Greetings to everyone. I am Giulio Maria Bianco, a Ph.D. student in GeoInformation at the Tor Vergata University of Rome. In these slides, I'm going to present my summary paper entitled "Radio wave propagation of LoRa systems in mountains for Search and Rescue operations".

Mountain Search and Rescue operations

- Mountain Search and Rescue (SaR) is a common event.
- In France, during the year 2012, 5,389 mountain SaR operations were recorded [1].
- The most common causes are lost hikers and avalanches.

Activity	Accidental deaths per year in France
Hiking	45
Mountaineering	32
Ski touring	16
Off-piste skiing	9
On-piste skiing	6.7
Paragliding	6.6
Rock climbing	5
Total	120.3

[1] B. Soulé, B. Lefèvre, E. Boutroy, V. Reynier, F. Roux, and J. Corneloup, "Accidentology of mountain sports", Situation, review & diagnosis, Crolles, 2014.

Mountain Search and Rescue operations are common events. For instance, in France during the year 2012, a number of 5,389 operations was recorded by the French national force for mountain rescue, causing 120.3 annual death estimated. Search and rescue operations consist of localizing a target person to help him or her. Search and Rescue operations can have very different causes, ranging from lost hikers to avalanches, including medical issues as for example heart attacks or injuries caused, for example, by a rockfall. Currently, there is no standard device for mountain Search and Rescue. Radiofrequency devices are used to localize avalanche victims, and wearable radiofrequency devices seem to be the best option to develop a device to make Search and Rescue operations in mountain faster and more successful.

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Golden standard

- Currently, RadioFrequency (RF) devices are used in mountain SaR to find avalanches' victims.
- The devices used are the avalanche beacons (ARVA, 457 kHz) and the RECCO systems (868 and 1736 MHz).
- RECCo systems are composed by an interrogator and a detector, which is embedded in clothes.

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The current golden standard of radiofrequency devices used for mountain Search and Rescue are the avalanche beacons, also known as ARVA, and the RECCO system. They are very different devices and are both used to find avalanche victims. The avalanche beacons can operate in transmitting and receiving mode. When mountaineering in a snowy area, people are requested to keep their personal ARVA on and in transmitting mode. When transmitting an ARVA transmits pulses at the frequency of 457 kHz. If an avalanche happens, rescuers turn their ARVA in receiving mode to localize the victims. RECCO system is, instead, an asymmetrical system, composed of an interrogator and a reflector. RECCO reflectors are usually embedded in clothes and are passive components. RECCO interrogators include highly directive antennas (usually a Yagi-Uda) that search for reflectors using an 868 MHz beam. When illuminated by the interrogator, the reflector doubles up the received signal frequency using a diode and then backscatters the signal.

Range limit and UAV

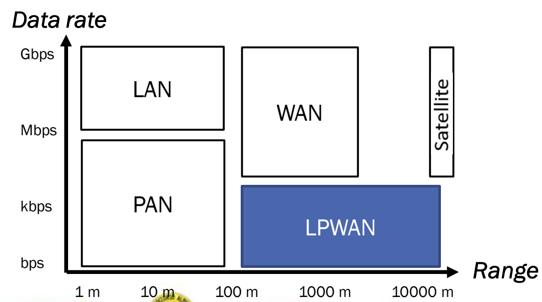
- Both the RF devices suffer from a limited range.
- In free space, the ARVA has a range of 60 m and the RECCO system of 120 m. In real operating conditions, the range can decrease down to 20 m.
- The limited range of the devices hinder the usage of Unmanned Aerial Vehicle (UAV)

The biggest limit of the current radiofrequency devices is their range, which is of about 60 meters for ARVA and about 120 meters for RECCO, in free space. Their range is decreased in an operational scenario because of the power absorption of the snow, especially when it's wet. In case of wet snow, the operating range of RECCO can be as low as 20 meters. Because of their limited range, they cannot be used to find lost persons successfully. If a long-range of communication is achieved, typical localization algorithms based for example on the received signal strength can be used for the mountain Search and Rescue. Moreover, the limited range of ARVA has, up to the day, hindered any attempt of using Unmanned Aerial Vehicles for this application. Unmanned Aerial Vehicles could be extremely useful for scanning huge areas of difficult mountain terrains in a low time. They could also gather the received signal strength measurements needed to have the aforementioned algorithms work.

