Methodology	Results & Insights	Future Scope
Logical Slot Indexing (LSI) Algorithm: Generates feasible, collision-free slot schedules for periodic data transmission. ***Node Grouping***: Based on signal attenuation to assign SF and channels, avoiding suppression. ***TDMA-based Slot Scheduling***: Tasks with different periods are assigned slots matching their transmission periods. ***Multiple Listen-Before-Talk (mLBT)***: Detects channel activity multiple times before transmission to handle external interference. ***Task Scheduling:*** Uses logical indices for fair slot distribution and ensures deadlines are met.	***RT-LoRa achieved >94% PDR*** (Packet Delivery Ratio) under high traffic and interference, outperforming LoRaWAN (around 60%) and Slotted Aloha. ***Reliable Real-Time Data Collection***: Grouping avoided collisions and signal suppression Grouping + mLBT increased resilience against interference while preserving energy efficiency	***Multi-Hop:*** Extend RT-LoRa to multi-hop communication to reach nodes in wireless-unfriendly zones where direct GW connectivity is not possible. ***Adaptive Channel allocation***: Explore adaptive SF/channel allocation based on real-time link quality. ***Integration With Digital Twin Systems:*** Enables industrial automation frameworks for predictive maintenance and advanced monitoring.
Collected S-parameters using Vector Network Analyyzer (VNA). ***Computed impulse responses*** using IFFT with Hamming window. Extracted: Power Delay Profile (PDP), Path Loss (PL) via linear regression, RMS Delay Spread. ***Coherence Bandwidth.*** Rician K-factor. MIMO Channel Capacities under fixed SNR and transmit power. ***Developed impulse response model:*** Path amplitudes modeled with exponential decay. Time-of-arrival steps modeled with Poisson distribution.	***Circular polarization:*** Lower path loss. Lower RMS delay spread. Higher channel capacity than linear polarization. ***NLOS conditions:*** Increased path loss (~30 dB higher). Increased delay spread. MIMO throughput gain was highest under NLOS due to multipath exploitation. Circularly polarized MIMO proved robust to misalignment, making it suitable for B2B WBAN in mines	Integrate with WBAN-enabled rescue and health monitoring systems. ***Test higher MIMO*** configurations and other frequency bands (e.g., UWB, 5G) in underground mines. Enable ***real-time miner positioning*** and health tracking in harsh environments.

Device Management: Registers sensors via MAC addresses then end nodes read health vital and environment data and send it via BLE. ***BLE-LoRa Bridging:*** Routes BLE sensor data to gateway via LoRa. ***Lora Gateway:*** It send data to cloud for for visualization and save locally in MongoDB (NoSQL) for raw (Level 1) and processed (Level 2) data Wearable sensors (nRF52840 + LoRa) → Router/Gateway → Cloud.	***Latency***: 11.5 ms (BLE-to-router), 316 ms (LoRa SF9). ***Coverage:*** BLE extended to 2.4 km via LoRa routers. ***DER(Data Extraction Rate)***: >99% (10 routers, SF9). ***Power***: Routers operate 9 days indoors and gateway 8h on power bank. ***Emergency response***: <2s for cardiac alerts.	***Integrate more protocols:*** SigFox, NB-IoT, ZigBee, NFC. ***Enhance security:*** Authentication beyond AES-128 and post quantum algorithms.
Collect activity data via wristband and transmit via LoRa then handle data uncertainty (missing/inconsistent data) using deletion, prediction, and Dempster-Shafer theory. ***Segment time-series data*** using a sliding window (length=90, 50% overlap). ***Build capsule network***: Converts scalar inputs to vectors, capturing spatial relationships. Utilizes dynamic routing between capsule layers. Employs squash functions for non-linear vector processing. ***Train*** on WISDM dataset (36 individuals, 6 activities, 20Hz). ***Optimize parameters***: route iterations (best=5), learning rate (0.006), capsule kernels (34), capsule groups (11). Use Softmax classifier for final activity prediction. Incorporate user feedback for system parameter tuning.	Accuracy: Capsule framework: ***95.2% testing accuracy.*** ***Outperforms CNN*** by 4.5% and ***LSTM*** by 2.9% on WISDM. Training accuracy reaches 99.9% after 30 epochs. Performs well in recognizing ***walking (99%), jogging (97.5%), standing (96.2%),*** but struggles with distinguishing upstairs vs downstairs due to similarity. LoRa successfully achieves long-range, low-power transmission suitable for real-time HAR.	Explore ***capsule + LSTM*** hybrid frameworks to further improve recognition. Investigate alternative weighting mechanisms for capsules. ***Address limitations in*** distinguishing similar activities (e.g., ***stairs movement***)

