# Performance Evaluation of Off-grid Mesh Network Communication using goTenna and Meshtastic

Gwangyeok Kim*, Keonwoo Lim†, Sujee Noh*, Younguk Maeng‡,
Baylasan Al Shubbar§, Xavier Lopez§, and Anthony Smith§

*Department of Computer and Software Engineering, Chonnam National University
†Department of Computer Science and Engineering, Kyonggi University
‡Department of Software Engineering, Soongsil University
§Department of Computer and Information Technology, Purdue University
Email: *{205334, 204654}@jnu.ac.kr, †kwlim1120ss@kyonggi.ac.kr,
‡aod8948@soongsil.ac.kr, §{balshubb, lopezx, ahsmith}@purdue.edu

***Abstract*—Off-grid mesh communications have the potential be a valuable aid for rescue operations in the aftermath of natural disasters that destroy infrastructure beyond repair. These mesh networks utilize wireless modulation techniques specialized for long-distance signal transmission, albeit at a lower data rate. This research compares two mobile radio systems, goTenna and Meshtastic, that function as external antennas with Bluetooth connectivity and GPS location transmission for text-based communications. While both systems have a similar GUI and complementary applications, there is a significant difference in price and accessibility. goTenna is a commercial solution with a proprietary protocol and frequency bands, while Meshtastic is an open-source project that uses license-free LoRa frequency. Conducting analysis of these two mobile mesh networking systems in various scenarios and environments is important as it generates informative feedback to rescue teams in need of mobile communication that is not possible via traditional radio or network technologies.**

***Index Terms*—LoRa, UHF, MCU, RSSI, GPS, mesh network, hop count, relay, Fresnel zone, goTenna, Meshtastic**

## I. Introduction

During natural disasters, the agile deployment of an emergency communication system is crucial when cellular network infrastructure is damaged. Without such a system, rescue efforts and relief operations may be hindered [1]. For example, Hurricane Sandy broke roughly 25% of cell towers across 10 states in 2012 [2], while Hurricane Harvey, Maria, Irma, and Florence caused over 3,000 facility damages and resulted in over 300 billion dollars in losses in 2017-2018 [3]. Hurricane Maria severely damaged essential parts of Puerto Rico's infrastructure, leaving 95% of the island without cell phone service [4].

Fiber and cellular networks have not been adequate for communication in the aftermath of natural disasters. Instead, a decentralized off-grid communication network is necessary for both robustness and ease of deployment. Simple and battery-powered Internet-of-Things devices can be instrumental in finding help and essential resources in such situations. These devices should be lightweight, long-lasting, cost-effective, and highly mobile to provide maximum coverage range.

There are various radio modulation technologies that aim to achieve the aforementioned criteria. Long Range Radio (LoRa) is particularly gaining awareness among users wanting to send small amounts of data at short intervals over long range on embedded systems [5]. Lora is a proprietary spread spectrum modulation scheme that is derivative of chirp spread spectrum modulation (CSS) [6]. Since LoRa transmits over license-free megahertz radio frequency bands, it is possible to configure inexpensive radios using micro controller units (MCU) with LoRa module and small antennas. This flexible accessibility allows various active community-driven projects.

Meshtastic is an open source project, providing firmware and complementary applications for LoRa radios as a long range off-grid communication platform in areas without existing or available communications infrastructure [7]. Meshtastic is also capable of forming a mesh network, each configured board being a node in a set area due to its mesh broadcast algorithm [8]. The project offers a user friendly out-of-the-box experience with a web browser based firmware flasher and an intuitive application design [9]. The firmware is installed on an ESP32 board, which is a type of MCU that has LoRa functionality. The board is then connected to a smartphone via Bluetooth. The application enables text-based communication and GPS location sharing with others through the use of LoRa frequency.

goTenna, on the other hand, operates on its own proprietary mesh network protocol called Aspen Grove, named after an interconnected root system of a single aspen tree. This technology allows long-range, short-burst mobile mesh networking through a unique approach that uses a novel zero-control-packet to achieve optimal network efficiency [10]. It broadcasts information and creates a decentralized mesh network, letting users to send texts messages and to share GPS locations in group and private chats via its own complementary application called goTenna Pro. The coverage of the mesh network can be expanded by hopping through other goTenna devices within range. goTenna devices function as an antenna; they connect to smartphones via Bluetooth as well without the need of Wi-Fi or cellular coverage, and are primarily used in military and in emergency rescues [11].