Low-Power Wide-Area Networks

- Low-Power Wide-Area Network (LPWAN) guarantee a kilometric communication range while maintaining a years-long battery life.

- The main limit of the LPWAN is their low data-rate. The data-rate is not required for SaR, thus the LPWAN are highly promising.



Our idea is to use a Low-Power Wide-Area Network technology to significantly extend the communication range while keeping the power consumption low, so to ensure long battery life. Low-Power Wide-Area Networks are very different communication protocols which aim to provide kilometric connectivity while mantainig years-long battery life. The most important Low-Power Wide-Area protocols are Long Range, also known as LoRa, LTE-Cat M1, NB-IoT, Ingenu, Sigfox, and the Weightless protocols. Compared to standard Personal, Local and Wide Area Networks, the Low-Power Wide-Area technologies achieve their extended range at the cost of a limited data-rate. In a typical mountain Search and Rescue operation, a high data-rate is not required, so the Low-Power Wide-Ares technologies seem highly promising to overcome the range limit of the current radiofrequency devices.

Possible LPWAN choices

- Between the possible choices, LoRa is the most promising LPWAN for mountain SaR.

LPWAN	Frequency in EU [MHz]	Cellular coverage required	Subscription required
Ingenu	2400	No	No
LoRa	433 or 868	No	No
LTE-M	LTE-M frequencies	Yes	Requires SIM
NB-IoT	800, 800 or 1800	Yes	Requires SIM
Sigfox	868 or 902	No	Yes
Weightless	400-800 MHz (W) sub 1 GHz band (N,P)	No	No

