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LORA COMMUNICATION MAINTENANCE AND SIGNAL PROPAGATION EVALUATION IN OBSTACLE-DENSE INDUSTRIAL ENVIRONMENTS: A WOOD PROCESSING APPLICATION

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Abstract:
Using various wireless communication methods to achieve some type of remote monitoring and/or controlling of processes and systems, in general, is a continuously thriving industry. The wood industry is not immune to that but the prevalence of such systems, automated to a certain level, remains low. Their rise and presence, however, are unavoidable and will continue to grow. Wireless devices are used to continuously monitor environmental factors as well as the structural moisture of wood in a wooden plank during the natural aspirated drying process and the forced drying process all in a controlled environment. An exemplary system based on LoRa communication interfaces is configured, adapted, and operationally tuned for the wood processing industry. The selected LoRa communication system operates on an EU compliant RF spectrum. Nevertheless, since such devices must be tightly integrated within a pack of planks, wireless signal propagation is greatly impacted. The pack of planks has an effect on radio signal dispersion because it creates a dense environment hostile to RF propagation. A technique to strengthen measurement devices and receive units for wireless signal propagation is proposed in order to maintain a high-quality communication link. Furthermore, practical procedures for maintaining a desirable signal level and their upkeep suggestions are presented for applications with numerous obstacles in the working environment.

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1. INTRODUCTION

Transceiver-to-receiver wireless communication systems heavily rely on the analysis of the radio frequency (RF) propagation channel. The transmitted signal weakens as it travels from the transmitter to the receiver due to the wireless channel characteristics. Therefore, understanding the RF propagation channel is crucial in designing and optimizing wireless communication systems to ensure reliable and efficient communication between devices. This knowledge is particularly important in various industries, such as telecommunications, transportation, and healthcare, where wireless communication plays a critical role, but other less important applications also feature its significance for better processing results [1-3]. When designing, developing, and ultimately deploying a communication strategy in real-time environments, there are a number of factors to take into account in order to address these problems. Due to obstacles and various important factors like reflections, diffractions, and scattering, there are many possible propagation paths between the transmitter and the receiver, each with a different delay [4]. As a result, the transmitted message is either received at a significant loss or not at all. This reduces the signal

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power and creates noise in the communication channel, slowing or significantly disrupting it. The project designer must be aware of these problems as the project is being developed and model communication appropriately. In applications where the working environment is saturated with obstacles for propagation waves, this problem is even more augmented, and without careful design of the network topology, results can be disastrous. It is crucial for the project designer to consider all the potential influences of physical barriers and interference on the communication network. They should also explore alternative communication technologies that may be more suitable for such environments if they are applicable for the given application, as is, for example, well stated and elaborated in [5] where the complexity of the network topology raises the optimization challenge to a new level.

More consumer-grade communication protocols [6-9] are constrained by small and strictly defined propagation characteristics in medium- to large-scale industrial environments where serving multiple clients with data packets of different sizes and high bandwidth are priorities. Data can be as simple as text or as complicated as streaming a video. A signal's time to reach the receiver and the arrival of data are also not given the priority. The majority of these priorities are normal and consumers will not care as long as the information is delivered in a timely manner. Priorities are very strict and different in industrial settings. Data must arrive on time and within predetermined margins and it must be a fixed size. The communication channel must be constantly open and experience very little downtime.

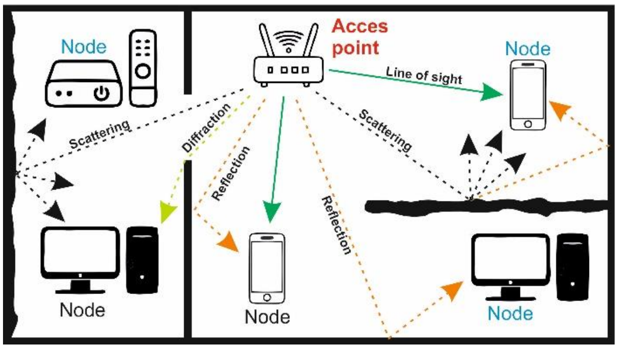
In this article, a distributed measurement system, that uses multi-node transceiving devices as local measurement devices, is described. This measurement system is applied in the wood processing industry where multiple devices simultaneously measure several parameters relevant for that specific application directly related to semi-processed or raw wooden products. Used measurement devices rely on LoRa based RF communication to exchange measurement results with the supervision node and server computer, respectively. Due to the spatial distribution of the measurement devices and the topology of the implemented site, this application encompasses all problems related to RF signal propagation with the addition of, for RF signal, obstacle dense application environment that distorts the communication signal even further. Here, transceiving devices are tightly coupled with the packs of wooden planks that are designated for natural or forced drying. They are placed inside of the pack and densely stored on a processing plateau. Thus, in this article, the authors propose a technique to strengthen measurement devices and (trans)receiving units for wireless signal propagation in order to maintain a high-quality communication link in a given environment and topology. Furthermore, practical procedures for maintaining a desirable signal level and their upkeep suggestions, for applications with numerous obstacles in the working environment, are presented.

The article is structured as follows: RF signal propagation, related to the communication quality and capability, is discussed in Section 2 along with the state of the art on survey and the problem statement of the characteristics of multipath propagation. To explain why various channel models are required, significant factors affecting wireless propagation channels are briefly discussed as well as the application of LoRa based communication in wood processing industry with implementation details in Section 3. In Section 4, the findings and solutions are analysed and presented.

