Performance of DS UWB with MUD Schemes

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Summary

UWB technology has specific advantages that make it ideal for high data rate wireless short range communication, including low transmission power, low implementation complexity and multipath resistance, and these advantages can be exploited for WPAN or Future Wireless Ad hoc Networks. This paper compares the performance of two MUD (Multiuser Detection) schemes known as successive interference cancellation (SIC) and parallel interference cancellation (PIC). The comparison is done analytically and through simulations, using Matlab. Before analytical details of these two suboptimal schemes, I will first propose the DS-UWB receiver system model, which employed the Iterative channel estimation and detection with PIC and SIC.

1. Introduction

Ultra wide-band (UWB) wireless communication system has recently drawn considerable attention among both researchers and stanrdadization communities. The Federal Communication Commission (FCC) has opened up 7,5000 Mhz of spectrum(from 3.1 to 10.6 GHz) for unlicensed use of UWB products with an indoor emission limit of -43.3 dBm/MHz. Thanks to convey information over impulse-like radio ware forms, UWB comes with uniquely attractive features: Low power density, low complexity baseband transceivers and a potential for major increase in multi-access capacity. There are several promising techniques for UWB communication, which can roughly be divided in two groups, single band and multiband. Hence singleband impulse radio can be implemented using techniques as time-hopping spread-spectrum impulse radio (TH-UWB) and direct-sequence spread-spectrum impulse radio (DS-UWB). This paper covers only single-band DS-UWB radio systems where narrow pulse (<1ns) are transmitted.

The DS UWB has benefit from the advantages of DSSS technique, however to bring the UWB potency to fruitition, UWB system designer has to cope with several challenges that included of: mitigation of effects of the frequency-selective fading propagation channel, design of high performance low complexity multi user receiver, and strict power limitation imposed by the desire to minimize interference between UWB communication. As indicated from papers [4, 3], the DS-UWB system performance is severely downgraded by inter-symbol and multiple access interferences.

One of the most promising measures to reach this goal is the use of MUD in the uplink of these systems [2]. When MUD is combined with coding, is it possible for the MUD to exploit reliability information generated by the decoding algorithm. Specifically, estimated symbols at the decoder output along with the reliability information can be use to cancel, or partially cancel multiple access interference (MAI).

Among the many MUD algorithms that have been developed [8], PIC and SIC seem to be the most interesting in terms of performance-complexity trade-off for employment in the UWB systems.

The idea of Iterative MUD in coded DS-UWB systems has been discussed in several publications. In [13], an iterative interference cancellation and decoding for coded synchronous UWB system using MMSE filters are considered. In [14], the authors studied the application of successive cancellation for channel estimation on the coherent UWB Rake receivers.

The objective of this paper is analysis and simulation the receiver DS-UWB system which uses an iterative scheme, PIC and SIC to compare its performance when the system operates in multiple access environments.

This paper is organized as follow, in section II, the conventional DS UWB system with multiple access channel and detection will be presented, section III will present about the iterative channel estimation and detection algorithms employing in the DS-UWB system: PIC and SIC, section IV shows the simulation model of DS-UWB systems, some key parameters' assumptions, from which the system performances are evaluated and compared for PIC and SIC scheme, and the last section devotes to conclusion and future research directions.

2. DS-UWB System

2.1 System Definitions

The UWB system described in this paper employs Direct-Sequence Spread Spectrum (DSSS) approach. The baseband signals compose the nanosecond GMC pulses. Each transmitted data bit is coded and pseudo-random spread over multiple pulses to achieve processing gain in the reception. In a typical direct sequence spreading scheme, the binary baseband pulse amplitude modulation (BPAM) information signal for user m can be expressed as [1]:

$$s^{(m)}(t) = \sum_{k=-\infty}^{\infty}\sum_{j=1}^{N}\omega\left(t - kT_d - jT_c\right)\left(c_p\right)_j^{(m)} d_k^{(m)} \qquad (1)$$