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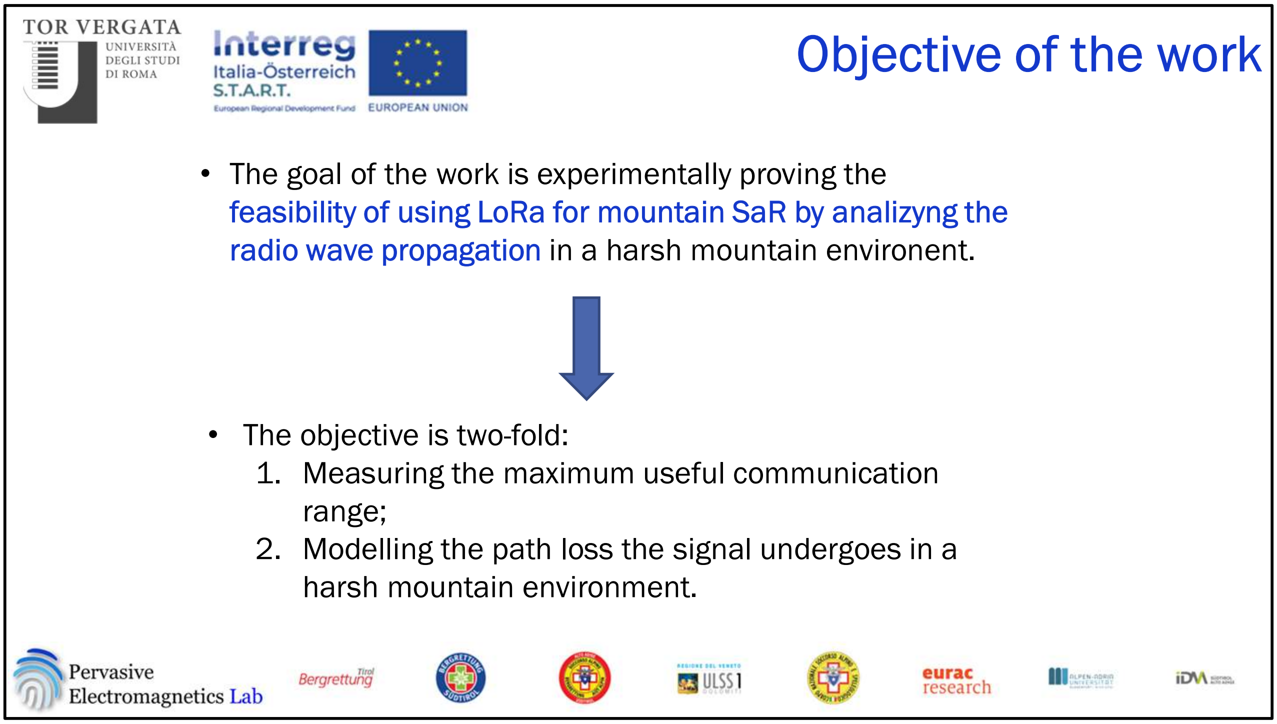
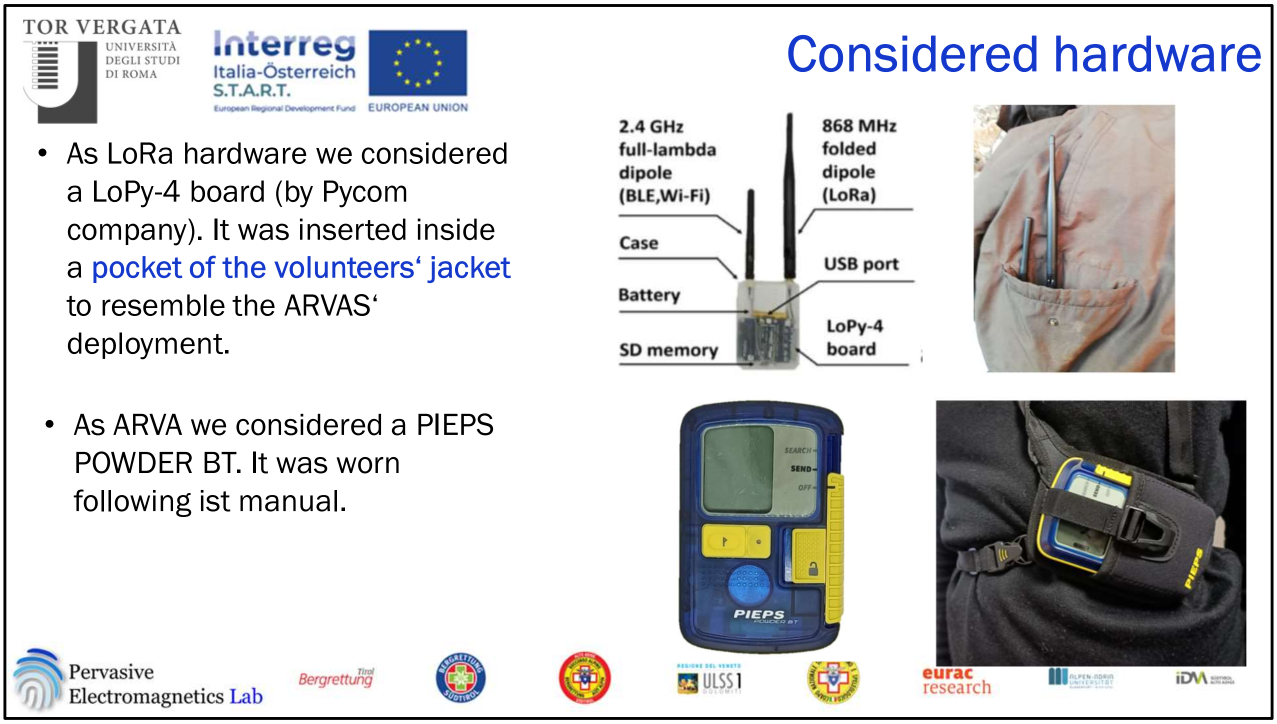
Of the aforementioned Low-Power Wide-Area technologies, Ingenu and Weightless are the least commonly used, and this could be a problem when deploying the system because of the limited hardware availability. Moreover, Ingenu works at 2.4 GHz, and the path loss is expected to be higher at higher frequencies, thus reducing the range. In literature, Weightless has a measured range of about 5 km, and it is significatively lower than other options. For example, LoRa was proven to reach up to 30 km. Narrowband IoT, as to say NB-IoT, and LTE-CAT M1 are cellular technologies and require cellular coverage, which is not available or reliable in most mountain areas. Sigfox has a network availability problems as the cellular Low-Power Wide-Area and its own connectivity is even more limited than theirs. LoRa is the most promising choice, due to the relative easiness of deploying a gateway in unconnected areas and because it does not require a subscription, greatly reducing the cost of the end device. Because of this reasoning, we chose LoRa as our Low-Power Wide-Area candidate for mountain Search and Rescue.



