# ECNeT: An Emergency Communications Network using Lora Technology

*Norbert Francis Baylon, Ann Marie Conlu, Hans Aldritz Esponilla,*
*Charlotte Gomez, Kendric Yuri Nonato, Cris Jay Veloso, Juliana Marie Vilay*

## COLEGIO SAN AGUSTIN-BACOLOD SHS STEM-EICT

**ABSTRACT.** *This study explores the capabilities of LoRa technology in developing ECNeT, an emergency communications network with a user-friendly interface, addressing the limitations noted in Macaraeg et al. (2021). The research involved technical testing to evaluate ECNeT's performance under varying levels of interference, measuring packet delivery ratio (PDR), signal-to-noise ratio (SNR), and received signal strength indicator (RSSI). Additionally, the System Usability Scale (SUS) was employed to assess the system's usability among 10 incoming student leaders at Colegio San Agustin-Bacolod Senior High School. Results indicate a significant difference in PDR, SNR, and RSSI across different interference levels, confirming that interference affects ECNeT's performance. The usability assessment via SUS demonstrated that the user interface is generally acceptable to users. This study underscores the potential of ECNeT as a reliable emergency communication solution, combining robust technical performance with satisfactory user experience.*

Keywords*: LoRa, Wifi, emergency communications, PDR, SNR, RSSI, user interface*

## Introduction

The Philippines is one of the most vulnerable countries to natural disasters. The country has been placed at the number one spot in the list of 'highest risk' countries and 4th in risk exposure in the World Risk Report for 2023. With such high risks come the dangers of communities being cut off from essential services, especially telecommunication links, which are essential to disaster response and prone to disruption by natural disasters (International Telecommunications Union, n.d.). Therefore, this study aims to address the need for a back-up, rapidly deployable emergency communications network for local government units and communities to utilize in the immediate aftermath of a natural disaster using an up-and-coming Internet of Things (IoT) technology: LoRa, and demonstrate its capabilities in both hardware and software.

A few emergency communications systems are already being developed and utilized around the world, based either on GSM like ROGER (Marciano et al., 2016), Wifi and Bluetooth connectivity like E-Explorer (Peng et al., 2015) and traditional radio communication (Quintevis & Ambatali, 2018). However, despite their promising potential, these systems suffer from technological constraints, prohibitive cost, or strict regulations which make them difficult to properly implement (Macaraeg et al., 2021).

The use of a LoRa-based communications network could prove to be a solution. LoRa (short for 'long range') is a long range, low power wireless platform developed by Semtech for use primarily in Internet of Things (IoT) applications (LoRa PHY | Semtech, n.d.). It is capable of data transmission rates of 27 kilobits per second (Kbps) up to 50 Kbps depending on the configuration used (Adelantado et al., 2017). While much lower than conventional internet connection speeds, it is more than enough for transmitting packets of texts and is made up for by the system's long communication range, theoretically reaching 2-5 kilometers (km) in urban areas and up to 15 km in rural areas. Given its potential, there is already interest in using LoRa as a basis for long range, emergency response applications like HELPER (Jagannath et al., 2019), LOCATE (Sciullo et al., 2018), and more recently an experimental study conducted by the University of the Philippines-Diliman for the Institute of Electrical and Electronics Engineers (IEEE) which explored the use of LoRa as a mesh emergency communications network, proving its viability while lacking an easy-to-use user interface (Macaraeg et al., 2021).

At its core, LoRa uses chip spread spectrum (CSS) modulation, a technique that utilizes frequency chirps with a linear variation of frequency over time to encode information (Augustin et al., 2016). It operates on the 433-, 868- or 915-MHz ISM bands, depending on the region in which it is deployed. This technique, along with LoRa's forward error correction (FEC) as part of Semtech's proprietary modulation standard, allows for transmission performances in environments with interference using relatively low power consumption and with high data integrity (Gbadoubissa, 2023). LoRa can be configured with the following physical attributes (PHY): Bandwidth, Spreading Factor, Coding Rate, and Transmission Power (Cattani et al., 2017). Each of these attributes affect the signal

integrity, range, data rate, and power consumption of a LoRa node, and balancing these attributes depends on environmental factors and the priorities of the user.

**Table 1**

*Summary of LoRa's Configurable Settings (PHY) and Their Impact (Adapted from Cattani et al., 2017)*

| Settings | Values | Effects |
|---|---|---|
| **Bandwidth** | 125 – 500 khz | Bandwidth affects how high the data rate is but comes at a cost of reducing the receiver sensitivity and communication range. |
| **Spreading Factor** | $2^6 - 2^{12}$ chips/symbol | Spreading Factor (SF) affects the signal to noise ratio, increasing sensitivity and range at the cost of higher power consumption. |
| **Coding Rate** | 4/5 – 4/8 | Coding rate augments LoRa's resilience to interference but increases the length of packets and its power consumption. |
| **Transmission Power** | -4 dBm – +20 dBm | Transmission power reduces the signal-to-noise ratio by increasing power consumption of the transmitter. |

LoRaWAN is the network protocol used in connecting LoRa devices with each other and to the internet. A typical LoRa network is configured as a "star-of-stars topology" wherein LoRa devices are connected to a gateway which connects to a server, typically in the cloud through the internet (Augustin et al, 2016). This architecture was primarily designed for IoT applications, as they typically have sensors which connect to gateways that in turn connect to a central server that controls specific applications. However, one aspect of the LoRaWAN network that is rarely discussed is device to device (D2D) connectivity (Saqib et al, 2021). D2D allows for direct communication between two LoRa devices without using gateways, making it more efficient. Regardless of connection, a LoRa device will send and receive the same LoRa frame format: a preamble which acts to

synchronize both devices, an optional header which carries information about the payload, the payload itself that contains the data being transmitted, and an optional Cyclic Redundancy Check (CRC) at the end (Bouguera et al, 2018).

With that context, it is important to measure the technical capabilities of LoRa in terms of connection quality. These measurable characteristics are packet delivery ratio, signal to noise ratio, and received signal strength indicator. The packet delivery ratio (PDR) between two LoRa devices defines the ratio of the number of packets sent by the source node and the number of packets received by the destination node. (Pradhan et al., 2019) and is dependent on environmental factors and PHY configuration, with studies demonstrating multi-kilometer distances with PDR above 70% (Macaraeg et al., 2020; Petäjäjär et al., 2015; Seye et al., 2018) making it possible for LoRa devices to communicate with each other within multi-kilometer ranges.