where k indicates the k^{th} bit number, $d_k^{(m)} \in \{-1,+1\}$

denotes user *m's* information bit in the f^{th} frame, the frame duration is T_f, $T_f = MT_c$, $(c_p)_j$ is the j^{th} spreading chip of the pseudo-random code, $\omega(t)$ is the pulse waveform with main-lobe duration T_c. N represents the number of pulses to be used per data bit, bit length $T_d = NT_c$. The pseudo- random codes can take values $\{-1,+1\}$ and are used to separate users and smooth spectrum. The length of the pseudo-random spreading code influences to the system's performance. For the short spreading code, it is more difficult to achieve the pure noise like sequences and the cross correlation and autocorrelation become higher. As a result, the BER of the DS UWB system rises. The user m's bit in the frame is mapped into a sequence of UWB pulses in the frame. Each of N pulses contains the information bit and the spreading code. For the same bit rate, the processing gain for DS UWB is defined as T_d/T_c and equals to the repetition gain N. In DS-UWB, it is a truly trade-off choosing proper the processing gain (the repetition gain), due to the fact that the BER and throughput depend proportionally on it. When the processing gain increases, the throughput is reduced, because it takes more pulses to transmit one bit. However the BER will be lowered as well, as the interpulse interference is lowered. But this increment will create will create strong multiple access interference to other users in the system. Typically the selection of the processing gain is N « M so that signals in one frame do not create interference with signals subsequent frames. Figure 1 explains how the data bit sequence is spread by pseudo- random coded UWB pulse train.

Table. 1 : The IEEE UWB Channel characteristic for four different scenarios.

Target Channel Characteristics	CM 1	CM 2	CM 3	CM 4
Distance (m)	0-4	0-4	4-10	
(Non) Line of sight	LOS	LOS	NLOS	NLOS
Mean excess delay (nsec) (τ_m)	5.05	10.38	14.18	
RMS delay (nsec) (τ_{rms})	5.28	8.03	14.28	25
NP_{10dB}			35	
NP(85%)	24	36.1	61.54	

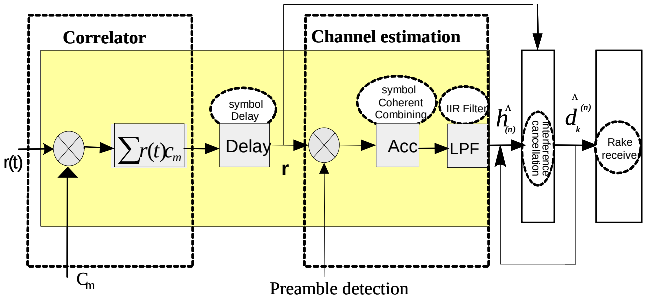

Fig. 1 General structure of iterative interference cancellation for UWB receiver

2.2 IEEE Channel Model

The IEEE UWB channel model is based on the Saled Valenzuela model where multipath components arrive in clusters [IEEE 802.15.3a]. The differences are that the amplitude has a log-normal distribution and the phase is randomly set to $\{\pm 1\}$. The multipaht channel can be defined as:

$$h(t) = X \sum_{l=0}^{L} \sum_{k=0}^{K} \alpha_{k,l} \delta\left(t - T_l - \tau_{k,l}\right), \tag{2}$$

where $\{\alpha_{k,l}\}$ are the multipath gain coefficients including amplitude and phase for cluster l and ray k. The $\{T_l\}$ is the delay (cluster lth arrives) of the l^{th} cluster, and its ray k arives at $\{\tau_{k,l}\}$ which is relative to the first path in cluster l i.e. $\tau_{0,l} = 0$. The interarrival time between two cluster $T_{l+1} - T_l$ or two rays within one cluster $\tau_{k+1,l} - \tau_{k,l}$ is exponentially distributed. Clearly, the interarrival time between any two rays is not an integer multiple of the pulse duration. Log-normal shadowing is modeled with $X = 10^{n/20}$ where n has a normal distribution with the mean equal to 0 dB and the standard deviation equal to 3 dB. There are four different models, CM1, CM2, CM3 and CM4, for different channel characteristics that are presented in Table I. LOS and NLOS is the abbreviation for line of sight and non line of sight. NP is the number of paths within 10 dB of the strongest path. NP 85% gives the number of paths containing 85 percent of the energy.

