

UWB Receiver Performance Comparison

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Abstract: The BER performance of the imperfect matched filter (IMF) is compared to the BER performance of the transmit reference (TR) receiver in a typical office multi-user scenario assuming LOS/NLOS conditions for the terminals. Due to the extremely high processing requirements of the matched filter, it is assumed that for an implementation the number of bits as well as the number of filter coefficients for the correlation template signal representation has to be as low as possible introducing implementation loss. Further imperfect channel estimation is taken into account. The resulting BER performance of the IMF receiver is compared to the BER performance of the TR receiver, which has been modified compared to original concept with regards to a) time gating, i.e. the integration is just performed in the time interval where significant pulse energy is received, b) 2PAM/M-PPM modulation, and c) optional reference pulse averaging. The results show, that both receiver types can reach the uncoded target BER of 10^{-2} in all environments investigated. However the IMF receiver outperforms the TR receiver by about 3 dB in LOS and by about 7 dB in NLOS. For the IMF receiver the required Eb/No ratio to achieve the target BER strongly depends on the number of filter coefficients. More details can be found in the final deliverable of the UWB work package of the European research project whyless.com [1].

1 Introduction

On February 14th 2002 the United States Federal Communications Commission (FCC) adopted a „First Report and Order“ that permits the marketing and operation of a new radio transmission technology. The technology referred to is Ultra Wideband (UWB) and it goes with „great promises for public safety, businesses and consumers in a variety of applications“. This high number of different applications in their specific environments require different types of UWB receivers regarding data rate, power consumption and implementation complexity. The original idea of UWB transmission was to apply impulsive, also called carrier-less, radio transmission schemes with low duty cycles (even if the current IEEE standardisation process only two final candidates are left – both not falling within this category). Basically very narrow impulses are transmitted occupying a huge amount of radio spectrum instantaneously following certain time hopping (TH) patterns, which differentiate the different transmission channels. This kind of transmission scheme allows a number of M-ary modulation schemes to be applied, as there are overlapping of disjoint pulse position modulation (OPPM, DJPPM) and pulse amplitude modulation (PAM) and their combination. All of them can be demodulated in the receiver with different concepts implying differences in complexity and performance. Examples are the MF, the RAKE or the TR. Any of them have been investigated in previous work [2, 3, 4]. For the MF the processing requirements for the correlation in the digital domain are extremely high due to

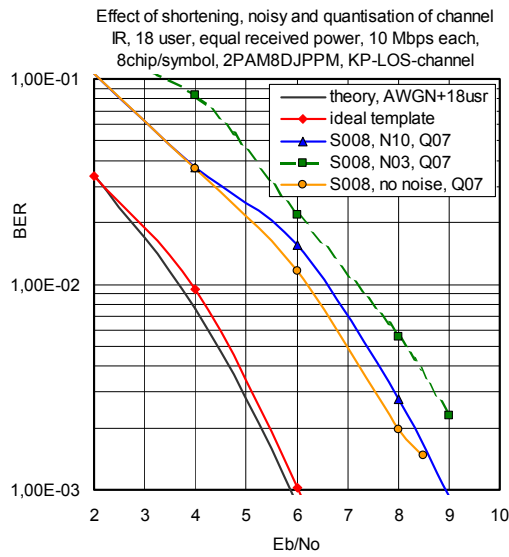
the a sampling rate in the order of GHz. When it comes to implementation, the number of bits for signal quantisation has to be significantly reduced, as well as the number of filter coefficients. With regards to the not perfect channel estimation the filter coefficients are wrong to a certain degree, which can be modelled by adding white Gaussian noise before quantisation. Many simulations in recent work assumed that the received pulse shape is perfectly known. Here the combined effect of having all three mentioned imperfections in the receiver is investigated in order to have a fair comparison with the TR receiver in terms of complexity. So the matched filter (MF) receiver becomes the imperfect matched filter (IMF) receiver. On the other side the TR receiver is not affected by quantisation as the correlation is done in the analog domain. Also timing errors are less critical, as long as the delay in between the reference pulse and the modulated pulse is exactly known. The TR performance is investigated in single and multi-user environments under LOS/NLOS conditions. For the latter, different system loads are analysed ranging from accumulated data rates in between 10 Mbps and 200 Mbps

