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Propagation measurements for a LoRa network in an urban environment

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ABSTRACT

LoRa is a relatively new proprietary communication technology that allows long-range communication distances while consuming very little power. It utilizes license-free Industrial, Scientific and Medical ISM frequency bands to exchange information at low data rates. LoRa is favourable when looking for limited exchange of data and low-cost devices and infrastructure.

This work presents some preliminary propagation measurements in a typical urban environment by using prototype transmitters and receivers working in a private network. Results highlight that LoRa can be used as a communication technology for different ad-hoc networks deployed in an urban area.

Keywords: LoRa; internet-of-things; IoT; wireless communication; electromagnetic measurements; electromagnetic propagation; urban environment.

1. Introduction.

The Internet of Things (IoT) is one of the key technologies of the near future [1]. IoT refers to the network of different devices, designed to provide smart services and applications without the need for human intervention [2]. Essentially IoT is a “system” where the network itself and all the connected devices have “less of everything”: less memory, less processing power, less available bandwidth, less available energy, etc. [3]. Nonetheless, the set of sensors and devices connected to the IoT is continuously increasing. It has been estimated that about 30 billion devices will be connected by 2020 [4]. IoT offers a wide range of possible applications. Currently, the basis of IoT is the pervasive, continuous and efficient collection of data. Data can be acquired, transmitted, stored and aggregated for different purposes [5,6,7] and the set of sensors and equipment from which IoT is made, constitutes a wide Distributed Measurement System (DMS) [8]. Among the infinite range of possibilities that IoT is able to offer, one of the most important is the implementation of smart cities. For example, pollution, environmental monitoring [9], and transportation control [10].

In order to build ad-hoc networks and DMSs, which are operative in an urban environment, LoRa technology is a good and flexible solution. LoRa is a proprietary wireless communication technology [11] emphasizing long-range capabilities, with low energy consumption [12] and low data rates [13]. Developed by Cycleo and acquired later by Semtech [14], LoRa uses the license-free Industrial, Scientific and Medical (ISM) frequency bands [15]. The mentioned characteristics make this technology appropriate for communications that require a modest amount of exchanged data [11] and for a situation requiring strict constraints for the transmitted power and the power supplier (e. g. the network nodes must be powered by batteries) [16]. During the last years, LoRa has increasingly become popular and it has been adapted to a variety of applications, see e.g. [17,18,19,20,21]. However, LoRa is only one of the available Low Power Wide Area Network (LPWAN) technologies in the market [10]. Among other existing technologies, it is possible to mention Sigfox [22], which offers a longer-range communication with respect to LoRa but with lower bandwidth, data rate [23] and service subscription costs [24]; NarrowBand IoT [25], which is a SIM-based cellular LPWAN technology operating in licensed bands [26]. Other technologies are also Weightless, 5by5 Wireless, HaLow, Zigbee. Examples of usage of Zigbee in urban environments are presented in [27,28].

This paper describes some preliminary propagation measurements that can be used to construct a network based on LoRa technology in an urban environment. Three different measurement setups were used. The first two setups were related to point-to-point communication. The transmitter and the receiver were placed in fixed positions at different distances and different heights, thus considering the effects of buildings. The basic idea was to determine the maximum reasonable communication range in an urban environment. The third setup consisted on a star-topology network with a single receiver and multiple transmitters. This configuration is the most common for DMS and smart city applications. The main measured quantity was the number of correctly received packets from each transmitter, thus indicating the overall performance of a fully operative network made by various network nodes. After a brief presentation of the LoRa technology (section 2), we focus on the theoretical analysis of propagation performance (section 3). The equipment used for the propagation measurements in the urban environment is presented in section 4. The results related to the propagation measurements are reported in section 5, and conclusions and outlooks are given in the last section.

2. LoRa Technology

The LoRa modulation scheme derives from the Chirp Spread Spectrum (CSS) modulation technique, which encodes the information in chirps [11, 29,30]. As the phrase “spread spectrum” suggests, this technique takes advantage of the entire allocated bandwidth to transmit the signal [31]. Because of this, LoRa exhibits robustness against noise and other channel degradation mechanisms such as multi-path fading (urban applications) [32]. It also mitigates the Doppler Effect, but this aspect is not investigated in this work.

