Modeling of the Influence of Body-Worn Antennas upon the Path Loss Variability in UWB WBAN Scenarios

Christophe Roblin[1,2] *and Alain Sibille*[2,1]

[1]ENSTA ParisTech, 32, Bd. Victor, 75739 Paris Cedex 15, France,
christophe.roblin@ensta-paristech.fr
[2]Télécom-ParisTech, 46 rue Barrault, 75013 Paris Cedex 13, France.
christophe.roblin@telecom-paristech.fr

Abstract

The achieved work on the propagation channel of Wireless Body Area Networks has reached today a significant level. However, a large dispersion of reported results, notably as regards Path Loss is observed, both in anechoic chamber and in indoor premises. This work is motivated by this context, the main objectives being on one hand to explain (at least partly) and on the other hand to reduce this dispersion. Measurements have been performed in an anechoic chamber with two human subjects over a 1–12 GHz frequency band. A comparative analysis of the Path Loss involving nine UWB antennas of various types is presented for the Hip-to-Chest and Hip-to-Wrist scenarios. A statistical analysis of the corresponding dataset with a parametric approach with respect to various UWB frequency bands, antenna distance from the body and arm position is exposed next. Parametric models depending on either parameter extracted for various bands, are finally provided. The main objective of is to reduce the variances of the resulting statistical models through a parametric approach and categorization of antennas.

1. Introduction

Wireless Body Area Networks (WBANs) have known a growing interest by the scientific and industrial communities in recent years, because of their potential applications in different domains such as health, surveillance, monitoring, sport, multimedia, entertainment, data transfer, etc. Since these wireless networks are implanted or body worn, they require specific investigations and optimizations under stringent constraints: the radiated power should be minimized because of regulation limits, mainly for public health and coexistence reasons, as well as the power consumption and device size, aspect ratio and weight. All these constraints are intimately related to the acceptability of such systems by future consumers. This is particular true at the antenna design level, which significantly impacts the radio link performance, notably via the channel behavior. In particular, detailed knowledge of the BAN channel is required to analyze and design properly systems at the PHY, MAC and Networking levels [1]. The on-body propagation mechanisms and channels have been already widely studied theoretically, experimentally (with human subjects or phantoms) and numerically. Models have been extracted from statistical analyses. However, among the numerous sources of variability of the channel, the characterization of antennas influence has not been yet carried out thoroughly enough (although partly tackled, e.g. in [2]–[4]): the purpose of this article is to contribute to clarify this matter with a more systematic approach. In section II, the context, motivation and objectives of the work are detailed. A comparative analysis of the measured Path Loss (PL) involving nine UWB antennas of various types is presented for two scenarios (Hip-to-Chest – *H2C* – and Hip-to-Wrist – *H2W*) in section 3. A statistical analysis of the dataset with a parametric approach with respect to various UWB frequency sub-bands and antenna distance δ from the body (and a few arm angle ϑ for the H2W scenario), and parametric models depending on δ or ϑ, extracted for various bands, are provided in section 3. Finally, conclusions and perspectives are drawn in section 4.

2. Context, motivation and objectives

It is reported in [6] that a very large dispersion of the results, notably as regards PL data and models are observed, both in anechoic chambers and in indoor premises [2]–[5], [7]–[17]. The reasons are manifold, but in particular antenna type and distance from the body play a key role.

Measurements have been performed in ENSTA-ParisTech anechoic chamber over a 1–12 GHz band. A few *scenarios Sc*, two human subjects *S*, several antenna types, the frequency *f*, the antenna-body separation distance δ, a micro-positioning μ (around a "Scenario location"), and a "fast multi sweep" parameter *s*, have been considered. The Channel Transfer Functions (CTF) are directly the measured $S_{21}^{a}(Sc, f, S, Ant, \delta, \vartheta, \mu, s)$ parameters.

