# Skynet: A Localized Mesh Communication Network

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***Abstract*—Wireless communication has become a vital part of modern society. Cell phones rely on wireless communication for the majority of their functions, however the existing infrastructure is limited in range. When a cell phone is used outside of the range of the existing wireless infrastructure, communication is limited or non-existent. We propose a localized mesh network that enables remote and emergency communication. The proposed network will provide wireless communication when users are outside of existing wireless coverage.**

## I. Introduction

Modern wireless communication relies heavily on an existing network infrastructure of cell towers and home routers. While these examples use two different wireless technologies, they are both helping people stay connected. These technologies keep people connected while we are within certain physical boundaries, but once we leave our house or office we lose WiFi connection and once we leave a city we may lose our cellular connection. Outside of these physical boundaries of connection, our many ways of connecting are lost.

The smartphone has become the most popular tool for wireless communication. The smartphone allows for both cellular and WiFi connections and has the most communication platforms available to it, from phone calls and text messaging to social media and private messaging apps. However, all of these communication platforms become unusable when a smartphone is taken out of the range of an existing wireless network. If two users were to stand across a large lake from each other in a remote forest, a smartphone would be unable to fulfill its purpose of connecting those users and allowing them to communicate.

Although most of the time people get the enjoyment of constant wireless connection, there are cases when people need to be outside the existing wireless network infrastructure. Emergency response teams still need to communicate during a natural disaster or when they are in a remote location, and groups still want to communicate with each other when they are in areas not covered by existing wireless infrastructure.

The proposed solution to this is an off-grid, localized mesh communication network that would take advantage of smartphones, Long Range (LoRa) antennas, and microcontrollers. A mesh network works as shown in Fig. 1, where any two nodes of the network are able to communicate by passing the message through other nodes in the network. The network would require each node to have a microcontroller to intercommunicate between a LoRa antenna module and a smartphone. The smartphone would be used to type out the text messages as well as send Global Positioning System (GPS) data and the LoRa antenna connect all the nodes into a mesh network. With this solution, a localized mesh communication network could be built.

Another problem with wireless communication in most remote locations is line of sight between communication nodes. In order to have a strong signal and maximize connection speed, a line of sight connection is required. To help solve this problem, the proposed solution will include a wireless node that is attached to a drone instead of a smartphone. The drone will be able to fly to a centralized location among connected nodes and change its position for optimal line of sight connections.

For this drone, individual components will need to be sourced and assembled. While a long flight time, small size and economic package are all desirable traits, small trade offs will be made. The drone will have a wheelbase or the distance between each motor between 15-20 inches in order to have enough thrust and space for the LoRa module and related components. Though a larger drone isn't as convenient, it allows for other devices like a camera to potentially be added. Drone assembly will be a simple process allowing for more complex tasks such as LoRa telemetry and automation to hopefully be completed as stretch goals. In a traditional operating mode with a remote control the range would be 1-2 km though integrating a LoRa module would increase range to close to 10 km. This in turn would permit users to communicate at 20 km given the right conditions.

The use cases for an off-grid, localized mesh communication network include emergency response team coordination in remote locations or during natural disasters, outdoor group communication in remote locations, private communication among a group, and communication when existing network infrastructure declines. This solution looks to bring wireless communication to people outside the range of the existing wireless infrastructure.

## II. Background

Communication systems are critical in coordinating teams, and current technologies are limiting the ability teams such as disaster response crews and search and rescue teams when generic systems such as cell-towers do not cover the target region. There are many emerging technologies promising to remedy the limitations of power, range, and cost.

### *A. Current challenges facing emergency response communication*

- During natural disasters, infrastructure such as cell towers go offline.
- Emergency response in remote regions is out of typical cellular service range.
- Long range communication is hindered by obstructions to line-of-sight.
- Devices such as walkie-talkies lack security.

