SL. no.	Paper Title	Problem Statement	Hardware Setup	System Architecture
1	A Real-Time LoRa (RT-LoRa) Protocol for Industrial Monitoring and Control Systems *"IEEE10.1109/ACCESS.2020.2977659 13 MARCH 2020"*	LoRa, while promising for industrial monitoring, it suffers from : High data collisions due to long time-on-air and uncoordinated transmissions Signal suppression when multiple devices transmit with different SFs but similar power levels Vulnerability to external interference from other ISM-band devices.	***Testbed:*** 1 Gateway + 15 end nodes ***End nodes*** : STM32 microcontrollers with SX1276 LoRa radio ***Uses SF7 and SF8:*** 100ms slots, 25.6s frame, with interference generated by additional nodes	***Star topology*** ***Star topology*** with direct end node-to-GW communication. Gateway connected to a server for data collection and control. ***SF based grouping***: Nodes grouped into GL (low attenuation) and GH (high attenuation) with adjacent SFs and separate channels. ***Uses frame-slot structure:*** Frame divided into slots, each sufficient for one packet. ***Downlink*** for time synchronization and control; ***Uplink*** for scheduled data transmission.
2	Body-to-Body Channel Characterization and Modeling Inside an Underground Mine *"IEEE TRANSACTIONS ON ANTENNAS AND PROPAGATION, VOL. 68, NO. 6, JUNE 2020"*	In-mine body-to-body (B2B) wireless channels lack proper characterization. This hinders reliable WBAN-based miner safety systems. Challenges: complex multipath, polarization effects, NLOS conditions in underground mines	***2×2 MIMO system*** with: Circularly and linearly polarized patch antennas (6.6 dBi gain). Operating at 2.4 GHz (measured across 2.3–2.5 GHz). Antennas worn on the chest of two students. Measurements taken using VNA. Conducted in a 20m underground mine gallery, with LOS and NLOS conditions.	Two people wear chest antennas inside a mine. Use 2×2 MIMO (***2 TX, 2 RX antennas)*** . Test circular vs linear polarization. Measure at 2.4 GHz using Vector Network Analyzer (VNA). Test in LOS and NLOS inside a 20m mine tunnel. Analyze path loss, delay spread, channel capacity for WBAN performance.

3	Edge-Based Hybrid System Implementation for Long-Range Safety and Healthcare IoT Applications *"IEEE INTERNET OF THINGS JOURNAL, VOL. 8, NO. 12, JUNE 15, 2021"*	Cloud-based IoT causes latency (unsuitable for real-time apps) Short-range protocols (e.g., BLE) require multiple gateways for wide coverage. High deployment cost and complexity	***Gateway:*** Raspberry Pi 3B+ with LoRa (RFM95 × 2), XBee-PRO 900HP, ZigBee, BLE (nRF52840 dongle), power management (5V/2.5A). ***Router:*** nRF52840 MCU with BLE 5/LoRa (RFM95), environmental sensor (BME280), solar harvester (ADP5090 + 2600mAh battery). ***Sensors:*** Wearable nodes (nRF52840 + LoRa + solar), ECG/health sensors (AD8232), BLE ID tags.	***3-Tier Layered*** ***IoT Layer:*** Sensors (BLE). ***Edge Layer:*** Hybrid router (BLE-to-LoRa bridging + basic edge tasks) + Gateway (multi-protocol support, data processing, cloud connectivity). ***Cloud Layer:*** Data storage/analysis.
4	Real-Time Human Activity Recognition (HAR) System Based on Capsule and LoRa *"IEEE SENSORS JOURNAL, VOL. 21, NO. 1, JANUARY 1, 2021"*	Existing HAR systems using CNN/RNN fail to capture spatial relationships among features, leading to incorrect recognition. Wireless transmission modes like Bluetooth/4G either lack long-range support or are power-hungry, making real-time HAR impractical in large-range, low-power scenarios.	***Wristband*** with: MPU-6050 (3-axis gyroscope + 3-axis accelerometer) for data collection. STM32 microcontroller for control. ***LoRa module (SX1278)*** for long-range, low-power wireless transmission. Tested transmission: 200 m range, 4.8 kbps rate, 3.7V Li-ion battery.	***Four layers:*** ***Perception layer***: Data collection via wearable sensors. ***Access layer***: LoRa for data transmission. ***Platform layer***: Preprocessing + Capsule network-based activity recognition. ***Application layer:*** User feedback and stability adjustments. LoRa enables low-power, long-distance transmission, making smart prison or large-area HAR feasible.