978-1-4244-6051-9/11/$26.00 ©2011 IEEE

The strong influence of the proximity of a "human subject" on the behavior of body-worn antennas appears significantly different in narrowband (NB) and in UWB. In both cases, the near field coupling to the body modifies antenna currents, impacting the input matching, and induces energy absorption. However, in NB, the dominant effect, and major drawback, is the shift of the resonance frequency causing a (strong) mismatch resulting in the collapse of the total efficiency (including losses inside the body). Conversely, in UWB, the proximity of the body often improves the matching (generally increasing the bandwidth) for two reasons: first losses favor the matching (lowering the S_{11} amplitude more or less as a whole); second, the high permittivity of the human tissues, acting as a sort of additional substrate (in particular for planar tangent antennas without "screening isolation") tends to shift-down the band. The consequence is that much attention should be paid first to the matching aspects in NB. In UWB, even though impedance matching is important, the true performance indicator– aiming eventually the channel characterization and radio link performance – should be found directly in the transmission characteristics. This is why, particularly in UWB, any analysis of body-worn antennas shouldn't be separated from the channel study.

Several types of UWB antennas, with a priori different behaviors, in particular in the vicinity of a human subject, have been identified, taking into account the antenna principal polarization (P) with respect to the body surface: 1. Balanced planar or quasi-planar (tangent P), 2. Grounded low profile thick monopole-like or monocone-like (normal P), 3. Planar or quasi-planar monopole-like, nor balanced, nor clearly grounded (tangent P), 4. Chip (Ceramic, LTCC, etc.), SMC soldered on small RF boards (tangent P); generally commercial, 5. Magnetic planar or quasi-planar, "slot-like" (tangent P), 6. Magnetic (low profile) loops (normal P). The first four were available at ENSTA-ParisTech to perform WBAN measurements. The purpose of this classification is not only to try to cover a small but representative "population" of antennas – credible from the applicative point of view –, but corresponds to various electromagnetic behaviors, precisely: 1. Small/medium size antennas, nor balanced nor clearly grounded, are prone to strong cable effects due to common mode currents (effects which are of course undesirable during the measurement process, as they won't exist in the applicative systems), 2. These antennas are also particularly sensitive to the proximity influence of strong scatterers, such as the human body, 3. Balanced antennas are much less sensitive to the common mode effect and measurements have shown that they are also less sensitive to the proximity effect, 4. Grounded antennas are almost insensitive to the common mode, and are considerably less sensitive to the body proximity when the ground is tangent to the body, isolating the radiating part by field screening. This is also true for any other field screening technique, such as inserting a ferrite sheet (or any absorbing material) between the radiating element and the body. All these considerations have consequences regarding both the measurement methodology and protocol and the parametric/statistical characterization and modeling.

The first objective is to reduce the dispersion of the results due to the measurement procedure itself. A rigorous measurement methodology, in particular based on a precise protocol is adopted for this purpose [18]. The main objective of a parametric approach is to reduce the variances of the resulting statistical models. It is fully in line with the "spirit" of the scenario-based approach which is also, wide sense, a sort of parametric modeling. The ultimate goal, not yet achieved, is to integrate these parametric models into a more general dynamic model.

3. Results

As a first step, the analyses have been restricted to the anechoic chamber environment so as to "separate" the problems. Two scenarios, H2C and H2W, have been investigated. Nine antennas have been considered and (at most) seven distances $\delta \in \{3, 5, 7, 9\ 12, 16, 20\}$ mm from the body: the DFMS (Dual-Fed Monopole in Stripline technology), DFMM (Dual-Fed Monopole in Microstrip technology), DFMM-DL (DFMM with a Dielectric "Lens"), PBD (Planar Balanced Dipole), Taiyo Yuden, PLPDA (Planar Log-Periodic Dipole Antenna), ALVA and "Staircase Monopole" (Fig. 1). The typical −6 dB matching BW of these antennas range between 2 – 3.5 GHz and 8.5 – 11 GHz. The DFMM-DL is chosen as an example (Fig. 1).

First a parametric analysis for the H2C scenario, considered antennas, distance to the body and standard sub-bands, for two human subjects is achieved. The means and standard deviations are computed for the two subjects. A particular distinction between tangent and normal polarization is highlighted. It appears clearly from these analyses that: 1. The staircase monopole is always the "winner", whatever the parameters. This antenna is normally polarized and benefit from a screening effect due to its ground plane. Moreover, its behavior is almost independent of δ, 2. The general trend (except for the former) is an increase of Path Gain (*PG*) as function of δ, 3. Generally, the higher the band, the higher the PL, 4. Although the statistical sample is extremely low (two subjects), it appears that the "population variability" can be very significant, typically a few dBs, but up to 15–20 dB for some cases, 5. Last, antennas are as well even a stronger source of variability: up to 30 dB! 6. The frequency behavior is mainly due to antennas, 7. Frequency trends are the same for the 2 individuals. The H2W scenario is analyzed in the same way although it is focused on the shadowing effect of the arm posture which appears to be generally dominant.

