Long-range body-to-body LoRa link at 868 MHz

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***Abstract*—In the context of the Internet of Things, LoRa is an important standard for low-power wide area sensor networks. LoRa communication employs chirp spread spectrum modulation in sub-GHz frequency bands, combining the benefits of both to enable low-power kilometer-range wireless data communication. LoRa modulation provides a high link budget and additionally, sub-GHz bands possess excellent radio propagation characteristics. A LoRa transceiver was integrated onto a textile substrate-integrated-waveguide antenna in order to set up long-range body-to-body communication links. The unit is a fully autonomous wearable wireless sensor node, including a transceiver, processor, sensors, flash memory and a low profile battery, all integrated on the feed plane of a textile antenna. The design and characteristics of the unit are described, including radiation patterns of the fully assembled unit. Finally, an outdoor long-range performance test is performed as a proof of concept. Communication was reliable for a range over 500 m and over 200 m with the antennas pointed towards and away from each other, respectively. In static conditions, a range of 1.44 km was observed.**

***Index Terms*—LoRa, SIW antenna, body-centric, propagation, measurement.**

I. Introduction

Recently, a number of modulation techniques have become popular for long-range wireless sensor networks, operating at sub-GHz frequencies. Different technologies are used in industry, of which LoRa [1], Sigfox [2] and DASH7 [3] employ licence-exempt I.S.M. (Industrial, Scientific and Medical) frequency bands. Their frequencies of operation correspond to wavelengths of 35 cm or more, which lead to better propagation in indoor as well as outdoor environments. In particular in the presence of obstacles, these radio waves have better penetration properties and/or diffract more around obstacles, compared to signals in the widely used 2.45 GHz I.S.M. band, where the wavelength amounts only to 12 cm.

The number of unlicensed frequency bands is limited. In Europe, for example, the available bands are 434 MHz, 868 MHz, 2.45 GHz and 5.8 GHz. Of these four bands, the 434 MHz has the best propagation properties, but as the wavelength approaches 70 cm, wearable antennas for this band tend to become rather large. The 868 MHz band allows excellent solutions, combining fairly compact wearable antennas with good propagation characteristics.

Of the different technologies which are currently popular, LoRa seems to provide the most flexibility. Compared to other modulations, the data rate can be adapted and a long communication range can be obtained, owing to the chirp spread spectrum modulation (CSS) providing a large spreading gain. Alternative solutions exist, of which Sigfox is also very popular, but the very small packet size and extremely limited duty cycle of Sigfox transmissions is a disadvantage for body-centric communication.

Recent publications about LoRa transmissions cover urban as well as suburban environments. Measurements with LoRa links are described in a number of recent publications [4]–[6]. Yet, to our knowledge, body-to-body communication using LoRa nodes has not been studied so far.

Channel characterization for a LoRaWAN device has been documented in [7] for a body-to-base-station link. The statistics of the propagation fit to a Nakagami distribution. However, the information in the paper is limited and, moreover, the measurements have been performed with an off-the-shelf LoRa device, not optimized for body-centric applications.

A substantially different approach is offered here, proposing fully integrated systems based on textile antennas. They can be conveniently worn on the body and unobtrusively integrated into garment. Recently a body-worn channel measurement node for the 868 MHz band was presented [8], accurately measuring signal strengths. In this paper, a fully functional wearable wireless LoRa sensor node for the 868 MHz band is presented, based on a similar SIW (Substrate Integrated Waveguide) antenna. The wearable LoRa node combines excellent radiation characteristics with a compact size.

The circuit board for the proprietary LoRa sensor node was developed recently [9] and is now integrated onto the SIW antenna. The design is made on a small FR4 PCB, attached to the back of the SIW antenna which is probe-fed by the circuit board, without a transmission line in between. The radiation pattern of the wearable LoRa node is measured in the anechoic chamber. The patterns for the fully integrated system are compared to those for the SIW antenna connected to the LoRa circuits board via an SMA connector. The radiation patterns are expressed in EIRP (Effective Isotropic Radiated Power).

