UWB Channel for Wireless Body Area Networks at Hospital

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***Abstract*—Wireless body area networks (WBAN) are expected to be a breakthrough in healthcare, leading to concepts like “telemedicine” becoming real, since the sensor nodes in WBANs, communicating through wireless technologies, can transmit data from the body to a home base station, from where the data can be forwarded to a hospital, clinic or elsewhere, real-time. WBANs have not only the potential to increase the quality of the medical care but also to keep under control the associated costs. The characteristics of radio propagation, in the case of WBANs, is expected to be distinct from the ones found in other environment, since the human body has a complex shape and consists of different tissues. In a reality, patients have various levels of mobility, e.g. walking, wheelchairing, eating, etc. It is a fact that for most medical conditions patients are encouraged to walk or move as much as they can tolerate in order to improve their recovery. The fluctuations of the radio channels in the proximity of a human body under dynamic situations should then be well understood for proper design of these body are networks. Our contribution in this paper is to elaborate the knowledge of the ultra-wideband (UWB) channel in the frequency range of 3.1-10 GHz, for the case of WBANs, in real hospital environments under both static and dynamic scenarios.**

I. Introduction

Wearable health monitoring systems integrated into a telemedicine system supporting early detection of abnormal conditions and prevention of its serious consequences have been experiencing continuous developments and improvements during recent years [1]. Many patients can benefit from continuous monitoring as a part of a diagnostic procedure, maintenance of a chronic condition or during supervised recovery from an acute event or surgical procedure. Such a technology can increase the level of comfort and mobility of the patient as well as has also the potential to reduce costs by decreasing the need of having medical personal in close proximity to patients at all times. Recent advances in wireless technology have led to the development of wireless body area networks (WBAN), where a set of compact intercommunicating sensors are either wearable or implanted into the human body, which monitor vital body parameters and movements [2]. By measuring the vitals and transmitting them to a control node or station, a WBAN allows for continuous monitoring of the patients’ health status without the burden of wires attached to their bodies or frequent visits by medical personal. Ultra-wideband (UWB) communications is a promising technology for WBAN due to its particular characteristics [3, 4]. The monitoring of vitals and movements requires a relatively low data rate which in the case of UWB translates into very small transmitting power requirements, i.e. longer battery life. This is a very desirable feature for devices that are going to be close to the body and meant to be used for extended periods of time. The design of UWB transmission systems requires a good understanding the corresponding radio propagation channel, which vary from one environment to another. For the case of indoor and outdoor scenarios comprehensive studies of the UWB propagation channel have been performed in recent years [3, 5, 6]. It is natural to expect that the channel characteristics for those cases will be different than the ones found in WBAN scenarios due to the effect of the human body with its complex shape and different tissues, each with a different permittivity. UWB measurements around the human body have been carried out by various researchers [7-9]. However, these experiments have been limited to scenarios that are questionable for most medical applications. Experimental measurements under conditions more likely to be approved in the medical care field was done in [10, 11]. UWB indoor measurements and modellings in a hospital environment were done in [12]. However, the effect of human body was not included in their study.

In this paper, we contribute in experimental measurements in real hospital environments under both static and dynamic conditions, namely, body movement in the scenarios which most likely happen in the medical care field. This is a continuation of the other works done in an anechoic chamber as a reference point and in a classroom [10, 11]. Comparing to the results in the classroom, we can see if the presence of the medical equipments or devices has any effect. The scenarios under consideration include the radio links between sensor nodes themselves and between a sensor node to a UWB control node or gateway few meters from the body [3], e.g., on a wall or the ceiling as shown in Fig. 1. The measurements obtained in this study are used to estimate the channel parameters needed to build mathematical models that can be used in WBAN medical applications.

