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Body-Centric LoRa Networks Based on System-Integrated Textile SIW Antennas

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Abstract

Building on recent innovations in wireless technology and antenna development, this paper presents several recent contributions investigating the performance of body-centric LoRa networks using a compact, wearable LoRa system with integrated textile substrate-integrated waveguide (SIW) antennas. Measurements were gathered in indoor and outdoor propagation environments, and for body-to-body and body-to-base-station link configurations. For each application environment, considerable range improvements were observed when compared to more traditional wireless technologies used for body-centric communication.

1 Introduction

In recent years, wearable technologies underwent a strong growth in popularity. However, the capabilities of many of these technologies are bounded by wireless range and power constraints. Yet, for certain applications that require less data rate, obtaining a larger range or link budget can be a key enabler for new functionalities. Consequently, the idea of introducing sub-GHz low-power wide-area network (LPWAN) technology into wearables is gaining a lot of interest. Related research on off-body LoRa communication describes the performance of commercial arm-mounted LoRa systems (LoRaMote) in body-to-base station contexts [1–3]. More specifically, [1] and [2] examine the performance of LoRa using different carrier frequency channels and modulation settings, whereas [3] is more tailored towards characterizing outdoor LoRa links. Regarding the use of textile antennas, [4] and [5] present the application of wireless systems outfitted with wearable textile antennas to monitor rescue workers using the 2.45 GHz band.

As mentioned earlier, this contribution is a compilation of several studies examining the real-time performance of body-centric LoRa networks in different environments, using system-integrated textile substrate-integrated waveguide (SIW) antennas at 868 MHz. It is structured as follows. In section 2, the wearable LoRa hardware used in the studies featured in this summary is discussed. Next, in section 3, the authors elaborate on how this hardware choice leads to choosing appropriate channel characterization strategies. Results and conclusions from a number of contributions are presented in sections 4 and 5, with the latter focusing on improving the wireless performance that is presented in the former. Finally, a conclusion is formulated in section 6.

2 Wearable LoRa Hardware

To characterize body-centric wireless channels, suitable measurement hardware must be chosen. By using lightweight wearable nodes [4, 5], a lot of drawbacks associated with using coaxial cables in combination with bulky channel sounding equipment can be overcome. As these measurement nodes are generally very similar to hardware used in actual off-body applications, they also provide performance indicators that are highly comparable to those expected in these real-world applications. All of the research featured in this work was performed using a custom-made LoRa system integrated onto a textile SIW antenna. Developing a custom measurement node allows the user to add measurement-specific hardware to the system, significantly enhancing its channel characterization capabilities. The custom LoRa hardware used for this research is thoroughly described in [6]. In summary, the main features of this hardware are the stepped attenuators included in the RF path, which allow the node to dynamically change its SNR measurement dynamic range according to the present propagation environment. As illustrated in the next section, these attenuators are very actively used when characterizing body-centric wireless channels.

Another key part of the body-centric channel characterization system is the integrated antenna. Naturally, this antenna is worn on the body, which, depending on the antenna type, may have a significant impact on its performance. Textile SIW antennas provide a good match with several off-body applications as they can be made very light and bendable. Additionally, being low-profile, they can often be integrated into the garments of the wearer. However, as efficient sub-GHz SIW antennas can be relatively big, there are fewer antenna placement options. The textile antenna used for this research measures 11 by 11 cm and can therefore only comfortably be worn on the front or back of the torso. The antenna consists of two coupled eighth-mode SIW cavities and is comprehensively described in [7]. Fig. 1 shows the body-to-body radiation pattern of the entire system when worn on the chest by a male test person and tracked by another test person, either facing or turned away from the device under test (DUT). In general, it is observed that the system performs excellent when transceiving signals across the front hemisphere around the body. Yet, as has been demonstrated in literature, body shadowing does have a considerable effect on the radiation pattern, producing a front-to-back ratio exceeding 30 dB [8].

