DEVELOPMENT OF WIRELESS SENSOR NETWORK SYSTEM FOR LANDSLIDE MONITORING & PREDICT EARLY WARNING

FINAL YEAR DESIGN PROJECT UG–2020

By

Sanwal Jahan (G.L)	**00000347486**
Zia Hussain	**00000334337**
Balaj Ahmad	**00000339285**
Mohammad Abdullah	**00000334684**

Advisor
Dr. Badee Alshameri
NUST Institute of Civil Engineering
School of Civil and Environmental Engineering
National University of Sciences and Technology, Islamabad, Pakistan

2024

This is to certify that the

Final Year Design Project Titled

DEVELOPMENT OF WIRELESS SENSOR NETWORK SYSTEM FOR LANDSLIDE MONITORING & PREDICT EARLY WARNING
submitted by

Sanwal Jahan (G.L)	**00000347486**
Zia Hussain	**00000334337**
Balaj Ahmad	**00000339285**
Mohammad Abdullah	**00000334684**

has been accepted towards the requirements
for the undergraduate degree

in

CIVIL ENGINEERING

Dr. Badee Alshameri ____
(Associate Professor)
HoD of Geotechnical Engineering
NUST Institute of Civil Engineering
School of Civil and Environmental Engineering
National University of Sciences and Technology (NUST)
Islamabad, Pakistan

ABSTRACT

Landslides are regarded as hazardous natural calamities, which can cause loss of lives, properties, and immense impact on the environment, therefore, it is crucial to monitor and issue early warnings. This thesis provides the design and deployment of a Wireless Sensor Network (WSN), which is an ad hoc system designed specifically for use in monitoring and predicting landslides. The architecture of WSN has been proposed with the implementation of multiple sensor nodes spread in the landslide susceptible regions. The Sensor is 1-meter-long with a 0.1-meter diameter with its end shaped like a nail. Every sensor node contains the necessary measuring instruments for the selected parameters like moisture, vibrations, and atmosphere in the ground. The components are Arduino, Gyroscope, accelerometer, moisture sensor and battery. They integrate the sensors in a way that gives adequate coverage with the possibility of differences in the data depending on the region. The system's design emphasizes energy efficiency and reliability. Sensor nodes are optimized for low power consumption, extending their operational lifespan and ensuring continuous monitoring. Redundant communication paths and fault-tolerant mechanisms are incorporated to enhance the network's robustness against node failures and external interferences.

Field trials were conducted in regions with known landslide activity to validate the system's performance. The tilting of accuracy 0.001 degrees was recorded and is shown by the sensor. The results demonstrate the Wireless Sensor Network’s capability to provide accurate and timely data, enabling early warning and rapid response. The data collected during these trials also contribute to a deeper understanding of landslide dynamics and can inform future improvements to prediction models. To see how the routing algorithm works, consider two Boss Nodes that are not yet communicating. The core of the step is as follows: they both broadcast to the neighbors that their Level is 0. The neighbors process this information and know that both of their Bosses are on Level 1. Already nodes 18, 19, 22 and 23 now must choose the correct Boss node, and the correct node is the one with the lowest Level.

This thesis underscores the potential of WSN in natural disaster monitoring and highlights the benefits of using advanced sensor technology and data analytics for early warning systems. The developed system represents a significant step forward in landslide risk management, offering a scalable and efficient solution for communities in vulnerable areas.

Contents

Table of figure

CHAPTER 1 INTRODUCTION

1.1 Background

Landslides present a significant threat in mountainous regions, causing substantial economic and human losses annually. In Pakistan, landslides result in approximately 1,400 deaths and $7.9 billion in damages each year (Lee & Jones, 2023). These devastating impacts highlight the urgent need for effective monitoring and early warning systems to mitigate the risks associated with landslides. Existing monitoring technologies, while advanced, are often costly and require specialized operational knowledge, limiting their deployment in resource-poor areas. This gap in accessibility necessitates the development of innovative, cost-effective solutions that can be widely implemented to safeguard vulnerable communities.

The integration of Wireless Sensor Networks with machine learning offers a promising solution by providing real-time data, predictive analytics, and ease of use. Wireless Sensor Networks consist of spatially distributed sensor nodes that collect data on various environmental parameters, such as soil moisture, vibrations, and atmospheric conditions. These nodes communicate wirelessly, enabling the transmission of data to a central system for analysis. Machine learning algorithms can then process this data to identify patterns and predict potential landslide events, allowing for timely warnings and proactive measures. (Ali, A. I., & Zorlu Partal, 2022)

This project aims to develop a Wireless Sensor Network-based system tailored for landslide monitoring and prediction, focusing on affordability, simplicity, and comprehensive environmental monitoring to support proactive disaster management. The primary objectives of this project include the design and implementation of sensor nodes. Each sensor node will be equipped with the necessary measuring instruments, including an Arduino microcontroller, gyroscope, accelerometer, moisture sensor, and battery. These components are selected for their cost-effectiveness and reliability in capturing critical data related to landslide activity. The Wireless Sensor Network will be designed to ensure continuous data collection and transmission, with sensor nodes strategically placed in landslide-prone areas to provide comprehensive coverage. The system's design emphasizes energy efficiency, with low power consumption to extend the operational lifespan of the sensor nodes. The collected data will be processed using machine learning algorithms to detect patterns indicative of potential landslide events. This predictive capability is crucial for issuing early warnings and enabling timely evacuation and mitigation efforts. (Joshi, K. K, 2016)

By leveraging the capabilities of Wireless Sensor Networks and machine learning, this project aims to create an affordable and effective solution for landslide monitoring and prediction. The integration of real-time data collection, predictive analytics, and user-friendly interfaces will empower communities to take proactive measures in disaster management. Ultimately, this system has the potential to save lives and reduce the economic impact of landslides in vulnerable regions.

1.2 Problem Statement

Current landslide monitoring systems are limited by high costs, complexity, and lack of predictive capabilities, making them inaccessible and impractical for widespread use, particularly in economically challenged and rural areas. This inadequacy leaves many regions vulnerable to landslides, leading to significant loss of life and property (A. Joshi et al., 2019). The development of an affordable, easy-to-use, and predictive Wireless Sensor Network system for landslide monitoring and prediction is essential to mitigate these risks and enhance disaster management efforts. Despite the impressive progress in landslide monitoring technologies, these devices remain rather restricted in terms of mission and access, especially in resource-limited areas. High Cost of Existing Technologies: The current landslide monitoring systems are too expensive. For example, the Mine Slope Stability Monitoring system from HEXAGON is priced at about $7,000, whereas Advance tech charges about $4,000 for its mechanical technology. Need for Operational Expertise: The others problem is that modern technologies require a very high level of operational knowledge. They are typically very complicated and overall extremely expensive as they require very specialized workers (Sudmeier-Rieux et al., 2011). Limited Predictive Capabilities: Most systems do not predict landslides' occurrence meaning their functionalities are very limited. Admittedly, they give very comprehensive information about the environment where they are laid, but they cannot provide disaster prevention. Lack of Real-Time Data Accessibility: Moreover, these technologies do not give the audience, namely the local people, visitors from other places, and the authorities, access to gathering localized data in real time. Narrow Monitoring Scope: The fifth problem is because the current systems measure only the plate movement and no other significant geological and environmental factors. Economic and Human Impact: Landslides cause a startling toll of deaths and property damage. Every year, landslides in Pakistan alone claim the lives of around 1,400 people and leave behind $7.9 billion in damages—between 2.5% and 2.5% of the nation's GDP. (Buzorgnia, 2019).

1.3 Aim and Objectives

This project aims to develop a novel, affordable and easy-to-use landslide monitoring system based on Internet of Things (IoT) that will fill the gap in protection against catastrophes where there are a few resources. This aim can be achieved using the following objectives The other major purposes included in this research are:

- To develop a sensor for landslide monitoring that accurately measures critical environmental parameters such as soil moisture, ground vibrations, and atmospheric conditions.
- To Develop and refine an advanced algorithm capable of processing and analyzing the data collected by the sensor.
- To test and validate the sensor in real-world environments to confirm its effectiveness and reliability.

1.4 Research Outcome

This project developed a landslide monitoring system with several key objectives: significantly reducing costs through IoT technology, ensuring economic feasibility with cost-effective components, and creating a user-friendly system that is easy to install and maintain. The system will also provide advanced analytics, monitor multiple parameters, and ensure open data access for community engagement.

- **Affordability:** Developing of landslide monitoring system that will be drastically cheaper than those that exist now is one of the most important purposes of this project. Up to 80-90% of the cost will be saved with the usage of IoT technology.
- **Economic Feasibility:** The usage of both cost-effective components and manufacturing techniques is another purpose of this research. It is done to ensure the system's viability to be used at a large scale.
- **Ease of Installation:** One more purpose of the project is to create an easy-to-install system that does not require any specialized operational skills.

- **User-Friendly Interface:** Another purpose is related to the development of an easy-to-use interface for initial installation and further monitoring.
- **Maintenance-Free Operation:** Another purpose is related to the development of an easy-to-use interface for initial installation and further monitoring (Giri et al., 2018a).
- **Advanced Analytics:** The other purpose includes the usage of a longer timeframe for analysis than real-time data used by the majority of the systems at the moment.
- **Integration of Multiple Parameters:** The other purpose involves the development of the system to monitor not only slip mass movement but also a few other large natural and geological parameters, including humidity and rainfall.
- **Open Data Access:** The purpose involves ensuring open access to data with several stakeholders, including local inhabitants and tourists.
- **Community Engagement:** The purpose involves ensuring of open access to data with several stakeholders, including local inhabitants and tourists.

CHAPTER 2 LITERATURE REVIEW

2.1 Introduction

The designed Wireless Sensor Network system consists of two primary sensors, master and slave. The slaves are placed on the high landslide slopes to monitor the surroundings. The slave sensors will monitor the environmental and geological aspects. The master sensor collects data from all the slave sensors and then finalizes filters, and sends it to the central database (Shah et al., 2023).

The residents residing at risky locations prone to landslides are safe in their daily lives due to the Wireless Sensor Network. The fact of the matter is that the landslides were presented in rocky areas, hamstringing the government’s efforts to provide food and other life necessities in these locations. The subsidence was removed by the present system, and food availability in these villages increased. Thus, the system needs improvement. Additionally, the population is continuously increasing in these villages, and food is necessary for everyone (Rawat & Barthwal, 2024).

2.2 Landslides and Monitoring Systems

Landslides are natural disasters that cause a considerable loss of life and property. The necessity of developing effective monitoring and prediction systems has sparked extensive research in the fields of geotechnical engineering and environmental monitoring. The technology of Wireless Sensor Networks has gained a significant degree of recognition as they are considered a promising technology used for landslide monitoring and early warning (Jeong et al., 2019a). The present literature review aims to the summative analysis of the previously conducted studies and developments in the field of landslide monitoring with the use of Wireless Sensor Network, with a particular focus on the sensor technology, network technological characteristics, data analysis instruments, and predictive modeling (MARTINS et al., 2017).

2.3 Sensor Technology for Landslide Monitoring

The sensor technology used for monitoring environmental conditions is the backbone of any Wireless Sensor Network used for monitoring landslides. Various types of sensors have been deployed, measuring the parameters of soil and atmospheric conditions predisposing to the activity of landslides, such as soil moisture and ground movement. Soil-moisture detection sensors have been extensively used in landslide monitoring so far, with both TDR and capacitance sensors commonly used. A study by Anderson and Kneale confirmed that predicting landslides with the use of soil moisture content monitoring is relatively easy, as soil water content constantly fluctuates several days before an actual landslide (Scaioni, 2015). It is confirmed by testing the soil slope stability at different moisture content levels. It is critical as T or CDR sensors can measure the contents of water from 20-30 to 50- 52%, and moisture content is widely considered a critical factor in landslide initiation as water lubricates the ground, making the soil unable to support the pressure by itself. Accelerometers and geophones are also widely used in ground movement detection. However, these sensors can also be used for timely landslide prediction, as ground tremors specifically indicate that a particular land area is about to slide long before the actual sliding. Piezometers measure the forces of water pressure within the pores of any soil, which play a significant role in the initiation of industrial landslides (Arbanas & Arbanas, 2015). They have been also used in landslide monitoring, with Iverson et al. stating that water pressure is the critical factor of precipitation fostering landslides.