Meanwhile, signal to noise ratio (SNR) which is the ratio of the received signal power to the noise floor, commonly used to determine the quality of the signal, and received signal strength indicator (RSSI) which is a relative measurement that helps you determine if the received signal is strong enough to get a good wireless connection from the transmitter (RSSI and SNR, n.d.), are found to be inversely proportional with SF (Fang et al., 2018; Sagir et al., 2019). Since SF is correlated with range and PDR, it means that there could be a tradeoff between signal integrity and range, depending on the settings used and environmental factors, especially considering that SNR has a floor depending on what SF settings are used (Cattani et al., 2017; Semtech, 2017). Furthermore, RSSI (and by extension, SNR) were affected by interference, both physical and signal-based (Tan et al., 2017; Wadatkar et al., 2019).

It is worth noting that while there is currently an increase in publications and documentation regarding LoRa networks and devices, gaps in literature still exist around real-world testing especially of D2D connections, which becomes a problem considering that practical models are not always accurate, and every hardware configuration changes these variables. In addition, there is currently a lack of literature that directly measures and

compares the effect of physical interference to LoRa's system, especially considering that comparing results between different studies is not always possible due to differing methodologies. However, this review gives the researchers enough context to conclude that, given its capabilities and an optimal configuration, LoRa could be effectively utilized as a low-power network system, so long as there is a balance between its PDR and range capabilities, and the requirements of high signal integrity, which are needed for an emergency communications network in the aftermath of disasters.

### *Framework of the Study*

LoRa is a low-power, long-range communications platform which is currently gaining the interest of researchers for its applications on emergency communications networks. In an experimental study by Macaraeg et al. (2021), they demonstrated the feasibility and capabilities of a LoRa-based emergency communications system in the Philippines, while lacking a user-friendly interface, citing the need for further research into the topic. In this experimental study, the researchers developed and demonstrated the capabilities of ECNeT, a LoRa-based emergency communications network in both the hardware side configurations and a robust, user-friendly front end software interface.

The schematic diagram of the conceptual framework in Figure 1 shows the different variables of the study, with focus given as to how interference affects the packet delivery ratio, signal to noise ratio, and received signal strength indicator between ECNeT nodes. Along with exploring the usability of ECNeT's mobile application, the researchers can gauge the effectiveness and overall feasibility of the system.

**Figure 1**

*Schematic Diagram of the Comparison of the Effects of Interference on the Packet Delivery Ratio, Signal to Noise Ratio, and Received Signal Strength Indicator Between Two ECNeT Nodes.*
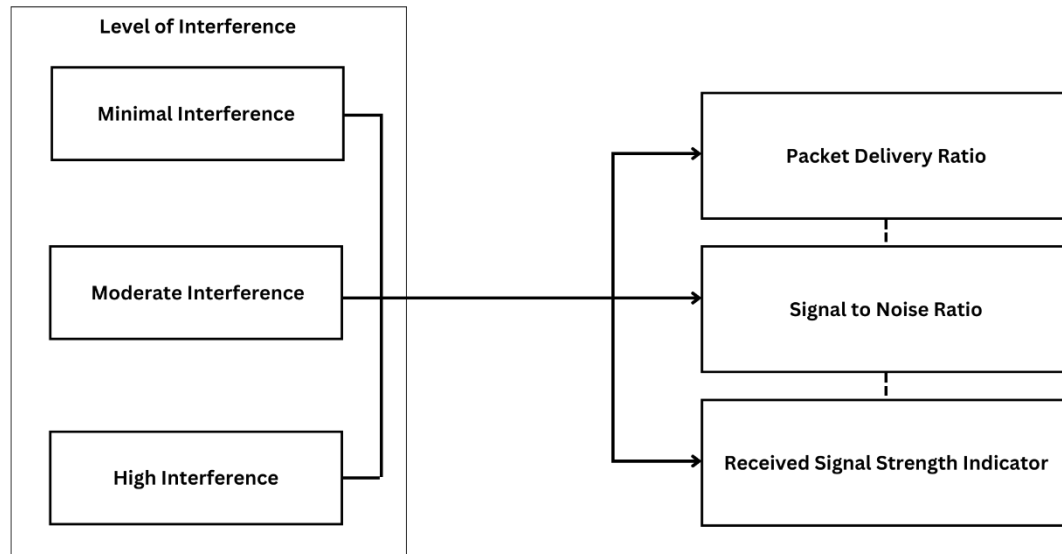


*Scope and Limitations*

The focus of this study is centered around developing ECNeT as a software and hardware solution for emergency communications using LoRa and demonstrating its capabilities in terms of packet delivery ratio, signal to noise ratio, received signal strength indicator, and usability.

Specifically, it tested the package delivery rate, signal to noise ratio, and received signal strength indicator between two ECNeT nodes and compared how different levels of interference affect these variables, as well as ECNeT's measure of usability. An important thing to note is that the focus of this study lies heavily on the technical aspects of LoRa, while also providing an initial test for the development of a mature user interface. Due to time and resources constraints, the researchers have decided to narrow the scope of this study. Therefore, this study has tested the following variables using the same settings, as reflected in the study's methodology.

The study was conducted with a structured and limited framework, focusing on the aforementioned variables and using a repeatable methodology and statistical analysis to infer the viability and effectiveness of ECNeT as a potential emergency communications platform.

### *Significance of the Study*

The findings of this study could offer beneficial insight into its potential to enhance disaster response and management across various levels of governance and sectors. For the national government, the study's findings provide a foundation for departments like the Department of the Interior and Local Government and the National Disaster Risk Reduction and Management Council to explore the implementation of LoRa-based emergency communications networks, such as ECNeT. These networks could be integrated into existing disaster response plans, potentially improving coordination and efficiency during emergencies.

At the local government level, the study offers a practical framework for City and Municipal Disaster Risk Reduction and Management Offices (DRRMO) and Barangay officials. By adopting ECNeT or similar networks, local authorities can significantly improve their disaster response capabilities. This could lead to faster, more reliable communication during crises, enhancing the safety and resilience of communities.

Non-governmental organizations (NGOs) can also benefit from this study by using its framework to implement LoRa-based emergency communication networks. For NGOs involved in disaster relief, such networks can streamline communication and coordination efforts, making their operations more effective and efficient. This can result in quicker, more organized responses to disasters, ultimately aiding affected populations more swiftly and effectively.

