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Enhanced LoRa-Based Underground Communication Using Repeaters for Range Extension

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Abstract: Reliable communication in underground mining environments remains a major challenge due to signal attenuation, tunnel obstructions, and the absence of conventional communication infrastructure. This project proposes an enhanced underground communication system using LoRa technology integrated with repeater nodes to improve long-range data transmission inside mining tunnels. The system consists of a transmitter node, repeater node, and receiver node built using Espress if Systems ESP32 controllers and Ai-Thinker SX1276 LoRa transceiver modules operating at 433 MHz . The transmitter node collects environmental and safety-related data through sensors such as temperature, humidity, and vibration sensors. This data is transmitted through a repeater node, which strengthens and forwards the signal to the receiver node located at a distant monitoring point. At the receiver side, an OLED display and buzzer provide real-time monitoring and alert generation. The repeater-based design improves signal coverage, reduces packet loss, and increases communication reliability in non-line-of-sight underground conditions. Performance evaluation is carried out using parameters such as RSSI, SNR, packet delivery efficiency, and communication range. The proposed system offers a low-cost, energy-efficient, and scalable solution for miner safety monitoring and emergency communication in underground mining operations. The system can also be expanded by deploying multiple repeater nodes to further extend communication coverage across large underground mining areas.

Keywords: LoRa, Underground Communication, Repeater Nodes, ESP32, Wireless Sensor Monitoring.

I. INTRODUCTION

Underground mining plays a major role in supplying essential minerals and resources for industrial development, but it also presents significant safety and communication challenges. Deep mine tunnels, narrow passages, and irregular rock formations make conventional wireless communication difficult because radio signals experience severe attenuation and obstruction. In emergency situations, the absence of reliable communication can delay rescue operations and increase risk to miners. Therefore, developing a robust underground communication system has become an important requirement for modern mine safety management.

Among available wireless technologies, LoRa has emerged as a suitable solution because of its long communication range, low power consumption, and ability to operate effectively in challenging environments. LoRa uses chirp spread spectrum modulation, which allows data transmission over long distances even under low signal strength conditions. Compared with short-range wireless methods, LoRa offers better penetration capability and reduced infrastructure cost, making it highly suitable for underground monitoring applications.

The proposed system uses Espressif Systems ESP32 microcontrollers integrated with Ai-Thinker SX1276 LoRa transceiver modules operating at 433 MHz to establish communication between multiple underground nodes. A transmitter node collects environmental information through sensors such as temperature, humidity, and vibration sensors. These parameters are important because sudden

environmental changes inside mines may indicate unsafe working conditions that require immediate attention.

Signal problems often block messages deep below ground. Bends in the tunnel bring on weakening, while blockages make it worse. Greater demands pile on top of that strain. Obstacles along the path contribute just as much. Even so, reaching farther remains tricky. For that reason, signals need help travelling further. Because of this challenge, engineers adjust how data moves across the network by introducing repeater nodes between the transmitter and receiver. Signals come in faint. A device grabs those whispers, freshens each one up, then sends those along to the following point, which keeps things moving forward, communication coverage and improving packet delivery. It works better now. The upgrade boosts how well it runs every time, effective in non-line-of-sight underground conditions, where words sometimes miss their mark when spoken straight out.

On arrival, what was sent shows up right away. A small screen shows the time, while sounds come through a beeping device. Signals appear if something runs off track. Performance of the system gets checked through measures like, sometimes, signal strength matters most. Yet noise levels can shift everything quickly. When packets start vanishing mid-transmit, connections weaken without warning. Distance plays a role too - farther often means fragile. The full look gives something cheap, uses less power, yet still works well. One way to check conditions deep inside mines, built so it works in many places at once, Miners might stay safer when systems spot dangers early. Spotting risks could happen faster through automated alerts. Hazards deep underground may get flagged before accidents occur in emergency communication systems.

