Short-Term Mobile Ad Hoc Network with LoRa Based Infrastructure in Disaster Relief

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***Abstract*—The network infrastructure suffers severe destruction when disaster strikes. As a result, the primary network powered by the electric grid is most likely destroyed. It makes communication between the victims and the rescue team much more difficult. This paper reviews past research to explore how different solutions can be rapidly deployed for disaster relief procedures. The research aims to provide a temporary network infrastructure to connect the victims during the disaster to speed up relief operations and provide alternative means to obtain data in a rescue process. The proposed solution takes advantage of how people nowadays carry their phones in their hands most of the time. A novel solution is suggested to use the mobile phone to connect to LoRa powered nodes to transmit information. LoRa powers the nodes to maximise the efficiency and coverage area.**

***Keywords*—LoRaWAN, mobile ad-hoc network, disaster relief communication network, rapidly deployable network**

I. Introduction

Over the years, natural disasters such as earthquakes, floods, hurricanes, tsunamis, or tornadoes killed many people every year. One of the most notable natural disasters in modern history, the 2010's Haiti Earthquake, took around 220,000 to 300,000 lives and left approximately 300,000 Haitians injured ((N.d.)., 2022). While death tolls of each natural disaster are usually less than 10,000 and 60,000 annually, those deaths can be decreased further if a proper solution is being implemented during the rescue mission. Nowadays, rescue missions rely heavily on sound, sight, smell, and other technologies like drones equipped with thermal cameras to detect survivors (Rahman-Jones, 2017). Nevertheless, these methods are proven to have a bit of hiccup, which is when something thick and dense is in between the victims and the outside; nobody can see, smell, hear or scan the victims. However, in some of the scenarios, the victims could be within reach of their mobile devices.

Still, they cannot send any messages due to the destruction of the power grid and the network infrastructure after the disaster (Burrington, 2017). As a result, the survivors will not access the internet or cellular services to connect with the rescue team or the outside world. This causes the survivors to lose precious time to receive help from the rescue team and contact their elderly or loved ones to confirm their safety. Thus, this study aims to provide a temporary mobile ad hoc network infrastructure to provide connectivity to the victims during the disaster. In addition, it will speed up the rescue process by implementing multiple low cost, interconnected LoRa- powered nodes (from now on referred to as nodes) throughout the disaster area and a central station to serve as a database to collect information about the survivors. More specifically, the main areas to explore in this research include:

- To provide a channel for survivors to include valuable information to the rescue team during disaster relief missions.
- To provide the most extensive possible coverage possible with the said channel with minimal amount of devices required, and
- To provide survivors' pinpoint accuracy and needs to the central rescue station.

According to the Malaysian Communications and Multimedia Commission (MCMC) study, the percentage of smartphone users rose from 68.7% in 2016 to 75.9% in 2017. On the other hand, the rate of feature phone users dropped by 22% from 2016 to 2017 ((N.d.-b).,2022). According to Statistics, an independent survey firm, 90.17% of the Malaysian population owns a smartphone, and they also projected that the figure would reach 97.4% by 2022 (Malaysia smartphone penetration 2019-2023., 2022). All smartphones should have equipped with connectivity functionality such as Wi-Fi and Bluetooth. A mobile phone equipped with such functionality can be connected to the nodes in case of disaster and send vital information such as GPS location, message, phone number, etc.

By implementing the system during severe disaster strikes such as high magnitude earthquakes, survivors could still communicate with the outside world if they are in reach with their smartphones even when the primary cellular network infrastructure is destroyed. This can potentially help save thousands of lives during a disaster stuck under rubble. The SOP by the United Nations is that they usually call off search and rescue attempts between five to seven days after a disaster. There are cases where people die not because of direct impact or harm caused to their bodies but simply because nobody can detect them. A case study during the Haiti earthquake in 2010 found that a man survived for 12 days under the rubble of a shop, and a Bangladesh woman who was discovered alive 17 days after disaster hit and stuck under debris (BBC News., 2021). If a similar case happens again, the survivors can potentially still communicate with the outside world, especially when statistic says that more than 90 percent of all Smartphone users say they have their phones within reach 24 hours a day, seven days a week (Gandolf, 2013). Their chance of survival can increase dramatically.