The first matter to address in order to deploy a LoRa-based system for mountain Search and Rescue is the radio wave propagation in a mountain environment. In literature, LoRa was proven to reach up to 30 km using 25 micro-Watts of transmitting power in Line-of-Sight conditions, but it is not clear if a kilometric range can be obtained in harsher environments like the mountain one. To assess the maximum LoRa range and the packet delivery ratio, as to say the ratio of received packets over the number of total packets sent, we experimentally characterized the Path Loss the LoRa signal undergoes in a mountain environment.



I programmed a LoPy-4 board to send 1 LoRa 5-bytes long packet every 3 seconds. Since the LoRa performances vary greatly depending on the transmission parameters selected, basing on the existing literature I selected a modulation spreading factor value of 7 and a bandwidth of the signal of 125 kHz. I did not select the maximum spreading factor of 12, which ensures the maximum possible range, because it would have increased the off-time of the device according to the EU regulations. For the same reason, I selected the 868 MHz band and not the 433 MHz one, which has both a lower expected path loss due to the lower frequency and a lower maximum transmitting power allowed, as to say a maximum of 10 dBm in the EU. I bypassed the medium access control so to transmit in raw LoRa mode. As reference ARVA, we used PIEPS POWDER BT.

Testbed: the Bletterbach canyon

- As testbed, we selected the Bletterbach canyon (40 m wide, 11 km long, 400 m deep), in Northern Italy. [1]
- Inside the canyon there is not cellular coverage nor strong GNSS signal. Geolocation is obtained using a GNSS station (by Leica company)

[1] https://www.bletterbach.info/it/

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As the testbed, we selected the GeoPark of Bletterbach in Northern Italy. The Bletterbach is a canyon in Aldein, South Tyrol, Italy; it is 40 meters wide, 400 meters deep and 11 kilometers long. Cellular coverage is not present, and the GNSS signal is very weak. To obtain the geolocation during our measurements, we used the GNSS station Leica GS10. We positioned both the LoRa and the ARVA transmitters on the ground at the center of the canyon, a few meters away from the stream which flows in Bletterbach. The receivers are body-worn like the typical ARVA deployment that you can see in the figure, so to account also for the presence of the body. The LoRa receiver was put inside the jacket of the volunteer performing the measurements.

Lognormal Path Loss Model

- The Path Loss (PL) is evaluated from measurd RSSI (Received Signal Strength Indicator) and SNR (Signal-to-Noise Ratio).

$$PL = |RSSI| + SNR + P_{Tx} + G_{Rx}$$

- From the measurements, the Expected Path Loss (EPL) is evaluated as first order fit.

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

- The shadow fading ($\boldsymbol{\sigma_{SF}}$) is modelled from the differences between data and EPL.

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

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The LoRa path loss was evaluated from the Received Signal Strength Indicator and the Signal-to-Noise ratio as shown by the first equation. The expected path loss is then evaluated by means of a first-order fit so to obtain a lognormal model. The difference between the measured data and the evaluated Expected Path Loss line is modelled as shadow fading, as to say the fading due to obstacles in the path. The shadow fading is a zero-mean lognormal variable completely characterized by its variance.