5	LoRaWAN Underground to Aboveground Data Transmission Performances for Different Soil Compositions "IEEE TRANSACTIONS ON INSTRUMENTATION AND MEASUREMENT, VOL. 70, 2021"	Evaluate LoRaWAN feasibility for underground-to-aboveground (UG2AG) data transmission. Analyze signal performance across different pure soil types (gravel, sand, clay). Address challenges in wireless underground sensor networks (WUSNs) due to soil attenuation for smart agriculture and environmental monitoring.	***Transmitter*** : B-L072Z-LRWAN1 Discovery Kit (STM32L072CZ MCU + Semtech SX1276 LoRa transceiver), λ /8 whip antenna (2 dBi), power bank, enclosed in IP56 box. ***Receiver (Gateway):*** Dragino LG308 with SX1257 and SX1301 LoRa modem, λ/8 whip antenna, 125 kHz bandwidth. ***Frequency:*** 863–870 MHz (8 channels). ***Transmission power*** : 14 dBm; CR: 4/5. ***Placement:*** Transmitter buried at 10, 20, 30, 40, 50 cm depths; gateway at 15 m on the ground.	***Start Topology*** LoRaWAN-based Internet of Underground Things system - Underground node ***periodically sends packets using LoRaWAN.*** Aboveground gateway forwards packets via MQTT to a Node-RED server. ***Data stored*** in a MySQL database for analysis of RSSI, SNR, and packet loss (PL). Uses frequency diversity across 6 channels to enhance reliability.
6	LTrack: A LoRa-Based Indoor Tracking System for Mobile Robots *"IEEE TRANSACTIONS ON VEHICULAR TECHNOLOGY, VOL. 71, NO. 4, APRIL 2022"*	Existing indoor tracking for robots often uses vision-based methods, causing privacy issues and limited coverage. RF-based systems need infrastructure, have limited range, or are costly (e.g., SDR/USRP-based AoA estimation). Need a low-cost, infrastructure-free, accurate indoor tracking system for mobile robots using LoRa while overcoming its lack of AoA capability.	***Anchor (gateway):*** LoRa SX1280 chip, circular antenna array (two 0.2 m separated omnidirectional antennas), HMC241 RF switch, rotary DC motor with encoder, PID control, installed on mobile robot. ***Tag (end device):*** SX1280 LoRa chip + STM32L476 microcontroller, 4 cm x 10 cm, low-power design. LoRa configuration: 2.4 GHz band, 1625 kHz bandwidth, SF5, 12.5 dBm transmit power.	***Anchor mounted on the robot:*** Sends/receives ranging packets from tag. Uses optimized ToF (Time of Flight) and TDoF (Time Difference of Flight) measurements with antenna switching. Rotates antenna array to create a virtual circular array for AoA estimation while eliminating blind spots. Uses Doppler shift analysis for movement estimation. Firmware on the robot: Receives AoA, ToF, and velocity data from the anchor. Calculates target location and navigates robot toward the target in real-time.

7	Energy Consumption Improvement of a Healthcare Monitoring System: Application to LoRaWAN *"IEEE SENSORS JOURNAL, VOL. 22, NO. 7, APRIL 1, 2022"*	Need for remote healthcare monitoring (temperature, SpO_2, BP, HR) with low power consumption and long battery life. Existing WBAN + LoRa solutions lack adaptive energy efficiency while maintaining medical monitoring requirements.	Wearable sensors: MAX30102 (Heart rate, SpO_2) BME280 (Body temperature) MPX4250AP (Blood pressure) Microcontroller: ATmega328P LoRa Module: SX1276 for LoRaWAN Class A transmission Power Source: 5V battery	***Three-tier architecture*** Wearable sensors on patient's body connected to MCU (first tier). LoRa transmitter sends data to a LoRa gateway (second tier). Gateway transmits to medical server via IP for doctor's review (third tier). Uses Early Warning Score (EWS) with Fuzzy Logic Controller to dynamically adapt: Sleep duration Data transmission rate Criticality (Risk Level) evaluation
8	LoRa-Based Smart Sensor for Partial Discharges PD Detection in Underground Electrical Substations *"IEEE TRANSACTIONS ON INSTRUMENTATION AND MEASUREMENT, VOL. 71, 2022"*	Underground substations need continuous PD (Partial Discharge or electrical spark) monitoring for predictive maintenance. Difficult wireless transmission from underground (reinforced concrete, EMI). Need for: Low-cost, low-power, reliable PD detection. Wireless connectivity with robust transmission in underground conditions. Local auto-calibration to environmental noise.	***Ultrasonic sensor***: MURATA MA40S4R, 40 kHz, high sensitivity for acoustic PD detection. ***FPAA (Anadigm QuadApex):*** Programmable analog filter (40 kHz center, 1.5 kHz BW) and amplifier. Allows on-site gain adjustment for noise adaptation. ***Microcontroller:*** STM32F446RE (Cortex-M4, 180 MHz) for acquisition and processing. ***LoRa Transceiver:*** SX1272 (via I-NUCLEO-SX1272D board).	***Analog Section:*** To detect ultrasonic signals generated by PD then filter and amplify these signals for reliable processing by using ultrasonic sensor and programmable conditioning circuit using FPAA (Field Programmable Analog Array) ***Digital Section with LoRa Transmission:*** To acquire, process, and analyze the analog signal. To detect PD events based on thresholds. To transmit alert messages using LoRa.