This research aims to provide temporary network infrastructure to connect the victims during the disaster to speed up the rescue process. In addition, this system should act as a medium for people who are stuck under rubble with their phone in their hands' reach to communicate with the outside world.

II. LITERATURE REVIEW

Choosing a suitable medium to collect data is essential to make a difference during a life-or-death situation for the victims. Thus, several domains are identified to make this research more effective and more factually accurate. These domains are:

- Current Network Infrastructure
- Temporary Mobile Ad Hoc Network Infrastructure
- Disaster Response

A. Internet of Things(IoT)

The current network infrastructure refers to the tools and technologies used widely by the world to communicate or access the Internet. In a research done by Pew Research Center in the year 2019, the median ownership of the smartphone is around 7 out of 10 phone owners in most developed countries (Chaoxu, 2019). According to an estimation made by WARC, almost three quarters, which is approximately 3.7 billion internet users, will be mobile-only by the year 2025 (Rosenberg, 2019). This is essential for the research because not all devices that can access the Internet are Wi-Fi enabled, while newer mobile devices such as tablets and smartphones are mostly Wi-Fi enabled. These can connect to the proposed system and utilise the expected functions of the system during the time of emergency.

In terms of cellular networks, some countries have made an effort to make the mobile telecommunication system off-grid (Handley, 2019). This increases the reliability during a power outage, which will become a problem when a disaster strikes, as seen in Hurricane (Kwasinski, 2009). Suppose the mobile telecommunication systems survive the disaster. In that case, the victims can use conventional ways of communicating with neighbours, relatives, or one another using texting via cellular data. However, suppose the telecommunication systems are being destroyed in the disaster. In that case, an alternative solution is needed to let victims contact the outside world from inside the rubbles.

Furthermore, several network topologies are available for various types of network infrastructure such as star, cluster and mesh and their performance, as mentioned in the research finding of Jung (Atagi, 2021). This is essential as it can give us insight into what type of topology should be used in our use case to maximise efficiency. The result obtained in this research can help compare and contrast between different topologies to ensure that the connection and data transfer between nodes will be reliable enough to relay a life-critical message back to the base station in our use case.

B. Temporary Mobile Ad Hoc Network Infrastructure

A temporary mobile ad hoc network is a network without fixed infrastructure and is used quickly. An ad hoc infrastructure, or more commonly called Mobile Ad hoc NETwork (MANET), comprises MANET routers (MR) capable of organising and maintaining a routing structure among themselves over a dynamic wireless interface. Most of the time, the MRs are attached to a set of nodes. Its wireless characteristics, network topologies, and communication links frequently state that it is mobile and the type of communication protocol used. Due to it being portable and lightweight, it can be deployed or retrieved before and after a mission within a short amount of time. Depending on the use case, a MANET can be both centralised and decentralised (Jung, 2007).

According to Fife & Gruenwald, power efficiency is a significant issue that has to be addressed. One of the ways to address this is by making the node not constantly communicate to the server (base station) but only start relaying and attempting to communicate to the server once it hears from another node (Fife,2004)(Rana,2021). A MANET can have a dynamic topology, and it is usually used in energy-constrained situations such as construction sites and disaster relief. (Jung, 2007), (Fife,2004) and (Magán-Carrión, 2016). However, it also has bandwidth limitations.

After accounting for external factors such as noise and interference, specific steps are required to optimise the data transmission to maximise efficiency. Several types of research also pointed out that one of the critical challenges of MANET is that making an efficient routing protocol as stated in (Magán-Carrión, 2016) (Fife,2004), and several pieces of research find the best way possible to route and relay a message back to the base station as efficient as possible. Rapidly deployable network infrastructure usually has easily transportable, stand-alone, and lightweight (Hallio, 2020). One of MANET properties is that it can be quickly deployable depending on its communication protocol. This is achieved by the nodes' self-healing and self-organising capabilities, as mentioned in (Jung, 2007).

