Performance of IEEE 802.15.4a Receivers in Randomized Multiuser Interference in AWGN Channel

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INTRODUCTION

In wireless networks, the development is generally going towards smaller networks as various applications are being developed for different purposes; from local area networks (WLAN) through personal area networks (WPAN) to body area networks (WBAN). For healthcare and welfare sector, WBAN applications offer new solutions for measuring physiological parameters or tracking people or devices. In this area, improvements are needed because the population is aging, in the developed countries especially, and therefore the need of a nursing staff is constantly increasing as well as the relating nursing costs. Wireless measurements enable patients to stay home since the location is not necessary an issue and the measured data can be transferred from various places to a database accessed by the nursing staff in the hospital. Free time activities are also a potential area for WBAN applications since the requirements of the equipment during various sport exercises are similar than in medical applications. [1]
At the moment, there is an ongoing work by the IEEE for a WBAN standard 802.15.6 for low power devices [2]. IEEE published the IEEE 802.15.4a standard in 2007 for low-data-rate, low-power and low-complexity wireless personal area networks [3]. Because WBAN is a part of the WPAN, the IEEE 802.15.4a standard is suitable for body area network studies also. In this paper, ultra wideband (UWB) specifications of IEEE 802.15.4a [3] are followed in the implementation of a Matlab® based simulator. UWB technology offers high bandwidth, ranging capability and reduced receiver complexity due to baseband pulses [4]. The performance of different types of receivers is simulated in additional white Gaussian noise (AWGN) channel in the presence of similar interfering signals as a desired information signal. AWGN is the simplest channel model and chosen as a reference for the future fading channel simulations. The interfering signals can be from the other users of the same or a similar wireless sensor network, i.e., multiuser signals, which are randomly overlapped with the desired signal.

SYSTEM MODEL

The simulator is implemented according to the IEEE 802.15.4a UWB specifications. In impulse radio transmitters, the UWB waveform is expressed as [3]

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

where $g_0^{(k)}$ and $g_1^{(k)}$ are position and phase modulated bits, respectively. Sequence $s_{n+kN_{cpb}} \in\{0,1\}$, n = 0, 1, …, N_{cpb} — 1, is the scrambling code used in the k^{th} interval and $h^{(k)} \in\{0, N_{hop}—1\}$ is the k^{th} burst hopping position defined by the scrambler also. $p(t)$ is the transmitted pulse waveform at the antenna input, T_{BPM} is the half length of a symbol for the position modulation of the burst, T_{burst} is the length of a burst and T_c is the length of a pulse.[3]

Fig.1 presents the symbol structure with eight planned users, each with allocated burst transmission timeslot inside symbol quarters. The first quarter of the symbol is for position modulated zero bit and the third quarter for position modulated one bit. With eight users, a burst can have 1, 2, 16 or 128 pulses with 15.60, 7.80, 0.98 or 0.12 MHz symbol rates, respectively. [3]

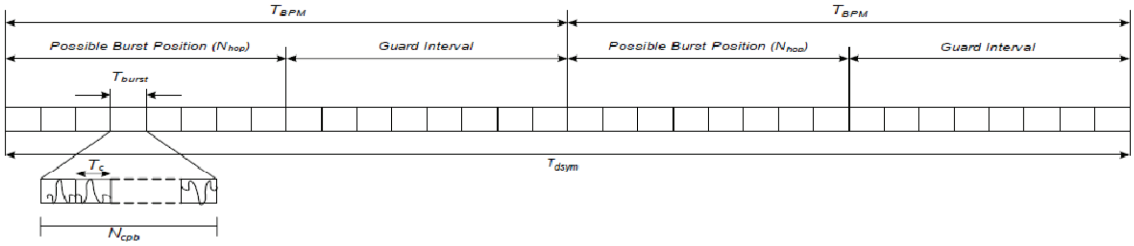

Figure 1. UWB symbol structure in IEEE 802.15.4a with eight users.

The other signals than the desired one are considered as multiuser interference, $x_{if}(t)$, and for the bursts of these signals, the time slot allocation $h^{(k)}$ is not utilized in the modeling. Waveforms from other radio systems are omitted. The starting instants of the transmission of the multiuser bursts are randomized by discrete uniform distribution to any given instant within a symbol quarter allocated by the position modulation. Therefore multiuser bursts can cause total or partial overlapping to the desired information burst, or in the best scenario, the bursts are not overlapping at all. Except for the timeslot allocation, the multiuser signals are built in similar way as the desired signal with equal length of bursts. Therefore, the modeling covers two different scenarios; *i)* the channel destroys the coordinated fashion of the symbol structure or *ii)* the interfering users are from another WBAN system in a close range.

Three different receiver types are investigated in this paper; a coherent receiver, a binary orthogonal non-coherent receiver with and without convolutional coding and an energy detector (ED). Reed-Solomon channel coding is utilized in all the receiver types due to the position modulation of the code bits. Convolutional channel coding is phase modulated and can be detected coherently only.

Coherent detection can be expressed as

$$v_i^{(k)} = \int_q^{q+T_{burst}} r(t-\tau)w(t)\,d\tau,\ i=0,1 \qquad (2)$$

where $r(t) = x(t) + x_{if}(t) + n(t)$, $n(t)$ is additional Gaussian noise and $w(t)$ is a reference burst, either equal to or opposite in polarity to the transmitted burst. $q = k2T_{BPM} + iT_{BPM} + h^{(k)}T_{burst}$, defines the starting point of the integration which is assumed to be known exactly.