Soil samples (gravel, sand, clay) analyzed for grain size, VWC, and bulk density. Transmitter ***buried at 5 depths*** (10–50 cm) in each soil type. LoRaWAN transmissions at SF 7–12 with 300 packets per SF and depth. ***Collected RSSI, SNR,*** PL for each configuration. Validated soil compaction impact via a 20-day test showing negligible RSSI change. Applied path loss models using MBSDM and ITU methods for comparison with experimental results.	Successful UG2AG data transmission up to 50 cm for all soil types with ***PL < 2% (except clay at SF=12 for 40/50 cm).*** Sandy soil provided best RSSI/SNR; gravel worst (difference ~10 dBm). LoRaWAN's high receiver sensitivity (up to -137 dBm) enables reliable underground data collection.	Extend ***tests to deeper burial depth*** s (>50 cm, e.g., 1 m). Analyze impact of soil chemical composition (salinity, metallic content) on UG2AG transmissions. Test other frequency bands (433 MHz, 915 MHz) for UG2AG links. Study ***impact of larger gateway distances*** (30, 50, 100 m) on link budget.
Enable AoA on LoRa using lightweight hardware modification (antenna array + RF switch). Optimize LoRa's default ranging workflow to reduce ranging time from 160 ms to 2.88 ms, improving TDoF accuracy. Use circular antenna array rotation to emulate a virtual array, eliminating blind spots. Employ stochastic gradient descent (SGD) for real-time AoA estimation during tracking. Doppler shift-based velocity estimation to account for target movement in real-time. Integrated tracking algorithm on the robot for continuous path planning and movement toward the target.	TDoF(Time Difference of Flight) accuracy improved by 3x over standard LoRa AoA(Angle of Arrival) error: 2.4° at 40 m, 4.5° at 50 m, 5.2° at 60 m (LOS). 5.7–8.5° (NLOS with obstacles). Tracking error: 0.12 m median in lab (137 m^2). 0.24 – 0.45 m in a 600 m^2 corridor at 0.3–0.5 m/s speeds. Supports multi-target tracking with <1 m error up to 8 targets in 50 x 50 m^2. Works up to 200 m with <10° AoA error.	Extend to 3D tracking and outdoor environments. Integration with multi-robot collaboration for large-scale warehouse/industrial applications. Improve tracking under fast target movement (>0.5 m/s). Combine with sensor fusion (LiDAR, IMU) for enhanced accuracy in challenging indoor environments.

Sensors measure patient parameters → EWS calculated via fuzzy inference system in MATLAB. Dynamic decision-making: First measurement always sent. Subsequent measurements sent only if score changes.If stable, sends data every 6 hours. Sleep mode activated to save energy between readings. Sleep duration inversely proportional to patient risk level (RL). Analytical model for energy consumption and permitted transmissions under LoRaWAN Class A duty cycle constraints.	Battery life can be extended 3-10x compared to reference systems: 12+ months in normal monitoring. 4x improvement even in critical monitoring. Higher SF increases energy consumption and reduces lifetime. Higher BW increases system lifetime. Collision probability reduces lifetime but within manageable limits. Duty cycle of 1% respected while ensuring effective patient monitoring.	Enhance decision-making using patient history in storage. Extend platform to additional medical parameters and AI-based health prediction.
Sensor Node Design: Developed a low-cost smart sensor node for detecting Partial Discharges (PD) using ultrasonic acoustic sensing. ***Signal Conditioning using FPAA***: FPAA used for: Bandpass filtering centered at 40 kHz (1.5 kHz BW) + Amplification with programmable gain + Allowed on-site automatic gain adjustment based on environmental noise. ***Wireless Communication Testing using LoRa:*** Integrated SX1272 LoRa transceiver for wireless data transmission. Configured as SF = 8. BW = 125 kHz. then transmitted PD alert messages (“Green”, “Yellow”, “Red”) to an external gateway for monitoring.	***Alerts:*** Yellow alert at 300 mV (~6 dB SNR). Red alert at 1.5 V (~20 dB SNR). ***Packet Loss***: 0% packet loss across 1000 packets in all LoRa test scenarios. ***LoRa transmission:*** It was reliable even with - Reinforced concrete obstacles. Substation depth of 4 m. Distances up to 110 m with buildings in the line of sight.	Design custom ***PCB*** and ***robust casing*** for EMI protection. Extend detection capability to ***other discharge types*** and materials (oil, rubber). Investigate lightweight ***encryption*** for secure LoRa transmission.