9	Efficient Energy Mechanism in Heterogeneous WSNs for Underground Mining Monitoring Applications *"IEEE 10.1109/ACCESS.2022.3188654 15 JULY 2022"*	High energy consumption in heterogeneous WSNs for underground mining due to: DEECP protocol ignoring node distance to BS during CH selection Failure to account for multi-level energy heterogeneity (low/high/super) in sensors Premature node death reducing network stability and lifetime	***Simulation:*** MATLAB ***Network Size:*** 200m × 200m area, 7m depth ***Nodes:*** 50-200 heterogeneous sensors ***Communication:*** ZigBee/802.15.4 ***Traffic:*** 200–1000 packets, 200–600 messages ***BS Position:*** Centralized	***Topology:*** Cluster-based ***Energy Model:*** Three-level heterogeneous (low/high/super energy nodes) ***Communication:*** Multi-hop inter-cluster routing ***Mine Structure:*** Room-and-pillar deployment
10	A Hand Hygiene Tracking System With LoRaWAN Network for the Abolition of Hospital-Acquired Infections *"IEEE SENSORS JOURNAL, VOL. 23, NO. 7, 1 APRIL 2023"*	Hospital-Acquired Infections (HAIs) are a major cause of preventable illness and death in healthcare facilities. Poor compliance with hand hygiene practices among healthcare workers and patients contributes significantly to HAIs, including community acquired pneumonia and hospital-acquired pneumonia. Existing monitoring solutions are either manual, intrusive, or technologically limited.	***Wearable Device***: Bluetooth Low Energy (BLE) wristband worn by healthcare staff and patients. ***Smart ABH Dispenser Unit***: TTGO T ESP32 IoT module + MLX90614 IR temperature sensor for human detection + Stepper motor to control sanitizer spray and door mechanisms. ***LoRa Gateway***: Uses LoRaWAN for long-range, low-power wireless transmission ***Local Server***: NVIDIA Jetson Nano GPU (128-core) for data processing. ***Application Server:*** Raspberry Pi 4B for IoT management and cloud integration.	***Hybrid Star Topology*** ***Inner Star (BLE Layer)***: Wearable BLE devices worn by staff/patients connect wirelessly (15 ft range) to smart sanitizer dispensers ***Outer Star (LoRaWAN Layer):*** All smart dispensers send data wirelessly over long distances to LoRa gateways in the hospital. then LoRa gateways forward data via Wi-Fi/Ethernet to a local Jetson Nano server. ***Local Server to Cloud:*** The Jetson Nano server syncs data to AWS IoT cloud and a Raspberry Pi application server for dashboards and alerts.