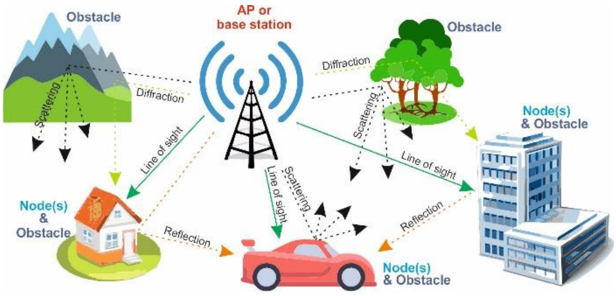
2. CHALLENGES IN COMMUNICATION AND BEHAVIOURISTICS OF RF SIGNAL PROPAGATION IN THE OBSTACLE DENSE ENVIRONMENT: THE LORA APPLICATION

In every communication system, there are several key ways for a signal to get from the sender to the receiver. However, in the obstacle dense environment, such as urban areas or indoor spaces, the signal propagation can be significantly affected by reflections, diffractions, and multipath fading, leading to challenges in communication and behaviouristics of RF signals.

In this paper, the LoRaWAN network's [10,11] principal topology is used as a low power wide area networking protocol in a communication system for structured measurement data delivery. Such networks are mainly built using IoT principles and embedded computers, thus having limited communication capability and flexibility sacrificed to the cost efficiency and spread presence in various applications and purposes that require offloading centralised computing infrastructure, [12,13]. The paper proposes a solution to overcome the challenges faced by RF signals in obstacle-dense environments by utilising the LoRaWAN network's low power consumption and wide area coverage capabilities. The proposed communication system aims to deliver structured measurement data efficiently and reliably in such environments. Several central mechanisms that may be linked to distinct propagation channels in order to model this system is presented (Fig. 1).



a) Indoor propagation examples of propagation paths



b) Outdoor propagation examples of propagation paths

Fig. 1. LoRaWAN network signal propagation properties in the indoor and outdoor environment

When the LOS path between the access point and clients is not blocked by any obstacles, as is the case in an indoor deployment, the communication is the most stable and reliable. The client is getting a lower quality signal because the signal is being reflected off a wall. Signal reaches client 2 after being refracted in the doorway and scattered off the rough wall. It is important to note that reflections can cause interference and weaken the signal while diffraction and scattering can help the signal reach its destination. Understanding these phenomena can help improve wireless communication in indoor environments. Contrary to the indoor implementation, the outdoor application of wireless networks has many similarities but has propagation paths that are highly dependent on the geo-structural topology of the implementation site. Implementation sites often have their own dynamics that are hard to model and predict in terms of distance, apparent size, reflectivity, etc. Therefore, the design of outdoor wireless networks requires careful consideration of the physical environment and the potential obstacles that may affect signal strength and quality, such as buildings, trees, and terrain. Additionally, weather conditions can also impact the performance of outdoor wireless networks, making it necessary to incorporate measures to mitigate their effects. Both cases emphasised the importance of obstacles, not only by their spatial position but also by their composition and absorbance and reflectance properties. That is especially important in cases where densely populated environments are at the core of network topology implementation [14]. To compete with such challenges, a thorough network tuning is required not only by its protocol-oriented parameters but also by its low-level communication parameters closely related to its RF spectrum properties of channel selection, modulation width and technique, transmitting allowance, etc. [15]. This tuning ensures that the network operates efficiently and effectively, providing reliable connectivity to all users. Additionally, regular monitoring and maintenance of the network are crucial to ensure its continued optimal performance. Furthermore, proper antenna placement and signal propagation analysis are crucial for achieving optimal network performance in such environments. It is essential to consider all these factors when designing and implementing a network topology in densely populated areas.

2.1 Propagation Along the Line-of-Sight

Signals travel along the line-of-sight (LOS) path when the receiver sends the signal from the transmitter to the receiver without any reflections, diffractions or scattering. On any given communication system, a line-of-sight connection has the shortest time delay and is typically the strongest signal that can be found. Between the transmitter and the receiver, there cannot be any signal obstructions that are not very far away or completely absent for there to be a line of sight. Fresnel zones are used to model such a system. Fresnel zones are elliptical regions that surround the direct line of sight and are used to calculate the amount of signal loss caused by obstructions. They take into account the frequency of the signal, the distance between transmitter and receiver, and the size and shape of obstructions. Here, the part related to the size and shape of obstacles is a matter of our investigation but without the mathematical modelling of signal spatial distribution.

This kind of communication topology is often modelled and used in the analysis as the "Free space propagation" model [16]. This is an idealised setting for the propagation mechanism when the transmitter (Tx) and the receiver (Rx) have direct LOS and are separated by a distance *d* between *Tx* and *Rx*. If *Pt* is the transmitted power, the received power P_r, a function of distance *d*, is given by (1)

$$P_r(d) = G_t G_r P_t \frac{\lambda^2}{(4\pi d)^2 L} = P_t \frac{A_{et} A_{er}}{(\pi d)^2 L}. \qquad (1)$$

where A_e, *G*, and *L* are, respectively, the effective area, antenna gain, and system loss factor. Subscripts ***t*** and ***r*** refer to the transmitter and receiver, respectively.

From this relationship, it is observable that the received power decays at a rate of 20 dB/decade as the distance increases linearly. This phenomenon is known as path loss and is a fundamental concept in wireless communication systems. Path loss can be mitigated by using techniques such as power control, antenna diversity, and signal amplification.

Instead of using mathematical models, investigations using experimental methods, such as measuring the signal strength between the transmitter and receiver in the field, or RSSI, are conducted, respectively. Furthermore, in this LoRa multi-nodal communication application project, the propagation strength without any obstructions between the transmitter and receiver is conducted and taken into account.

2.2 Non-Line-of-Sight Propagation

When a transmitted signal travels through communication paths other than the LOS path, non-line-of-sight (NLOS) propagation occurs. When it finally reaches the receiver, the signal that was sent there has travelled along one or more indirect paths, each of which has its own unique frequency attenuations and delays. It is utilised for providing signal coverage in environments that are dense and rich in obstacles, such as a city that contains a large number of buildings and other types of obstructions. Those obstructions are responsible for propagation mechanisms like reflection, scattering, and diffraction, which are responsible for most of the communication to be made.

