A Comparison of UWB WBAN Receivers in Different Measured Hospital Environments

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Abstract—**Wireless technology has been developing fast for years and is spreading to new areas of everyday life. One of the newest areas is healthcare and welfare sector where it can be a significant way to save costs and improve existing procedures. The coming years are going to be challenging as the population, in the developed countries especially, is aging fast and more patients are going to need treatment but with the same or even smaller number of nursing staff than nowadays. Therefore there is a clear need for both improvement of methods and cutting down the costs. In this paper, the performance of different ultra wideband (UWB) receivers implemented following the IEEE 802.15.4a requirements are being compared in different hospital environments. Wireless body area network (WBAN) radio channel models used in the simulations are based on the measurements carried out in a real hospital environment in Oulu, Finland.**

Keywords-component; IEEE 802.15.4a; WBAN; coherent receiver; binary orthogonal non-coherent receiver; energy detector; hospital environment;

I. Introduction

In the future, there is going to be more wireless technologies in use in the hospital environments as the wireless applications have been increasing in broad areas of everyday life. The advantages of wireless technology in medical applications can be, for example, simpler measurements of vital physiological parameters, cost savings and tracing patients and portable devices. Physiological parameters are heart rate, oxygen level or electrocardiograph measurements, to mention few. Measuring vital parameters can be done in a way where a patient is carrying a vest of wireless sensors which measure the parameters and transfer data to an access point near the body, i.e., on a wrist in a clocklike device. From there on, the information is transferred, for example, via wireless local area network to an electronic data base. In such a way, the mobility of the patients is improved which is an advantage in most of the recovery periods. This way the measurements can be done in a simpler manner, and the time of a nursing staff is saved since there is no need to be next to the patients writing down the results. The results can be followed even online if wanted. The tracing of patients and devices inside of a hospital is also possible as well as the recovery periods spent mostly at home since the wireless body area network (WBAN) of the vest is quite simple to establish in various places, even in an ambulance during transportation. [1]

The challenges of the wireless technology can be, for example, interference by and to the other devices, battery life and reliability of transmissions. In the hospital environment especially, it is important that any device is not causing harmful radiation to humans or interference to other electronic devices. The reliability of transmissions is extremely important since wrong data can cause wrong conclusions which in the case of physiological parameters can cause even life threatening treatments.

There exist several possible technologies for WBAN, i.e., Bluetooth, ZigBee and UWB, each with advantages and disadvantages. ZigBee offers low power consumption but with restricted data rate. Bluetooth is mature and cheap technology with fairly high power consumption. UWB offers high bandwidth and reduced receiver complexity but low enough power usage is still a challenge for WBAN solutions. [2-3]

In the recent years, number of UWB propagation channel studies [4-6] show that the channel characteristics are different when the transmission is effected by a human body. The complex shape and different tissues, each with different permittivity, have an impact on the propagation. The environment effects also on the UWB propagation [7-8]. UWB simulations carried out earlier are typically not based on any standard and the used WBAN channel models are not specified in a real medical environment. [9]

In this paper, the UWB simulations are executed based on the IEEE 802.15.4a standard for low-rate wireless personal area networks [10]. The performance of different IEEE 802.15.4a receivers are being compared in real hospital environments. For this purpose, WBAN channel models measured in real hospital environment [6] are used in the simulations. The IEEE 802.15.6 for WBAN [11] has not been published yet and therefore IEEE 802.15.4a is used for the UWB WBAN simulations. A wireless personal area network includes a wireless body area network and therefore it can be used for WBAN studies also. The channel model for IEEE 802.15.6 [12] was published in spring 2009 but it does not cover the hospital environment as precise as the measured UWB channel from [6], as shown in [13]. The presented results are extending the results of [14] and the purpose in this paper is to study and compare how different surroundings inside of a hospital influence the performance of the UWB WBAN receivers.

