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Analysis and Design of Optimum Interleaver for Iterative Receivers in Indoor Wireless Optical IDMA Scheme

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Abstract

This paper deals with the design of interleavers in a uncoded Wireless Optical IDMA (WO-IDMA) system, where at the receiver an iterative turbo-like structure is employed to perform multiuser detection. The choice of the interleavers affects both the Maximum-Likelihood (ML) performance and the impact of the suboptimality of the iterative receiver. For implementation of the interleavers in IDMA, the challenge is to fabricate them at affordable decoding complexity with available technology. In this paper, we first introduce various interleavers like random interleaver, master random interleaver, prime interleaver and tree based interleaver in wireless optical IDMA scheme. Then, we perform comparison on their BER performance and implementation complexity.

Keywords: AWGN Model, Iterative Chip-by-Chip (CBC) Detection, On-Off Keying (OOK), Optical-IDMA (OIDMA) Scheme

1 Introduction

The increasing customer demands for higher data rate and higher security have motivated recent interest in indoor Optical Wireless Communications (OWC). The main advantages offered by OWC are the unlimited license-free bandwidth, high speed, high security, low coherency, free from harmful radiation interferences and so on.

Initially, Time Division Multiple Access (TDMA) was the most widely used multiple access technique for high performance optical networks[10]. Later, this TDMA scheme was outperformed by Wavelength Division Multiple Access (WDMA) and optical code division multiple access (OCDMA)[1–5].

To overcome the disadvantages of Wireless Optical CDMA systems we switched over to Wireless Optical IDMA systems. As the optical CDMA systems suffer from MAIs from other simultaneous users and multiple access interference (MAI) and Inter Symbol Interference (ISI) are two major factors that affect the performance of wireless communication systems.

A newly developed multiple access scheme known as IDMA has demonstrated better performance to conventional CDMA scheme[16]. In IDMA scheme, the user specific interleavers are referred as the only way of user separation[7,17].

This work mainly focuses on the IDMA scheme to mitigate MAI and ISI. The IDMA systems provide an efficient and effective solution to high rate multi user wireless communication. The low complexity and high performance properties make the IDMA scheme a competitive candidate for next generation wireless systems. Data rate is also increased as this scheme is capable enough to handle the multipath channel.

In this paper, the performance analysis of a novel optical multiple access technique incorporating the merits of optical system along with IDMA scheme named as Optical Interleave-Division Multiple-Access technique (OIDMA) over indoor wireless channel model using various interleavers has been studied.

The paper is organized as follows: Section II presents system model of wireless optical IDMA scheme. In Section III describes different types of interleavers used in wireless OIDMA. Section IV presents a comparative study of various interleavers. Section V presents simulation results of these interleavers over new system. Finally section VI concludes the paper.

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2 System Model of Wireless Optical Interleave Division Multiple Access Technique

In Wireless optical CDMA systems, signature sequences are used for user separation. In that system first data was converted into the optical form and then modulation is being done by different techniques. Then data is sending for encoding and then transmitted. Whereas in Wireless Optical IDMA system, as shown in Figure 1, consists the coder of low code rate is employed to produce a coded sequences. Coder block can be either same or unique for different users. It can be an FEC code, or a spreading sequence or a combination of both[12]. From performance point of view, it is advantageous to use a low-rate FEC code[18,12] that can provide an added coding gain.

The key principle of IDMA is that the interleavers {π(k)} should be specific for individual users. We assume that the interleavers are generated independently and randomly. For simplicity, we consider time-invariant single-path channels with real channel coefficients and BPSK signaling scheme. In wireless optical IDMA system we use BPSK modulation technique along with random interleaver and then randomly generated data is transmitted[9].

In wireless optical IDMA system we have also used a gauss pulse in transmission of signal and that pulse is added with the coded sequence and then transmitted through wireless optical channel by using laser[8]. The transmission of data can also be done through led but here we have considered laser.

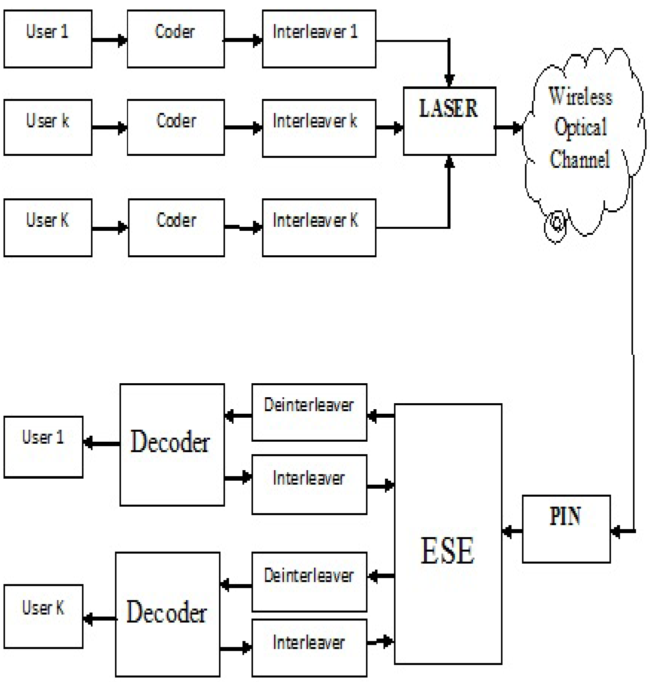

Figure 1. System model for wireless optical IDMA.