11	Activity Monitoring and Location Sensory System for People With Mild Cognitive Impairments *"IEEE SENSORS JOURNAL, VOL. 23, NO. 5, 1 MARCH 2023"*	Rising global aging population increases prevalence of dementia/mild cognitive impairment (MCI), leading to loss of independence and caregiver burden. Existing solutions for patient monitoring suffer from high power consumption, limited outdoor coverage, inaccuracy in room-level indoor positioning.	***IR Beacons:*** ESP32-PICO-D4 SoC emits 4-bit coded IR signals (38 kHz carrier) every 2s. ***Wireless Wearable Sensor (WWS):*** External 2Ah LiPo Battery + Ublox MAX-7Q GNSS module (outdoor positioning, ± 2.5m error) + LIS3DH accelerometer (step detection) + BME680 (temperature/humidity/gas) + IR receiver (room identification) + RAK811 LoRaWAN module (SX1276 transceiver) ***Gateway*** : Lorix-One 868 MHz LoRaWAN gateway (2km urban/12km rural range)	**Hybrid Star Topology** **LoRaWAN Layer (Wide Star Topology):** Wearable devices (WWS) act as end nodes transmitting data directly to LoRaWAN gateways over 868.9 MHz. Multiple WWS devices → single LoRaWAN gateway (star) **Indoor Localization Layer (Room-Level Proximity Grid):** IR beacons (fixed in each room) emit IR code Wearable devices detect these codes to determine room-level location without complex fingerprinting **Backend Layer (Star Topology):** TTS forwards decoded packets to Node-RED (processing engine) All backend services are centralized and connect around Node-RED, forming a processing star topology
12	An Autonomous IoT-Based Contact Tracing Platform in a COVID-19 Patient Ward *"IEEE INTERNET OF THINGS JOURNAL, VOL. 10, NO. 10, 15 MAY 2023"*	Manual contact tracing in hospitals is slow, recall-dependent, and error-prone. Healthcare workers (HCWs) face high COVID-19 exposure risk and existing digital solutions drain batteries, raise privacy concerns, and are impractical for HCWs to carry continuously.	***BLE Wearable Tags:*** Nordic nRF52840 SoC, 400mAh Li-Po battery (3+ days runtime), size 55×46×10.5mm (15 units deployed). ***Hybrid Transceivers*** : Patient rooms (nRF52840 + LoRa RFM95 + laser proximity sensors + microSD); common areas (BLE/LoRa only). ***IoT Edge Gateway*** : Raspberry Pi 3B + with LoRa module.	***Layered Star Topology*** ***BLE Wearables Layer:*** Track HCW-HCW proximity via RSSI Hybrid ***Transceivers Layer:*** Aggregate BLE proximity data from nearby wearables and transmit this data via LoRa to the edge gateway here LoRa star topology implemented where multiple hybrid transceivers act as LoRa end nodes communicating with the edge gateway. ***Edge Gateway Layer:*** Receives LoRa packets from hybrid transceivers and stores intermediate data in MySQL for reliability then forwards data securely to the remote server over the internet ***Remote Server Layer:*** Receives encrypted data, decrypts, and stores in the cloud database A centralized dashboards provide actionable insights for infection control.

13	RTEPMS: Real-Time Environmental Parameters Monitoring System Using IoT-Based LoRa 868-MHz Wireless Communication Technology in Underground Mines *"IEEE 10.1109/ACCESS.2024.3350429 18 JAN 2024"*	Manual monitoring of environmental parameters (gases, temperature, humidity) in underground mines using portable multi-gas detectors is infrequent, lacks real-time alerts, and is costly. Existing systems suffer from poor wireless signal propagation in curved tunnels, data packet loss, and limited scalability.	***Sensors:*** MQ-4 (CH_4), MQ-7 (CO), MQ-8 (H_2), MQ-136 (H_2S), MH-Z19C (CO_2), DHT11/22 (temp/humidity). ***Microcontroller:*** ESP32 with Wi-Fi/Bluetooth. ***Communication:*** HPD13A-SX1276 LoRa 868 MHz transceivers. ***Storage:*** Micro SD cards. ***Peripherals:*** RTC (DS1307), LCD, buzzer, 6/7 dBi antenna.	***Start Topology*** ***Transmitter:*** Sensors → ESP32 → LoRa module (868 MHz) → SD card (local storage). ***Receiver:*** LoRa module → ESP32 → SD card/ThingSpeak cloud (via Wi-Fi) → LCD/alerts. ***Power:*** 12V battery → LM2596 (5V) → AMS1117 (3.3V) for low-power components.
