DESIGN AND PERFORMANCE ANALYSIS OF AN IMPULSE RADIO ULTRAWIDEBAND MULTIUSER TRANSMISSION SCHEME FOR WIRELESS PERSONAL AREA NETWORKS APPLICATIONS

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ABSTRACT

A scalable Impulse Radio (IR) Ultrawideband (UWB) air interface is proposed for Low Data Rate (LDR) Wireless Personal Area Network (WPAN) applications. Reduced-complexity transmitter and receiver designs are also proposed. The performance of the proposed IR-UWB multi-user system is investigated in PAN propagation environments. Various different receiver detection techniques are compared and it is shown that in the case of a multipath channel, the Windowed Signal Multiplication (WSM) scheme outperforms other potential detectors based on pulse template generation.

1. INTRODUCTION

Impulse Radio (IR) Ultra WideBand (UWB) technology is a well known transmission scheme using very narrow pulses (nominally picoseconds to nanoseconds) in the time-domain. If the transmitted pulse is of duration T_m in the time-domain, its energy is spread between DC and approximately $2/T_m$ Hz in the frequency domain. We consider IR UWB as a multi-user transmission scheme and we investigate its suitability for the short range (to about 10m) transmission scenarios in the PAN framework. The envisaged data rate transmission is low data rate, in range of 1kbps up to 10Mbps. Previous studies for low-complexity IR-UWB systems focused on transmission schemes for single user scenarios, without time-hoping codes, e.g. [1]. The investigated reference system model[1] in MAGNET [2] employs a time-hopping transmission scheme for multiple access users. The used time hopping codes are of a fixed length and are chosen as pseudo-random variables (integers) taking values in a given range, according to the number of users accommodated. The transmitted signal corresponding to each user is linearly distorted by the propagation channel. The superposition of all channel outputs is corrupted by additive interference and noise. The receiver demodulates the signal of the k^{th} transmitter, which is considered as the signal of interest whereas the other transmitters are considered as interferers.

2. SYSTEM MODEL DESCRIPTION

A schematic block diagram of the IR UWB multi-user system is given in Figure 1 and a corresponding simulation chain implemented with Matlab/SIMULINK was developed. The transmitter uses on-off keying (OOK) of a sinusoidal carrier at 4 GHz (400 x 10 MHz). The UWB transmitter is characterised by the parameters shown in Table 1.

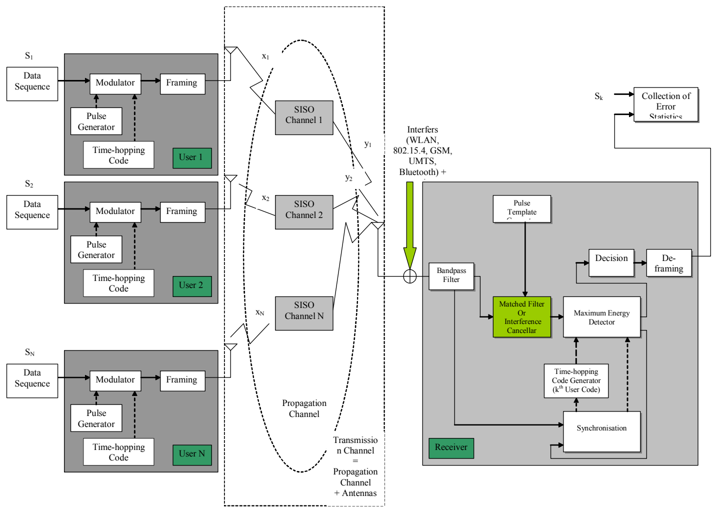

Figure 1: Schematic block diagram for the IR UWB multiuser system

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Table 1: UWB transmitter parameters

System parameter	Value	Unit
Modulation scheme	On-Off Keying	
Center frequency	4	GHz
Bandwidth –20 dB	2.5	GHz
Peak power	+2	dBm
Average power	-21	dBm
Duty cycle	0.01	
Pulse repetition frequency	10	MHz
Pulse envelope	half period cosine	
Pulse duration	1	Ns
Maximum bit rate	up to 10	Mbit/s

