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AIR QUALITY ANALYSIS IN THE SURROUNDING ENVIRONMENTS USING A LORA NETWORK

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Abstract: *This paper conducts an analysis and comparison of air quality in diverse settings, spanning indoor and outdoor environments. The objective is to identify avenues for improving well-being and informing larger organizations about essential monitoring priorities for optimal breathable air. The paper comprises three core sections. The initial segment focuses on air quality analysis and the utilization of sensors for indoor and outdoor measurements. The subsequent part elaborates on data transmission via the LoRa Wan protocol, utilizing an ST gateway and end nodes to relay analyzed data for centralized processing, with a particular exploration of LoRa transmission ranges in urban areas. The final section outlines future developments and key investigations using various sensors.*

Key words: *LoRa, Gateway, Air Quality, Pollution, RSSI, IOT*

1. INTRODUCTION

Our daily work and lifestyle are significantly impacted by our surroundings, with air quality playing a pivotal role in our lives. To effectively manage this aspect, it is imperative to conduct measurements and establish benchmarks for the betterment of our well-being.

In typical indoor settings, air quality often remains overlooked. Consequently, after spending extended periods indoors, concentration levels gradually decline, fatigue sets in, and energy is depleted rapidly. Many individuals may not fully grasp this situation. However, simply opening a window for a few minutes can alleviate most of these symptoms. This phenomenon occurs due to oxygen consumption within the room and an increase in carbon dioxide levels [1].

These issues gained prominence, particularly with the onset of the Covid-19 pandemic, which compelled people to work from home, creating makeshift offices in their residences. Consequently, employee productivity began to decline, and for a while, the cause remained somewhat elusive.

Typically, each city's Town Hall or government deploys one or two air quality sensors. However, these sensors often fall short of providing comprehensive coverage for precise air quality measurements throughout the entire city. Hence, this paper seeks to analyze the range of LoRa devices to facilitate the installation of multiple end nodes across the city, thereby enhancing the precision of air quality assessments.

2. AIR QUALITY MEASUREMENTS

2.1 Sensor used for the measurement.

The sensors employed for data collection are overseeing the tracking of various parameters, which include Carbon Dioxide (CO_2), Dust (PM2.5), Nitrogen Dioxide (NO_2), Relative Humidity, Air Pressure, Carbon Monoxide (CO), Temperature, Airborne Chemicals (VOCs), and Ozone (O_3) [2][3].

Indoor Measurements

The key elements crucial for indoor measurement are Carbon Dioxide and TVOC (Total Volatile Organic Compounds).

Carbon Dioxide (CO_2) is one of the many molecules present in the atmosphere. While it is a colorless gas that poses minimal harm in small quantities, its health implications become more pronounced as its concentration rises. CO_2 primarily originates from human respiration but can also result from various combustion processes like cooking and vehicle emissions. Elevated CO_2 levels in the air can manifest as symptoms such as headaches, mental discomfort like drowsiness or restlessness, and have been linked to reduced productivity and health issues. Typically, the measurement of Carbon Dioxide is expressed in parts per million (ppm).

Volatile Organic Compounds (VOCs)[4] represent organic compounds that easily transition into vapor or gas forms. They emanate from a wide spectrum of everyday items, encompassing solvent-based paints, air fresheners, fragrances, adhesives, and more. In indoor settings, VOC concentrations are often approximately ten times greater than those found outdoors, presenting potential health risks both in the short term and over prolonged periods. These compounds are commonly introduced into residential spaces through newly acquired furniture, fabrics, office equipment, aerosol sprays, chemical cleaning agents, disinfectants, as well as various types of paints and solvents.

While some VOCs may have minimal impacts on individuals, others possess high toxicity and can lead to health issues when individuals are exposed to them over extended durations.

Indoor Measurements – Carbone Dioxide

The initial air quality analysis was conducted within a room measuring 30.5 m^3, and the data presented in Figure 1 spans a full day, encompassing various activities and varying occupant numbers.