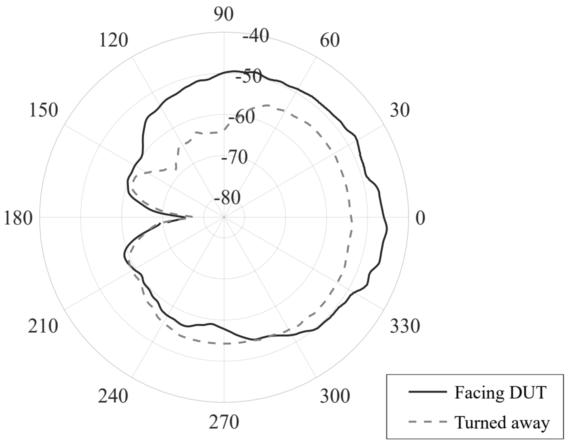

Figure 1. Radiation pattern (received power in dBm) of the body-worn LoRa node with integrated textile antenna transmitting in continuous wave mode at 868 MHz with a transmission power of 10 dBm tracked by a similar node at a distance of 4.3 m.

3 Channel Characterization Strategies

As discussed in the previous section, compact and lightweight wearable nodes were used to gather data for all of the research contributions featured in this paper. However, as these nodes are based on commercial hardware, a sound measurement strategy has to be considered in order to characterize the wireless links. The commercial hardware integrated on the system presented in Section 2 originally only supported gathering SNR values. Earlier research determined that the dynamic range for gathering these SNR values was seriously limited [9]. As introduced earlier, the hardware presented in [6], uses programmable RF attenuators to shift the dynamic range for gathering SNR values in order to adapt to the current state of the channel. However, when characterizing a mobile channel, signal levels are expected to fluctuate severely. Consequently, an algorithm that adapts the dynamic range settings to the current state of the channel by reacting based on the SNR of previously received packets is principally too slow. As comprehensively explained in [10], this is solved by continuously probing the channel at different dynamic range settings. These subranges are combined in post-processing, using redundancy to avoid saturated measurements. When aiming to perform quasi real-time link monitoring in this kind of channel, achieving a high probing rate is critical. Consequently, a low LoRa spreading factor (SF) of 7 was used in all of the measurement campaigns to limit the air times of the packets.

4 Wireless Performance in Different Application Environments

It is useful to subdivide the wide range of possible body-centric applications for LPWAN technologies based on their relevant propagation environments and applied network configurations. With regard to the propagation environment, a straightforward distinction can be made between indoor and outdoor environments. These both exhibit unique behaviour in terms of path loss, scattering and multipath behaviour. In indoor environments, performance is usually more capricious due to the presence of numerous obstacles and scatterers close to the mobile user. Conversely, outdoor propagation environments are generally more predicable as the primary source of attenuation is free space path loss. Yet, in outdoor environments, the Doppler effect may add additional complexity. In both environments, wireless links can significantly benefit from the large link budget provided by modern LPWAN technologies. Two variations of off-body link configurations are body-to-body and body-to-base-station links. Body-to-body links can be used to form mesh networks between moving nodes. These can be useful for several body-centric applications, for example those monitoring rescue workers presented in [4] and [5]. Body-to-base-station links are more likely to be found in networks with a star topology. In applications using such a topology, the base-station will generally be used to monitor one or more separate mobile users. As shown in Fig. 2, a body-to-base-station link can also be used as an anchor link for one of the mesh network applications described earlier. In the following sections, general results from three different channel characterization studies are presented, with each of them being set up in a different application environment.

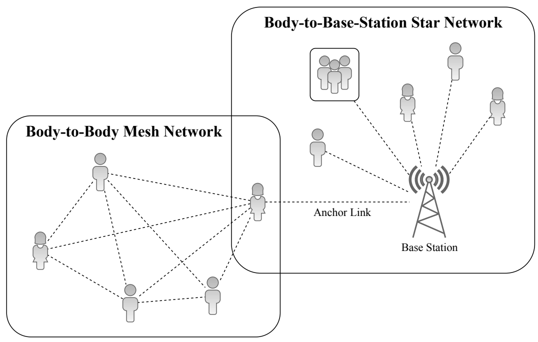

Figure 2. Example of a network featuring body-to-body and body-to-base-station links.

4.1 Indoor Body-to-Body

In [11], a large number of indoor body-to-body measurements gathered in a modern office environment are presented and discussed. It is shown that when both test persons are on the same office floor, a near-perfect link can be established using an SF of 7, even when the nodes are separated by the heavy concrete core of the building. When moving across two adjacent floors, an average signal loss of 18 dB is measured and packet reception ratios (PRRs) are seen to decline. A third type of measurements describes the link quality in the concrete stairwell. Here, an average loss of 14 dB was measured for each intermediary floor between the test persons. In all of the measurements presented in [11], body shadowing is present, but it is sometimes mediated by the high amount of reflections that occur in the indoor environment. This leads to the conclusion that LoRa is an excellent modulation technique for low-power and low data rate body-centric communication in challenging indoor environments, even when using a low spreading factor. It should also be mentioned that performance is expected to increase significantly when using higher spreading factors.