2.1 PAN Channel Model

There were three types of channel models used for the analysis presented herein: (1): AWGN channel using band-limited white Gaussian noise, (2): IEEE 802.15.3a channel model proposal for PAN free-space scenarios [4] and, (3): *Simplyfied* MAGNET PAN-FD[2] channel model using the IEEE 802.15.3a proposal with modified parameters for *free-space* and *user-proximity* scenarios [3].
The channel models No.2 and No.3 are based on the Saleh-Valenzuela time-delay channel model with parameter values/ranges modifications introduced for the UWB propagation description in the considered scenarios/ environments.
Both the channel models No.2 and No.3, implement the time-domain variations with a log-normal fading and band-limited white Gaussian noise was added in order to simulate different average SNR values in the communication channel. The variations of the average path-loss were *not* simulated, thus the average TX-RX distance was considered constant.
The IEEE 802.15.3a channel model is proposed for point-to-point PAN scenarios [4]. This channel model does *not include* effects of the user-proximity and it was derived from measurements performed with 'ideal' UWB bi-cone antennas (flat frequency response, linear phase, etc.).
There are three main variants of the IEEE 802.15.3a channel model for different radio propagation scenarios used in our simulations: 0-4m LOS with 5ns RMS delay spread (CM1), 0-4m NLOS with 11ns RMS delay spread (CM2) and extreme NLOS with 25ns RMS delay spread (CM4).
These models were used with a time-delay resolution of 167ps, corresponding to the 0GHz to 6GHz system bandwidth. The *simplified* MAGNET PAN-FD channel model is proposed for point-to-point PAN scenarios [2] and *includes* the effects of the user-proximity and user handling of small/ medium-size terminals. The channel parameters were derived based on extensive channel measurements using typical scenarios and UWB antennas for hand-held devices.
There are two main variants of the *simplified* MAGNET PAN-FD channel model corresponding to the *free-space* and *user-proximity* scenarios used in our simulations. The channel parameters were derived from investigations in three different propagation environments: 3-10m, laboratory/professional (LAB), 3-10m, conference/meeting room (CAN) and 5-15m, hallway/shopping area (HAA) [3].
These models were used with a time-delay resolution of 400ps, corresponding to the 3.5GHz to 5.5GHz system bandwidth used in experimental channel investigations presented in [1]. The main parameters for the adopted channel models are listed in Table 2 [2].

[2] PAN with Fixed Device scenarios: 1-10m TX-RX range, for communication between a medium-size stationary device or a small-size stationary/dynamic device and a medium/large-size fixed device located at a height above the user devices (e.g. laptop PC, hand-set, PDA to information kiosk, etc.) [MAGNET D.3.1.2a].

Table 2: Main parameters for channel models

Radio channel type	Average power decay factor [dB/ns]	RMS delay spread* [ns]	90% energy window length* [ns]	Standard deviation of the Log-Normal fading: cluster / wide-band power [dB]
IEEE 802.15.3a CM1 (LOS)	0.60	7	16	3.3 / 3.0
IEEE 802.15.3a CM4 (NLOS)	0.18	24	55**	3.3 / 3.0
Simplified MAGNET PANFD-FS (LOS)	0.11	36	90	0.2 / 3.5
Simplified MAGNET PANFD-US (NLOS)	0.15	30	70**	2.3 / 4.5

Note: * The parameters were estimated from the exponential power decay of the impulse response with the given decay factors over 200ns. ** For the NLOS channels the 90% energy window is measured from the first tap of the impulse response, which is randomly delayed relative to the case of LOS channels.