LoRa is the physical (PHY) layer [33] (the lowest layer in OSI communication stack) implementation and it works regardless of the technology operating on upper layers [11]. In this respect, the LoRa Alliance™ has developed the open-source LoRaWAN specification [34]: 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 [11,35]. In principle, to realize ad-hoc networks in urban environment, both LoRa (wireless modulation) and LoRaWAN (communication protocol and system architecture) [13] can be used. However, in this work, LoRa technique is used since it gives the possibility to create an entire ad-hoc network (using plain LoRa communication) without using the available public network LoRaWAN. It is possible to configure different LoRa parameters (bandwidth, spreading factor, code rate) [36] in order to adapt the technology to the working scenario.

In this work, we make some propagation measurements to study how the LoRa technology works in a typical urban environment. To configure the prototypal network nodes (made by simply LoRa transceivers properly programmed), we used a set of parameters defined by previous experiments.

3. Analysis of propagation performance of LoRa technology

In order to get a deeper insight of the maximum distance that could be covered in urban areas considering the European LoRa operative frequency, in this section we present an analysis of the propagation, in term of range and received power. As it is well-known, wireless channel characterization is determined by path loss, shadowing, and multipath fading [37]. The last two quantities are extremely important in an urban environment due to the higher presence of non-line of sight (NLOS) conditions and multipath signal components of the transmitted signals that may heavily affect the propagation performance of a radio link.

Considering $\mathrm{P_T}|_{\mathrm{dBm}}$, the power radiated by the transmitter, $\mathrm{G_T}|_{\mathrm{dB}}$ and $\mathrm{G_R}|_{\mathrm{dB}}$, the antenna gains respectively of the transmitter and receiver, $\mathrm{L_P}|_{\mathrm{dB}}$ the path loss attenuation caused by the distance between the transmitter and the receiver and the different characteristics of the surrounding environment, the received power $\mathrm{P_R}|_{\mathrm{dBm}}$ can be calculated as:

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

Until now, there is not a specific path loss model to estimate $L_P|_{dB}$ in the case of LoRa technology. However, there are many empirical propagation models. These models were developed and/or derived from experimental data using different standards, different frequency, and in various propagation conditions.

Some of these models can be used in the frequency band dedicated to LoRa in Europe. For instance, in [38], the Erceg model [39] is used with promising results compared with experimental data with a maximum difference of 100 m in the useful range. However, the Erceg model tends to overestimate the distances in an urban environment due to the dampening by buildings and other urban structures.

In [40], the authors present an analysis and some optimizations of the Lee propagation model [41], which can be used for both area-to-area, and point-to-point communications. The model predicts the path loss over flat terrain, but it is possible to adapt it to urban areas. The application of the Lee propagation model is possible as far as a proper set of specific parameters is determined for each city. Unfortunately, in the case of Turin, (Piedmont, Italy) this information is not available. However, we can use the standard parameters defined for urban areas and already applied in some cities (e.g. Newark, USA, [41]). The results obtained can give an insight of the propagation performance of LoRa systems.

In urban areas, if the frequency of the radio link is between 100 and 1500 MHz, very good results can be obtained with the empirical Okumura-Hata model [42]. In fact, this model was specifically developed for wireless communication in urban environments. The path loss in terms of the operating frequency (MHz), the transmitter and receiver heights (meters), the correction parameter, $\mathrm{a(h_R)}$, due to the area type (urban area or country area, equation (3)) and the distance between transmitter and receiver (Km) is given by:

$$\mathrm{L_P|_{dB}} = 69.55 + 26.16 \log_{10} \mathrm{f} - 13.82 \log_{10} \mathrm{h_T} - \mathrm{a(h_R)} + \\ + (44.9 - 6.55 \log_{10} \mathrm{h_T}) \log_{10} \mathrm{d} \qquad (2)$$

where for large cities:

