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SUITABILITY STUDY OF DS-UWB AND UWB-FM FOR MEDICAL APPLICATIONS

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ABSTRACT

In this paper, the suitabilities of direct sequence ultra wideband (DS-UWB) and ultra wideband frequency modulation (UWB-FM) are studied for medical applications. The system performances are studied by applying the measured hospital channels. The channel measurements were done at the Oulu University hospital in 2005. The measurement campaign included three different hospital environments, i.e. the operating room, intensive care unit and x-ray operating room. The measured frequency range was from 3.1 GHz to 6.0 GHz. The simulation results indicate that UWB-FM outperforms DS-UWB with low data rates, i.e. less than 1 Mbps, due to the simpler implementation. When data rate increases, DS-UWB is reasonable choice for medical applications.

I. INTRODUCTION

Nowadays, cables attaching patient monitoring sensors to monitoring devices disturb and obstruct nursing staff. Vital parameters, such as blood pressure, electrocardiography (ECG), respiration rate, heart rate and temperature, from patient who is in critical condition are measured all the time. Wired connections make free redeployment of patient between separate units more difficult. In addition, wires complicate the movement of the patient. Wireless connections will offer quick and easy way to redeploy the patient, e.g., from an operating room to an intensive care unit (ICU) and make the movement of patient more easier.

The current wireless techniques applied in hospitals are based on wireless medical telemetry service (WMTS) and wireless local area network (WLAN) standards [1]. Nevertheless, data transmission from patient monitoring sensors to monitoring devices has no viable solution. The potential solution for short range communication in the hospitals can be found from the wireless body area network (WPAN) standards, e.g., ultra wideband (UWB), ZigBee and Bluetooth [1].

In this paper, two singleband UWB systems, i.e., direct sequence UWB (DS-UWB) and UWB frequency modulation (UWB-FM), are studied in the measured hospital channels. In the traditional DS-UWB technique, the energy of the information signal is spread with a pseudo random code sequence. When a very narrow chip waveform is applied, it inherently generates ultra wide spectrum [2]. The UWB-FM technique is based on the dual frequency modulation [3]. These systems are discussed in Section II in more details.

The channel measurements from 3.1 to 6.0 GHz were carried out at the Oulu University hospital [4]. At the time of the measurements, the Federal Communications Commission (FCC) was the only governing body that allowed UWB system to operate in the frequency range from 3.1 to 10.6 GHz [5]. Therefore, the studies are focused on the UWB frequency range defined by the FCC. The measurements were carried out in three environments; an operating room, an intensive care unit and an x-ray examination room.

The paper includes the following paragraphs; Section II presents the system models and channel models. In Section III, the simulation parameters and configurations are discussed. The results are presented in Section IV. In the end, the paper is concluded by Section V.

II. SYSTEM MODELS

In this section, the system models for DS-UWB, UWB-FM and hospital channel models used at the simulations are discussed.

A. DS-UWB

In the DS-UWB technique, the energy of the information signal is spread by utilizing pseudo random codes. When the very narrow pulse is applied as a chip waveform, the energy of the signal is spread over ultra wide spectrum. At a receiver, a selective rake receiver is applied. The rake receiver improves the performance by utilizing time diversity, i.e. by capturing the signal energy propagated through a channel by different paths and combining the signal components. [2]

Maximum ratio combining (MRC) is an optimal combining technique by weighting received signal components with estimated received amplitude and then coherently combining them. The decision variables in MRC is given by [2]

$$U_{i,\mathrm{MRC}} = \sum_{n=1}^{N} a_n^* \int_0^{T_\mathrm{b}} r(t-\tau_n) w_i(t) dt, \quad i = 0,1, \tag{1}$$

where n is the multipath component, a_n is the complex gain of the n^{th} multipath component, T_b is the duration of the data bit, $r(t)$ is the received signal, t is time, τ_n is the delay of the n^{th} multipath component and $w_i(t)$ is the pulse waveform of the data bit i.

