Channel characterisation for indoor wearable active RFID at 868 MHz

Cotton, S. L., Cully, W., Scanlon, W. G., & McQuiston, J. (2011). Channel characterisation for indoor wearable active RFID at 868 MHz. In *2011 Loughborough Antennas and Propagation Conference (LAPC)* (pp. 1-4) https://doi.org/10.1109/LAPC.2011.6114085

Published in:
2011 Loughborough Antennas and Propagation Conference (LAPC)

Document Version:
Peer reviewed version

Queen's University Belfast - Research Portal:
Link to publication record in Queen's University Belfast Research Portal

Publisher rights
© 2015 IEEE. Personal use of this material is permitted. Permission from IEEE must be obtained for all other uses, in any current or future media, including reprinting/republishing this material for advertising or promotional purposes, creating new collective works, for resale or redistribution to servers or lists, or reuse of any copyrighted component of this work in other works.

General rights
Copyright for the publications made accessible via the Queen's University Belfast Research Portal is retained by the author(s) and / or other copyright owners and it is a condition of accessing these publications that users recognise and abide by the legal requirements associated with these rights.

Take down policy
The Research Portal is Queen's institutional repository that provides access to Queen's research output. Every effort has been made to ensure that content in the Research Portal does not infringe any person's rights, or applicable UK laws. If you discover content in the Research Portal that you believe breaches copyright or violates any law, please contact openaccess@qub.ac.uk.

Open Access
This research has been made openly available by Queen's academics and its Open Research team. We would love to hear how access to this research benefits you. – Share your feedback with us: http://go.qub.ac.uk/oa-feedback

Download date:09. Nov. 2024

Channel Characterisation for Indoor Wearable Active RFID at 868 MHz

Simon L. Cotton[#1], William Cully[#2], William G. Scanlon[#3], Jonathan McQuiston[*4]

[#] *ECIT Institute, Queen's University Belfast*
Queen's Island, BT3 9DT, United Kingdom
[1] `simon.cotton@qub.ac.uk`
[2] `wcully01@qub.ac.uk`
[3] `w.scanlon@qub.ac.uk`

[*] *ACT Wireless Limited*
ECIT Institute, Queen's Island, BT3 9DT, United Kingdom
[4] `johnny@act-wireless.com`

Abstract— **Active radio-frequency identification systems that are used for the localisation and tracking of people will be subject to the same body centric processes that impact other forms of wearable communications. To achieve the goal of creating body worn tags with multiyear life spans, it will be necessary to gain an understanding of the channel conditions which are likely to impact the reader-tag interrogation process. In this paper we present the preliminary results of an indoor channel measurement campaign conducted at 868 MHz aimed at understanding and modelling signal characteristics for a wrist-worn tag. Using a model selection process based on the Akaike Information Criterion, the lognormal distribution was selected most often to describe the received signal amplitude. Parameter estimates are provided so that the channels investigated in this study may be readily simulated.**

I. INTRODUCTION

Radio Frequency Identification (RFID) technology has found use in a number of different applications including the tracking of high value assets and equipment [1], and more recently people [2]. RFID systems typically fall in to one of three categories: active, semi-active and passive. In passive RFID, the electromagnetic energy coupled into the tag from the reader is used to power its operation. In semi-active RFID, the tag uses its own on-board power supply to operate circuitry with the reader used to power communications. However, active RFID makes use of an internal battery to operate all on-board circuitry including communications.

To design active RFID tags which are capable of multiyear lifespans it will be necessary to develop a full understanding of the typical channel conditions in which they will operate. This will help determine important parameters such as the minimal signal power required for the desired range of operation, interrogation rate and density of readers. As most RFID personnel tracking applications will operate indoors (e.g., patient tracking in healthcare facilities, students on University campuses etc.), not only will the characteristics of the interrogation process be impacted by body centric processes [3], but also multipath generated by the surroundings and shadowing events caused by indoor obstacles such as furniture and partitions.