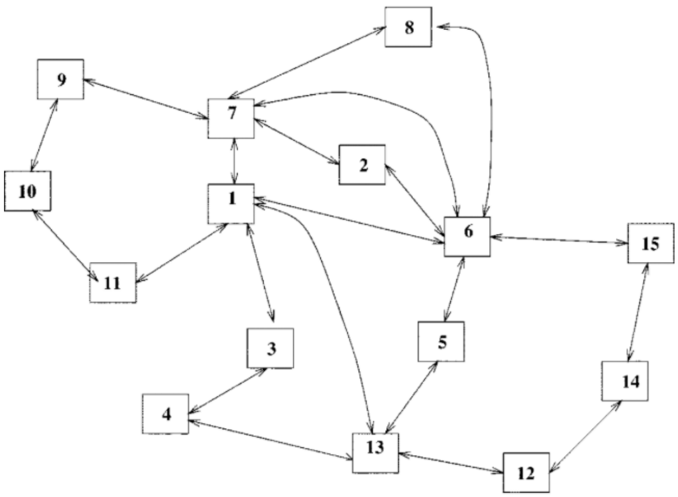



Fig. 1: A visual display of a mesh network. This shows how any two nodes can communicate by passing the message through other nodes in the network. Figure edited from Keyao Zhu and B. Mukherjee [1].

### B. Current technologies

The conventional communication platform for emergency response is the walkie-talkie. Walkie-talkies typically operate within 136 MHz to 900 MHz range and have a range of up to twenty miles on high-end devices. Although the walkie-talkie is decentralized and allows for wireless communication outside of existing wireless infrastructure, they are relatively bulky, only allow for voice communication, and are open to anyone that is on the frequency. This causes security issues when conversations need to be kept private.

Another communication technology, used by many search and rescue teams, is Very High Frequency (VHF) radio. VHF radios use frequencies from 30 MHz to 300 MHz and rely upon powerful base stations, akin to A.M/F.M radio stations in order to get maximum range. The advantage of this system is that the base stations are able to provide a robust signal reaching upwards of 60 miles. Base stations limit VHF radios because the infrastructure has to be in place already in order to create the communication network. VHF radio modules also require up to 25 watts during transmission, so they are difficult to make highly mobile. Using a more reasonable 5 watts of transmission power limits the range to 6 miles [2].

### C. Emerging technologies

LoRa is a low-power, wide-area network technology which promises to solve all of the major challenges facing emergency response communication. LoRa was originally developed by Cycleo of Grenoble and later acquired by Semtech. The frequency LoRa utilizes in the United States is 915 MHz, falling in the same sub-gigahertz band as many of the other communications frequencies such as walkie-talkies and VHF radios [3].

Skynet is the name of the proposed system we will develop which will use LoRa transceivers to transmit text messages across a localized network. This system allows the users to communicate using a mesh network, expanding the range from endpoint to endpoint by relaying messages across other nodes in the system, as shown in Fig. 1. The deployed drone will also have an antenna to increase distances between individuals while maintaining a connection.

The GoTenna and Beartooth devices are examples of similar mesh communications available today. The issue with these products is that they are not yet mainstream, are expensive, and don't have the same range capabilities LoRa has to offer. The GoTenna and Beartooth devices are both limited to 4 miles of range for text messaging, and 2 miles of voice messaging on the Beartooth [4], [5]. On top of the limited range, as of March of 2020, the GoTenna devices are $179 for a pair, and the Beartooth is $249 for a pair. Skynet hopes to reduce the cost of the systems and allow for a much greater range.

The LoRa technology has three main advantages in a local mesh network use case. First, it is a range of up to 20 miles. This is important in the off-grid communication network because the long-range ability will allow users to be spread further apart and still maintain a reliable connection. Second, LoRa modules are cheap and easy to use. Third, LoRa modules are low-power nodes, consuming as little as 120 mW during transmission and 10-15 mW for MCU operations [3].

In addition to each network user carrying a client transceiver, the Skynet system will include a drone equipped with a transceiver. The drone will help increase line-of-sight distance in scenarios where tall obstructions such as trees or buildings stand between clients on the ground. Small Unmanned Aerial Vehicles (UAV's) have grown in popularity for both hobbyist and filmmakers as well as in military applications. They are becoming smaller and cheaper with increased capabilities. One example is a drone designed to provide high speed WiFi in disaster/military environments [6]. This would allow first responders or military personal the ability to communicate in environments where the existing communication infrastructure may be destroyed.