Equal gain combining (EGC) is similar to MRC, but it does not weight the signal components with the estimated received amplitude [2]. Square-law combining (SLC) is non-coherent approach, where the phase of the signal is considered to be unknown. This leads to simpler implementation of the receiver with the cost of the performance. The decision variables in SLC are [2]

$$U_{i,\mathrm{SLC}} = \sum_{n=1}^{N} \left| \int_0^{T_\mathrm{b}} r(t-\tau_n) w_i(t) dt \right|^2, \quad i = 0,1. \tag{2}$$

B. UWB-FM

UWB-FM is a simple technique for UWB communication with low data rates. It applies a double frequency modulation (FM): digital frequency shift keying (FSK) with a low modulation index followed by analog FM with a high modulation index. This yields to the FM signal $V(t)$ [3]:

$$V(t) = A\sin(\omega_c t - \beta\cos(\omega_m t) + \varphi_0), \quad (3)$$

where A is the amplitude, ω_c is the angle frequency of the carrier signal, β is the modulation index, ω_m is the angle frequency of the modulating signal and φ_0 is the arbitrary but time-independent constant.

At the receiver, the FM signal is demodulated with a delay-line FM demodulator. This approach does not need any frequency translation. Therefore, no local oscillator and no carrier synchronization are required. This reduces the complexity of the transceiver. In the delay-line FM demodulator, the received signal is delayed with time that is equal to an odd multiple of a quarter period for the carrier frequency of the FM signal. FSK demodulation can be done with a bandpass filter followed by a phase-locked loop. [3]

C. Hospital Channel Models

The channel measurement campaign was carried out at the Oulu University hospital in 2005 [4]. The measurements were done in three different environments; an operating room (OR), an x-ray examination room (XR) and an intensive care unit (ICU) in the frequency range from 3.1 GHz to 6.0 GHz. The environments were static during the measurements, i.e. there were no movement inside a room when recording the data, expect in the ICU. The multipath model was obtained by investigating the multipath propagated signals in the power delay profile (PDP). The model was shown to be similar as a modified IEEE 802.15.3a channel model defined in [6]. The modified IEEE 802.15.3a parameters for the hospital environments are presented in Table 1. The example channel realizations for the environments are illustrated in Figure 1.

The parameters occurred in Table 1 are [6]

- Λ = Cluster arrival rate,
- λ = Ray arrival rate,
- Γ = Cluster decay factor,
- γ = Ray decay factor,
- σ_1 = Standard deviation of cluster lognormal fading term,
- σ_2 = Standard deviation of ray lognormal fading term and
- σ_x = Standard deviation of lognormal shadowing term for total multipath realization.

Table 1: Modified IEEE 802.15.3a model parameters for hospital.

Model parameters	**Operating room (OR)**	**X-ray room (XR)**	**Intensive care unit (ICU)**
Λ [1/ns]	0.04	0.05	0.09
λ [1/ns]	2	1.5	2
Γ [ns]	9	13.3	16
γ_r [ns]	8	10	5
σ_1, σ_2 [dB]	3.4	3.4	3.4
σ_x [dB]	1.5	1.5	1.5

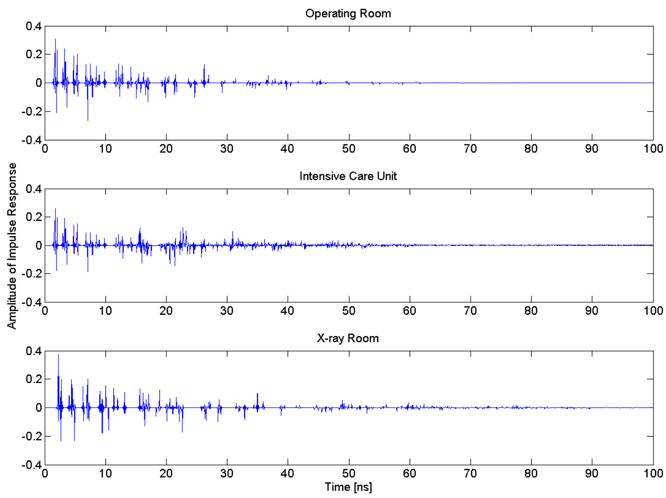

Figure 1: One channel realization for each environment.