As a proof of concept, an outdoor measurement has been performed to assess the range that can be achieved in case of body-to-body communication. The measurement environment corresponds to a suburban environment with a line-of-sight path, but surrounded by trees and buildings. The path loss is assessed with the antennas directed towards each other as well as with the antennas away from each other. A range of over a kilometer was demonstrated in this first test.

The paper is further organized as follows. The design of the LoRa unit is presented in Section II, the characteristics in Section III, body-to-body long-range communication tests in IV and finally the conclusions in Section V.

II. Wearable LoRa Unit

A. Textile SIW antenna

The textile antenna on which the design is based was extensively documented in [10]. The antenna is an eight-mode substrate integrated wave-guide design, which can be easily assembled thanks to the automated manufacturing of its main components. Electro-textile materials, as well as dielectrics are accurately laser-cut to their appropriate sizes, including notches and cut-outs that guide the convenient assembly of the full antenna structure. The polarization of the antenna is elliptical and its radiation is directed away from the body, with the antenna pattern covering approximately a half space in front of the body, when wearing the device on the torso.

The antenna, with the LoRa unit connected via an SMA connector is displayed in Fig. 1. This is before integration of the circuit on the back of the antenna. Radiation patterns will further document the difference between this system and the fully integrated unit.

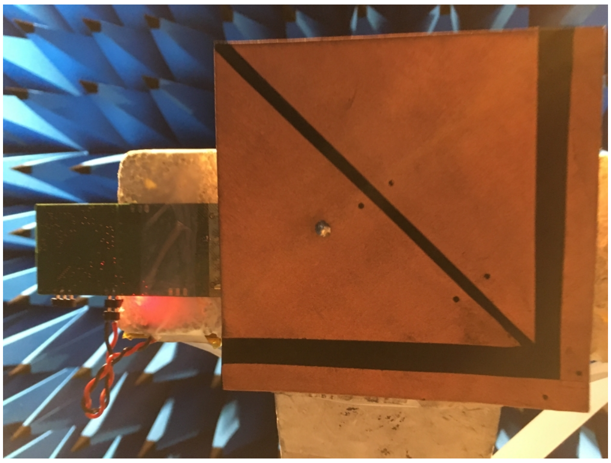

Fig. 1. LoRa unit in the anechoic chamber, connected to antenna by an SMA connector.

B. Hardware

A top and bottom view of the SIW antenna including the integrated PCB is shown in Fig. 2. The circuit board employs the RN2483 LoRa transceiver module by Microchip®, configured by means of a low-power micro controller. The board is also equipped with flash memory, a real-time clock and a sensor unit. The sensor unit includes a 3-axis accelerometer, gyroscope and magnetometer, all in one chip. Ample flash memory is available to store months of measurement results. The real-time clock is a very low power device, allowing to keep track of the time and date also with the battery disconnected, extracting power from a 0.5 Farad supercapacitor on the board. The hardware is fully autonomous, being powered by a low profile LiIon battery that is also integrated at the back of the antenna. A special feature of this design is the use of stepped attenuators for both RF connections. These attenuators can be configured from 0 to 31.5 dB in steps of 0.5 dB and enable measurements with a larger dynamic range [9].

C. Measurement protocol

Embedded software, written in C, controls the operation of the system. The mode of operation depends on the nature of the measurements to be performed. For the measurement in the anechoic chamber, the transmit node is programmed in CW mode, transmitting a continuous carrier signal at a fixed frequency and power.

For the outdoor measurement, a transmitting node sends LoRa packets of which the payload contains packet numbers, time stamps and information about the transmit power. The following LoRa parameters are employed: 125 kHz bandwidth, $4/5$ coding rate, a preamble length of 10 chips and a bandwidth spreading factor of 12, with Cyclic Redundancy Check (CRC) active. The CRC guarantees that all received packets are error free, which is important in order to obtain accurate measurement data. The data rate is 293 bps with this configuration. Each packet is transmitted at 4 different transmit powers, employing the transceiver's power settings combined with the stepped attenuators. Another node is configured as the outdoor receiver, logging signal-to-noise ratio (SNR), packet numbers, power information and time stamps into local flash memory.

