P-Rake Receivers in Different Measured WBAN Hospital Channels

Ville Niemelä, Matti Hämäläinen, *Senior Member*, IEEE,
Jari Iinatti, *Senior Member*, IEEE, Attaphongse Taparugssanagorn, *Member*, IEEE
Centre for Wireless Communications
University of Oulu
Oulu, Finland
firstname.lastname@ee.oulu.fi

***Abstract*—In wireless applications, power consumption has been, and will be, one of the important characteristics when designing any wireless device. This is the case especially in sensor networks where a single sensor may be functioning, hopefully for very long time, without external power source. Generally, the architecture complexity reduces the battery life, but the performance increases with complexity. The best performance is achieved with the most complex devices which, however, consume a lot of power. Rake receivers can offer a good trade-off between complexity and performance. In the near future, due to the aging of population, personal medical applications are most likely increasing in number and gaining more attention in industry. This paper presents simulation results for IEEE 802.15.4a ultra wideband (UWB) rake receivers in measured hospital channel. Oulu University Hospital in Oulu, Finland, was the location of the wireless body area network (WBAN) channel model measurements.**

I. INTRODUCTION

Developed countries especially are facing challenges in the coming years due to the aging of population. For a medical sector, this means continuous improvement seeking. Wireless communication is seen as one potential way on helping to face the challenges of the aging population. [1] Studies show that the environment is effecting on the propagation of an ultra wideband (UWB) signal [2-3]. The human body with complex shapes and different tissues, each with different permittivity, has also an impact on the propagation [4-5]. These two aspects are combined in a wireless sensor network attached onto a human body. The body is impacting the wireless transmission and typical human is moving around in different environments. On top of this, a good trade-off between complexity and battery life should be found for different applications. Generally coherent receivers consume more energy than non-coherent ones but there are ways to make coherent receivers less complex and less power consuming. [6]

A rake receiver collects different multipath propagated signal components and coherently combines these in order to form a complete replica of a transmitted signal. There exist different complexity rake receivers. An all-rake (a-rake) sums up all the multipath components and in theory, collects all the signal energy. A-rake is the most complex and power consuming type of the rakes. Selective-rake (s-rake), on the other hand, collects the *n* strongest multipath propagated signal components and sums them up for the detection. It is more realistic rake implementation than a-rake. However, both of the fore mentioned rake receivers require computationally expensive channel estimation and therefore are quite complex and power consuming rake types. S-rake needs calculation algorithm too for the decision of the strongest signal components to be utilized. [6]

A third rake type is a partial-rake (p-rake) where the *n* first arriving signal components are processed at the receiver. This is the simplest rake receiver since synchronization and estimation of all the multipath components are not required. Being less complex and less power consuming than either a-rake or s-rake, partial-rake can still be almost as good in performance. In a line-of-sight channel, the majority of the signal energy is in the couple of tens of first arriving multipath components. Therefore the *n* first taps only can be enough for a reliable decision. [6]

This study continues the work presented in papers [7], [8] and [9]. In this paper, the previous papers' points of view are combined and extended as the performance of p-rake receivers is compared in different hospital environments with various numbers of rake fingers. IEEE 802.15.4a ultra wideband definitions [10] for wireless personal area networks are used for the system model and the used wireless body area network (WBAN) channel model is based on the measurement campaign performed in Oulu University Hospital, Oulu, Finland [3]. Presumably this year, a new standard IEEE 802.15.6 [11] is going to be published. Its channel model [12] was published in 2009 but as pointed out in [13], it does not cover the hospital environment as precise as the measured channel model used in this study. IEEE 802.15.6 is targeted for WBANs but because it is unpublished and personal area network includes body area network, the IEEE 802.15.4a standard's system model is used here.

978-1-4244-9444-6/11/$26.00 ©2011 IEEE

II. SYSTEM MODEL

The IEEE 802.15.4a standard definitions on UWB [10] were followed when the impulse radio signaling based transceiver was being implemented. The simulator was constructed with Matlab® simulation tool in time domain.