The environment, measurement system and experiments performed to assess the influence of the human body movements and local surroundings on active RFID systems are described in Section II. In Section III the statistics of the received signal and are reported alongside parameter estimates for a number of popular distributions which may be used to model the channels used for tag interrogation in this study. Finally, Section IV summarises the work with some concluding remarks.

II. EXPERIMENTAL SET-UP

A. System Overview

The localization system was based on *activ*Campus, a commercial, ultra-low power, secure, active RFID system supplied by ACT Wireless Ltd. The selected arrangement consisted of a wrist-worn tag and four *activ*Reader RFID reader units operating at 868 MHz. The wrist-worn tag was an eZ430-Chronos from Texas Instruments that was programmed with custom firmware that allowed interrogation by the *activ*Reader RFID readers. The wrist-worn arrangement was chosen so that the experiments conducted in this study could be considered to be representative of scenarios typically encountered by patients or healthcare personnel, who are to be localized, within medical centres. The proprietary active RFID reader units utilized a meander line printed monopole antenna and allowed all interrogations from the RFID tags to be forwarded using an on-site Wi-Fi network for storage at a remote server. This set up allowed the data analysis to be conducted off-line, in post processing. Overall, the system was configured in such a way as to allow synchronous recording of RSSI at multiple readers during each interrogation.

The proprietary protocol used in the measurement system included a packet sequence number and this permitted the identification of any missing RSSI data during initial post-processing. Missing values were then synthesized via linear interpolation with the surrounding data. Because of RFIDs low interrogation rate requirements compared to other channel characterisation campaigns [4] which aim to study not only first, but second order statistics, the sampling rate used in this study was set at a lower rate of 6.7 Hz, which is oversampled for most active RFID applications.

B. Experimental Environments and Scenarios

All of the experiments conducted in this study were performed in an open office area of the first floor of the ECIT Institute in Belfast, United Kingdom. The building was of recent construction, consisting mainly of metal studded dry wall with a metal tiled floor covered with polypropylene-fibre, rubber backed carpet tiles, and a metal ceiling with mineral fibre tiles and recessed louvered luminaries suspended 2.7 m above floor level. In the measurement environment four readers were placed at the corners of an open plan office area within the same building. This office measured 10×12 m and contained a number of desks constructed from medium density fibreboard, PCs and, low-level soft partitions, which have a maximum height of 1.3 m. In order to minimize multipath generated from the partitions, the readers were placed 2.2 m above the floor as shown in Fig. 1.

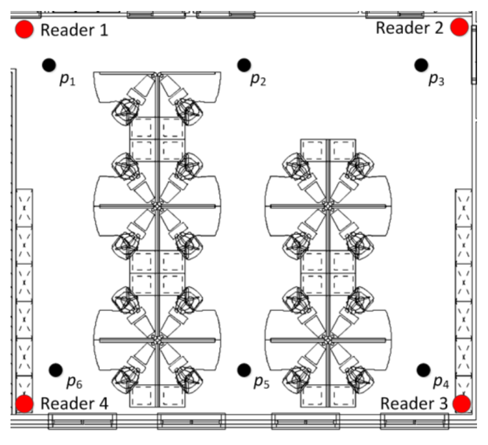
A series of experiments were then conducted using the system described above where a user with the wrist-worn RFID tag took a number of different paths within the open office area environment. A single tag was used for all scenarios and it was always worn on the subject's left wrist. The same subject (weight 83 kg, height 182 cm) was used for all tests. Additionally during these measurements great care was taken to ensure the immediate area was unoccupied as it was anticipated that other pedestrians would act as slow moving scatterers and shadowing objects [5].

The scenarios considered in this study may be broadly categorised as straight line paths (scenarios 1 to 4) where the test subject followed a straight line path between two points before returning along the reverse path, and multiple point paths (scenarios 5 and 6) where the test subject followed several paths passing through multiple points before returning along the reverse trajectory (see Fig. 1). Three individual experimental trials were conducted for each scenario, with the resultant data being combined to increase the sample set size and remove the effects of variability between trials.