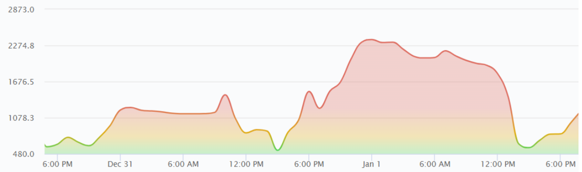

Fig.1. The fluctuation of the Carbon Dioxide inside a room with a size of 30.5 m^3

Figure 1 illustrates the indoor air quality measurements, specifically tracking the fluctuations in Carbon Dioxide (CO_2) levels within the 30.5 m^3 room over a 24-hour period, from December 30, 2022, to January 1, 2023.

The graph's starting segment, spanning from 18:00 to 22:00, coincides with a period when a window was open to facilitate the circulation of fresh, clean air. During this phase, the lowest recorded CO_2 concentration was 616 ppm. Subsequently, following the window's closure, CO_2 levels began to rise, reaching 1248 ppm by 01:30, at which point the room was vacated.

Between then and 10:00 the following day, CO_2 concentration remained relatively constant at approximately 1144 ppm. Upon re-entry into the room, CO_2 levels quickly surged to 1456 ppm. However, with the window opened for ventilation at 11:00, the concentration gradually declined, reaching 539 ppm by 16:00.

Subsequently, CO_2 levels continued to ascend until 01:00, reaching a peak of 2373 ppm and remaining above 2000 ppm until another window was opened at 12:30. This action led to a decrease in CO_2 concentration to 582 ppm.

Indoor Measurements – TVOC (total volatile organic compound)

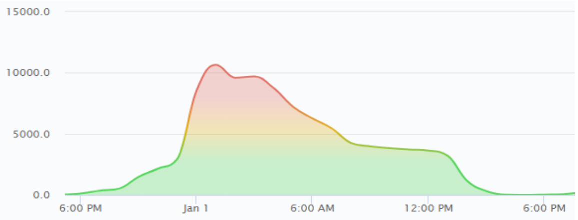

Fig.2. The fluctuation of the TVOC inside a room with a size of 30.5 m^3

The graph in Figure 2 illustrates the variations in Total Volatile Organic Compounds (TVOC) levels within a 30.5m^3 room, influenced by indoor smoking and an increased number of occupants.

Following the introduction of fresh air into the room, the initial TVOC concentration at 18:00 measured 114 $\mu g/m^3$. Subsequently, it exhibited a steady increase, peaking at 01:00 with a reading of 10661 $\mu g/m^3$. After reaching this zenith, the TVOC levels began a gradual descent, reaching 4243 $\mu g/m^3$ by 08:00. The rate of decline then slowed until 13:00 when it stabilized at 3199 µg/m³. It was at this juncture that fresh air was reintroduced into the room, resulting in a significant reduction to 15 µg/m³ within a span of three hours.

2.2 Outside Measurements

To cover a broad spectrum of scenarios, we carefully selected various conditions for our outdoor measurements. These scenarios encompassed measurements taken on a heavily trafficked road, an unoccupied road, during morning and evening timeframes, on a hill during a period of elevated pollution when the outside temperature dropped below -5 degrees Celsius, and during a 24-hour scanning session near a parking lot. Among these scans, the most noteworthy was the one conducted on the heavily trafficked road.

Measurement on a Heavily Trafficked Road:

This measurement occurred during the morning rush hour, when the streets were bustling with commuters heading to work or dropping off their children at school. This allowed us to observe the typical pollution levels in a densely congested area heavily influenced by traffic. Notably, only two elements exhibited significant deviations from their usual levels in this specific scenario: Nitrogen Dioxide (NOx) and Particulate Matter 2.5 (PM2.5).

Particulate matter (PM) is a term used to describe minuscule particles originating from complex interactions between liquid droplets and solid particles in the atmosphere. These particles come in various sizes, with some visible to the naked eye, like dust and smoke, while others are so small that an electron microscope is required for observation.

