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Article

Long Range Radio Communication for Urban Sensor Networks

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SUMMARY
Society's technological landscape is growing rapidly. In the era of smart cities, wireless technologies and their novel applications have begun to permeate almost every aspect of urban life. From controlling traffic signals to monitoring air quality, the Internet of Things (IoT) has emerged as a field with much potential, but some challenges. Being a relatively new field of research, there is much more to discover about IoT. Before developing proposed applications of the technology in smart cities, it is imperative to fully understand how IoT-based technologies work, including Long-Range Radio Communication (LoRa). This study aimed to test the feasibility of LoRa devices in the bustling, urban environment of New York City to identify limitations in the technology. Using a testbed containing two LoRa radio modules and a monopole antenna, we determined the relationship between the distance of the radios and received signal strength to be inversely proportional. We hypothesized that Received Signal Strength Index values from the transmissions could be used to determine the maximum range. Our results supported this hypothesis by determining the maximum range to be 250 meters. In addition, we found that the relationship followed an exponential decay curve. These findings will help future researchers further understand the limitations of LoRa in urban sensor networks and ultimately create stronger IoT smart city applications.

INTRODUCTION
As technology in society rapidly advances, the applications for new innovations become more widespread. Network communication technology, which allows devices to communicate independently with each other, has become vital to modern-day life, especially in cities where new technological devices are used daily. In fact, the Internet of Things (IoT) has emerged as a way of conceptualizing the digitally connected universe of billions of physical devices that collect, process, and share data with each other (1). Wireless Sensor Networks (WSNs) are a subset of IoT that use many self-controlled nodes to process and send information to a central unit (2).

Within the concept of IoT, Long Range Radio Communication (LoRa) technology has been implemented in devices to streamline the transmitting and receiving of messages. LoRa was found to be extremely well suited for IoT applications due to its wide coverage, long range, and low battery consumption (3). Therefore, it has increasingly garnered attention, especially for uses in urban environments where life is much more crowded and densely-populated. As a result, a multitude of applications have been proposed for LoRa-based WSNs in urban settings. For example, LoRa-based technology has been proposed in smart street lighting systems to detect faults instantly and more accurately, reducing the high costs of manually maintaining street lighting (4). It has also been proposed for monitoring real-time Particulate Matter (PM) concentration for air quality indications in urban areas (5).

Along with other proposed uses in home sensors, vehicular systems, climate sensors, and water sensors, LoRa-based technology is just now being recognized for its potential to improve the quality of life in cities. What is still missing to fully implement the technology, however, is the extensive testing of LoRa-based WSNs as a new, interdisciplinary field (6). A characterization of LoRa's capabilities would help bring these ambitious proposals into perspective by providing an accurate sense of the maximum possible range in controlled urban environments.

In this project, an urban wireless testbed was developed on Columbia University's Morningside Heights campus in New York City (NYC), one of the world's biggest hotspots for LoRa-based applications due to its densely populated environment. This testbed featured two LoRa radios, operating at the US LoRa standardized frequency of 915 MHz. The radios sent packages from the transmitter to a receiver while simultaneously collecting the Received Signal Strength Index (RSSI) value, a standard indicator in the field of wireless communication of the power level received from a transmitted signal. We hypothesized that the RSSI values could be used to determine the maximum range of the technology in urban sensor networks, which found to be approximately 250 meters. These findings will inform how proposed solutions of LoRa applications in urban settings should be designed, leading to a holistically stronger understanding in the field of urban sensor networks.

RESULTS
In order to test the feasibility of LoRa radios, we hypothesized that range would be one of the most crucial components to understand. We tested LoRa radios in New York City, a densely populated urban environment where the need for adaptable LoRa-based IoT technology is strong. To determine the true maximum range, the LoRa radios were tested in a near ideal path: a direct line of sight on Columbia University's campus. The test began with the receiver and transmitter right next to each other, where the signal connection was maximized and the RSSI value was around 0 decibels per milliwatt (dBm). A RSSI value at 0