2.2 Time Hopping Codes

A third aspect of this multi-user communication system, which has to be analysed, is the TH code sets to be used. In Table 3, a set of 16 TH codes generated for hopping over 8 time slots, 12.5ns each (8 x 12.5 = 100ns), are given as an example. In multi-user scenarios we use orthogonal codes for mitigating multiple access interference (MAI). For the first choice, the group #1 to #8 and group #9 to #16 are good candidates for an 8 users system. Please note, that any 2 codes taken from the two separate groups are *not* fully orthogonal to each other. The codes in the first group #1 to #8 present, however, an undesired characteristic: namely the TH sequences contain consecutive numbers which results in hopping on consecutive TH slots, 8th and 1st, for consecutive transmitted pulses. In AWGN and low dispersion radio channels (<12.5ns) this aspect of the TH does not cause any problems. In radio channels with signal dispersion over at least 2 TH slots (25ns), however, the TH codes #1 to #8 will cause inter-pulse interference, thus higher BER. Naturally, in channels with higher signal dispersion, an even higher separation is required between consecutive TH slots in order to avoid inter-pulse interference. As an example, the second group of codes, #9 to #16, provides a minimum separation of 2 TH slots (25ns). A similar observation can be made for the multi-user case, where the inter-user interference can be reduced by an appropriate choice of TH codes. An example for this is the choice of codes #9 and #12 for a two user system, which also provide a minimum separation of 2 TH slots between users. These conclusions will be illustrated in the following analysis.

Table 3: Example of 16 time-hopping codes for hopping over 8 time slots. codes #1 to #8 and codes #9 to #16, with the latter having the property of minimum 2TH slots distance between any two consecutive hops

#1	0	4	2	6	1	5	3	7
#2	1	5	3	7	2	6	4	0
#3	2	6	4	0	3	7	5	1
#4	3	7	5	1	4	0	6	2
#5	4	0	6	2	5	1	7	3
#6	5	1	7	3	6	2	0	4
#7	6	2	0	4	7	3	1	5
#8	7	3	1	5	0	4	2	6
#9	7	3	5	1	6	2	4	0
#10	0	4	6	2	7	3	5	1
#11	1	5	7	3	0	4	6	2
#12	2	6	0	4	1	5	7	3
#13	3	7	1	5	2	6	0	4
#14	4	0	2	6	3	7	1	5
#15	5	1	3	7	4	0	2	6
#16	6	2	4	0	5	1	3	7

3. SIGNAL DETECTION

In our simulations we have chosen two fixed energy detector threshold values between -20dB and -10dB relative to the *average* received signal power.. The AWGN was generated with a bandwidth of 0-6GHz. The template generator block (see Figure 1) can be considered in two cases. The first case corresponds to a coherent like receiver, where mainly the transmitted sinewavelet is regenerated with the exact phase. First the receiver determines the shift (in number of samples) according to the corresponding of the time-hopping code. Then the regenerated sinewavelet is shifted according to the shifting value and multiplied with the signal coming from the output of the propagation channel. The result is then fed into the decision block. The second case corresponds to the use of uniform square template at the receiver. The template can be seen as a selection window with size 1250 samples. This window serves to select the 1250 samples of the received signal (at the output of the propagation channel) shifted according to the corresponding element of the time-hopping code. This windowed signal is then self-multiplied and the result is fed to the decision block. The receiver with an early-late synchronisation scheme is shown in Figure 2. The sub-blocks coloured in black show the pulse-multiplication receiver. The sub-blocks in red colour implement the closed-loop control of an early-late synchroniser for OOK. The sub-blocks in blue implement the channel models (see Table 2).

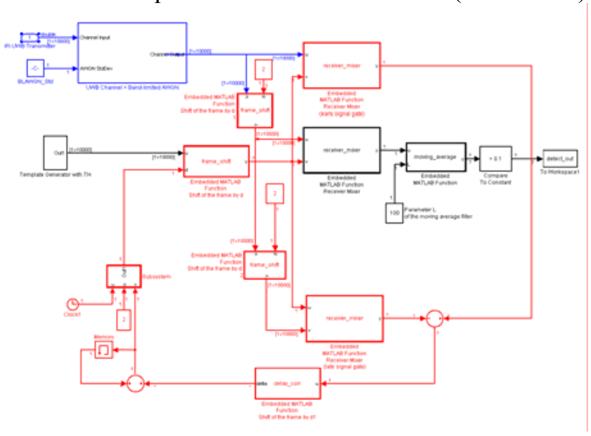

Figure 2: Simulink receiver model with early-late synchroniser.