D. Applications

Electrocardiography (ECG) is an essential tool for investigating cardiac arrythmias. It is also useful in diagnosing cardiac disorders such as myocardial infarction [7]. The standard ECG measurement contains information from 12 leads. The six chest leads (V1 to V6) measure the activity of the heart in the horizontal plane. The activity in the vertical plane is measured by the six limb leads (I, II, III, aVR, aVL and aVF). When the sample rate of 1250 samples per second and the resolution of 12 bits/sample are applied, the total data rate (R_b) from the ECG measurement is 180 kbps [8].

The physiological properties of the muscles at rest and in contraction are evaluated and recorded by using a technique called electromyography (EMG). In a surface EMG, measurements are done non-invasive and it can be applied to, e.g., childbirth to measure the contraction intervals. In the surface EMG, the signals from reference and two detection electrodes construct the EMG signal [9]. Each of the electrode produces the information rate of 600 kbps with the sample rate of 50 samples per second and the resolution of 12 bits per sample [8]. Hence, the total data rate is 1.8 Mbps.

A possible application for x-ray examination is to transmit wirelessly the taken images from a measurement device to a viewer, e.g., to computer. Since uncompressed x-ray images are very large, the wireless link should be fast enough. The data rate for the x-ray imaging application is chosen to be 24 Mbps.

III. SIMULATION CONFIGURATIONS

In order to evaluate the suitability of the DS-UWB and UWB-FM systems for the link between the patient monitoring sensors and the monitoring devices, software simulators were implemented in Matlab©. In this section, the simulation parameters and configurations are presented and justified. The parameters for the systems are chosen so that the systems are occupying approximately the same frequency band. The spectrum allocations of the systems with defined parameters are depicted in Figure 2.

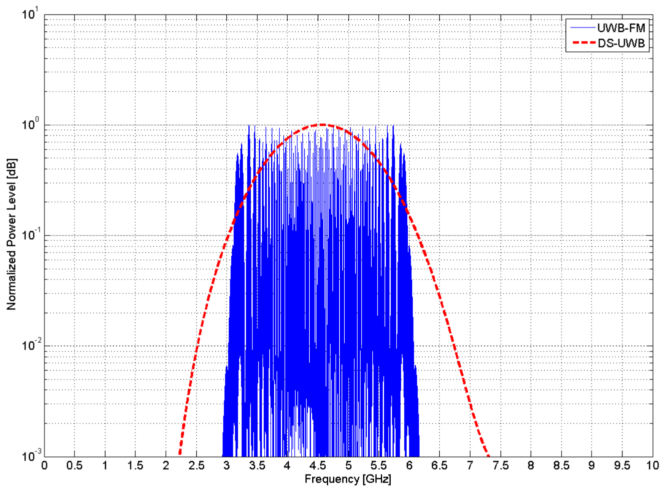

Figure 2: Spectrum allocations of UWB-FM and DS-UWB with defined parameters.

The chip waveform for DS-UWB was chosen to be 10^{th} derivative of the Gaussian monocycle with the pulse length (T_p) of 0.7 ns, thus having the center frequency (f_c) of 4.57 GHz and bandwidth (W) of 3.11 GHz. The studied receiver algorithms for DS-UWB are chosen to be coherent MRC and EGC and non-coherent SLC with 8-finger selective rake receiver. The selective rake receiver with 8 fingers has been shown to be adequate in order to trade-off between complexity and performance [10]. The modulation scheme for coherent detection algorithms is binary pulse amplitude modulation (BPAM) and on-off keying (OOK) for non-coherent detection algorithm, respectively. BPAM cannot be applied for SLC, because the polarity of the data bit is needed in the decision. In OOK, nothing is transmitted in the case of bit "0". The pulse power of OOK is twofold compared to BPAM to attain same average transmitted power. According to the data rates, presented in Section II, pulse repetition processing gains are adjusted. The pulse repetition processing gain in decibels is defined as

$$PG = 10 \cdot \log_{10}\left(\frac{1}{R_b T_p}\right). \quad (4)$$

Therefore, the processing gains for 1.8 Mbps and 24 Mbps are 29.0 dB and 17.7 dB, respectively. With the data rate of 180 kbps and the pulse length of 0.7 ns, the processing gain is as much as 39 dB. This requires a huge calculation capacity, and therefore it is not feasible for the medical sensor applications.

