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Radio wave propagation of LoRa systems in mountains for Search and Rescue operations

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Abstract

Search and Rescue (SaR) operations in mountain environments are common events. However, current transceivers for mountain SaR suffer from a limited range, making operation slow. The emerging Low-Power Wide-Area Network (LPWAN) technology is very promising thanks to its extended range and to the long battery life. LoRa (Long Range) is one of the most popular LPWAN. In this paper, we experimentally evaluate the effectiveness of body-worn LoRa in an extreme mountain environment by measuring the range and deriving the path loss by the means of a log-normal model. The measured LoRa range in the mountain landscape, under the condition of at least 50% of packet reception, was 300 m. This values, even if much smaller than the usual ranges of LoRa in flat environments (some kilometers), is, however, more than five times the ARVA operating range in the same conditions. Accordingly, LoRa system can be considered valuable for faster SaR operations.

1 Introduction

Mountain Search and Rescue (SaR) operations are common events that occur in mountains while people perform sports, work and recreational activities. Only in France, during the year 2012, 5,389 operations were registered [1]. The current radiofrequency devices used for mountain SaR are ARVA [2] and RECCO systems [3], both suffering from a limited operating range. The mountaineer could be localized sooner by exploiting the recently introduced Low-Power Wide-Area Networks (LPWANs). LPWANs are characterized by an extended communication distance and by an improved battery life as compared to standard wireless local area networks but they provide limited data rates [4]. LoRa (Long-Range) is one of the most investigated LPWAN technologies, and its maximum measured range is 30 km [5]. LoRa uses a proprietary modulation technique based on chirp spread spectrum, usually combined with a Medium Access Control (MAC) called LoRaWAN. When a LoRa radio is used bypassing the MAC, it broadcasts and works in "*LoRa-MAC*" (or "*raw LoRa*") mode [6]. LoRa-based localization was proposed both using GPS [7] and using techniques that are based on the RSSI (Received Signal Strength Indicator) [8]. In this contribution we investigate the usage of LPWAN for SaR in mountain areas, collecting data from a body-worn LoRa receiver in a harsh mountain environment. From the experimentally collected data, we

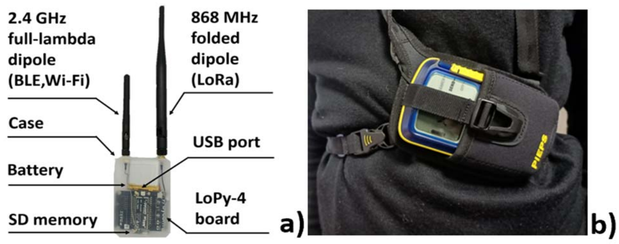

Figure 1. a) Lopy-4 expansion board tested in Bletterbach canyon. b) Reference body-worn ARVA: PIEPS POWDER BT

derive a path loss model accounting also for the presence of the human body. The communication range of LoRa is finally compared with the operating range of a commercial ARVA device.

2 Measurement setup and test

Two Pycom Lopy-4 expansion boards [9] were used because they can work with LoRa both in LoRaWAN and raw LoRa mode and they are at accessible cost (Fig. 1.a). Since LoRa performances can greatly vary depending on the selected transmission parameters, according to [10] we set: the maximum transmitting power at 14 dBm; the carrier frequency at 868 MHz; the spreading factor at 7; the bandwidth at 125 kHz; the coding rate at 4/5. The ARVA devices used for subsequent performance comparison were two PIEPS POWDER BT (Fig. 1.b), having nominal range of 60 m which is the typical range of ARVAs [2]. The payload length of the LoRa transmitted signal was set to 5 bytes as it is the longest payload with the lowest possible feedback frequency (3 seconds) while complying with the duty-cycle regulations.

We tested the proposed solution in a complex mountain environment. We selected the canyon of Bletterbach, localized in Aldein, South Tyrol, Italy (Fig. 2). The canyon is 40 m wide, 8 km long and its maximum depth is of 400 meters [11]. We selected this environment due to the extreme testing conditions since no GPS and telephony signal is available. Inside of the canyon we placed transmitting LoRa and ARVA devices. A volunteer wore a receiving ARVA and inserted a receiving LoRa radio inside a pocket of his jacket, then he walked away from the base until less than 50% of sent LoRa packets were received.

Figure 2. Range measurements in Bletterbach canyon for LoRa and ARVA systems.

