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***Abstract*— LoRa is a proprietary radio communication technology exploiting license-free frequency bands. It allows low-rate information exchange with a very low-power consumption. LoRa is very convenient when the amount of transmitted data is limited and when a low cost infrastructure is required. This work presents some preliminary propagation measurements in a noisy urban environment by using prototypal transmitters and receivers as network nodes. Results highlights that LoRa can be used for different ad-hoc networks deployed on an urban area.**

Keywords—LoRa, propagation, wireless communication, electromagnetic measurements, urban environment.

I. Introduction

LoRa is a proprietary wireless communication technology featuring long-range capabilities, with low-power consumption although with low data rates. Developed by Cycleo and acquired by Semtech in 2012, it uses license-free sub-gigahertz radio frequency bands. Its characteristics make it suitable for communication over wide areas and where there are strict constraints concerning the transmitted power and the power supplier (e. g. the network nodes must be powered by batteries). In addition, it requires a modest amount of exchanged traffic.

LoRa is only one of many Low Power Wide Area Network (LPWAN) technologies available nowadays [1]. Among the others we have: Sigfox, which offers longer-range communication with respect to LoRa but has service subscription costs; NarrowBand IoT, which focuses on indoor coverage (which is not the case of our experiment). Other similar technologies even if they are not exactly developed for the same purpose, are for example Weightless, 5by5 Wireless, HaLow and Zigbee. Examples of the use of Zigbee in urban environment are presented in [2-3].

In order to realize ad-hoc networks operative in a noisy urban environment, LoRa technology is a good and versatile solution. LoRa based networks can be specifically designed and installed for various purpose: environmental monitoring, traffic monitoring, realization of various Distributed Measurement Systems (DMS) [4]. The technology can be used also for emergency: a proprietary network can be set up quickly and with low cost concerning infrastructures and deployment.

In this work, describes a feasibility analysis for a potential network based on LoRa technology considering the propagation aspects is introduced. Some preliminary propagation measurements considering a point-to-point and a star configuration in an urban environment are presented.

II. LoRa Technology

The LoRa technology modulation scheme derives from the Chirp Spread Spectrum (CSS) modulation technique, which encodes the information in chirps [5]. As the expression spread spectrum implies, this technique uses the entire allocated bandwidth to transmit the signal. For this reason, it exhibits robustness to noise and other channel degradation mechanisms such as multi-path fading present in urban environments. It also mitigates the Doppler effect for what concern the mobile applications.

LoRa is the physical (PHY) layer (the lowest layer in OSI communication stack) implementation and it works regardless of the technology operating on upper layers. In this respect, the LoRa Alliance™ has developed the open-source LoRaWAN specification [6]: an infrastructure consisting of media access control (MAC), network and application layers built on top of LoRa. LoRaWAN is organized in a star-of-stars topology in which gateways relay messages between end-devices and a central network server; gateways are connected to the network server via standard IP connections, while end-nodes use single-hop LoRa communication to reach gateways.

It is possible to use different configuration of LoRa in order to adapt the technology to the working scenario and the needs of the network to be realized. The main parameters are:

- the bandwidth, defining how wide the transmitted signal is (to be chosen among 125, 250 and 500 kHz);
- the spreading factor indicating how many bits are used to encode each symbol (a number in the range 6-12);
- the code rate specifying the proportion of useful transmitted bits (non-redundant) (from 4/5 to 4/8).

In this work, a set of standard parameters (FSK modulation, bandwidth B_W=125 kHz, Spreading Factor

SF=10, equivalent bit rate B_R=0.976 Kb/s, Receiver sensitivity R_{Xsens}=-132 dBm [7]) were selected to configure the prototypal network nodes and perform a set of measurements to study how the LoRa technology works in an urban environment.

III. Analysis of LoRa propagation in urban environment

The path loss, the shadowing and the multipath fading are the main parameters for the characterization of a wireless channel. In an urban environment, shadowing and multipath fading may heavily affect the propagation performance of a radio link. A preliminary analysis of the propagation performance in an urban environment in term of range and received power was performed.