In the UWB-FM technique, the channel bandwidth is adjusted with the modulation index of FM. The UWB-FM system is studied with the channel bandwidths of 500, 1000, 2000 and 2900 MHz. The centre frequency of the carrier is 4.55 GHz. Through the simulations, the modulation index of FSK is set to one.

IV. RESULTS

The results of the simulations are presented in this Section. The singleband UWB systems, i.e. DS-UWB and UWB-FM, were simulated in the measured hospital channels. The bit error rate (BER) performance is studied as a function of bit energy-to-noise power density ratio (E_b/N_0).

Figure 3 and Figure 4 illustrate the bit error rate (BER) performance of the UWB-FM system with 180 kbps in the ICU and OR channels. As it can be seen, the performances with the bandwidths of 500 and 1000 MHz saturates to the certain BER level. In the OR channel, the performance with the full bandwidth, i.e. W = 2900 MHz, is approximately 3 dB better than with W = 2000 MHz at the BER level of 10^{-5}. In the ICU channel, the performance of UWB-FM with the bandwidths of 2000 MHz and 2900 MHz are similar.

The performance of DS-UWB system with MRC and SLC receiver algorithms and the UWB-FM system with various channel bandwidths in the OR and ICU channels are presented in Figure 5 and Figure 6, respectively. The data rate was set to 1.8 Mbps. The performance of UWB-FM with various channel bandwidths saturates in the both studied channels. The exception is the performance with W = 2000 MHz in the OR channel where the performance improves when the E_b/N_0 increases. In UWB-FM, the spreading gain, i.e. the ratio between RF and subcarrier bandwidths, decreases when the data rate is increased and RF bandwidth is fixed. Therefore, it might be a reason for the performance degradation. The performance difference between coherent and non-coherent DS-UWB receiver algorithms seems to be approximately 20 dB at the BER level of 10^{-2} or smaller.

The results indicate that the UWB-FM system is suitable for data rates below 1 Mbps. In addition, the UWB-FM system has simple implementation and this makes it favourable for low data rate health monitoring applications.

Figure 7 presents the performances of the studied DS-UWB receivers with data rate of 24 Mbps in the XR channel. The coherent approaches have almost the same performance, and they outperform the non-coherent algorithm by 8 dB at the BER level of 10^{-3}. It is obvious that when the data rate increases, the DS-UWB system is better than UWB-FM due to the performance saturation of UWB-FM when data rates increases. When short pulse length is applied to low data rates, it requires high pulse repetition processing gains that means need for high computational capacity, and therefore DS-UWB is not convenient for low data rate applications.

V. CONCLUSION

In this paper, the suitabilities of two singleband UWB systems, i.e., DS-UWB and UWB-FM, were studied for health monitoring and medical applications. The simulation results indicated that UWB-FM is suitable for the applications with data rates below 1 Mbps. The low data rates require very high pulse repetition processing gains with the short pulse lengths in the case of DS-UWB. This sets high demands for the computational capacity of the devices. Therefore, it is not feasible for the low data rate applications, i.e. $R_b < 1$ Mbps. The non-coherent receiver algorithm of DS-UWB is simpler but it needs 20 dB higher E_b/N_0 than coherent algorithm to obtain the BER level of 10^{-3} with the data rate of 1.8 Mbps. When the data rate increases, the performance difference decreases between coherent and non-coherent detection. With data rate of 24 Mbps, the non-coherent algorithm needs 8 dB higher E_b/N_0 than coherent algorithms to obtain the BER level of 10^{-3}.

In future, the performances of the systems will be studied by applying the wireless body area network (WPAN) channels.

