Performance of UWB Receivers Using IEEE802.15.4a's Minimum Burst Lengths

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Abstract – In this paper, the performances of different kinds of IEEE802.15.4a receivers, which are suitable for the modulation methods and their combinations defined by the standard, are compared using two dissimilar channel models for wireless body area networks. The reference channel model is the one defined by the IEEE802.15.6 standardization group, and the other one is based on the channel measurements carried out by the Centre for Wireless Communications, University of Oulu, Finland. Both channel models are targeted for wireless body area network applications. The studied information signal structure follows the IEEE802.15.4a standard, having two pulses in a burst, and either two or eight burst positions per symbol quarter. This signal structure is non-mandatory according to the standard. Following the standard, the mode with two pulses per burst and two hopping positions gives the shortest symbol duration. Because this symbol duration is shorter than a delay spread of the channel, the signal is vulnerable for severe inter-symbol interference. Our main interest is to compare the performances of this specific signal structure, with different receiver structures from the standard, and compare the results to the corresponding results of the mandatory mode signaling presented in our earlier publications.

Index Terms - channel model; coherent; energy detection; non-coherent; ultra wideband;

I. INTRODUCTION

Wireless body area networks (WBAN) can be seen as one of the growing application areas in the personalized communication. WBAN can provide tools for remote monitoring of human physiological parameters in medical, welfare or sport applications, as well as being part of the entertainment activities.

For example, the IEEE802.15.6 standardization group has been developing a new standard for WBAN use [1]. When writing this, the final standard is not publicly available yet. However, the general ideas about the functionalities of the IEEE802.15.6 are available. Before going into details on the performances of the receiver's that are based on the coming standard, the existing IEEE802.15.4a [2], which is also possible technique for WBAN communication, has been studied in more details. IEEE802.15.4a defines signal structure enabling the use of different receiver types for impulse radio ultra wideband (UWB) communication. The standard defines several combinations for UWB physical layer with different data rates, timing related parameters and two modulation methods. In addition, [2] defines a mandatory mode, which need to be supported by all the devices that are compatible with the standard. This paper extends the performance studies out of the mandatory mode of the standard which is covered more thoroughly.

The comparative studies for mandatory mode UWB receivers' performances have been reported, e.g., in [3]-[9]. Mandatory mode is utilizing symbol structure, which consists of 16 pulses per symbol and eight orthogonal time slots providing more multiuser interference rejection, and can be allocated for eight orthogonal users. This paper is focused on the signal structure, which is consisted of two pulses per symbol, and burst duration of 4.01 ns. In the mandatory mode, the burst duration is around 32 ns [2]. As can be seen, there is a big difference in the burst durations. In all the studied cases here, the burst length has been 4 ns due to the pulse width that follows the standard being 2 ns. Two different symbol lengths have also been taken into account.

II. SYSTEM MODEL

As already mentioned, the system model in this study follows the IEE802.15.4a standard. The channel models used in the study are IEEE802.15.6 model [10] and CWC's WBAN channel model for hospital environment, reported in [11]-[12]. The results in this paper are presented for the case with one active user only.

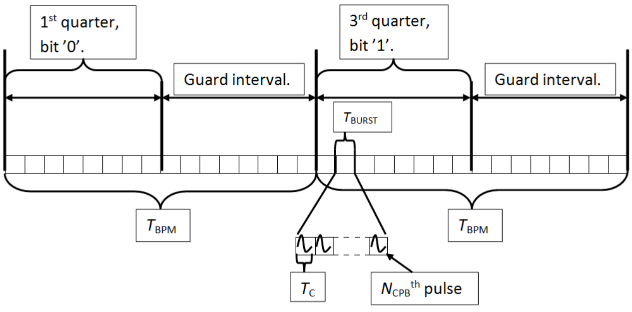

Figure 1. The frame structure for the IEEE802.15.4a symbol.

As Figure 1 shows, the frame structure of the IEEE802.15.4a symbol is based on four quarters, where the 1st and the 3rd quarters are reserved for position modulated information burst. The 2nd and the 4th quarters are guard intervals which are used to minimize inter-symbol interface (ISI) caused by the radio channel. Depending on the number of pulses used to create a burst, number of burst hopping positions to form one symbol, and a selected data rate for a system, the overall length of a symbol frame is changing. At the minimum, the symbol duration can be as small as 32.05 ns, if only two pulses per burst are used, and the symbol quarter consists of two burst hopping positions. On the other hand, the maximum symbol duration consisting of either 512 or 32 burst hopping positions per symbol is 8205.13 ns [2].