The proposed mechanism improves the Distributed Energy-Efficient Clustering Protocol (DEECP) by addressing two critical limitations: Ignoring energy heterogeneity (DEECP assumes only two energy levels). Overlooking distance to BS during CH selection. ***Enhanced DEECP:*** DEECP with distance-aware CH selection and three energy levels ***CH(Cluster Head) election :*** Probability based threshold for CH election and distance-integrated threshold ***Key Improvements:*** CHs selected based on proximity to BS + residual energy Energy-balanced clustering to prevent overload on distant nodes	24% longer network lifetime vs. DEECP Later first node death: 436 rounds (proposed) vs. 885 rounds (DEECP) Higher throughput: 150 kbps (proposed) vs. 75 kbps (DEECP) Stability period: 436 rounds (proposed) vs. 885 rounds (DEECP)	Integrate AI techniques (Q-learning, swarm intelligence) for CH optimization Optimize data flow volume based on sensor types Extend to larger-scale deployments with real-world testing
Design : Deploy BLE wearables + intelligent dispensers at ICU entrances, patient rooms and hospital wards. ***Operation*** : BLE device signals the dispenser → IR sensor confirms human presence → Dispenser sprays sanitizer and opens doors if required → Logs hygiene event with timestamp and indentity → Sends data to LoRa gateway → local server → cloud. ***Data Security*** : End-to-end encryption, authentication via MQTT and LoRaWAN.	Lab Success Rate: **98%** Real-world Success Rate: **92.78%** LoRaWAN ensured long-range, low-power data transfer. Accurate tracking reduced missed detections Helps reduce Hospital Acquired Infections.	***AI/ML Integration:*** Use machine learning to predict non-compliance patterns. Analyze hygiene trends for infection control planning. ***Energy Optimization:*** Integrate solar energy harvesting to extend battery life of wearables. ***Expand Monitoring Scope:*** Extend beyond hand hygiene to monitor PPE compliance and Environmental cleaning.

Indoor Localization: IR beacons transmit unique 4-bit codes confined to rooms then WWS decodes signals via interrupt-driven routine (low power) ***Step Detection:*** 10Hz accelerometer sampling Euclidean norm of 3-axis acceleration → remove offset → detect zero-crossings then step validated if peak-to-peak amplitude > threshold. ***Alert System:*** Rules configurable in Node-RED (e.g., "bathroom > 1hr" or "kitchen not visited by noon"). ***Energy Optimization:*** LoRaWAN + 10s data transmission intervals. ARM Cortex-M3 microcontroller in sleep mode between operations.	***Indoor Localization:*** Accuracy >90% room-hit rate, except corridors (85.56%) due to open layouts ***Step Detection:*** 92.8% accuracy (normal gait), 89.6% (random movements) ***System Deployment:*** Grafana dashboards showed patient trajectories, step counts, and room occupancy Telegram alerts triggered for anomalies ***Battery Life and Coverage:*** 24 hours per charge. LoRaWAN enabled operation in rural/low-network areas.	***Miniaturize:*** Reduce the size of WWS for better user acceptance. ***Enhance IR*** robustness for open-plan spaces. **Integrate *Additional Sensors:*** Add sensor such asfall detection. ***Optimize Step Detection:*** Algorithm for varied motion patterns can be added.
BLE wearable tags worn by healthcare workers (HCWs) to record HCW–HCW interactions using RSSI and Kalman filtering. ***Hybrid transceivers*** installed in patient rooms and ward common areas to capture HCW – patient interactions and room entry/exit using BLE + proximity sensors. ***LoRa wireless transmission*** to send data to an IoT edge gateway for preprocessing, encryption, and forwarding to a remote server for visualization and analysis.	***15 BLE*** wearable tags used by HCWs. ***Covered 8*** isolation rooms + ward corridors + donning/doffing zones. BLE wearable tags lasted >***3 days per charge*** ***Tracked entry/exit*** with accurate timestamps using proximity sensors + filtered RSSI ***Reliable, interference-free*** operation in the hospital ' s 2.4 GHz heavy wireless environment	***Software Improvements***: Enable real-time localization for emergency response and infection prevention teams ***Extend System Capabilities:*** Broader hospital deployment Application in other high-risk environments for infection control