When a wave strikes a smooth surface, it is reflected back into the wave's direction of travel. When light reflects, it also refracts (transmission of the wave through the object). According to the nature of the material, the intensity of the reflected and refracted waves can vary. According to Snell's law [17], the angles and indices of reflection and refraction can be calculated. This kind of mechanism for the transmitter setup is needed. When a signal frequently encounters rough and uneven objects, the waves that are being transmitted are broken up into smaller waves as a result. This phenomenon is known as scattering, and it typically results in a loss of energy for the signal. When a wave is split, its energy is dispersed over a larger and more extensive area. This results in increased background noise in the communication channel, which makes it more difficult for other signals to travel through. The signal is received over multiple communication paths all with different time delays. This property is extremely important during project development for communication congestion during high network traffic. Waves are said to "bend" when they go around sharp corners, such as when they go over the tops of buildings, around street corners or through doorways. This phenomenon is known as diffraction. Diffraction is one of the primary methods that makes it possible to provide cellular coverage in urban and busy industrial settings where every signal is important. This is because diffraction spreads out the signals.

3. LORA NETWORK IMPLEMENTATION AND EVALUATION IN THE OBSTACLE-DENSE ENVIRONMENT: A WOOD PROCESSING INDUSTRY MONITORING APPLICATION

The implementation and evaluation of a LoRa network in the obstacle-dense environment are discussed in this paper, with a focus on its application in monitoring the wood processing industry and its adjacent sectors. The article examines the network's performance in terms of signal strength, packet loss, and overall reliability in wood processing industry Spačva, Vinkovci, Croatia. At the premises of Spačva, a system for constant wood structural moisture content, as well as environmental parameters, is monitored and used for the purpose of yielding better processing efficiency and optimising corresponding production costs. The exact purpose and working principle of a device used for Spačva's purpose is not discussed here, i.e. the part where communication is of main concern and interest is.

As can be seen in Fig. 2, the LoRaWAN network is being utilised for this project because of its dependability in harsh industrial settings, high signal penetration capabilities at low frequencies such as 32 kHz to 500 kHz, and the ability to provide wireless connectivity in expansive open areas.

Fig. 2. Area for storing and drying cut wood before going to production

The area shown in Fig. 2 is used for testing signal penetration and coverage. The red rectangle marks the placement spot of the gateway, on a nearby lamppost, with the general direction of the antenna described with a yellow arrow. The subjects of interests are all pack of planks shown in Fig. 2.

In addition, networks that are based on LoRa have a low power consumption and offer a degree of flexibility in the way that the frequency configuration of their signals can be set up. It gives us the ability to format data packets in sizes that are appropriate for the specific task at hand. Those tasks typically involve straightforward measurement data, just like our project does. Because of this, modelling projects based on the exchange of data using very little power is possible. To reduce the amount of power that is used, the exchange needs to be completed quickly with as little assistance from hardware and software as possible. It is essential that data is transmitted quickly and accurately. It is necessary for the software layer to quickly acknowledge and process messages sent between the LoRa node device and the gateway. At any given time, there may be up to one hundred devices connected to the network.

3.1 LoRa devices and LoRaWAN network specification

The LoRaWAN stack is composed of two distinct levels. To get started, a device that is equipped with LoRa, which is also referred to as a node, is needed. This device will act as the basis for the first layer of the network. It is possible that the device in question is a printed circuit board (PCB) that was designed specifically for the customer or a unit that was mass-produced by another company. In order to reduce the overall production expenses, an 868 MHz SX1276-based module was built onto a custom printed circuit board. The SX1276-based module is a popular choice for long-range wireless communication applications due to its low power consumption and high sensitivity. The custom PCB design may have often included additional components or features tailored to the specific needs of the customer. In order to communicate with a server, LoRa protocol requires a standalone device that is referred to as a concentrator. A concentrator that possesses multiple LoRa modules and at least one communication channel can be referred to as a gateway.

Gateways are essential components in LoRaWAN networks as they enable bidirectional communication between end-devices and the server. They also provide network coverage and can support a large number of end-devices. Our project makes use of a single communication channel and a LoRa-enabled device that was sourced from *Dragino(.com)*. Inter-device (LoRa end-node) communication over LoRa is handled by Microchip's *Atmega328p*. The whole device structure and inside content of the device is shown in Fig. 3. Next, server-to-client connections are managed by an *ARM* chip operating the *OpenWRT Linux* distribution that is based on custom *Dragino* solution.

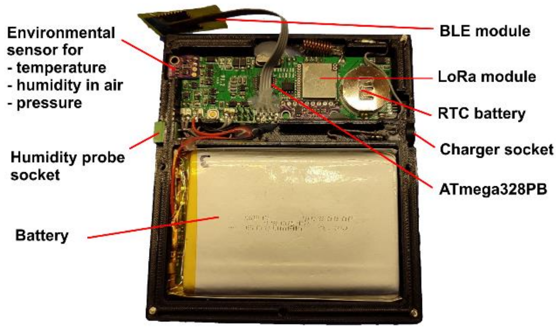


Fig. 3. LoRa end-node structure - Inside of a measurement device

3.2 LoRa parameters and requirements

Several parameters allow us to balance obstacle penetration with speed and coverage in densely populated environments (Fig. 4). LoRa *Spread Factor* or *SF* [18] represents the number of symbols sent per bit of information. A higher SF results in a longer transmission time but better resistance to interference, while a lower SF allows for faster transmission but with reduced range and sensitivity. It is important to find the optimal SF for a given environment to achieve the desired balance between penetration, speed, and coverage [19-21].