A. Channel model

The main difference between the channel models used in the study are related to impulse response and the energy deviation within them. The average numbers of detectable propagation paths in the standard model and CWC model are 38 and >500, respectively. The corresponding path separation times are 1.85 ns and 0.125 ns, and delay spreads ~90 ns and less than 10 ns, respectively. The energy distribution, thus the form of the channel impulse response, is more focused on shorter delays in the CWC's model than in the IEEE802.15.6 model, as shown in [9], and Figure 2. Comparison between the models and their impact on the system performances are discussed in [13] in more details. As can be seen, different channel models are deviating significantly from each others. Depending on the signal structure, the impact of the channel model on system performance may also deviate a lot. For example, if a delay spread is long, short symbols will meet severe ISI in the channel but long symbols may be correctly detected.

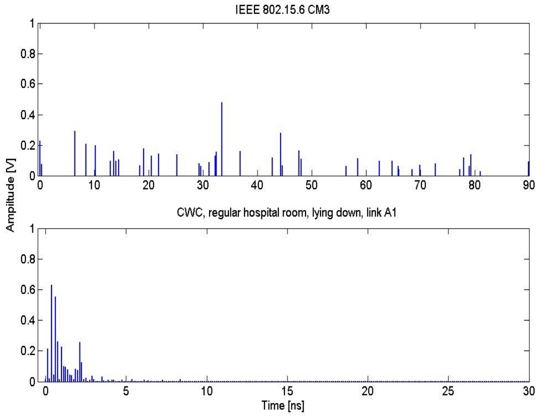

Figure 2. WBAN channel models used in the study.

B. Receiver types and signal structure

The IEEE802.15.4a standard based receivers are energy detector (ED) and binary orthogonal non-coherent receiver. The latter one is utilizing both burst position modulation (BPM) and binary phase shift keying (BPSK). The detection combinations for different types of receivers can be found from [7]. Based on the standard signal modeling, there are altogether six different kinds of receiver structures and combinations of detection methods which are used in this study. The simplest detector is a pure energy detector. The other detector types are using either coherent detection or combination of both non-coherent and coherent methods. Also the impact of convolutional coding on non-coherent detector is presented here.

The comparative results for mandatory mode signaling of IEEE802.15.4a system can be found from [3]-[9]. In this paper, the signal structure, which is utilizing the shortest symbol duration from [2], is studied yet having the same burst duration of 4 ns and compared to a longer symbol duration, which results can be found from the referred earlier publications. The most important deviation in the comparison presented here is the ratio between the symbol length and the length of the delay spread (in both studied channels), as the burst length is kept the same all the time. In the mandatory mode, the symbol length is around 1025 ns, which is considerably longer than the channel's delay spread, and therefore ISI is not too bad. The compared symbol lengths are 32 ns and 128 ns. If a transmitted symbol is combination of two pulses each lasting 2 ns, ISI can have a major impact on the system performance.

III. RESULTS

In this chapter, the results are analyzed and a comparison between the corresponding results for mandatory mode signal is presented. As has been pointed out in Chapter II, the channel impulse response has a great influence on the studied system performance. When dealing with short symbols, whose length is shorter than the channel's delay spread, like is the case in this study, the channel's role will be emphasized from the system's performance viewpoint.

The following comparison is carried out for performances of the receivers utilizing either selective rake (S-rake) [14] or partial rake (P-rake) receiver [15]. The difference between S- and P-rake receivers is that S-rake collects energy from the N strongest propagation paths but P-rake utilizes the N first distinguishable paths, which are not necessary the strongest ones.

Comparing the results from Figures 3 and 4, it can be seen that the performances of different kinds of S-rake detectors with 5 fingers will deviate significantly depending on the channel characteristics. If the channel model has energy concentration in shorter delays, like is the case in CWC's model, all the receivers will fit within 5 dB in the bit-error-rate (BER) level of 10^{-3}. Receivers in the IEEE802.15.6 standard CM3 channel model, however, give rather good performances, but also qualities that cannot be accepted. Some detectors will saturate above the reference 10^{-3} BER-level. In the case of CWC's model, the length of the symbol, being either 32 or 128 ns (i.e., the number of burst positions inside a symbol quarter is 2 and 8, respectively), gives similar performance. The IEEE802.15.6 model causes deviation also for different symbol lengths. In this channel, the longer symbol gives better performance. The receivers with the mandatory mode's signals in CWC's channel are performing almost the same than with the short bursts, as shown in [9]. However, if the channel model is the one proposed by the IEEE802.15.6, the use of short symbols decreases significantly the system performances of the simplest detectors. If signal can be detected coherently, receivers with both symbol structures are behaving similarly. Always, when using two pulses per symbol, the case where more empty time slots are between the consecutive bursts within a symbol performs better in the IEEE802.15.6 channel, and therefore deviates also less from the performance of the mandatory mode's signaling.