Lastly, the study serves as a valuable reference for future researchers. It opens avenues for further exploration into LoRa-based communications networks and their various applications. By building on this research, future studies can develop new insights

and innovations, potentially leading to even more advanced and effective communication solutions in disaster management and beyond.

### *Objectives of the Study*

This study aims to develop ECNeT as a LoRa-based emergency communications network and investigate its effectiveness in terms packet delivery ratio (PDR), Signal to Noise Ratio (SNR), Received Signal Strength Indicator (RSSI), and usability when tested in an urban environment with varying levels of interference.

Specifically, the research aims to answer the following questions:

1. What is the average packet delivery ratio (PDR) when sending a packet from one ECNeT node to another from a distance of around 100 meters with the following levels of interference:
   a. Minimal Interference (Line of Sight, little/no obstruction)
   b. Moderate Interference (Line of Sight, mild foliage obstruction)
   c. High Interference (No line of Sight, concrete obstruction)
2. What is the average signal to noise ratio (SNR) when sending a packet from one ECNeT node to another from a distance of around 100 meters with the following levels of interference:
   a. Minimal Interference (Line of Sight, little/no obstruction)
   b. Moderate Interference (Line of Sight, mild foliage obstruction)
   c. High Interference (No line of Sight, concrete obstruction)
3. What is the average Received Signal Strength Indicator (RSSI) when sending a packet from one ECNeT node to another from a distance of around 100 meters with the following levels of interference:
   a. Minimal Interference (Line of Sight, little/no obstruction)
   b. Moderate Interference (Line of Sight, mild foliage obstruction)
   c. High Interference (No line of Sight, concrete obstruction)
4. What is ECNeT's measure of usability among prospective student leaders?

5. Is there a significant difference in average packet delivery ratio (PDR) when sending a packet from one ECNeT node to another from a distance of around 100 meters among varying levels of interference?

6. Is there a significant difference in average signal to noise ratio (SNR) when sending a packet from one ECNeT node to another from a distance of around 100 meters among varying levels of interference?

7. Is there a significant difference in average Received Signal Strength Indicator (RSSI) when sending a packet from one ECNeT node to another from a distance of around 100 meters among varying levels of interference?

## Materials and Method

### *Study Design*

The study made use of two quantitative research designs to measure the technical and usabillity asspects of ECNeT. For measuring its technical aspects, an experimental research design is used. According to Zubair (2023), experimental research design is a scientific method of conducting research in which one or more independent variables are altered and applied to one or more dependent variables in order to determine their influence on the latter. Meanwhile, for measuring the usability of ECNeT, a quasi-experimental one group posttest only design is used, where a researcher measures a dependent variable for one group of participants following a treatment. (Privitera & Ahlgrim-Delzell, 2018). In this case, the system would be tested by users who would then rate its usability using a questionnaire. While flawed, this method allows the researchers to have an initial overview over the system's usability using a standardized test, which would prove essential for further development.

### *Subjects of the Study*

The data from this study were quantified from the results obtained from real-world tests using command line interface (CLI) commands for each of the respective variables of

packet delivery ratio, signal to noise ratio, and received signal strength indicator of ECNeT nodes. This data was then be used as basis for inference and statistical analysis.

On the technical side, the three variables was be measured on two ECNeT node prototypes created in house using results generated in the Command Line Interface of the ECNeT node. Meanwhile, on the usability testing, 10 club/organization officers acted as participants for the usability survey.

*Materials*

This study made use of data tables to record the values from the tests conducted for each variable of packet delivery ratio, signal to noise ratio, and received signal strength indicator. Each set of tests had their own column on the table, which made it easier for the researchers to keep track of the results and apply statistical analysis afterwards.

In addition, a survey questionnaire was used to gauge the usability of ECNeT's user interface. Specifically, it utilized the System Usability Scale, a standardized test to measure perceived ease of use developed by John Brooke in 1986. It is widely used in UX design and has been proven to have high consistency and high validity (Lewis & Sauro, 2009). Modeled after the Likert scale, it has a set of 10 questions consisting of positive statements in odd numbers and negative statements in even numbers, with a rating of 1 (strongly disagree) to 5 (strongly agree). To calculate the SUS, first sum the score contributions from each item. Each item's score contribution will range from 0 to 4. For items 1,3,5,7,and 9 the score contribution is the scale position minus 1. For items 2,4,6,8 and 10, the contribution is 5 minus the scale position. Multiply the sum of the scores by 2.5 to obtain the overall value of System Usability. SUS also allows the researchers to calculate scores per individual question by multiplying the normalized score of each question and multiplying it by 25 to align with the scale used for the overall SUS score, allowing researchers to look into specific usability issues.