Range and PDR

- We considered a useful communication range a range where Packet Delivery Ratio (PDR) at least 50 %.

- The useful LoRa range is about six times the ARVAs‘ range, reaching 300 m whereas the ARVAs reach a range of 51 m.

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

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I walked along the same path with both the LoRa and the ARVA receivers. You can see the canyon path in blue in the figure. The transmitters are placed at the base point. LoRa measurements were interrupted when the packet delivery ratio was approximatively 50 % because a lower value of packet delivery ratio would be useless to localize targets basing on the received signal strength. Moreover, measurements corresponding to a lower packet delivery ratios are less accurate. The ARVA measured range is of 51 meters, similar to the typical ARVA range of 60 meters in clear Line of Sight. The measured 50 % packet delivery ratio range is of about 300 meters, as to say about six times the maximum range of ARVA. Definitively, LoRa overcomes the main ARVAs’ limit of a short-range.

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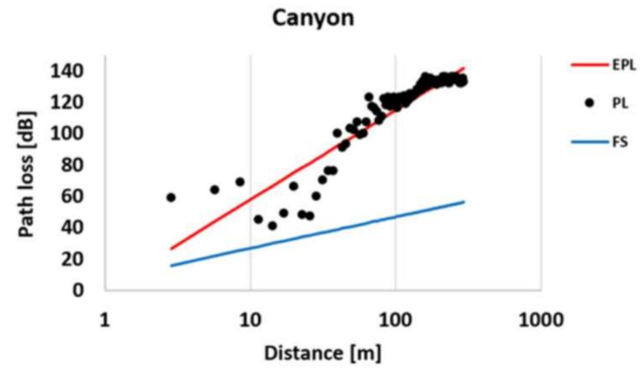
Path Loss Exponent

- The evaluated path loss exponent is 5.54. For comparison, the path-loss exponent is equal to 2 in free space and to 6 in indoor, Non-Line-of-Sight conditions.
- The evaluated shadow fading is of 9.41 dB, a value similar to those of urban mobile phones' links (9-11 dB).