II. SYSTEM MODEL

A. IEEE 802.15.4a symbol structure

The UWB WBAN simulator in time domain is implemented with Matlab®. The IEEE 802.15.4a standard requirements are followed strictly performing an impulse radio signaling based UWB transceiver [10]. The transmitted UWB waveform during the k^{th} symbol interval is expressed as [10]

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

where $g_0^{(k)}$ is a position modulated bit and $g_1^{(k)}$ is a phase modulated bit. 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 defining the position of the burst in the symbol, T_{burst} is the length of a burst and T_c is the length of a pulse. The symbol structure is presented in Fig. 1. [10]

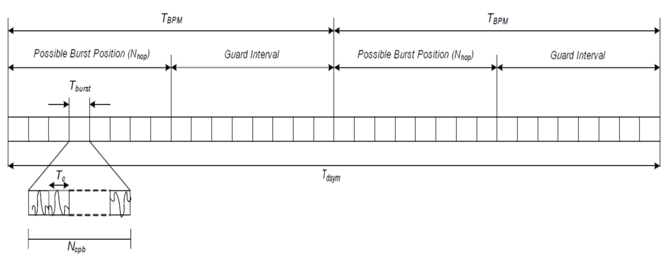

Figure 1. UWB symbol structure in IEEE 802.15.4a.

The k^{th} received symbol can be written as [15]

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

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

B. Receiver structures

In this study, three different types of receivers have been compared.

- A coherent receiver representing a reference receiver of the best possible performance.
- A binary orthogonal non-coherent receiver with and without convolutional channel coding.
- An energy detector (ED).

Coherent detection can be expressed as

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

where $w(t) = \left(\sum_{n=1}^{N_{\text{cpb}}} \left[1 - 2s_{n+kN_{\text{cpb}}}\right] \times p(t - nT_c)\right) * h(t)$ is a locally generated reference, T_w is the length of the locally generated reference, T_c is the length of single pulse and $s = k2T_{\text{BPM}} + iT_{\text{BPM}} + h^{(k)} T_{\text{burst}}$. Generating $w(t)$ in such a way, an all-rake receiver is performed collecting all multipath components of the propagated signal. This requires a good channel information, and in reality, is quite complex to build.

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

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

i.e., if $v_0^{(k)}$ is bigger than $v_1^{(k)}$, the received bit is "0". Otherwise it is "1". Note that, since the transmitted signal is also phase modulated, the detection of the position modulated bit is to be done in a non-coherent manner.

For the detection with convolutional coding, the Viterbi decoder gets as an input 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). The phase detection is expressed as

$$v_0^{(k)}, v_1^{(k)} \underset{\text{"0"}}{\overset{\text{"1"}}{\gtrless}} 0. \quad (5)$$

If the correlation output is bigger than zero, the phase detected bit is "1", otherwise it's "0".

In the reference coherent receiver, the position modulated bit is assumed to be known and only the phase modulated bit is detected according to (3) and (5). In non-coherent receiver without convolutional decoding, only the position modulated bit is detected as presented in (3) and (4). Convolutional coded bits are always phase modulated. In case 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).

The received signal in ED is first passed through a band-pass filter (BPF) in order to reduce the noise. Assuming that the BPF does not cause distortion to the received signal, the decision variable for the position modulation can be written as

$$w_i^{(k)} = \int_s^{s+T_{\text{burst}}} r(t)^2\, dt,\ i\text{=0,1}. \quad (6)$$

The decision on the received bit is based on the comparison between the decision variables and is expressed as

$$w_0^{(k)} \underset{\text{"1"}}{\overset{\text{"0"}}{\gtrless}} w_1^{(k)}. \quad (7)$$

In the ED, the transmitted burst length defines the integration time. Due to the channel effects and un-optimized integration times at the receiver, part of the signal energy can be lost. Therefore the performance of the ED is expected to be somewhat worse than it could be. Note that, due to the ED receiver structure (6), as the burst length increases the longer integration time increases the effect of noise.

C. Modulation methods

Based on the standard, the information bits are always position modulated and redundant convolutional parity bits are phase modulated. With this modulation structure, the information bits can be received by both coherent and non-coherent receivers. Difference is that the coherent receiver can utilize the convolutional encoding to improve its performance. Both receiver types can utilize Reed-Solomon encoded parity check bits which are always position modulated, therefore visible for both types of the receivers. According to the standard, different options regarding number of users and data rates are presented in Table 1. [10]

Table 1. Simulation parameters and number of pulses per burst.

