# Dynamic Adaptation of LoRaWAN Traffic for Real-time Emergency Operations

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***Abstract*—Modern standards for IoT communications support fast deployment, large coverage in the order of kilometers, and physical layer adaptations to increase link robustness under time-varying propagation and interference conditions. A possible use of such IoT technologies is in case of emergency scenarios where first responders (FRs) arrive after a disastrous event. Indeed, an important challenge for emergency management is the need to (re)establish real-time communication capabilities and to offer integrated decision making facilities based on information gathered by FRs acting on the crisis site.**

**In this paper, we present a system architecture based on LoRaWAN technology for connecting emergency operators in real-time and reliably communicating environmental information, audio streams/messages, and vital signs received from the first responders' sensors. In particular, based on LoRa modulation parameters, we propose an adaptation algorithm which adjusts user's voice messages and the resolution of the data flows to keep alive communications also when link quality is critically low, thus avoiding delay and saturation problems. Opportunistically, audio signals can be processed locally by the first responder's equipment with a speech-to-text conversion, thus significantly reducing traffic requirements. We demonstrate that the adaptation scheme can be performed real-time, even on a per-packet basis. Thanks this innovative system, FRs can communicate from the crisis site in an efficient and cost-effective way.**

***Index Terms*—First Responder, Emergency, LoRaWAN, LoRa, speech-to-text, LIDAR.**

## I. Introduction

Innovative IoT technologies are transforming how emergency situations are handled in smart cities. These new and flexible technologies may complement standard LTE/5G services which, under critical conditions, might not work properly or might not be available. Indeed, when disasters disrupt conventional communication infrastructures, IoT networks can be used to support First Responders (FRs) in the real-time delivery of control messages to/from the control room, in addition to the possibility of gathering, integrating, and processing large amounts of data from the crisis scenario. Among the many IoT communication technologies, LoRaWAN [1] has already been considered for sending emergency communication messages [2], to manage emergency and alarm communications in industrial scenarios [3], to provide localization data in GPS-less emergency scenarios [4] and for remote safety monitoring [5], just to name a few. Indeed, this technology and its physical modulation LoRa, patented by Semtech [6], have been demonstrated to be very robust to interference, easily deployable with high replicability, as well as energy and cost efficient. The LoRaWAN network has a star-of-stars topology and the End Devices (EDs) are not associated with a specific GateWay (GW). Each GW simply forwards packets to the Network Server (NS) which, according to the implemented service, delivers the data to the corresponding Application Server (AS). Moreover, LoRaWAN supports several Data Rates (DRs) by exploiting six different spreading factors (SFs), namely from SF7 to SF12, and it considers two BandWidths (BWs), 125KHz and 250KHz. Finally, the combination of SF and BW defines the transmission DR [7]. Table I reports the DRs available in LoRaWAN, together with the associated SF and BW, as well as the channel bit rate and sensitivity. Clearly, lower DRs are characterized by an improved sensitivity, translating in increased noise immunity and greater coverage (tens of kilometers [8]). LoRaWAN works in unlicensed band, with duty cycle constraints of 1% or 10%, according to the selected channel (uplink or downlink, etc.). However, in emergency we consider that such limits can be exceeded.

TABLE I: LoRaWAN DRs and relation with SF and BW. The table shows also the associated bit rate and sensitivity.

| DR | SF | BW [KHz] | Rate [bit/s] | Sensitivity [dBm] |
|---|---|---|---|---|
| 0 | 12 | 125 | 250 | -137.0 |
| 1 | 11 | 125 | 440 | -134.5 |
| 2 | 10 | 125 | 980 | -132.0 |
| 3 | 9 | 125 | 1760 | -129.0 |
| 4 | 8 | 125 | 3125 | -126.0 |
| 5 | 7 | 125 | 5470 | -123.0 |
| 6 | 7 | 250 | 11000 | -122.0 |

In this work, we propose a new LoRaWAN-based system to support FRs in the following ways: 1) exploits IoT sensors like microphones, LIDAR (Laser Imaging Detection and Ranging) or wrist-worn wearables to map the


Fig. 1: The First Responder's sensing equipment considered in this work.