II. Channel Measurement Setup and Scenarios

The channel measurement system described in this paper consists of an HP Agilent 8720ES [13], a vector network analyzer (VNA), SkyCross SMT-3TO10M-A antennas [14], 5-m long SUCOFLEX® RF cables [15] with 7.96 dB loss and a control computer with LabVIEW™ 7 software. The

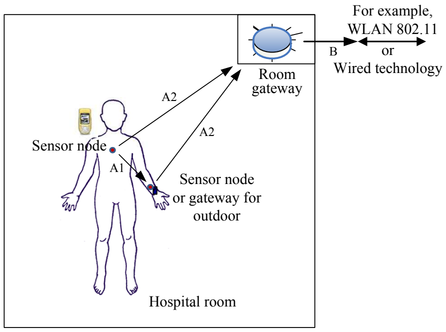

Fig. 1. Channel links in wireless medical communications: (A) the WBAN channels: (A1) the channels between sensor nodes themselves or (A2) the channels from sensor nodes to a gateway, (B) the channel from a gateway to some other wireless networks.

antennas are azimuthally omni-directional with their radiation patterns as shown in [14]. The VNA is operated in a transfer function measurement mode, where port 1 and port 2 are the transmitting and the receiving ports, respectively. This corresponds to a S_{21}-parameter measurement set-up, where the device under test (DUT) is the radio channel. The frequency band used in the measurements is from 3.1 GHz to 10 GHz, which is the entire frequency range of the antennas. Therefore, the bandwidth B is 6.9 GHz. The maximum number of frequency points per sweep M is 1601, which can then be used to calculate the maximum detectable delay $\tau_{\max}$ of the channel as

$$\tau_{\max} = (M-1)/B. \tag{1}$$

Using (1), the maximum detectable delay, $\tau_{\max}$ of the channel is 231 ns, which corresponds to 69.3 m in free space distance. Here we are interested in the first 20 ns, i.e., at most 6 m away from the body. We have learnt in [10-11] that the radio link is significantly improved with a dielectric separation between the body and the antennas. Therefore, a 1.2 cm dielectric separation is applied for the entire experiments in this paper. The measurements setups are designed with more realistic scenarios in mind. This means that the number of antennas near the body should be small. Also, only comfortable locations on the body where to place the antennas are selected. In addition, the transmit (Tx) power is 1 mW (0 dBm) according to Bluetooth class 3 radiation.

The UWB channel measurement experiments were conducted in hospital environments. The measurements were taken at three different places, i.e., in a regular hospital room with the size of 6.3 m×7.2 m×2.5 m as shown in Fig. 2, along a corridor, and in a surgery room. Both radio links A1 (between sensor nodes) and A2 (between a sensor node and a room gateway) defined in Fig. 1 were done for each place. In the regular room and along the corridor, dynamic measurements emulating the mobility of a patient were conducted, whereas the patient is supposed to still lay down in a surgery room. All measurements of each scenario in the hospital are compared to the ones done in an anechoic

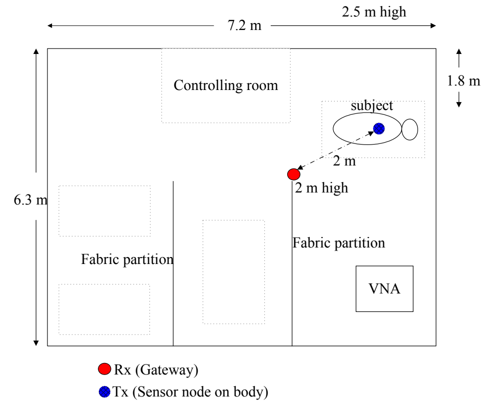

Fig. 2. Floor plan of a regular hospital room, where the $1^{\text{st}} - 3^{\text{rd}}$ sets of measurements was conducted..

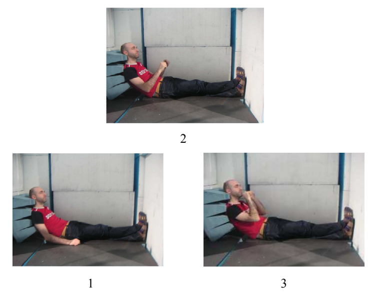

Fig. 3. Arm movements in a laying down position emulating, e.g., having a meal on the patient bed.

chamber.