2 Performance of MF-like Receiver

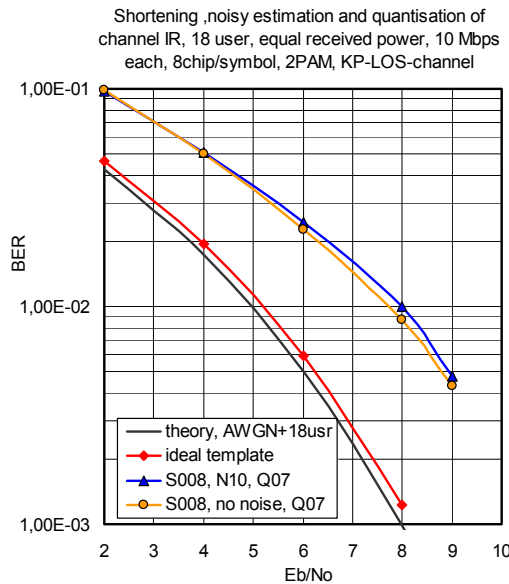
The performance of MF filter like implementations will degrade from the ideal performance including real world constraints such as finite word width of template (quantisation of filter coefficients), noisy channel estimates due to varying channel conditions, and last but not least finite length of the correlation template or say number of filter coefficients depending on the implementation of the receiver. As the influence on the BER performance of the receiver is hardly possible to predict, a large number of computer simulations have been performed to estimate the degree of degradation of receiver performance. The *ideal receiver* performance has been simulated and calculated for 2PAM, 2PAM-2DJPPM, 2PAM-4DJPPM and 2PAM-8DJPPM and is shown in [1]. Simulation parameter are set as in this work. There are 18 user links with 10 Mbit/s user data rate each, which are completely asynchronous and separated by their TH-code only. The received power level is the same for all links (as in a power controlled up-link scenario of a central station). All use the same modulation scheme. The UWB radio channel is modelled using the model developed by Kunisch and Pamp [5]. An office of 5m x 5m size is assumed where the 18 user are randomly distributed. One of them is the receiver under observation while the others are the interfering users. The radio channel model is hybrid, combining deterministic and stochastic parts, so the 18 users are correlated in a sense by the room geometry. For more information please refer to [1] and [5].

The significant UWB impulse response in indoor environment has about 20-40 ns excess delay. At a sampling rate of 12.8 GHz this corresponds to 250 to 500 MF coefficients for the case of ideal MF. Figure 2.1 shows

the effect of limiting the number of filter coefficients down to 512, 256, 128, 64, 32, 16 and 8 for 2PAM8DJPPM in the given multi-user scenario in LOS [5] environment assuming that only one pulse is used for a symbol transmission. It appears interesting to note, that once the template length has been cut down to 64 a further reduction to 32, 16 and even down to 8 coefficients hardly changes the BER performance. In NLOS [5] case the template limited to 512 coefficients already causes a loss of about 2 dB compared to the case of the unshortened template. The effect of shortening the correlation template (or reducing the number of filter coefficients) degrades the UWB system much more severe in case of NLOS, where the impulse responses typically have a very large excess delay of 40 ns or even more up to 60 ns.



a) 2PAM8DJPPM



b) 2PAM (pulse flipping)

Figure 2.1 Combined effect of shortening, noisy channel estimate and coefficient quantisation for KP-LOS, 18 user, 10 Mbps each, 8 pulses per symbol.

There have been numerous sets of simulation performed before selecting the number of samples to be shortened down to, the variance of the noise to be added (to consider not perfect channel estimation) and the number of quantisation steps for this combined simulation. The motivation was to reduce the MF receiver complexity as much as possible keeping the possibility to provide an uncoded BER of about 10^{-2} , which is shown to sufficient applying TURBO codes for the forward error correction [1]. Finally the parameter set derived for LOS environment is: shortening down to 8 samples, degrading the SNR of the template down to 10 dB and reducing the number of quantisation levels down to 7. The results for 2PAM and 2PAM8DJPPM for this set of parameter is shown in Figure 2.1. The implementation degradation at the target BER of 10^{-2} is about 3 dB. For the NLOS case there has been a different parameter set derived: shortening variable from 8 to 64 samples, template SNR: 10 dB, quantisation levels: 15. The shortening has the most significant influence in case of NLOS. Therefore the results are displayed in more detail in Figure 2.2.