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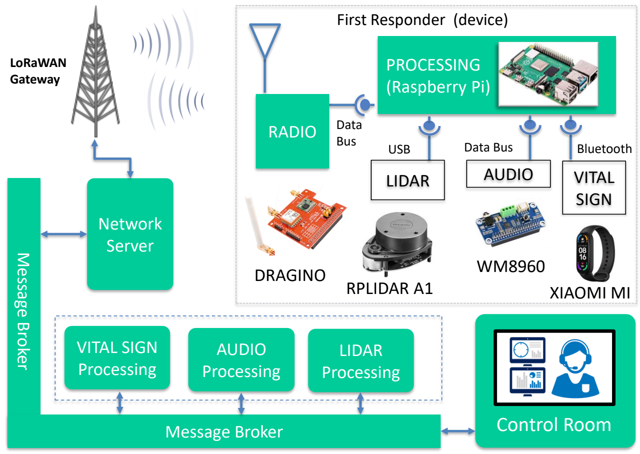


Fig. 2: Architecture of the proposed system.

surrounding environment, monitor vital signs of FRs and communicate through voice messages (see Fig. 1); 2) transmit such data in real-time or near real-time, adapting the amount and type of traffic to the quality of the link. In particular, we design an innovative and dynamic system allowing the transmitter to take decisions about the type of data to be transferred to the remote control room: we propose a traffic adaptation algorithm that, based on the current device DR configuration, adapts the voice traffic and reduces the rate of sensor data to keep alive communications also when DR is critically low. If needed, audio signals can be processed locally by the FR's equipment with a speech-to-text conversion, thus reducing traffic requirements significantly. We demonstrate that such dynamic adaptation can be performed real-time, even on a per-packet basis. Through this system, we are able to provide emergency live voice communications with high DR or delayed voice messages with intermediate DRs, while the system activates the onboard speech-to-text module with low DRs, transferring the obtained transcripts only. Note that previous works employing LoRa for voice communications, such as [9]–[11], are not focused on emergency scenarios and can not work in low DR conditions. To the best of our knowledge, we are the first to offer an adaptive emergency service for real-time voice communications over LoRa.

The rest of this paper is organized as follows. The system architecture is described in Section II. Section III shows the performance of the proposed system. Finally, Section IV concludes this paper.

## II. System Architecture

In Fig. 2 it is depicted the overall system architecture. Since disasters can sometimes cause service interruptions in the normal communication infrastructures, the adoption of LoRaWAN is a robust and low-cost communication system for such emergency scenarios. Indeed, this IoT technology is cost-effective, easy to setup and allows long range communications between FRs and Control room. Although LoRa/LoRaWAN network performances might seem limited for real-time communications, recent improvements can boost the available capacity significantly [12], [13].

The proposed FR's Emergency-Node is represented in the top-right part of Fig. 2. The node is a multi-technology and multi-radio embedded device composed by a Raspberry Pi 3 processing unit and equipped with the following sensors and modules: 1) the DRAGINO LoRaWAN radio module [14], to create the communication link; 2) the 2D RPLIDAR A1 [15], to map the surrounding environment; 3) the WM8960 sound card, to collect audio signals; 4) the integrated Bluetooth Low Energy (BLE) interface, to connect wearable sensor devices (in our case, Xiaomi Mi Smart Band 4). Moreover, Fig. 2 also shows the remote processing modules which are deployed in the cloud: the messages flow from the GW towards the NS which in turns forwards messages to three separate modules, one for each type of information exchanged with the FR's Emergency-Node. In particular, data received from FR's Emergency-Node by the NS is forwarded through a message broker to the AS and vice-versa, while the AS provides processed information to the control room. A Python application runs in the embedded processing unit, as well as in the AS, for managing the produced data. On the Emergency-Node software side, three modules run in the Raspberry to process radio and environmental data of the surrounding environment, monitor health conditions of the FR and transmit voice messages, depending on the LoRaWAN DR configured. In particular, when the DR is not high enough to send voice messages, a speech-to-text algorithm [16] is used to significantly reduce the amount of data to be sent. The speech to text conversion is made through the PocketSphinx [17] module of PyAudio [18] library. Finally, we exploit the BLE interface also as a radio proximity device for search and rescue purposes: the BLE interface scans the wireless channel to detect Signal Strength of smartphones or other personal devices in order to detect the presence of possible victims.

### A. Adapting data traffic to link quality

As shown in Table I, depending on the SF and BW combination (which in turn determines the DR), LoRaWAN transmissions are characterized by different bit rate and receiver sensitivity. As specified in the LoRaWAN standard [1], the choice of the DR depends on the Received Signal Strength Indicator (RSSI) metric, following the Adaptive Data Rate (ADR) algorithm [19]. Thus, corresponding to the DR suggested by the ADR, we dynamically adapt the data traffic to be transferred by the FR to maintain close real-time communications also when DR is critically low. Other network optimization algorithms (e.g. [20], [21]) could be exploited instead of the standard ADR (which only uses RSSI), but this is left as a future work.