A. Transmitter

At the transmitter, a single k^{th} burst is formed as [10]

$$x^{(k)}(t) = \left[1 - 2g_1^{(k)}\right] \sum_{n=1}^{N_{\text{cpb}}} \left[1 - 2s_{n+kN_{\text{cpb}}}\right] \times p\left(t - g_0^{(k)} T_{\text{BPM}} - h^{(k)} T_{\text{burst}} - nT_{\text{c}}\right) \quad (1)$$

where $g_0^{(k)}$ is a position modulated bit and $g_1^{(k)}$ is a phase modulated bit. N_{cpb}, depending on the data rate, defines the number of pulses per burst. Sequence $s_{n+kN_{\text{cpb}}} \in \{0,1\}$, $n = 0, 1, \ldots, N_{\text{cpb}} - 1$ is the scrambling code used in the k^{th} interval and $h^{(k)}$ is the k^{th} burst hopping position defined also by the scrambler. $p(t)$ is the transmitted pulse waveform at the antenna input, T_{BPM} is the half length of a symbol, T_{burst} is the length of a burst and T_{c} is the length of a pulse.

The k^{th} received symbol is expressed as [14]

$$r^{(k)}(t) = x^{(k)}(t) * h(t) + n(t) \quad (2)$$

where $x^{(k)}(t)$ is a transmitted signal as in (1), $h(t)$ is the channel impulse response, '*' states convolution and $n(t)$ is a white Gaussian noise.

B. Modulation methods and channel coding

According to [10], two different modulation methods and two different channel coding procedures are enabled by the standard. The modulation methods are binary burst position modulation (BPM) and binary phase-shift-keying (BPSK). Channel coding procedures are Reed-Solomon and convolutional channel coding. In modulation, BPM is always used for information bits and for Reed-Solomon encoded bits and can be used by both coherent and non-coherent receivers. BPSK is used for convolutional encoded bits and can be utilized in coherent receivers only. Both of the channel coding procedures are systematic meaning that the actual information bits are transmitted unchanged and the channel coded bits, redundant bits, are added to the information bit stream. Therefore a receiver can improve its performance by decoding the additional bits or gain in simplicity by discarding the redundant bits.

For detailed information of the standard requirements and definitions, such as symbol structure, number of users and data rate, the reader is referred to [10], for a comprehensive overview to [15] and for a brief presentation to [7] or [8].

C. WBAN channel model inside a hospital

A measurement campaign in a real hospital surrounding at the Oulu University Hospital, Finland [3] is the basis of the UWB WBAN channel model used in the simulations. Inside the hospital, the campaign covered a hospital corridor, a regular hospital room and a surgery room. Examples of the channel models were shown in [8]. In this paper, the main hospital environments under observe are a regular hospital room and a surgery room. In a regular hospital room the patient is lying down on a hospital bed and in surgery room on a surgery table. The links used in the channel models are line-of-sight links from the center of the body to a left wrist [3].

D. Rake receivers

As mentioned, this paper continues the study of rake receivers in medical environments. In [7], energy detector's (ED) and different a-rake receivers' performances were presented in generally. It was done by showing differences in receiver performance between additional white Gaussian noise channel and the measured medical channel. Performance comparisons with different data rates were executed also. It was noticed that the burst length has quite big impact on the performance of the receivers. In [8], energy detector's and a-rake receivers' performances were compared in different hospital environments. The results showed that the impact of the hospital environments on the receiver performance is rather small. In [9], s- and p-rake receivers' performances in the same hospital environment were introduced. Inside the hospital, the performance of the receivers was compared in between and to a performance of an energy detector. A few curves on complexity vs. performance were provided.