Finally, the volunteer stopped and stood in order to gather sufficient data for an accurate Path Loss (PL) and Packet Delivery Ratio (PDR) estimation. A PDR of 50% was chosen as limit as it corresponds to a feedback every 6 seconds on average, and less frequent transmissions would have been useless to localize the transmitter basing on the signal strength. Data collected were used for the derivation of the path loss propagation models (Section 3).

3 Path Loss model

A log-normal path loss model based on measured RSSI was selected to evaluate the Expected Path Loss (EPL) as in [5]. The PL is obtained from measured RSSI and SNR (Signal Noise Ratio) as follows:

$$PL = |RSSI| + SNR + P_{Tx} + G_{Rx} \quad (1)$$

where P_{Tx} is the transmission power and G_{Rx} is the gain of the receiving antenna. Then EPL is evaluated from the measured PL by the means of first order fit so that:

$$EPL = PL(d_0) + n * log_{10}(d/d_0) \quad (2)$$

where d_0 is a reference distance and n is the path loss exponent. The Shadow Fading (SF) is described by the standard deviation of the difference between measured and expected PL:

$$\sigma_{SF} = std(PL - EPL) \quad (3)$$

4 Results

The measured 51 m range for ARVA (Fig. 2) is in line with the typical nominal range of this class of devices (60 m, [2]). The 50% PDR range measured for LoRa was instead 300 meters, about six times the operating range of ARVA. The body shadowing and the canyons reflection greatly decrease the typical kilometric range of LoRa. The measured PL corresponding to 50% PDR is about 135 dB (Tab. 1). From the collected RSSI and SNR values a log-normal path loss model in the canyon was obtained, as shown in Fig. 3. The channel conditions change from line of sight to non-line-of-sight after 163 m because of the

Table 1. Measured statistics at 300 meters of distance from the transmitter

Distance (PDR 50%)	**300 meters**
Average PL	135.4 dB
PL std	0.9 dB
PDR	53%
Number of packets sent	150

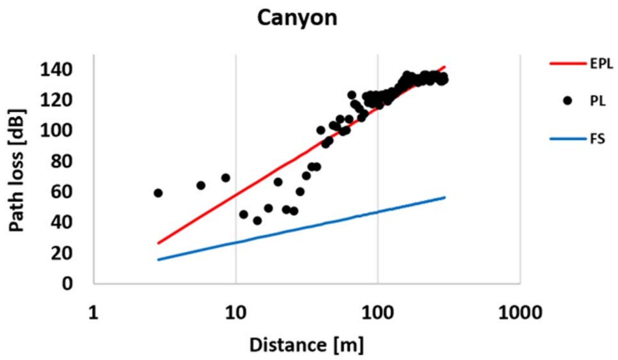

Figure 3. LoRa (868 MHz) Expected (EPL) and measured (PL) Path Losses compared with the Free Space (FS) model.

canyon topology, but no sharp variation of PL is visible thanks to the canyon waveguiding effect. No remarkable shadow fading is observed from the (σ_{SF}) values collected (Tab. 2), probably thanks to the low frequency used. The very high EPL exponent is coherent with the harsh link condition, i.e. body shadowing and reflections due to the ground and canyon walls. The evaluated EPL intercept is lower than the theoretical Free Space (FS) $PL(d_0)$ because the path loss model appears to be valid only for distances greater than 30 m. The body shadowing and the body-worn receiver orientation are the dominating effects at a close distance from the transmitter, causing the unstable RSSI values observed.

5 Discussion and conclusions

Communication with body-worn LoRa was tested in a canyon, which is an extreme mountain environment. The measured distance wherein the packet delivery ratio is at least 50% is about 300 meters, which is six times the operating range of the commercial ARVA systems. The improved LPWAN range can be exploited to localize people faster. Moreover, drone equipped scanners and Internet of Things networks for the search and rescue can greatly benefit from the hundreds of meter range ensured by LoRa. The effectiveness of RSSI-based localization methods can be hindered by the RSSI fluctuations at close

Table 2. Canyon Path Loss model parameters

Environment	Canyon	Free Space
EPL exponent (n)	5.54	2
EPL intercept ($PL(d_0)$)	10.7	23.5
σ_{SF}	9.41	-
Number of packets sent	206	-

distances due to body motion and shadowing, also the duty cycle limitation is a big limit. The obtained results demonstrate the feasibility of using LPWAN as a solution to increase the operating distance of a transceiver. We continue working on the improvement of the system that will include an orientation user guidance (direction of the victim) and potentially the insertion of the device into an unmanned aerial vehicle.

6 Acknowledgements

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