3. Iterative Channel Estimation and Detection

Estimating the channel parameters in DS-UWB is a challenging task. This is due are typically unsynchronized and, as a consequence, not truly orthogonal. This creates Multiple Access Interference (MAI) and Inter-Symbol Interference (ISI) at the receiver, thus limits the accuracy of channel estimation and data symbol detection. The need for accurate channel estimation and detection in the presence of MAI and ISI has led to the developments of multi-user interference cancellation detections and parameter channel estimation techniques. The basic idea is to estimate interference contributions given in equation (6). Each of contributing terms may be estimated from tentative decisions on the data symbols from each user and complex channel gains for all involved users. As shown on Figure.1, the tentative decision is come from a single detection. Once these MAI and ISI estimates are available, they can be subtracted from the received signal and come for single detection for second time and so on.

3.1 Successive Interference Cancellation

In the successive interference cancellation (SIC), the detection/ cancellation processes occur successively. At each loop all users are ranked according to their signal power, but only the strongest signal is detected and canceled. At the beginning of each loop, all remaining users have to be ranked in order to detect the strongest user have to be ranked in order to detect the strongest user of that loop. Averaging the data bits of each user and canceling them all together can decrease the frequency of ranking. These processes are until all users have been detected.

We denote $y(t)$ the output from filter matched $\psi(t)$, i.e. $y(t) = r(t) * \psi(-t)$. In case that the fading processes are slowly time-varying and there is no synchronization error, then:

$$\begin{aligned} y(t) &= r(t) * \psi(-t) \\ &= \left[\sum_{l=1}^{L} \sum_{m=0}^{N_u - 1} a_{l,m} s(t - \tau_{l,m}) + n(t) \right] * \psi(-t) \end{aligned} \tag{3}$$

If we assume that the bandwidth of the matched filter is large enough to pass the signal components undistorted and the sampling rate is high enough to avoid aliasing, the equation (3) can be written as:

$$\begin{aligned} y(t) &= r(t) * \psi(-t) \\ &= \left[\sum_{l=1}^{L} \sum_{m=0}^{N_u - 1} a_{l,m}(jT_d) s(t - \tau_{l,m}) \right] * \psi(-t) \end{aligned} \tag{4}$$

We denote the received vector $r(j)$ due to transmission of i^{th} symbol in the symbol observation window as:

$$r(j) = \left[y(0), y(T_c), \ldots, y((QN-1)T_c) \right]^T, \tag{5}$$

where Q is the over sampling factor. Then the received vector can be rewritten as:

$$r(j) = S(j) h(j) + n(j). \tag{6}$$

As we model the MAI as Gaussian noise, and n as random Gaussian vector:

$$n(j) = \left[n(0), n(T_c), \ldots, n((QN-1)T_c) \right]^T, \tag{7}$$

with zero mean and covariance matrix $C_n = \{ n * n^H \} h(j)$ is the matrix of the channel impulse response vectors of the j^{th} symbol:

$$h(j) = \left[h_0(j), h_1(j), \ldots, h_{Nu-1}(j) \right]^T \tag{8}$$

$$h_m(j) = \left[h_{m,1}(jT_d), h_{m,2}(jT_d), \ldots, h_{m,L}(jT_d) \right]^T \tag{9}$$

And matrix $S(j)$ is defined as:

$$S(j) = \left[S_0(j), S_1(j), \ldots, S_{Nu-1}(j) \right]^T \tag{10}$$

$$S_m(j) = \left[s_{m,1}(\tau_m), s_{2,m}(\tau_m), \ldots, s_{m,L}(\tau_m) \right]^T \tag{11}$$

where $s_{m,1}(\tau_m)$ is a matrix of entries $s_{m,L}(nT_c - \tau_{l,m})$, $0 \le n \le QN-1, 1 \le l \le L$.

From [12], the complex channel gain and delay can be estimated as follows:

$$\hat{\tau} = \arg \max_{\vec{\tau}} \left\{ \frac{\left| S^H(\tilde{\tau}) C_n^{-1} r^{(1)} \right|^2}{\left| S^H(\tilde{\tau}) C_n^{-1} s(\tilde{\tau}) \right|^2} \right\} \tag{12}$$

$$\hat{a}_l = \frac{S^H(\hat{\tau}_l) C_n^{-l} r^{(l)}}{S^H(\hat{\tau}_l) C_n^{-1} s(\hat{\tau}_l)} \tag{13}$$

where $\tilde{\tau}$ is the trial value of τ, 2 ≤ l ≤ L, s is the single path vector of **S**, and:

$$r^l = r - \sum_{m=1}^{l-1} \hat{a}_m s(\hat{\tau}_m) \tag{14}$$

In the second stage, the estimated values of $\tilde{\tau}_l$, and $\tilde{a}_1$ are computed by replacing $r^{(l)}$ into equations (12) and (13), and the process is subsequently iterated until it converges to a practical BER.