Technologies such as LoRa provide self-healing capabilities (Navarro-Ortiz, 2019), which means that it is a deploy-and-forget system where you turn the nodes on. They should transmit data without human intervention as long as they are within each other's radio line of sight. Several companies provide commercial rapidly deployable network solutions for temporary use such as construction sites, warehouses, public events and so on to provide high-speed WAN in 48 hours.

Disaster Response

After a disaster happens, most countries have a series of very vague protocols to handle post-disaster tasks such as disaster relief, damage assessment, affected area assessment, etc. Disaster relief plans must be strictly scenario or situation-based rather than a fixed set of standard operating procedures (SOP) (Leelawat, 2015). In terms of technologies and efforts to assist the survival rate in disasters, community organisations volunteer to give their expertise in their field to help with the disaster relief process (Disaster response network, 2022).

The research covers the possibility of space technology place of destructed telecommunication system ((N.d.)., 2022). In the Japan earthquake in the Tohoku region in 2011, Tohoku University deployed a robot to help search for the victim in the rubbles to search for survivors, so humans do not have to physically climb into it with the risk of building collapsing again (Guizzo, 2011). Other than that, a component in geographic information system (GIS) called computer-aided dispatch (CAD) is one of the critical technologies that help rescue teams coordinate with each other for emergency response. The CAD system can provide insight into how much a building is destroyed, the nearest fire hydrants, and such. This can help save lives by not wasting precious time distributing the workforce in a rescue team (Mukhopadhyay, 2015). A Trilogy Emergency Relief Application (TERA) system is used by IFRC, famously known as the International Federation of Red Crescent//Cross Society.

TERA is a system that utilises SMS to convey messages to the victims. It also uses some fuzzy logic automated chatbot that helps solve problems faced by the victims in a disaster ((TERA), 2022). However, since it uses an SMS system, it relies heavily on the telecommunication system. Therefore, if the telecommunication system in the area fails, it will not work at all. Other than that, as seen in a news report done by the BBC interviewing the disaster relief team about what kind of systems Mexico used during the earthquake in 2017, several technologies are being used, which mixes both old and new technology(Shanmugam, 2021). The older technologies are usually information gathered by survivors by asking if they know anyone is trapped, sniffers dogs that are trained to find bodies, pure hearing of sound. In comparison, newer technologies such as drones equipped with cameras, thermal imaging cameras and so on are being used by the Mexico disaster relief team to locate the victims. However, the rescue team also noted that these technologies would never work if the person is stuck under a massive slab of the concrete wall of the destroyed building (Rahman-Jones, 2017).

III. System Functionality

The system mainly contains three components, base station, node, and victims' mobile devices. The base station is located in an evacuation center that can process the data received and give relevant instructions such as sending food supplies to victims. A node is a small, waterproof, lightweight package containing a microcontroller that can broadcast Wi-Fi signals and establish a self-healing and self-connecting LoRa connection. It is being deployed throughout the disaster impact site. It also includes a battery that can let the node runs for days.

Firstly, the nodes are scattered around the disaster site with a distance of around 3-4 km. This is because LoRa can maintain a good connection within 5km. The nodes contain a microcontroller with an onboard Wi-Fi chip that supports Wi-Fi broadcast such as ESP32. It will broadcast a Wi-Fi signal throughout the disaster area for victims to connect with their devices.

When the victim first connects to the open Wi-Fi system broadcasted by the node, the user is automatically redirected to a predefined website containing text fields such as needs, GPS location, message, etc. This can be modified easily depending on the use case. Standard front-end markup and a scripting language such as HTML and CSS are used, reprogramming relatively easy and quick to provide proper guidance.

