Channel Characterisation for Wearable LoRaWAN Monitors

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Abstract

This paper presents the results of a campaign to investigate the empirical characterisation and mathematic modelling of the radio channel for a body-centric LoRaWAN (**Lo**ng **Ra**nge **W**ide **A**rea **N**etwork) transceiver for various operating distances across various environments including urban, suburban, and rural. The radio channel for a wearable LoRa transceiver device was explored, as well as anechoic measurements to understand body-shadowing effects. Results indicate that the best fit model for all recorded received signal strength measurements (using the Akaike information criterion to fit) is the Nakagami distribution with mu = 0.52 and Ω = 662.13. Anechoic measurements indicated typical additional effects regarding the orientation of the user with respect to the gateway location. This work highlights LoRaWAN as a credible wearable wireless technology.

1 Introduction

The Internet of Things (IoT) has being billed as the next technological revolution [1] and it is anticipated that IoT will be a disruptive technology throughout industry, healthcare, education, and everyday activities; 20.8 billion connected devices are forecast by the year 2020 [2]. The Internet of Things proposes to interconnect a myriad of sensors embedded into buildings, food cartons, bins, cars, luggage, utility meters, consumer electronics, as well as living organisms like people and animals to facilitate the orchestrated collection and exchange of data [3]. The market for this technology is predicted to grow to $662 billion (USD) by 2021 [4] with the global manufacturing sector being committed to the expedition of the proliferation of IoT-enabled sensors [5]. Low Power Wide Area Network (LPWAN) techniques include an array of technologies such as Sigfox, LoRa, LTE-M, NB-IoT, etc.

A key emerging IoT technology for (LPWAN is LoRaWAN which uses a Chirp Spread Spectrum (CSS) technology [6] and offers long range communications in the license-free Industrial Scientific and Medical (ISM) bands with devices in Europe and Asia operating at 868 MHz, and at 915 MHz in North America [6,7]. The technology boasts 3 encryption layers and a maximum of 62,500 devices per gateway [6].

Range testing for LPWAN has previously been reported for fixed gateways and LoRa devices on the roof-rack of a car and on the radio mast of a sailing boat [8], measurements from a bicep-worn node for a mobile pedestrian inside the University of Oulu [9], received signal strength (RSSI) measurements in an urban area around Glasgow Caledonian University [10], urban measurement and modelling campaign for a free-standing antenna at a range of heights (0-2 m) with and without a passenger vehicle being present [11], and an urban-based tactical troop tracking system trial using a U-LoRa device over a 500m separation distance in the 434 MHz band [12]. LPWAN technology has been presented as a solution to remotely monitor health and wellbeing [13] including portable body-worn monitoring [9]. The LoRa solution is particularly attractive as it requires no mobile network device (and thus no subscription SIM card), nor does it require the home to have Wi-Fi or even a personal landline.

There have been a number of non-LoRa measurement campaigns for off-body wearable transceivers at 868 MHz [14,15] addressing indoor and outdoor empirical modelling. However, these activities were conducted to investigate indoor Selection Combining Based Macro-Diversity [14] and antenna diversity for indoor communications [15]. These devices also did not implement the particular LoRa chirp spread spectrum modulation techniques; LoRa boasts additional range due increased link budget improvement over conventional narrowband modulation techniques [16]. This paper presents empirical characterisation and mathematical modelling for a body-centric LoRaWAN transceiver. Such wearable IoT devices will enable future solutions including domiciliary healthcare monitors and patient tracking devices, as well as the effective monitoring of felons, vulnerable adults, etc. The technology inherently offers long range communications and exceptionally low power consumption which reduces the requirement for regular recharging.

Fig. 1. Semtech LoRamote device used for testing including the inverted-F antenna

2 Experimental methods

2.1 Experimental equipment

A privately owned network was used for research purposes. The gateway device used was the Ideetron Lorank8 [17] and a 800mm high-gain omnidirectional co-linear antenna ($1/4\lambda$ + $2\times1/2\lambda$ co-linear) with a gain of 5-8.15 dBi at 868 MHz (Sirio GP-901-C) was connected to the Lorank8 gateway. The gateway was a fixed external installation located at the NIBEC research centre, Harry Ferguson Engineering village, Ulster University, N. Ireland (GPS: 54°41'15.5"N 5°52'42.9"W). The gateway traffic was managed using a standard PC with two Network Interface Controller (NIC) cards; the PC relayed data to the back-end secure cloud server and the data was read from the server using a MQTT client (MQTT.fx) to monitor received traffic.

Wirelessly-enabled small form-factor devices can connect with the gateway to transmit their data to the back-end server; a range of devices and demonstrators have been created [18-20] to facilitate wireless implementation. The selected portable device used for testing was a Semtech LoRamote [20] (Fig. 1) which is small enough to be worn on the body, uses a 0 dBi planar inverted-F antenna (PIFA), and delivers 20 dBm at 868 MHz. It records GPS location using the integrated u-blox UP501 GPS receiver with embedded antenna and transmits the location via the LoRa network. It has been previously utilised for research activities by [8,9]. The gateway records the RSSI value of the incoming signal.