In this paper, two receiver types utilizing coherent detection are being studied. The first one is called as a reference coherent receiver and the second one a binary orthogonal non-coherent receiver with and without convolutional channel coding. The reference coherent receiver represents a receiver of the best possible performance. In the simulations with the reference receiver, the system model's position modulated bit, $g_0^{(k)}$, is assumed to be known and only the phase modulated bit is being detected, thus giving a good reference point for comparison. A binary orthogonal non-coherent receiver is the second studied receiver structure. In this one, the detection of the position modulated bit is done in a non-coherent manner and after that the convolutionally coded bit is detected coherently. In both of the receiver types, an exact synchronization is assumed.

Coherent detection is expressed as

$$v_i^{(k)} = \int_q^{q+T_w} r(t-\tau) w(t)\, d\tau, \; i = 0,1 \quad (3)$$

where $w(t) = \left(\sum_{n=1}^{N_{\text{cpb}}} \left[1 - 2s_{n+kN_{\text{cpb}}}\right] \times p(t - nT_{\text{c}})\right) * h(t)$ is a locally generated reference, '*' stating convolution, T_{w} being the length of the $w(t)$, T_{c} is the length of one pulse and $q = k2T_{\text{BPM}} + iT_{\text{BPM}} + h^{(k)} T_{\text{burst}}$.

In s-rake receiver, the n strongest taps of the channel impulse response $h(t)$ are being used by the receiver when implementing the locally generated reference $w(t)$. In p-rake, the n first taps of $h(t)$ are used for the same purpose.

In non-coherent receiver, the position modulated bit is defined by the comparison of the absolute values

$$\left|v_0^{(k)}\right| \underset{\text{"1"}}{\overset{\text{"0"}}{\gtreqless}} \left|v_1^{(k)}\right|, \quad (4)$$

i.e., if $v_0^{(k)}$ is bigger than $v_1^{(k)}$, the received bit is “0”. Otherwise it is “1”. Since the transmitted signal is phase modulated also, the position modulated bit is detected in a non-coherent manner.

As an input for the detection of convolutional coding, the Viterbi decoder gets the sequence of bits obtained by both position and phase modulated bits. The phase modulated bits are detected by taking the correlation output described in (3) according to the burst position detected by (4). For the larger decision variable v_i (i = 0 or 1) from (4), the phase detection is expressed as

$$v_i^{(k)} \underset{"0"}{\overset{"1"}{\gtrless}} 0. \tag{5}$$

If the correlation output is bigger than zero, the phase detected bit is “1”, otherwise it’s “0”.

As explained, the position modulated bit is assumed to be known in the reference coherent receiver, and only the phase modulated bit is detected according to (3) and (5). In non-coherent receiver without convolutional coding, only the position modulated bits are detected as presented in (3) and (4). Convolutional coded bits are always phase modulated. If the coding is used in non-coherent receiver, the phase detection is done according to (3) and (5), based on the information provided by (4).

E. *Simulations and verifications*

In the simulations, 1.5×10^6 bits per each signal-to-noise ratio, E_b/N_0, were executed. E_b states energy of a bit, i.e., energy over one burst and N_0 is a zero mean Gaussian noise. The simulations in different hospital environments were performed with different symbol rates (R_s) and number of users (N_{hop}), according to the standard [10]. Verification of the simulation model was done by comparing the reference BER curve in AWGN channel without channel coding to the theoretical antipodal bit error probability curve. The curves were identical. In binary orthogonal non-coherent detection without channel coding, the difference to the theoretical antipodal bit error probability curve is, in theory, 4 dB. In the simulations, the results were converging to the theory. The results are presented in bit error rate (BER) as a function of number of rake fingers and as a function of E_b/N_0.