The 1^{st} set of measurements study the radio link A1 when a subject is laying down on a bed in the regular room as illustrated in Fig. 2. The receive (Rx) antenna was at the middle front of the torso and the Tx antenna was placed on the left hand wrist. These locations are comfortable for most

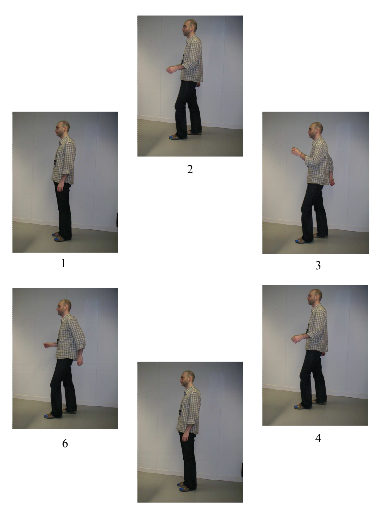

Fig. 4. Each position of a walking cycle.

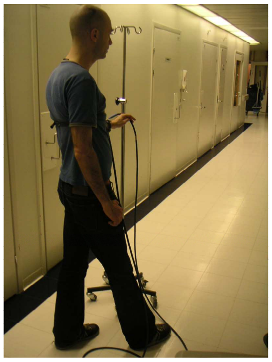

Fig. 5. A corridor, where the 4^{th} set of measurements was conducted.

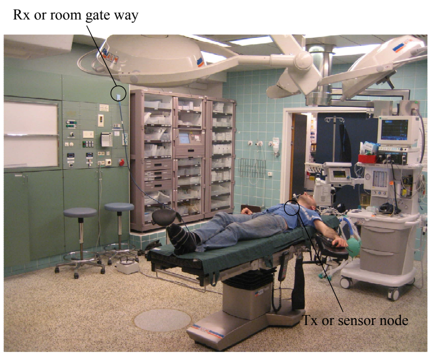

Fig. 6. A surgery room, where the 5^{th} set of measurements was conducted.

patients and they are potential places for antennas/transceivers connected to electrocardiogram (ECG) sensors and a pulse oximeter. We also investigate when the subject is laying down and is moving his arm during having a meal as illustrated in Fig. 3. Considering that a single frequency domain measurement in the 3.1-10 GHz band lasts for several seconds, a real-time measurement of the radio channel fluctuations due to the body movement is not technically feasible over a frequency band of several GHz. Instead, a pseudo-dynamic measurement method was applied, where each position of the patient's arm was keeping still for a measurement duration (e.g. 100 snapshots in our measurements).

The 2^{nd} set of measurements study the radio link A2 for the same laying down position, where the Rx antenna was placed on a 2-m high pole locating 2 m away from the subject and the Tx antenna was on the left hand waist. The arm movement measurements are also included.

In the same room, a pseudo-dynamic measurement method emulating a walking cycle as illustrated in Fig. 4 was applied in the 3^{nd} set of measurements.

Fig. 5 shows the 4^{th} set of measurements along a corridor. Both situations when a patient walks with and without drippole were taken.

Finally, the 5^{th} set of measurements was done in a surgery as depicted in Fig. 6, where the medical equipments can be turned on or off.

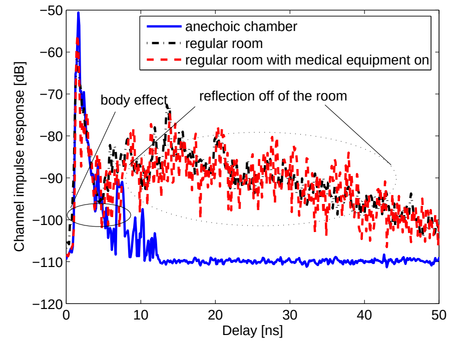

Fig. 7. The average channel impulse responses of the 1^{st} set of measurements, when the subject is laying down in a regular hospital room. The Rx antenna and the Tx antenna are at the middle front of the torso and at the left hand wrist, respectively.

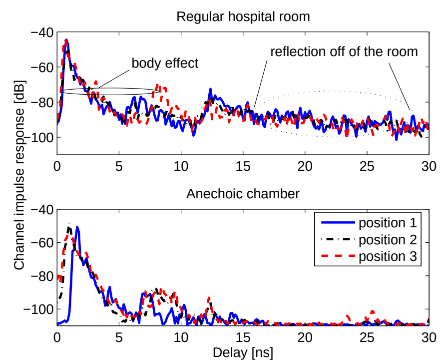

Fig. 8. The average channel impulse responses of the 1^{st} set of measurements, when the subject is laying down and having a meal in a regular hospital room. The Rx antenna and the Tx antenna are at the middle front of the torso and at the left hand wrist, respectively.