4. PERFORMANCE RESULTS

For all the simulation results presented in the following section a number of 2500 pulses have been used, providing reliable BER values down to 4e-3. A larger number of pulses would have increased the computational time too much without providing significantly more information. For luck of space reasons we will stick with the performance results obtained in the single user case. The performance results of the multiuser case will be included in a coming contribution.

4.1 Perfect Synchronisation Receiver

First, the simple scenario without time-hopping code is considered (transmission in TH slot 0). In the receiver detection mechanism, the signal energy was detected only in the first 12.5ns window relative to the ideal position of the transmitted pulse (ideal synchronisation). The performances of the two energy detection mechanism types, pulse template multiplication (PTM) and windowed signal self-multiplication (WSM) -are presented in Figure 3 for the AWGN and CM1 (LOS) channels. These simulations used a relative detector threshold of –10dB, -16dB and –20dB. A clear improvement can be noticed in the dispersive channels when the WSM detection mechanism is used. For all the following simulations the energy detector used the WSM detection mechanism.

Simulations have been performed in order to compare the BER performances in the CM1 (LOS) and CM4 (NLOS) radio propagation channels when different detector threshold values between -20dB and -16dB are used. These simulations were performed without time-hopping. In the CM1 (low dispersion) channel a performance improvement can be observed with the lower threshold value only in the high SNR region, while in the low SNR region the higher detector threshold provides better performance. These results highlight the necessity for different detector threshold values depending on the actual SNR in AWGN and radio channels with small signal dispersion. In the CM4 (high dispersion) channel the BER performance improvement is minimal when lowering the detector threshold. The high BER floor compared to the CM1 case is the result of the missed detections induced by the NLOS type of impulse response (random time-of-arrival for the first signal cluster). Based on these observations, for all the following simulations the energy detector used the WSM detection mechanism with a relative threshold of -16dB. In AWGN and low dispersive channels, where the integration window captures most of the signal energy, the time-hopping code does not have any influence on the BER results.

In channels with signal dispersion over multiple TH slots (CM1, CM4, PANFD-FS, PANFD-US) the choice of TH code will affect the correct detection of the received (and spread) pulse energy. In order to illustrate this aspect, simulations have been performed for the single user scenarios in CM1, CM4 and PANFD-FS channels with time-hopping active and without time-hopping. The TH code was chosen from the Table 3 to be the code#1. When no time-hopping was used, the receiver was still using the WSM detection mechanism, thus the signal energy was detected only in the first 12.5ns window. Figure4 shows these obtained comparative results. With time-hopping code, the performance curves show a BER floor depending on the signal spread in the channel relative to the minimum TH chip distance. In the case of CM4 and PANFD channels the signal spread is significantly larger than 2-3 TH slots. As Figure 3 and Figure 4 illustrates, without time-hopping, in the CM1 channel the BER floor is not present, while with time-hopping code #1 the BER floor appears at SNR values above 0dB. This leads to the observation that the used TH code #1 is not optimal. By using code #9 from Table 3, in the CM1 channel the BER floor can be eliminated due to the minimal distance of 2 TH slots between consecutive hops. Furthermore, the CM4 and PANFD-US are typical NLOS channels, resulting in a random time-of-arrival for the first tap of the impulse response. Thus, even without time-hopping the main part of the received signal energy can be significantly shifted outside the observation window used and this phenomena leads to the BER floors obtained. Note that the AWGN BER curve in Figure 3 is a lower bound on the obtained curve in any considered scenario (CM1, CM2…) at the considered SNR.