## Methods or Procedures

**Figure 2**

*Experimental Procedures*
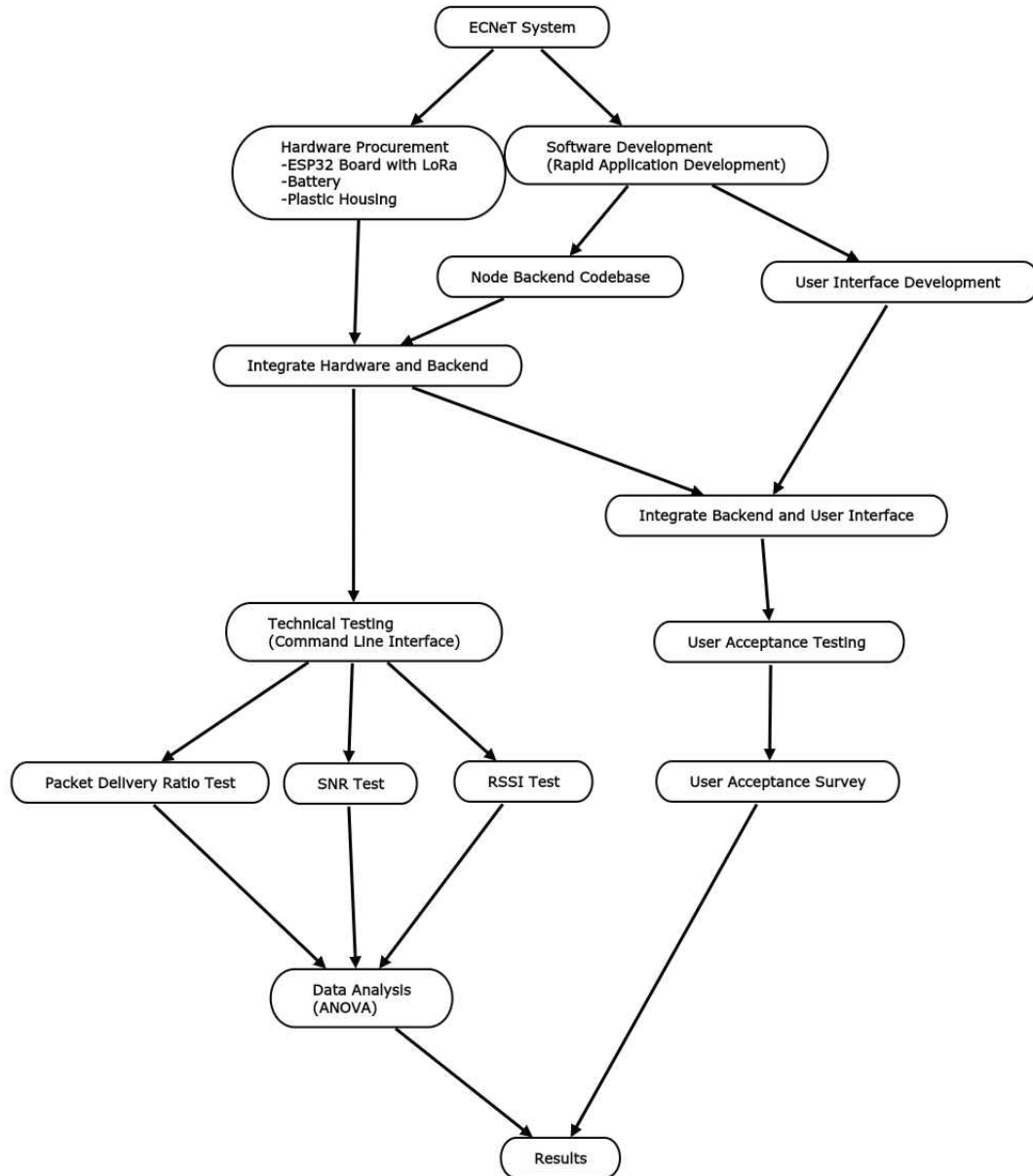


The study made use of a browser user interface, preexisting hardware based on the ESP32 platform acting as a node running a custom code and connected to a battery as a power source enclosed in a plastic chasis. The software side was developed using the Rapid

Application Development (RAD) framework. Rapid application development is a software development methodology that uses minimal planning in favor of rapid prototyping (SDLC - RAD Model, n.d.). This allows for parallel development of multiple modules, integrating them together into a prototype, and implementing changes in the overall design rapidly as the team receives feedback from internal and external beta testing.

**Figure 3**

*Rapid Application Development Flowchart*
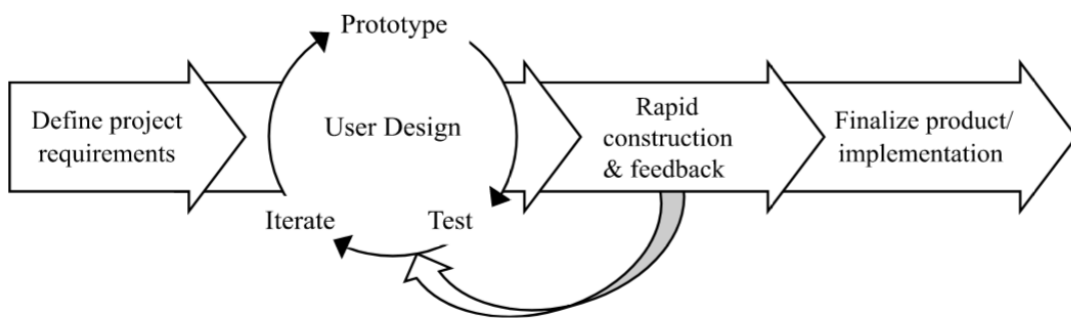


In this case, the user interface was adopted from an open source web serial terminal known as WebSerial Lite. It was hosted directly from each node and took advantage of the WiFi connection so it would be accessed by the user. The back-end code deployed into each ECNeT node was developed in Arduino IDE using pre-existing packages that allowed each ECNeT nodes to act as WiFi access points and interface with Android phones and each other. Both codebase would be developed in parallel to each other. Internal and external testing would follow, with the guide of an expert adviser, and the application development process will iterate until a stable prototype, capable of real-world testing, becomes feasible.

**Figure 4**

*Simplified Software Development Flowchart*
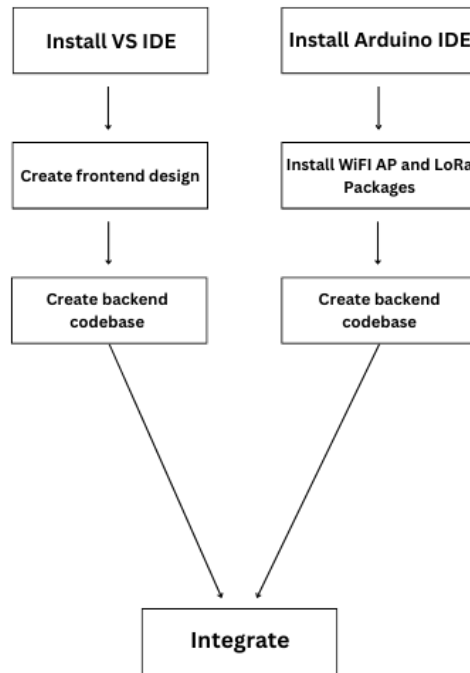


On the hardware side, an ECNeT node is composed of an ESP32 board with a LoRa module and antenna built in, as well as a battery enclosed in a small box. The ESP32 provided the processing power to run the code for LoRa transmissions and act as a local access point for devices to connect into. The ESP32 module was programmed in Arduino IDE using a PC, where all the necessary libraries for LoRa and WiFi connectivity were installed. The ESP32 is configured in Access Point (AP) mode in order for phones to connect to it with a secure SSID and password. Each ESP32 powered node were configured to the same PHY settings and code word in order to receive the message. These settings were configured after preliminary testing and literature review had determined them to be optimal for both signal integrity and power/thermal constraints.