Number of users	**Symbol rate (MHz)**	**Pulses (2ns) per burst**
$N_{hop} = 2$	0.12 0.98 7.80 31.20	N_{cpb}=512 N_{cpb}=64 N_{cpb}=8 N_{cpb}=2
$N_{hop} = 8$	0.12 0.98 7.80 15.60	N_{cpb}=128 N_{cpb}=16 N_{cpb}=2 N_{cpb}=1
$N_{hop} = 32$	0.12 0.98 1.95 3.90	N_{cpb}=32 N_{cpb}=4 N_{cpb}=2 N_{cpb}=1

D. Channel models

UWB channel models used in the simulations are based on the measurement campaign in a real hospital surrounding at Oulu University Hospital, Finland [6]. Compared scenarios, i.e., channel models, are explained in Table 2. Scenarios 1 and 2 are measured in a regular hospital room, 3 in a hospital corridor and scenario 4 in a surgery room. In scenarios 1 and 4, the patient was lying down during the measurement, in 2 and 3 standing. In all the scenarios, the link is a line-of-sight from the middle of the body to a sensor on the left wrist. [6]

Table 2. Channel models with the number of multipath components.

Scenario	**Scenario description**	***L* = average number of arrival paths**
1	Regular hospital room, lying down	468
2	Regular hospital room, standing	531
3	Hospital corridor, standing	550
4	Surgery room, lying down	296

In Figures 2 and 3, simulated average channel impulse responses are presented from scenarios 1 and 4, and from scenarios 2 and 3, respectively. Averaging is performed over 100 simulated impulse responses, based on the measurements. Figure 2 present some small differences between a regular hospital room and a surgery room. The average number of arrival paths is smaller in the surgery room than in the regular hospital room [6]. In Figure 3, the channel impulse responses of the hospital room and the corridor are quite the same, not much differences. Some multipath components are stronger in a regular room than in a corridor, visible in plottings.

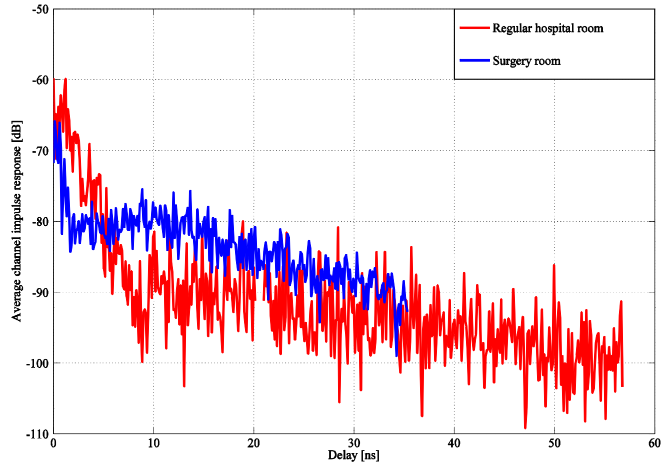

Figure 2. Average channel impulse responses of scenarios 1 and 4.

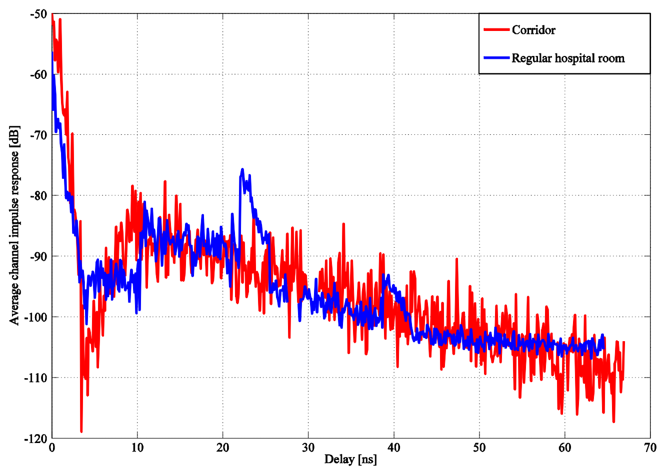

Figure 3. Average channel impulse responses of scenarios 2 and 3.

E. Simulations and verification

The simulations have been executed with 1.155×10^6 simulated bits per one E_b/N_0 value, where E_b states energy of a bit, i.e., energy over one burst and N_0 is a zero mean Gaussian noise. Different symbol rates and number of users (N_{hop}) were covered with different length of bursts. The standard defined symbol rates and N_{hop} values are presented in Table 1 [10].

The results are presented as bit error rate (BER) per E_b/N_0 value. Verification of the simulations was done by comparing the reference BER curve with the theoretical antipodal bit error probability curve in AWGN channel without channel coding. The curves were identical. In binary orthogonal non-coherent detection without channel coding, the difference to the theoretical antipodal bit error probability curve is 4 dB in theory. In the simulations, using decision variables from (4) gave the same result.