With LoRa, you can adjust the data transfer rate and the sensitivity independently.

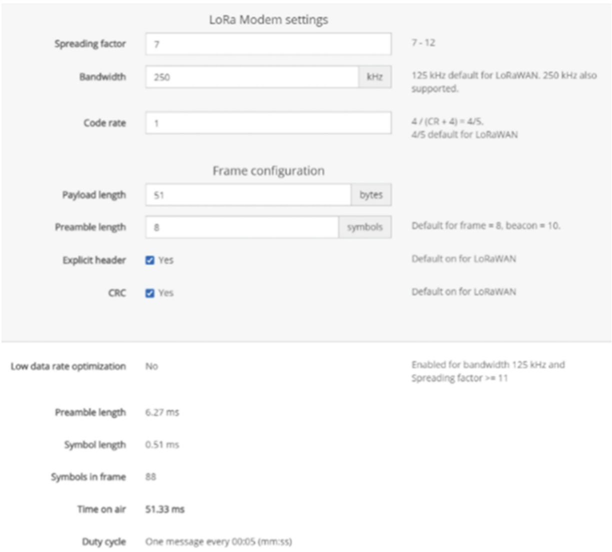


Fig. 4. Gateway’s parameter tuning and calculation interface regarding the LoRa communication protocol

Additionally, more information regarding the LoRa communication protocol can be seen in Fig. 4, which includes details such as the requirements and limits of communication for a given data size or payload length. Additionally, the length of time required for message transmission from the client to the access point is displayed.

As was presented, a lower SF means that more data can be encoded per second, while a higher SF means that less data can be encoded per second. As more data can be sent gradually thanks to the lower SF, power use goes down. This is helpful when communicating over long distances in sparsely populated areas with at least some line of sight between the transmitter and receiver. If messages are not too large, it can be a useful to link sensors spread out over a wide area. Higher SF allows for more airtime, which allows the receiver to sample the signal power more frequently, leading to increased sensitivity. To further strengthen its resistance to interference, LoRa employs forward error correction coding [22] in addition to the aforementioned methods. During testing, LoRa network was deployed in stages, with each stage tailored to the specific needs of the project, the available network bandwidth, and the expected environmental conditions.

Before the network is set up, several requirements are set based on the project's general requirements for the amount of data traffic between nodes, clients, and servers. Such requirement analyses yield the following properties of the desired communication channel:

- LoRa client needs to send 42 bytes of data in total per transaction, which is in accordance with LoRa's general purpose and application;
- to ensure a safe and trustworthy data exchange transaction up to 5 retries are allowed for data exchange;
- data exchange time needs to be less than a second (highly desirable) but not more than two seconds (max);
- has the ability to work reliably in high humidity and temperature environments.

Also, the following network connectivity cases were made to set up a reliable network and find the best topology for reliable communication:

- it has to be a wide area network, with the connectivity mainly in the line of sight as much as possible, according to test and implementation environment topology features;
- network connectivity in a designated testing area;
- data transmission times for two sets of frequencies (125 kHz and 250 kHz) and spreading factors from 9 to 12, [18].

According to the LoRaWAN specification, the *Access Node* or *Gateway* need to be installed in a location that is relatively elevated. It is beneficial if it is constructed in such a way that it is the highest point in the area where there are no obstructions present. In the beginning, when designing and testing, the gateway is positioned up high on a lamppost alongside a fixed antenna that was connected directly to the transmitter.

Gateway was combined with two distinct omnidirectional antennas operating at the frequency of 868 MHz. When the conditions were just right, a smaller omnidirectional antenna was used for larger open areas, while a larger antenna was used for smaller to medium indoor spaces. This was done in order to reduce the overall cost of the project and to evaluate the signal coverage in the area that was designated for testing for future reference. At a later point in time, the smaller antenna that had been used is upgraded with a larger one (Fig. 5), which is utilised for higher frequency use cases.

Fig. 5. Antennas and LoRa gateway used in the testing and implementation of the project – Stock 2dBi and 5dBi for upgrade

Because of the obstacles and the fact that LoRa has a restricted bandwidth at higher spreading factor values, the client or node only had a limited amount of time to deliver the data packet to the gateway [23-25]. The customers were positioned in the midst of the wood pallets (Fig. 6). Signal quality and strength can vary depending on factors such as the time of delivery, the number of active connections, and the placement of nodes within the wood pallet. Other factors include the weather. Inside of each node, a miniature helical antenna is placed. The data from the measurements were recorded and saved in the CSV-like file, which was subsequently used for the analysis (Fig. 7).

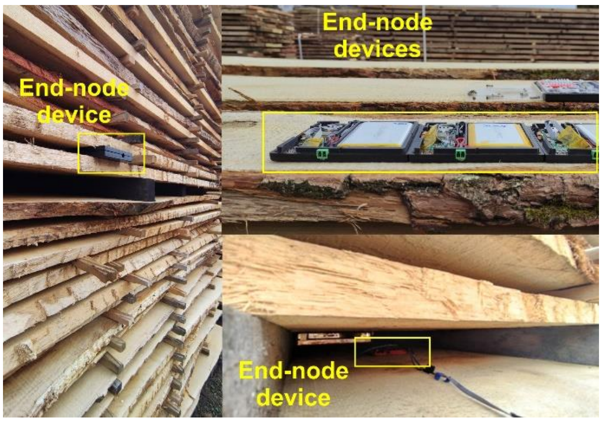


Fig. 6. Installation of communication devices (LoRa end-nodes) within stacked wood pallets

After initial testing of LoRa signal coverage with a small "white" antenna, a large omnidirectional antenna was deployed (a 5dBi) for wider area communication on a larger field and for improved signal quality during message transmission with substantial obstructions.