Indicating with P_T the power radiated by the transmitter, G_T and G_R the antenna gains of both the transmitter and receiver, respectively, L_P the path loss attenuation, the received power, P_R, can be calculated as:

$$P_R|_{dBm} = P_T|_{dBm} + G_T|_{dB} + G_R|_{dB} - L_P|_{dB} \quad (1)$$

There are not path loss models specifically introduced for LoRa technology in order to estimate $L_P|_{dB}$. However, there is a large number of empirical propagation models derived from measurements using different standards, different frequency and in various propagation conditions. Some of them can be used for the frequency band dedicated to LoRa in Europe. For instance, Erceg model [8] can be used with promising results compared with experimental measurements with a difference of maximum 100 m in the useful range [9]. However, the Erceg model tends to overestimate the distances in urban environment due to dampening by buildings and other urban structures. An analysis of the Lee propagation model [10], which can be used for both area-to-area, and point-to-point communications is introduced in [11]. The applicability of Lee's propagation model is efficient as soon as a proper variant is determined for each specific city, but in the case of Turin, where the measurements were made, the specific coefficients for Lee's model are not available.

When dealing with transmissions between 100 and 1500 MHz in urban areas, the empirical Okumura-Hata (O-H) model [12], specifically developed for wireless communication in urban environment can be used. The path loss L_P can be evaluated from (2) by knowing the operating frequency f in MHz, the transmitter and receiver heights h_T and h_R expressed in meters and the distance d between transmitter and receiver expressed in kilometer.

$$\begin{aligned} L_P|_{dB} &= 69.55 + 26.16\, log_{10} f + \\ &-13.82\, log_{10} h_T - a(h_R) + \\ &+ (44.9 - 6.55\, log_{10} h_T)\, log_{10} d \end{aligned} \quad (2)$$

The correction parameter $a(h_R)$ is due to the area type and considering large cities it is given by:

$$a(h_R) = 3.2[log_{10}(11.75 \cdot h_R)]^2 - 4.97. \quad (3)$$

IV. Measurements setup description

The measurement setup is formed by a single receiver and one or more transmitters according to the different tests to be performed (Fig. 1). All the transmitters and the receiver are equipped with the same electronic components, the same microcontroller μC (Arduino© Nano), the same communication module and the same quarter-wave monopole antenna with a gain G=3.16 dB (Linx Technologies, model ANT-868-CW-RCS), operating in the band 860-868 MHz. A specific controlling software was developed for each test using the Arduino© Integrated Development Environment (IDE).

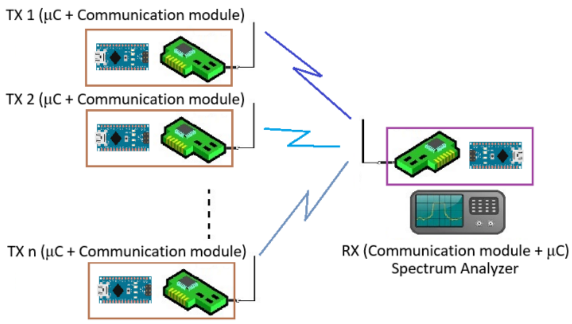

Fig. 1. Block scheme of the measurement setup. The number of transmitters is n=1 for point-to-point measurements and n=5 for star-topology network measurements

A. Communication module

The communication module installed on the prototypal network nodes (both receiver and transmitter), is the Adafruit® Feather 32u4 LoRa Radio RFM95. It is an embedded module, which contains a LoRa® transceiver RFM95 and an ATmega32u4 microcontroller (Fig. 2). The chip has 32 kB of flash memory and 2 kB of RAM memory. The radio module can be powered using 3.3 volts either by using a micro USB or an external battery. Among its main features, there are the small size (51 mm x 23 mm x 8 mm) and the lightweight (5 g), which are fundamental for the radio probes. Moreover, the operative frequency range is 868-915 MHz, including the band around 868 MHz allowed by the European laws, and the transmitted power ranges between 5 dBm to 20 dBm.

The module is controlled by an Arduino© microcontroller, since the microcontroller of the Adafruit® Feather 32u4 LoRa Radio RFM9 can be programmed with the same libraries of Arduino©.

Fig. 2. Adafruit® Feather 32u4 LoRa Radio RFM9 on the left and LoRa Radio RFM9 transceiver module on the right.

B. Spectrum Analyzer

The received power was measured using a Spectrum Analyzer model R&S ZVL connected to the receiver module. The setting parameters are listed in Table I.