III. RESULTS

A. Scenarios 1 to 4 (Straight line paths)

Fig. 2 shows a boxplot of the measured received signal power in dBm for scenario 1. As anticipated, the two readers closest to the test subject's trajectory (1 and 4) recorded the highest median received signal power (> –68 dBm) as shown by the red lines in Fig. 2. For readers 2 and 3, the median signal power level and interquartile range (distance between the top and bottom of the blue boxes in Fig. 2) were comparable (~6 dB), possibly due to the non-line of sight (NLOS) nature of the channel meaning that both of these links would have been sustained by multipath propagation. As an example, Figs. 3 and 4 show the received signal power time series for all four readers. In Fig. 3, the increase in signal power as the test subject moves towards reader 1 and subsequent decrease in signal power at reader 4 can be seen quite clearly around the 10 s mark. Comparing the variation of the waveforms depicted in Fig. 3 shows that the overall received signal power characteristics (Fig. 2) measured by the NLOS readers (2 and 3) are largely unperturbed by the test subject's movement.



Scen.	Path
1	p_6, p_1, p_6
2	p_5, p_2, p_5
3	p_4, p_3, p_4
4	p_3, p_1, p_3
5	$p_6, p_1, p_2, p_5, p_2, p_1, p_6$
6	$p_6, p_1, p_2, p_3, p_4, p_3, p_2, p_1, p_6$

Fig. 1 Open office area environment showing reader positions and the paths followed by the test subject during each scenario (scen.).

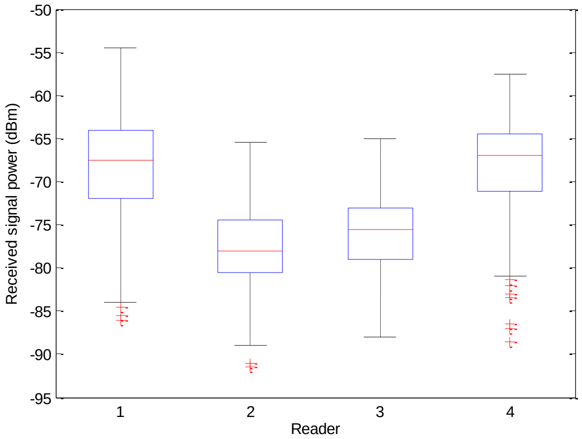


Fig. 2 Box plot showing the statistics of the received signal power in dBm for scenario 1.

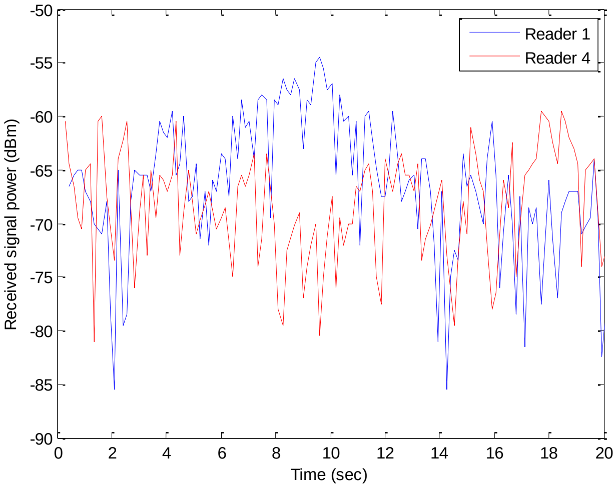


Fig. 3 Received signal power for readers 1 and 4 (closest to test subject) in scenario 1 (trial 1).