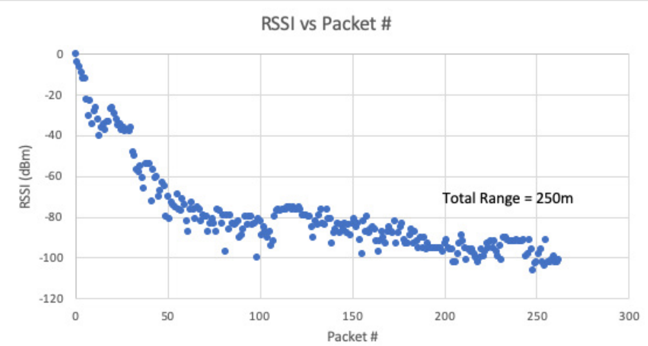

Figure 1: Inverse Relationship of Packet # versus RSSI values

dBm is the strongest connection, with a power level of 1 mW, meaning no antenna or power loss occurred during the transmission. Decibels per milliwatt represents the ratio of the power level from the transmitted signal, which decreases as the signal weakens. As the range between the transmitter and receiver radios consistently widened with the increasing packet number marking the current transmission number, the corresponding RSSI values were recorded. We deemed the final range when the receiver could no longer detect a signal from the transmitter and the RSSI value neared -110 dBm, the threshold often associated with no signal (7).

In total, 263 packets were transferred from the transmitter to the receiver. Those packets were graphed against their corresponding RSSI values (**Figure 1**), where the points resemble an exponential decay function ($y = ae^{-t}$) in which the first few RSSI values were the highest and decreased throughout the test. Bearing the assumption that the receiver was moving at a constant speed throughout the trial, the packet number is directly proportional to the distance between the two radios. In other words, as distance between the transmitter and receiver increases, the signal strength decreases because the signal gets more diluted by space and other interferences in the path. Thus, this indicates an inverse relationship between distance and signal strength.

The natural log of the points (ln(y) vs -t) were graphed to model the exponential decay function (**Figure 2**). The linearized exponential decay produced points clustered around the trendline $y = 0.4318x + 2.3231$, resulting in a strong exponential decay correlation ($R^2 = 0.8524$) between signal strength, packet number, and distance.

The standard deviations of the RSSI values at each point differed dramatically in different parts of the graph; for example, the points at the 100th packet were widely scattered but became a tight cluster around the 110th packet. The final range for the 915 MHz LoRa Radio Modules, recorded at the point where the RSSI value reached -110dBm, we determined to be around 250 meters through a GPS-tracking map of the path (**Figure 3**).

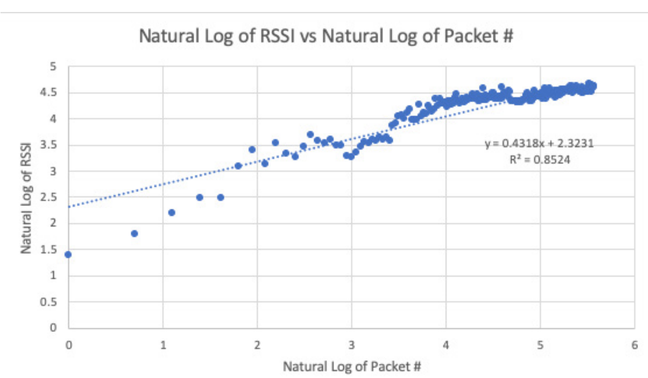

Figure 2: Linearized Exponential Decay Curve (ln(y) vs. x)

DISCUSSION

The packet number, resembling distance in meters, was graphed versus RSSI (**Figure 1**). Supporting the hypothesis, the maximum possible range of LoRa radio transmission was determined from the graph to be about 250 meters. While the points generally follow an inversely proportional shape, there are large deviations in the RSSI values especially around packet 100 and 225. In both cases, the values after these large spreads seemed to be very precise and stronger than it had been, suggesting some sort of recalibration internally from the radio.

While this project revealed the feasibility and relationship of components in LoRa technology, a series of limitations encountered in the experiment may have impacted the results and the experiment's reproducibility. One limitation occurred with the monopole antenna, a simple stripped wire, which was effective but not ideal for transmitting over long ranges. Another limitation was the public testing environment which was not completely in a clear line of sight and affected by people walking in between the signal's path, restricting the full potential of the maximum range obtained.

In future studies, using active impedance matching antennas, which have been shown to perform well in changing environments (8), might help obtain more accurate results. Using a better radio frequency (RF) module may have increased the wireless communication's efficiency. Additionally, setting a higher power to those devices would increase signal strength and maximum range.