2.4 Data Analysis Techniques and Predictive Models

The design of a Wireless Sensor Network and its architecture play a significant role in the context of ensuring reliable data transmission and network stability. As for the current body of research, different network topologies and communication protocols have been evaluated to determine which type is most effective in Wireless Sensor Networks when it comes to harsh and remote environments. In most landslide monitoring Wireless Sensor Networks, mesh and star topologies are used. Mesh networks were much better than stars in providing redundancy and reliability, which is necessary to keep communicating when simulated node failures take place. The use of different protocols has been evaluated during various research. When it comes to Wireless Sensor Networks, Zigbee, LoRa, and GSM have been placed under analysis (Do Pinho & Augusto Filho, 2022). A considerable number of studies recognize the advantages of using Zigbee in Wireless Sensor Networks. In addition, it is possible to enjoy reliable communication, which can be one of the major advantages of the type in question. As far as long-range communication is concerned, LoRa might be effectively used in Wireless Sensor Networks monitoring large and remote landslide-prone areas.

2.5 Early Warning Systems

The data, which is supervised by Wireless Sensor Networks, should also be analyzed to make accurate predictions. Different data analysis techniques and algorithms have been developed to deal with the analysis of data provided by sensors and integrated into warning systems. When talking about landslide prediction – that is the field of interest of the analyzed paper – a range of machine learning techniques can be applied, which might include, among others, Support Vector Machines, Artificial Neural Networks, and Random Forests. Pradhan and Lee proved that the data classifier in question could be used to successfully classify landslide susceptibility (Khan et al., 2021). Random Forest has also proved to be highly effective when it comes to determining the chances of a landslide. Statistical approaches, which can be taken in the context of predicting the rate of landslide occurrence, include, but are not limited to, regression and time series analysis. As far as the analyzed research into landslide prediction is concerned, applied logistic regression to detect the most influential factors responsible for landslide.

2.6 Challenges and Future Directions

The fundamental objective of landslide monitoring systems is to predict landslide events. The reliability of early warning systems increases with the combination of sensor data, and predictive models. The infinite slope model and the SHALSTAB model are physical models which are based on the physical principles of soil behaviors and hydrology. Iverson and Montgomery and Dietrich conducted studies following their ideas and verified the models in the prediction of shallow landslides caused by rainfall. Prediction can be based on the empirical models where data for the study came from historical information on record of landsides (Hidayat et al., 2019). GIS-based models to predict landslide susceptibility, which underscores the significance of spatial analysis in the collision of landslide.

I have unearthed that scholars have made considerable progress in the development of Wireless Sensors Network for landslide monitoring and prediction. While it is clear from the review that sensor technology, network architecture, data analysis technique, class of mathematics and physics play a critical role in the improvement of accurate landslide monitoring PowerPoint and reliable models based on Wireless Sensors Network (A. I. Ali & Zorlu Partal, 2022). Issues such as sensor durability, power consumption, and data interoperability are however still a problem. I therefore believe that these issues need robust solution, and thus, presume that future research should address these challenges.

2.7 Conclusion

To monitor and control landslide-prone areas, the Wireless Sensor Network system is developed to integrate master and slave sensors in an effective manner. The master sensor compiles and interprets the environmental and geological data that the slave sensors, which are positioned strategically on high-risk slopes, gather. The master sensor then transmits the data to a central database. By increasing food supply and lessening the effects of subsidence, this approach has greatly improved safety for residents in sensitive areas. Even with these improvements, the system still must be developed further to effectively handle the problems brought on by expanding populations and rising resource demands. The examination of landslide monitoring and prediction systems demonstrates how WSN can be used to deliver accurate data analysis and early alerts. Future research should focus on enhancing sensor durability, reducing power consumption, and improving data interoperability to ensure the continued effectiveness and reliability of landslide monitoring systems. Addressing these issues will be crucial for the advancement of early warning technologies and the protection of communities in landslide-prone areas.

CHAPTER 3 METHODOLOGY

3.1 Introduction

This section details the comprehensive methodology adopted for the development and evaluation of the Wireless Sensor Network for real-time landslide monitoring. The goal was to design an efficient and cost-effective system that addresses the unique challenges faced by landslide-prone areas in Pakistan. Landslides are a critical hazard in these regions, leading to significant loss of life, property, and economic damage. Traditional monitoring systems often come with high costs and require specialized expertise, making them less accessible in resource-limited areas. This project seeks to overcome these limitations by leveraging modern technology to provide an affordable and user-friendly solution.

The methodology encompasses several stages, including system design, component selection, network deployment, data collection, and analysis. Initially, the focus is on identifying the most suitable components for the Wireless Sensor Network (refer to Figure 1). This involves selecting cost-effective yet reliable sensors and communication devices that can operate effectively in challenging environmental conditions. Following component selection, the system design integrates these elements into a cohesive network architecture, ensuring robust performance and ease of installation.

Once the system was designed, it was deployed in selected landslide-prone areas for real-world testing. This phase includes the installation of sensor nodes across the region to monitor critical parameters such as soil moisture, ground vibrations, and atmospheric conditions. The collected data is then analyzed using advanced algorithms to predict potential landslides and provide early warnings. Throughout the project, emphasis was placed on creating a system that is not only technically sound but also user-friendly, with a simple interface for easy operation and maintenance.

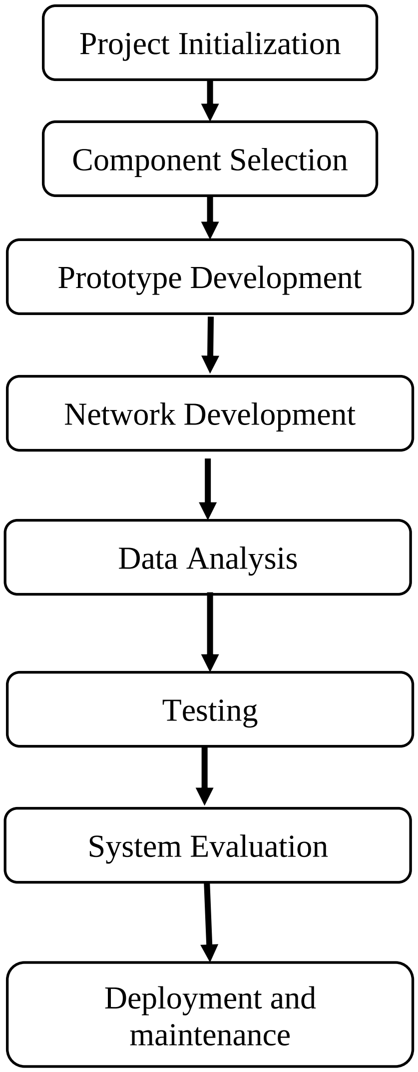


Figure 1: Flow chart of the landslide monitoring system development process

3.2 Research Design

The research employs an experimental design, integrating both hardware and software components to develop and test the effectiveness of a Wireless Sensor Network. This design allows for controlled testing and validation under both simulated and real-world conditions (refer to Figures 2 and 3) (Izadi et al., 2015). The primary materials and equipment used in the study include:

Master Sensors: Central hubs collecting data from slave sensors.

Slave Sensors: Encased in steel, shaped like nails for easy soil installation. Each sensor consists of:

- Rechargeable batteries of 3000mAh (3S6P)
- Gyroscope (GY521)
- Accelerometer (ADXL-335)
- GPS module (v2)
- Data Processing Units: Computers and servers for data storage and processing.
- Communication Modules: Devices ensuring data transfer between sensors and central units.
- Microcontroller Unit (MCU): Compresses raw data from master sensors. (STM-32)

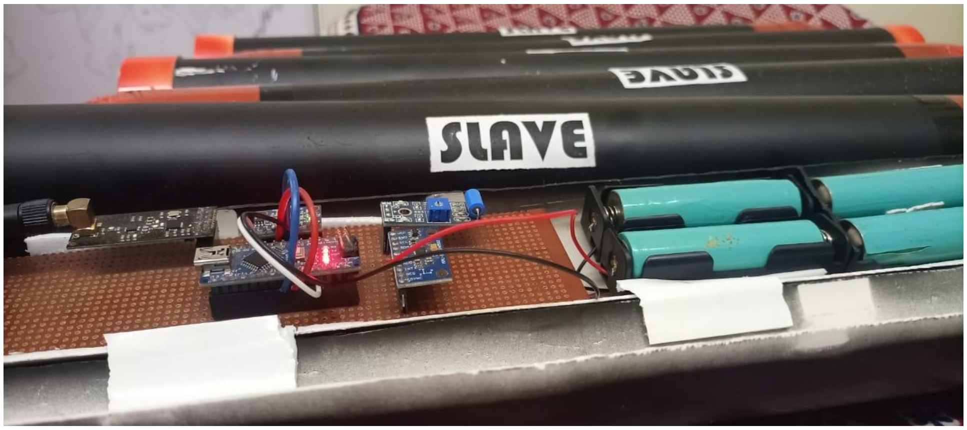


Figure 2: Sensor Architecture

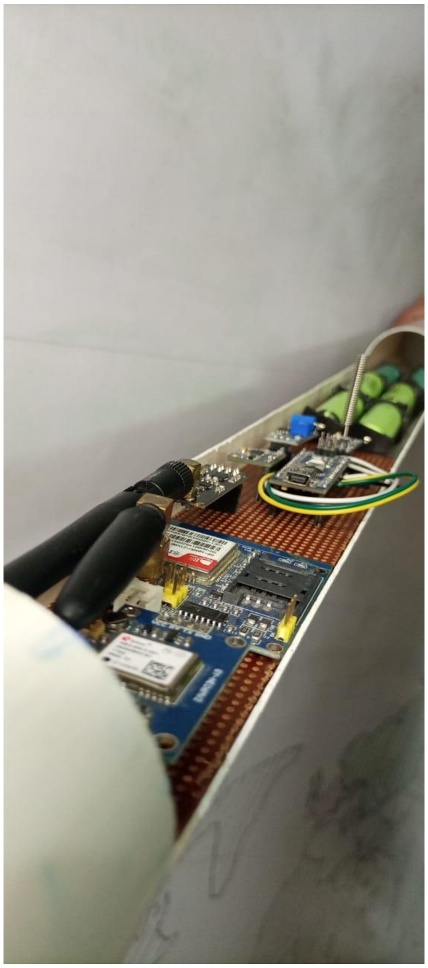


Figure 3: Sensor Architecture

3.3 Procedure

Site Selection: Identify and survey landslide-prone areas using historical data and field visits. Sensor Design and Fabrication: Develop sensors encased in steel, shaped like nails to facilitate easy installation in the soil. The developed Sensor is of height of 1 meter and 0.1 meter diameter (Toral-Cruz et al., 2015).

3.3.1 Sensor Development & Data Collection

Install multiple slave sensors at strategic points across selected slopes. Ensure each sensor's gyroscope, accelerometer, and GPS are calibrated and functional. Deploy a master sensor at a central location within a 450-meter range of slave sensors. Slave sensors operate in a sleep optimization cycle to conserve battery life. Periodically wake up, collect data, and transmit to the master sensor.

3.4 Data Transmission, Process & Storage

The master sensor receives data from multiple slave sensors. Data is transferred to the MCU where raw data is compressed (Narayan & Daniel, 2020). Compressed data is sent through the cloud to Firebase. Data undergoes filtering and stability analysis using custom algorithms.