Both goTenna and Meshtastic exist to circumvent the infrastructure-reliant nature of the conventional communications system. Albeit the seemingly close resemblances between goTenna and Meshtastic, there are a number of differences that distinguish one from the other. The most notable aspect is the fee; a goTenna Pro X is priced at $900 as it is a commercial solution, while ESP32 boards with a built in GPS module cost around $40 per unit. Distinct frequency bands usage is yet another differing factor. goTenna transmits over licensed very high frequency (VHF, 142 to 175 MHz) and ultra high frequency (UHF, 445 to 480 MHz), rather than license-free LoRa frequency (915 MHz).

Therefore, an in-depth performance evaluation of these two mobile mesh networking systems is important as it provides useful feedback to rescue teams who rely on communication that is not possible via traditional radio or networking technologies.

## II. Related Work

Prior researches have evaluated the performance of the LoRa protocol, goTenna Pro X, and Meshtastic in diverse scenarios. Based on these related works, the proposed approach can be compared to the three technologies to determine its effectiveness in providing reliable communication in situations where wired and wireless networks are not available.

### A. LoRa Network performance evaluation

Carlsson *et al*. [12] demonstrated the performance, possibilities and limitations of LoRa in urban, dense forest and open space. In an open space environment, a strong signal was maintained up to a distance of 1100m which could potentially connect to several more kilometers. Though SNR(Signal-to-nose) was recorded in negative numbers on 500m, the packets of LoRa could be received and read, if at all which meant no interference with LoRa connection. However, in an urban environment, a reduction of 32% in signal quality was observed at a distance of 300m.

Vithayathil *et al*. [13] estimated performance of LoRa based wireless network for disaster rescue operation assuming specific circumstance such as indoor, outdoor and weather condition. The signal strength became weak for distance beyond 1.5km in plain are of outdoors. The RSSI (Received Signal Strength Indicator) value in urban was highly influenced by height as approximately 30 dBm difference for 200m distance. When it comes to transmission power, the signal strength tend to be higher when transmission power increases. The paper of Vithayathil coped with evaluating performance of LoRa PHY layer under specific condition, but this document compares performance of two networks with the different frequencies based on RSSI.

### B. goTenna Network performance evaluation

Zimbelman and Keefe [14] assessed VHF-based mesh network of goTenna using connection proportion while one mobile goTenna passed through the zone 5 stationary goTenna set up. 6 connectivity level which all nodes were linked each other accounted for the highest portion, roughly 32.6%. On the one hand, 1 connectivity level which any node were not to linked to moving node occupied 18.2%, the second highest ratio. Unlike the research of Zimbelman, this document conducted experiment without moving device.

Ramanathan *et al*. [10] described architecture and protocol of goTenna. Furthermore, this research showed performance difference of ECHO, the protocol used for broadcasting, by comparison with other protocols such as Flooding and Multi-Point Relay in aspect of packet delivery ratio (PDR), average battery and worst battery. The testbed for this experiment consisted of 12 goTennas using VINE and ECHO with attenuators in the middle of each devices to control communication. The researchers gathered information about the packet delivery rate while switching the topology of the testbed with attenuators from parking lot topology to sparse topology. The result showed ECHO surpassed both Flooding and Multi-Point Relay in several criteria, transferring roughly 26% more packets at 50 nodes. Specific evaluation related to comparing VINE, protocol used for unicasting, with AODV was uncovered because of space constraints.

### C. meshtastic Network performance evaluation

Suryadevara *et al*. [15] explained the implementation of meshtastic in detail and analysed the data which is attained while broadcasting a 58.4 kB text file with variable packet size between 33 bytes to 256 bytes. The result showed meshtastic has the lowest delay and highest throughput broadly in condition of (bandwidth=500, error correction rate=5, spreading factor=7).

## III. Methodology

This section outlines the impact of operating frequency, power level, and bandwidth on the performance of goTenna Pro X and Meshtastic configurations. goTenna Pro X and LILYGO TTGO T-Beam V1.1 were used for testing.