VI. ACKNOWLEDGEMENT

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REFERENCES

[1] M. Paksuniemi, H. Sorvoja, E. Alasaarela and R. Myllylä, ”Wireless Sensor and Data Transmission Needs and Technologies for Patient Monitoring in the Operating Room and Intensive Care Unit,” in *Proc. of the 27th IEEE Annual Conference on Engineering in Medicine and Biology*, 2005, pp. 5182 – 5185.

[2] I. Oppermann, M. Hämäläinen and J. Iinatti (Editors). *UWB Theory and Applications*. John Wiley&Sons Ltd, Chichester, England, 2004.

[3] J.F.M. Gerrits et al., “Principles and Limitations of Ultra-Wideband FM Communications Systems,” *EURASIP Journal on Applied Signal Processing*, vol. 2005, issue 3, pp. 382-396, 2005.

[4] L. Hentilä, A. Taparungssanagorn, H. Viittala and M. Hämäläinen, ”Measurement and Modelling of an UWB Channel at Hospital,” in *Proc. of t he IEEE International Conference on Ultra-Wideband*, 2005.

[5] Federal Communications Commission, “Revision of Part 15 of the Commission’s rules regarding ultra-wideband transmission systems,” First Report and Order, ET Docket 98-153, 2002.

[6] J. Foerster, “Channel Modeling Sub-Committee Report Final,” IEEE P802.15-02/490r1-SG3a, Feb. 2003.

[7] S. Meek and F. Morris, “ABC of Clinical Electrocardiography: Introduction,” *BMJ Journal*, vol. 324, 2002, pp. 415-418.

[8] S. Arnon, D. Bhastekar, D. Kedar and A. Tauber, “A Comparative Study of Wireless Communication Network Configurations for Medical Applications,” *IEEE Wireless Communications*, Feb. 2003, vol. 10, no. 1, pp. 56 – 61.

[9] Delsys Incorporated, “Surface Electromyography: Detection and Recording,” Tutorial, 1996.

[10] R. Tesi, “Ultra Wideband System Performance in the Presence of Interference,” Licentiate Thesis, Department of Electrical and Information Engineering, University of Oulu, Oulu, Finland, 2004.

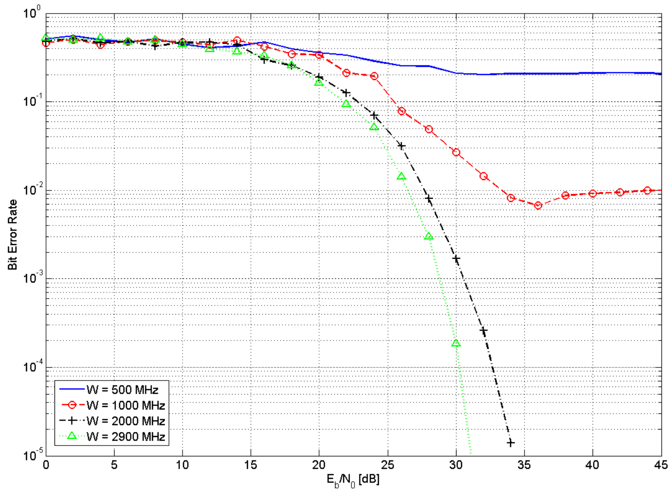

Figure 3: UWB-FM system with various channel bandwidths and data rate of 180 kbps in the OR channel.

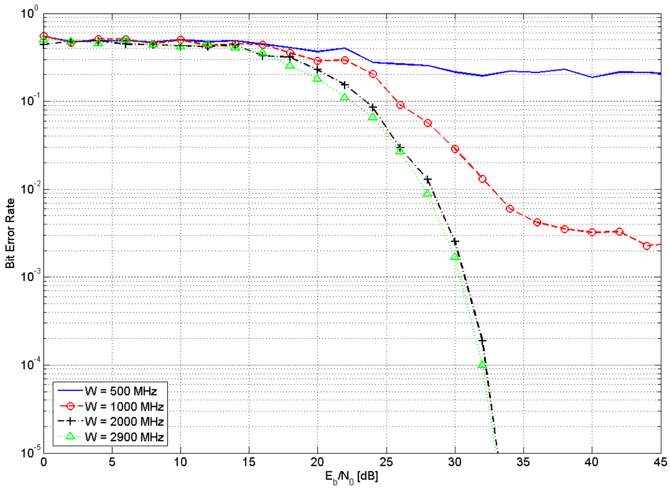

Figure 4: UWB-FM system with various channel bandwidths and data rate of 180 kbps in the ICU channel.