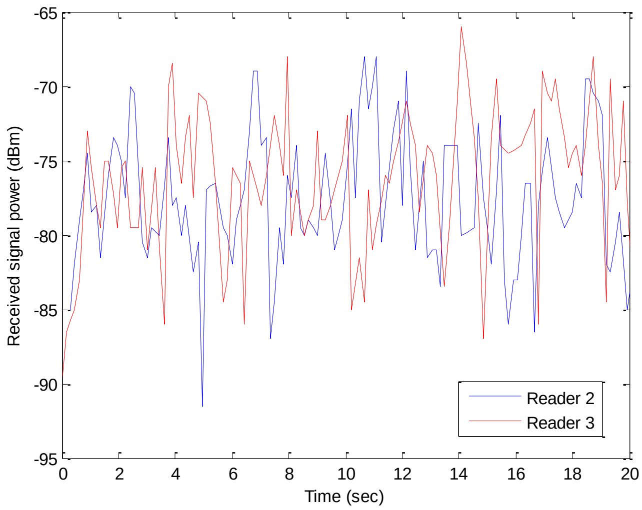


Fig. 4 Received signal power for readers 2 and 3 (furthest from test subject) in scenario 1 (trial 1).

A number of probability density functions (PDFs), all with previous wireless channel modelling motivation, were fitted to the signal amplitude of the measured data using maximum likelihood estimation (MLE). These were the lognormal PDF with scale and shape parameters μ and σ, respectively; Gamma PDF with scale and shape parameters θ and k, respectively; Weibull PDF with scale and shape parameters λ and α, respectively and Rice PDF with non-centrality and scale parameters A and s, respectively. An example of the fitting process is given in Fig. 5 for reader 3 in scenario 1. Model selection was based upon the Akaike Information Criterion (*AIC*) [6]. Fort *et al.* [7] provide a comprehensive discussion of the *AIC*'s use and its limitations in the selection of fading models in body-centric channels. In a similar manner to the analysis presented in [7] we use the second-order *AIC* often denoted AIC_c given by

$$AIC_c = -2\log\left[l\left(\hat{\theta}\,|\,data\right)\right] + 2P + \frac{2P\left(P+1\right)}{\left(n-P-1\right)} \qquad (1)$$

where $\log\left[l\left(\hat{\theta}\,|\,data\right)\right]$ is the maximized log-likelihood for the parameters θ, given the data set and model under test, P is the number of adjustable parameters available in the chosen model and n is the sample size. Table 1 provides the parameter estimates for the PDFs adjudge by the *AIC* to have been the most likely candidates for generating the received signal amplitude data. In scenario 1, the lognormal distribution was selected twice (readers 2 and 3), with the Gamma and Weibull distributions both selected once (readers 1 and 4, respectively).

In scenario 2, the test subject walked directly along the centre of the open office area, approximately equidistant from all of the readers. This is reflected in the characteristics of the received signal power from the interrogations which were statistically similar as seen from the box plots shown in Fig. 6. For this scenario, the Gamma distribution was selected for two of the readers, with the lognormal and Weibull each accounting for 1 (Table 1). For scenario 3, the test subject moved to the right side of the open office area and walked along a straight line path closest to readers 2 and 3. While in scenario 4, the test subject walked along the top of the open office area closest to readers 1 and 2. Similar to the preceding 2 straight line path scenarios, the interquartile range for all of the readers in scenarios 3 and 4 (not shown) was within 10 dB of the median signal level. For scenario 3, the lognormal distribution was found to best describe the received signal for readers 2 and 3 while the Gamma distribution accounted for the remaining two readers. As shown in (Table 1), in scenario 4, the lognormal distribution was selected by the *AIC* as the model most likely to have generated the received signal data for all of the readers.

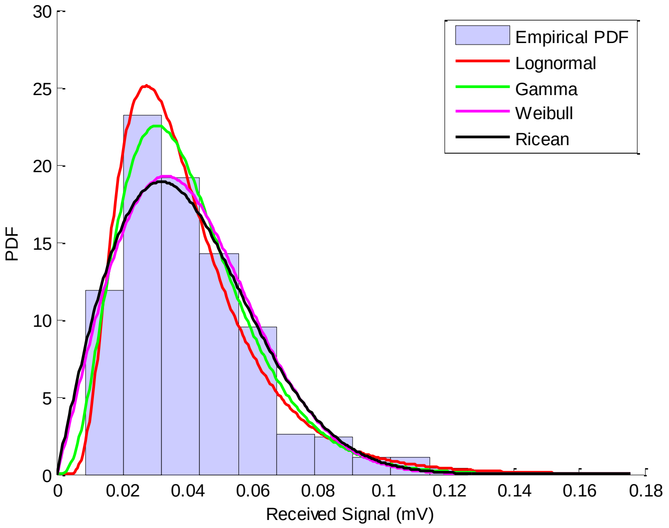


Fig. 5 Example of MLE fitting process for reader 3, scenario 1.