### A. goTenna configuration

goTenna devices were provided with UHF antennas, we picked up an arbitrary starting point in the given range. It was recommended by the official guide from goTenna to set power output and bandwidth to the maximum value for the optimal performance, and the channel spacing for 11.8 kHz bandwidth to 0.025 MHz, the range of 300 MHz to 3 GHz defined by the International Telecommunications Union. Table 1 depicts a frequency set used on the devices. The number of each control and data channels were also specified as 3 and 13 respectively [16].

TABLE I
FREQUENCY SET OF GOTENNA DEVICES

| *Option* | *Value* |
|---|---|
| Power Level (watts) | 5.0 |
| Bandwidth (KHz) | 11.8 |
| Control Channel (MHz) | 474.000 |
| | 474.025 |
| | 474.050 |
| Data Channel (MHz) | 474.075 |
| | 474.100 |
| | 474.125 |
| | 474.150 |
| | 474.175 |
| | 474.200 |
| | 474.225 |
| | 474.250 |
| | 474.275 |
| | 474.300 |
| | 474.325 |
| | 474.350 |
| | 474.375 |

### B. Meshtastic configuration

Setting up a Meshtastic radio requires a Meshtastic supported microcontroller unit (MCU). The latest v2.0.20.7100416 alpha firmware was installed on LILYGO T-Beam boards through the web based firmware flasher. Moreover, 915 MHz Antenna with 5 dBi gain were installed on the boards. Table 2 and 3 describe specifications of the board and radio settings for the meshtastic application.

TABLE II
SPECIFICATION OF LILYGO TTGO T-BEAM V1.1

| *Function* | *Details* |
|---|---|
| ESP32 | Lastest ESP32 Version: REV1 |
| | WiFi |
| | Bluetooth |
| LoRa | Operating frequency : 915 MHz |
| | Transmit Power : +20 dBm |
| | Frequency Error : +/-15 kHz |

TABLE III
MESHTASTIC SOFTWARE CONFIGURATION

| *Option* | *Value* |
|---|---|
| Power level (watt) | 0.1 |
| Bandwidth (kHz) | 250 |
| Frequency (MHz) | 915 |
| Data rate (kbps) | 0.67 |
| SF/Symbol | 11/2048 |
| Coding Rate | 4/8 |

## IV. EXPERIMENT

goTenna Pro X and Meshtastic were tested in two different environment settings, on a university campus and on a farm. Two different location highlights the contrast between urban and rural environments. The human populations, buildings, and infrastructure are greater in urban areas, therefore, LoRa communication is disrupted by buildings, infrastructure, and motor noises. Z A Tan *et al.* [17], tested LoRa communication in urban, suburban, and rural areas, with results showing that rural areas had better radio propagation and maximum distance from a LoRa receiver. Moreover, environmental factors such as temperature, humidity, rain, and foilage can also affect LoRa communication [18]. On the other hand, farms are less interfered with radio waves because of fewer structures.

The project aims to test the performance for both devices. While testing on campus may affect results, the test was implemented, disregarding infrastructure disturbances. Due to limited testing areas near the campus, the parking lot was the optimal choice for testing, which allows to create different testing scenarios. For instance, moving to other places such as roofs, inside the parking lot, outside the parking lot, and tunnels. The second part of the project is to determine the maximum communication range on the farm, a wide open space with less infrastructures.

### A. Testing Environment

*1) In Campus:* The preliminary experiment was tested with three nodes located in parking lots. The endpoints were roughly 770m apart from each other, with a relay node positioned in between endpoints as shown in Figure 1. In Figure 2 [19], one of the endpoints (P3) was fixed while the other (P1) changing various positions such as on the roof, inside and outside the parking lot, and tunnel. During the test in the tunnel, goTenna Pro X and Meshtastic had weak antenna signals, thus resulting failed radio communication. Though not entirely unexpected, the relay node (P2) moved to different positions within the parking lot to receive the message, but it did not successfully receive any messages. Additionally, the relay node was only about 200m away from P3, which made it uncertain whether the message was relayed to the endpoints. This experiment had unexpected challenges, and thus had to alter the process slightly.