The small white antenna was found to have a limited range and was not suitable for the project's requirements. The large 850-900 MHz omnidirectional antenna provided better coverage and signal quality making it ideal for the project's implementation.

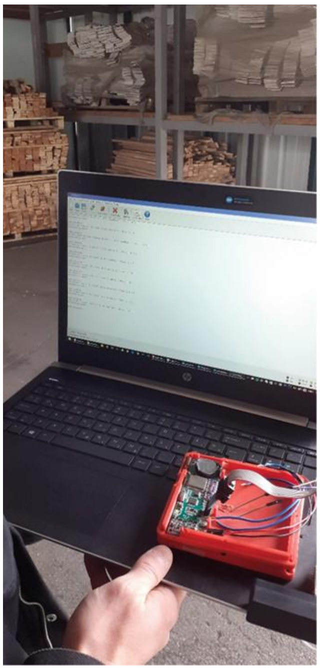


Fig. 7. Analysis of collected data samples on the field, debugging firmware, analysis of messages that were successfully sent between the client and the access point

The communication devices, which are installed inside the stacked wood pallets, are instructed to transmit up to ten messages to the access point at any given time. When the device is removed, the number of messages that were successfully transmitted is counted and checked. The procedure is carried out for each stack of wood pallets until each and every message is delivered without success. This method lets us keep track of the pallets as they move through the supply chain and makes sure that any problems or delays can be quickly found and fixed.

4. MEASUREMENT AND RESULTS

After preparation of all elements for on-field deployment (measurement devices programmed, i.e. LoRa end-nodes, tuned for on-field deployment, gateways set-up, batteries fully charged), devices are deployed and tested as aforementioned. Testing was conducted during August 2021 in an environment that was harsh with respect to irradiated heat, elevated humidity, lack of airflow, and large temperature swings during the day-night cycle. Such conditions usually peak in August in the northern part of the globe, where the test was conducted.

Nevertheless, the 18-day period allotted for the test was completed without a hitch and passed with flying colours. The test revealed that there are multiple problems with the communication channel. During an average day with temperatures that are higher than 28°C, the LoRa parameters need to reflect a higher data rate along with a spreading factor and frequency that correspond to this higher data rate. This ensures that the vast majority of measurement data in the immediate vicinity of a gateway can be transmitted as quickly as possible. This was primarily caused by the thermal throttling of devices that had been subjected to high temperatures for an extended period of time. As a result of the high temperatures, the signal strength (also known as RSSI) gradually decreases over time (as shown in Fig. 8), as can be seen from the dates ranging from Aug. 7th to Aug. 15th.

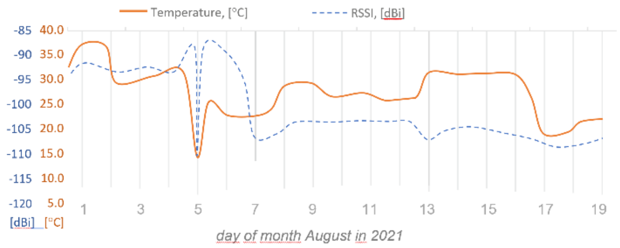


Fig. 8. Changes in signal intensity as a function of temperature from August 4th to August 10th

A decrease in signal strength can be seen in Fig. 8 in the period from August 4th to August 10th. The reason for such strength decay is correlated with the high temperature conditions of the open field area where the test wood pallets were placed.

More users mean more potential for network congestion, which can disrupt the service. Two-pronged approach to fix the problems are used. The client stores the data for the next cycle, where two messages with data will be sent if it is unable to send the message during the first cycle. Client-side encoding is the second option. This approach ensures data redundancy and improves the reliability of the message transmission. However, it may increase overall transmission time and client-side resource utilisation. When encoding data packets, it is necessary to know the data types involved and the allowed values for those types. The third option involves limiting the number of times transmission can be attempted again. This is particularly important in wireless communication, where the signal strength can vary and lead to transmission errors. By limiting the number of transmission attempts, the system can avoid wasting resources and move on to other packets.

4.1 Client-side analysis

We implemented a small circular queue on the receiver side that accepts messages for a limited time. This method of polling clients before responding adds flexibility when the time to respond to received messages comes and, if necessary, pass messages further across the network. By using this approach, it is possible to ensure that the messages are processed in a timely manner and any potential backlog of messages is prevented. Three processes which are active only for a limited time and can be terminated sooner if certain conditions are met are implemented. The distance between the transmitter and the client is important for delivering messages on time. The farther away the client is, the longer it takes to send the message and more energy is consumed in the process.

4.2 Antenna placement and effects on signal strength

Measurement analysis revealed that a difference of 5-15 dBm is possible just by using the correct antenna, which resulted with an extra boost or gain. Adjustments to gain have little effect on the closest clients to the receiver. A higher frequency was selected because of the need to transmit data faster and with less interference over longer distances. Adjustments to gain have little effect on the closest clients to the receiver. A higher frequency was selected because of the need to transmit data faster and with less interference over longer distances. However, this can result in weaker signals and more susceptibility to interference from other sources. Therefore, it is important to carefully balance the trade-off between frequency and signal strength to ensure reliable communication. For the modules at the farthest distance, a higher spreading factor is used to further suppress interference in the data transmission channel. Data transmission can be significantly impacted by environmental factors, especially humidity or simple water vapour due to our node's location in the middle of wood pallets. Water from snow, hail, fog or even simple rain can damage those wooden pallets. Poor signal reception and mobile signal issues can occur when water interferes with or scatters radio waves. Water's ability to conduct electricity slows down a signal wave. However, water's other properties, including its ability to reflect and/or refract radio waves and absorb their energy, converting it to heat, also contribute to the propagation delay effect. In particular, wood is vulnerable to water. It can rapidly increase its water absorption capacity by up to 50% in a matter of minutes or hours. Daytime temperatures turn the absorbed water into water vapour allowing it to escape. Water vapour and heat have a devastating effect on electronics reducing their signal strength dramatically. Between the late July 31st and the beginning of Aug. 1st, nearly 10% of the moisture that had been lost returns (Fig. 9). Since the vapour cannot escape the pallet all at once, it accumulates inside until the next cycle as was clearly visible in the period form the mid of August 1st to the beginning of August 2nd.