Whatever the use case, drones provide several key benefits. Drones are able to move in an environment free of obstacles allowing for more efficient and quicker movement between two locations. They are also able to get a better overview of a location due to its centralized and elevated positioning. Another distinct advantage that we are seeking to utilize is a drone's ability to keep line of sight between target units and itself. This line of sight allows for increased communication range. Despite these advantages, drone's are still limited by range and battery life. These will be taken into consideration throughout our design process, though a proof of concept is our main goal given our time and budget constraints.

## III. Design and Implementation

### A. Android Phone Application

The user interface for this project was designed for Android devices and used a simple interface for basic communication. The application facilitated text communication by allowing any ASCII characters supported by each device's operating system. The interface also allows for map representations of relative client positions in two different formats. Finally, the application also allows the users to command a drone in the network.

The phone application was designed so that the user is able to connect via Bluetooth to a client transceiver. Once connected to a transceiver, the user is able to send and receive text messages through the mesh network. The phone application will display an error if the Bluetooth connection fails at startup or anytime during transmission. Additionally, the phone application will seek confirmation that the messages being sent are being forwarded through the mesh network. An error is displayed if the message was unable to be confirmed as forwarded throughout the network. In order to increase reliability, messages are sent multiple times until the message is confirmed or can no longer be confirmed. The user interface for text communication is shown in Fig. 2. Additionally, the phone application will start to send GPS data to other participants in the mesh network and receive GPS data for mapping purposes.

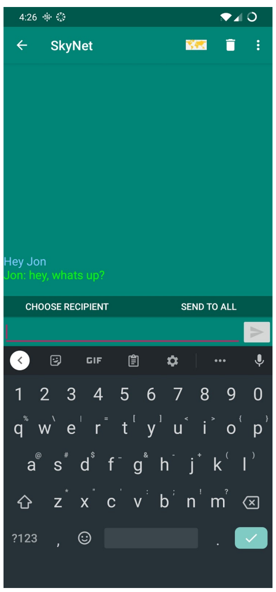
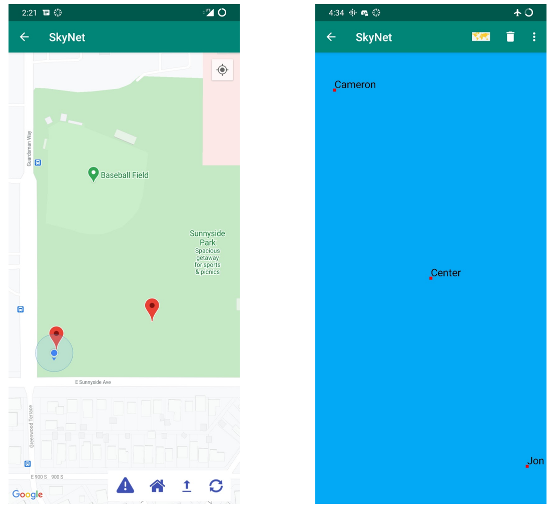



Fig. 2: The user communication interface.

As a result of sending and receiving location data in the mesh network, the phone application is able to map positions of the client devices in the network. This allows for coordination between users in the network. If the user has internet connectivity, the map feature will use the Google Maps API Fig. 3a. If the user is farther away and unable to get an internet connection then a simple relative map can be displayed Fig. 3b

The user interface also allows for drone commands to be sent either via buttons on the Google Maps interface or through the menu of the relative map as well as text interface. The drone commands allow for drone takeoff, drone land, drone return to home, and send drone to a central location. This allows the users of the mesh network to optimally position the drone to increase network coverage in real-world environments. Each command type has a separate encoding to make identification on the drone's flight controller simpler. These commands will be forwarded by other client devices active on the network as necessary.




(a) Google Map (b) Relative Map

Fig. 3: Screenshots of the map interfaces. (a) shows the google map interface and (b) shows the relative map interface.

