoRa end-node transmitter to the LoRa end-node receiver. The round yellow dot also represents that either of the end-node-to-node communication is carried out by swapping each time during experimentation. Similar observations were taken by changing the antennas after each iteration, and the distance was
measured with change in altitude (m), distance (m), RSSI values, SNR values and SF values, respectively. The hardware parameters used for testing is as shown in the Table 2.

### Table 2: Hardware Parameters Used for Testing

| Parameters               | Values                      |
|--------------------------|-----------------------------|
| Lora Modules             | SX 1276 / SX1278            |
| Battery Type             | Lithium-Ion                 |
| Battery Rating           | 3.3V, 4000 mAh              |
| Data Payload Length (Bytes) | 11                         |
| Coding Rate              | 4/8                         |
| Bandwidth                | 125 kHz                     |
| Communication Frequency  | 868Hz                       |

### Table 3: Antenna Type and Horizontal Range Testing

| Line of Sight / Antenna Type | JEM type thin-film copper | ANT-CW-RAH with SMA connector compliant | Helical type |
|------------------------------|----------------------------|----------------------------------------|--------------|
| CLOS Distance (m)            | 27.08                      | 52.99                                  | 102.99       |
| NC-LOS Distance (m)          | 5.64                       | 36.11                                  | 81.78        |

### Table 4: Antenna Type and Vertical Range Testing

| Line of Sight / Antenna Type | JEM type thin-film copper | ANT-CW-RAH with SMA connector compliant | Helical type |
|------------------------------|----------------------------|----------------------------------------|--------------|
| CLOS Distance (m)            | 11                         | 58                                     | 84           |
| NC-LOS Distance (m)          | 6                          | 12                                     | 40           |

From Table 3, it is observed that, the distance measured between LoRa-end-node-to-node communication in CLOS horizontal testing is 27.08 m for thin-film type copper antenna, 52.99m for ANT-CW-RAH with SMA connector compliant antenna and 102.99 m for helical type antenna. Whereas, the distances measured in horizontal NC – LOS becomes 5.64m, 36.11 m and 81.78 m for thin-film, ANTC-CW-RAH and helical type antennas, respectively. Hence, horizontally the helical type antenna is suitable for data transmission up to 102.99 m in CLOS and 81.78 m in NC - LOS.

From Table 4, the distances measured between LoRa-end-node-to-node communication in CLOS vertically for thin-film type copper antenna, ANT-CW-RAH with SMA connector compliant antenna and for helical type antenna are 11 m, 58 m and 84 m, respectively. Whereas, with NC – LOS the distances measured is 6 m, 12m and 40m, respectively. Hence, vertically it is observed that the helical type of antenna is suitable for data transmission up to 84 m in CLOS and 40 m in NC - LOS.

From Table 5, annotates the measurement of various parameters of LoRa end-node transceiver performance. The performance of the LoRa experiment corresponds to the type of antenna, altitude, distance, RSSI and SNR values. It is observed that in CLOS, the helical type antenna has more distance coverage in less altitude and more SNR. The power consumption is similar to the JEM type thin-film copper antenna, but the distance covered is more in case of helical type antenna. If the gauge of the helical type antenna is increased while keeping a same number of turns then, more distance can be covered. In case of NC – LOS, the helical type antenna performs satisfactory with more distance and less power consumption.
Table 5: Measurement of Various Parameters of Lora End-Node Transceiver Performance

| Line of Sight (LOS) | Antenna Type                          | Figure Nos. | Altitude (m) | Distance (m) | RSSI (dB) | SNR (dB) |
|---------------------|---------------------------------------|-------------|--------------|--------------|-----------|----------|
| Clear Line of Sight (CLOS) | JEM type thin-film copper              | 4 (a)       | -14          | 27.08        | -99.2     | 5.96     |
|                     | Helical type                           | 4 (b)       | -13          | 102.99       | -99.2     | 7.86     |
|                     | ANT-CW-RAH with SMA connector compliant | 4 (c)       | -14          | 53.99        | -98.0     | 6.4      |
| Non-Clear Line of Sight (NC-LOS) | JEM type thin-film copper              | 5 (a)       | -18          | 5.64         | -110.8    | 4.32     |
|                     | Helical type                           | 5 (b)       | -16          | 81.78        | -98.2     | 7.08     |
|                     | ANT-CW-RAH with SMA connector compliant | 5 (c)       | -14          | 36.11        | -99.2     | 5.0      |

5. Conclusion
In this paper, the performance of the different types of LoRa antennas at 868 MHz was evaluated using practical experimentation in horizontal and vertical environment for the detection and measurement of the distances between two LoRa node-to-node communications. The comparative analysis of these antennas on the basis of distances was presented. For using the low range node-to-node data communication, this comparative analysis may prove useful for the selection of antennas of the same frequency for any end-to-end low-distance application. From the experimentation, it is observed that as the distance increases, the horizontal and vertical data transmission of the data-packet operate depends upon the altitude, RSSI and SNR values between the LoRa transmitter and receiver. However, for longer ranges of the node-to-node communication, the distance of the sender-node and receiver-node can be adjusted by changing the data-packet payload size. The proper selection of antenna at 868 MHz frequency value depends on distance between LoRa transmitter and receiver. This decision can vary based on the type of antenna and table presented in this paper, which can be used as guidelines to be followed between LoRa node-to-node communications.