Nitrogen Dioxide (NO_2) is a reddish-brown gas emitted during the combustion of fuels. It is commonly found in vehicle emissions and the fumes produced by burning fossil fuels such as propane, kerosene, natural gas, and wood. When present in high concentrations, NO_2 has the potential to irritate the airways within the human respiratory system, potentially leading to costly hospital visits. Prolonged exposure to NO_2 can contribute to the development of chronic illnesses and respiratory infections. Nitrogen Dioxide measurements are typically expressed in parts per billion (ppb).

Outdoor Measurements – Nitrogen Dioxide (NO_2)

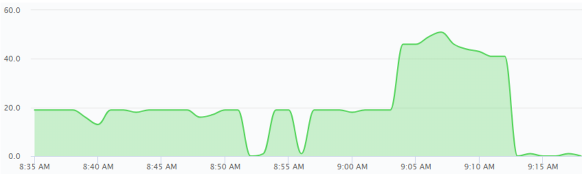

Fig.3. The fluctuation of the Nitrogen Dioxide on a heavy transited road

In typical circumstances, within an unpolluted environment devoid of nearby traffic, Nitrogen Dioxide (NO_2) levels are expected to register at approximately 0 ppb. Nevertheless, our current analysis reveals readings indicating levels hovering around 20 ppb. Furthermore, during a brief 10-minute period of intensified traffic activity, these values surged to 45-50 ppb. Following this peak, as traffic congestion eased (presumably after school drop-offs were completed), road traffic rapidly decreased, resulting in a return of NO_2 levels to the baseline of 0 ppb.

To effectively gauge the transient nature of this pollution, it is crucial to conduct meticulous monitoring at multiple locations throughout the city, particularly in proximity to significant establishments like schools, hospitals, and offices. This comprehensive monitoring approach ensures a precise assessment of pollution levels over an extended period.

Outdoor Measurements – Particle Matter (PM2.5)

Fig.4. The fluctuation of the PM 2.5 on a heavy transited road

In our study, the measurement of particulate matter demonstrates a range of values that are impacted by the sensor's proximity to traffic. Furthermore, the presence of air currents generated by the movement of vehicles introduces variations and fluctuations in the measurements. In the absence of dust or airborne particles, the anticipated reading for PM 2.5 would typically be close to 0 ppb.

3. LORA PROTOCOL USED FOR DATA TRANSMISSION

3.1 Why LoRa?

Why was the LoRa protocol chosen over alternatives like ZigBee, Wi-Fi, or Bluetooth? This choice was primarily based on its low power consumption and extensive range [5], making it possible to establish stable communication with only a large number of end nodes and a few gateways covering an entire city [6]. These key characteristics guided our selection of this protocol.

3.2 LoRa Measurements:

In the subsequent section of this paper, we delve into the process of establishing connections between nodes and gateways across various locations within the city. To gauge the signal quality, we measured the Received Signal Strength Indicator (RSSI) and subsequently calculated the distances in meters for each measurement, mapping out the results. It's important to note that all measurements were conducted with an unobstructed line of sight between the end node and the gateway [7].

The initial step involved establishing communication between the end node and the gateway, which can be observed in Figure.5.

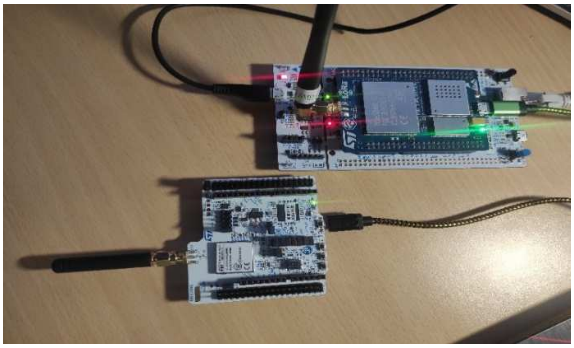

Fig.5. LoRa Gateway and End Node

This communication setup was achieved through the Internet of Things (IoT) network.