### B. Drone

The drone was added as a way to increase range or improve signal quality between nodes. This is useful in environments where large obstacles like a mountain ridge may prevent users from having line of sight communication. In this scenario users may fly the drone to a central location above the obstacle and allow for line of sight for each node. Aside from the motors, battery and electronic speed controllers (ESCs), the drone consists of a flight controller, a companion computer, and a LoRa radio module as shown in Fig. 4.

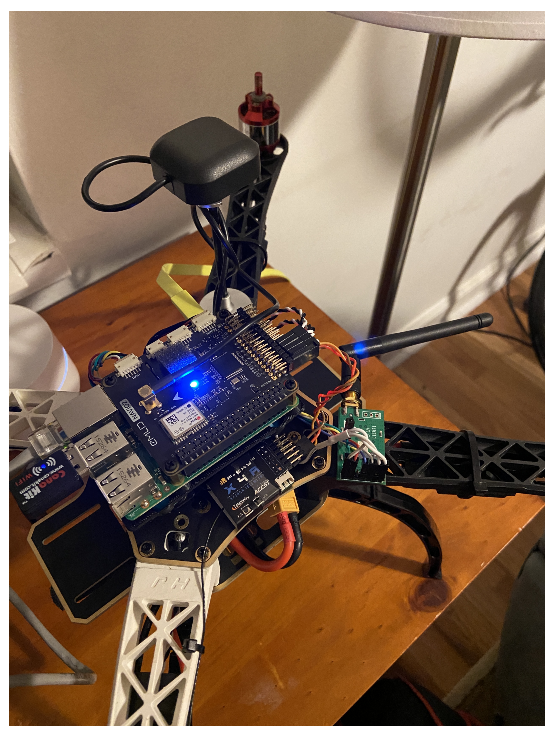


Fig. 4: Drone with flight controller, Raspberry pi, and LoRa radio

The flight controller used was an Emlid Navio2 Fig. 5. This device is a Raspberry Pi hat which includes various sensors like a GNSS receiver for GPS positioning, gyroscopes, magnetometers, and accelerometers for orientation and motion sensing, and a barometer for accurate elevation sensing. This is all run through an open source autopilot software system called Ardupilot. This device was used specifically since it includes all the necessary flight control hardware as well as an interface to interact with the Lora module through the Raspberry Pi which it sits on top of.


Fig. 5: Emlid Navio2 autonomous flight controller hat

The Raspberry Pi acted as a companion computer running along side the flight controller. Here serial data from a LoRa module could be read from one of the available UART ports. Communication between the Raspberry Pi and the flight controller was done through telemetry messages over a local UDP port. These messages from the flight controller could be read and displayed in almost real time. In the opposite direction messages can be sent to the flight controller in the form of a MAVLink message[1] to be executed on the flight controller. To develop an app to be able to control the drone through the LoRa network the Dronekit API [7] was used. This python library provided a simple way to automate the flight behavior.

## C. Client Device

Client devices were developed in order to easily combine all the pieces necessary for users to connect to the mesh network. The client devices contain a Bluetooth module, a LoRa antenna, an STM32 blue pill microcontroller, and a charge/discharge circuit connected to a battery. All of these components were soldered together on a custom-designed PCB and enclosed in a 3D printed case. Three completed devices can be seen in Fig. 6.


Fig. 6: Three completed devices in the custom enclosures.

At the core of the client device is the STM32 blue pill microcontroller, as shown in Fig. 7. This microcontroller used an Arm Cortex-M3 processor and has 128kB of on-board memory. The microcontroller is responsible for translating UART signals received by the LoRa antenna from the network to UART signals that are transmitted by the Bluetooth module to the phone, and vice versa. The Bluetooth module in the client device is an HC-05, which allows for quick configuration and easy connecting by users. The LoRa module used is an E32-915T20D, which operates at the 915MHz frequency. The LoRa