III. Results Analysis

One hundred individual realizations of the channel impulse responses were measured and averaged for each position. Fig. 7 shows the average channel impulse responses in the 1^{st} set in the static case. The effects of human body and environment can be separately seen. The energy of these responses during the human body effect laying on the first 15-20 ns decays rapidly, whereas the reflections off of the hospital room cause a large number of multipath components afterwards. This is different from the UWB indoor measurements in a hospital environment presented in [12], which provides channel parameters corresponding to the modified Saleh-Valenzuela (SV) model in time domain and autoregressive (AR) model in frequency domain extracted from the measurement data, since the human body is not taken into account in their study. In addition, the multipath components get faster fluctuated when the medical equipments are turned on. The variability in amplitude and delay of the wave of each arm position pointed out in Fig. 8 can cause severe problems in cross layer including medium access control (MAC) design. There is a bit longer delay of the first arriving wave in the position one than in the other two positions since the Tx antenna is farther

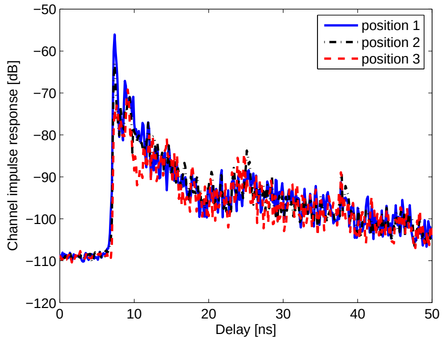

Fig. 9. The average channel impulse responses of the 2^{nd} set of measurements, when the subject is laying down and having a meal in a regular hospital room. The Rx antenna and the Tx antenna are placed on a 2-m high pole locating 2 m away from the subject and on the left hand waist, respectively.

from the Rx antenna. However, the difference is small in the regular hospital room. The difference is even insignificant as seen Fig. 9 in the scenario when the Rx antenna and the Tx antenna are placed on a 2-m high pole locating 2 m away from the subject and on the left hand waist, respectively. Moreover, since the radio link A2 is distant from the human body, the effects of human body and environment are not clearly devided. Fig. 10 shows the average channel impulse responses of the 3^{rd} set of measurements, when the subject is standing in a regular hospital room. The Rx antenna and the Tx antenna are at the middle front of the torso and at the left hand wrist, respectively. Likewise to the 1^{st} set of measurements, the effects of human body are seen first and the multipath components from the reflections off of the hospital room come later. This is compared to the measurements done in an anechoic chamber and a class room. As we can see, the environment in the regular hospital room gives more scattering and reflections than in the classroom. Fig. 11 shows the average of the magnitude of the channel impulse responses of each position in a walking cycle in the 3^{rd} set. As we can see, the arm movement during a walking cycle has a significant impact on radio link from the Tx antenna on the left wrist to the Rx antenna at the middle front of the torso. For instance, when the left hand moves to the uppermost position 3 in Fig. 4, the strongest path arrives earlier than in the other positions due to the shorter distance between both antennas. There are also more significant paths due to the reflections of the wave out of the arm and the shoulder. The shadowing due to blocking of the body is shown in the position 6, where the left hand moves to the lowermost position. After 15-20 ns, the reflections off of the hospital room appear.

Unlike in a regular room, more additional peaks due to the reflection of the corridor in a corridor environment arise as plotted in Fig. 12. Moreover, the drippole causes faster fluctuation of multipath components.

Fig. 13 shows the average channel impulse responses of the 5^{th} set of measurements, when the subject is laying down in a surgery room. The Rx antenna and the Tx antenna are placed on a 2-m high pole locating 2.5 m away from the subject

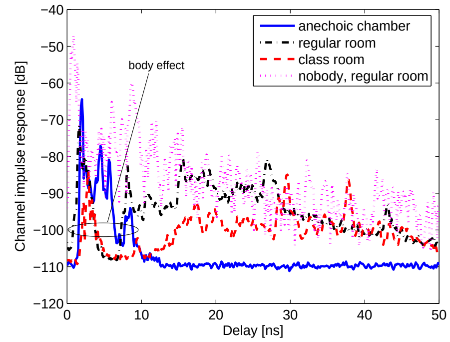

Fig. 10. The average channel impulse responses of the 3^{rd} set of measurements, when the subject is standing in a regular hospital room. The Rx antenna and the Tx antenna are at the middle front of the torso and at the left hand wrist, respectively.