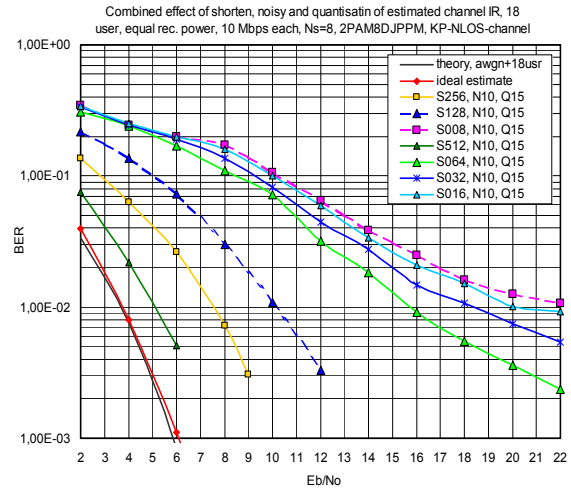


Figure 2.2 Combined effect of shortening, noisy channel estimation and coefficient quantisation for 2PAM8DJPPM in KP-NLOS, 18 user, 10 Mbps each, 8 pulses per symbol.

For 2PAM8DJPPM the implementation loss at the target BER of 10^{-2} is about 18 dB if the shortening is reduced down to 8 samples, see Figure 2.2. If the template length however is allowed to have 64 samples, the implementation loss then comes down to 12 dB and if the template could be as long as 128 samples the loss still is about 6 dB compared to the ideal MF receiver. There is hardly any difference if $N_s=1$ or $N_s=8$ pulses are used for a symbol transmission, however $N_s=8$ performs slightly better. More details can be found in [1]. In case of 2PAM there is hardly any difference visible between $N_s=1$ and $N_s=8$ simulation results. In Figure 2.3 there is the result for $N_s=1$ shown as an example. The BER performance of the 2PAM scheme is slightly worse than the 2PAM8DJPPM scheme. The implementation loss is about 15 dB for the shortening down to 64 samples template length and about 7 dB for a template length of 128. As in the case of 2PAM8DJPPM the influence of shortening the correlation template (or the filter implemented in the receiver) is significant. However, if there is sufficient E_b/N_0 available the target BER of 10^{-2} can be reached in all cases maintaining the cumulative data rate of 180 Mbit/s for all 18 users in the area.

A major result of this investigation is the feasibility of a MF like receiver to operate in the LOS and NLOS environment with various UWB modulation schemes ranging from 2PAM up to 2PAM8DJPPM, even if its implementation complexity is reduced very much to a fair grade compared to a TR receiver demodulator implementation.

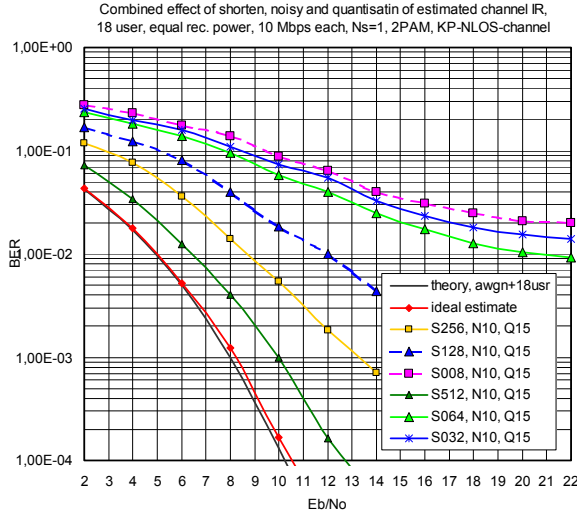


Figure 2.3 Combined effect of shortening, noisy channel estimation and coefficient quantisation for 2PAM in KP-NLOS, 18 user, 10 Mbps each, 1 pulse per symbol.