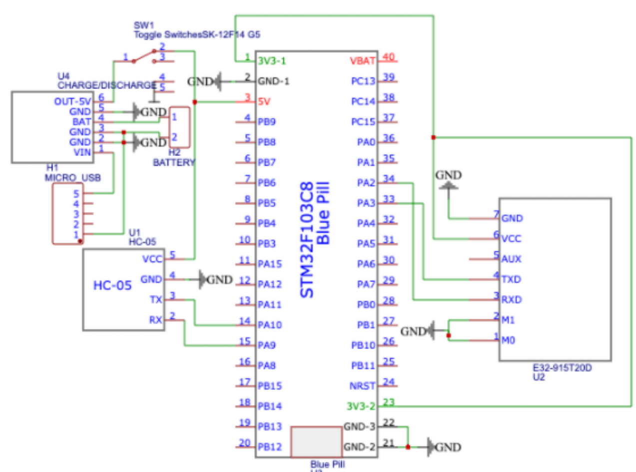



Fig. 7: A layout of the PCB with all components connected.

[1]MAVLink (Micro air vehicle link) is a standard protocol for communicating with small unmanned vehicles

module was configured to 19.2kbps in order maximize the data that could be sent across the network. At this data rate, the LoRa antenna has a range of 3km. The advantage of the modules chosen is that they both communicated over UART, allowing for simple communication with the microcontroller.

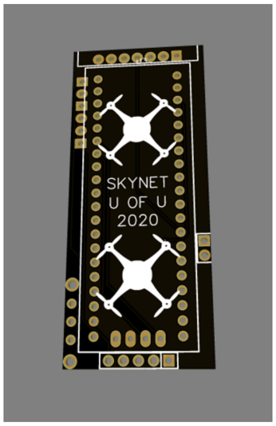
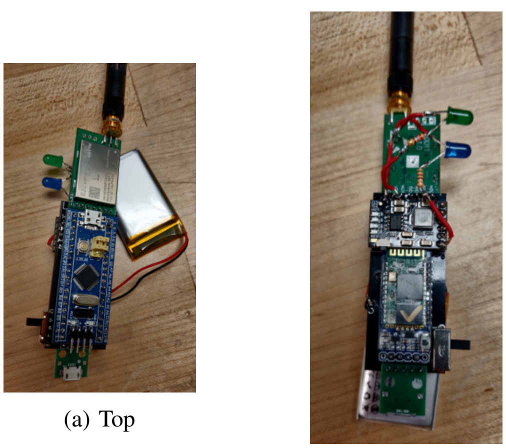



Fig. 8: 3D model of the finalized PCB.

In order to more easily connect all the components, a custom PCB was designed and fabricated. The layout for the PCB is shown in Fig. 7, and the completed PCB design is shown in Fig. 8. All of the components were soldered and stacked on both sides of the PCB in order to keep the client device as compact as possible. In Fig. 9a the microcontroller and LoRa antenna can be seen on the top side of the PCB. In Fig. 9b the charge/discharge board, Bluetooth antenna, on/off switch, and micro-USB charging board are shown on the bottom side of the PCB. During assembly, two LEDs were added to the charge/discharge circuit to indicate power on and charging. After assembly, a case was designed and 3D printed to better protect the client device.



(a) Top

(b) Bottom

Fig. 9: The client device outside of the enclosure

Power for the devices was managed by a MH-CD42 charge/discharge board. The charge/discharge boards included over charge and over discharge safety features to ensure the LiPo batteries were not damaged, and boosted the battery's 3.7 V output to a 5 V output for the microcontroller. At a 3.7 V input voltage to the charge/ discharge board, the client devices used an average of 90 mAh during communication, giving the devices an estimated 12 hours of battery life using the included 1100 mAh battery.

## IV. Conclusion

SkyNet was able to create a successful mesh network that is able to use an aerial drone as an additional highly mobile node. The mesh network is capable of sending messages from any node to either a specific node or broadcast to all nodes. The messages are routed as necessary from other nodes until it reached its target or targets. GPS data is also shared between the various clients to allow for mapping of clients, which is displayed in the phone application. Lastly, users are able to command the drone's flight and landing to further the range or robustness of the mesh network.

## References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