14	LoRaAid: Underground Joint Communication and Localization System Based on LoRa Technology *"IEEE TRANSACTIONS ON WIRELESS COMMUNICATIONS, VOL. 23, NO. 5, MAY 2024"*	Underground wireless applications (e.g., mine rescue, earthquake rescue) require communication and precise localization simultaneously under: Severe underground signal attenuation, Limited hardware resources, Restricted communication opportunities. Existing systems typically handle communication and localization separately, leading to inefficiency in emergencies. Need for a lightweight, low-power system enabling simultaneous underground communication and decimeter-level localization using one signal.	***Wearable LoRa device*** carried by individuals in underground environments. ***Multiple buried LoRa nodes*** (anchors) connected to a gateway/data center. Devices used: ***USRP 2954R SDR*** s with VERT 900 antennas. Operate ***at 900 MHz,*** with Spreading Factors SF7 – SF12, BW = 125 kHz, CR = 4/5.	LoRaAid system with: A wearable LoRa transmitter (target) sending signals during emergencies. Multiple buried receivers(LoRa Transceiver) capturing the signal and sending it to the data center. Data center: Combines signals from multiple nodes for diversity reception. Uses noise-reduced RSSI-based trilateration for localization. Uses Maximal Ratio Combining (MRC) with coherent demodulation and Equal Gain Combining (EGC) with non-coherent demodulation for flexible deployment based on precision and hardware constraints.

15	IoT-Enabled Real-Time Health Monitoring via Smart Textile Integration With LoRa Technology Across Diverse Environments *"IEEE TRANSACTIONS ON INDUSTRIAL INFORMATICS, VOL. 20, NO. 11, NOVEMBER 2024"*	Conventional wearable health monitoring systems face challenges: Limited communication range. Rigid, uncomfortable antenna designs. Interference in congested frequency bands (e.g., 2.45 GHz). Need for flexible, low-power, long-range wearable health monitoring in IoT-enabled healthcare. Requirement to monitor heart rate, ECG, and temperature with comfortable integration in clothing.	Digitally embroidered triple-band textile monopole antenna (433, 610, 915 MHz) on cotton fabric. Adafruit Feather M0 microcontroller with RFM69 packet radio transceiver for LoRa communication. Sensors: PPG sensor for heart rate. MAX30205 sensor for temperature. AD8232 sensor for ECG. SMA connectors with conductive adhesives for seamless textile integration. Battery-powered system for on-body operation.	Transmitter (Tx): ***Embroidered textile antenna.*** LoRa module operating at 433 and 915 MHz. Sensors to collect heart rate, ECG, and temperature data. Data ***transmitted*** wirelessly via ***LoRa***. Receiver (Rx): LoRa receiver with identical frequencies. Connected to a laptop for real-time data monitoring. Peer-to-peer LoRa communication system enabling long-range, low-power, continuous monitoring.
16	Design and Study of LoRa-Based IIoT Network for Underground Coal Mine Environment *"IEEE10.1109/ACCESS.2024.3470120 9 JAN 2025"*	Designing a low-power, scalable, flexible LoRa-based IIoT monitoring network in underground coal mines, which face challenges like severe attenuation, dust, toxic gases, and power restrictions while ensuring reliable data transmission for safety and monitoring.	***LoRa End Devices :*** It consist of ESP32 microcontroller, sensors, LoRa transceiver, Antenna, Battery(Li-ion 2000 mAh) ***LoRa transceiver:*** 433 MHz, 125 kHz bandwidth Provides long-range, low-power wireless transmission in harsh mine environment. ***LoRa Gateway with ESP3:*** Receives LoRa packets wirelessly from underground end devices	***Mesh Multi-Hop System*** ***Multi-Hop Mesh:*** LoRa end devices deployed at face, roadway, and shaft, data is forwarded hop-by-hop from deeper mine devices to the gateway as Multi-Hop Mesh also optimizes spreading factor, bit rate and power consumption dynamically ***LoRa gateways:*** The gateway at the surface collecting underground data then network servers forwarding to mining authorities.

17	Design of a Wireless Cyber – Physical System for Gas Leak Detection with LoRa *"IEEE INTERNET OF THINGS JOURNAL, VOL. 12, NO. 14, 15 JULY 2025"*	Industrial and residential areas require low-power, long-range, real-time gas leak detection for safety Existing systems face high power consumption, limited coverage, unreliable detection, making continuous monitoring impractical.	***LoRa-enabled sensor nodes:*** It consist of ESP32 microcontroller, sx1276 LoRa transceiver, MQ series gas sensors (MQ-2, MQ-3, MQ-135), temperature and humidity sensors and powered by 2000 mAh Li-ion batteries. ***LoRa gateway:*** It connected to a central monitoring unit for data aggregation.	***Star Topology*** ***LoRa Sensor Nodes (End Devices):*** Act as leaf nodes in the network, each node senses gas concentration and transmits data directly to the LoRa gateway. ***LoRa Gateway (Central Hub):*** It Acts as the central coordinator in the star topology which receives packets from all LoRa sensor nodes forwards data to the cloud using Wi-Fi and operates in asynchronous Aloha-type MAC.