The following experiment was conducted with four nodes to form a mesh network. To improve the results of the previous experiment, an additional relay node (P2) was placed in the same parking lot, as illustrated in Figure 4 [20]. The fixed endpoints (P1, P4), located in the tunnel and on the roof respectively, were connected by the relay node (P3), which was positioned inside the building. During the experiment, the new relay node (P2), was moved from the roof to inside and outside the parking lot. Throughout the experiment, the main goal was to verify if it could send messages from tunnel to other nodes. In addition, the experiment allowed for a close examination

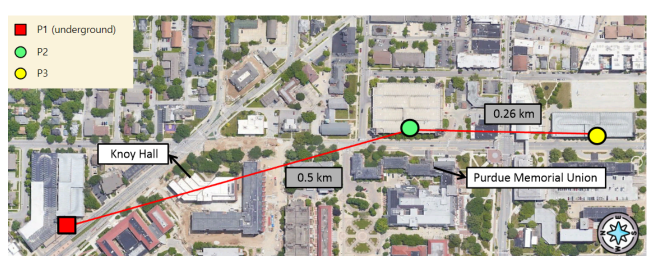


Fig. 1. Preliminary test map in campus

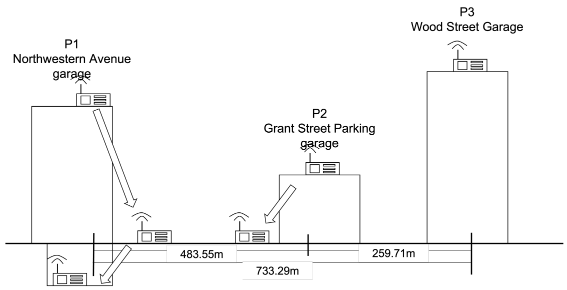


Fig. 2. Preliminary test diagram in campus

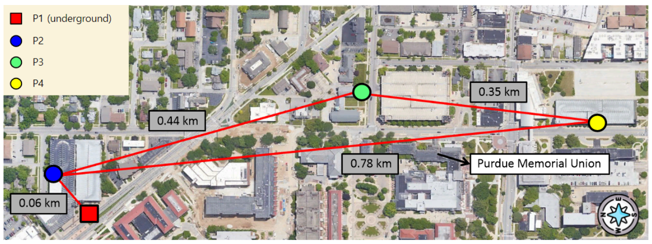


Fig. 3. Following experiment map

of the Fresnel zone and the differences in frequency bands as evident from the results.

Radio waves near the surface of Earth propagate in slightly curved paths due to refraction in the atmosphere [21]. This forms a Fresnel zone: an ellipsoidal region of space between two antennas. When the refraction occurs in such a way that a radio wave is received but is out of phase, the power of the received signal is reduced as two waves cancel each out. The Fresnel zone needs to be as clear from any sources of obstruction and reflection as possible in order to minimize the signal loss. The primary Fresnel zone is required to be at least 60% clear of any obstruction to ensure the highest performance of wireless link [22].

For this experiment, lowband UHF was used for goTenna rather than VHF. In the buildng, UHF performs better than VHF when penetrating metal, concrete, and densely wooded areas, therefore, it reaches further through the building[cite needed].

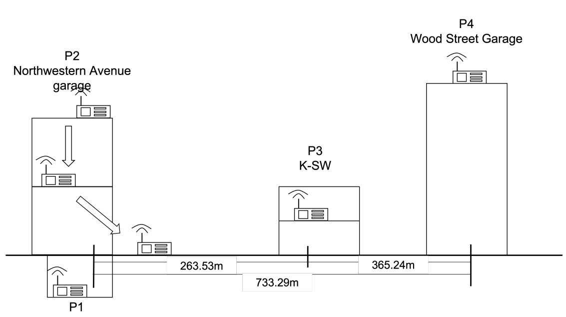


Fig. 4. Following experiment map

*2) Farm:* The objective of this experiment was to determine the furthest distance from point to point communication, instead of simulating an disaster situation like in the past. This experiment was conducted on a farm, located roughly 30 minutes away from the campus. It was wide and obstruction-free with a clear line of sight. While considering a fair way to conduct an experiment in the same conditions, two people was fixed in the starting point in the field.