In particular, when the DR does not allow real-time (RT) audio streams, we employ non real-time voice messages (VM) if the transmission delay is low enough (we set a threshold to 4 times the message length), and finally we activate the speech-to-text (S2T) processing for the lowest DRs. This is shown in Fig. 3, which reports the number of simultaneously active users that may be supported by the LoRaWAN system, as a function of RSSI and the corresponding DR. The figure shows that proposed system allows emergency live voice communications if the DR is at least DR6, while delayed voice messages are used with DR4 and DR5. Instead, with DR3 or lower, the onboard

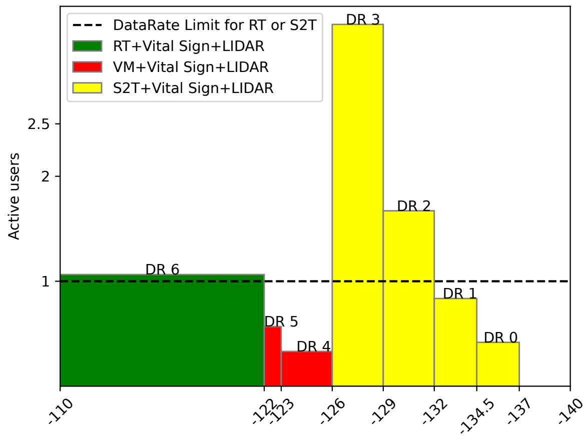


Fig. 3: Number of active users supported and corresponding DR, as a function of RSSI.

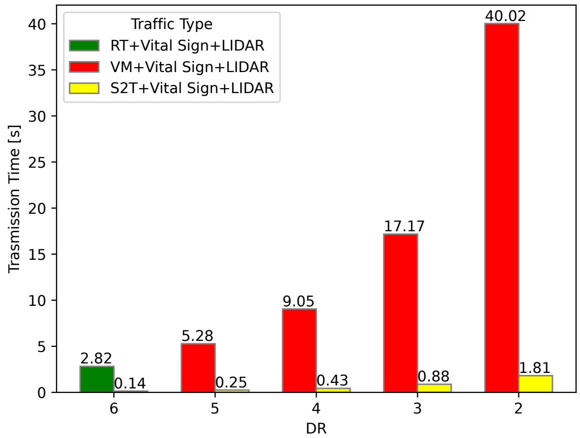


Fig. 4: Time required to transmit a voice or text message of 3 seconds as a function of LoRaWAN's DR.

speech-to-text module is activated, thus transferring only the obtained text transcripts. Note, however, that state of the art S2T libraries have a conversion accuracy of about 85%, so transmitting the original audio signal is preferable when the DR allows it.

### B. Bluetooth Low Energy Proximity Detection

BLE technology can help FRs in rescue activities. Indeed, most smartphones and wearable devices use BLE for data transmission and detection/advertisement (i.e. sending periodical information to close devices). Moreover, BLE transmissions can be useful to estimate radio distance between FRs and a possible target. Finally, BLE can be used to connect wearable devices and provide vital signs information (e.g. hart rate) of the users.

### C. LIDAR scanner parameter

We employ a RPLIDAR A1 [15] laser-scanner which provides a 2D distance measurement, with 1.5 degree resolution and a maximum sampling frequency of 200Hz. A complete scan produces 480 Bytes of data (240 samples, 2 Bytes for each sample), thus a maximum generated data rate of 768 kbps. Such data stream overcomes the maximum LoRaWAN DR available and is thus unfeasible. For this reason, we reduce the amount of transmitted data by down-sampling both in time and in space domains: we reduce the sampling frequency to 1 Hz and transmit data with angle resolution of 15 degrees (thus 24 samples per second, i.e. 48 Bytes/seconds). As we will show, this is a sufficient resolution to detect large obstacles and obtain a rough map of the surrounding environment.

## III. Experimental results

In order to analyze the performance of the proposed system, we emulated an emergency scenario, where the FR' Emergency-Node sends predefined data, including a fixed length voice message, vital signs information (the FR's heart rate and the BLE RSSI), and a reading of the 360° LIDAR scan. The audio signal is collected by the sound card using 16-bit samples at an 8kHz sampling rate. The G.729a [22] audio standard compression is used, which produces a 16:1 rate compression. As a result, a data rate of $8kbps(8k*16/16)$ is needed to transmit the audio stream in real-time. According to Tab. I, only DR 6 permits this real-time transmission. In particular, the voice message used for the experimental test has a length of 3 seconds, which in wave format occupies 46.875 kB of memory, but using the G.729a codec becomes a compressed file of 2.93 kB (16:1 compression). An additional $48 + 20 = 68$ Bytes are used to send LIDAR and vital sign information respectively (we consider a single data acquisition). All this data is sent in 14 LoRaWAN packets of 222 Bytes (the maximum packet size for DR4 or higher [7]). As described earlier, when the DR is not high enough to send voice messages with low delay, the speech-to-text algorithm is used to significantly reduce the amount of data to be sent. In this case, all the above information is sent in a single packet (or 3 packets with the lowest DRs).