4.2 Outdoor Body-to-Body

In terms of outdoor body-to-body measurements, a basic range test is presented in [12]. This test is performed in an open environment, next to a 2.3 km straight watersports track. With their chest-worn nodes continuously sending packets to one another, two test persons walked towards and away from each other along this track. Very reliable packet reception was observed for both situations across distances up to 200m. When the antennas were pointed towards each other, this range was seen to increase to approximately 500 m. More fragmented packet reception was recorded for ranges up to 1440 m. In the first 100 m of the trajectory, radio propagation was seen to be dominated by path loss. For both walks, path loss exponents were determined that lie in the range 3-5. At larger distances, the influence of multipath effects were perceived to be more pronounced.

4.3 Outdoor Body-to-Base-Station

Two outdoor body-to-base-station measurement campaigns are presented in [10]. The main topic of this contribution is improving wireless performance by using front-to-back diversity, which will be discussed more thoroughly in section 5. When looking at single-node performance in the body-to-base-station configuration, an excellent communication range of over 1.5 km was observed between the test person moving at a steady walking pace of 6 km/h and the fixed base-station, placed on top of a 53 m high office building. Thanks to the excellent location of this base station, very high PRRs were observed. Moreover, the attenuative impact of certain buildings, vegetation and other obstacles on the link are clearly discernable in the presented data. Additionally, [10] also presents measurements gathered at a higher speed of 31 km/h. These show no significant difference when compared to the data gathered when walking, leading to the conclusion that for cyclists or users of alternative personal transportation vehicles, Doppler effects are not strong enough to measurably impact communication. This confirms statements made in related research on the matter [13–15].

5 Improving Wireless Performance

In general, two methods were investigated that improve the performance of the wireless system. In [10], the performance gain achieved by using front-to-back diversity is examined. Additionally, [16] explores how the communication system can increase the data rate and packet rate according to the available link budget.

5.1 By Means of Receiver Diversity

Applying receiver diversity is a well-known communication improvement strategy in body-centric communication [17]. By wearing two nodes, one on the front and one on the back of the torso, the effects of body shadowing can be largely mitigated. In [10], the performance gains achieved by using two common diversity methods, selection combining (SC) and maximum ratio combining (MRC), are analyzed w.r.t. two single-receiver configurations. It is shown that packet reception is significantly better for the diversity configurations in non-line-of-sight (NLoS) areas near the edge of the communication range. Additionally, signal level enhancements up to 5.5 dB were observed. Finally, the data presented in [10] also show that the MRC method provides only a marginal performance improvement when compared to SC diversity, which should be taken into account given the additional complexity and cost of an MRC-capable system. In general, the presented measurement campaigns demonstrate the superior robustness and range of using sub-GHz LPWAN technologies in comparison to more traditional solutions for body-centric wireless applications. However, it should also be mentioned that achieved data rates are very low due to bandwidth and duty-cycle restrictions imposed on LPWAN technology.

5.2 Through LoRa Parameter Optimization

Many modern wireless systems actively change communication parameters based on the present link budget. With the purpose of exploring similar strategies for body-centric LoRa applications, [16] presents a number of channel measurements gathered in an outdoor body-to-base-station context, also featuring the application of front-to-back diversity. During the measurement campaign, the channel was continuously probed using different spreading factors to determine the coverage for each of these settings. In post-processing, the theoretical channel throughput was determined as a function of the SNR, based on a set of reference measurements. Based on these data, optimal spreading factor switching parameters were determined to optimize the overall data rate of the link while maintaining the largest possible coverage area. This contribution primarily concludes that due to the limited differences in performance between neighbouring spreading factors, an SF switching algorithm should optimally only use two or three SF options to limit the amount of overhead added to the communication.

6 Conclusion

This contribution presents the use of LoRa technology in a number of body-centric wireless applications. Channel performance results were gathered in a diverse set of propagation environments, using various network configurations. Additionally, two methods for improving the performance of body-centric LoRa links are examined and discussed. In general, it is shown that body-centric wireless applications can greatly benefit from using modern LPWAN technologies such as LoRa on a platform with state-of-the-art system-integrated SIW antennas.

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