2.1 Transmitter Section

The upper part of Figure 1 shows the transmitter section of an wireless optical IDMA system. The n-th bit of $d_n^{(K)}$, $n = 1, 2, \ldots, N$, $k = 1, 2, \ldots, K$, in the input data stream $d_n^{(K)}$ from user-k is initially spread by a length-S spreading sequence $S^{(K)}$, then interleaved by a chip level interleaver {π(k)} that maps $S^{(K)}$ to $x^{(K)} = \left\{x^{(K)}(1)\ldots x^{(K)}(j)\ldots x^{(K)}(j), j=1,2,\ldots j\right\}$. The elements in $x^{(K)}$is called "chips"[15]. The basic principle of IDMA is that the interleavers {π(k)} should be unique for individual users.

After the user-specific interleaver generation, electrical to optical converter (E/O) is used to get optical pulses. The electric field of mode locked laser can be given[21],

$$E_{MLL} = e^{iwot}\sum_{k=0}^{k-1} e^{ik(\Delta w)t} \tag{1}$$

where, K is the number of modes in the mode locked laser, and Δw is the channel spacing between two consecutive modes in the mode locked laser. Now the output of MLL is modulated with interleaved data $X_k(j)$ which is usually a simple OOK modulation. Then the transmitted data can be written as:

$$E_{MLL}X_k(j) = X_k(j)e^{iwot}\sum_{k=0}^{k-1} e^{ik(\Delta w)t} \tag{2}$$

where $X_k(j)\,\varepsilon(1,0)$.

2.2 Optical Channels

Usually the optical channels are optimal while employing Intensity Modulation and Direct Detection (IM/DD)[19,20], as the modulation of the frequency or phase of the light is more difficult. When the background noise is low, the channel can be modelled as a Poisson process. In the presence of significant background light, the Additive White Gaussian Noise (AWGN) model is more appropriate[20,22]. In terms of calculation complexity, the Gaussian approximation is much simpler than various approaches.

Using Gaussian approximation model, the output current at the receiver section, $y(t)$ is given by

$$y(t) = \int_{-\infty}^{+\infty} x(\tau)h(t-\tau) + n(t) \tag{3}$$

where, $x(t)$ is the optical power of the transmitted signal, $h(t)$ represents multi-path dispersion factor in channel and $n(t)$ represents the white Gaussian noise. Also, $x(t)$ must satisfy:

$$x(t) \geq 0 \text{ and } \lim_{T\to\infty}\frac{1}{2T}\int_{-T}^{T} x(t)dt \leq P \tag{4}$$

Directed LOS links do not suffer from multipath dispersion[19], but require alignment between transmitter and receiver, limiting user mobility.

2.3 Receiver Section

At the receiver section we have first used the PIN photodiode[24] which receives the coded signal. Optical detectors must have a broad bandwidth and sharp response to achieve the high bit-rate which is necessary by such a system[19]. Resposivity of PIN photodiode can be given[23,24]:

$$R = \frac{I_p}{P_o} \tag{5}$$

where, I_p is the photocurrent (mA), P_o is the average light power (mW).
Quantum efficiency can be given[23,24]:

$$\eta = \frac{I_p hc}{qP_o \lambda} \tag{6}$$

The probability that a specified number of photons are absorbed from an incident optical field by an PIN detector over a chip interval with $\boldsymbol{T_c}$ is given by a Poisson distribution[24]. The average number of absorbed photons over $\boldsymbol{T_c}$[23,24]:

$$\lambda_s = \frac{\eta P_o}{hf} \tag{7}$$

where, $\boldsymbol{\lambda_s}$ is the photon absorption rate, $\boldsymbol{P_o}$ is the received laser power, $\boldsymbol{\eta}$ is the quantum efficiency, $\boldsymbol{h}$ is Planck's constant ($6.628{*}10^{-38}$ J/s), and $\boldsymbol{f}$ is the optical frequency, $\boldsymbol{q}$ is the electron charge ($1.6{*}10^{-19}$ C).

The receiver section also consists of Elementary Signal Estimator (ESE) and A Posterior Probability (APP) Decoder (DEC). The ESE exchanges information with the DEC in a turbo-type manner[18]. Particularly, the constraint of Coder is ignored in the ESE. The output of the ESE is defined by the Logarithm Likelihood Ratio (LLR).