If studying P-rake's performance as a function of number of rake fingers, it can be seen that the performance saturates with smaller amount of rake fingers in the CWC channel than in the IEEE channel. These results are shown in Figures 5 and 6. This behavior can be explained by the sparsely populated propagation paths in the IEEE model. The model includes more energy in longer delays, and therefore increasing the number of fingers will also improve the system performance. The same BER level will be achieved using 5 to 7 fingers more, if shorter symbol is transmitted instead of using a mandatory mode's length. If the channel impulse response follows the CWC's model, there is no need for more than 10 fingers with the fixed E_b/N_0 = 13 dB. The IEEE model gives performance improvement also with high, meaning useless, amount of fingers from the implementation point-of-view. If comparing the P-rake results having short symbols to the corresponding results for mandatory mode signaling which are presented in [9], it can be noticed that there is no difference in the performances between different receiver structures. The results are more or less the same for longer symbol having two pulses per burst though the symbol duration is eight time shorter than in the case of mandatory mode's symbol. If the minimum length symbol is transmitted, there is a need for 5 to 7 more rake fingers to keep the same performance. As always, the final decision is a trade of between the implementation and quality-of-service.

In Figure 7, the performance of energy detector is studied in a manner that the integration time is extended from the symbol duration. Again, similar kinds of trends in behaviors than in P-rake's case can be seen if longer symbol is used. The IEEE channel provides more energy in longer delays than the CWC's model, which can be exploited by increasing the integration time. The best performance is obtained with 55 – 60 ns extension when longer symbols are used. However, using a very short symbol, the overall system performance is unfit for real operation. On the other hand, the signal energy is concentrated on shorter delays if CWC's channel model is valid, and that is why there is no need to extend the integration time too much. Only minor improvement can be seen if increasing the integration time from the burst duration. Additional extension starts to collect more noise and is decreasing the system performance. This is more severe in the case of short symbol duration. If comparing the results to the mandatory mode's performance, short symbols need more integration time extension to maintain the same BER. However, this is due to the fact that mandatory mode is using longer symbols, which are longer than the channel's delay spread. In this case, the straight comparison between the extension times cannot be done due to the lengths of the relative durations if compared to the actual burst durations.

IV. CONCLUSIONS

This paper provides a comparative analysis between two signal structures for IEEE802.15.4a based UWB WBAN system. The performance analysis is carried out for two different WBAN channels; IEEE802.15.6 and CWC's WBAN channel models. Our previous papers have been studied IEEE802.15.4a receiver performances using the mandatory mode of the signaling, proposed by the standard. In this paper, we have carried out comparative studies using two the shortest symbol lengths the standard defines, still having 2 pulses per burst. The main goal has been to study the applicability of short symbols in WBAN communications because the signal structure is highly affected by the channel delay spread, which is now much longer than the symbol duration.

Based on the simulations, it can be showed that also signal which consists of two pulses per burst, and either two or eight burst positions per symbol can be used in WBANs. A frame structure which supports higher data rates (i.e., shorter symbols) gives reasonable results if the energy in the channel is concentrating on the short delays. The system performance degrades when the energy will disperse in the delay domain.

For example, a mandatory mode and shorter symbols are reaching the same BER=10^{-3} level using similar S- or P-rake, the IEEE802.15.6 model causes much higher deviation, or even prevent the use of certain detectors, especially with the 32 ns symbol duration. At CWC's channel, the performances are comparable. The ED detector, however, is unusable if the channel profile follows the one of IEEE802.15.6 and shortest symbol structure is used.

ACKNOWLEDGMENT

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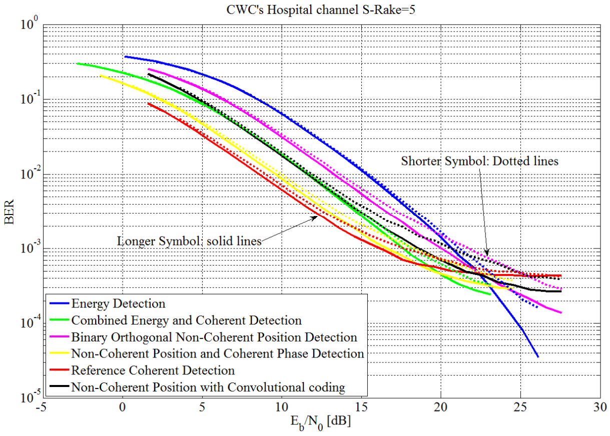

Figure 3. BER as a function of E_b/N_0. S-rake with 5 fingers. CWC's WBAN channel model for hospital environment.