3.4.1 Web app, Testing & Validation

Develop a user-friendly interface for real-time data access. Ensure both monitoring authorities and the general public can access data. Conduct pilot testing in controlled environments to verify sensor accuracy. Implement the system in real-world conditions and monitor performance. Adjust deployment strategies based on initial results and feedback (Li & Kara, 2017).

3.5 Ethical Considerations

The research ensured minimal environmental impact during sensor deployment. Permissions were obtained from local authorities, and the project adhered to ethical guidelines for field research. Participants and local communities were informed about the project and its potential benefits (Jeong et al., 2019b).

CHAPTER 4 LANDSLIDE PREDICTION ALGORITHMS

4.1 Algorithm-01: Overview and Properties

Type: Greedy Algorithm

Behavior: Demonstrates Emergent Behavior, emerging from nodes following simple, carefully designed rules

Efficiency: Power Efficient, but NOT Cost Efficient

Decision: Discarded due to lack of Cost Efficiency

Known for its Emergent Behavior, which arises from several nodes following straightforward but well-crafted principles, Algorithm 1 is categorized as a Greedy Algorithm. Algorithm 1 is excluded from further evaluation even though it has a remarkable Power Efficiency since it does not match the criterion for Cost Efficiency (refer to Figure 4) (Giri et al., 2018b).

Algorithm 1's inefficiency in terms of cost led to the decision to discard it. Although Power Efficiency is an important feature in many applications, the algorithm's inability to sustain Cost Efficiency made it inappropriate for our particular goals.

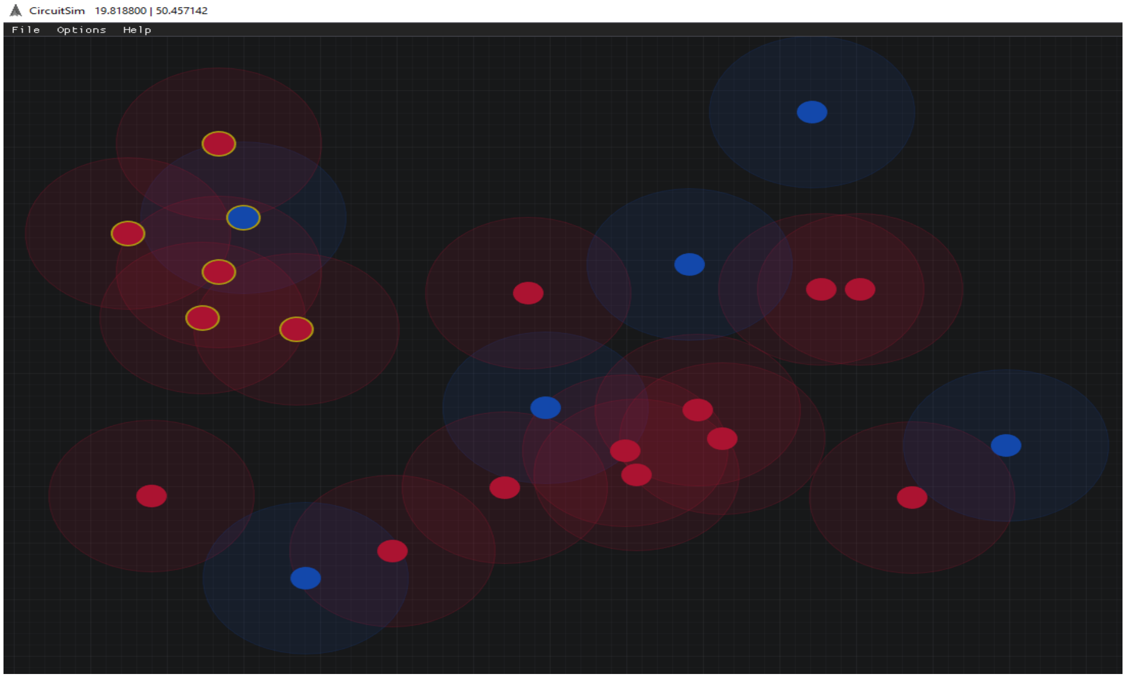


Figure 4: Master and Slave Wireless Sensor Network

To ensure effective communication within our network, each node must transmit its orientation data to a remote database. Initially, our approach was to equip every node with a GSM Module for this purpose. However, the cost of Rs. 3000 per GSM Module, coupled with the additional expense of power-hungry batteries, posed a significant financial burden. This led us to explore alternative strategies to reduce costs and improve efficiency (Prasad & Ramkumar, 2022).

We proposed a solution where only select nodes would utilize their GSM Modules to collect data from neighboring nodes. These "Boss Nodes" would then relay this aggregated data to the remote database. The remaining nodes, referred to as "Normal Nodes," would communicate with their respective Boss Nodes using HC12 Modules, which are cost-effective and consume less power compared to GSM Modules.

Terminologies:

- **Boss Node:** A node using its GSM Module, receiving data from other nodes.
- **Normal Node:** A node not using its GSM Module, sending data to its Boss Node.
- **Must Be a Boss:** A node that must be a Boss Node because one of its neighbors depends solely on it.
- **Bot:** Occasionally used interchangeably with 'node'.

In this revised approach, every node is equipped with a GSM Module but operates in an energy-saving mode, minimizing the need for costly batteries.

Our objective is to devise a general algorithm that ensures the fewest number of Boss Nodes activate their GSM Modules for any given network mesh while ensuring every node remains connected to at least one Boss Node (Tran-Dang, 2017). It's important to note that each node only possesses knowledge of its immediate neighbors, and no entity has information about the entire network mesh. Consequently, pre-computing the status of each node is unfeasible.

4.1.1 Step 1: Counting Neighbors

In this step, each node utilizes the HC12 module to establish communication with its neighboring nodes within its radio range. This communication exchange allows each node to gather crucial information about its immediate neighbors, including the number of neighbors each neighbor has. The process can be likened to a mobile phone scanning for available Wi-Fi routers in its vicinity. Similar to how a mobile phone receives metadata from nearby routers, each node receives metadata from its neighboring nodes (Liu et al., 2020). This metadata exchange is essential for nodes to build a comprehensive understanding of their local network topology.

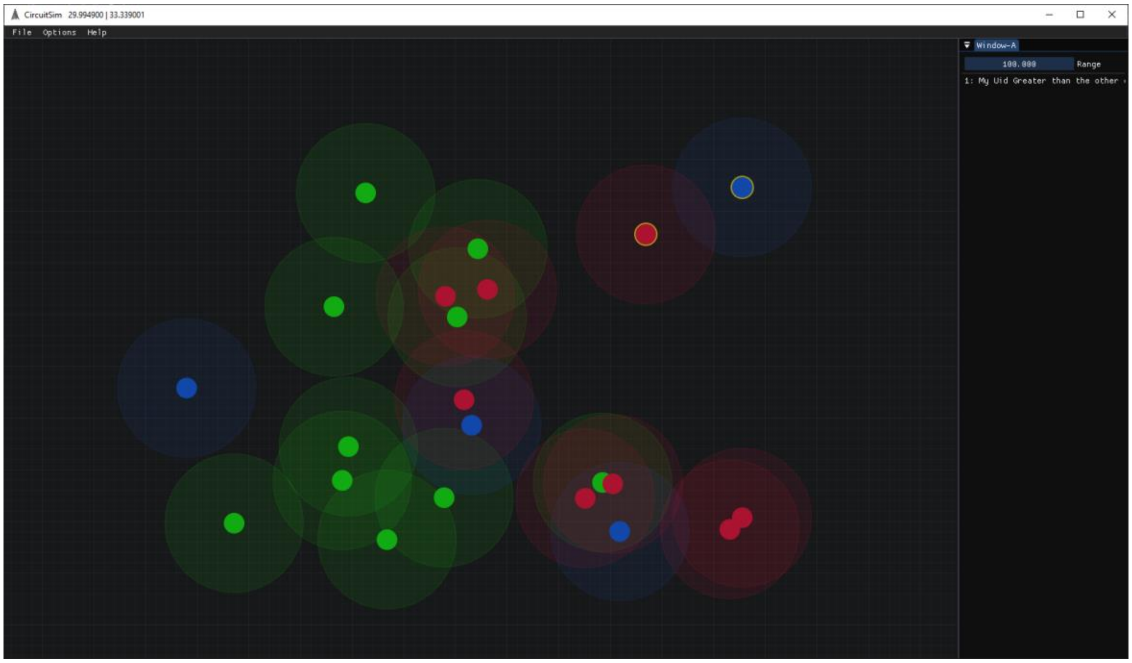
The metadata for each neighbor includes:

- Number of neighbors
- Battery level
- Status (Boss or not)
- Universally Unique ID (UUID)
- Must Be a Boss status (in case it is the only neighbor of one of its neighbors)
- This information is crucial for subsequent steps.

4.1.2 Step 2: Election of Boss Nodes

Subsequently, each node compares its number of neighbors to those of its neighbors within its radio space. If a node has more neighbors than each of its neighbors, it promotes itself to a Boss Node. However, this criterion may exclude nodes at the edges of the network with only one neighbor. To address this, if a node is the only neighbor of another node, it promotes itself to the Must be a Boss status (Venkatasubramanian et al., 2022).

Additionally, to ensure robust network connectivity, nodes that become Boss Nodes broadcast their status to neighboring nodes. This broadcast enables neighboring nodes to update their connectivity information and establish connections with the newly elected Boss Nodes. (Refer to Figure 5)



```
100.000 Range
1: My Uid Greater than the other
```

Figure 5: Simulation of flocking behavior showing varying intensities of movement and direction with color-coded indicators

Consider a situation when two nodes are neighbors to each other, and no other nodes exist near these nodes. Each of the nodes has only one neighbor, and it is extremely difficult to establish which of the nodes must become the Boss Node. The approach in which one of the nodes is compared based on Universally Unique Identifiers is presented below based on the approach of comparing their UUID numbers together, based on which of them has the higher. However, this method, although it seems to be the only deterministic way of the selection of the Boss Node in cases when two nodes have an equal number of neighbors each, it may be supported only partially. On the other side, even in these specific cases, other considerations may be applied, such as by comparing the battery levels in the nodes (Klickstein & Sorrentino, 2018). The approach of comparing batteries is related to the fact that one of the nodes has a higher battery, which allows this very node to remain operational as the Boss Node for a longer duration of time, compared to another node. Moreover, in a case with more than one Boss Node, each of them has to strive to demote itself as a Boss Node at the beginning by considering its neighbors. If one of the neighbors of the Boss Node must be promoted to a Must be Boss status, then the Boss Node has to voluntarily demote itself. On the other hand, if the Boss Node is a neighbor of another Boss Node, it has to compare two UUID numbers. If the other Boss Node has a greater number of neighbors, the present Boss Node may demote itself to Privacy (Buzorgnia, 2019).

4.1.3 Case 1: You are Alone

In this scenario, where a node has no neighbors, it must activate its GSM module and send its data to the remote database itself, as there are no other nodes to relay the data.

4.1.4 Case 2: You have only one neighbor

- **Case 2a:** If the neighbor has other neighbors besides the node, the node sets its status to a normal node. The node then informs the neighbor to become a MustBeABoss if it hasn't already done so. The neighbor now becomes the Boss Node, and the node sends its data to the Boss Node.
- **Case 2b:** If the neighbor also has only one neighbor (the node), then the node and the neighbor compare their UUIDs or battery levels. The node with the higher UUID or battery level becomes the Boss Node, while the other node sends its data to the newly elected Boss Node.