### B. Testing Method

*1) In Campus:* As indicated in Figure 4, the endpoints and P3 are fixed in location, with P1 in the tunnel, P3 in the building, and P4 on the roof. Furthermore, the P2 was initially on the roof and the position was changed afterwards. Before the experiment, mobile network such as WiFi and Cellular were turned off, and held the antennas above the chest. The test consists of three steps. (1) Send a broadcast chat for three times (2) Send a private chat for three times (3) Record the results and change the location of P2. During the broadcast chat, P1 sent a message and the other nodes replied back. If a message from P1 was lost or not received at other nodes, the results were recorded. After broadcasting three times, private messages were sent from P1 to P4, a point to point communication. Finally, P2, the new relay node which was initially positioned on the roof, switching its location from roof to inside and outside the parking lot after step (1) and (2).

*2) Farm:* This experiment is conducted to understand the maximum communication range, a point to point communication for both devices. The fixed endpoint remained stationary, one equipped with goTenna and the other with Meshtastic, while the other two traveling in one direction. Every 5 seconds, a broadcast message was sent from the fixed endpoint, and a reply was sent back when the message was received. The communication continued until the endpoints lost connection. The moving endpoint would move closer to the starting point until connection was reestablished. Once the point of successful connection was identified, the location and maximum range was recorded. By using this method, a fair experiment with goTenna and Meshtastic was possible and a reliable data was collected.

### C. Data Collection

The two nodes at the edge are endpoints, placed with an iOS smartphone to collect the data because goTenna Pro X

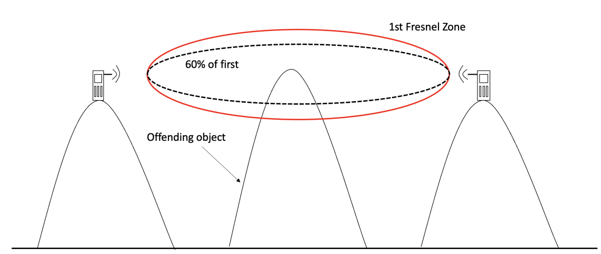


Fig. 5. Fresnel zone diagram

application for iOS supports an enhanced diagnostic log as shown in Figure 7 [cite needed], providing more information than Android. The other nodes are located between the end-points to act as relays. For Meshtastic, PuTTY, a popular open-source terminal emulator[cite needed], was used by connecting LILYGO TTGO T-BEAM board to the laptop via USB port. After that, as depicted in Figure 8, the data logs are accessed by entering serial lines and baud rate in PuTTY.

Fig. 6. goTenna Pro X and enhanced diagnostic log on iOS smartphone

Fig. 7. Meshtastic log with PuTTY on laptop

## V. Result

This section presents the findings of an analysis conducted on two mesh radio products. The study evaluated the performance of these products in various environments and scenarios.

### A. *In Campus*

*1) P2 on the rooftop:* When the relay node was positioned on the rooftop, the study results showed that both systems had similar performance, with all messages being received. However, goTenna had higher RSSI values. The private messages were also relayed without the relay node having access to the content.

*2) P2 on the third floor:* When the relay node was placed on the 3rd floor of the parking lot, goTenna had better performance than Meshtastic. The RSSI values were higher, and the messages were delivered more reliably. The endpoint on the roof did not receive any messages directly from the 3rd floor. Instead, all messages from the tunnel were passed along by the relay node.