III. RESULTS

Figures 1 and 2 present the performance comparisons of p-rake receivers with N_{hop}=8 and R_s=0.98 MHz. This is the mandatory mode of the IEEE 802.15.4a standard [10], in which a single burst has 16 pulses. The compared environments inside the hospital are a regular hospital room and a surgery room. In Figures 3 and 4, the same comparisons are presented but with a shorter burst of 2 pulses, thus higher data rate. Figures 1 and 3 present the performances in BER as a function of number of p-rake fingers. In Figures 2 and 4, the performances are presented in BER as a function of E_b/N_0.

The results in Figures 1 - 4 show scenarios where the differences in rake receiver performance between different hospital environments were found to be the most significant, based on numerous simulation runs. Therefore the receiver comparisons between regular hospital room and hospital corridor are not presented since the performance difference is insignificant and follows closely the a-rake results presented in [8]. The reason is the same for neglecting the s-rake receiver results. The performance differences are similar but smaller than in the case of p-rake receivers. The fixed E_b/N_0, 13 dB, in Figures 1 and 3 is based on, and follows, the results presented in [9]. The fixed number of p-rake fingers 10 in Figures 2 and 4 is based on the results from Figures 1 and 3.

Energy detector’s BER curves in Figures 1 and 3 are presented simply as a another reference to see where the performance level of p-rake receivers stand in relation to a simple non-coherent and low cost receiver, such as, the ED. A more precise comparison of the ED and different rake receivers, as well as the ED receiver structure, was provided in [9].

The results in Figure 1 with the mandatory mode of the standard, 16 pulses in a burst, show that the performance of p-rake receivers with 16 or less number of fingers is better in a surgery room than in a regular hospital room. When the number of fingers is increased, the differences are getting closer to the results of a-rake receivers in [8] where the environment inside the hospital has only a small effect on the performance. The difference is the biggest with approximately 10 fingers. In a surgery room, 4 fingers in p-rake are needed to have better performance than the one of ED. In regular hospital room, the required number of fingers is 6. P-rake having 12 fingers in a surgery room reaches the saturation level of performance when E_b/N_0 = 13 dB. In a regular hospital room, the saturation level is achieved with 30 fingers though the improvement from 20 to 30 fingers is rather small. The required number of fingers for the saturation level is quite the same with other E_b/N_0 values as well.

Figure 2 shows, with 10 p-rake fingers, that difference in performance between a surgery room and a regular hospital room is increasing as the E_b/N_0 increases. For example with E_b/N_0 = 20 dB, the difference is quite big, one decade in BER.

The same comparisons are shown in Figure 3 and 4 but with a short burst of two pulses. The performance in general is slightly poorer with the short burst than with the long burst of the mandatory mode. It can be seen that the environment has a similar impact on the p-rake receivers but the differences in performance are bigger, i.e., the same color (and the same marker) of curves are further apart in BER with the short burst than with the long burst. With the short burst, a p-rake receiver in surgery room has better performance up to 20 fingers. Having more than 20 fingers the differences are closing the differences of a-rake receivers where the performance of an a-rake receiver is better in a regular hospital room than in a surgery room. With a short burst, more rake fingers are also needed to have better performance than ED but this is more to do with the receiver structure of ED than environment. With a short burst in ED, less noise is integrated than with a long burst and therefore the general performance level of ED is better when the burst is shorter, as shown in [7].