Each node is identified as a single user, which means that ideally, only one device (a phone running the companion app) would be connected to its access point, however due to a current bug with how the specific ESP32 board handled WiFi passwords, the Access

Point has no password and multiple devices could connect to it. When a user sends a message through the app, it is sent to the ESP32 module through WiFi as a text string, which would then be converted into a LoRa signal. ECNeT nodes tuned to the same frequency and listening for the same signal word would be able to receive this signal and decode it at the other end, printing the text string in its command line interface (CLI) and then converting the LoRa signal into WiFi, allowing the browser interface on the other end to display the text string in its UI to the user. Since a packet being sent through LoRa is limited, the amount of text a user can send will be limited by the app.

The locations have been determined through a thorough line of sight and mapping survey of the locations around CSA-B, with the zero point located outside the SHS faculty room at the 4$^{th}$ floor of C-Building. In the end, three locations were chosen based on their perceived level of interference: Hallway for minimal interference, A-Building for moderate interference, and Cozy Coffee for high interference. The researchers set up the receiving and sending node to face each other as much as possible. For consistency, the SUS testing was also conducted in the Hallway location.



*Location A: Hallway (Minimal Inteference)*
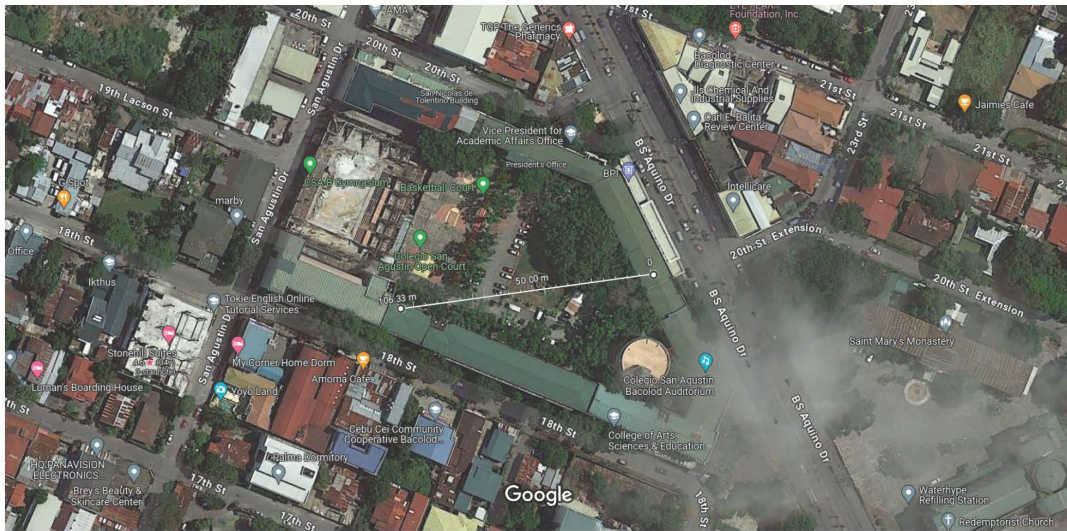
*Location B: A-Building (Moderate Interference)*



*Location C: Cozy Coffee (High Interference)*

## Treatment of Data

The statistical tool used in this study depended on the characteristics of the data collected from testing. After taking the mean of each variable and assuming a normal distribution, the study made use of one-way ANOVA to determine whether there is a significant difference in PDR, SNR, and RSSI when testing ECNeT nodes from different distances. One-Way ANOVA ("analysis of variance") compares the means of two or more independent groups in order to determine whether there is statistical evidence that the associated population means are significantly different (LibGuides: SPSS Tutorials: One-Way ANOVA, 2023).

## Ethical Considerations

The study was approved by the Research Ethics Committee (REC) of Colegio San-Agustin Bacolod and followed the necessary safety protocols in order to ensure the safety of the environment, researchers, and participants. One of the ethical considerations that was considered while conducting this research was the use of electronic equipment and batteries, which could pose a hazard to the researchers as well as the environment. To counter this, researchers are were trained and educated in handling electronic equipment carefully with the help of an experienced technical adviser. Informed Consent, privacy, and data confidentiality was practiced for the participants of the System Usabilitty Scale, and the system did not collect any hiddent data from the users or store them in a server since ECNeT is a decentralized system. The researchers also adhered to a strict code of ethics in collecting and presenting information. The results obtained from tests conducted shall be free from tampering, and all values, data, and information contained within this study are veracious and free from plagiarism.

## Results and Discussion

In this study, all tests have been performed using the same settings (866.3 Mhz Frequency Band, 125khz Bandwidth, SF 9, +10dB Transmit Power).

*Packet Delivery Ratio*

Packet Delivery Ratio (PDR) is a measure of the proportion of packets received versus packets sent (Pradhan et al., 2019). Previous studies have shown that PDR depends on both environmental factors and settings set (Macaraeg et al., 2020; Petäjäjär et al., 2015; Seye et al., 2018). In the results of this study, we specifically see how interference affects PDR when the same settings are used.

**Table 1**

*Difference in PDR*

| Location | Mean | F-value | p-value | Statistical Difference |
|---|---|---|---|---|
| Hallway (Minimal Interference) | 0.99 | | | |
| A-Building (Moderate Interference) | 0.88 | 22.150 | .000 | Significant |
| Cozy Coffee (High Interference) | 0.55 | | | |

*p-value ≤ 0.05, significant.*

Table 1 shows that there is a significant difference in PDR between locations (F=22.150; p=0.000), therefore, the null hypothesis is rejected at 0.05 level of significance. The result indicates that the PDR of three locations is statistically different. As expected from the literature, the location with the least interference (Hallway) had the highest PDR out of all locations with a mean of 0.99 out of five trials, with increasing interference leading to lower PDR results (0.88 for A-Building; 0.55 for Cozy Coffee). Post hoc test was further used to determine which locations show significant difference.

**Table 2**

*Post-hoc test, PDR*

| Location (I) | Location (J) | Mean Diff (I-J) | p-value | Statistical Difference |
|---|---|---|---|---|
| Hallway | A Building | .10600 | .310 | Not Significant |
| Hallway | Cozy Coffee | .44000* | .000 | Significant |
| A Building | Cozy Coffee | .33400* | .001 | Significant |

*$p$-value $\leq 0.05$, significant.*

Table 2 reveals that there is no significant difference between the PDR in locations Hallway and A-Building, meaning that the reliability of connection between the two should not be too different (within a 95% confidence level). Meanwhile, comparisons between Hallway and Cozy Coffee and A-Building and Cozy Coffee show statistically significant differences in PDR, which means that the reliability of the two locations are not comparable to each other. Taken together, the results indicate that in terms of PDR, interference has a significant effect on the reliability of connection, especially when interference reaches a point where buildings and foliage blocks line of sight between nodes.