4.2 Synchronisation Based Receiver

In the presence of synchronisation errors, the uncoded bit error probability will increase with respect to the perfectly synchronised case. Synchronisation errors can be classified into timing offsets and timing jitter. It is the purpose of the synchronisation procedure in the IR-UWB receiver to eliminate the delay offsets at the expense of minimal introduction of timing jitter. An early-late synchroniser was chosen. Since the self-multiplying receiver is an incoherent detector, its sensitivity to timing errors is much lower when compared to other types of receivers. This situation is illustrated in Figure 5. Figure 6 shows simulation results for the single user scenarios with the receiver using the early-late synchronisation loop. The parameters of the synchronisation loop were set as follows: 'initial delay' = 'early delay' = 'late delay' = 20% of the TH slot. For the case of the CM1 and PANFD-FS channels (LOS) there is no significant performance improvement compared to the ideal synchronisation scenarios in the previous section. For the CM4 channel (NLOS) the BER floor is slightly lower than with ideal synchronisation. This is due to the 'early-late' mechanism, which practically tracks the window with the main signal energy (in the limits set by the parameters used).

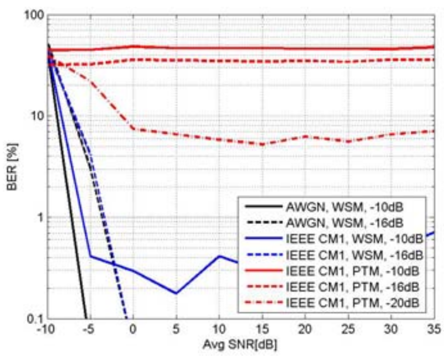

Figure 3 – BER performance for single user system – AWGN-CM1 channels - Time-hopping was not used.- Detector threshold = 16dB

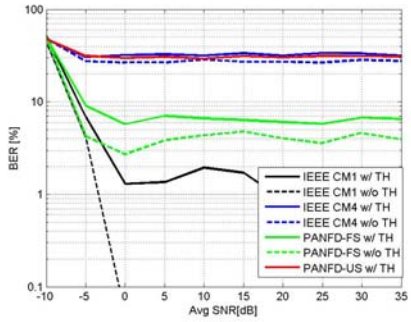

Figure 4– BER performance for single user system - multipath radio channels with and without time-hopping - a relative threshold of -16dB.

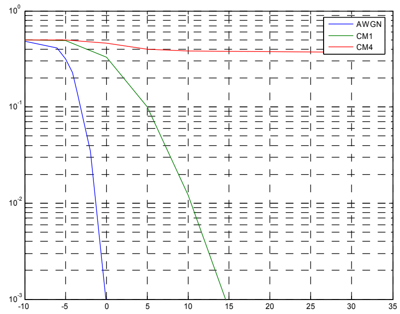

Figure 5: Comparison of BER on AWGN, CM1 and CM4 channel models (the synchronization is used and Detection Threshold = 0.1)

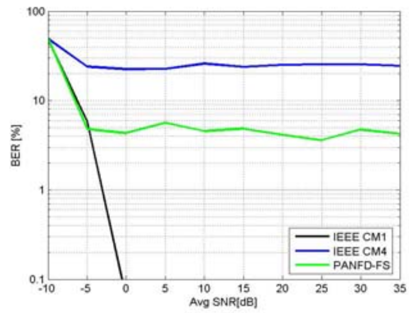

Figure 6 – BER performance for single user system- CM1, CM4 and PANFD radio channels with the receiver using the early-late synchronisation loop - without time-hopping - a relative detector threshold of -16dB.

5. CONCLUSIONS

We proposed a scalable IRUWB for LDR WPAN applications and investigate its performance in PAN environments. We showed that the WSM based receiver outperforms other receiver detection techniques and leads to an efficient and reduced-complexity architecture when incorporating the described early-late synchroniser.

6. REFERENCES

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