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

Even if a LoRa receiver can have a sensitivity up to -157 dBm [41], a lower reasonable limit for the received power has been set to -120 dBm since, in this work, a private network with two Lora transceivers (point-to-point communication radio link) was adopted. It is a hypothetical receiver sensitivity value, which ensures a correct reception within a good margin, including all the possible source of additive path losses (e.g shadowing, diffraction, destructive interference, etc…). According to LoRa specifications and European regulations, the transmitter power can vary from 0 dBm to 14 dBm [43]. Therefore, in this section, the expected ranges using the Okumura-Hata model were computed using three different output power values: 0, 5 and 14 dBm. The LoRa operating frequency was set to 865 MHz. The heights of transmitter and receiver were chosen both equal to 3 m; then the receiver height was assumed 20 m in order to simulate a different scenario in an urban environment. By means of equations (1), (2) and

(3), and considering an antenna with gain equal to 3.16 dB, the maximum communication ranges reported in Table 1 can be obtained.

Table 1**.** Transmitted power and maximum range using the Okumura-Hata model for urban environment and two receiver heights h_r=3 m and h_r=20 m.

Transmitted power (dBm)	**Maximum range (m)**	
	h_r=3 m	**h_r=20 m**
0	552	923
5	727	121
14	1194	1998

The obtained results using the Okumura-Hata model formulas are reasonable for the deployment of a DMS based on LoRa technology in an urban area. A LoRa transmitter can communicate with a receiver less than 500 m apart transmitting only 0 dBm. Of course, this range can be increased using antennas with a gain greater than 3.16 dB.

4. Measurement setup description

The system is made up by a single receiver and a variable number of transmitters according to the different tests to be performed. All the transmitters and the receiver have the same hardware: electronic components, a microcontroller and a monopole antenna with a gain =3.16 dB, operating in the band 860-868 MHz. A controlling software was developed for each specific test using the Arduino© Integrated Development Environment (IDE). The communication module is based on the module Adafruit® Feather 32u4 LoRa Radio RFM95. It is an embedded module, which contains a LoRa transceiver RFM95 and an ATmega32u4 microcontroller. 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. The operative frequency range is 868-915 MHz, including the band around 868 MHz allowed by European laws, and the transmitted power ranges between 5 dBm to 20 dBm. The modules are 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©. The measurements were made using a Spectrum Analyzer (SA) model R&S ZVL connected to the receiver module. The setting parameters of the SA are listed in Table 2.

Table 2. 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

5. Results

In order to assess the practical capabilities of LoRa technologies to be used for an ad-hoc proprietary network, a static test was done from March to May 2018, in a typical urban area surrounding the Politecnico di Torino (Italy). The aim of this first static test was to check the signal quality of LoRa technologies, considering distances and power that can be used in a potential ad-hoc network set up in an urban environment. The measurements were made with two configurations: point-to-point and star configuration. Two distinct setups were considered for point-to-point measurements in order to examine different communication ranges.

5.1 Point-to-point measurements: setup 1

In this case, both the transmitter and the receiver were at placed a height of about 20 m. The receiver was placed in Via Boggio, Torino, Italy and a transmitter was placed in three different positions (P1, P2, and P3): above the roof of Politecnico di Torino, Corso Castelfidardo, Torino, Italy (see Figure 1). The distances between the transmitter and the receiver are comparable to the maximum distance between two network nodes that can be deployed for a DMS. The receiver module was programmed 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 transmitted signal consists of blocks of 200 packets for each sensor transmitter. The settings and the configurations used for transmitter and receiver are reported in Table 3.

Table 3. LoRa settings and parameters for setup 1.

Parameters for measurement (setup 1)	
Transmitted power	5 dBm
SF	10
Bandwidth	125 kHz
Frequency	865.2 MHz
Antennas gain	3.16 dB

Figure 1. Setup 1. Position of the transmitters (P1, P2, P3) and of the receiver (Rx) with relative distance.

The receiver positions P1 and P3 were in line of sight with the transmitter while the position P2 was behind an obstacle. This fact allowed also to check the signal quality when the transmitter is not completely in line of sight with the receiver. This is a common situation for an urban environment where potential transmitters can be partially, or totally shielded by houses. It is important to mention also that, below the receiver position P3 and along the south side of the roof, there was a metal structure that could also introduce additional losses to the system.