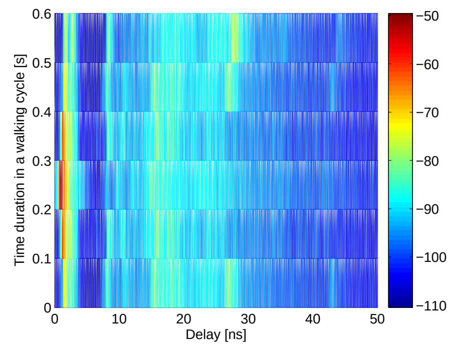

Fig. 11. The magnitude of the channel impulse responses of each position in a walking cycle in a regular hospital room. The Rx antenna and the Tx antenna are at the middle front of the torso and at the left hand wrist, respectively.

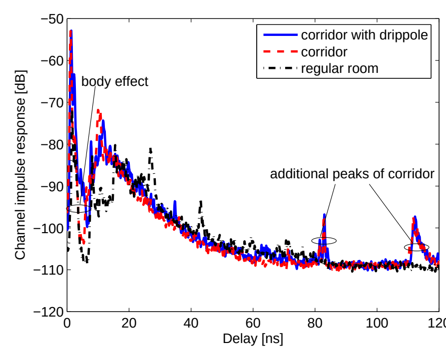

Fig. 12. The average channel impulse responses of the 4^{th} set of measurements, when the subject is standing in a corridor and a regular hospital room. The Rx antenna and the Tx antenna are at the middle front of the torso and at the left hand wrist, respectively.

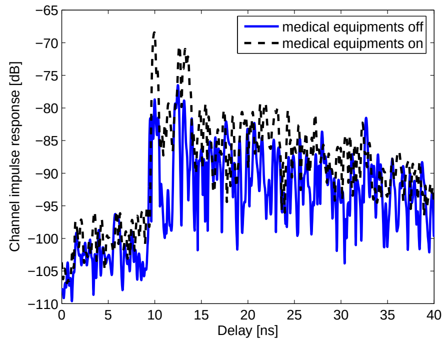

Fig. 13. The average channel impulse responses of the 5^{th} set of measurements, when the subject is laying down in a surgery room. The Rx antenna and the Tx antenna are placed on a 2-m high pole locating 2.5 m away from the subject and on the left hand waist, respectively.

TABLE I
RMS DELAY SPREAD τ_{RMS} OF THE MEASUREMENTS.

Measurement Scenario	**RMS delay spread**	
	Mean [ns]	Std [ns]
A1: Standing in anechoic chamber	0.11	0.05
in class room	8.02	0.89
in regular hospital room	8.86	1.42
in corridor	9.51	0.11
in corridor with drippole	9.50	0.25
A1: Laying down in anechoic chamber	0.08	0.01
in regular hospital room	9.22	0.62
in surgery room	7.57	0.53
A2: Standing in anechoic chamber	0.09	0.02
in regular hospital room	9.86	0.50
in corridor	10.43	0.14
in corridor with drippole	10.49	0.24
A2: Laying down in anechoic chamber	0.19	0.06
in regular hospital room	10.29	0.50
in surgery room	8.65	0.24

and on the left hand waist, respectively. As can be seen, the multipath components get faster fluctuated and their amplitude get higher when the medical equipments are turned on.

In addition, we evaluate the delay dispersion within the radio channel in terms of root mean square (RMS) delay spread τ_{RMS}. To calculate it, all measured channel impulse responses are first truncated above the noise threshold set to four times of the noise standard deviation, i.e., -108.2 dB. The dynamic range varies depending on the different cases of the measurements. The means μ and standard deviations σ of the RMS delay spreads of the channel links A1 and A2 are summarized in Table I.