III. RESULTS

Figures 4 - 7 present the performances of different types of receivers (Section *II.B*) in three different hospital environments: a regular hospital room, a hospital corridor and a surgery room. The result comparisons are made between scenarios 1 and 4 and between 2 and 3. In scenarios 1 and 4 the patient is lying down, and in 2 and 3 standing. Therefore the only variable changing between the compared scenarios is the environment. Figures 4 and 5 present the longer burst (slower data rate) results between a hospital room and a surgery room, and between a hospital room and a corridor, respectively. Figures 6 and 7 present the same comparison between different hospital environments but with the shorter burst, thus, higher data rate. In the longer burst, there are 16 pulses in a burst and in the shorter burst 2 pulses (Table 1).

In each of the figures, different color presents different type of a receiver. The performance order of the receivers in terms of BER remains the same in every scenario. The reference coherent receiver has naturally the best performance in BER, the non-coherent receiver with convolutional coding second best, without convolutional coding third and the ED fourth. The difference in dB between the first three receivers stays approximately the same in every scenario, being around 2.5 dB. The coherent receiver is performing 2.5 dB better than the non-coherent with convolutional coding which is performing the same 2.5 dB better than the same receiver without convolutional coding.

The performance of ED on the other hand depends on the burst length as explained in Section *II.B*. The difference is from 4 dB with shorter bursts up to 8 dB with longer bursts when compared to the non-coherent receiver without convolutional coding. The differences in performance between the different receiver types follow the AGWN results, partly presented in [14]. In other words, the more complex receiver structure, better performance is achieved. With ED, the un-optimized integration times influence the performance, especially with shorter burst. The other three receivers are all-rake type showing the best achievable performance of each receiver.

From Figures 5 and 7, it can be seen that the differences in the performance on each receiver type between a hospital room and a corridor remains quite the same with both of the burst lengths. In other words, the mentioned environments are quite the same from the wireless UWB transmission point of view. Only a small difference is with the shorter burst of ED between corridor and regular room, shown in Figure 7. It is assumed that the corridor is more of an “empty” surrounding compared to hospital room with beds and possible chairs and might be therefore better for wireless transmission.

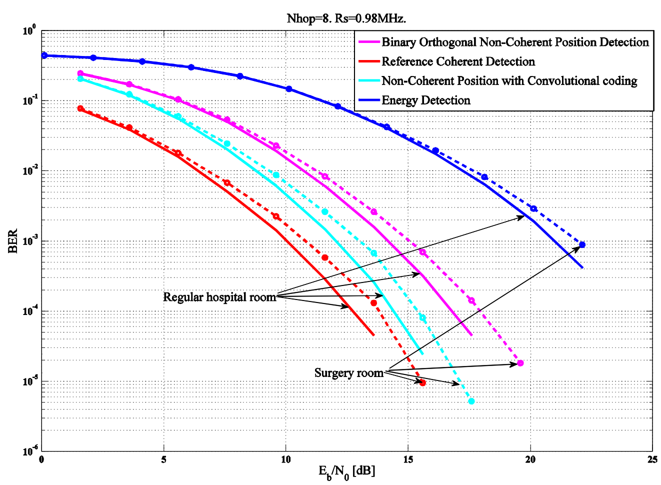

Figure 4. Performance in scenarios 1 and 4 with longer burst.

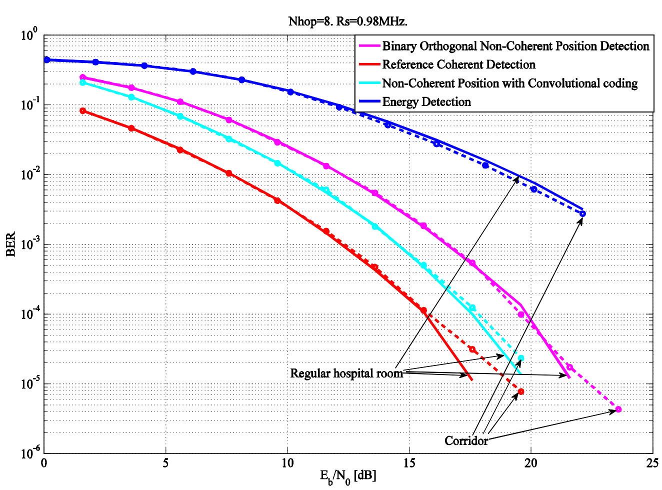

Figure 5. Performance in scenarios 2 and 3 with longer burst.