After successfully establishing the connection between the end node and the gateway, we employed two distinct approaches for obtaining the Received Signal Strength Indicator (RSSI) data. The initial method entailed accessing the RSSI within "The Things Stack" page and the communication is presented in figure 6. In contrast, the second method necessitated additional configuration to facilitate device mapping and data forwarding through an API to "Cayenne My Devices." This setup allowed us to decrypt the payload transmitted from the end node to the gateway, enabling the utilization of additional sensor data.

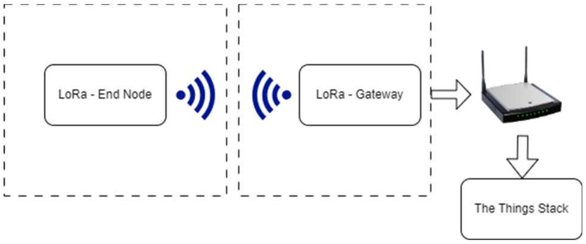

Fig.6. LoRa communication between devices and The Things Stack

Based on our measurements, we constructed the following two tables that displays the RSSI values alongside their corresponding distances from the gateway to the end node[8], where each measurement was conducted.

First set of measurements

Table 1 displays the recorded data obtained during midday within an environment characterized by moderate air pollution. To illustrate this moderately polluted air, envision a bustling, populous city where rain has not effectively cleared the fine particles from the atmosphere, resulting in an electrified atmosphere and reduced visibility for distant landmarks.

Table 1: Values of the signal in different locations in a medium polluted air

Nr.	Value	Unit	Data Type	Distance on map
1	-52	dBm	RSSI	2 m
2	-104	dBm	RSSI	300 m

3	-116	dBm	RSSI	6200 m
4	-115	dBm	RSSI	5500 m
5	-116	dBm	RSSI	6300 m
6	-113	dBm	RSSI	2160 m

In this situation, we aimed to provide six measurements conducted within the city. The initial measurement was taken in close proximity between the devices, with the highest precision achieved within the same room at a distance of 2 meters. This measurement was designed to assess connectivity and measure the RSSI value. The second measurement was conducted outside the building where the gateway had been installed, near a heavily trafficked road. The presence of noise, indicated by the substantial number of passing cars near the end node during the measurement, as well as some obstructive vegetation affecting the direct line of sight, contributed to the RSSI value as mentioned earlier. The third, fourth, and fifth measurements were conducted on the opposite side of the city, in an open field with an unobstructed line of sight. As indicated by the data, we were able to achieve distances exceeding 6000 meters in this specific scenario. In the sixth measurement, we selected an area within the city center park. In this location, factors such as traffic congestion, pollution, and the absence of a clear line of sight due to tree obstructions led to a range of 2160 meters.

The visual representation of where all the measurements were performed inside the city of Cluj-Napoca, can be observed in Figure 7.

The accompanying image provides a visual representation of the measurements taken within the city and illustrates the signal's origin.

Based on our measurements, it's noteworthy that in a direct line of sight with no obstructions along the communication path, we successfully received messages from various locations at distances exceeding 6000 meters. However, it's important to consider that this distance measurement was unidirectional, originating from the source. In the most favorable scenario, this implies a coverage radius of 6 kilometers, roughly corresponding to an area of approximately 113 square kilometers.

This implies that in a densely populated city, strategically placing a gateway, such as along a prominent boulevard, to establish an unobstructed path to the sensors, could potentially offer coverage for more than half of the city using only a single device.