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	-

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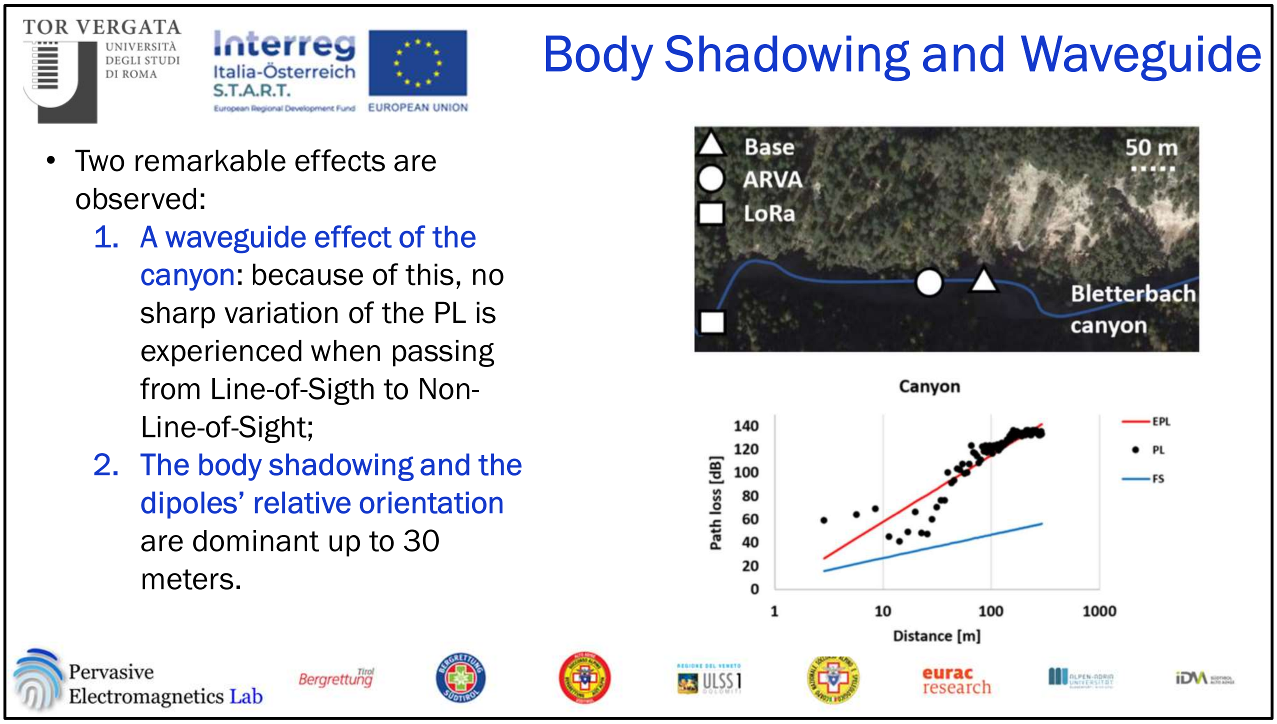
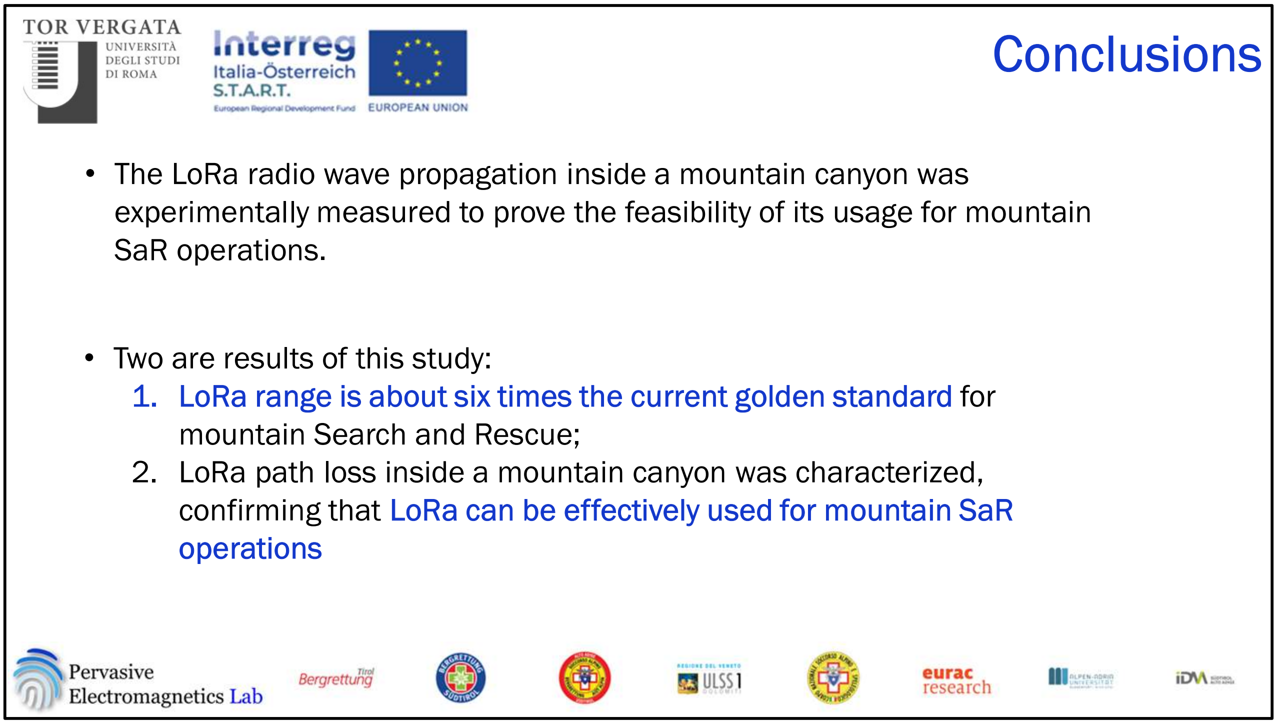
We can see that the lognormal path loss model fits the measured data very well at the greatest distances. By comparing the free space model and the derived line we can see that the path loss exponent is 5.54, almost three times that of the free space and similar to the path loss exponent of indoor non-line-of-sight link, which is equal to six. As the line has a higher exponent, the 1-meter intercept is almost half of the free space theoretical value, meaning that the model is valid only for distances greater than 30 meters and at close distances the PL values greatly vary. The shadow fading standard deviation is very high and comprised between 9 and 10 dB. Such high values are typical of urban links, characterized by multiple obstacles. This is reasonable since the canyon is an extremely harsh environment and the frequencies used are low compared to the typical 3G/4G frequencies.