TABLE I. Spectrum Analyzer Parameters

Center frequency (CF)	865 MHz
Resolution bandwidth (RBW)	10 kHz
Video bandwidth (VBW)	30 kHz
Sweep time	5 ms
Span	500 kHz
Measurement mode	Max hold

V. RESULTS

In order to assess the practical capabilities of LoRa technologies to be used for an ad-hoc proprietary network, a set of measurements were done from March to May 2018 in the surrounding of Politecnico di Torino (Italy) in a noisy urban environment with two configurations point-to-point and star topology.

A. *Point-to-point measurements*

A set of static measurements was performed with the receiver placed in a fixed position and the receivers along Corso Castelfidardo in different positions (P1, P2, and P3) as shown in Fig. 3.

Fig. 3. Positions of the transmitter (P1, P2 and P3) and of the receiver (Rx), with relative distances for the point-to-point measurements.

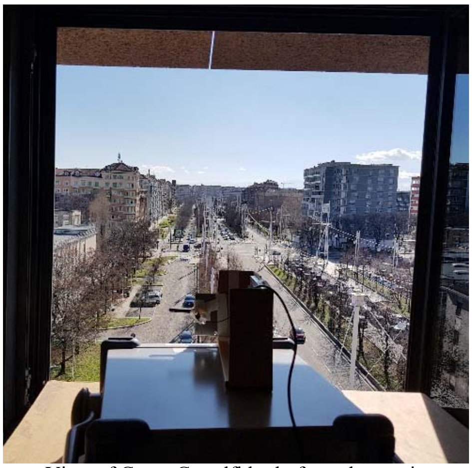

Fig. 4 View of Corso Castelfidardo from the receiver position.

The distance between the transmitter and the receiver was 375 m for P1, 615 m for P2 and 840 m for P3. The receiver was placed at a height of 20 m above the street and the transmitter at a height of 3 m. For all the positions, the transmitter was in line of sight with the receiver.

All the positions were in line of sight with the receiver. The distance between the transmitter and the receiver is comparable to the maximum distance between two nodes of a network than can be deployed in urban environment.

The receiver module was programmed in order to provide useful information about the signal quality: Received Signal Strength Indicator (RSSI) of the packets, Signal to Noise Ratio (SNR) and Received Signal Strength Indicator mean. The set of analyzed data consists of blocks of 1000 packets for each transmitter position The settings and the configuration used for transmitter and receiver are reported in Table II.

TABLE II. PARAMETERS FOR POINT-TO-POINT MEASUREMENTS

Transmitted power	14 dBm
SF	10
Bandwidth	125 kHz
Frequency	865.2 MHz
Antennas gain	3.16 dB

The results of the measurements and the comparisons with the theoretical performance obtained with the Okumura-Hata model described in Section III, are reported in Table III.

TABLE III. RESULTS OF POINT-TO-POINT MEASUREMENTS

Tx position	**P1**	**P2**	**P3**
Distance (m)	375	615	840
SNR max (dB)	1	-1	-6
RSSI max (dB)	-90	-132	-140
Packet Lost	<1%	<1%	4%
Rx power (dBm)	-78	-85	N/A
Okamuru-Hata Rx power (dBm)	*-88*	*-97*	*-103*

Note the possibility to measure negative values of SNR when the signal power level is below the noise level. According to the LoRa specifications a negative value for SNR indicates the ability to receive signal power below the receiver noise floor. This can happen when the communication range is sufficiently long and/or the communication is very noisy, as it is the urban environment.

The RSSI of the packets, as expected, decreased for larger distance. However, the majority of the packets was received correctly. In fact, for P1 and P2, the number of packet losses was lower than 1% while for P3 (distance greater than 800m)the percentage of losses reached 4%.

Concerning the position P3, it was not possible to measure the received power with the SA, since the power was below the noise floor of the instrument with the settings used.

All the received power values were compared to the theoretical values computed with the O-H model (last row og Table III). The measured power is higher, first of all because the model has not been developed taking into account the characteristic of CSS modulation used for LoRa. Moreover, the point-to-point propagation link study with O-H model does not take into account the so called "canyon effect", because the receiver is placed in the middle of a street surrounded by tall buildings. These buildings create many reflected contributions that can be summed constructively at the receiver

B. *Star-topology network measurements*

In order to check how LoRa works in a star topology net, static measurements were performed with a star configuration. Aim of this test was to check how a LoRa based star topology network works. This configuration could be the most suitable for an ad-hoc deployed network, regardless its purpose.