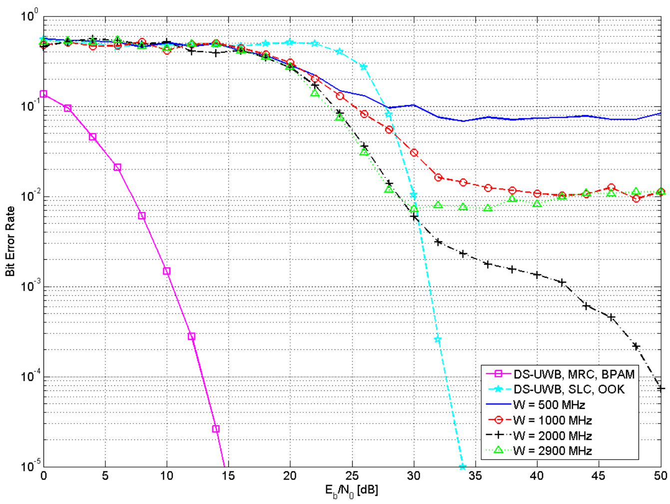

Figure 5: DS-UWB and UWB-FM systems with data rate of 1.8 Mbps in the OR channel.

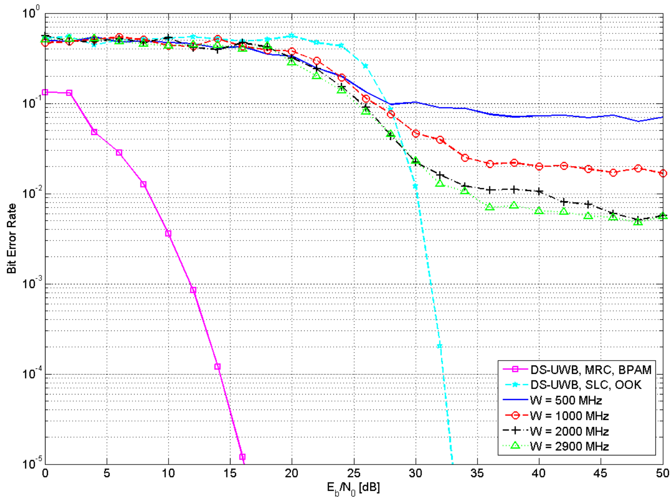

Figure 6: DS-UWB and UWB-FM systems with data rate of 1.8 Mbps in the ICU channel.

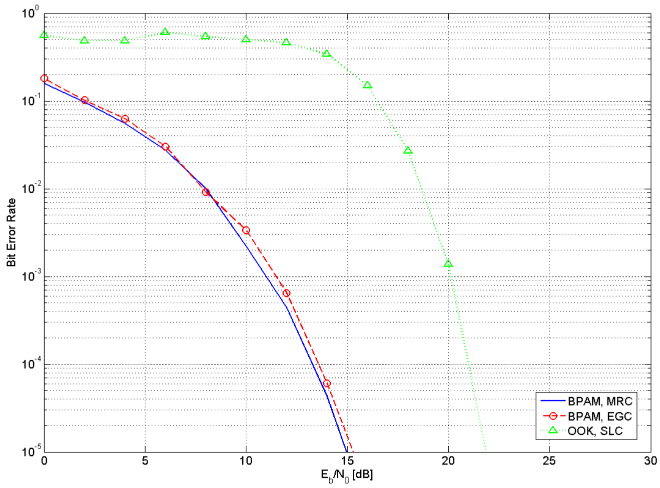

Figure 7: DS-UWB system with different receiver algorithms and data rate of 24 Mbps in the XR channel.