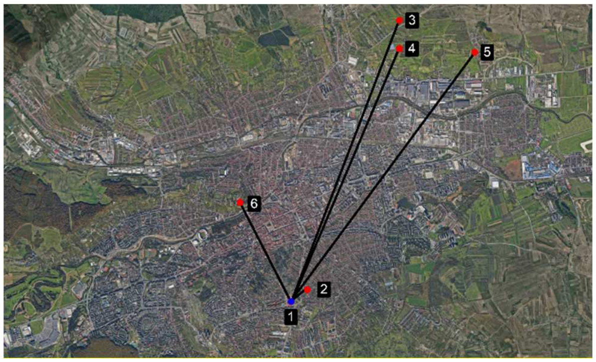

Fig. 7. LoRa Gateway and Initial End Node Measurement

Second set of measurements

For the second set of measurements, we attempted to conduct them in the same locations with some minor adjustments. However, the key difference for these measurements was that we waited for a heavy storm with significant rainfall to achieve cleaner and less polluted air. This allowed us to observe whether the RSSI values would improve or not. Consequently, we created another map depicting all the points where these measurements were carried out, as illustrated in Figure 8.

Table 2: Values of the signal in different locations in a clean air (after a heavy storm)

Nr.	Value	Unit	Data Type	Dist. on map
1	-47	dBm	RSSI	1.5 m
2	-101	dBm	RSSI	300 m
3	-115	dBm	RSSI	6200 m
4	-115	dBm	RSSI	5500 m
5	-109	dBm	RSSI	6300 m
6	-112	dBm	RSSI	2160 m
7	-113	dBm	RSSI	6600 m
8	-117	dBm	RSSI	6750 m

The first measurement took place in the same room as before, but we obtained a better result because the distance was half a meter shorter. It's worth noting that the first value doesn't provide a meaningful basis for comparison since it did not align with the original scenario. In the second measurement, the RSSI value closely resembled the initial one. This suggests that for short distances, air pollution does not significantly affect the transmitted signal.

For measurements three, four, and five, we obtained values that were either similar to the first measurement or even better. Notably, in the case of the fifth measurement, the original measurement yielded an RSSI value of -116 dBm, while the second measurement at the same location resulted in -109 dBm. This reaffirms our hypothesis that polluted air can diminish signal strength.

Additionally, we conducted two new measurements at greater distances than the original one, further substantiating that in a sufficiently clean atmosphere, the signal can travel over longer distances, thus expanding our coverage range.

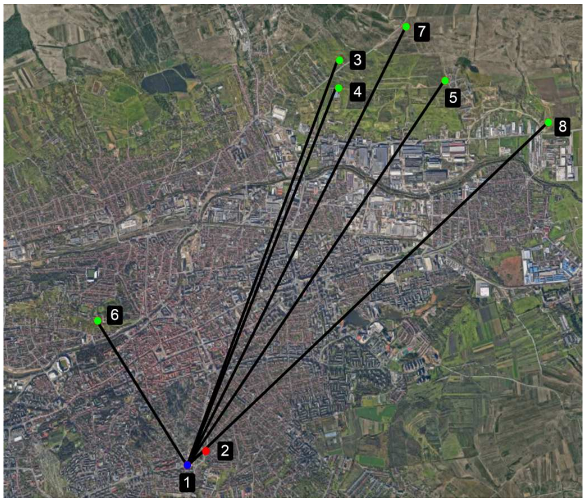

Fig.8. LoRa Gateway and End Node second measurement

It's worth noting that the precise distance measurements presented in the table were conducted on a map. In cases where the sensor's exact location isn't available or if it's in motion, we can calculate the distance between the transmitter and receiver using the following formula [9]:

Distance = 10 ^ ((Measured Power – RSSI) / (10 * N))

Here, "Measured Power" should represent the RSSI received at a distance of 1 meter between the devices, and "N" is a constant dependent on environmental factors, ranging from 2 to 4.

While we do have the capability to gauge the distance between two points using the RSSI value, there are situations where this approach may not be practical. The rationale behind this lies in the fact that the distance measurement can vary significantly from one scenario to another, contingent on factors like the value of "N," which in turn can be influenced by variables such as air pollution and ground noise (such as vehicular traffic, pedestrians, trees, and other objects).