II. LITERATURE SURVEY

Deep below ground, signals struggle to travel through stone and winding passages. Because of this, staying in touch across mine sites gets tricky. Devices like LoRa fit well here. Even so, gaps still appear where messages drop. To fill those spots, extra units repeat the message deeper into the tunnels. With each added booster, coverage grows just enough to reach another team. Safety climbs quietly as fewer zones stay out of contact

[1] Ankita Ray Chowdhury et al. proposed a LoRa-based Industrial Internet of Things (IIoT) system for underground coal mine monitoring. Their system introduced an adaptive data rate algorithm for mesh network topology to improve communication coverage while minimizing power consumption. The system achieved a data rate of 1.46 Kbps and a maximum communication range of 180 m in an operational mine environment.

[2] Philip Branch and Tony Cricenti proposed a LoRa-based relay communication system for remotely detonating explosives in underground mines to improve safety. The system uses multi-hop LoRa nodes (Initiator, Relay, and Detonator) to transmit detonation commands through underground tunnels. Their experiments analyzed signal strength and distance, showing that LoRa can transmit up to 170 m with line-of-sight, while signal quality decreases rapidly without line-of-sight.

[3] Ankita RayChowdhury, Ankita Pramanik, and Gopal Chandra Roy proposed a system for localization and smart data transmission in underground mines using Visible Light Communication (VLC) and LoRa technology. Their system used VLC to estimate the location of miners while LoRa modules transmitted underground data to the surface control room. The study also analyzed SNR performance of VLC and evaluated LoRa communication range for reliable underground connectivity.

[4] Jeremiah Shibalabala and Theo G. Swart proposed a wireless mesh network (WMN) system to analyze communication performance in underground mines. Their system used multiple wireless mesh nodes to transmit data, voice, and video from underground tunnels to surface operators. The study evaluated network parameters such as throughput, latency, and signal-to-noise ratio to determine the feasibility of mesh networks in mining environments.

[5] Kaiqiang Lin and Tong Hao proposed a LoRa-based wireless underground sensor network to analyze communication link quality for underground monitoring applications such as pipeline monitoring and soil assessment. Their system experimentally evaluated LoRa communication performance for underground-to-aboveground and aboveground-to-underground channels. The study analyzed parameters such as RSSI, SNR, packet delivery ratio, and burial depth to determine reliable communication range in underground environments.

[6] C. Ebi, C. Gisi, M. Schläpfer, and M. Eugster proposed a synchronous LoRa mesh network to monitor processes in underground infrastructures such as sewer systems and tunnels. Their system used synchronized sensor nodes and repeater nodes to forward data to a LoRaWAN gateway. The study showed that the LoRa mesh approach significantly improved transmission quality and reduced packet error rates in underground environments.

[7] Lloyed Emmanuel, Wisam Farjow, and Xavier Fernando proposed a LoRa-based wireless communication system to analyze link performance in underground mining environments affected by multipath propagation. Their study used MATLAB simulation with Rayleigh multipath and AWGN channel models to test LoRa performance under different spreading factors. The results indicated that multipath propagation lowers signal quality and increases the bit error rate in underground mine conditions.

[8] Philip Branch, Binghao Li, and Kai Zhao proposed a LoRa-based linear sensor network for underground mining communication to transmit the location details of miners and equipment during emergency situations. Their system used relay nodes to forward data through a linear network structure

toward a headend gateway. The study evaluated network reliability, scalability, and fairness for underground mining communication.

III. PROPOSED SYSTEM

The proposed system is designed to establish reliable underground communication using LoRa technology with repeater assistance to overcome signal attenuation in mining environments. The architecture consists of three main nodes: transmitter node, repeater node, and receiver node. Each node is built using Espressif Systems ESP32 microcontrollers integrated with Ai-Thinker SX1276 LoRa transceiver modules operating at 433 MHz. The transmitter node is responsible for sensing environmental conditions and transmitting data, while the repeater node extends communication range by forwarding received packets to the receiver node.

The transmitter node includes sensors such as temperature, humidity, and vibration sensors to monitor underground environmental conditions and possible safety risks. Sensor data collected by the ESP32 is encoded and transmitted through the LoRa module. Because underground tunnels contain bends, obstacles, and dense rock layers, direct signal propagation becomes weak over distance. To address this, the repeater node receives the transmitted signal, amplifies communication coverage by retransmitting the same packet, and helps maintain stable data flow across longer tunnel sections.