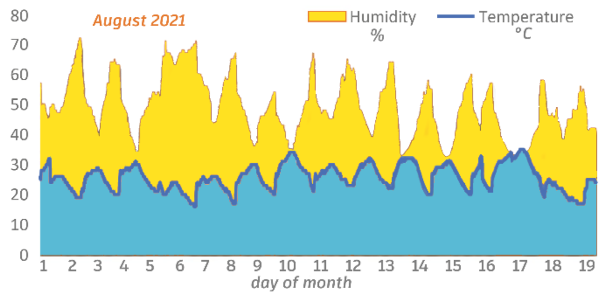


Fig. 9. Relationship between relative humidity and air temperature during the experiment

On the graph in Fig. 9, temperature peaks during the day along with the effect of the humidity release in the wood during the measurement cycle are shown. With a higher temperature, moisture release ramps up and causes high humidity conditions resulting in high signal and energy losses.

Depending on signal coverage, the right antenna must be chosen. The antenna choice is crucial in achieving optimal signal strength and minimising energy losses, especially in areas with high humidity conditions. Therefore, it is important to select the appropriate antenna based on the specific signal coverage requirements. A specific location to conduct the test is selected in order to evaluate the extent to which the signal reaches and penetrates the surrounding area as in Fig. 10.

Fig. 10. Testing site and signal strength measurement spots

In Fig. 10, transparent-blue circles indicate locations where measurements were taken. This represents the only valid point of wide-area coverage with obstructions. This emphasises the importance of selecting the proper testing area for wide-area signal testing before performing any other tests.

Using a compact omnidirectional antenna, extensive field tests are performed. It was replaced because the signal did not reach all expected locations. In most cases, a larger antenna with a gain of 5 dBi was installed instead of a smaller one. It sat on a metal stand that was placed 1 meter away from the lamppost (Fig. 12). The extra cable length was required. The longer cable causes transmission impedance, which weakens the advertisement. The solution to these problems was to boost the signal power gain, which typically results in higher power consumption, which is fine for a gateway that never leaves the box.

As Table 1 and Fig. 10 show, in summary, the influence of the communication (end-nodes) positions does not allow us to logically conclude that the best position for module placement is the nearest one. Contrary to that, some positions farther away from the gateway can yield much better reception than the other one, which is probably closer to the gateway. The only thing it can yield with a reasonable conclusion is that the environment where the variety and number of obstacles are present and the environment, which is saturated with moisture either in the air or in the obstacles influences RF signal propagation significantly and prevents planning and positioning of the communication equipment without on-field probing with real measurement. The environment where packs of raw-cut planks are densely stored and in close proximity to each other does not present desirable environment for communication, not only LoRa, but all, like for spots in 5th roe on positions 33 and 34 where the reception does not occur (in Table 1 marked as ‘x’).

Furthermore, the analysis of signal coverage, in terms of connectivity maintenance, is conducted on the entire storage area for packs of wood planks as in Fig. 11. The analysis has shown that, in general, applies the rule ‘closer-to-the-transmitter the better communication’ applies to transportation corridors and vice-versa. In Fig. 11, green colour means that the connection is established and has good signal strength with no communication fails; the yellow-coloured areas designate connection established areas with seldom communication intermittence, relatively poor reception and signal strength, respectively. The red-coloured areas designate no communication areas and exceptionally low or absent signal strength, hence communication is not possible by any means.

Table 1. Signal strength (RSSI) distribution for the given test site

ROW				
1	**2**	**3**	**4**	**5**
Spot# ***-dBm***	Spot# ***-dBm***	Spot# ***-dBm***	Spot# ***-dBm***	Spot# ***-dBm***
1 ***111***	6 ***115***	15 ***116***	22 ***136***	28 ***136***
2 ***119***	7 ***132***	16 ***117***	23 ***128***	29 ***139***
3 ***117***	8 ***126***	17 ***116***	24 ***128***	30 ***115***
4 ***126***	9 ***123***	18 ***117***	25 ***132***	31 ***123***
5 ***123***	10 ***124***	19 ***126***	26 ***125***	32 ***128***
	11 ***126***	20 ***129***	27 ***136***	33 ***X***
	12 ***127***	21 ***128***		34 ***x***
	13 ***133***			
	14 ***117***			

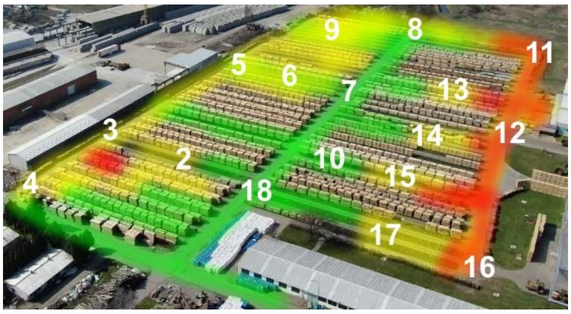


Fig. 11. View of the field/test-site where wooden pallets are stored to dry and be prepared for use

This analysis shows that despite relatively short communication distances of this implementation site, there are some spots or areas where the signal does not propagate successfully disallowing communication at all. Furthermore, the areas designated with the number spots (except 3) 11, 12 and 16 are the places populated with relatively fresh stock of raw wooden plank that are greatly saturated with water. It leads to the conclusion that the high content of water in such fresh stock dampens RF signal strength significantly and it should be taken care of when the maintenance of communication at the given site is concerned. The placement of the stock should be planned carefully or establishing completely new gateways and gateway places along points of interest on the entire implementation area in order to make proper coverage and increase the quality of reception should be taken in consideration.