***Signal to Noise Ratio***

Signal to Noise Ratio (SNR) is a measure of the ratio between received signal power in proportion to the noise floor of the environment (RSSI and SNR, n.d.). Several factors could affect the SNR of a given packet, including but not limited to the strength of the Received Signal (thus its connection with RSSI), the noise floor, and the settings used (RSSI and SNR, n.d.; Fang et al., 2018; Segir et al., 2019). The following results focus on the effects of interference to the SNR of the system as configured.

**Table 3**

*Difference in SNR*

| Location | Mean (dBm) | F-value | p-value | Statistical Difference |
|---|---|---|---|---|
| Hallway (Minimal Interference) | 5.21 | | | |
| A-Building (Moderate Interference) | -8.47 | 2654.093 | .000 | Significant |
| Cozy Coffee (High Interference) | -12.10 | | | |

*p-value ≤ 0.05, significant.*

Table 3 shows that there is a significant difference in SNR between locations (F=2654.093; p=0.000), therefore, the null hypothesis is rejected at 0.05 level of significance. The result indicates that the SNR of three locations is statistically different, with the location of least interference (Hallway) having a positive average SNR (+5.21dBm), while locations with moderate (A-Building) and high (Cozy Coffee) levels of interference have negative average SNR (-8.47 dBm for A-Building; -12.10 dBm for Cozy Coffee) proving that an increase in interference means a significant decrease in signal-to-noise ratio. Post hoc test was further used to determine which locations show significant difference.

**Table 4**

*Post-hoc test, SNR*

| Location (I) | Location (J) | Mean Diff (I-J) | p-value | Statistical Difference |
|---|---|---|---|---|
| Hallway | A Building | 13.68352* | .000 | Significant |
| Hallway | Cozy Coffee | 17.31028* | .000 | Significant |
| A Building | Cozy Coffee | 3.62676* | .000 | Significant |

*p-value ≤ 0.05, significant.*

Table 4 indicates that SNR significantly decreases with an increase from minimal (Hallway) to moderate (A-Building) interference, and that SNR continues to decrease as interference increases from moderate to high (Cozy Coffee), albeit at a smaller scale. This makes sense, as theoretically, the system can only handle -12.5 dBm SNR at SF9 SX1272/73 DATASHEET, 2017) and practically, the system was only able to record up to -15.5 dBm SNR, meaning that there is a floor to how low a given packet's SNR could be, and anything beyond that mark would simply not be decoded. On the whole, the results indicate a significant negative effect that interference has on SNR, which could adversely affect the number of packets that the system could decode, and subsequently, its packet delivery rate (PDR) and connection reliability.

### *Received Signal Strength Indicator*

Received Signal Strength Indicator (RSSI) is a measure of received signal power (*RSSI and SNR*, n.d.). Being a proxy for received signal power, RSSI is directly correlated with SNR, meaning that they are affected by similar factors. For this study in particular, the focus of the analysis is on the effects of interference, something that has been demonstrated by previous studies for RSSI explicitly (Tan et al., 2017; Wadatkar et al., 2019). The results below help validate those effects.

**Table 5**

*Difference in RSSI*

| Location | Mean (dBm) | F-value | p-value | Statistical Difference |
|---|---|---|---|---|
| Hallway (Minimal Interference) | -89.49 | | | |
| A-Building (Moderate Interference) | -106.57 | 2394.156 | .000 | Significant |
| Cozy Coffee (High Interference) | -120.73 | | | |

*p-value ≤ 0.05, significant.

Table 5 shows that there is a significant difference in RSSI between locations (F=2394.156; p=0.000), therefore, the null hypothesis is rejected at 0.05 level of significance. The result indicates that the RSSI of three locations is statistically different, proving that similar to SNR, RSSI decreases significantly with an increase in interference. The location with minimal interference (Hallway) had the highest average RSSI recorded at -89.49 dBm, followed by moderate (A-Building) and high (Cozy Coffee) interference locations, with -106.57 dBm and -120.7 dBm respectively. Post hoc test was further used to determine which locations show significant difference.

**Table 6**

*Post-hoc Test, RSSI*

| Location (I) | Location (J) | Mean Diff (I-J) | p-value | Statistical Difference |
|---|---|---|---|---|
| Hallway | A Building | 17.07499[*] | .000 | Significant |
| Hallway | Cozy Coffee | 31.23985[*] | .000 | Significant |
| A Building | Cozy Coffee | 14.16486[*] | .000 | Significant |

*p-value ≤ 0.05, significant.

Table 6 shows a similar dynamic to Table 4, albeit the gap between the mean difference of minimal and moderate, and moderate to high interference is smaller. Like SNR, RSSI has a practical floor on how low it could get before the system would not be able to decode the packet. For LoRa, the typical minimum is -120 dBm, assuming a high noise floor (RSSI and SNR, n.d.). Practically, the system was able to record only up to -126 dBm, before the packets were dropped. Overall, these results are in line with what Tan et al. (2017) had recorded when testing in areas of differing interference.

***System Usability Scale***

The System Usability Scale (SUS) is a scale that measures the usability of a given system (Brooke, 1996). While self-described as a "quick and dirty" way to assess usability, it has become a standard for many UX testing for the last few decades and has remarkable validity (Lewis & Sauro, 2009). For this study, SUS is used to give a preview on the usability of the ECNeT system.