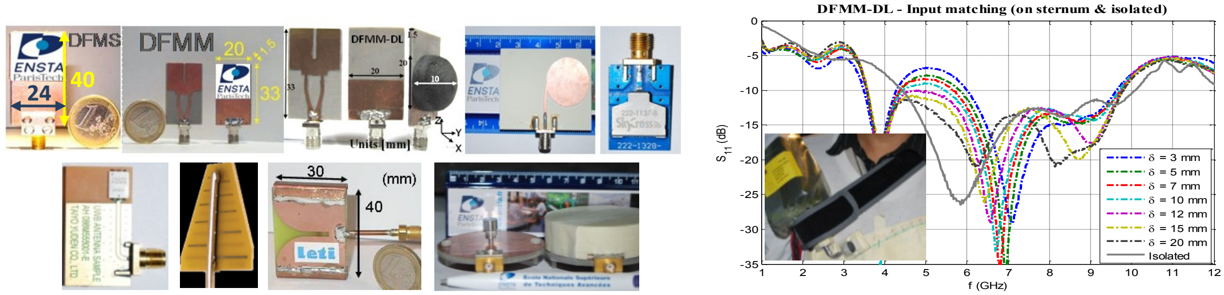

Fig. 1. The 9 analyzed UWB antennas (left); DFMM-DL isolated and on-body input matching (right).

The empirical statistics and models of the PL over the three bands of interest (3.1 – 4.8, 6 – 8.5 and 3.1 – 10.6 GHz) with δ as parameter, and for: 1. aggregated data, over four (quasi)-planar tangent antennas (DFMS, DFMM, Skycross® and Taiyo Yuden®), 2. the PBD, 3. the PLPDA, 4. the ALVA, and 5. the Staircase monopole antennas are computed and given for the cases 1 and 5 (Fig. 2) over the 1st band.

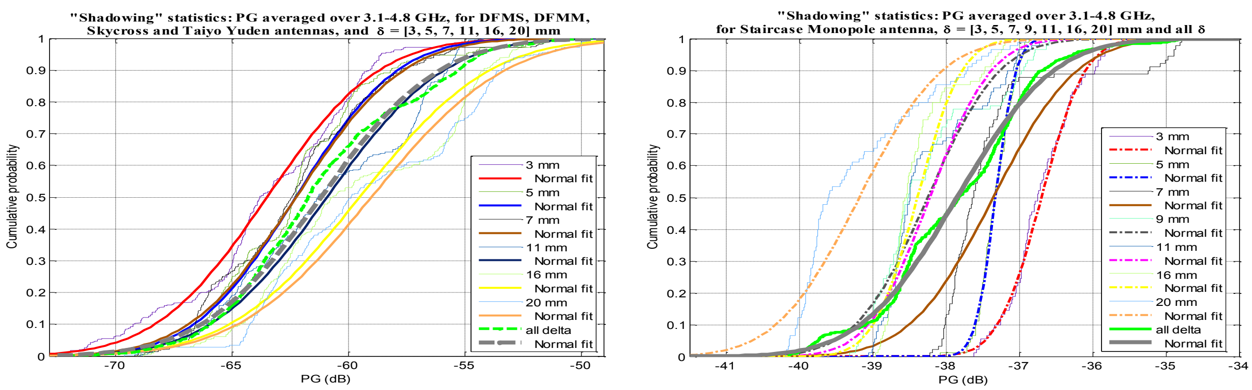

Fig. 2. H2C: Empirical statistics and models of the PL for aggregated data over (quasi-)planar tangent antennas (left) and the Staircase monopole (right) with δ as parameter. First band 3.1 – 4.8 GHz.

All the fitted models are normally distributed, although the normality is sometimes dubious and better models can be found for several cases. The purpose is however simplicity of modeling under at least an acceptable accuracy. For each case, an "aggregated model", irrespective of δ is also provided. It is particularly useful for the cases for which the PL is weakly dependent on δ, for example, for the ALVA, and particularly for the staircase monopole. The good PG of the PBD is due to its balanced nature and good matching, the PG almost independent of δ of the ALVA is due to its ground plane screening effect and its correct PG is due to its balanced nature, the good PG of the PLPDA, despite its very poor matching, is due to its directivity, and the very good PG of the staircase monopole is due to its normal polarization (TE polarization, "matched" to the creeping wave mode) and finally, the quasi-independence of its PG of δ is due to the strong screening effect of its ground plane. Finally a linear model of the mean PG ($PG_0(\delta) = PG_{00} + \kappa\delta$) for each "antenna type" and the three bands is proposed (Table I).