The receiver node collects forwarded data and presents it through an OLED display for continuous monitoring. A buzzer is connected to generate alerts whenever abnormal sensor values are detected, enabling immediate attention to unsafe conditions. The proposed system improves communication reliability, reduces packet loss, and enhances signal strength in non-line-of-sight underground environments. Performance is evaluated using RSSI, SNR, packet delivery rate, and communication distance to verify system effectiveness under mining conditions.

3.1. Modelling and Analysis

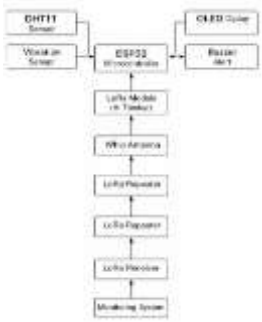


Fig. 1. Block diagram

DHT11 Sensor

The DHT11 sensor is a digital device for tracking humidity and temperature in environments. It uses a thermistor and a humidity sensing element to monitor its surroundings on a regular basis. Checking the temperature and humidity in mining areas is important because abrupt changes can indicate dangerous circumstances like inadequate airflow, rising equipment temperatures, or other dangerous conditions. The ESP32 microcontroller receives digital data directly from the sensor, reads it, and then gets ready to send it via the LoRa communication module. Despite its limited accuracy, the DHT11 is a popular c for prototype systems due to its low power consumption, ease of connection, and dependability for simple environmental monitoring..

Vibration Sensor

The vibration sensor is used to detect the mechanical vibrations, shocks, or sudden movements in the mining environment. It helps identify events such as rock disturbances, equipment movement, or possible structural instability inside underground tunnels. When vibration exceeds a defined threshold, the sensor generates a signal that is read by the ESP32 controller. This information can serve as an early warning for dangerous situations. Vibration monitoring is crucial in underground mining safety systems because unexpected ground movement can indicate a risk of collapse or problems with equipment.

ESP32 Microcontroller

The ESP32 microcontroller serves as the system's core processing unit. It gathers sensor data from the DHT11 and vibration sensor, processes these readings, and manages communication among all connected modules. The ESP32 was selected due to its substantial processing power, numerous GPIO pins, efficient power consumption, and straightforward integration with wireless modules. Within this project, it formats sensor data into packets prior to transmission via the LoRa transceiver. Moreover, it controls output devices on the receiving end, such as the OLED display and the buzzer. This allows ESP32 to ensure the reliable data handling in real - time , while also conserving power.

Ai-Thinker LoRa Module (Ai-Thinker / SX1276)

The LoRa module is what helps things talk to each other from away. It uses something called LoRa modulation. This special way of sending messages lets the LoRa module talk to things from very far away. It can even go through rocks and other things that would normally stop the signal. The LoRa module is also very good at using power, which is important for things that need to run for a long time.

When you are in a mine normal wireless signals do not work well because of all the rocks and tunnels.. The LoRa module

can still talk to other things from far away even when the signal is not very strong. The LoRa module that uses 433 MHz is a choice for this because it can go through rocks and other things better than other modules that use higher frequencies.

Whip Antenna

The whip antenna is connected to the LoRa module so it can send and get radio signals well. This makes the signals stronger lets them travel further and makes the reception better. When we talk about communication systems that're underground the antenna is very important because it can affect how far the signal can travel. This is because the signal gets weaker fast when it is, inside tunnels. If the whip antenna is set up right it helps the transmitter, repeater and receiver nodes talk to each other in a stable way.

OLED Display

The OLED display is used to show what is going on with the sensors now like the temperature, how humid it is, if there is any vibration and messages from other devices. We like to use OLED displays because they're easy to read do not use a lot of power and work well, with the ESP32. In your project the person watching the monitors can see what is happening underground at that moment. They do not need any other computers to do it.