**Table 7**

*System Usability Scale Assessment*

| | | Strongly Disagree | Somewhat Disagree | Neutral | Somewhat Agree | Strongly Agree | AVG Raw | Score |
|---|---|---|---|---|---|---|---|---|
| 1. | I think I would like to use this tool frequently. | - | 1 | - | 3 | 6 | **3.4** | **85** |
| 2. | I found the tool unnecessarily complex. | 7 | 3 | - | - | - | **3.7** | **92.5** |
| 3. | I thought the tool was easy to use. | 2 | 1 | - | 5 | 2 | **2.4** | **60** |
| 4. | I think that I would need the support of a technical person to be able to use this system. | 6 | - | 2 | 2 | - | **3.0** | **75** |
| 5. | I found the various functions in this tool were well integrated. | - | - | 2 | 6 | 2 | **3.0** | **75** |
| 6. | I thought there was too much inconsistency in this tool. | 4 | 4 | - | 1 | 1 | **2.9** | **72.5** |
| 7. | I would imagine that most people would learn to use this tool very quickly. | - | - | - | 2 | 8 | **3.8** | **95** |
| 8. | I found the tool very cumbersome to use. | 10 | - | - | - | - | **4.0** | **100** |
| 9. | I felt very confident using the tool. | - | - | - | 2 | 8 | **3.8** | **95** |
| 10. | I needed to learn a lot of things before I could get going with this tool. | 6 | 3 | - | - | 1 | **3.3** | **82.5** |
| **SYSTEM USABILITY SCORE** | | | | | | | **3.33** | **83.25** |

Table 7 shows the results of the SUS Testing conducted on 10 selected participants. As shown here, the average System Usability Score out of all participants is 83.25 which according to the classification by Jeff Sauro (2018), is an A-Grade user experience or within Acceptable territory. The breakdown of the verbal interpretation per question appears in the table below.

*Table 8*

*Acceptability/Grade of SUS Results (Sauro, 2018)*

| | Score | Grade | Acceptability |
|---|---|---|---|
| 1. I think I would like to use this tool frequently. | 85 | A+ | Acceptable |
| 2. I found the tool unnecessarily complex. | 92.5 | A+ | Acceptable |
| 3. I thought the tool was easy to use. | 60 | D | Marginal |
| 4. I think that I would need the support of a technical person to be able to use this system. | 75 | B | Acceptable |
| 5. I found the various functions in this tool were well integrated. | 75 | B | Acceptable |
| 6. I thought there was too much inconsistency in this tool. | 72.5 | B- | Acceptable |
| 7. I would imagine that most people would learn to use this tool very quickly. | 95 | A+ | Acceptable |
| 8. I found the tool very cumbersome to use. | 100 | A+ | Acceptable |
| 9. I felt very confident using the tool. | 95 | A+ | Acceptable |
| 10. I needed to learn a lot of things before I could get going with this tool. | 82.5 | A | Acceptable |
| **SYSTEM USABILITY SCORE** | 83.25 | A | Acceptable |

Almost all questions passed as Acceptable, with the only exception being question 3, which is rated as Marginal or D Grade. Six questions attained a Grade of A and above (questions 1, 2, 7, 8, 9, and 10), and these questions were related to the ease of use, barrier to entry, and familiarity with the system. Meanwhile, three questions were rated B (questions 4, 5, and 6), and these questions were related to the consistency and integration of the system. It is worth pointing out that the question with the lowest percentile score (question 3) which had a score of 60 and the question with the highest percentile score (question 8) with a score of 100 are both variations of a fundamentally similar question on usability, which raises some concerns about the validity of the results. However, such errors are to be expected with a small sample size and a student demographic (especially considering that the word "cumbersome" may not be fully familiar to every student), and the results give us a point of reference for the current state of ECNeT's user experience, with ease of use and integration being its current challenges and places of future improvement, while familiarity and ease of adoption being its strengths.

**Conclusions and Recommendations**

This study has been conducted primarily to explore the capabilities of LoRa and develop ECNeT, an emergency communications network, based on the technology. Macaraeg et al. (2021) proved the viability of a similar system, while lacking an easy to use user interface, something that ECNeT was developed to have. Technical testing was conducted to measure ECNeT's capabilities in varying levels of interference, using packet delivery ratio, signal to noise ratio, and received signal strength indicator as variables to be tested to see whether interference had an effect on the system. Additionally, System Usability Scale was used to measure the usability of the system on a sample of 10 incoming student leaders in Colegio San Agustin-Bacolod Senior High School.

According to the analysis of the data collected, it is found that overall, there is a significant difference in PDR, SNR, and RSSI during transmission between two ECNeT nodes when tested under minimal, moderate, and high levels of interference. Between minimal and moderate levels of interference, PDR doesn't display a significant difference (within a 95% confidence interval), however for SNR and RSSI, the differences are

amplified to be statistically significant. All three variables post significant differences between minimal and high levels interference, as well as moderate and high levels of interference. These results support what had been demonstrated in other studies, about how interference (and physical interference specifically) negatively affects the signal strength (and therefore, signal integrity) of LoRa significantly (Tan et al., 2017). In addition, the SUS results reveal that the current interface used for ECNeT (along with its other facets) are acceptable to most users, being a familiar experience while needing some improvements in ease of use and integration.

The study's findings significantly advance the development of LoRa-based communication technologies by enhancing understanding of physical interference effects on signal reliability, which aids developers in optimizing system configurations. It also emphasizes the need for user-friendly interfaces, making the technology accessible to non-technical users, such as disaster response teams. By demonstrating that LoRa can be integrated with intuitive interfaces, the study lowers the technical barrier, enabling broader adoption of this potentially life-saving technology in disaster response plans, thus improving communication and coordination during emergencies.

The study recommends several areas for further exploration and development to improve the technical capabilities and user experience of ECNeT and other LoRa-based communication technologies. These include optimizing hardware and software configurations to ensure system suitability and stability, investigating other technical aspects such as latency and power consumption, and implementing a true mesh network to enhance system range. Additionally, better cooling solutions should be developed to overcome current thermal constraints. The user interface should also be improved based on SUS results and further usability tests, and software integration should be enhanced by creating an APK version to ensure all features are well-implemented and user-friendly.

# References

11.1: One-Way ANOVA. (2021, August 10). Statistics LibreTexts. https://stats.libretexts.org/Bookshelves/Introductory_Statistics/Mostly_Harmle ss_Statistics_(Webb)/11%3A_Analysis_of_Variance/11.01%3A_One-Way_ANOVA

Adelantado, F., Vilajosana, X., Tuset-Peiro, P., Martinez, B., Melia-Segui, J., & Watteyne, T. (2017). Understanding the Limits of LoRaWAN. IEEE Communications Magazine, 55(9), 34–40. https://doi.org/10.1109/mcom.2017.1600613

Augustin, A., Yi, J., Clausen, T., & Townsley, W. (2016, September 9). A Study of LoRa: Long Range & Low Power Networks for the Internet of Things. Sensors, 16(9), 1466. https://doi.org/10.3390/s16091466Zacko

Bouguera, T., Diouris, J. F., Chaillout, J. J., & Andrieux, G. (2018, September). Energy consumption modeling for communicating sensors using LoRa technology. In 2018 IEEE Conference on Antenna Measurements & Applications (CAMA) (pp. 1-4). IEEE.