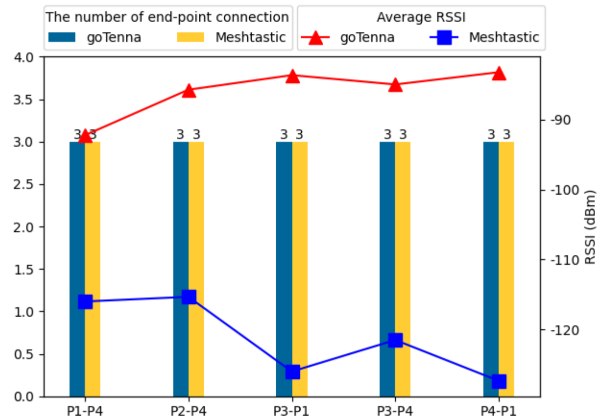


Fig. 8. Average RSSI value of broadcast chat on the rooftop

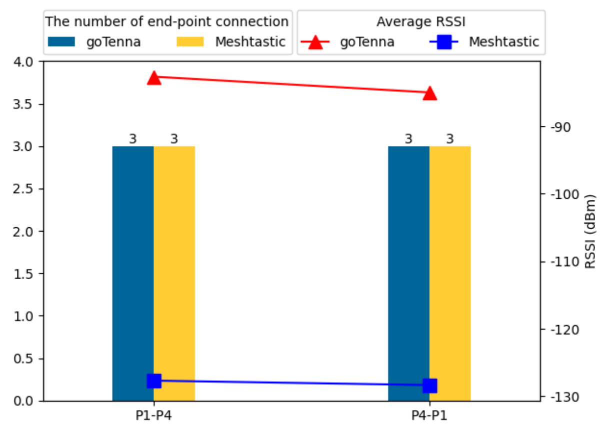


Fig. 9. Average RSSI value of private chat on the rooftop

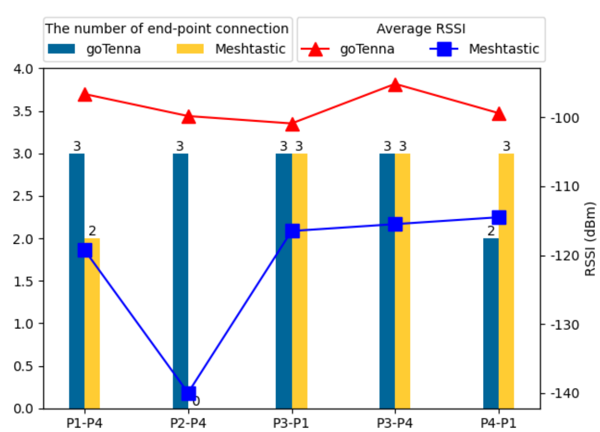


Fig. 10. Average RSSI value of broadcast chat on the thrid floor

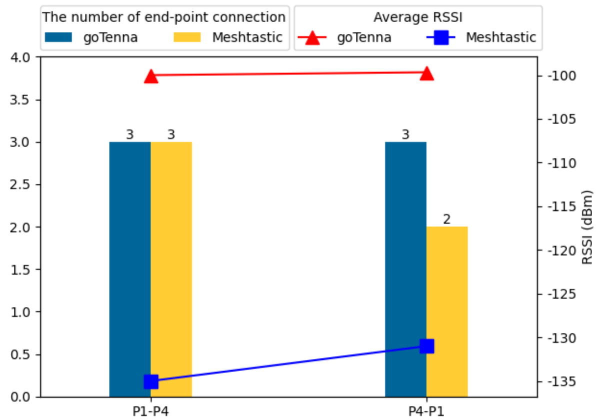


Fig. 11. Average RSSI value of private chat on the third floor

*3) P2 on the ground:* When the relay node was on the ground, there was a significant difference in the RSSI values between communications from ground to roof and roof to ground.

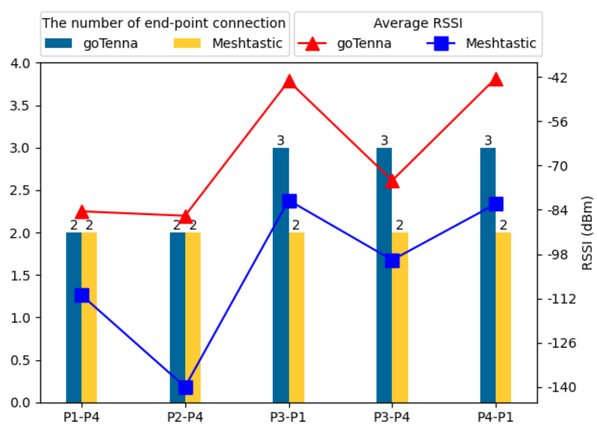


Fig. 12. Average RSSI value of broadcast chat on the ground

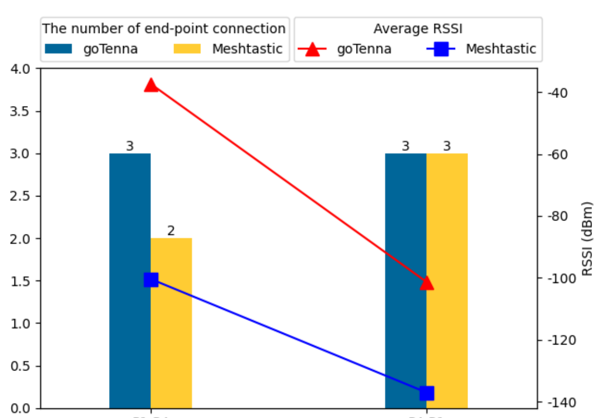


Fig. 13. Average RSSI value of private chat on the ground

In urban areas, goTenna showed more reliable message delivery with higher RSSI values, while Meshtastic had higher receiver sensitivity. In rural areas, both devices maintained connectivity at distances greater than 9 km. This indicates that with proper relay node placement, the mesh network can be scaled effectively over long distances.