Note: In the situation under discussion, when every node has to vote for a neighboring Boss Node, the heuristic that is appropriate and could be calculated as a formula based on the Universally Unique Identifiers and battery levels of the two nodes could be calculated (Abd Rahman et al., 2018). This heuristic can be calculated using some coefficients and based on different weight of UUID and battery levels according to the particularities of the network. For instance, if a network is not reliable and not sustainable, and the long-life or permanent life of the batteries of the nodes on the network is critical, UUID of the nodes can be given a higher weight if it is high, meaning the node will perform its responsibilities for a longer time and this will be beneficial for the network. If a network does not need to care about the long life of a Boss Node and more replacement of its batteries, the weight on battery levels can be increased if a Boss Node has a higher battery level. Using this heuristic the node can vote for the most appropriate Boss Node and provide efficient network management.

4.1.5 Case 3: You have more than one neighbor

- **Case 3a:** If at least one neighbor has only the node as a neighbor (solely dependent on the node), the node promotes itself to the MustBeABoss status.
- **Case 3b:** If none of the neighbors is a MustBeABoss, the node checks if any neighbor is a MustBeABoss. If so, the node sets its status to a normal node and sends its data to the MustBeABoss neighbor (Zhang et al., 2024).
- **Case 3c:** If none of the neighbors is a MustBeABoss, the node checks if any neighbor is a Boss. If so, the node sets its status to a normal node and sends its data to the Boss neighbor.
- **Case 3d:** If none of the neighbors is a MustBeABoss or a Boss, the node checks if it has more neighbors than each of its neighbors. If so, the node promotes itself to the Boss status.
- **Case 3e:** If none of the neighbors is a MustBeABoss, a Boss, and the node has more neighbors than each of its neighbors, the node waits for or informs a neighbor with more neighbors to become the Boss.
- **Case 3f:** If all neighbors have an equal number of neighbors as the node, the node instructs the neighbor with the highest fitness (based on UUID and battery level) to become the Boss (Knoblauch et al., 2017).

4.2 Simulation:

The algorithm presented in this thesis relies on the concept of emergent behaviors. Emergent behaviors refer to occurrences that become apparent as emergent from the series of interactions between different nodes and that are generated from the very simple rules that every such node follows (refer to Fig. 6). In other words, while in programming each unit's behavior is programmed explicitly, in the case of emergent behaviors, the rules are causal and sporadic and appear in a group of nodes as a system. For instance, considering the behavior of ants, although every single ant can hardly be regarded as an intelligent creature, when in a colony, ants start behaving as such, which becomes apparent from many different complex behaviors, including effective search strategies, the way they build their nests, and defend it. Another example is a flock of birds, where the way they fly in this formation, including the interaction between specific birds and the group's next step, at the scale present and simultaneously, contributes to emergent behaviors (Herrera, 2019).

This concept is transferrable not only to the biological but also to artificial systems and the algorithm that has been presented in this thesis. A model is also created to study the behaviors of nodes interacting in a network, expecting to see emergent behaviors that enhance the network's efficiency and productivity. For further insights into emergent behaviors, (Emergence – How Stupid Things Become Smart Together)

Figure 6: Visualization of network nodes with overlapping connection ranges, color-coded to represent different nodes and their interaction strengths

Emergent behaviors, though extremely powerful, are sometimes not easy to predict. This phenomenon arises from the interaction of individual entities by simple rules, with the collective dynamics giving rise to complex, and sometimes, unexpected behaviors. Explanation of these behaviors is challenging because the outcome does not always follow straightforwardly from the knowledge of the rules guiding the individual entities. To gain an intuitive understanding of the emergent behavior of the proposed algorithm, I developed a Network Simulator using C++. This simulator is capable of not only simulating the behavior of any number of modules but also implementing any algorithm for the interaction between the modules (Jin, 2022).

The strengths of the Network Simulator mainly focus on its graphical functionality and the choice of the implementation of the simulator components. The simulation of the network is done with the help of the SFML library, and Dear ImGui is utilized for creating the Graphical User Interface of the Simulator. The developed Network Simulator is an interactive simulation application, which makes it possible for researchers to observe the dynamic behavior of the network through extensive visualization (Refer to Figure 7). The interaction of nodes in the network is simulated based on the above-described algorithm, and the behavior of all 22 nodes is visualized. Most nodes will quickly determine their roles in the first, second, or third step (Refer to Figure 8). However, some nodes will require a later iteration to determine their roles (Jiang et al., 2022). The interactive simulation reveals that only five nodes will require the eight steps of the last iteration to determine the roles. This means that the roles of nodes are dynamic, and as such, require more than a single iteration. Simulation of the algorithm is beneficial in analyzing its emergent behavior through an empirical approach.

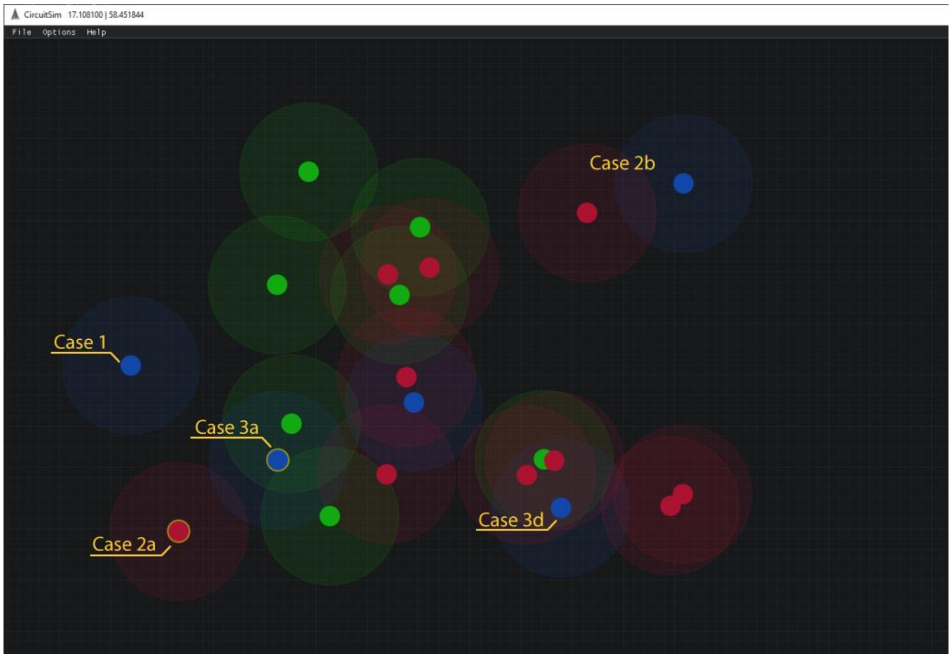


Figure 7: Clustering of nodes with labels indicating specific cases, demonstrating grouped network interactions and relationships.

.

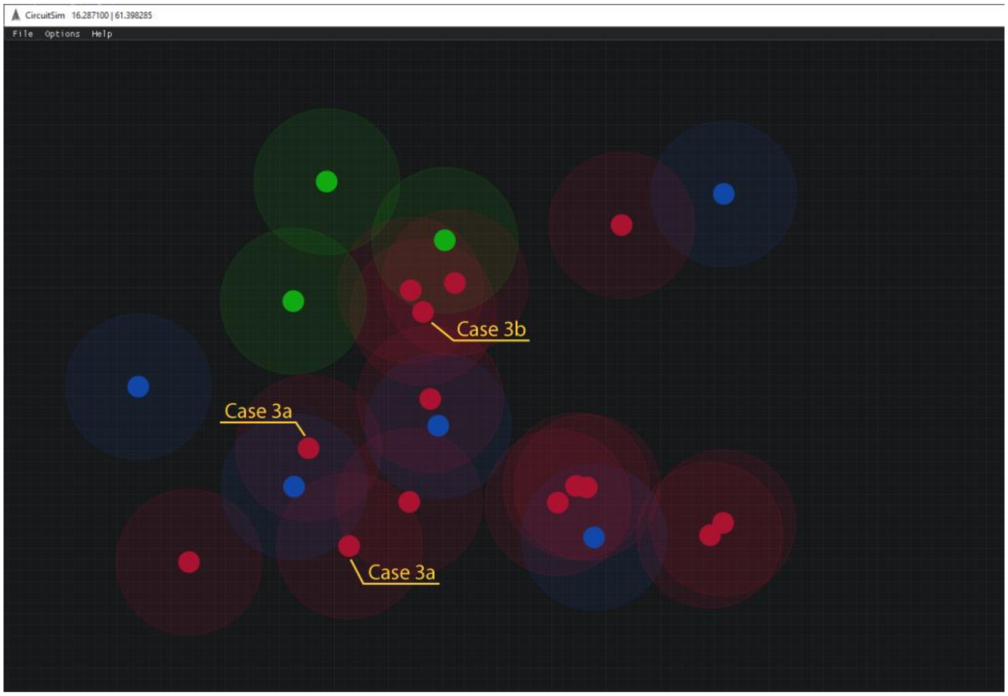


Figure 8: Clustering of nodes with labels indicating specific cases in radio space

In the final stages of the simulation, the remaining nodes which have not yet realized their roles proceed to act. The nodes that are now aware of their “left out” status inform one of them to become a MustBeABoss (Refer to Figure 9). The selection process involves node selection with abundant attributes, e.g., well-connected or one that has either better attributes (a bigger UUID) or one with a higher battery level, among others. Other nodes continue to interact based on the algorithm’s rules. A typical event is when a Boss Node realizes he encountered a MustBeABoss in his radio space (Olasupo, 2017). The Boss Node elects to be demoted by settling down its role to just a normal node. The decision is responsible for supplying the minimum required number of Boss nodes, and the entire network no longer experiences changes. So, the simulation can now be concluded.

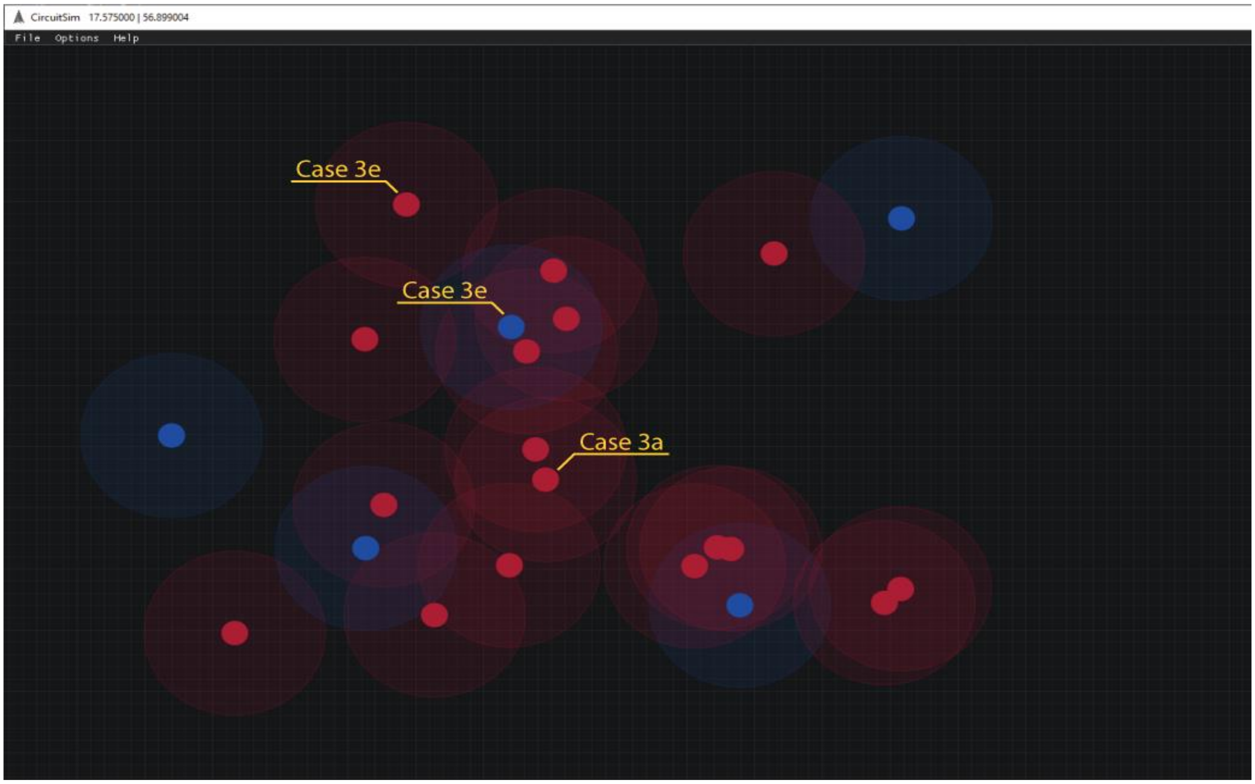


Figure 9: Network visualization with labeled cases and color-coded nodes, illustrating different clusters and their interactions within the network

Upon completion of the simulation using the proposed algorithm, a notable finding emerged: only 5 out of the 22 nodes actively utilized their Energy Intensive GSM module. This strategic utilization resulted in a remarkable 77.3% reduction in energy consumption related to communication costs. Such a significant reduction underscores the algorithm's efficacy in optimizing energy utilization within the network.