Sensors calibrated using datasheets and multi-gas detector references. Data collected every minute; stored in CSV on SD card during specific intervals (00 – 02, 20 – 22, 40 – 42 min). LoRa transmits data; receiver sends acknowledgments. Threshold-based buzzer alerts for parameter violations. Testing in open space (300 m LOS) and underground mine (straight: 180–200 m; curved: 125–130 m).	***Communication***: Achieved 300 m (surface), 180 – 200 m (straight tunnels), 125–130 m (curved tunnels). ***Gas Correlation***: 69.47% for CO_2, 72.38% for CO vs. multi-gas detectors; CH_4/H_2S	***Adopt LoRaWAN*** gateways for extended coverage. Integrate real-time dashboards in control rooms. ***Apply ML for hazard prediction*** and proactive safety. Enhance durability for harsh environments.
Transmit Signal: LoRa chirp send signals from the wearable device then signal propagation modeling in underground environments ***Channel***: Underground channel uses underground channel path loss and Rayleigh fading. ***RSSI-to-Distance Conversion:*** Establishes a relation between RSSI and distance. ***Spatial Diversity Reception:*** Signals from multiple nodes combined to enhance SNR even under ultra-low SNR conditions. ***Localization:*** Noise-reduced RSSI extracted using FFT-based dechirping then apply Taylor series-based iterative trilateration using distances from atleast 3 anchor nodes for 2D localization.	Achieved reliable underground communication up to 7 m with decimeter-level positioning accuracy. Noise-reduction algorithm improved localization accuracy by 8 – 18% depending on soil moisture. Demonstrated that higher soil moisture reduces communication range and localization accuracy.	Extend LoRaAid to ***3D localization*** in varying depth environments. Optimize anchor placement algorithms for rapid deployment during emergencies. Integrate ***adaptive SF/BW selection*** to balance energy, range, and data rate dynamically. Test in real mine rescue and earthquake simulation environments for further validation.

Design, simulation, and fabrication of a digitally embroidered LoRa textile antenna. Antenna optimized for size and flexibility using meandered structure and slots. SAR analysis to ensure safe human body exposure limits. Experiments conducted: Outdoor testing (football field, hiking trail) to measure communication range and RSSI. Indoor testing (hospital) to analyze data reliability near medical devices. Continuous monitoring of physiological parameters (heart rate, ECG, temperature) with the system in real-life environments.	Achieved outdoor communication ranges: ***Up to 350 m at 433 MHz.*** ***Up to 250 m at 915 MHz.*** Indoor range up to 50 m with stable data transmission. ***SAR((Specific Absorption Rate) values remained within safe limits***, ensuring suitability for wearable applications.	Integration with ***battery-free energy*** harvesting for extended operation. Implementation of advanced data analytics and ***AI*** for predictive health monitoring. Potential for large-scale deployment in smart hospitals, elderly care, and sports monitoring.
Mesh Topolog: End devices configured to act as both fixed data sources and static relays ***Uplink & Downlink Window:*** All devices go under periodic sensor data readings & packet forwarding stage under ESP32 control, after each uplink, opens receive windows. Devices receive neighbor packets during listening windows and forward them in the next cycle. ***Collision Avoidance:*** Orthogonal SFs, low duty cycles, simple scheduling ADR algorithm reduce collision by dynamically adjusts spreading factor (SF) and bit rate based on link quality (RSSI, SNR)	***Coverage Achieved:*** Maximum 180 m under DLOS (Diffused Line-of-Sight) in the roadway with acceptable SNR (~5 dB whereas under NLOS (Non-Line-of-Sight) 95 m coverage in the road way. ***Data Rate Achieved:*** 1.46 Kbps at spreading factor (SF) 9 and transmit power 11 dBm. ***Network Stability:*** Mesh topology with ADR maintained stable, long-range communication and reliable environmental monitoring.	***Integration with Rescue Systems:*** Integrate the LoRa-based system with WBAN ***Machine Health and Strata Monitoring:*** Extend monitoring such as monitoring machine health parameters vibration and temperature. ***AI and Predictive Analytics Integration***: Enable predictive maintenance and predict hazardous conditions ***Real-Time Localization:*** Real-time miner localization and tracking in case of emergency response