According to ETSI TR 103 526 and ECC recommendation $70 - 03$, the maximum allowed duty-cycle of transmissions is 1%. Therefore, only one full signal strength measurement is possible every two seconds, at which the transmitter sends four subsequent short packets at different power levels, in steps of 10 dB with a maximum power of 14 dBm.

III. Characteristics of the LoRa unit

The radiation patterns of the wearable LoRa unit are shown as captured with a standard gain horn in vertical and horizontal polarization in Figs. 3 and 4, respectively. The diagrams are plotted as EIRP (Effective Isotropic Radiated Power) and correspond to the maximum power setting of the unit, being 14 dBm.

Two curves are plotted, one for the SIW antenna connected to the transceiver board via an SMA connector, and one for the fully integrated transceiver, corresponding to Figs. 1 and 2, respectively. Both patch antennas were mounted as visible in Fig. 1 and rotated in the azimuth plane.

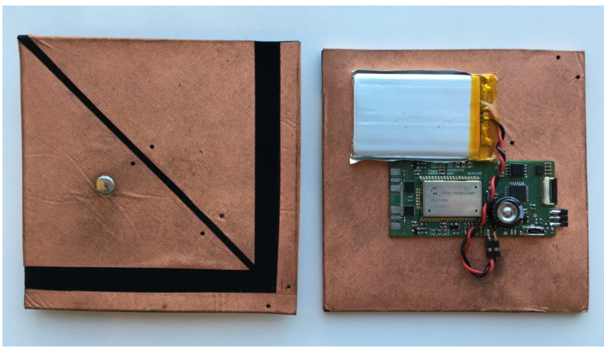

Fig. 2. Complete LoRa unit with integrated TX.

The radiation pattern measured with a vertically polarized standard gain horn is displayed in Fig. 3, showing a directional radiation pattern with most radiation broadside, at 180°. When worn with the ground plane towards to human body, the main lobe is directed away from the body. Interestingly, the EIRP is significantly higher for the fully integrated antenna, compared to the antenna connected via an SMA. Clearly some losses could be avoided thanks to the direct connection of the antenna to the circuit board.

A difference in peak EIRP is also visible for the pattern measured with horizontal polarization in Fig. 4. Some influence of radiation from the PCB is visible for the SMA-connected unit. As shown in Fig. 1, the PCB is rather long and narrow, causing the polarization of radiation from it to be predominantly horizontal.

Note the radiated power remains well below the maximum allowed EIRP. ETSI TR 103 526 defines the maximum ERP (relative to a half-wave dipole) as 25 mW, corresponding to 14 dBm. The EIRP (relative to an isotropic radiator) is 2.15 dB higher, resulting in 16.15 dBm maximum allowed EIRP.

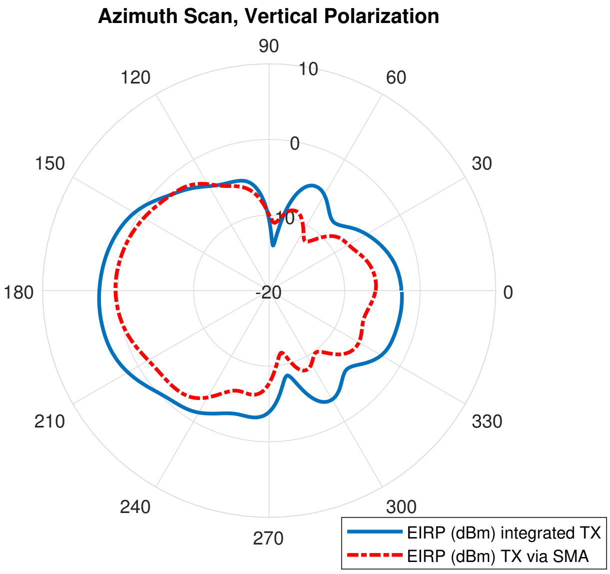

Fig. 3. LoRa unit in the anechoic chamber, azimuth scan, measured with vertically polarized standard gain horn.