After completing the simulation using the given algorithm, it turned out that only 5 nodes of the network out of 22 under consideration had utilized their Energy Intensive GSM module. As a result, communication costs have been reduced by 77.3%, which is a highly impressive figure. To further improve the functioning of this current algorithm, consideration of the use of a device by all the nodes would be beneficial (Merghadi et al., 2020). The question to ask is, however, whether the current algorithm would apply to real-life devices needing a GSM module for each of their nodes. The simulation allowed me to understand that it would be an excellent opportunity to establish a transaction in the real-life flow of data, but the issue to consider is that the Energy Intensive GSM module installed in all the devices would cause high expenses in equipping each node with such a GSM module. In large-scale applications, it is vital for the network to remain cost-efficient, leading to the necessity of the development of another model to maximally conserve energy while new transactions begin viable to serve as the basis for another algorithm. To adapt the new algorithm to the needs of real life, it is important to perform another modification and develop another algorithm that would be designed to effectively decrease the expenses on energy while remaining applicable in the real-life flow of data. Many processes are started simultaneously, leading us to the idea that it would be wise to develop a new algorithm immediately (Pourghasemi & Rahmati, 2018). However, we will probably need to consider multiple other strategies and rethink the algorithm before making it and trying to maximize its efficiency to decrease the expenses on energy.

4.3 Algorithm-02: Converging Paths to Idea Path

In Algorithm 2, the objective is to converge paths within the network to ideal paths, ensuring efficient data transmission and communication. Unlike Algorithm 1, which focuses on minimizing the number of nodes using energy-intensive GSM modules, Algorithm 2 emphasizes routing and communication optimization.

Terminologies before we start:

- **Boss Node:** The node that is using its GSM module, and is receiving data from other nodes
- **Normal Node:** The node that is Not using its GSM module, and is sending its data to its Boss

- **Level:** Number of connections away from the nearest Boss Node

4.3.1 Routing Optimization:

One of the most important problems concerning Algorithm 2 that needs to be solved is related to the choice of the optimal path for the data transmission from the normal node to the Boss Node. Given the fact the number of Boss Nodes in the network is very limited, most normal nodes have no Boss Node within their trail's radius, which means the data should be passed from this normal node to the Boss Node via other normal nodes (Ranjan, 2015). Thus, the problem with routing arises, namely, the task for each normal node to select the shortest path to the nearest Boss Node without any cycles. To solve this problem, it is necessary to create a dynamic routing algorithm of transmission, which allows adapting the condition at the nodes and their interconnections and receiving the guaranteed methods of the fast delivery of the data to the destination point.

To solve this problem, it is suggested to use the modified version of the Dijkstra algorithm for path selection, which will be running at each of the normal nodes and keeping the routing table of normal nodes of their nearest Boss Nodes. In this case, the algorithm of the shortest path routing of the data transfer in the network will allow finishing the creation of the modulated data deflection packets. At the same time, it should be considered that the routing algorithm must consider the changes in the network and the time of the effective work, that is, the elimination or adding of the new nodes (K. K. Joshi, 2016).

4.3.2 Communication Optimization:

In addition to routing optimization, Algorithm 2 must also address the issue of communication between nodes. Specifically, Boss Nodes needs to know the optimal path to send confirmation messages for data packets back to the originating node. This requires each Boss Node to maintain a routing table that maps each normal node to the optimal path for sending confirmation messages. Like routing optimization, communication optimization requires a dynamic algorithm that can adapt to changes in the network topology. By continuously updating routing tables based on network changes, Algorithm 2 can ensure efficient and reliable communication between nodes.

4.3.3 Simulation and Evaluation:

To evaluate the effectiveness of Algorithm 2, a simulation can be conducted using a network simulator similar to the one used for Algorithm 1. By simulating the behavior of nodes in a network with varying topologies and sizes, researchers can assess the algorithm's performance in different scenarios.

Through simulations, researchers can analyze factors such as network latency, packet loss, and overall efficiency (Kantekin, 2024). By comparing the results of simulations with different parameters, researchers can fine-tune the algorithm to achieve optimal performance in real-world scenarios.

In conclusion, Algorithm 2 represents a significant advancement in optimizing routing and communication in Wireless Sensor Networks. By converging paths to ideal paths, Algorithm 2 ensures efficient data transmission and communication, making it suitable for various applications, including smart cities, environmental monitoring, and industrial automation.

4.3.4 Routing: Converging Paths to Nearest Boss Nodes

In Algorithm 2, the routing strategy is designed to route every normal node to its nearest Boss Node for effective data transfer. Since, the number of Boss Nodes is very few and may vary, as a result, the number of total nodes in a network can be in different location. Here determining an optimum path to the nearest Boss Nodes would be a difficult task. To solve this problem, the concept of Level is used by the routing algorithm to show the distance of a specific normal node to the nearest Boss Node (Baroudi et al., 2019). Moreover, every time a Boss Node initiates its level into ‘0’ to its neighboring normal nodes it shows that it is the closest Boss Node. After that, these neighboring normal nodes initiate their level value into ‘1’. Then it indicates they are one hop away from a Boss Node. In the same fashion every time a level value is updated by their neighbors to get the net distance to the nearest Boss Node. Now it keeps on continuing this process recursively. It means that every node shares its level information with its neighbors, which determines the shortest route to the Boss Node. Now based on their level, every normal node only selects that neighboring node to be the parent node or acceptable peer node which has less value of level. Finally, normal nodes can decide by themselves which neighboring node is currently the closest route for the Boss Node to transfer the data. Due to this every normal node arrives at the globally optimal paths/routes by themselves from each node to its nearest Boss Node (Mahadevan, 2020). No normal node knows the location of the nearest Boss Node, but it knows which of its neighbors is close to the Boss Node based on the value of the Level. On applying this novel mechanism, the emergent behavior of the entire algorithm is to select the neighbor and transfer data to the Boss Node which is very close to the Boss Node at each normal node.

4.3.5 Visualization of Routing:

To understand how the routing algorithm works, consider two Boss Nodes that are not yet communicating. The core of the step is as follows: they both broadcast to the neighbors that their Level is 0. The neighbors process this information and know that both of their Bosses are on Level 1. Already nodes 18, 19, 22, and 23 now must choose the correct Boss node, and the correct node is the one with the lowest Level. Thus, for simplicity, we state that nodes always choose a neighbor with a lower Level. This simple process eventually Brings the system to its ideal state, where all the paths from the nodes converge from every simple node to the closest Boss (Liu et al., 2020).

Thus, we see that the routing algorithm from the input Sequence to Algorithm 2 is trivial. The inclusion of the Level parameter and its usage for guiding how messages should be sent make all paths not just “short” but “globally optimal”. This approach uses minimum information and results in an incredibly effective operation, as it effectively captures the essence of a practically ideal routing of the path. This conclusion seems incredibly logical, as the algorithm allows the behavior of very complex systems, and changes in interaction that occur both locally and highly inefficiently.

- First the Bosses set their Level to ‘0’ (Refer to Figure 10)
- After seeing a Level ‘0’, neighbors of Bosses have updated their Level to ‘1’ (Refer to Figure 11)
- After seeing a Level ‘1’, neighbors of Level 1 nodes have updated their Level to ‘2’ (Refer to Figure 12)
- After seeing a Level ‘2’, neighbors of Level 2 nodes have updated their Level to ‘3’ (Refer to Figure 13)
- After seeing a Level ‘3’, neighbors of Level 3 nodes have updated their Level to ‘4’ (Refer to Figures 14 and 15)

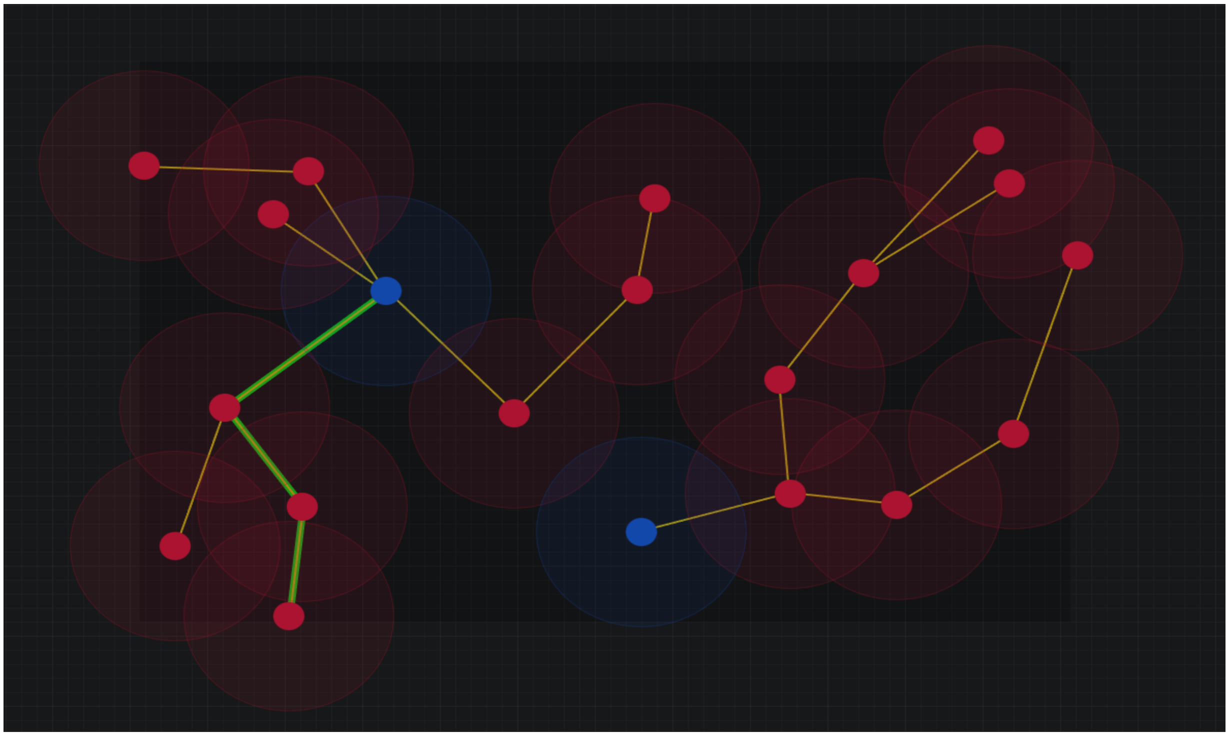


Figure 10: Visual representation of a complex network topology

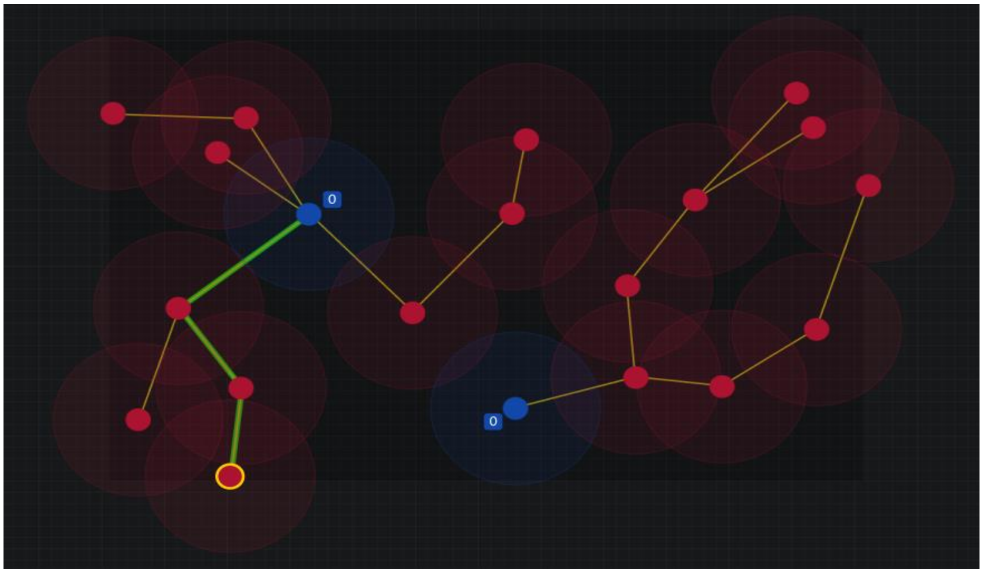


Figure 11: Visual representation of a complex network topology showing their Level to ‘0’