TABLE I
ESTIMATED PARAMETERS FOR SIGNAL AMPLITUDE DISTRIBUTION

Scenario	**Reader 1**	**Reader 2**	**Reader 3**	**Reader 4**
1	$k = 2.20$, $\theta = 0.05$	$\mu = -3.53$, $\sigma = 0.52$	$\mu = -3.33$, $\sigma = 0.51$	$\lambda = 0.12$, $\alpha = 1.90$
2	$k = 3.31$, $\theta = 0.02$	$\mu = -3.21$, $\sigma = 0.55$	$k = 3.45$, $\theta = 0.02$	$\lambda = 0.07$, $\alpha = 2.02$
3	$\mu = -3.47$, $\sigma = 0.57$	$\mu = -2.85$, $\sigma = 0.72$	$k = 2.93$, $\theta = 0.03$	$k = 4.02$, $\theta = 0.01$
4	$\mu = -2.79$, $\sigma = 0.78$	$\mu = -2.85$, $\sigma = 0.70$	$\mu = -3.49$, $\sigma = 0.56$	$\mu = -3.21$, $\sigma = 0.62$
5	$\mu = -2.48$, $\sigma = 0.86$	$\mu = -3.26$, $\sigma = 0.69$	$\mu = -3.42$, $\sigma = 0.49$	$k = 2.49$, $\theta = 0.02$
6	$\mu = -2.66$, $\sigma = 0.87$	$\mu = -3.00$, $\sigma = 0.85$	$k = 4.50$, $\theta = 0.01$	$\mu = -3.05$, $\sigma = 0.74$

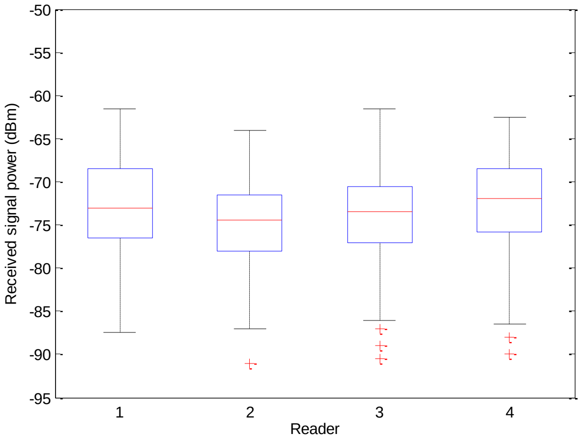


Fig. 6 Box plot showing the statistics of the received signal power in dBm for scenario 2.

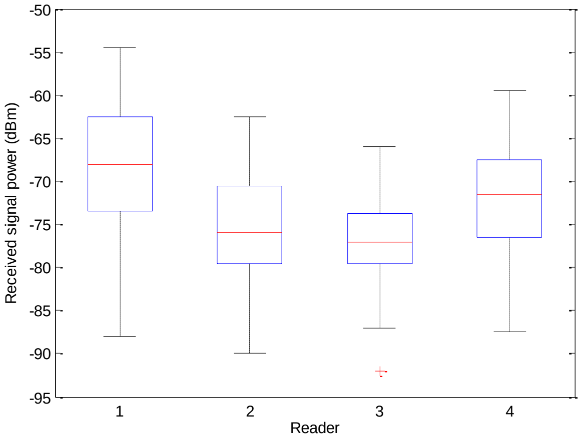


Fig. 7 Box plot showing the statistics of the received signal power in dBm for scenario 5.