3.2 Parallel Interference Cancellation

In the Parallel Interference Cancellation, the processes occur simultaneously. All users' create replicas of their interference contributions to other users' signals and after that these replicas are subtracted simultaneously from these users' signals. At the first iteration, each user is detected and replica estimates. In order to detect an user, the regenerated contributions from other users detect an user, the regenerated contributions from other users are subtracted from the received signal, then are detected again by using RAKE receiver. The estimation process is iterated in several stages to achieve better data estimation until the convergence of BER is found.

The channel impulse response can be estimated from the estimated data symbol $\hat{d}_k^{(m)}$ [11]:

$$\hat{h}(j) = \hat{S}^t(j) r(j) \tag{15}$$

where $\hat{S}^t$ denotes the left pseudo-inverse of the estimated, $\hat{S}^t$ which is found by replacing the detected symbols of each user from the last iteration into equations 1, 10 and 11. The estimates can be further improved by using FIR filter smoothing procedure. In next section, through simulation, the performance of DS-UWB receiver, which uses iterative channel estimation and detection, will be evaluated and compared to conventional receiver.

4. Performance Comparison Evaluation

4.1 Simulation Setup

The antipodal binary pulse amplitude modulation (BPAM) is chosen, however other modulation techniques can be employed. Other assumptions and parameters are:

The raw data rate is set to 100 Mbps and the packet length is 16384 bits. The pulses rate or chip rate is 6.4 Gpulses/s. The duration value for GMC pulses transmitted pulses T_c is 0.15625 ns. The processing gain 18 dB and the repetition gain is 18dB or 64pulses/ bit. The user spreading codes are the over sampled Walsh codes with period $2^7 - 1$. The perfect sampling frequency of the chip matched filter is 6.4 GHz and of the symbol spaced receiver is 100Mbps. The simulation is carried out for various signal to noise ratios ($10\log E_b / N_0 = 2.5 \sim 15dB$), where E_b is the received energy per bit. The Synchronization is assumed to be perfect, i.e., the arrival of the first path is perfectly known.

The effects from the antennas have been neglected. The simulation is done for packets of 4096 symbols, and new propagation delay were draw from an uniform distribution of every 4096 symbols.

Different Iterative channel estimation detection methods for receiver DS-UWB system are simulated on CM1-CM4, however for the comparison PIC and SIC the results are quite similar on CM1-CM4, hence only the results on the CM1and CM2 presented here.

The simulation results for the modeled DS-UWB system with different Iterative channel estimation detection methods on CM1-CM4 will be presented in this subsection. The system is operated in multipath MAI environment. The performance is compared in terms of bit error rates (BERs) for different values of the received signal to noise ratios. The modeled system performances on CM1, CM2 for conventional, SIC and PIC algorithms are compared in Figure. 2 and figure. 3, the results are showed after iterations and nearly similar on CM3 and CM4. It can be seen that the system performances with both PIC and SIC algorithms are improved comparing to the conventional receiver. The BERs as functions of the number of users are still rather lower when applying the algorithms. However the performance improvements are reduced and eventually become useless in case of too large number of interfered users.

4.2 Numerical results

The comparison of the modeled system when applying the PIC and SIC algorithms is further illustrated in Figure. 4. In this figure, it compares the BER performance for different received SNRs. As can be seen, the bit error probability is reduced when a higher SNR is applied for both cases of PIC and SIC. In this case PIC also had a better performance than SIC, however when the MAI interference is small, i.e. smaller number of users in the system, the performance differences between the PIC and SIC are small, and these differences become larger when the number of users is increased or SNR is higher.

With respect to complexity, SIC appears to be simpler, and requires less hardware than PIC. Because more iterative states of parallel cancellation improves the BER performance and better than SIC, but it required more hardware complexity and processing delay.