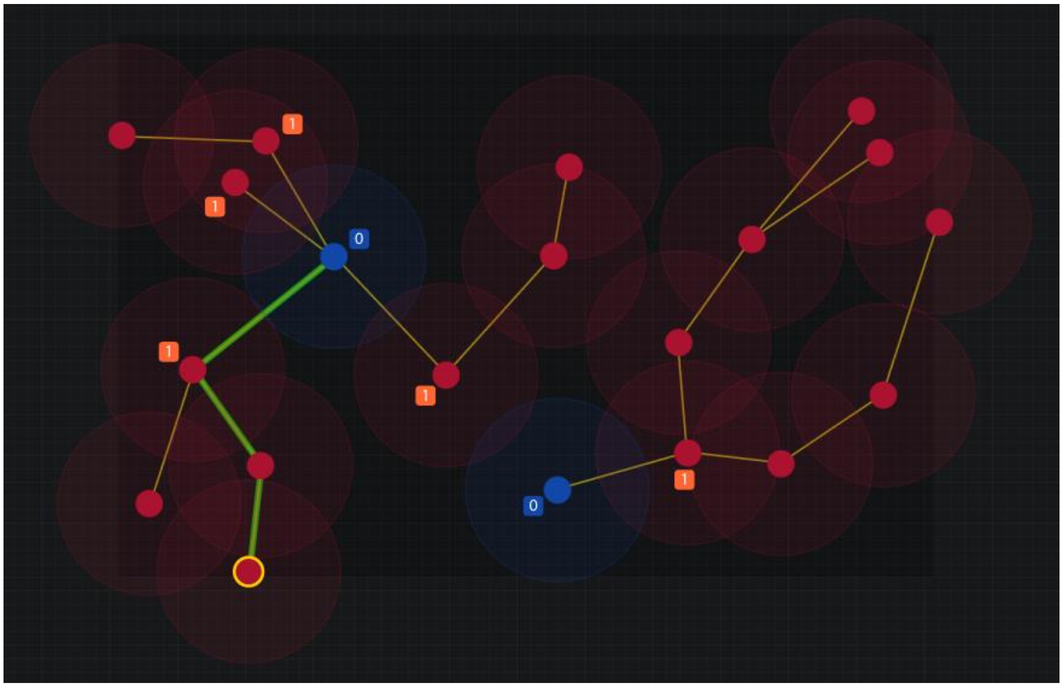


Figure 12: Network graph highlighting nodes with different roles and distances

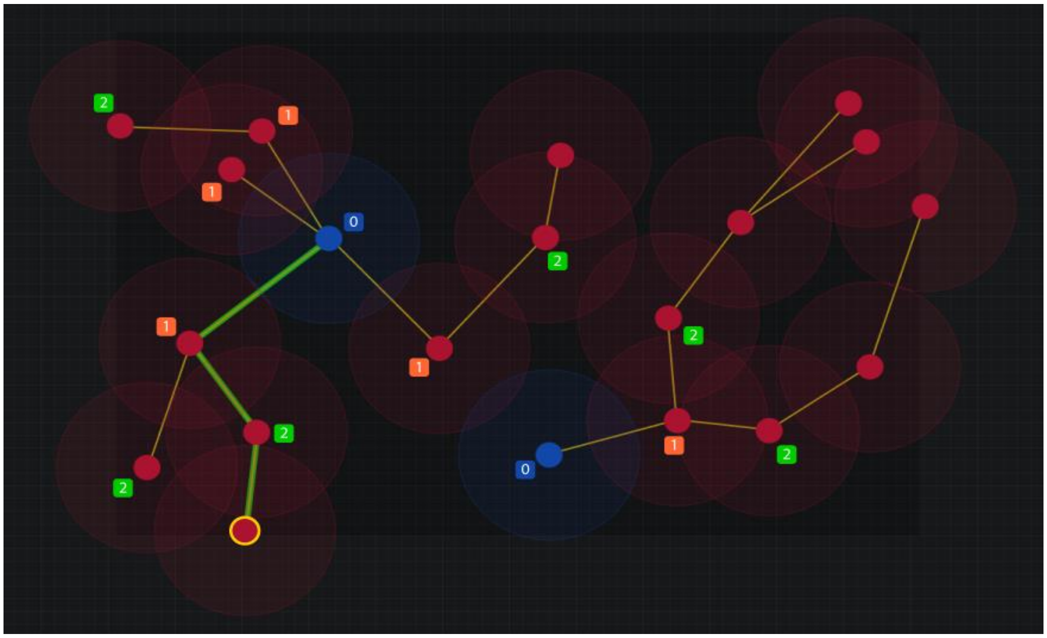


Figure 13: a Level ‘1’, neighbors of Level 1 nodes have updated their Level to ‘2’

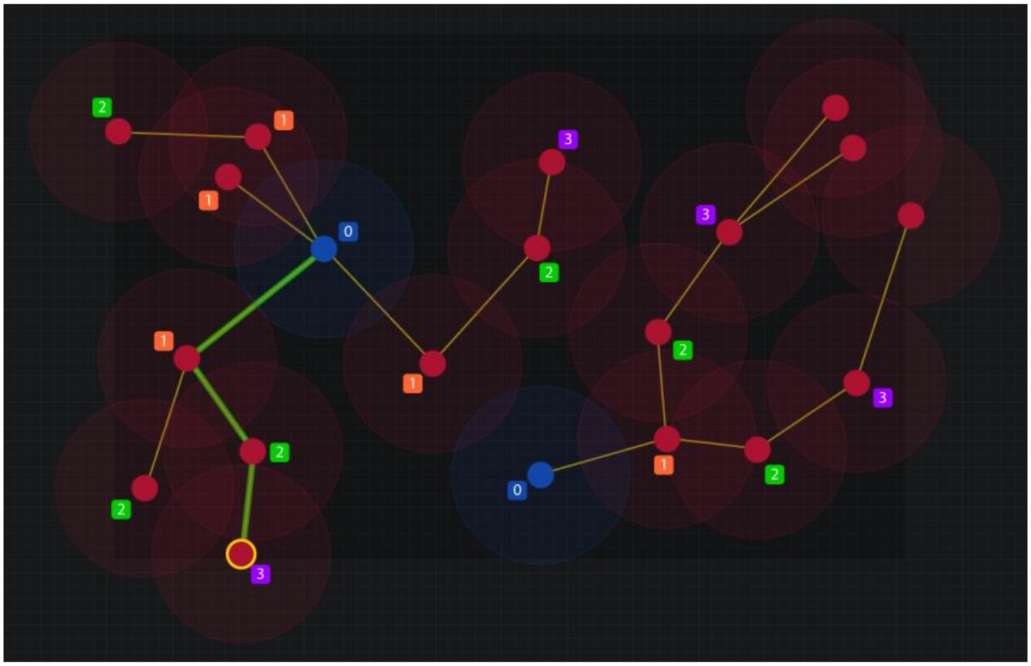


Figure 14: Network graph highlighting nodes with Level ‘2’, neighbors of Level 2 nodes have updated their Level to ‘3’

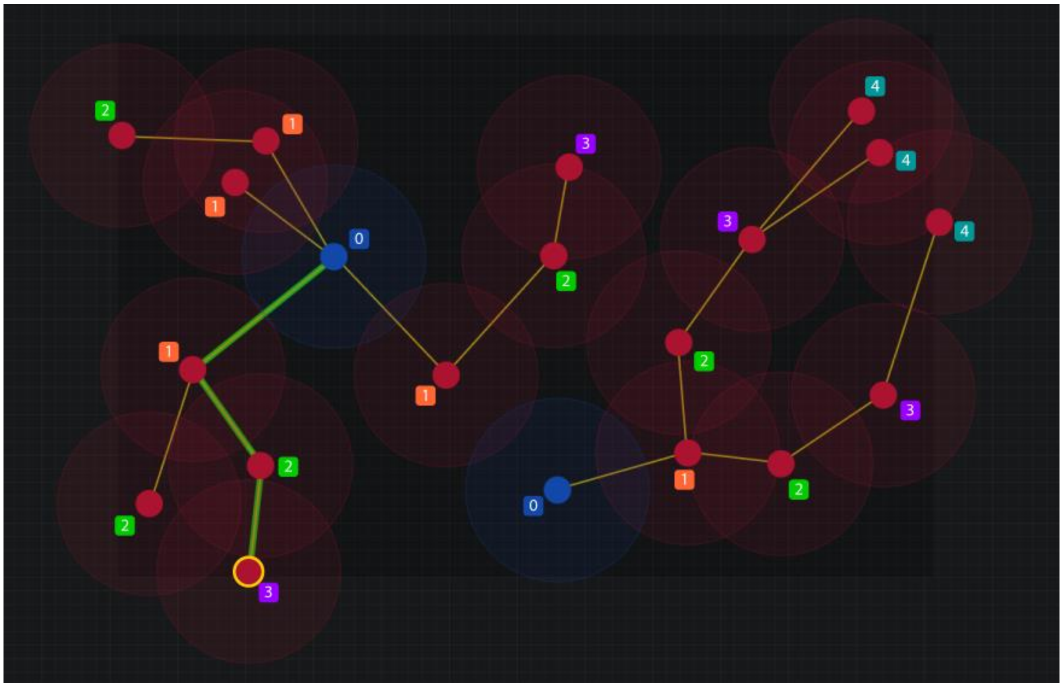


Figure 15: Network graph highlighting nodes with different roles Level ‘3’, neighbors of Level 3 nodes have updated their Level to ‘4’.

4.3.6 Achieving Globally Shortest Paths

In Algorithm 2, the concept of Levels is crucial for achieving globally shortest paths from each node to its nearest Boss Node. By continuously updating their neighbors about their Levels and selecting neighbors with lower Levels for data transmission, nodes collectively converge towards the nearest Boss Node, ensuring efficient routing without the need for explicit knowledge of the Boss Node's location.

4.3.7 Constant Level Updates

The key to this routing strategy lies in the constant updating of Level information. Nodes achieve this by including an extra integer representing their Level in the metadata of each communication with their neighbors. This simple yet effective mechanism ensures that every node is aware of its neighbors' Levels and can make informed decisions about which neighbor to transmit data to.