IV. Long-range communication test

An outdoor long-range communication test has been performed along the Watersports Track in Gent, Belgium. As seen in Fig. 5, the total track is about 2.28 km long, while the environment can be considered suburban, as it is situated out of the city center but includes a number of high buildings nearby. The propagation is Line of Sight (LoS).

Two test persons are carrying a wearable LoRa node on the torso. The nodes are deployed onto their shirts, which are worn underneath a jacket, such that the unit is not visible to bystanders. One node is configured as the transmitter and the other node logs the received signal strength into its local flash memory. In order to increase the dynamic range of the measurement, the on-board attenuators are configured such that they avoid saturation of the receiver's Signal to Noise Ratio (SNR) measurement. The SNR is further converted to received signal power in dBm, as outlined in [9].

To obtain information about the distance covered, both test persons are using a sports tracker app on their smart phones. Data from the sports trackers is obtained in steps of 50 m distance covered, together with their time stamps. Linear interpolation is performed on these data, providing a pair of distances to the starting point for every second of measurement. As centered in Fig 5, the Watersports Track is perfectly straight, hence the total distance covered is determined by simple addition of the distances from the two sports trackers.

The measurement is started halfway the Watersports Track with line-of-sight propagation conditions. First the persons are walking away from each other, up to a distance of 1.44 km

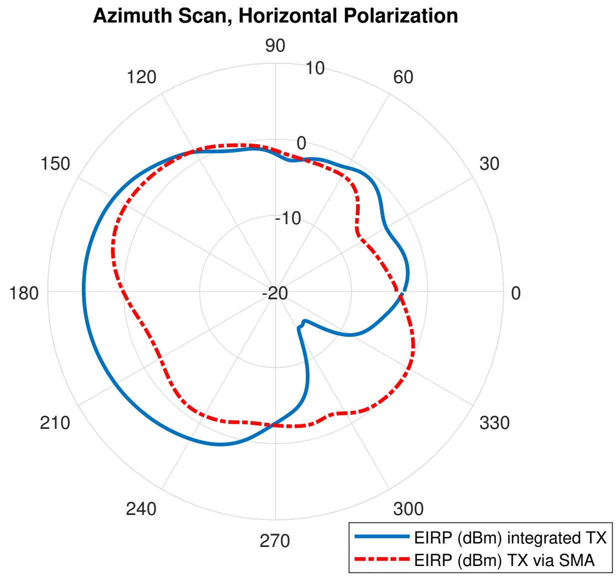

Fig. 4. LoRa unit in the anechoic chamber, azimuth scan, measured with horizontally polarized standard gain horn.

Fig. 5. Google Maps image of the 2.28 km long Watersports Track in Gent, Belgium. Coordinates: 51.0495404 N 3.6814373 E