Since the transmitted signal is both position and phase modulated, the detection of the position modulated bit has to be done in a non-coherent manner. The comparison of the absolute values defines which position modulated binary number has been received in the non-coherent receiver

$$\left|v_0^{(k)}\right| \underset{"1"}{\overset{"0"}{\gtrless}} \left|v_1^{(k)}\right|. \tag{3}$$

If $v_0^{(k)}$ is bigger than $v_1^{(k)}$, the received position modulated bit is '0', otherwise '1'.
The phase modulated bit is detected by taking the correlation output described in (2) based on the position modulation result in (3)

$$v_0^{(k)}, v_1^{(k)} \underset{"0"}{\overset{"1"}{\gtrless}} 0\ . \tag{4}$$

Comparison is made to zero, i.e., bigger than zero, the phase modulated bit is '1', '0' otherwise.
In ED, an ideal band-pass filter is used to reduce the noise. The decision variable in ED is expressed as

$$w_i^{(k)} = \int_q^{q+T_{burst}} r(t)^2\, dt,\ i=0,1. \tag{5}$$

A comparison is made between the decision variables in order to detect the received bit

$$w_0^{(k)} \underset{"1"}{\overset{"0"}{\gtrless}} w_1^{(k)}\ . \tag{6}$$

RESULTS

Fig.2 presents the results for two different data rates, thus different burst lengths. With data rate of 0.98 MHz there are 16 pulses in a burst and with 7.80 MHz 2 pulses in a burst [3]. Different colors of the curves present different receiver types. The bit error rate (BER) results are presented as a function of E_b/N_0, i.e., energy of bit over noise. The energy of a bit, independent of the number of pulses in a burst, is always normalized to one. In the simulations, 1.155×10^6 bits per E_b/N_0 value was simulated.
Coherent receiver offers the best performance in terms of BER. Non-coherent receiver with convolutional channel coding has approximately 2 dB worse performance. Without the convolutional coding in the non-coherent receiver, the difference in performance is approximately 4.5 dB worse when compared to the reference coherent receiver.
The performance of ED depends on the burst length, due to the receiver operation presented in (5). With long burst, the integrated noise increases and therefore the performance with short burst is better. The difference in performance compared to non-coherent receiver without convolutional coding changes from 2 dB to approximately 5 dB, depending on the burst length in ED.
For coherent and non-coherent receivers, having more pulses in a burst offers robustness against randomized overlapping multiuser interference in AWGN. For a short burst, multiuser interference seems to have more impact on the performance of coherent and non-coherent receivers. With both burst lengths, ED seems to be very

vulnerable for the multiuser interference as can be seen from the Fig.2. Even one randomly overlapping multiuser signal corrupts the detection of the desired signal.

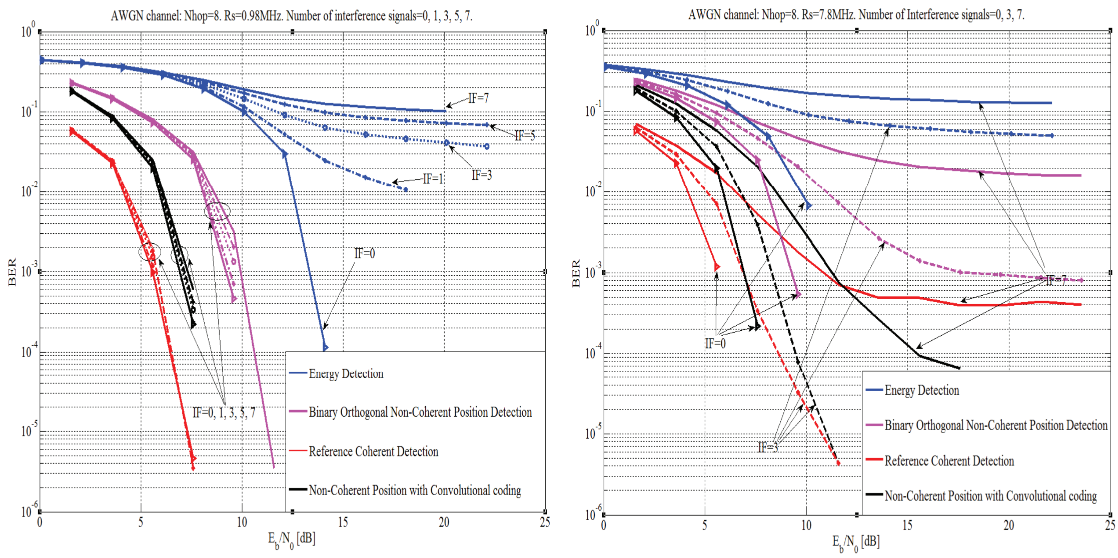

Figure 2. Effect of multiuser interference on different receiver types.

CONCLUSIONS

The presented results are in AWGN, without the time slot allocation for the interfering signals and the signals are randomly overlapping. In a real WBAN channel, the time slot allocation would be applied but on the other hand the channel would lenghten the signal causing inter symbol interference and multiuser interference.

The results show a general conclusion that with the most complex receiver structure is achieved the best performance, coherent receiver being the best and ED the worst receiver in terms of BER. In non-coherent receiver with short burst especially, having convolutional channel coding in the case of many multiuser signals provides significant improvement in the performance when compared to the non-coherent receiver without convolutional coding. From the burst length point of view, longer the burst, thus smaller data rate, better the robustness against multiuser interference signals. Only exception is ED, which is equally vulnerable to multiuser interference with different lengths of bursts, i.e., with different data rates.

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