Example Scenario:

Consider a scenario where Node A and Node B are neighbors, and Node A is one hop away from a Boss Node while Node B is two hops away (Venkatasubramanian et al., 2022). Initially, both nodes set their Levels accordingly (A: Level 1, B: Level 2). When Node A sends data to Node B, it includes its Level in the metadata. Upon receiving this data, Node B compares its Level with the Level of Node A and updates its Level to Level 2 (A's Level + 1).

4.3.8 Benefits of Constant Level Updates:

- **Efficient Path Selection:** Nodes can select the neighbor with the lowest Level for data transmission, ensuring that data is routed through the shortest path to the nearest Boss Node.
- **Dynamic Adaptation:** The routing algorithm can adapt to changes in the network topology, such as node additions or failures, by continuously updating Levels based on the current network configuration.
- **Minimal Overhead:** The inclusion of an extra integer representing Level in the metadata of each communication incurs minimal overhead, making the routing strategy efficient and scalable.

By leveraging the concept of Levels and continuously updating Level information, Algorithm 2 achieves globally shortest paths from each node to its nearest Boss Node, ensuring efficient and reliable data transmission within the network.

4.3.9 Communication: Utilizing Tickets for Message Routing

In Algorithm 2, communication between nodes is facilitated through the use of tickets, which serve as unique identifiers for data packets. These tickets enable nodes to route data towards Boss Nodes and back to the originating nodes for confirmation messages, without the need for explicit knowledge of the Boss Node's location.

4.3.10 Ticket Generation and Assignment

When a normal node generates a data packet, it assigns a unique ticket to that packet. This ticket serves as a reference for the data packet throughout its journey towards the Boss Node and back (Zhang et al., 2024). Each ticket is unique within the network and ensures that data packets are correctly routed and processed.

4.3.11 Routing Data Towards Boss Nodes

Upon generating a data packet with a ticket, a normal node uses the routing strategy described earlier to determine the optimal path towards the nearest Boss Node. The node forwards the data packet to the neighbor with the lowest Level, ensuring that the data packet is efficiently routed towards the Boss Node.

4.3.12 Confirmation Message Routing

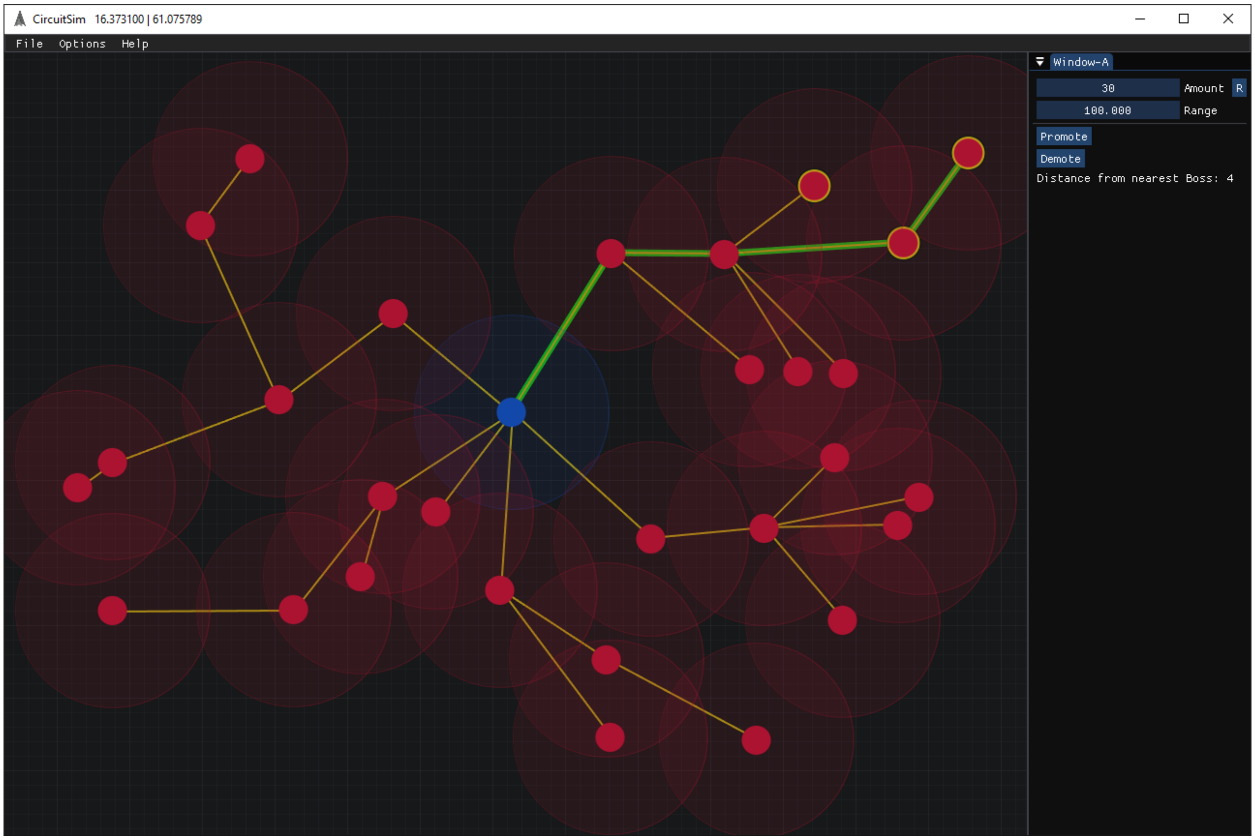
Once a Boss Node receives a data packet, it processes the data and generates a confirmation message. This confirmation message contains the ticket of the original data packet and is routed back towards the originating node for acknowledgment. Similar to routing data towards Boss Nodes, the confirmation message is routed through the network based on the Level information of each node (Knoblauch et al., 2017).

4.3.13 Benefits of Using Tickets:

- **Efficient Message Routing:** Tickets enable nodes to route data packets towards Boss Nodes and confirmation messages back to the originating nodes through globally optimal paths/routes. (Refer to Figure 16)
- **Message Identification:** Each ticket serves as a unique identifier for data packets, ensuring that messages are correctly processed and acknowledged.

- **Decentralized Communication:** The use of tickets allows for decentralized communication within the network, as nodes can route messages based on Level information without centralized coordination.

By utilizing tickets for message routing, Algorithm 2 ensures efficient and reliable communication between nodes in the network, enabling data packets to reach their destinations and confirmation messages to be sent back to the originating nodes (Herrera, 2019).



30 Amount

100.000 Range

Distance from nearest Boss: 4

Figure 16: Network graph highlighting nodes

4.3.14 Simulation: Evaluating Algorithm 2 in Action

Simulation plays a crucial role in evaluating the effectiveness and performance of Algorithm 2 in a controlled environment. By simulating the behavior of nodes in a network, researchers can analyze various metrics such as routing efficiency, message delivery latency, and network throughput. These simulations provide valuable insights into how Algorithm 2 performs under different scenarios and network conditions.

4.3.15 Setting Up the Simulation Environment

To conduct the simulation, a network simulator is used to model the behavior of nodes and their interactions. The simulator allows researchers to define the network topology, node characteristics, and communication protocols. In the case of Algorithm 2, the simulator would incorporate the routing and communication strategies described earlier, including the use of Levels and tickets for message routing (Jin, 2022).

4.3.16 Running the Simulation Scenarios

Several simulation scenarios can be designed to evaluate Algorithm 2's performance. These scenarios can vary in terms of network size, node density, and movement patterns (if nodes are mobile). For each scenario, key metrics such as average path length, message delivery ratio, and energy consumption can be measured to assess the algorithm's effectiveness.

4.3.17 Analyzing Simulation Results

After running the simulation scenarios, the results are analyzed to evaluate Algorithm 2's performance. Researchers look for patterns and trends in the data to understand how the algorithm behaves under different conditions (Refer to Figure 17). This analysis helps identify the strengths and weaknesses of the algorithm and provides insights for potential improvements.

Figure 17: Field Testing & Results of Sensors

4.3.18 Improving Algorithm 2 Based on Simulation Findings

Based on the simulation findings, Algorithm 2 can be refined and optimized to enhance its performance. This iterative process of simulation, analysis, and refinement is crucial for developing robust and efficient algorithms for Wireless Sensor Networks (Olasupo, 2017).

4.3.19 Links:

In Algorithm 2, the convergence of paths to ideal paths is a pivotal feature that ensures efficient routing in Wireless Sensor Networks. This section provides essential resources related to Algorithm 2, including the GitHub repository and simulators for testing the algorithm's effectiveness and performance.

4.4 GitHub Repository:

The GitHub repository for Algorithm 2 serves as a central hub for accessing the most recent updates, source code, documentation, and resources pertaining to the algorithm. Researchers, developers, and enthusiasts can leverage this repository to delve into the intricate implementation details of Algorithm 2. By exploring the algorithm's inner workings, users can gain a deeper understanding of its design principles and functionalities (K. K. Joshi, 2016). Moreover, the repository provides an interactive platform where users can engage with the algorithm's community, collaborate on development efforts, report bugs, propose enhancements, and stay abreast of the latest developments in Algorithm 2.

4.5 Simulators:

In the evaluation and determination of the performance of Algorithm 2, there is the need for simulation tools. Therefore, there is the description of at least three code simulators which are part of the evaluation of the performance of the mathematical algorithm, and they include the following: ns-3, OMNeT++, and MATLAB. Using the simulation tools, the researchers are likely to come up with network simulations, possibly real network simulations. The simulation tool is a crucial step to assess the effectiveness of the algorithm in a case scenario like a real scenario as well as to research the effects. For example, the researcher can determine the routing efficiency of the Algorithm 2 and possibly evaluate at least another routing algorithm (Kantekin, 2024). Through simulating the routing mechanism, the research is likely to make a recommendation based on the algorithm’s efficiency, withdraw support if it is supportive, and possibly develop new modules to add to the tactical support of the algorithm. Research to determine the algorithm efficiency is attainable and reports developed.

GitHub repository is the location of the Arduino code used in the implementation of the algorithm. Other people interested in the implementation and evaluation of the algorithm can assess the code and develop their design of the algorithm. In conclusion, therefore, the simulation tools’ assessment and the description of the GitHub repository and user code help future researchers to develop, assess, and implement the algorithm.

CHAPTER 5 CONCLUSIONS AND RECOMMENDATION

5.1 Conclusion

One of the significant achievements related to Wireless Sensor Network technology is the development of a real-time landslide monitoring system. The project corresponds to the current needs of people in Pakistan and is a cost-effective and reliable solution to the problem. The advanced system involved the use of up-to-date sensor technology, algorithm optimization in data processing, and friendly interfaces (Zhang et al., 2024). The combination of these elements facilitates the work of both scientists and public authorities who receive timely notifications and collected data. The deployment of master and slave sensors in the most vulnerable parts of the slopes guarantees the collection of objective and relevant data. It means that the realization of the project not only helps save people's lives and reduce the potential loss of life but also guarantees to avoid the loss of tourists or the local community and related economic spheres.

I am confident that our research and development of the Wireless Sensor Network solution will help to generate important lessons for those people who want to address environmental problems and are interested in this sector. Particularly, the latter project may be a good example to be used by scientists and developers in other regions since one of the primary benefits of the realized R&D developments is the possibility to elaborate a cheap and effective solution and reduce risks due to natural hazards. At the same time, the Wireless Sensor Network installation has some limitations, and there are several ways in which this technology may be potentially limited (Herrera, 2019).

5.2 Limitations

- **Environmental Impact:** The process of installing sensors is potentially harmful to the local environment. Steel casings may unfavorably affect the ecosystem, and additional actions should be discussed to limit their impact on the installation.
- **Weather Conditions:** Sensors should be cost-effective, and none of the unusual or expensive materials should be used in this situation. However, the weather will still restrict their functionality, and low-quality installations will work only a limited period since the sensors' work might be affected by a heavy amount of snow or rainfall
- **Data Transmission:** The device's location bordering the remote mountain area may not guarantee the highly symmetrical signals for master and slave sensors (Liu et al., 2020).
- **Battery Life:** Sensors normally work on a cycle of sleep optimization to save power, and they will last up to a decade in normal use. However, if extensive monitoring of remote locations is required, the battery may be stressed, requiring more frequent maintenance and charging dates. The sensor required to monitor the area may not be optimally designed, requiring additional power to transmit data. Even with advanced batteries and energy harvesting technologies, batteries may still be an issue. However, annual maintenance times could be seen as inefficient as they do not prevent batteries or weather problems.

