Quantitative Characterization of LoRa Signal Propagation: Discrepancies Between Analytical Link-Budget Models and Empirical Field Measurements for a Novel Ground-Based LoRa Grid Network Tracking and Search-and-Rescue System

Yuan, William (School: Fairmont Preparatory Academy)

Wilderness search-and-rescue (SAR) operations across U.S. national parks exceed 4,000 to 4,500 incidents annually, with over 40,000 missions between 2015 and 2025. In August 2024, a multi-day search at Grand Canyon National Park highlighted how steep canyon topography, limited line-of-sight, and unreliable cellular infrastructure delay SAR detection and coordination. These limitations emphasize the need for infrastructure-independent tracking systems capable of maintaining situational awareness in complex topography. To address this, a novel ground based LoRa tracking system was developed to operate off-grid without infrastructure. The full system consists of a wearable Tracker, Ground Station, and a PC interface. The Tracker includes an EFR32MG24 ARM Cortex M33 microcontroller, u-blox SAM M10Q GNSS receiver, 6 axis IMU, MEMS microphone, 32 MBIT SPI flash memory, and 3.7 V LiPo battery. The Tracker transmits telemetry at 5 Hz using a 915 MHz RFM95W LoRa transceiver through a multi node grid network system which includes autonomous SOS alerts based on sensor fusion that detects fall events, prolonged inactivity, acoustic distress, and relays alerts across nearby nodes. A theoretical and in-field frequency analysis test was conducted to evaluate the performance of Yagi, Flat Whip, and Omnidirectional antennas at 433 and 915 MHz to determine the most optimal combination for LoRa grid-based long range performance. Results show: RSSI decreased from -86 dBm to -112 dBm from 50 m to 1000 m, with deviations under 2.5% from theoretical predictions, while SNR declined from 34 dB to 8 dB. The results also substantiate the 915 MHz flat whip antenna combination as the most effective configuration thus supporting the feasibility of a long range LoRa tracker for search-and-rescue use.

Awards Won:

Third Award of $1,200

Qorvo: Qorvo Innovator Award - 2nd Place

Association of Old Crows Educational Foundation: 3rd Place