IV. Conclusions

We have conducted a series of UWB WBAN measurements in the frequency range of 3.1-10 GHz at real hospital environments. The measurements were taken at three usually important places in hospitals, i.e., in a regular hospital room, along a corridor, and in a surgery room. The effects of human body and environment were separately seen. The energy of these responses during the human body effect laying on the first 15-20 ns decays rapidly, whereas the reflections off of the hospital room cause a large number of multipath components afterwards. This is differ from the typical UWB indoor measurements, where the effects of human body are not included. In a reality, patients have various levels of mobility, e.g. walking, wheelchairing, eating, etc. It is a fact that for most medical conditions patients are encouraged to walk or move as much as they can tolerate in order to improve their recovery. The fluctuations of the radio channels in the proximity of a human body under dynamic situations should then be well understood for proper design of these body are networks. A pseudo-dynamic measurement method was applied since a real-time measurement of the radio channel fluctuations due to the body movement is not technically feasible over a frequency band of several GHz. In addition, the medical equipments in hospitals can affect more or less the radio propagation characteristics.

References

[1] State-of-the-Art Telemedicine/Telehealth: An International Perspective. Mary Ann Liebert, Inc., 2 Madison Avenue, Larchmont, NY 10538.

[2] P. Coronel, W. Schott, K. Schwieger, E. Zimmermann, T. Zasowski, H. Maass, I. Oppermann, M. Ran, and P. Chevillat, “Wireless body area and sensor networks,” in *Proc. Wireless World Research Forum (WWRF) Briefings*, Dec. 2004.

[3] R. J. Cramer, R. A. Scholtz and M. Z. Win, “An Evaluation of the Ultra-Wideband Propagation Channel,” *IEEE Trans. Antennas Propagation*, vol. 50, no. 5, pp. 561-570, May 2002.

[4] S. Gezici and Z. Sahinoglu, “Theoretical Limits for Estimation of Vital Signal Parameters Using Impulse Radio UWB,” *IEEE Communications Society subject matter experts for publication in the ICC 2007 proceedings*, 2007.

[5] S. S. Ghassemzadeh and V. Tarokh, “The ultra-wideband indoor path loss model,” Tech. Rep. P802.15 02/277r1SG3a, AT&T Labs, Florham Park, NJ, USA (IEEE P802.15 SG3a contribution, June 2002).

[6] B. Kannan et al., “Characterization of UWB Channels: Large-scale parameters for indoor and outdoor office environment,” IEEE P802.15 Working Group for Wireless Personal Area Networks (WPANs) (IEEE 802.15-04-0383-00-04a, July 2004).

[7] A. Alomainy, Y. Hao, Y. Yuan, and Y. Liu, “Modelling and Characterisation of Radio Propagation from Wireless Implants at Different Frequencies,” in *Proc. European Conference on Wireless Technology*, Sep. 2006.

[8] T. Zasowski, F. Althaus, M. Stäger, A. Wittneben, and G. Tröster, “UWB for noninvasive wireless body area networks: channel measurements and results,” in *Proc. IEEE Conference on Ultra Wideband Systems and Technologies (UWBST)*, Nov. 2003.

[9] A. Fort, C. Desset, J. Ryckaert, P. De Doncker, L. Van Biesen, and P. Wambacq, “Characterization of the ultra wideband body area propagation channel,” in *Proc. International Conference ICU*, pp. 22-27, 2006.

[10] A. Taparugssanagorn, C. Pomalaza-Ráez, A. Isola, R. Tesi, M. Hämäläinen, and J. Iinatti, “UWB Channel Study for Wireless Body Area Networks in Medical Applications,” submitted to *IEEE Trans. Information Technology in BioMedicine*.

[11] A. Taparugssanagorn, C. Pomalaza-Ráez, A. Isola, R. Tesi, M. Hämäläinen, and J. Iinatti, “UWB Channel Modelling for Wireless Body Area Networks in Medical Applications,” in *Proc. International Symposium on Medical Information and Communication Technology (ISMICT)*, Feb. 2009.

[12] L. Hentilä, A. Taparugssanagorn, H. Viittala, M. Hämäläinen, “Measurement and modelling of an UWB channel at hospital,” in *Proc. IEEE International Conference ICU*, 16-20 May 2005.

[13] http://www.alliancetesteq.com/.

[14] http://skycross.com/Products/PDFs/SMT-3TO10M-A.pdf.

[15] http://www.hubersuhner.com.