Overall, this analysis of LoRa's feasibility in an urban environment is important as it highlights the flaws within LoRa technology, leading future researchers to better understand how proposed LoRa applications should be designed using

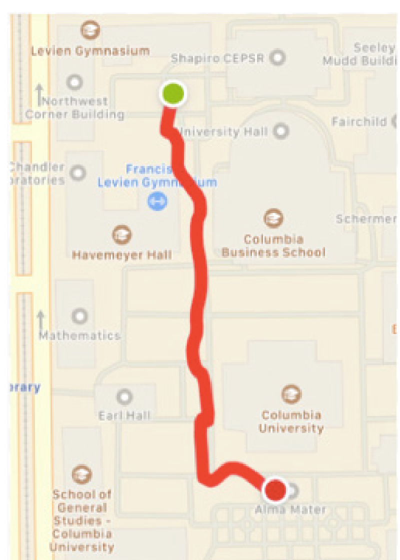

Figure 3: GPS-Tracked Path of Transmitter on Columbia University's Morningside Heights campus in New York City

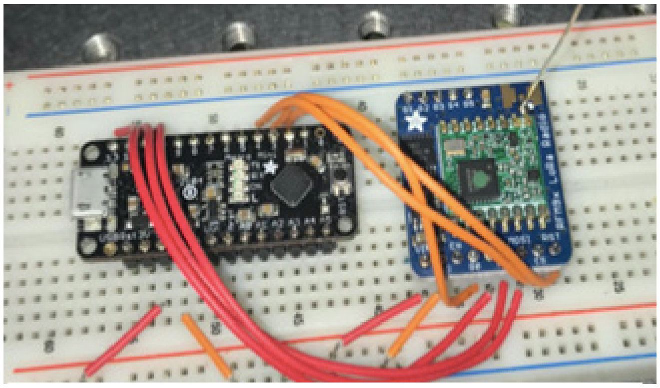

Figure 4: Photograph of Transmitter/Receiver Mechanism containing microprocessor Metro Mini and LoRa Radio on a Breadboard

stronger matched antennas and RF modules. Ultimately, the findings impact not only the field of LoRa communication, but also IoT Wireless Sensor Networks which rely on LoRa implementation in smart city devices.

METHODS

Hardware Configuration

To measure LoRa technology's feasibility in urban settings, a unique testbed containing two LoRa RFM 9x 915 MHz Radio Modules and two Metro Mini microcontrollers was created. The chips were soldered onto headers and placed on a breadboard (**Figure 4**). A monopole antenna was designed using the following equation to calculate wavelength from frequency (9):

$$\lambda = c/f$$

$$\lambda = (3.00 * 10^8)\frac{m}{s}/(9.15 * 10^8)Hz$$

$$\lambda = .328\, m = 32.8\, cm$$

$$\frac{\lambda}{4} = 8.20\, cm$$

The simple monopole antenna, *λ/4* or 8.20 cm long, was soldered onto a conductive ground plane similar to the design in **Figure 5**. The signal pin from the antenna was then used to transfer and receive signals from the radios. The radio's ground (GND), power (VIN), and Serial Peripheral Interface (SPI) logic pins were connected to the Metro Mini to analyze the obtained information. Although the physical setup of the two configurations was the same, the code sent to the radios was differentiated between the receiver and the transmitter.

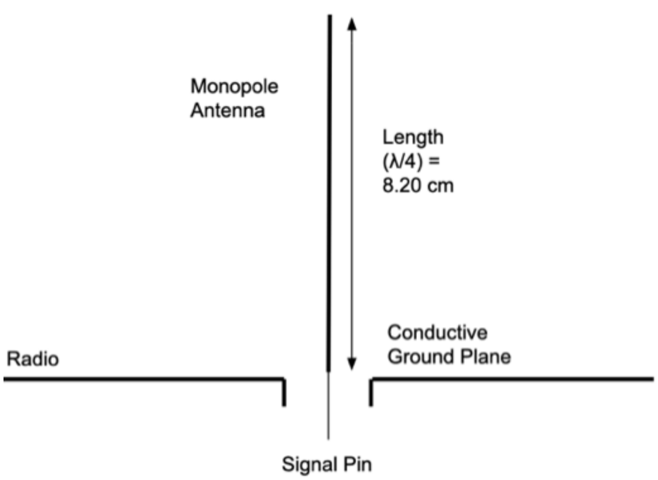

Figure 5: Design of the Monopole Antenna with Length *λ/4* for Packet Transmission

Algorithm

Arduino IDE Software was used to program the Metro Mini. Shown in the block diagram, the transmitter code loads necessary packages, defines the proper ports, and resets the radio before checking if it is fully initialized (**Figure 6**). Once fully initialized, the loop of the program is entered where the radio first creates a packet that contains the message "Hello World" along with the nth iteration of the loop. It sends the packet, waits for acknowledgement that it was received, and searches for a reply message from the receiver. Once a reply message is received, the message is sent through an RS232 serial connection to the device running the program, printing the message and the corresponding RSSI value of the transfer. RSSI values start at 0 dBm being the strongest signal and decrease as the signal becomes weaker. A paper analyzing smart home WiFi signals determined that the RSSI values for WiFi connections can fluctuate anywhere between -60 and -80 dBm (10). These actions repeat continuously approximately every five seconds while the number in the "Hello World" packet will increase by one, accompanied by a new RSSI value on the Serial Monitor.