In Table 4, the results of the measurements, i.e. the signal to noise ratio (SNR), the Received Signal Strength Indicator (RSSI), the indicator of the lost packets, and the received power using the Spectrum Analyzer are reported. In the last column of Table 4, the values computed with the Okumura-Hata model are also shown.

Table 4. Result of the point-to-point measurements (setup 1).

Tx POSITION	**DISTANCE (m)**	**SNR mean (dB)**	**RSSI mean (dBm)**	**LOST PACKETS (%)**	**Received power with Spectrum Analyzer (dBm)**	**Received power estimate with O. – H. model (dBm)**
1	341	6	-94	0	-83.39	-87.06
2	274	1	-95	0	-86.79	-83.06
3	350	0	-95	0	-86.79	-87.41

5.2 Point to point measurements: setup 2

In the second point-to-point measurements setup, 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 receiver, connected to the SA was placed on the rooftop of the DET of the Politecnico di Torino, whereas the transmitter was placed in three different positions (P1, P2 and P3) along Corso Castelfidardo, Torino, Italy, from a minimum distance of about 370 m to a maximum of about 840 m (Figure 2). All the transmitter’s positions were in line of sight with the receiver. The configurations and the setup of both transmitters and receiver are shown in Table 5.

Table 5. LoRa settings and parameters for measurements of setup 2.

Parameters for experimental measurement	
Transmitted power	14 dBm
SF	10
Bandwidth	125 kHz

Frequency	865.2 MHz
Antennas gain	3.16 dB

Figure 2. Setup 2. Transmitters (P1, P2 and P3) and receiver (Rx) position, with relative distance indications.

The results of the measurements are reported in Table 6. Negative values of SNR should be because the signal power level is below the noise level. However, according to the LoRa specifications and the CSS modulation, a negative value of SNR indicates the ability to receive signal power below the receiver noise floor [44]. This happens when the communication range is very long and/or the communication channel is affected by fading, as in an urban environment. This behaviour highlights the robustness of LoRa technology and the possibility to communicate in a very troublesome environment with good performances of the communication link.

The RSSI of the packets, as expected, decreased for larger distance. However, the large majority of the packets were received. In fact, for P1 and P2, the number of packet losses was lower than 1%. When the separation distance was bigger than 800 meters (P3), the percentage of losses reached 4%.

When the transmitter was in 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 values computed with the Okumura-Hata model.

Although the measured power was higher than the power computed using the Okumura-Hata propagation model, the accuracy of the model is still adequate for urban environments [45]. The discrepancy can be due to limitations of the model itself. For instance, the exclusion or underestimation of some factors (terrain profiles, antenna heights, buildings, vegetation) [46, 47], differences between the environment in analysis and the environment in which the model was derived [45,46], and due to partial or total obstruction of the Fresnel zone [47]. In addition, other authors have reported similar results in terms of variability of the measured and calculated path loss and power when using the same or other empirical formulation models [45-51].

Table 6. Result of the second group of point-to-point measurements

Tx POSITION	**DISTANCE (m)**	**SNR mean (dB)**	**RSSI mean (dBm)**	**LOST PACKETS**	**Received power with Spectrum Analyzer (dBm)**	**Received power estimate with O. – H. model (dBm)**
1	376	1	-99	< 1%	-78	-88
2	616	-2	-97	< 1 %	-85	-97
3	839	-7	-98	4 %	NA	-103

5.3 Star topology network measurements

In order to test the performance of LoRa with a star topology network, we performed another group of static measurements with a receiver in the middle and five peripheral transmitters around it. This configuration could be the most suitable for an ad-hoc deployed network and for a DMS used for smart cities applications.

Star topology tests were performed in the campus of the Politecnico di Torino, with the receiver at ground level in the middle of the test area and the transmitters spread around at a distance of approximately 100 m (see Figure 3). The transmitters were named node 20 to 24 for convenience in order to properly identify which one is transmitting a specific packet. The power transmitted was equal to 5 dBm and all the transmitters were equipped with the same antennas used in the point-to-point measurements. The settings of this setup are presented in Table 4, and the results are summarized in Table 7.