2.2 Experimental procedure

The portable LoRamote device was programmed to collect GPS location information and RSSI data and testing was conducted for a multitude of pre-selected outdoor locations. The device was worn on the waist (in the fashion of a medical bleeper) and held in place using an elasticated strap as per [21]. Around 100 measurements were taken during a 6 month period over a range of 0.01Km to 10Km from the gateway (typical range depicted in Fig. 2). This allowed a sizable volume of data to be gathered from the bodyworn LoRa device to inform the statistical analysis.

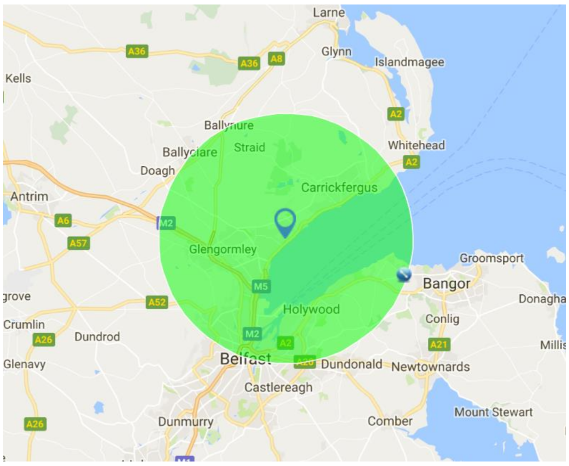

Fig. 2. 10 Km radius around LoRaWAN gateway (positioned at NIBEC, Ulster University.

In addition, measurements were made in an anechoic chamber to understand wearable LoRa transceiver device shadowing effects. It is well recognised that when a wireless device is placed in close proximity to the human body the resonant frequency and the radiation pattern of the antenna is affected [22,23]. Measurements were made for the waist-worn LoRa device for the user (and device) directly facing a receive antenna (a 50 ohm Taoglas TI.08.0A.0111 868 MHz dipole Omni-directional antenna) positioned at a height of 1.5m from the chamber floor, which was attached to a spectrum analyser using a co-axial cable. This allowed a relative comparison between RSSI values for the device in LOS, NLOS, and free standing arrangements. Rotation measurements were made with an antenna-antenna separation of 1m and an average taken to reduce the effects of measurement inconsistencies due to user movement and positioning. For comparison a free-standing antenna was positioned at a height of 1.1m on a wooden non-conductive pole to reproduce the relative height differential of the device when worn on the waist.

3 Results

3.1 User effects

To investigate the effects of having the antenna worn by a person, received power was characterised. The radiation pattern for the waist-mounted device is presented in Fig. 3. The measurements were made in an anechoic chamber with the antenna vertically polarised to understand the variations in link power due to the shadowing effects inherent in body-centric communications. The averaged RSSI values for the device in LOS, NLOS, and free standing arrangements are -15 dBm, -42 dBm, and -18 dBm respectively. Moreover this indicates a relative increase of 3 dB for the LOS scenario compared to the free-standing antenna (this will be a compound value between the additional directionality the body contributes offset against potential antenna detuning when positioned onto the human body), and a relative decrease of 24 dB for the NLOS compared to free-standing.

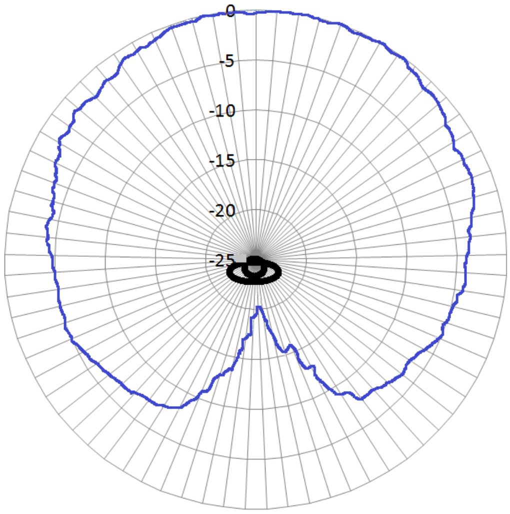

Fig. 3. Radiation pattern for bodyworn LoRaWAN device (anechoic chamber measurement normalised to 0 dBm)

This result allows an understanding of the potential variation of RSSI for an outdoor user that is facing the direction of the gateway compared to facing away from the gateway.

3.2 Off-body LoRaWAN channel modelling

To explore mathematical modelling of the wearable LoRaWAN radio channel a Cumulative Density Function (CDF) for received power for the wearable LoRa device was generated. All received power data gathered during the 6 months of testing was initially organised into bins according to the Freedman-Diaconis rule. The received power results were then transformed into a CDF with respect to the mean value [24] as displayed in Fig. 4. To mathematically describe the channel parameters, the maximum likelihood (ML) estimates of received signal amplitude were calculated for popular statistical distributions (Rician, Lognormal, Rayleigh, Nakagami, Gamma, etc.) and the Akaike information criterion (AIC) was used to select the closest fitting distribution.