Fig. 5. Configuration of one of the used transmitters for star-topology network measurments. The prototypal transmitter is powered with a power bank connected to the electronic board through a USB cable. The antenna is inside the plastic enclosure.

Star topology tests were performed in the campus of Politecnico di Torino (Fig. 6). The receiver module (R_X) is at ground level in the middle of the test area and the transmitters are spread around at a distance of approximately 100 m. The transmitted power for the sensors was equal to 5 dBm and all the transmitters were equipped with the same antennas used during the point-to-point test (Table II).

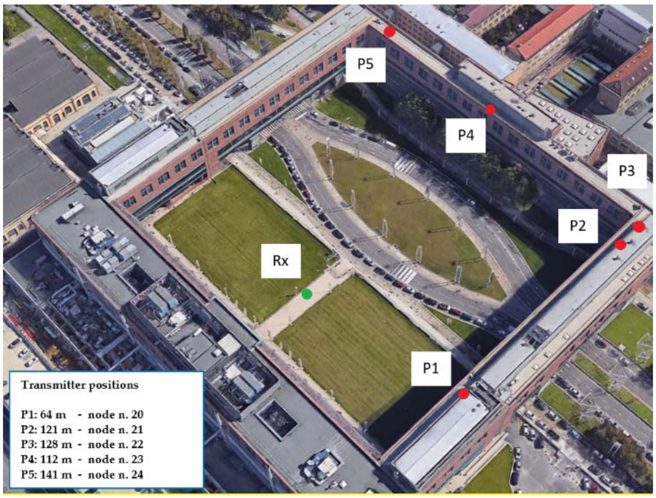

Fig. 6. Sensor nodes (P1, P2, P3, P4, P5) and receiver (Rx) position, with relative distance indications for the star-topology network measurements.

Results of the star topology measurements are reported in Table IV. The signal received from all the 5 end-nodes higher than the receiver sensitivity and the SNR had values lower than zero only for the transmitter in the furthest position. Concerning the RSSI, all the values are coherent with the distance between the sensor node and the receiver. The main difference between the star-topology measurements and the point-to-point tests is mainly on the number of correctly received packets (i.e. without packet error detected automatically by the receiver). Since the transmitters are not so distant from each other, there were many collisions on the communication channel and some packets were lost: on average, 17% of the packets were lost, going from a minimum of 6% (the closest node to the receiver) to a maximum of 36% (the farthest node from the receiver). The redundant transmission mechanism implemented in the network can reduce the potential packet losses.

TABLE IV. RESULTS OF STAR TOPOLOGY NETWORK MEASUREMENTS

Tx position	**P1**	**P2**	**P3**	**P4**	**P5**
Distance (m)	64	121	128	112	141
SNR min (dB)	0	4	1	1	-1
SNR max (dB)	8	8	9	8	8
RSSI packet min (dB)	-93	-101	-116	-114	-101
RSSI packet max (dB)	-82	-93	-86	-90	-78
RSSI LoRa min (dB)	-122	-122	-122	-122	-122
RSSI LoRa max (dB)	-88	-83	-92	-116	-84
Packet Lost	6%	17%	12%	16%	36%

VI. CONCLUSIONS

LoRa is a wireless communication technology featuring long-range capabilities and low-power consumption although with low data rates.

In this paper, we described some propagation tests for a point-to-point and a star topology network. The capability of the system to receive data, in term of both received power and packet error rate, over a range of about 800 m, shows that LoRa can be used in an urban noisy environment. At the same time, the second test with a star topology configuration involving more transmitter together, highlights the possibility of using a star topology network for various purposes. In this case, it is necessary to pay attention to the problem of the collisions:. It may cause a substantial increase of the packet losses, especially when the nodes are close to each other. Particular attention should be paid to the choice of the distance between two network nodes and on the implementation of a collision detection mechanism.

The feasibility analysis presented in this work indicates that a LoRa based network can be deployed in a urban noisy environment and can be used for various applications, including various Distributed Measurement Systems (DMSs) for pollution, structure health monitoring, environmental monitoring and transportation control.

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