5.3 Recommendations

- **Environmental Monitoring and Mitigation:** Reduce environmental impact via the best practices for installation of the sensors. Research could be conducted on biodegradable materials for the casing or less intrusive housings, or the widespread use of wood and through smaller fences that limit intrusion (Venkatasubramanian et al., 2022).

- **Regular Assessments:** Before and after the installation of the sensors, ensure that impact assessments are conducted to ensure minimal disruption, recovery of the natural environment, and use if needed if sensors must be relocated.
- **Enhance Weather Resilience:** Research and develop an indestructible housing for the sensor or one that is highly weather-proof. The sensor must be replaced before and after severe weather events as part of a contingency routine. It should be part of the routine; there should be a weather event, then another time before the sensor data and therefore the energy used by the batteries is transmitted.
- **Improve Data Transmission:** Use signal transmission at a distance to ensure data provided, including satellite transmission. Make sure that it has a low power alternative network to connect (Klickstein & Sorrentino, 2018).
- **Optimize Power Usage:** It could be a more optimal use of resources and compromise the operation with solar panels and other such functions. A higher capacity or different battery to have on hand during maintenance. The advanced capacity battery should reduce the annual maintenance to prevent disruptions to a three-year select increase in breakrooms.
- **Community Involvement and Training:** It shows that the sensors operate and continue to do so through continuous usage and therefore need information and protection against the weather. It is the purpose of the training. Train the local population and town government agencies to gather information on the operation and maintenance of the IEC to continue its use in the future. The venues should be held in public during public town meetings for awareness and continued maintenance (Pourghasemi & Rahmati, 2018).

References

Abd Rahman, N. A., Ibrahim, N. H., Lombigit, L., Azman, A., Jaafar, Z., Abdullah, N. A., & Mohamad, G. H. P. (2018). GSM module for wireless radiation monitoring system via SMS. *IOP Conference Series: Materials Science and Engineering*, *298*(1), 012040. https://iopscience.iop.org/article/10.1088/1757-899X/298/1/012040/meta

Ali, A. I., & Zorlu Partal, S. (2022). Development and performance analysis of a ZigBee and LoRa-based smart building sensor network. *Frontiers in Energy Research*, *10*, 933743.

Ali, A., Ming, Y., Chakraborty, S., & Iram, S. (2017). A comprehensive survey on real-time applications of Wireless Sensor Network. *Future Internet*, *9*(4), 77.

Arbanas, S. M., & Arbanas, Ž. (2015). Landslides: A guide to researching landslide phenomena and processes. In *Transportation Systems and Engineering: Concepts, Methodologies, Tools, and Applications* (pp. 1393–1428). IGI Global. https://www.igi-global.com/chapter/landslides/128730

Baroudi, U., Bin-Yahya, M., Alshammari, M., & Yaqoub, U. (2019). Ticket-based QoS routing optimization using genetic algorithm for Wireless Sensor Network applications in smart grid. *Journal of Ambient Intelligence and Humanized Computing*, *10*(4), 1325–1338. https://doi.org/10.1007/s12652-018-0906-0

Buzorgnia, D. (2019). *Fast convergence in consensus control of leader-follower multi-agent systems* [PhD Thesis, Concordia University]. https://spectrum.library.concordia.ca/id/eprint/986306/

Do Pinho, T. M., & Augusto Filho, O. (2022). Landslide susceptibility mapping using the infinite slope, SHALSTAB, SINMAP, and TRIGRS models in Serra do Mar, Brazil. *Journal of Mountain Science*, *19*(4), 1018–1036. https://doi.org/10.1007/s11629-021-7057-z

Giri, P., Ng, K., & Phillips, W. (2018a). Wireless Sensor Network system for landslide monitoring and warning. *IEEE Transactions on Instrumentation and Measurement*, *68*(4), 1210–1220.

Herrera, M. (2019). Landslide Detection using Random Forest Classifier. *Delft University of Technology, Delft, Https://Doi. Org/10.13140/RG*, *2*(31365.91369). https://www.researchgate.net/profile/Meylin-Herrera/publication/338677679_Landslide_Detection_using_Random_Forest_Classifier/links/5e23967b92851cafc38fd677/Landslide-Detection-using-Random-Forest-Classifier.pdf

Hidayat, M. S., Nugroho, A. P., Sutiarso, L., & Okayasu, T. (2019). Development of environmental monitoring systems based on LoRa with cloud integration for rural area. *IOP Conference Series: Earth and Environmental Science*, *355*(1), 012010. https://iopscience.iop.org/article/10.1088/1755-1315/355/1/012010/meta

Izadi, D., Abawajy, J. H., Ghanavati, S., & Herawan, T. (2015). A data fusion method in Wireless Sensor Network s. *Sensors*, *15*(2), 2964–2979.

Jeong, S., Ko, J., & Kim, J. (2019a). The effectiveness of a Wireless Sensor Network system for landslide monitoring. *IEEE Access*, *8*, 8073–8086.

Jiang, S., Li, J., Zhang, S., Gu, Q., Lu, C., & Liu, H. (2022). Landslide risk prediction by using GBRT algorithm: Application of artificial intelligence in disaster prevention of energy mining. *Process Safety and Environmental Protection*, *166*, 384–392.

Jin, Z. (2022). *Landslide prediction based on mechine learning methods*. https://www.politesi.polimi.it/handle/10589/199078

Joshi, A., Grover, J., Prasanna Kanungo, D., & Kumar Panigrahi, R. (2019). Real-time landslide monitoring, detection and early warning system for tangni landslide. *Proceedings of the 5th International Conference on Cyber Security & Privacy in Communication Networks (ICCS)*. https://papers.ssrn.com/sol3/papers.cfm?abstract_id=3511001

Joshi, K. K. (2016). Review on Landslide Detection by Using Wireless Sensors & GSM. *International Journal of Electronics and Communication Engineering (IJECE)*, *5*(5), 1–8.

Kantekin, S. (2024). *The impact of incomplete landslide inventories on susceptibility mapping: Assessment and solutions* [Master’s Thesis, Middle East Technical University]. https://open.metu.edu.tr/handle/11511/110078

Khan, R., Yousaf, S., Haseeb, A., & Uddin, M. I. (2021). Exploring a Design of Landslide Monitoring System. *Complexity*, *2021*, 1–13. https://doi.org/10.1155/2021/5552417

Klickstein, I., & Sorrentino, F. (2018). Control distance and energy scaling of complex networks. *IEEE Transactions on Network Science and Engineering*, *7*(2), 726–736.

Knoblauch, J., Sethuraman, A., & Hey, J. (2017). IMGui—A desktop GUI application for isolation with migration analyses. *Molecular Biology and Evolution*, *34*(2), 500–504.

Lee, E. M., & Jones, D. K. (2023). *Landslide Risk Assessment: Third edition*. ICE Publishing. https://doi.org/10.1680/lra.66236

Li, W., & Kara, S. (2017). Methodology for monitoring manufacturing environment by using Wireless Sensor Networks and the internet of things (IoT). *Procedia CIRP*, *61*, 323–328.

Liu, Z., Guo, D., Lacasse, S., Li, J., Yang, B., & Choi, J. (2020). Algorithms for intelligent prediction of landslide displacements. *Journal of Zhejiang University-SCIENCE A*, *21*(6), 412–429. https://doi.org/10.1631/jzus.A2000005

Mahadevan, A. (2020). *Vote Prediction Models for Signed Social Networks* [Master's Thesis]. https://aaltodoc.aalto.fi/handle/123456789/44988

MARTINS, T. D., VIEIRA, B. C., FERNANDES, N. F., OKAFIORI, C., & MONTGOMERY, D. R. (2017). Application of the SHALSTAB model for the identification of areas susceptible to landslides: Brazilian case studies. *Revista de Geomorfologie*, *19*(1), 136–144.

Merghadi, A., Yunus, A. P., Dou, J., Whiteley, J., ThaiPham, B., Bui, D. T., Avtar, R., & Abderrahmane, B. (2020). Machine learning methods for landslide susceptibility studies: A comparative overview of algorithm performance. *Earth-Science Reviews*, *207*, 103225.

Narayan, V., & Daniel, A. K. (2020). *Design consideration and issues in Wireless Sensor Network deployment*. https://www.indianjournals.com/ijor.aspx?target=ijor:ijst1&volume=13&issue=3&article=001

Olasupo, T. O. (2017). *Optimization Framework for Deployment of Wireless Sensor Network s*. https://repository.fit.edu/etd/904/

Pourghasemi, H. R., & Rahmati, O. (2018). Prediction of the landslide susceptibility: Which algorithm, which precision? *Catena*, *162*, 177–192.

Prasad, N. L., & Ramkumar, B. (2022). 3-D deployment and trajectory planning for relay based UAV assisted cooperative communication for emergency scenarios using Dijkstra's algorithm. *IEEE Transactions on Vehicular Technology*, *72*(4), 5049–5063.

Ranjan, H. (2015). *Quality Driven Wireless Sensor Network* [PhD Thesis]. http://ethesis.nitrkl.ac.in/6934/

Rawat, P. S., & Barthwal, A. (2024). LANDSLIDE MONITOR: A real-time landslide monitoring system. *Environmental Earth Sciences*, *83*(8), 226. https://doi.org/10.1007/s12665-024-11526-0

Scaioni, M. (Ed.). (2015). *Modern Technologies for Landslide Monitoring and Prediction*. Springer Berlin Heidelberg. https://doi.org/10.1007/978-3-662-45931-7

Shah, N. A., Shafique, M., Ishfaq, M., Faisal, K., & Van der Meijde, M. (2023). Integrated approach for landslide risk assessment using geoinformation tools and field data in Hindukush mountain ranges, Northern Pakistan. *Sustainability*, *15*(4), 3102.

Sudmeier-Rieux, K., Jaboyedoff, M., Breguet, A., & Dubois, J. (2011). The 2005 Pakistan earthquake revisited: Methods for integrated landslide assessment. *Mountain Research and Development*, *31*(2), 112–121.

Toral-Cruz, H., Hidoussi, F., Boubiche, D. E., Barbosa, R., Voznak, M., & Lakhtaria, K. I. (2015). A survey on Wireless Sensor Network s. In *Next Generation Wireless Network Security and Privacy* (pp. 171–210). IGI Global. https://www.igi-global.com/chapter/a-survey-on-wireless-sensor-networks/139430

Tran-Dang, H. (2017). *3D Spatial Modeling of Stacked Containers based on Wireless Sensor Network : Application to the physical internet* [PhD Thesis, Université de Lorraine]. https://theses.hal.science/tel-01643949/

Venkatasubramanian, S., Suhasini, A., & Vennila, C. (2022). An Efficient Route Optimization Using Ticket-ID Based Routing Management System (T-ID BRM). *Wireless Personal Communications*, *127*(3), 1923–1942. https://doi.org/10.1007/s11277-021-08731-6

Winter, M. G., Shearer, B., Palmer, D., Peeling, D., Harmer, C., & Sharpe, J. (2016). The economic impact of landslides and floods on the road network. *Procedia Engineering*, *143*, 1425–1434.

Zhang, Q., Ning, Z., Ding, X., Wu, J., Wang, Z., Tsangaratos, P., Ilia, I., Wang, Y., & Chen, W. (2024). Hybrid Integration of Bagging and Decision Tree Algorithms for Landslide Susceptibility Mapping. *Water*, *16*(5), 657.