Fig. 4 shows the total time required for the transmission of the emergency data when the LoRaWAN DR changes from 6 to 2. The transmission of speech-to-text (S2T) transcripts is shown in yellow bars, while RT communications and non RT VMs are shown in green and red bars respectively. Note that only DR 6 is able to transmit the 3 seconds audio message and all other emergency information in less than 3 seconds, while using S2T it is always possible to transmit such data without delay, even with low DR. Fig. 5 shows an example of traffic adaption of the system in response to link quality changes: from top to bottom, the figure shows packet arrival events over the time (each dot in the top plot represents the reception of a single packet), the RSSI, DR and traffic type (same labels of the previous figure). In particular, the DR configuration reflects the distance from the GW (or, more precisely, the received RSSI), and the traffic type is adapted accordingly: simulating a FR moving away from the GW, Fig. 5 shows a reduction of the perceived RSSI, and consequently, the ADR reduces the DR proportionally. The variation of DR triggers in turn the change from RT audio (DR6) to voice messages (with DR4/5), and finally, with DR3 or lower, the onboard speech-to-text module is activated, transferring the obtained transcripts only. In this way, all information can be transmitted in only one to three packets, including vital signs and environment data too. Note that, with low DRs,

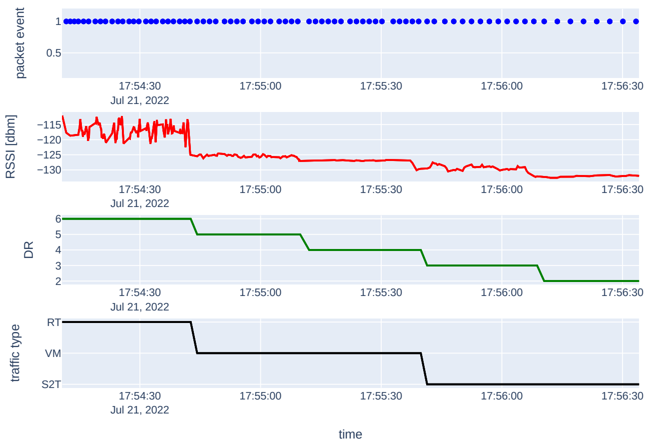


Fig. 5: Example of the system's adaptation to the quality of the link.

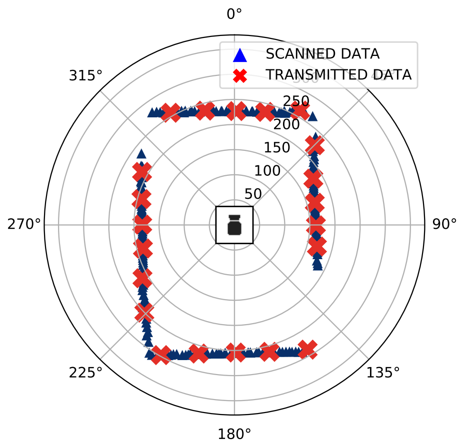


Fig. 6: Lidar scanned data and transmitted (sampled) data.

the number of packet arrivals is reduced as a consequence of the increased time on air.

Finally, Fig. 6 shows the experimental results obtained from the LIDAR scanner. In our tests, the device is located in the center of a 1.75m x 2.45m room. In the figure, blue triangle points are the real scanned values (the ground truth), while the red crosses are the 24 points sampled, which are transmitted and used to describe the environment with just 48 Bytes.

## IV. Conclusion

In this paper, an adaptable LoRaWAN system was proposed for reliably transmitting environment information, voice streams/messages, and vital signs data in real-time. The system exploits a dynamic adaptation scheme to process audio signals on the mobile device through a speech-to-text module, in order to reduce data traffic when the quality of the link decreases. The proposed system represents an innovative and efficient system design, which allows the transmitter to take decisions about the combination of data to be transferred to the remote control room. When the link quality is high enough, the system can perform real-time audio streaming between FRs and control room, through the LoRaWAN technology.

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