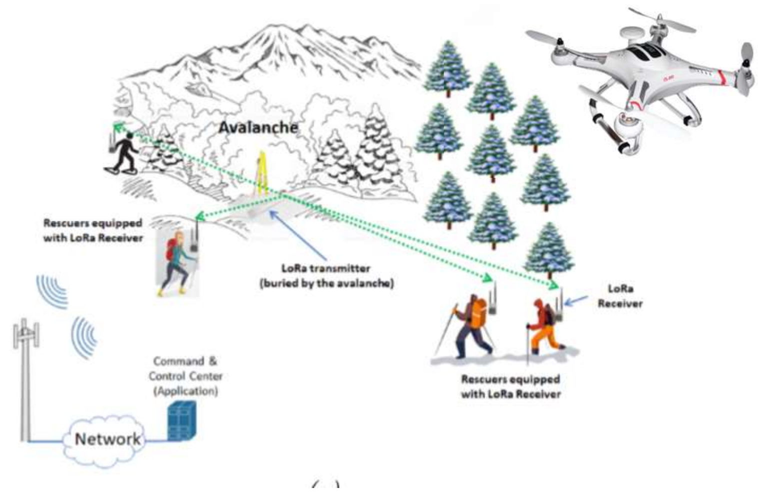
Two remarkable effects are worth noticing. Firstly, as said before, the model fits the data at distances greater than 30 meters. Body shadowing and dipole's relative orientations are the dominant effects at close distances, causing highly unstable RSSI values. Secondly, due to the canyon topology, the link conditions change from Line of Sight to Non-Line-of-Sight after 163 meters, but no sharp variation in the Path Loss is experienced, thanks to a kind of waveguiding effect of the canyon itself. Because of this experienced effect, the canyon can be approximated as a line having a very high path loss exponent, as done in this paper.



In conclusion, the communication of a body-worn LoRa was tested in a mountain canyon. Although the kilometric range typical of the Low-Power Wide-Area technologies reduces to a few hundreds of meters, the measured range of 300 meters is about six times the range of the current commercial devices employed in mountain Search and Rescue. In particular, the LoRa signal's received signal strength is highly unstable at distances closer than a few tens of meters, because of the body effects on the body-worn receiver. A remarkable waveguiding effect was observed in the canyon during the measurements. The LoRa Low-Power Wide-Area technology is highly promising for mountain Search and Rescue applications since it overcomes the historical limit of a limited range enabling the usage of Unmanned Aerial Vehicles for mountain Search and Rescue.

Ongoing Work

- A system for mountain SaR based on LoRa is currently under development. It will be tested in real operational scenarios, including the scenario of the avalanches.



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Based on these first results, the authors are working on a LoRa-based system for mountain Search and Rescue operations. The system under study includes a wearable transmitting helmet antenna, a receiving Unmanned Aerial Vehicle which collects the path loss measurements and an ad-hoc localization algorithm based on the received signal strength. Ground-based receiving stations will gather additional path loss measurements useful to localize the target. The system is going to be validated in a real scenario, including also dry and wet snow, which are expected to cause a massive power absorption.

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