3 Performance of a TR receiver type

The transmit reference (TR) concept allows to exploit the multi-path diversity without requiring channel estimation in the receiver. Instead of sending one modulated pulse per frame, the TR transmitter places a second unmodulated pulse in front of the modulated pulse, which serves as a reference for the correlation in the receiver. Certainly, using a noisy reference signal is a suboptimum solution, but it allows to implement the correlation in the analog domain, which significantly simplifies the receiver implementation. Furthermore, the performance can be improved by time gating, reducing the integration to the time interval where significant pulse energy is present instead of integrating over complete frames as proposed in [4].

This section examines the performance of a TR based transceiver concept in multi-user environments as a function of the total data rate in the system. The simulation assumptions are identical to those reported in the previous section. The TR scheme is combined with 2PAM/ M -PPM modulation assuming a PPM offset of 10 ns, which is also equal to the distance between the reference pulse and the first possible PPM position of the modulated pulse. Two different implementations of the TR are taken into account. The ‘basic’ concept assumes that only the reference symbol of the actual frame is used for the correlation, while the ‘averaging (av)’ concept applies an averaging on the reference pulses of three successive frames in order to improve the SNR.

For LOS conditions a significant part of the received energy is concentrated in the direct path. The optimum filter length has been shown to be in the order of the transmitted pulse length. Using a sampling rate of 12.8 GHz for the simulation this corresponds to a filter length (FL) of 10 samples. The uncoded BER results measured at the basic and the

averaging TR receiver output are presented in Figure 3.1 for different E_b/N_o ratios.

The figure in the upper left corner assumes an E_b/N_o of 12 dB, the figure on the right side an E_b/N_o of 18 dB and finally the figure in the second row a E_b/N_o of 24 dB. The different data rates on the x -axis are obtained by simultaneously modifying the data rates of all links. For the basic concept the transmit energy is equally distributed on the reference and modulated pulse. Nevertheless, the energy of the reference pulse should be smaller when using the averaging concept. Simulations have shown that the optimum value is in the order of 35% to 40% of the transmitted bit energy for the considered simulation scenarios. The latter value has been used for the simulations presented. As the amount of multi-user interference depends on the received pulse shapes of the 18 links, it is reasonable to perform the simulations on different sets of LOS responses. The BER results are an average on 10 different LOS scenarios.

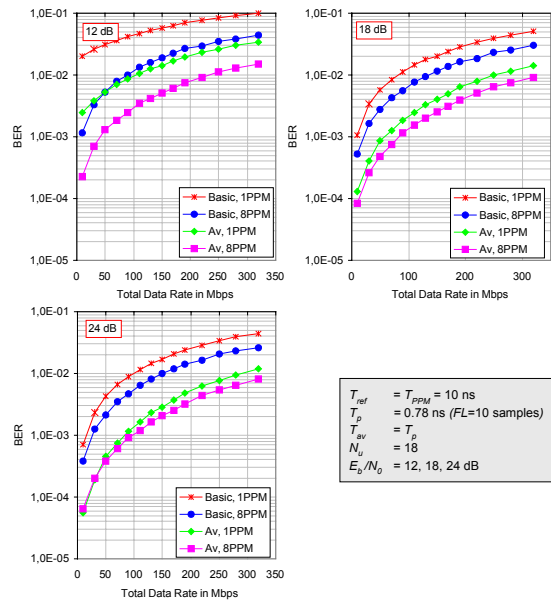


Figure 3.1: Mean BER results of the basic and the averaging (av) concept as a function of the accumulated data rate, the PPM size M (1, 8) and the E_b/N_o ratio.

If a maximum uncoded BER lower than 10^{-2} is assumed to be a reasonable value, the maximum total data rate in the system is in the order of 100 Mbps for the basic TR concept with 2PAM modulation. The supported data rate can be increased to 150 Mbps by adding PPM modulation with 8 pulse positions. Finally, the 3 reference pulse averaging concept allows to transmit a total data rate of 270 Mbps using 2PAM and slightly above 300 Mbps for 8PPM/2PAM. It is interesting to see that the difference between 2 PAM and 8PPM/2PAM is larger for smaller E_b/N_o values, while the gain of increasing the PPM size becomes significantly smaller in an interference limited scenario.