GPS location will also be automatically fetched using a built-in GPS tracker in a phone. After the user fills in the details, the data is being relayed back to the base station using the node closest to the base station using LoRa. The data can be seen on a website in the base station, and the crew in the base station can respond accordingly.

A. *ESP32*

ESP32 has a dual-core processor compared to ESP8266 and Arduino. When there are many clients connected to the device, the processing power of ESP32 can be an advantage to help process the requests and prevent network hiccups. ESP32 can also create a Wi-Fi access point without the aid of an additional module. This is essential as the access point is essentially what the victims connected. Having onboard non-volatile storage allows us to store web resources like HTML and CSS files on board to serve the victims with a more pleasant-looking web form interface.

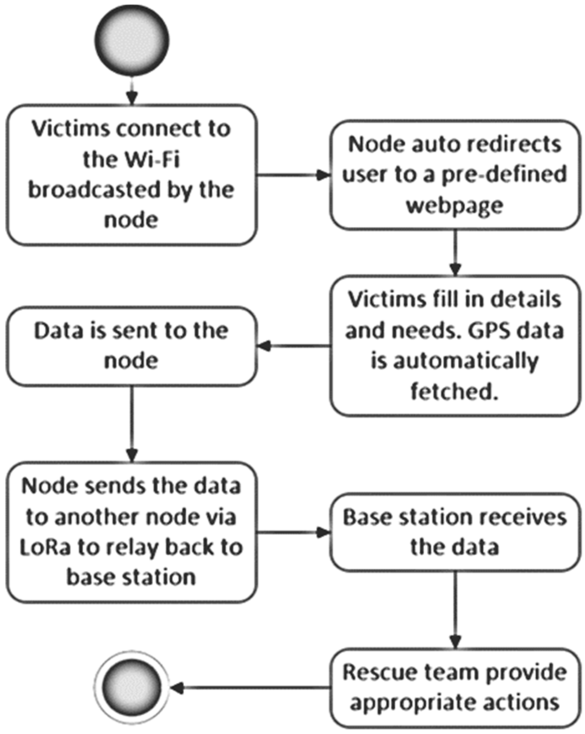

Fig. 1. Activity diagram of the system

B. *LoRa*

LoRa is chosen because it uses the free sub-GHz frequency band, compared to its closest competitor – NB-IoT. Its module is also comparatively cheaper than NB-IoT: LoRa also works off-grid, meaning that it can work independently without other network infrastructures that are most likely destroyed after a disaster. With its peak current usage of ~30 mA and sleep current of ~1 μA, it is a very good technology to be used when battery life is one of the key factors (Lipka,2020). Its low cost also means that it is financially less impactful when the device is destroyed or compromised. There are several different types of LoRa chips, but the frequency that the LoRa uses has to match local regulations. The most widely used LoRa chips are Semtech LoRa devices (SX126x, SX127x, and SX128x).

C. *Raspberry Pi*

Raspberry Pi is being chosen as the gateway device. Several reasons are being thoroughly considered before reaching this conclusion, which mainly revolves around the cost per unit processing power in the project and community support of the said device. The first reason for choosing a Raspberry Pi is that the cost per unit processing power is relatively high compared to its counterparts, such as the Intel Aaeon board. Other than that, the community support of

Raspberry Pi is generally better. For example, it is challenging to use Python to access Aaeon's GPIO pins. On the other hand, the same can be done on Pi very effortlessly due to Python's native support on Raspberry Pi, which is not directly searchable on any forums because the community support is not there.

D. System Design

From the perspective of how the data flows uplink to the rescue station, the victim first uses their smartphone to connect to the open, unsecured Wi-Fi transmitted by the Nodes. Then, the victim will be automatically redirected to the page once they relate to the Wi-Fi network. This can be achieved by using the internal smartphone internet. The smartphones will automatically check if the Wi-Fi can access the outer Internet. If it does not, the phone will show the portal predefined by the node – similar to how connecting to free Wi-Fi in public will automatically redirect users to their landing page. Still, instead of a log-in page, a simple form is being presented to the victim. That form contains fields that allow victims to fill their needs to be sent back to the rescue station.