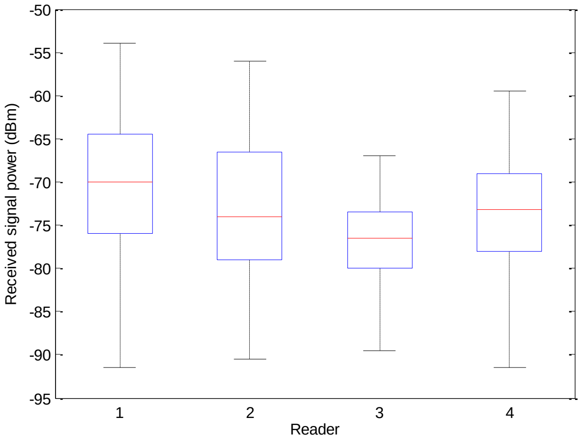


Fig. 8 Box plot showing the statistics of the received signal power in dBm for scenario 6.

B. *Scenarios 5 & 6 (Multiple point paths)*

In scenario 5, the test subject walked along the outside of the open office area environment closest to readers 1 and 4 and then along the centre path from points p_2 and p_5 before returning along this path. As the test subject was closest to readers 1 and 4, these two readers recorded the highest median received signal power albeit with greatest variation (Fig. 7). Readers 1 to 3 in this scenario recorded received signal amplitudes which were best described by the lognormal distribution, with reader 4 following the Gamma distribution.

During scenario 6, the test subject walked along the outside of the open office area environment. The statistics calculated for this scenario were similar to those for 5. Reader 1 in this scenario reported the greatest range (shown by the black whiskers in Fig. 8) of received signal power values over all of the experiments conducted in this study (>35 dB). The *AIC* selected the lognormal distribution for readers 1, 2 and 4, and the Gamma distribution for reader 3 in this scenario.

IV. CONCLUSIONS

The characteristics of the received signal for an indoor wearable RFID system have been presented. For the majority of scenarios where a test subject with a wrist-worn tag moves in a straight line path either normal or parallel to a set of RFID readers, the interquartile range of the received signal recorded at the RFID reader during the interrogation process was below 10 dB. A number of probability distributions commonly encountered in the modeling of wireless communications channels have been fitted to the data. Using the Akaike Information Criterion it was found that the lognormal distribution was favoured in the majority of scenarios considered in this study.

REFERENCES

[1] H. Hakim, R. Renouf and J. Enderle, “Passive RFID Asset Monitoring System in Hospital Environments,” *Proceedings of the IEEE 32nd Annual Northeast Bioengineering Conference*, pp.217-218, 2006

[2] W. P. L. Cully, S. L. Cotton, W. G. Scanlon and J. B. McQuiston, “Localization algorithm performance in ultra low power active RFID based patient tracking,” *to be presented at IEEE Personal, Indoor and Mobile Radio Conference (PIMRC)*, Toronto, September 2011.

[3] S. L. Cotton, G. A. Conway & W. G. Scanlon, “A time-domain approach to the analysis and modeling of on-body propagation characteristics using synchronized measurements at 2.45 GHz,” *IEEE Trans. Antennas & Propagation, Special Issue on Antennas & Propagation on Body-Centric Wireless Communications*, vol. 57, no. 4, pp. 943–955, Apr. 2009.

[4] S. L. Cotton & W. G. Scanlon, “Characterization and modeling of the indoor radio channel at 868 MHz for a mobile bodyworn wireless personal area network,” *IEEE Antennas & Wireless Propagation Letters*, vol. 6, pp. 51–55, 2007.

[5] A. J. Ali, W. G. Scanlon, and S. L. Cotton, “Pedestrian Effects in Indoor UWB Off-Body Communication Channels,” *Loughborough Antennas & Propagation Conf., Nov. 2010*, pp. 57-60.

[6] H. Akaike, “A new look at the statistical model identification,” *IEEE Trans. Automatic Control*, vol. 19, no. 6, pp. 716–723, Dec. 1974.

[7] A. Fort, C. Desset, P. De Doncker, P. Wambacq and L. Van Biesen, “An ultra-wideband body area propagation channel Model-from statistics to implementation,” *IEEE Transactions on Microwave Theory and Techniques*, vol. 54, no. 4, pp. 1820–1826, June 2006.