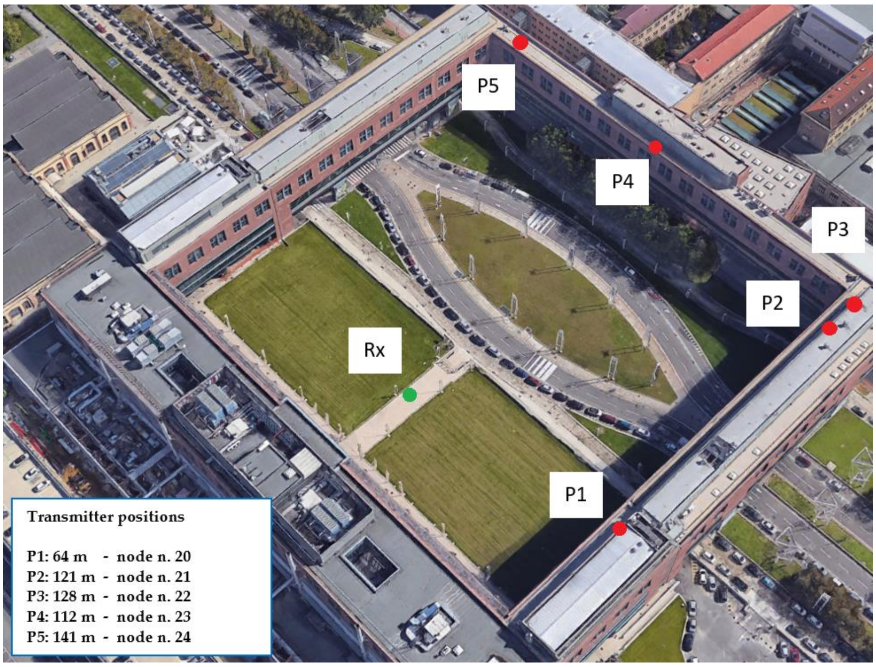

Figure 3. Transmitters (P1, P2, P3, P4, and P5) and receiver (Rx) position, with relative distance indications for the star-topology network measurements.

Table 7. Results of the star-topology network measurements.

Tx POSITION	DISTANCE (m)	SNR mean (dB)	RSSI mean (dBm)	LOST PACKETS
P1	64	6	-88	6 %
P2	121	6	-99	17 %
P3	128	6	-95	12 %
P4	112	6	-98	16 %
P5	141	6	-92	36 %

As expected, the power signal received from all the five transmitters was higher than the receiver sensitivity since, the distances between the receiver and the transmitters were shorter than for the previous setups. In addition, few SNR values were lower than zero only for the most distant from the receiver. Concerning the RSSI, all the values are coherent with the distance between the transmitters and the receiver.

The main difference between the star-topology measurements and the point-to-point tests is the number of correctly received packets (i.e. packets without error detected automatically by the receiver). Since the transmitters are not too distant from each other, there were some collisions on the communication channel and some packets were not received: on average, 17% of the packets were lost, going from a minimum of 6% (transmitter and receiver close to each other) to a maximum of 36% (the farthest the receiver and the transmitter were from one another). A potential redundant transmission mechanism can reduce the potential packet losses, as well as increasing the distance between the potential network nodes.

Fig. 4 shows the SNR of the packets of the most relevant configurations: P1, transmitter close to the receiver, P2 transmitter and receiver at intermediate distance, and P5 transmitter far from the receiver.