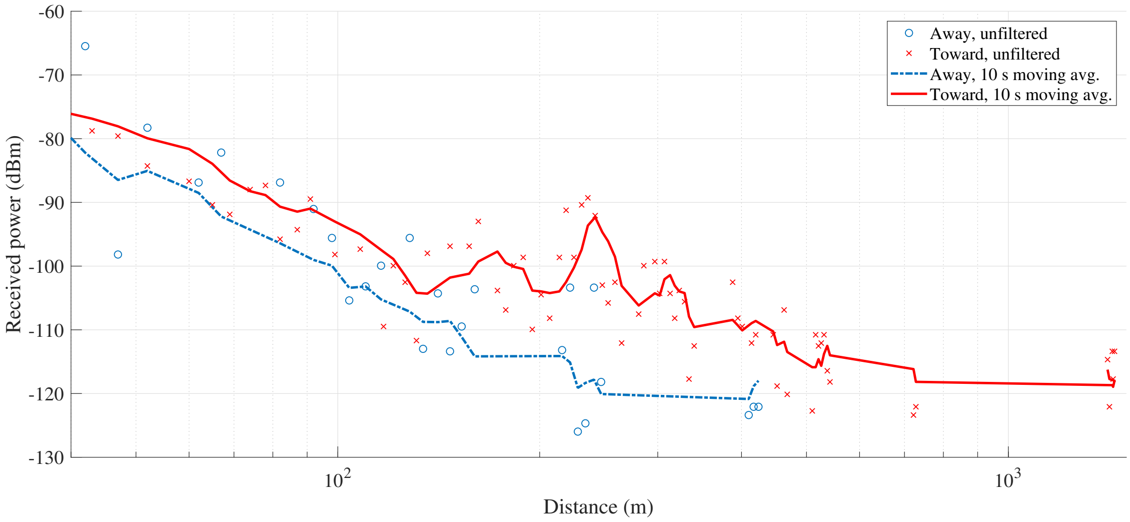

Fig. 6. Received signal powers along the Watersports Track

with the antennas oriented away from each other. At the end of this path, both persons turn around and approach each other again, until they meet. Clearly, the directional radiation pattern of the wearable antennas is expected to produce a large difference when antennas are oriented away from or toward each other.

The resulting received powers are displayed in Fig. 6, with separate curves for the walks away and toward each other. The markers show the raw measurements, whereas the lines display the moving average over the last five received packets. Without packet loss, this corresponds to 10 seconds of measurement.

As expected, the received power is higher when the antennas are directed towards each other. Comparing the signals for equal distances for the first 100 m, the difference is 6 dB. For these first 100 m the direct LoS path is clearly dominant and based on linear fitting the path loss was determined in this region.

Approaching each other, the received power is approximated as

$$P_{RX} = -52 \cdot log_{10}(d) + 11 \text{ dBm} \quad (1)$$

by means of a linear fit of P_{RX} in dBm to $log_{10}(d)$, with d the distance in meters.

The resulting path loss PL is given as

$$PL(d) = PL(d_0) + 10 \cdot n \cdot log_{10}(\frac{d}{d_0}), \quad (2)$$

with the path loss exponent $n = 5.2$ and $d_0 = 1$ m.

Similarly, with the test persons walking away from each other, the path loss exponent is found to be 3.9. According to [11], the expected path loss exponents for a suburban environment are in the range 3-5.

For larger distances, in particular with the antennas pointed toward each other, the signal fluctuations become more apparent. This indicates the increasing influence of ground reflections and probably also reflections on the surrounding buildings.

The range which is obtained with little packet loss is about 200 m with the antennas away from each other whereas it is easily more than 500 m with the antennas pointed toward each other. As the signals become weaker, a lot of packet loss occurs, with only two packets received around 700 m during the walk. For larger distances nothing is received while walking.

Note however, that at the end of the trajectory, at 1440 m distance, several packets are received. At the end of the path, the test persons were standing still for a while. While walking, the mobile transmissions produce Doppler shift and signal variation on the already noisy signals at this distance. The LoRa transceiver can clearly decode the packets better when the channel is more invariant and without Doppler shift. Note the specifications for the LoRa SX1276 transceiver chip, on which the Microchip RN2483 unit is based, mention the importance of an accurate crystal oscillator as a reference, indirectly revealing significant sensitivity of the receiver to frequency offsets (and Doppler shift).

V. Conclusion

A textile-antenna-based fully autonomous wearable LoRa node was successfully designed, implemented and tested in an outdoor scenario. The radiation patterns of the node have been measured, highlighting the benefits of direct integration of a transceiver on the antenna. In the outdoor measurement, communication was reliable for a range over 500 m and over 200 m with the antennas pointed towards and away from each other, respectively.

The decoding of weak signals appears to suffer from movement during the transmission. Channel fluctuation and Doppler shift compromise the link at greater distance. In static conditions, a range of 1.44 km was observed.

The radio propagation is dominated by path loss in the first 100 m, whereas at larger distances the influence of multi-path propagation is more pronounced. Within the first 100 m the path loss exponents were found to be 3.9 and 5.2, with the antennas pointed towards and away from each other, respectively.

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