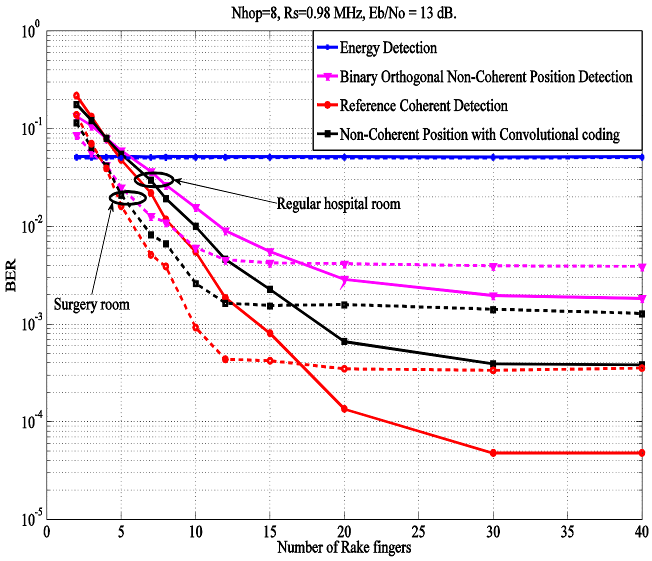

Figure 1. P-Rake comparison between a regular hospital room and a surgery room with fixed E_b/N_0 of 13 dB and a long burst.

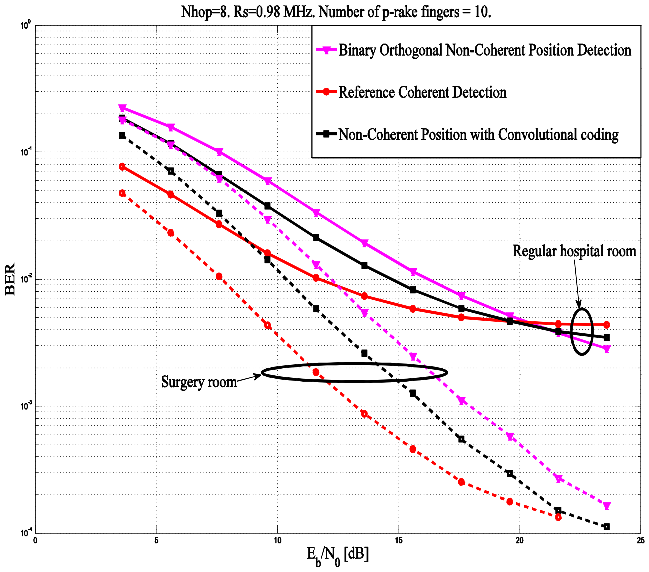

Figure 2. The effect of the environment on p-rake receivers with the mandatory mode, i.e., a long burst.

Since p-rake receivers have better performance with small number of fingers in a surgery room than in a regular hospital room, it is assumed that the first arriving signal cluster in a surgery room contains proportionally more energy than the first arriving cluster in a regular hospital room. The reason for this can be the fact that in the surgery room there is more medical equipments in a close range of a human body and thus later arriving signal components are more scattered in the surgery room than in the regular hospital room. Therefore collecting more signal components in a surgery room is not improving the detection as much as in a regular room where the later arriving components are less scattered.

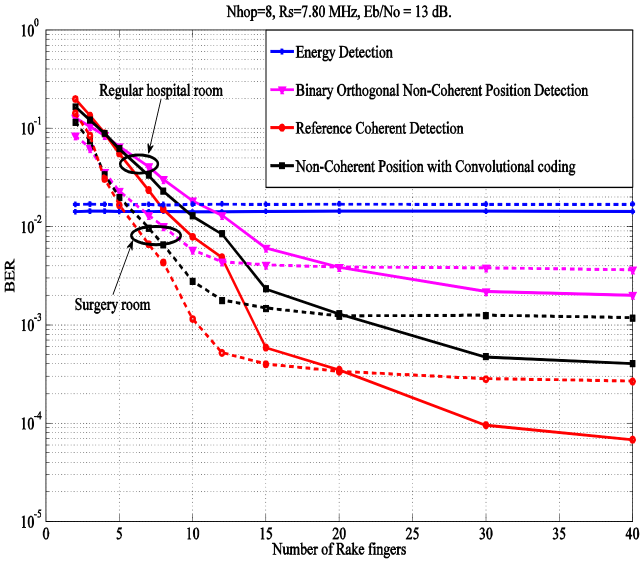

Figure 3. P-Rake comparison between a regular hospital room and a surgery room with fixed E_b/N_0 of 13 dB and a short burst.