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References
[1] R. Kerkouche, R. Alami, R. Féraud, N. Varsier and P. Maillé (2018) Node based optimization of LoRa transmissions with Multi-Armed Bandit algorithms, 25th International Conference on Telecommunications (ICT), St. Malo, 2018, pp. 521 - 526.
[2] A. Biral, M. Centenaro, A. Zanella, L. Vangelista and M. Zorzi (2015) The challenges of m2m massive access in wireless cellular networks, Digital Communications and Networks, vol. 1, no. 1, pp. 1 - 19.
[3] M. Centenaro, L. Vangelista, A. Zanella and M. Zorzi (2015) Long-range communications in unlicensed bands: the rising stars in the IoT and smart city scenarios, arXiv preprint arXiv:1510.00620.

[4] B. Reynders, W. Meert and S. Pollin (2016) Range and coexistence analysis of long range unlicensed communication (2016), 23rd International Conference on Telecommunications (ICT), Thessaloniki, pp. 1 - 6.

[5] Aranda, J., Mendez, D., Carrillo, H., & Schözel, M. (2020). A Framework for MultiModal Wireless Sensor Networks. Ad Hoc Networks, 102201.

[6] Kim, S., Lee, H., & Jeon, S. (2020). An Adaptive Spreading Factor Selection Scheme for a Single Channel LoRa modem. Sensors, 20(4), 1008.

[7] O. DIENG, C. PHAM and O. THIARE (2019) Outdoor Localization and Distance Estimation Based on Dynamic RSSI Measurements in LoRa Networks: Application to Cattle Rustling Prevention, International Conference on Wireless and Mobile Computing, Networking and Communications (WiMob), Barcelona, Spain, pp. 1-6.

[8] Georgiou, O., Psomas, C., Skouroumounis, C., & Krikidis, I. (2020). Optimal Non-Uniform Deployments of LoRa Networks. IEEE Wireless Communications Letters.

[9] Bor, M. (2020). Towards the efficient use of LoRa for wireless sensor networks (Doctoral dissertation, Lancaster University).

[10] Alves, H. B., Lima, V. S., Silva, D. R., Nogueira, M. B., Rodrigues, M. C., Cunha, R. N., ... & Ferrari, P. (2020, June). Introducing a survey methodology for assessing LoRaWAN coverage in Smart Campus scenarios. In 2020 IEEE International Workshop on Metrology for Industry 4.0 & IoT (pp. 708-712). IEEE.

[11] Glória, A., Dionísio, C., Simões, G., Cardoso, J., & Sebastião, P. (2020). Water Management for Sustainable Irrigation Systems Using Internet-of-Things. Sensors, 20(5), 1402.

[12] García, L., Parra, L., Jimenez, J. M., Lloret, J., & Lorenz, P. (2020). IoT-Based Smart Irrigation Systems: An Overview on the Recent Trends on Sensors and IoT Systems for Irrigation in Precision Agriculture. Sensors, 20(4), 1042.

[13] Ameloot, T., Van Torre, P., & Rogier, H. (2020, March). Experimental Parameter Optimization for Adaptive LoRa Modulation in Body-Centric Applications. In 2020 14th European Conference on Antennas and Propagation (EuCAP) (pp. 1-5). IEEE.

[14] Kumar, S., Buckley, J. L., Barton, J., Pigeon, M., Newberry, R., Rodencal, M., ... & O’Sullivan, D. (2020). A wristwatch-based wireless sensor platform for IoT health monitoring applications. Sensors, 20(6), 1675.

[15] Pandey, A., & Nair, M. D. (2020). Inset Fed Miniaturized Antenna with Defected Ground Plane for LoRa Applications. Procedia Computer Science, 171, 2115-2120.

[16] V. A. Dambal, S. Mohadikar, A. Kumbhar and I. Guvenc (2019) Improving LoRa Signal Coverage in Urban and Sub-Urban Environments with UAVs, International Workshop on Antenna Technology (iWAT), Miami, FL, USA, pp. 210-213.

[17] Ameloot, T., Van Torre, P., & Rogier, H. (2020). Lora Base-Station-to-Body Communication with SIMO Front-to-Back Diversity. IEEE Transactions on Antennas and Propagation.

[18] Liu, Z., Zhou, Q., Hou, L., Xu, R., & Zheng, K. (2020, May). Design and Implementation on a LoRa System with Edge Computing. In 2020 IEEE Wireless Communications and Networking Conference (WCNC) (pp. 1-6). IEEE.

[19] https://lora-alliance.org/about-lorawan
[22] Naik, N. (2018, October). LPWAN technologies for IoT systems: choice between ultra narrowband and spread spectrum. In 2018 IEEE International Systems Engineering Symposium (ISSE) (pp. 1-8). IEEE.

[23] Vangelista, L. (2017). Frequency shift chirp modulation: The LoRa modulation. IEEE Signal Processing Letters, 24(12), 1818-1821.

[24] Marquez, L. E., Osorio, A., Calle, M., Velez, J. C., Serrano, A., & Candelo-Becerra, J. E. (2019). On the Use of LoRaWAN in Smart Cities: A Study With Blocking Interference. IEEE Internet of Things Journal, 7(4), 2806-2815.

[25] Sujatha, R., & Ezhilmaran, D. (2016). “A new efficient SIF-based FCIL (SIF–FCIL) mining algorithm in predicting the crime locations”. Journal of Experimental & Theoretical Artificial Intelligence, 28(3), 561-579.