Brooke, J. (1996). Sus: a "quick and dirty'usability. Usability evaluation in industry, 189(3), 189-194.

Cattani, M., Boano, C. A., & Römer, K. (2017). An experimental evaluation of the reliability of LoRa long-range low-power wireless communication. Journal of Sensor and Actuator Networks, 6(2), 7.

Gbadoubissa, J. E., Abba Ari, A. A., Radoi, E., & Gueroui, A. M. (2023, June 6). M-Ary Direct Modulation Chirp Spread Spectrum for Spectrally Efficient Communications. Information, 14(6), 323. https://doi.org/10.3390/info14060323

Fang, H., Tan, R., Han, Y., Chen, X., & Zhao, J. (2018). An Experimental Analysis of SNR Performance for LoRa Communication. 2018 IEEE 4th International Conference on Computer and Communications (ICCC). doi:10.1109/compcomm.2018.8780989

International Telecommunications Union. (n.d.). Telecommunications Save Lives: The Role of Information and Communication Technologies in Disaster Response, Mitigation, and Prevention. In International Telecommunications Union.

Jagannath, J., Furman, S., Jagannath, A., Ling, L., Burger, A., & Drozd, A. (2019, June). HELPER: Heterogeneous Efficient Low Power Radio for enabling ad hoc emergency public safety networks. Ad Hoc Networks, 89, 218–235. https://doi.org/10.1016/j.adhoc.2019.03.010

Lewis, J. R., & Sauro, J. (2009). The factor structure of the system usability scale. In Human Centered Design: First International Conference, HCD 2009, Held as Part of HCI International 2009, San Diego, CA, USA, July 19-24, 2009 Proceedings 1 (pp. 94-103). Springer Berlin Heidelberg.

LibGuides: SPSS Tutorials: One-Way ANOVA. (2023, December 18). One-Way ANOVA - SPSS Tutorials - LibGuides at Kent State University. https://libguides.library.kent.edu/SPSS/OneWayANOVA

LoRa PHY | Semtech. (n.d.). LoRa PHY | Semtech. https://www.semtech.com/LoRa/what-is-LoRa

Macaraeg, K. C. V. G., Hilario, C. A. G., & Ambatali, C. D. C. (2020, October). LoRa-based mesh network for off-grid emergency communications. In 2020 IEEE Global Humanitarian Technology Conference (GHTC) (pp. 1-4). IEEE.

Marciano, J. J. S., Ramirez, P. R., Martinez, P., & Barela, M. C. (2016, October). ROGER: Robust and rapidly deployable GSM base station and backhaul for emergency response. In 2016 IEEE Global Humanitarian Technology Conference (GHTC) (pp. 128-135). IEEE.

Peng, D., Zhao, X., Zhao, Q., & Yu, Y. (2015). Smartphone based public participant emergency rescue information platform for earthquake zone–"E-Explorer". Vibroengineering Procedia, 5, 436-439.

Petajajarvi, J., Mikhaylov, K., Roivainen, A., Hanninen, T., & Pettissalo, M. (2015, December). On the coverage of LPWANs: range evaluation and channel

attenuation model for LoRa technology. In 2015 14th international conference on its telecommunications (itst) (pp. 55-59). IEEE.

Privitera, G. J., & Ahlgrim-Delzell, L. (2018). Research methods for education. Sage Publications.

Quitevis, C. P., & Ambatali, C. D. (2018, October). Feasibility of an amateur radio transmitter implementation using Raspberry Pi for a low cost and portable emergency communications device. In 2018 IEEE Global Humanitarian Technology Conference (GHTC) (pp. 1-6). IEEE.

RSSI and SNR. (n.d.). The Things Network. https://www.thethingsnetwork.org/docs/LoRawan/rssi-and-snr/

Saqib, N., Haque, K. F., Yelamarthi, K., Yanambaka, P., & Abdelgawad, A. (2021, June). D2D-LoRa Latency Analysis: An Indoor Application Perspective. In 2021 IEEE 7th World Forum on Internet of Things (WF-IoT) (pp. 29-34). IEEE.

Sagir, S., Kaya, I., Sisman, C., Baltaci, Y., & Unal, S. (2019). Evaluation of Low-Power Long Distance Radio Communication in Urban Areas: LoRa and Impact of Spreading Factor. 2019 Seventh International Conference on Digital Information Processing and Communications (ICDIPC). doi:10.1109/icdipc.2019.8723666

Sauro, J. (2018, September 18). *5 Ways to Interpret a SUS Score – MeasuringU*. Retrieved May 16, 2024, from https://measuringu.com/interpret-sus-score/

Sciullo, L., Fossemo, F., Trotta, A., & Di Felice, M. (2018, December). Locate: A LoRa-based mobile emergency management system. In 2018 IEEE global communications conference (GLOBECOM) (pp. 1-7). IEEE.

SDLC - RAD Model. (n.d.). SDLC - RAD Model. https://www.tutorialspoint.com/sdlc/sdlc_rad_model.htm

Seye, M. R., Ngom, B., Gueye, B., & Diallo, M. (2018, July). A study of LoRa coverage: Range evaluation and channel attenuation model. In 2018 1st International Conference on Smart Cities and Communities (SCCIC) (pp. 1-4). IEEE.

SX1272/73 DATASHEET (2017). Semtech Corporation

Tan, Z. A., Rahman, M. T. A., Rahman, A., Hamid, A. F. A., Amin, N. A. M., Munir, H. A., & Zabidi, M. M. M. (2019, November 1). Analysis on LoRa RSSI in Urban, Suburban, and Rural Area for Handover Signal Strength-Based Algorithm. IOP Conference Series: Materials Science and Engineering, 705(1), 012012. https://doi.org/10.1088/1757-899x/705/1/012012

Wadatkar, P. V., Chaudhari, B. S., & Zennaro, M. (2019). Impact of Interference on LoRaWAN Link Performance. 2019 5th International Conference On Computing, Communication, Control And Automation (ICCUBEA). doi:10.1109/iccubea47591.2019.912841

World Risk Report. (2023, September 20). WeltRisikoBericht. WeltRisikoBericht. Retrieved February 4, 2024, from https://weltrisikobericht.de/en/

Zubair, Ahsanul. (2023). Experimental Research Design-types & process. Academia Open.