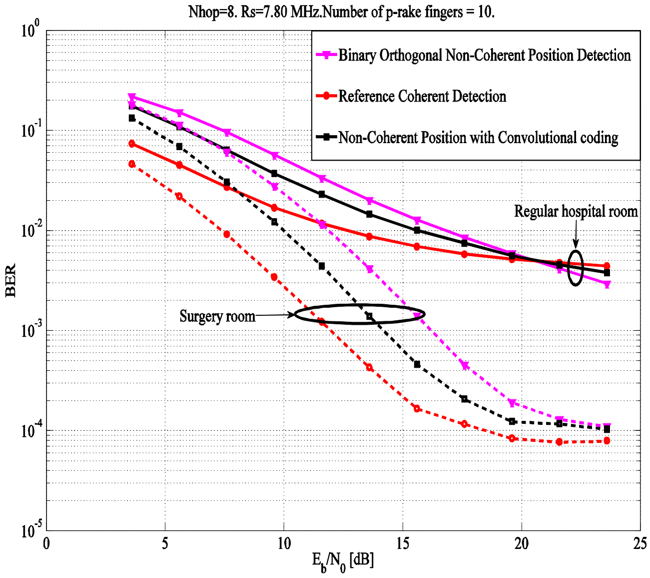

Figure 4. The effect of the environment on p-rake receivers with a short burst.

In each of the presented scenarios above, having more complex receiver, in here s-rake, generally means better performance than having a simpler type of a receiver such as p-rake, i.e., in more complex rake receivers, less fingers is required to reach either the performance level of ED or the saturation level. Also the differences in performance between hospital environments are smaller with s-rake than p-rake receivers. In other words, the performance of s-rake receiver is less dependent of the environment than the performance of the simpler p-rake receiver.

IV. CONCLUSIONS

In the previous section, the p-rake receiver performance in two different hospital environments, in a regular hospital room and in a surgery room, was presented. The same comparison with a-rake receivers is shown in [8]. S-rake receiver performance is following the p-rake receiver performance but differences between different hospital environments are smaller and therefore closer to the a-rake results.

Depending on the receiver type, the environment is seen to have an effect on the performance. With a-rake and energy detector the differences in performance, as presented earlier, are quite small but with s-rake receiver, the differences are slightly increasing. P-rake seems to be the most vulnerable on changes of the hospital environment due to differently propagated multipath signal components. On the other hand, this is a straight forward conclusion since p-rake processes the n first arriving taps of the transmitted signal. To make the detection, the first taps might not be the best, i.e., the strongest taps.

An interesting point of view is that when planning wireless receivers, the environment should be taken into account even inside a single building as was shown here inside the hospital. For example in cognitive networks, intelligent wireless receivers could simply recognize the environment and adapt to the environment specific a priori channel characteristics by selecting only n first or strongest taps in contrary to $n + m$ taps of another environment. Usually other aspects such as price, power consumption and complexity are ruling in the designing process. In some scenarios p-rake receivers, being the simplest of rake receivers, can perform almost as well as s-rake receivers. On the other hand, quite big differences were spotted on p-rake receiver performance between different hospital environments. In some cases, even an ED might be the best option in terms of price vs. performance.

A potential future work includes a study of the performance of receivers build according to the IEEE 802.15.6 standard together with IEEE 802.15.6 channel model.

ACKNOWLEDGMENT

The authors would like to thank Dr. Alberto Rabbachin from European Commission’s Joint Research Centre, Ispra, Italy for his valuable contribution during the development of the simulator.

REFERENCES

[1] Hämäläinen M., Pirinen P., Shelby Z. (2007) Advanced Wireless ICT Healtcare Research. Mobile and Wireless Communication Summit, 1-5 July 2007. 16th IST, Budapest, Hungary.

[2] Cramer R. J-M., Scholtz R. A., Win M. Z., (2002) Evaluation of an Ultra-Wide-Band Propagation Channel. IEEE Transactions on Antennas and Propagation, Vol. 50, No. 5, May 2002.