Finally, a comparison among the three configurations analysed in the paper is done in Table. 8

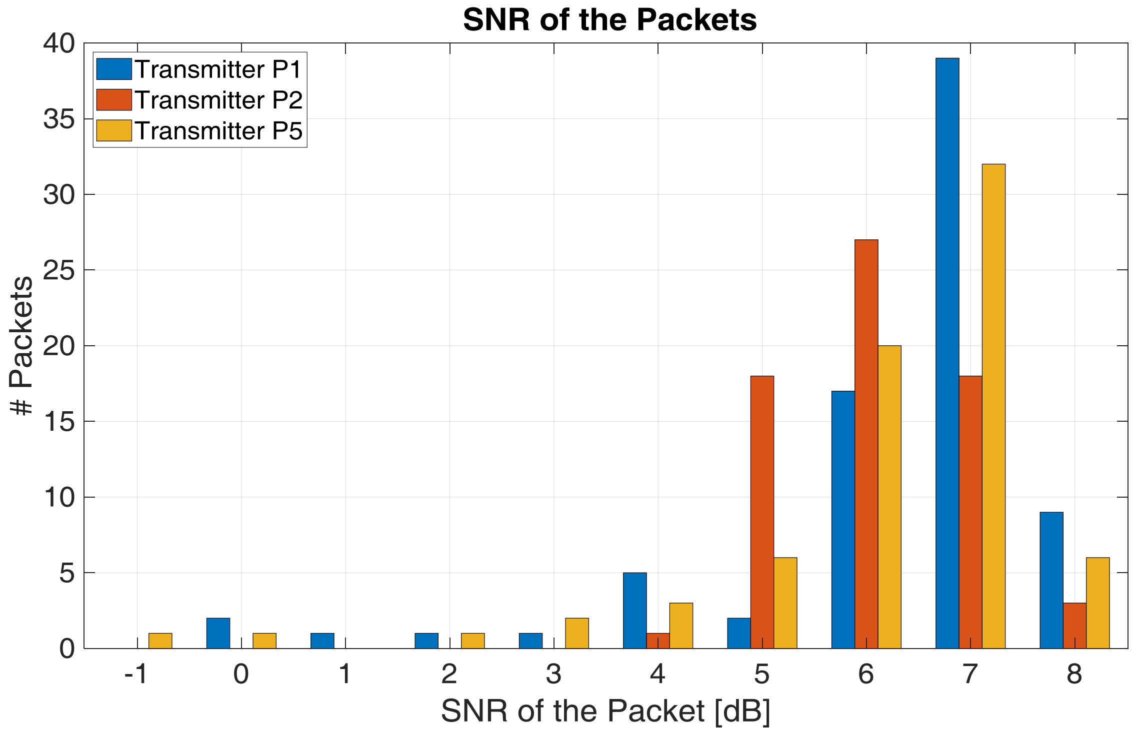

Figure 4. Signal-to-Noise Ratio of the received signals from transmitters (P1, P2, and P5) for the star-topology network measurements.

CONFIGURATION	Tx POSITION	DISTANCE TO THE RECEIVER (m)	LOST PACKETS
Setup 1: Point-to-point	**1**	341	0
	2	274	0
	3	350	0
Setup 2: Point-to-point	**1**	376	< 1%
	2	616	< 1 %
	3	839	4 %
Setup 3: Star topology	1	64	6 %
	2	121	17 %
	5	141	36 %

Table 8. Results of the configurations used: Point-to-point (setups 1 and 2) and star topology (setup 3)

7. Conclusions

LoRa is a wireless communication technology which features long-range capabilities and low-power consumption but with low data rates. It can be used to set up new ad-hoc networks without using already existing public network LoRaWAN.

In this work, some preliminary propagation tests for a point-to-point and a star topology network are presented. Three different measurement setups were used: the first two were related to a point-to-point communication, while the third setup was based on a star-topology network. The capability of the system to receive data correctly, in terms of both received power and packet error rate, over a range of about 800 m, highlights that LoRa can be used in a typical urban environment. At the same time, the star-topology test indicates a possible DMS setup, which can overcome the problems of collisions. However, this setup causes a substantial increase in the packet losses, especially when the nodes are close to each other. Particular attention should be paid to the choice of the distance between the two network nodes and on implementation of collision detection mechanisms.

The propagation measurements presented in the paper indicate that a LoRa based network can be deployed in a typical urban environment and can be used for different purposes, including various DMSs for pollution, medical buildings, monitoring, environmental monitoring, and transportation control.

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