Using the AIC it was found that the closest fitting distribution for the received power was the Nakagami distribution (model parameters are presented in Table 1; empirical RSSI CDF and best fit model are presented in Fig. 4). Nakagami fading is a general expression with the component *m* being the Nakagami factor and corresponds to the amount of fading [25].

$$P_{m(r)} = \frac{2m^m \cdot r^{(2m-1)}}{\Gamma(m)\Omega^m} \cdot e^{-\left(\frac{m}{\Omega}r^2\right)} \tag{1}$$

where $m \geq \frac{1}{2}$, Ω is the time averaged power of the received signal (mean square value of the amplitude) and $\Gamma(m)$ is the gamma function.

4 Further discussions

The overall results demonstrate how a wearable LoRaWAN device can offer reliable connectivity in urban, sub-urban, and rural operating environments. The measured RSSI values ranged from -48.9 dBm to -109.2 dBm. The lowest RSSI recorded (as part of initial ranging work) was -121 dBm (at a distance of 14.1 Km); this portrays the extent of the receiver sensitivity and potential for further reliable geographical coverage. Determination of the average path loss exponent (n) for all of the test locations using a classical empirical first order model [26] yields a value of n=2.72 with standard deviation 0.42. While each test site has its own path loss exponent the standard deviation indicates the values do not typically differ too excessively from the mean.

The anechoic chamber measurements illustrate how body positioning for the LoRaWAN device can influence the path loss experienced; typically a user is unaware as to whether they are facing towards or away from the gateway and the large volume of results gathered incorporates a multitude of positions and geometrical arrangements.

This work focused on a single LoRaWAN gateway; as LoRaWAN becomes increasing popular there will be multiple gateways in urban and sub-urban areas [27] which will ensure robust links for future deployed wearable solutions. While the measurements were made for LoRaWAN they can be generally applied to other similar IoT wireless technologies in this frequency band (such as NB-IoT, Sigfox, EC-GSM, etc.) with the caveat that they each employ different schemes and parameters (modulation type, operational bandwidth, etc.) and therefore cannot be assured as comparable; such differences may significantly affect the modelling accuracy.

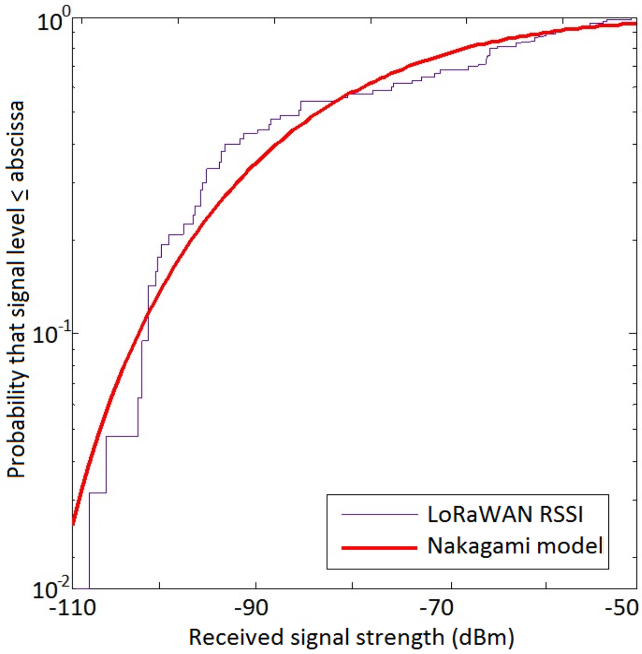

Fig. 4. CDF of received signal strength for bodyworn LoRaWAN unit with Nakagami mathematical model fit

5 Conclusions and future exploration

This paper has presented results of an investigation into the empirical characterisation and mathematic modelling of the radio channel for a body-centric LoRaWAN transceiver for various operating distances and environments. The best fit model for all gathered data (using AIC) is the Nakagami distribution with mu = 0.52 and Ω = 662.13. Anechoic measurements also indicated typical additional gains or losses incurred depending on the orientation of the user with respect to the gateway location.

There exist a number of avenues and areas in which this work could be further developed. The antenna used for testing was

Mean signal strength	Standard deviation	Variance
-77.8 dBm	38.4 dB	280.4

		Parameter Est.	Std. Err.
Model Parameters	**mu**	0.52	0.08
	omega	662.13	195.82

Table 1: Empirical statistics and best-fit model parameters

the standard PIFA antenna which clearly has not optimised in any way for wearable applications. Further research work would therefore benefit from the design and implementation of wearable flexible antennas for testing. The presented tests were also conducted on one user which ensures good consistency of measurement parameters but lacks depth to create a definitive model; more user types are thus required to extend the work. Additionally, the wireless technology will be used for users who are indoors, thus further testing could investigate the path loss for wearers who are inside various types of buildings. Such investigations will help better define the limits of operation for wearable LoRaWAN devices and will help advise on base station deployment strategies.

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