Buzzer Alert

The buzzer is like an alarm. When there's much shaking or the environment is not safe. The ESP32 chip then makes the buzzer sound. This gives a warning to the people operating it. Sound alerts are really helpful because they let people respond fast, even if they're not always looking at the screen. Sensor readings are important for keeping things safe and it also provides a sound to warn operators about issues with the sensor readings. This way operators can take action away to fix problems.



Fig. 2. circuit diagram

Transmitter Node

out of the dark corners of the mine messages begin their journey here built around an esp32 chip paired with an ai thinker lora add-on it runs without guzzling power when hooked up to sensors or switches details start flowing in temperature shifts air quality urgent knocks miners might trigger these warnings by hand when things go wrong underground that incoming stream gets sorted instantly by the brain of the unit the esp32 wireless pulses then carry the message upward through rock and tunnel thanks to loras reach even blocked zones wont kill the signal weak spots dont stop it easily because regular radio waves often fail down there this setup makes all the difference hidden pathways beneath earth rely on such steady electronic whispers without this link pushing data out silence would win too fast

Repeater Node

The repeater node helps make communication between transmitter and receiver nodes happen over distances.In mines, tunnels and obstacles often make wireless signals weak. This makes it hard to communicate directly.A repeater node solves this problem. It picks up the LoRa signal from one node. Sends it to another node.This process uses an ESP32 and an AI Thinker LoRa module. They work well together for this task.By placing repeater nodes in spots inside the mine the signal can travel far without getting weak.
This way miners can stay in touch with the monitoring station without breaks in communication. The repeater node is very useful for keeping communication going in places like mines.The LoRa signal is important, for making this communication happen over distances. The LoRa signal helps.Repeater nodes ensure that the LoRa signal stays strong. The LoRa signal is key.

Receiver Node

The receiver node is where information being sent stops. This is where the information is gathered and used. The receiver node has a computer called an ESP32 microcontroller. The module gets signals from nodes that repeat them.

When the receiver node gets the information the ESP32 computer figures out what it means. It gets the information ready so people can see it on a computer or a special display. The people in charge can use this information to control things.

The receiver node is usually in a room where people in charge can see whats going on in the mine. They get warnings if something is wrong. The receiver node is important. It helps keep people safe by giving real-time information about whats happening in the mine. The receiver node is part of a system. This system helps the receiver node do its job. The job is to get information from the mine and show it to people, in charge. They use the node to stay safe.

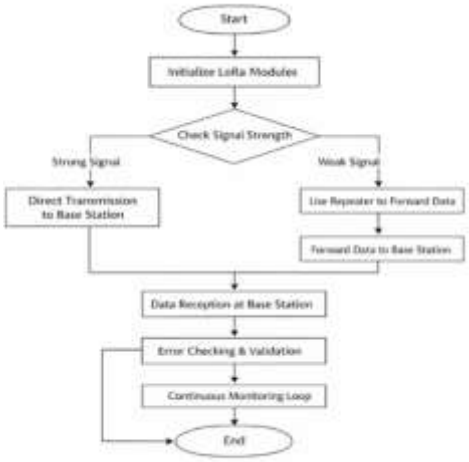


Fig. 3. Flow chart

IV. RESULTS & DISCUSSION



Fig. 4 . Lora Based Input transmitter



Fig. 5 . Lora Based Repeater



Fig. 6 . Lora Based output receiver



Fig. 7 . Lora Rockfall output



Fig. 8 . Lora humidity and temperature output

V. CONCLUSION

The project **"**Enhanced LoRa Based Underground Communication for Mining Using Repeaters**"** focuses on improving communication in underground mining environments. Underground areas usually face signal loss and communication difficulties due to obstacles and long tunnels. In this system, the ESP32 microcontroller collects data from sensors such as the DHT11 sensor and vibration sensor. The data is displayed on the OLED display and alerts are generated using a buzzer during abnormal conditions. The LoRa RA-02 module with a whip antenna is used for long-range wireless communication. Repeaters are used to extend the communication range inside tunnels. This system provides reliable monitoring and improves safety for miners in underground environmentsora humidity and temperature outpu

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