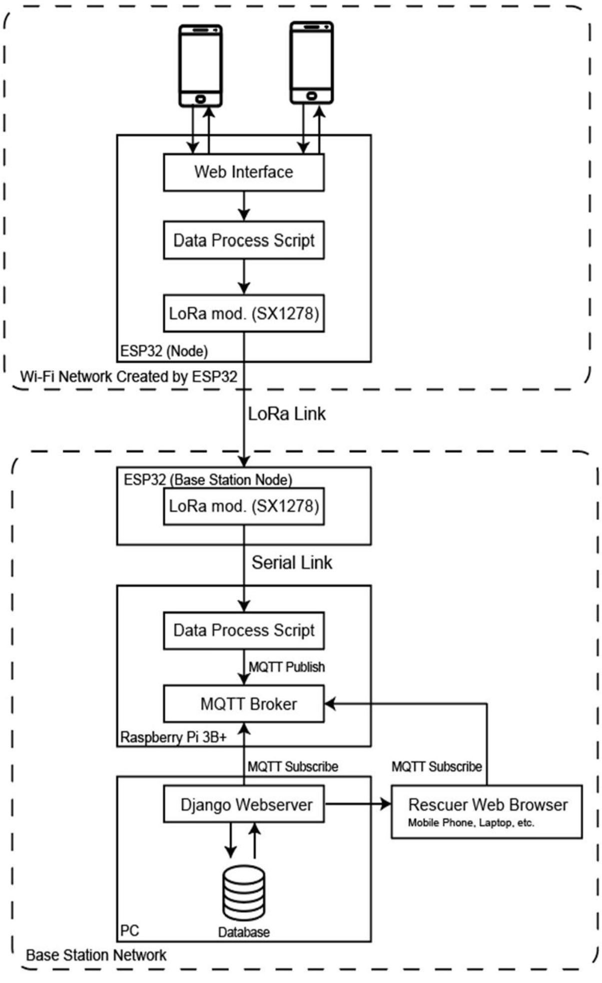

Fig. 2. System Architecture Diagram

Once the victim submits the form, the form data is sent to the node, packaged in compact form, and transmitted back to the LoRa gateway using LoRa links. Since those nodes are interconnected and exist in a mesh network, the node does not have to be in direct LoRa range with the base station as they can relay the message to another node within the base station. This can exponentially increase the scalability of the system. Other than that, adding new nodes into the system is just by flashing another node with the software with the appropriate setting, and it will automatically find its route to hop data back to the base station.

When the LoRa gateway receives new incoming data, the data will be unpackaged from its compact form and sent to both databases for historical storage and sent to the Django webserver using MQTT to display real-time data. The rescuers from the base station can then read the incoming data using a web interface hosted in Django.

IV. Proposed System Limitations

At the moment, there are still some limitations when it comes to implementing this research. These limitations are depicted below:

- Precise GPS location cannot be taken using this implementation. Theoretically, the only way to capture the GPS data of the victim is only by using HTML5's Geolocation API. However, it is deemed impossible in this implementation as the said API requires HTTPS, which is not achievable without the Internet. Self-signing certificates can create HTTPS context technically, but those are usually blocked by most of the major browsers as it is seen as a security threat.
- The proposed system runs on a battery that makes the system vulnerable to downtime, as the battery needs to be changed when it depletes.

V. Conclusion

This research provides an alternative mean to use the current IoT based technologies to perform disaster relief. It provides opportunities and increase chances of survival for the victims stuck in the disaster-hit area that are not discoverable using conventional means. Taking advantage of the fact that most people have their smartphones by their side most of the time, the proposed system can be proved really effective when the primary network powered by the electric grid is most likely destroyed.

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