4. FUTURE DEVELOPMENT

The aim of the third section of this paper is to deploy air quality sensors on LoRa end nodes and distribute them throughout key areas of interest within the city. This approach enables simultaneous data collection from multiple locations, facilitating a comprehensive analysis of pollution patterns in a large urban environment. To accomplish this, sensors like the BOSCH BME680 [10] gas sensor can be affixed and integrated into the end nodes.

Once the end nodes are configured and equipped with the sensors, careful consideration should be given to the strategic placement of gateways to ensure optimal coverage for all the sensors. Building on the measurements discussed in Chapter 3, the objective is to establish three gateways to cover the entirety of Cluj-Napoca, and this can be observed in figure 8. This well-thought-out gateway positioning will streamline data collection and analysis, aiding in the identification of areas with elevated pollution levels that require attention and remediation.

Fig.8. LoRa Gateway possible coverage for Cluj-Napoca

Understanding the relationship between air quality and transmission range underscores the need for ongoing monitoring and maintenance of LoRa networks[11]. This knowledge can contribute to sustainable and resilient network operations.

Further research and experimentation in varying environmental conditions can refine our understanding of LoRa technology's performance and guide the development of adaptive transmission strategies, ensuring robust performance under changing air quality conditions.

5. CONCLUSIONS

The initial section of this paper entails an examination of air quality, both indoors and outdoors, to establish the key parameters for a comprehensive air quality assessment.

For indoor air quality analysis, the critical elements to monitor include:

- Carbon Dioxide
- TVOC (Total Volatile Organic Compounds)
- PM2.5 (Particulate Matter 2.5)
- Carbon Monoxide

Conversely, for outdoor air quality analysis, the crucial parameters to observe encompass:

- TVOC (Total Volatile Organic Compounds)
- PM2.5 (Particulate Matter 2.5)
- Nitrogen Dioxide
- Carbon Dioxide
- Temperature
- Humidity
- Air Pressure

Frequently, these elements exhibit interdependencies, enhancing the precision of our predictions regarding potential values.

The LoRa measurements have unveiled a significant revelation: when there's a clear line of sight, messages were successfully received from various locations, spanning distances well beyond 6000 meters. However, it's crucial to emphasize that this distance measurement was one-way, originating solely from the source. Consequently, this technology holds the potential to effectively blanket nearly the entire city's expanse with only a minimal number of devices, opening up promising prospects for extensive coverage.

Another noteworthy observation is the substantial impact of air pollution on signal quality. The greater the level of air pollution, the more challenging it becomes for the signal to traverse longer distances. As evidenced in the latter portion of this paper, in scenarios with significantly reduced air pollution, we were able to transmit information over 1000 meters farther than in situations with moderate air pollution. (In essence, we extended the range from 6000 meters to nearly 7000 meters.)

The improved transmission capabilities in clean air open doors for diverse applications, including environmental monitoring, precision agriculture, and smart city infrastructure. These applications can thrive in areas where air quality is closely managed.

6.ACKNOWLEDGMENTS

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Analiza calității aerului în medii inconjuratoare, folosind o rețea Lora.

Abstract: Această lucrare realizează o analiză și o comparație a calității aerului în diverse medii, acoperind medii interioare și exterioare. Obiectivul este de a identifica căi de îmbunătățire a bunăstării și de a informa organizațiile mai mari despre prioritățile esențiale de monitorizare pentru aer optim respirabil. Lucrarea cuprinde trei secțiuni principale. Segmentul inițial se concentrează pe analiza calității aerului și pe utilizarea senzorilor pentru măsurători interioare și exterioare. Partea ulterioară elaborează transmisia de date prin protocolul LoRa Wan, utilizând un gateway ST și noduri terminale pentru a transmite datele analizate pentru procesare centralizată, cu o explorare specială a intervalelor de transmisie LoRa în zonele urbane. Secțiunea finală prezintă evoluțiile viitoare și investigațiile cheie folosind diferiți senzori.

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