The receiver code has the same general structure of initializing the radio at the start of each experimental run, but in the main loop of the program, the order of the commands is reversed with the radio first searching for a packet and then sending a reply. The transmitter and receiver codes run simultaneously to ensure a complete and accurate test.

Procedure

This experiment was carried out on Columbia University's Morningside Heights campus in NYC. The packets were transmitted at a frequency of 915 MHz, the standard for the radios. After the configuration was assembled and the code was uploaded to both radios, the radios were carried, walking

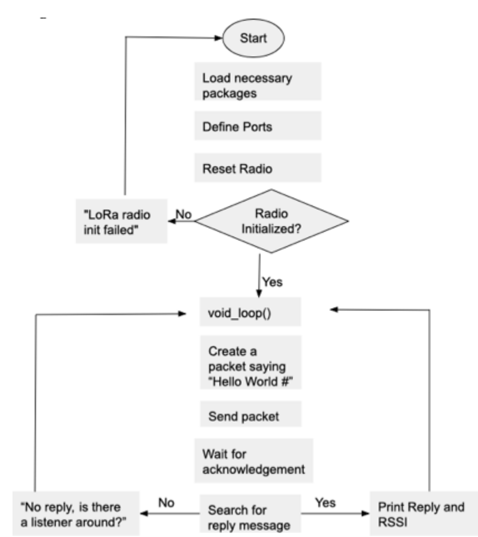

Figure 6: Overall Flowchart Block Diagram of Transmitter Radio Code

on foot at a constant speed until the signal could no longer be detected. The test was repeated two times although only the last test was used for data processing. In total, each trial lasted around four minutes.

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REFERENCES

1. Jorke, Pascal, *et al*. "Urban Channel Models for Smart City IoT-Networks Based on Empirical Measurements of LoRa-Links at 433 and 868 MHz." *2017 IEEE 28th Annual International Symposium on Personal, Indoor, and Mobile Radio Communications (PIMRC)*, 2017, doi:10.1109/pimrc.2017.8292708.
2. Jais, Ilman, *et al*. "Received Signal Strength Indication (RSSI) Code Assessment for Wireless Sensors Network (WSN) Deployed Raspberry-Pi." *2016 International Conference on Robotics,* Automation and Sciences (ICORAS), 2016, doi:10.1109/icoras.2016.7872618.
3. Ouanounou, Emmanuel, *et al*. "LoRaWAN & MQTT: What to Know When Securing Your IoT Network." Security Boulevard, 15 Oct. 2020, securityboulevard.com/2020/10/lorawan-mqtt-what-to-know-when-securing-your-iot-network/.
4. Bingol, Ezgi, *et al*. "A LoRa-Based Smart Streetlighting System for Smart Cities." *2019 7th International Istanbul Smart Grids and Cities Congress and Fair (ICSG)*, 2019, doi:10.1109/sgcf.2019.8782413.
5. Yun, Jaeseok, *et al*. "Real-Time PM Monitoring System Based on oneM2M IoT Platform and LoRa Networks." *2019 IEEE Sensors*, 2019, doi:10.1109/sensors43011.2019.8956570.
6. Fernandes, Rui, *et al*. "On the Real Capacity of LoRa Networks: The Impact of Non-Destructive Communications." *IEEE Communications Letters*, vol. 23, no. 12, 2019, pp. 2437–2441., doi:10.1109/lcomm.2019.2941476.
7. Mammen, S. "Making Sense of Signal Strength/Signal Quality Readings for Cellular Modems," *Industrial Networking Solution Tips & Tricks*, blog. industrialnetworking.com/2014/04/making-sense-of-signal-strengthsignal.html
8. Laxpati, S., and R. Mittra. "Antenna Impedance Matching By Means Of Active Networks." *Electrical Engineering Research Laboratory University of Illinois,* Jan. 1962, doi:10.21236/ad0291766.
9. Albarracín, Ricardo, *et al*. "On the Use of Monopole Antennas for Determining the Effect of the Enclosure of a Power Transformer Tank in Partial Discharges Electromagnetic Propagation." *Sensors*, vol. 16, no. 2, 2016, p. 148., doi:10.3390/s16020148.
10. Jiang, H, *et al*. "Smart Home Based on WiFi Sensing: A Survey." *IEEE Access*, 7 Mar. 2018, p. 2., doi:10.1109/ACCESS.2018.2812887.