For the LOS simulations inter-pulse interference of a single link has only a minor impact as the pulse distances are considerably larger than the channel delay spread. If the LOS conditions are replaced by NLOS, the received energy is widely spread in time and inter-pulse interference may significantly deteriorate the TR performance. Nevertheless, the interference impact can at least partly be eliminated by simple DC offset compensation prior to the 2PAM detection [1]. The dependency of the uncoded BER as a function of

the accumulated data rate for NLOS conditions is shown in Figure 3.2 for two different E_b/N_o ratios.

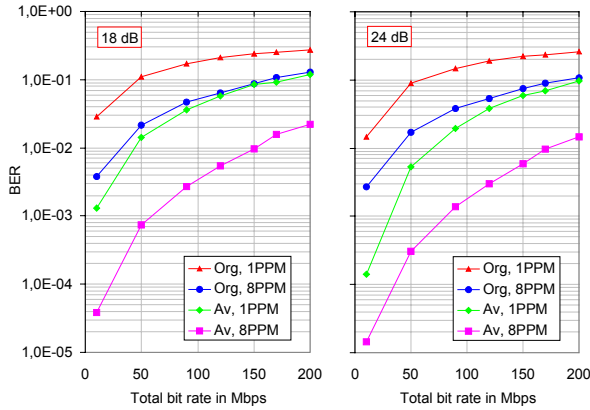


Figure 3.2: Mean BER results of the basic and the averaging (av) concept as a function of the accumulated data rate, the PPM size M (1, 8) and the E_b/N_o ratio.

The parameters are identical to the parameters of the LOS simulation, despite the integration length which is increased to 10 ns for both concepts. The figure on the left side assumes an E_b/N_o of 18 dB, while on the right side the results are shown for an E_b/N_o of 24 dB. The maximum achievable data rate is now limited to 170 Mbps using a 2PAM/8PPM averaging concept with respect of a BER of 10^{-2} . Without PPM modulation this value is reduced to 70 Mbps. The basic concept just allows for a data rate of around 40 Mbps applying 2PAM/8PPM modulation. For the simplest concept the total data rate is even below 10 Mbps.

4 Conclusion

The performance of two receiver concepts, i.e. the imperfect matched filter (IMF) and the TR receiver, is now compared for a total data rate of 180 Mbps and a target uncoded BER is 10^{-2} . For the MF a 7 level quantisation is applied, while the pulse template is assumed to be quite accurately known (SNR=10 dB). If all links are in LOS with the desired receiver, the imperfect MF requires an E_b/N_o of around 8 dB for a filter length of 8 samples and 2PAM modulation. One additional dB can be gained extending the modulation scheme to 2PAM/8PPM. For the TR receiver, the total data rate of 180 Mbps is already too high to achieve the target BER with the basic concept. The averaging concepts needs an E_b/N_o of around 14 dB applying 2PAM modulation and 11 dB using a 2PAM/8PPM scheme. Compared to the short imperfect MF this concludes in a loss of approximately 3 to 4 dB.

The performance loss is significantly larger in a NLOS scenario. If only 2PAM modulation is used, the minimum filter length of the MF is now in the order of 64 samples to achieve the target BER with a E_b/N_o ratio of 20 dB. Nevertheless 8 dB can be gained by doubling the filter length to 128 samples. Using 2PAM/8PPM modulation

reduces the required E_b/N_o to 16 dB for a filter length of 64 samples and to 10 dB for 128 samples. The basic TR receiver concept is again not able to achieve the target BER in the considered E_b/N_o range and also the averaging concepts needs to be combined with a higher order modulation scheme. A combination with 2PAM/8PPM modulation requires a E_b/N_o of 23 dB, which is around 7 dB above the 64 sample MF result.

Although one can argue that the MF additionally suffers from timing jitter, one can conclude that the MF is capable to considerably outperform the TR receiver at the cost of complexity. The simulation results presented in [1] proof that at least in NLOS situations the required filter length might be quite large. Furthermore, the filter coefficients need to be estimated and tracked. While the MF is well suited for high data rate applications, the high processing requirements hamper the production for low cost, low power transceivers. The low cost market can be much better addressed using the TR based concept, where the typical required data rates are significantly lower.

5 Acknowledgement

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