[3] Taparugssanagorn A., Pomalaza-Raez C., Tesi R., Isola A., Hämäläinen M., Iinatti J. (2009) UWB Channel for Wireless Body Area Networks in a Hospital Environment. The 12th International Symposium on Wireless Personal Multimedia Communications (WPMC’09), Sendai, Japan, Sep. 7-10, 2009.

[4] Fort A., Desset C., Ryckaert J., De Doncker P., Van Biesen L., Wambacq P. (2006) Characterization of the Ultra Wideband Body Area Propagation Channel. IEEE International Conference on Ultra-Wideband, ICU 2005, Zurich, Switzerland, September 5-8, 2005.

[5] Zasowski T., Meyer G., Althaus F., Wittneben A. (2005). Propagation Effects in UWB Body Area Networks. IEEE International Conference on Ultra-Wideband, ICU 2005, Zurich, Switzerland, September 5-8, 2005.

[6] Cassioli D., Win M.Z., Vatalaro F., Molisch A.F. (2007) Low Complexity Rake Receivers in Ultra-Wideband Channels. IEEE Transactions on Wireless Communications, Vol. 6, No. 4, April 2007

[7] Niemelä V., Rabbachin A., Taparugssanagorn A., Hämäläinen M., Iinatti J. (2010) Performance of IEEE 802.15.4a UWB WBAN Receivers in a Real Hospital Environment. The 4th International Symposium on Medical Information and Communication Technology (ISMICT 2010), Taipei, Taiwan, March 22-25, 2010.

[8] Niemelä V., Rabbachin A., Taparugssanagorn A., Hämäläinen M., Iinatti J. (2010) A Comparison of UWB WBAN Receivers in Different Measured Hospital Environments. The 3rd International Symposium on Applied Sciences in Biomedical and Communication Technologies. (ISABEL 2010), Rome, Italy, November 7-10, 2010.

[9] Niemelä V., Iinatti J., Hämäläinen M., Taparugssanagorn A. (2010) On the Energy Detector, P- and S-Rake Receivers in a Measured UWB Channel Inside a Hospital. The 3rd International Symposium on Applied Sciences in Biomedical and Communication Technologies. (ISABEL 2010), Rome, Italy, November 7-10, 2010.

[10] IEEE Standard 802.15.4a: Part 15.4: Wireless Medium Access Control (MAC) and Physical Layer (PHY) Specifications for Low-Rate Wireless Personal Area Networks (WPANs), Amendment 1: Add Alternate PHYs. IEEE Computer Society, IEEE Std 802.15.4a–2007 (Amendment to IEEE Std 802.15.4 –2006), NY, USA. 187 p.

[11] IEEE 802.15 WPAN Task Group 6 (TG6) Body Area Networks. http://www.ieee802.org/15/pub/TG6.html Page available at 26.1.2010.

[12] IEEE P802.15 Working Group for Wireless Personal Area Networks (WPANs). Channel Model for Body Area Network (BAN). (2009). IEEE 802.15.6 channel modeling subcommittee.

[13] Viittala H., Hämäläinen M., Iinatti J., Taparugssanagorn A. (2009) Different Experimental WBAN Channel Models and IEEE802.15.6 Models: Comparison and Effects. 2nd International Symposium on Applied Sciences in Biomedical and Communication Technologies (ISABEL 2009), Bratislava, Slovakia, Nov. 24-27, 2009.

[14] Molisch A.F. (2005) Wireless Communications. John Wiley & Sons Ltd, The Atrium, Southern Gate, Chichester, West Sussex, England.

[15] Zhang J., Orlik P.V., Sahinoglu Z., Molisch A.F., Kinney P. (2009) UWB Systems for Wireless Sensor Networks. Invited Paper. Proceedings of the IEEE. Vol. 97, No. 2, February 2009.