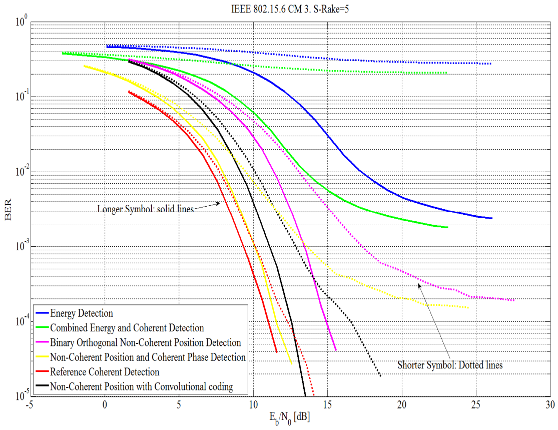

Figure 4. BER as a function of E_b/N_0. S-rake with 5 fingers. IEEE802.15.6 WBAN channel model.

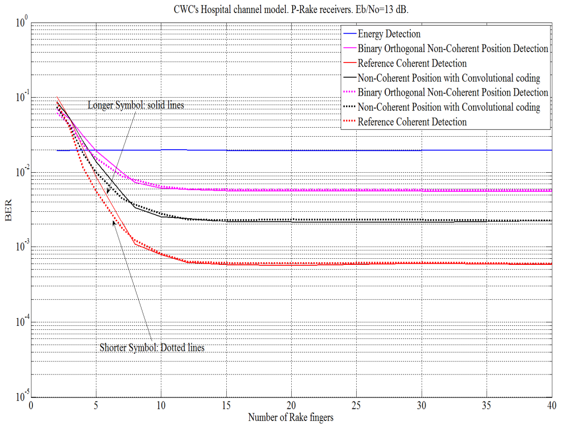

Figure 5. Impact of rake branches on bit error rate. P-rake, E_b/N_0 = 13 dB. CWC's WBAN channel model for hospital environment.

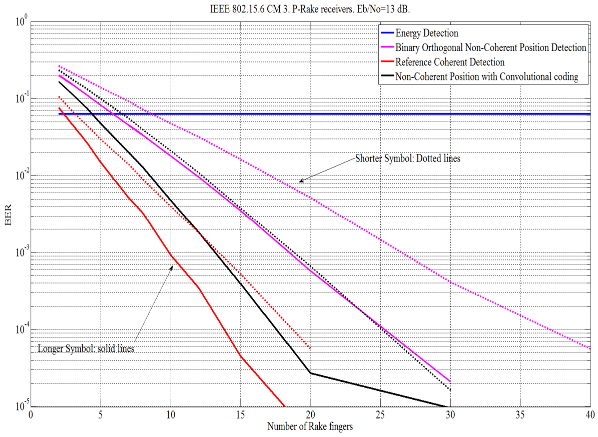

Figure 6. Impact of rake branches on bit error rate. P-rake, E_b/N_0 = 13 dB. IEEE802.15.6 WBAN channel model.

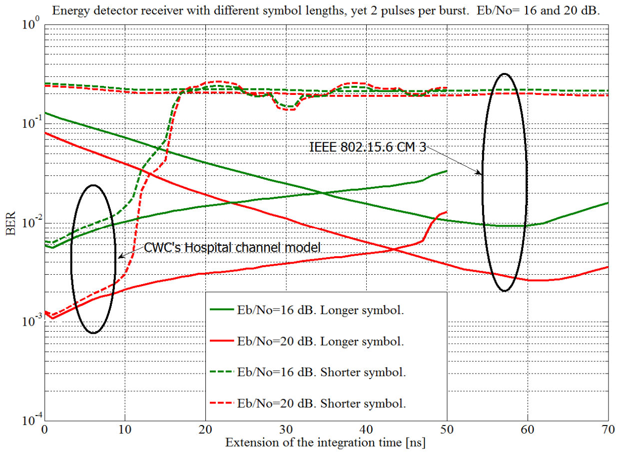

Figure 7. Impact of extension in integration time for energy detector. Both IEEE802.15.6 and CWC's channel models are used.