18	Parameter Configuration Scheme for Optimal Energy Efficiency in LoRa-Based Wireless Underground Sensor Networks *"IEEE TRANSACTIONS ON VEHICULAR TECHNOLOGY, VOL. 74, NO. 6, JUNE 2025"*	Energy inefficiency in LoRa-based WUSNs due to high signal attenuation in soil, requiring higher transmit power. Battery replacement difficulty for buried nodes. Collision-induced packet loss in densely deployed nodes. Existing solutions (Adaptive Data Rate, Adaptive Selection of Transmission Configuration for LoRa-Based WUSNs) either sacrifice Energy Efficiency for reliability, lack adaptability, or ignore collisions.	***Buried LoRa sensor nodes*** with soil moisture sensors Aboveground gateway receiving Underground-to-AboveGround transmissions Operating parameters: Central frequency = 915 Mhz Soil properties: Sand fraction S = 51%, Clay fraction = 9%	***EnergySaver framework:*** Nodes measure soil moisture (VWC) and send data to gateway. Gateway uses underground channel model to estimate SNR based on VWC, transmit power, and node location. Calculates Packet Delivery Ratio(PDR) and Energy Efficiency(EE) for all parameter combinations (SF, TP, BW, CR) using closed-form EE expression then selects configuration maximizing EE with PDR >90%. Sends optimal parameters back to nodes. For collisions: Uses unaligned-window decoding to resolve concurrent transmissions.

19	Low-Cost LoRa-Based System for Continuous GHGs Monitoring in Cattle: Enhancing Agricultural Sustainability *"IEEE 10.1109/ACCESS.2025.3532471 29 JAN 2025"*	Livestock (especially cattle) emit significant methane (CH_4) and carbon dioxide (CO_2), contributing to climate change. Existing monitoring systems: Are fixed, costly, and not scalable. Lack livestock-level real-time data. Do not integrate manure management and seasonal variability.	***Cattle Collar System:*** Sensors: MG-811 (CO_2), TGS2611 (CH_4). Seeeduino board + LoRa RFM95 module (925 MHz). LiPo battery (3.7V, 5000 mAh). Small fan for airflow to sensors. ***Closed Feeding Slot System:*** Same sensors as above, mounted near the feeding slot. ESP32-C3 microcontroller + LoRa RFM95 (920 MHz). Powered by 3.7V 9900 mAh battery. ***LoRa Gateway:*** ESP32-C3 with 2.4 GHz WiFi. 10 dBi antenna. Data uploaded every 15s.	Two data collection points: Cattle Collar (movable, on-animal monitoring) Closed Feeding Slot (fixed near feeding area) LoRa network transmits sensor data up to 400m. WiFi gateway uploads real-time data to the cloud. Data analytics enabled via Google Sheets.
20	Near-Ground Propagation Channel Modeling and Analysis in Underground Mining Environment at 2.4 GHz *"IEEE OPEN JOURNAL OF ANTENNAS AND PROPAGATION, VOL. 6, NO. 2, APRIL 2025"*	Lack of detailed near-ground wireless channel modeling at 2.4 GHz in underground mines. Underground mines have complex multipath, attenuation, and harsh conditions impacting communication reliability. Needed for Mine IoT, safety, automation, and Mine 4.0.	Anritsu MS4647A Vector Network Analyzer (10 MHz – 70 GHz). 200 MHz bandwidth at 2.4 GHz for frequency-domain channel sounding. 9 dBi omnidirectional antennas. Broadband Radio-over-Fiber (RoF) link for extended measurement range. Tx-Rx antenna heights: 10 cm, 30 cm, 60 cm, 120 cm. Measurements in Old Lamaque underground gold mine (depth: 90–91 m, 150 m tunnel length). Tx moved from 1 m to 100 m, Rx fixed, covering LOS and NLOS.	Tx Node: Sends 2.4 GHz signal via VNA → RoF → 9 dBi antenna at low heights (10/30/60/120 cm). Channel: Underground tunnel acts as complex multipath network link (LOS & NLOS). Rx Node: 9 dBi antenna + RoF + VNA captures signal. Measurements: S21(f): Channel Transfer Function (CTF). CIR: Channel Impulse Response via chirp-Z. 40 positions tested (27 LOS, 13 NLOS, 1 – 100 m range). Analyzes: Path Loss (PL) RMS Delay Spread (τ_{rms}) Coherence Bandwidth (Bc) Power Delay Profile (PDP)