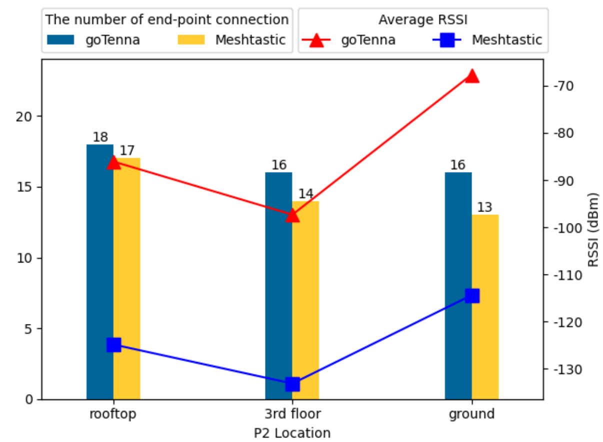


Fig. 14. Average RSSI value in each environment

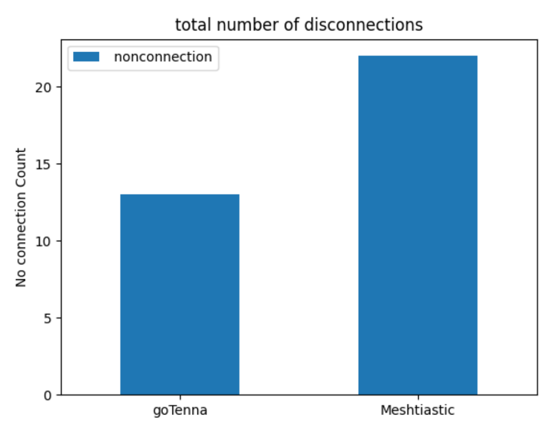


Fig. 15. total number of disconnections

## B. Farm

In rural areas, it was observed that both devices maintained connectivity at distances greater than 9 km. This indicates that, by strategically positioning relay nodes, the mesh network can be effectively extended over long distances.

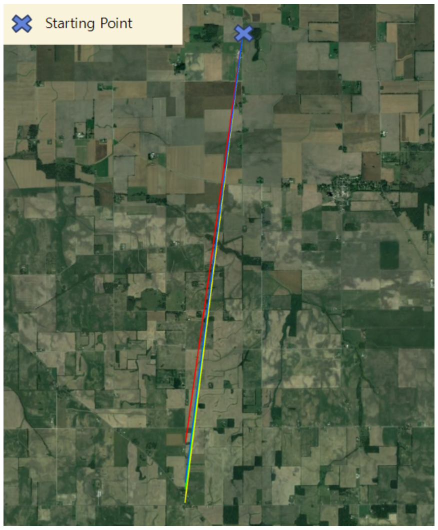


Fig. 16. Overall test map in farm

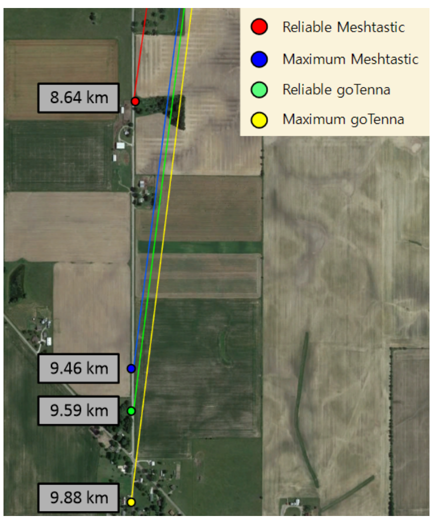


Fig. 17. Enlarged test map in farm

### C. Conclusion

In conclusion, both systems exhibited poor performance in urban areas, but were able to maintain connectivity at distances greater than 9km in rural areas. Although goTenna performed slightly better than Meshtastic overall, considering the significant price difference between the two, we conclude that Meshtastic is a comparable alternative to goTenna.

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