The significant factor that influences the communication quality is the placement of the gateway and its antenna. According to general rules, applied on the dipole antenna, it is necessary to physically elevate the antenna above the horizon of the desired propagation coverage and remove obstacles that dampen, reflect or diffract the emitted RF wave. In the described case, the gateway and antenna are placed on a nearby lamppost, which makes it an ideal choice for the given purpose.

The lamppost is vertical and the antenna is at least a meter away as can be seen in Fig. 12. The lamppost stands in a field where wooden pallets are being dried, which is another convenience. During the course of the testing, it was found that the antenna needs to be at least one meter away from any object and this distance is particularly important when the object in question is made of metal. Noticeable signal reflection, which resulted in gaps in the testing area where there was no signal or it was dampened by the previously mentioned reasons, is detected.

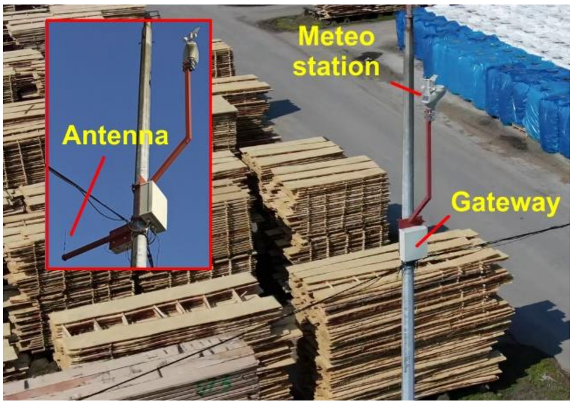


Fig. 12. Lamppost placement of the LoRa receiver (Gateway) and antenna

Moreover, it is noted that high swings in the environment temperature and humidity greatly impact the signal strength and propagation, respectively. As can be seen from Fig. 13, in the period from the mid of Aug. 4^{th} to the mid of Aug. 5^{th}, the humidity in the test site shows rapid and relatively large increase of humidity. Also, that increase strongly correlates with RSSI spiking-down. A closer analysis indicates that not all humidity rises cause a significant drop in RSSI. The explanation for that lies in fact that humidity rising, which causes a significant drop of RSSI, has its swing to the highest humidity value in the entire monitoring period and exceeding 70%. After stabilising in the humidity change, RSSI gained back its level, which means that the released water vapour (from structural humidity in wood planks) changes its phase to liquid (condensed) and electronic components of the (LoRa) end-node measurement device get wet. That fact is supported even by the temperature dynamics shown in graph in Fig. 8, which illustrates that the great temperature drop occurs at the same time causing a rapid humidity increase up to the point of a cold-surface-contact condensation effect.

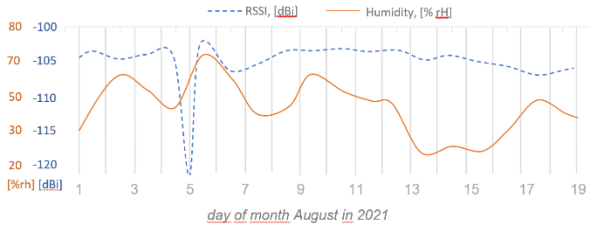


Fig. 13. The correlation between the moisture in the air and the strength of the signal over time (in a period during high humidity cycles when the signal strength drops significantly)

5. CONCLUSION

This paper demonstrated the tested, presented and elaborated on LoRa communication challenges in densely populated environments with obstacles where signal propagation behaviours, with respect to environmental factors. The findings are used to make the best-practice recommendations for establishing a reliable and design-proven LoRa based network topology with the application in the wood processing industry. The wood processing industry is known for its challenging environment, where the signal interference and obstructions are common. The recommendations presented in this article can help the industry establish a reliable and robust LoRa network that can enhance their operational efficiency and productivity.

When using the LoRaWAN stack, the factors that influence communication channels and address the resulting challenges are explained in detail. It is possible to model different communication channels to meet the requirements, taking into account the environment, weather, and obstacles. The network also excelled in providing predictable results during testing at long ranges, where it demonstrated its superiority. It is absolutely necessary to select an antenna that is suitable for the task at hand, as well as to place it in an appropriate location.

Furthermore, the final conclusion leads to the fact that packs of raw wood planks stored in dense arrangements represent a great challenge for establishing good and reliable communication. The tight places, high moisture (water in structure of the wood), dense arrangement of packs of planks, great swings in temperature and humidity greatly influence the RF signal propagation and communication overall. Careful planning of gateway(s) placement is crucial. Finding appropriate spots for the placement is inevitable but that can be done only with a proper implementation site survey alongside on-field real measurements.

The local environmental condition is also of a great importance because the condensation of water vapour and a great swing of environment temperature can lead to the formation of hostile environment of the atmospheric element, which can even further lead to dampening RF signal propagation abilities.

That being said, the environment with densely populated obstacles (for RF signals) makes planning and deploying of such networks very difficult and challenging to maintain. This article demonstrates that the wood processing industry is no exception and presents a textbook demonstration example for RF signal propagation challenges. It demands the synergy of careful planning alongside on-field (on-site) testing, measuring and real-time validating. All that, in unison only, can lead to a success in the proper maintenance of a desired communication structure with obstacles in densely populated places/sites.