TABLE I
HIP-TO-CHEST: MEAN PATH GAIN LINEAR FITS ($PG_0(\delta) = PG_{00} + \kappa\delta$)

Subject1†	Monopole-like‡		PBD		ALVA		PLPDA		Staircase M.	
Band (GHz)	PG_{00}	κ (mm^{-1})	PG_{00}	κ (mm^{-1})	PG_{00}	κ (mm^{-1})	PG_{00}	κ (mm^{-1})	PG_{00}	κ (mm^{-1})
3.1 - 4.8	-64.26	0.2706	-60.66	0.4434	-61.08	0.1110	-60.79	0.6385	-36.56	-0.1339
6 - 8.5	-64.31	0.2288	-58.23	0.509	-61.58	0.1388	-64.49	0.6128	-44.56	-0.2238
3.1-10.6	-64.78	0.2577	-60.47	0.5280	-62.26	0.1259	-62.41	0.5859	-41.06	-0.1601

† Male: h = 1.83 m, m = 83 kg, BMI = 24.77 kg/m². ‡ "Monopole-like" = {DFMS, DFMM, Skycross, Taiyo Yuden}

The PL empirical statistics and models of the H2W scenario in the same conditions as above, but with ϑ as parameter, are given Fig. 3.

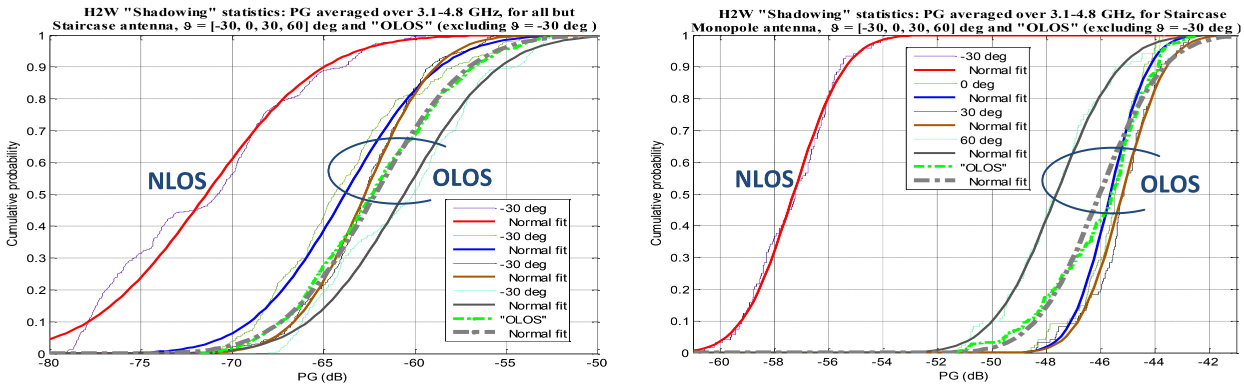

Fig. 3. H2W: Empirical statistics and models of the PL for all but Staircase antennas (left) and Staircase monopole (right) with ϑ as parameter. First band 3.1 – 4.8 GHz.

4. Conclusion

Statistical models with a parametric approach regarding antenna types, distance from the body and posture has been proposed for the H2C and the H2W scenarios. This approach reduces significantly the variances with respect to "agglomerate" models. Further work will consist in completing the modeling with other useful scenarios (such as Hip to Foot, etc.) and, more important, to integrate these models into more general, notably *dynamic*, models.

7. References

[1] M. Maman, F. Dehmas, R. D'Errico, and L. Ouvry, "Evaluating a TDMA MAC for Body Area Networks Using a Space-Time Dependent Channel Model," in *Proc. of IEEE 20th International Symposium on Personal, Indoor and Mobile Radio Communications (PIMRC 2009)*, Tokyo, Japan, pp. 2101–2105, Sept. 2009.