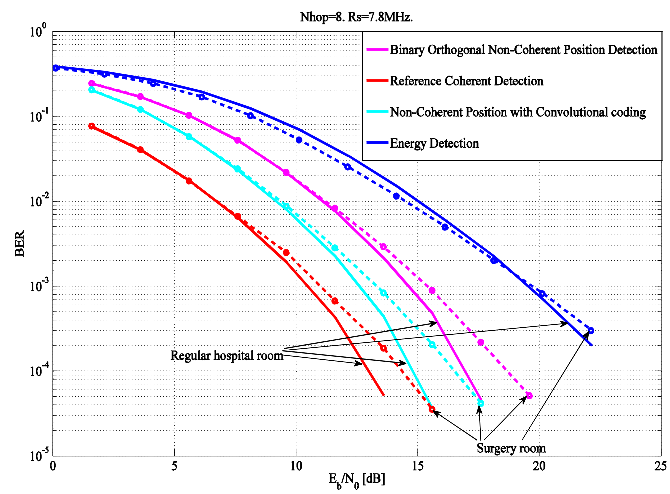

Figure 6. Performance in scenarios 1 and 4 with shorter burst.

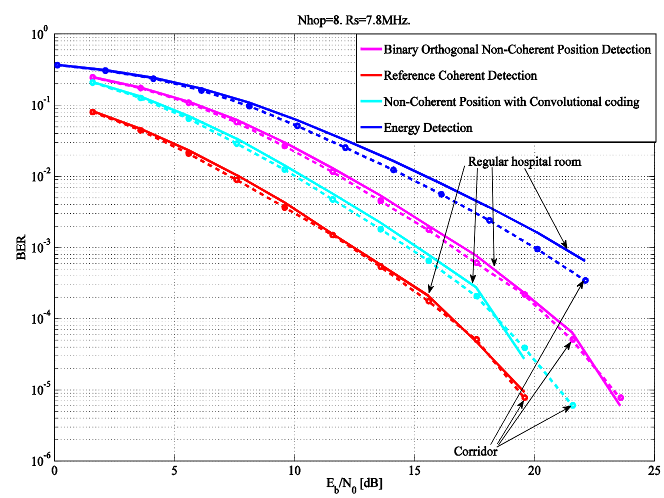

Figure 7. Performance in scenarios 2 and 3 with shorter burst.

The similar comparison is presented in Figures 4 and 6 but between a surgery room and a regular hospital room. The performance of different receivers seems to be slightly weaker in the surgery room than in the regular room. The explanation is that most likely in the surgery room, there are more medical equipments in the close proximity of the human body and therefore more scattering of the signal.

IV. CONCLUSION AND FUTURE WORK

All the presented scenarios were simulated in the system built according to the IEEE 802.15.4a standard. The used UWB WBAN channel models were measured in a real hospital environment. The results show that there is not much of a difference on the receiver performances between the different environments inside the hospital. After all, the links are line-of-sight links and less than one meter in distance.

Small differences were spotted if the room or space has furniture or other objects, i.e., hospital equipments, close to the human body. ED seems also to be the most sensitive for multipath propagation as was shown in the comparison of the corridor and the regular hospital room with the short burst in Figure 7.

A future work includes comparisons with a longer link, for example 2 meter distance from the body to a base station. As an enlightened guess, in the case of the longer link, the environment starts to play bigger role inside a hospital or in any other environment.

Both the coherent and the binary orthogonal non-coherent receivers were built with all-rake structure, thus collecting all the possible multipath components. In reality it is a complex way to implement receivers and requires exact channel estimation. Therefore the performance of these receivers outperforms ED which is simpler, thus cheaper, receiver type to implement in reality since it does not require the channel estimation. Another possible future work includes partial-rake and selective-rake receivers as well as optimizing the integration times of ED. With these modifications, the performance comparison of different receiver types would better correspond to reality in low-complexity and low-power consuming receivers, especially in the case of partial-rake and ED receivers as the selective-rake receiver requires channel estimation and thus is more complex to implement.

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