In addition to comparison, processing delay becomes the biggest drawback to SIC if total number of active users N_u is a lot more than the number of iterative stages, I . Because only a single user bit is decoded at each iterative state, it take N_u bit-times to decode all users for each bit and in the case of PIC, it takes i bit-times to decode all users for each bit.

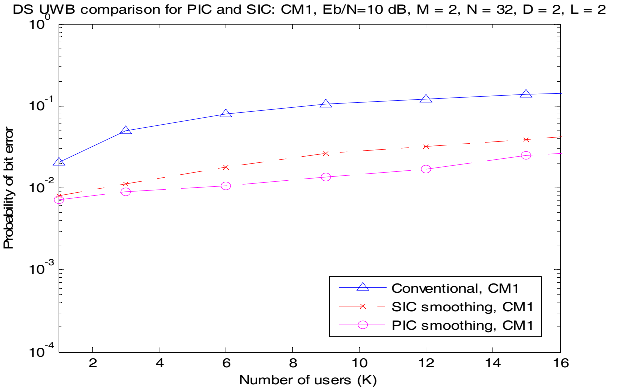

Fig. 2 Performance comparison of the modeled DS UWB system on CM1 with SIC and PIC in terms of the bit error rate after 10 iterations as a function of the number of users at $E_b/N_0 = 10$dB.

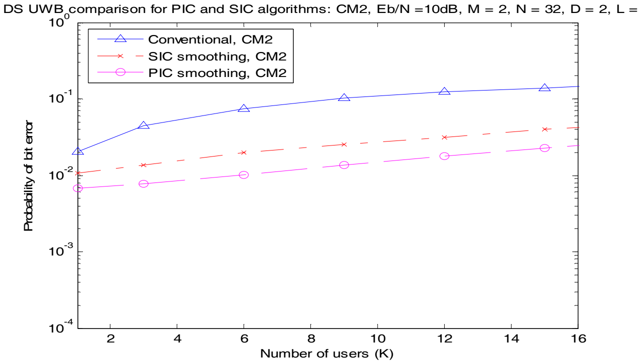

Fig. 3 Performance comparison of the modeled DS UWB system on CM2 with SIC and PIC in terms of the bit error rate after 10 iterations as a function of the number of users at $E_b/N_0 = 10$dB.

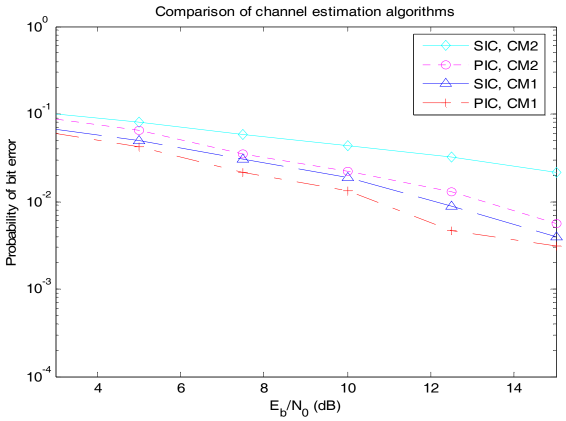

Fig. 4 Performance comparison of the modeled DS UWB system with SIC and PIC in terms of the bit error rate after 10 iterations as a function of the receive signal to noise ratio E_b / N_0.

5. Conclusion

This paper studied on the DS-UWB system that employs iterative channel estimation/multiuser detection for MAI interference cancellation. Two iterative interference cancellation algorithms, PIC and SIC, were compared to the DS-UWB system. From the comparison results, it is clear that both successive and parallel interference cancellation scheme have better performance than the conventional UWB Receiver. PIC had a better performance than SIC, PIC appears to be more resistant to interference than SIC, and achieves better results with regard to BER and capacity performance. With respect to complexity, SIC appears to be simpler, and requires less hardware than PIC. Although this paper has analyzed and studied on the application of iterative interference cancellation algorithms to the DS-UWB system, many research issues occur. The capacity or the reliability of the DS-UWB system can be gained by applying various kinds of methods to the UWB rake receiver as well as to the other modules of UWB system in order to limited implementation complexity.

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