[2] IEEE P802.15-08-0780-09-0006 (K. Y. Yazdandoost and K. Sayrafian-Pour), "Channel Model for Body Area Network (BAN)," IEEE 802.15 Working Group 6 Document, April 2009.

[3] P. S. Hall and Y. Hao, Ed., Antennas and Propagation for Body-Centric Wireless Communications, Artech House, 2006.

[4] H. Ghannoum, S. Bories, R. D'Errico, "Small-size UWB planar antenna and its behaviour in WBAN/WPAN applications," in *Proc. of IEE Seminar on Ultra Wideband Systems, Technologies and Applications*, London, Apr. 20, 2006.

[5] A. Alomainy, Y. Hao, C. G. Parini, and P. S. Hall: *UWB on-body radio propagation and system modelling for wireless body-centric networks,* IEE Proc.-Comm., vol. 153, n° 1, Feb. 2006.

[6] C. Roblin, R. D'Errico, J.M. Gorce, J.M Laheurte and L. Ouvry, "Propagation channel models for BANs: an overview," *COST 2100*, Braunschweig , Germany, 16-18/02/2009.

[7] IEEE P802.15-04-0662-02-004a (A. F. Molish *et al*.), "IEEE 802.15.4a channel model – Final report", Nov. 2006, http://www.ieee802.org/15/pub/TG4a.html.

[8] A. F. Molisch, D. Cassioli, C. Chong, S. Emami, A. Fort, A. Kannan, J. Karedal, J. Kunish and H. G. Schantz, "A Comprehensive Standardized Model for Ultrawideband Propagation Channels," *IEEE Transactions on Antennas and Propagation*, vol. 54, n° 11, Nov. 2006.

[9] T. Zasowski, G. Meyer, F. Althaus and A. Wittneben, "Propagation Effects in UWB Body Area Networks," *in Proc. of 2005 IEEE International Conference on Ultra-Wideband*, Zurich, 5-8 Sept. 2005.

[10] A. Fort, C. Desset, P. De Doncker, P. Wambacq and L. Van Biessen, "An Ultra-Wideband Body Area Propagation Channel Model–From Statistics to Implementation," *IEEE transactions on MTT*, vol. 54, n° 4, April 2006.

[11] A. Fort, C. Desset, J. Ryckaert, P. De Doncker, L. Van Biessen and S. Donnay, "Characterization of the Ultra Wideband Body Area Propagation Channel," *in Proc. of 2005 International Conference on Ultra-Wideband*, Zurich, 5-8 Sept. 2005.

[12] A. Fort, J. Ryckaert, C. Desset, P. De Doncker, P. Wambacq and L. Van Biessen, "Ultra-Wideband Channel Model for Communication Around the Human Body," *IEEE JSAC*, vol. 24, n° 4, April 2006.

[13] J. Ryckaert, P. De Doncker, R. Meys, A. de Le Hoye and S. Donnay, Channel model for wireless communication around human body," *Electronics Letters*, vol. 40, n°. 9, 29th april 2004.

[14] S. V. Roy, C. Oestges, F. Horlin and P. De Doncker, "On-body propagation velocity estimation using ultra-wideband frequency-domain spatial correlation analysis," *Electronics Letters*, vol. 43, n° 25, Dec. 2007.

[15] P. S. Hall, Y. Hao, Y. I. Nechayev, C. Constantinou, C. Parini, M. R. Kamarudin, T. Z. Salim, D. T. M. Hee, R. Dubrovka, A. S.Owadally, W. Song, A. Serra, P. Nepa, M. Gallo, and M. Bozzetti,: "Antennas and Propagation for On-Body Communication Systems," *IEEE AP Mag*., vol. 49, n° 3, June 2007.

[16] S. L. Cotton and W. G. Scanlon, **"**A Statistical Analysis of Indoor Multipath Fading for a Narrowband Wireless Body Area Network," *Personal Indoor and Mobile Radio Communications*, 2006 IEEE.

[17] S. L. Cotton and W. G. Scanlon, **"**A Higher Order Statistics for Lognormal Small-Scale Fading in Mobile Radio Channels," *IEEE Antennas and Wireless Propagation Letter*, vol. 6, 2007.

[18] Ch. Roblin and N. Malkiya, "Parametric and statistical analysis of UWB BAN channel measurements", COST 2100, Athens, Greece, 3–5 Feb. 2010.

[19] http://www.banet.fr