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REFERENCES

[1] M. Stefanovic, S.R. Panic, R.A.A. de Souza, J. Reig, Recent Advances in RF Propagation Modeling for 5G Systems. *International Journal of Antennas and Propagation*, 2017, 2017: 4701208. https://doi.org/10.1155/2017/4701208

[2] L. Rauchhaupt, Methods for a reliable wireless communication in the industry. *at - Automatisierungstechnik*, 67(1), 2019: 3-6.

https://doi.org/10.1515/auto-2018-0143

[3] F. Xiaohai, Application of wireless communication technology in distribution network. *Research on Wireless Communication*, 2(2), 2020: 37-43. https://doi.org/10.35534/rwc.0202006c

[4] Y.-Q. Jin, Wave Propagation, Scattering and Emission in Complex Media. *World Scientific Publishing,* Beijing, 2004.

[5] Z.K. Wang, Application of Complex Network Theory in Computer Network Topology Optimization Research. *Advanced Materials Research*, 989-994, 2014: 4237-4240. https://doi.org/10.4028/www.scientific.net/amr.989-994.4237

[6] M.O. Farooq, I. Wheelock, D. Pesch, IoT-Connect: An Interoperability Framework for Smart Home Communication Protocols. *IEEE Consumer Electronics Magazine*, 9(1), 2020: 22-29. https://doi.org/10.1109/mce.2019.2941393

[7] A. Jyotsana pandey, Review of protocols used in Multicasting Communication. *International Journal of Engineering and Computer Science*, 6(1), 2017: 19960-19962. https://doi.org/10.18535/ijecs/v6i1.18

[8] W. Mardini, Y. Khamayseh, Algorithms and Protocols in Information and Communication Systems. *Network Protocols and Algorithms*, 4(3), 2012: 1-3. https://doi.org/10.5296/npa.v4i3.2469

[9] J.J.P.C. Rodrigues, Smart Communication Protocols & Algorithms. *Network Protocols and Algorithms*, 4(2), 2012: 1-4. https://doi.org/10.5296/npa.v4i2.1970

[10] What are LoRa and LoRaWAN?, The Things Network, 2022. https://www.thethingsnetwork.org/docs/lorawan/what-is-lorawan/ (Accessed on November 19, 2022).

[11] A. Kowol, Internet of Things – an Example of Implementing the LoRaWAN Protocol. *Pomiary Automatyka Robotyka*, 23(2), 2019: 61-68. https://doi.org/10.14313/par_232/61

[12] S.-M. Park and J.-Y. Choi, Embedded Platform Development for LoRaWAN End Node Device. *The Journal of Korean Institute of Information Technology*, 19(10), 2021: 37-43. https://doi.org/10.14801/jkiit.2021.19.10.37

[13] T. Lipka, Internet of Things (IoT) – LoRaWAN w praktyce. *Nafta-Gaz*, 76(2), 2020: 119-124. https://doi.org/10.18668/ng.2020.02.06

[14] T.D. Paul, V. Rathinasabapathy, Evaluation of LoRaWAN In A Highly Dense Environment With Design Of Common Automated Metering Platform (CAMP) Based On LoRaWAN Protocol. *KSII Transactions on Internet and Information Systems*, 16(5), 2022: 1540-1560. https://doi.org/10.3837/tiis.2022.05.007

[15] A.B. Mirmanov, Methodology for calculating LoRaWAN network parameters. *Scientific Development Trends and Education*, 55-2, 2019: 14-19. https://doi.org/10.18411/lj-10-2019-23

[16] T.S. Rappaport, Wireless Communications. *Prentice Hall*, 2002.

[17] H.G. Zimmer, Geometrical Optics. *Springer Berlin, Heidelberg*, Vol.9, 2012. https://doi.org/10.1007/978-3-642-86831-3

[18] LoRaWAN Spreading factor, range, data rate in LoRa System, LoRaWAN Spreading factor, range, data rate in LoRa System, 2022. https://www.rfwireless-world.com/Terminology/LoRaWAN-Spreading-factor-Range-and-Data-Rate.html (Accessed on November 20, 2023).

[19] S. Dawaliby, A. Bradai, Y. Pousset, Joint slice-based spreading factor and transmission power optimization in LoRa smart city networks. *Internet of Things*, 14, 2021: 100-121. https://doi.org/10.1016/j.iot.2019.100121

[20] G. Pasolini, On the LoRa Chirp Spread Spectrum Modulation: Signal Properties and Their Impact on Transmitter and Receiver Architectures. *IEEE Transactions on Wireless Communications*, 21(1), 2022: 357-369. https://doi.org/10.1109/twc.2021.3095667

[21] J.-T. Lim, Y. Han, Spreading Factor Allocation for Massive Connectivity in LoRa Systems. *IEEE Communications Letters*, 22(4), 2018: 800-803. https://doi.org/10.1109/lcomm.2018.2797274

[22] K. El-Abbasy, R. Taki Eldin, S. El Ramly, B. Abdehamid, Optimized Polar Codes as Forward Error Correction Coding for Digital Video Broadcasting Systems. *Electronics*, 10(17), 2021: 2152. https://doi.org/10.3390/electronics10172152

[23] M. Jimenez, A. Medina, L. Navarro, A. Osorio, D. Robles, M. Calle, J.E. Candelo-Becerra, Obstacles, Speed and Spreading Factor: Insights in LoRa Mobile Performance. *International Journal on Communications Antenna and Propagation (IRECAP)*, 9(3), 2019: 228-231. https://doi.org/10.15866/irecap.v9i3.17296

[24] P. Branch, Measurements and Models of 915 MHz LoRa Radio Propagation in an Underground Gold Mine. *Sensors*, 22(22), 2022: 8653. https://doi.org/10.3390/s22228653

[25] K.A. Ahmad, J.D. Segaran, F.R. Hashim, M.T. Jusoh, LoRa Propagation at 433 MHz in Tropical Climate Environment. *Journal of Fundamental and Applied Sciences*, 9(3S), 2018: 384. https://doi.org/10.4314/jfas.v9i3s.31