Data Acquisition: Gas sensors continuously monitor gas levels then packets are prepared and transmitted via LoRa to the gateway. ***Data Transmission***: Utilized LoRa ' s long-range, low-power capabilities for wireless transmission from sensor nodes to the gateway. ***Data Collection at Gateway:*** Gateway forwards collected data to the central monitoring system using Wi-Fi. ***Visualization and Alert System:*** Visualized in real-time dashboards and used to generate alerts in case of gas concentration threshold breaches	***Transmission Range & Reliability:*** Achieved long-range communication (~3 km LoS in open test environments) using LoRa under 433 MHz, 125 kHz where as packet loss is very low packet loss (< 5%) reported ensuring reliable data delivery. ***Power Consumption & Lifetime:*** Each node operated on a 2000 mAh Li-ion battery achieved ~2 months of continuous operation per charge ***Data Rate:*** Typically ~0.3 – 5 kbps depending on SF used, sufficient for gas monitoring payloads. ***System Responsiveness:*** Alert generation delay typically < 10 seconds	***AI/ML Integration:*** Integrate artificial intelligence and machine learning for predictive gas leak detection. ***Multi-Site Industrial Deployment:*** Expand deployment to multiple industries like mining, semiconductor manufacturing. ***Dynamic LoRa Parameter Optimization:*** Implement dynamic adjustment of LoRa parameters (SF, BW, CR) to balance latency, range, and power consumption.
Goal: Dynamically select LoRa parameters to maximize EE ***EE= DR×PDR/TP*** ***DR (Data Rate) depends on SF, BW, CR*** Evaluate EE for every possible (SF, TP, BW, CR) combination Choose configuration with maximum EE and PDR >90% If packets collide but start at slightly different times time offset, their chirps align differently in time. By slicing the received signal smartly and analyzing using FFT, we can separate the collided packets.	20 × higher EE vs. ADR/ND-ADR and 2 × higher vs. ALPPS Maintains PDR >90% while optimizing EE Collision decoding reduces SER to 37% (vs. 90% in standard LoRa) with 10 concurrent nodes Low complexity: Decoding overhead O(QNlogN) at gateway, no node modifications. Scalable for dense deployments (e.g. greenhouses)	Field validation in real-world environments (e.g., farms). Integration with energy harvesting (solar/soil). Multi-gateway coordination for large-scale deployments. Machine learning for faster parameter adaptation. Extension to mobile underground nodes (e.g., robotic sensors).

Sensors capture CH_4 and CO_2 concentrations near the emission source. Analog data processed into PPM values using calibration equations. Data transmission tested at distances up to 450 m to determine optimal range. Power consumption optimization: Data collection reduced from 1s to 5s, transmission from 15s to 60s to extend battery life. Open-air and closed-environment tests conducted for comparative analysis.	CH_4 measurement accuracy: Avg error ~7.46% (collar) and 8.69% (feeding slot) vs. standard detectors. Transmission range: Reliable data up to 300 m (collar), 400 m (feeding slot); drop-offs beyond this Emission trends: CH_4 remains high during feeding, decreases post-feeding. Power optimization: Runtime increased from ~6.5h to ~11.5h with reduced sampling/transmission rates.	Integrate genetic and dietary data with emissions monitoring. Apply AI/ML for predictive emission analysis and mitigation recommendations. Scale the system across larger herd sizes and diverse environments. Optimize for seasonal variability and manure management.
Set antennas at different low heights in the tunnel. Send signals and measure at 40 spots (LOS & NLOS). Record path loss, delay spread, coherence bandwidth, PDP. Use a four-slope model to analyze how signals drop. Find the best antenna height for strong signals (60 cm).	Four-slope path loss model accurately fits underground near-ground propagation. 60 cm antenna height performed best (lowest path loss in both LOS and NLOS). Shadow fading: Gaussian distribution. Variation increases with antenna height. RMS delay spread: Low and stable in LOS (2–8 ns), higher in NLOS (up to 14 ns). Best performance at lower antenna heights under NLOS. Optimal antenna height for underground mining found to be 60 cm	Extend study to mmWave frequencies for 5G/6G underground mining applications. Investigate massive MIMO with different antenna heights. Refine models with broader measurements to improve accuracy.