The DEC section consists of K local APP decoders. The kth local APP decoder performs an APP decoding of Coder for the kth user using e_{ESE}, after suitable deinterleaving, as its input. Its output is the so-called extrinsic LLR[15] given below:

$$\left\{e_{ESE}\left(x_K(j)\right)\right\} = \log\left[\frac{p\left(r_j \mid x_k(j) = +1, h\right)}{p\left(r_j \mid x_k(j) = -1, h\right)}\right] \tag{8}$$

The receiver section operation is based on the received signal $r\{r_j, j = 1 \ldots J$ with $h[h^{(1)}, \ldots, h^{(k)}, \ldots, h^{(K)}$ as the channel coefficients given[25]:

$$r(j) = h_k x_k(j) + \zeta_k(j) \tag{9}$$

where

$$\zeta_k(j) = r(j) - h_k x_k(j) = \sum h_k x_k(j) + n(j) \tag{10}$$

is the distortion (interference and additive noise) contained in $r(j)$ with respect to the desired $x_k(j)$. Denote the mean and variance as $E(.)$ and Var(.) respectively. We will use the CBC detection algorithm in single path channel.

2.4 The CBC Algorithm

Assume

$$e_{DEC}\left(x_k(j)\right) = 0 \tag{11}$$

$$E\left(x_k(j)\right) = \tan h\left(e_{DEC}\left(x_k(j)\right)/2\right) \tag{12}$$

$$Var\left(x_k(j)\right) = 1 - \left(E\left(x_k(j)\right)\right)^2 \tag{13}$$

$$E\left(r(j)\right) = \sum_{k'=1}^{K} h_{k'} E\left(x_{k'}(j)\right) \tag{14}$$

$$Var\left(r(j)\right) = \sum_{k'=1}^{K} \left|h_{k'}\right|^2 \left(Var\left(x_{k'}(j)\right) + \sigma^2\right) \tag{15}$$

$$E\left(\zeta_{k,l}(j)\right) = E\left(r(j)\right) - h_k E\left(x_k(j)\right) \tag{16}$$

$$Var\left(\zeta_k(j)\right) = Var\left(r(j)\right) - \left|h_k\right|^2 Var\left(x_k(j)\right) \tag{17}$$

$$e_{ESE}\left(x_k(j)\right) = 2h_k \cdot \frac{r(j) - E\left(\zeta_k(j)\right)}{Var\left(\zeta_k(j)\right)} \tag{18}$$

Here "h" denotes for channel coefficient for "k" data bit. After the APP decoding in the DECs is performed to generate the LLRs $\{e_{DEC}(x_k(j)), \forall k, j\}$

$$e_{DEC}\left(x_k\left(\pi(j)\right)\right) = \sum_{j=1}^{S} e_{ESE}\left(x_k\left(\pi(j)\right)\right) \tag{19}$$

Then go back to equation (12) for the next iteration[15,17].

3 Different Types Of Interleaver

Interleaving is a method of rearranging the data sequence in a one to one deterministic format. Interleaving is a convenient method to improve the error correcting capability of coding. In turbo coding, interleaving is used before the data is encoded by the second component encoder. The fundamental role of an interleaver is to construct a long block codes from small memory convolution codes, as long codes can approach the Shannon capacity limit[18]. Secondly, it spreads out burst errors in message sequence. The interleaver provides scrambled information to the second encoder and decorrelates inputs to the two component decoders so that an iterative suboptimum-decoding algorithm based on uncorrelated information exchange between the two component decoders can be applied. The final function of the interleaver is to split low weight input sequences, and hence increase the code free hamming distance or reduce the number of code words with small distances in the code sequence. The size and structure of interleavers play a key function in the performance of turbo codes. There are a number of interleavers, which can be implemented.

3.1 Random Interleavers

Random interleavers scramble the data word of various users with different pattern (Figure 2). Patterns of scrambling the data of users are generated randomly. Because of the scrambling of data, burst error of the channel is randomized at the receiver section. The user specific Random Interleaver rearranges the elements of its input vector using a random permutation[25]. The incoming data is rearranged using a series of generated permuter indices. A permuter is a device that generates pseudo-random permutation of given memory addresses. The data is set according to the pseudo-random order of memory addresses. If random interleavers are employed for the purpose of user separation, then lot of memory will be required at the transmitter and receiver end for the purpose of their storage. Also, significant amount of bandwidth will be consumed for transmission of all these interleaver. After randomization of the burst error it will be easily to detect and correct errors. Spreading is the important attribute of random interleavers[15].

3.2 Master-Random Interleavers

In this user interleaver is defined as: user Interleaver = (master interleaver)^n, where n is the user number in the transmitter side. Assume if this interleaver have Π number of master interleaver. Then we can generate the K interleavers using interleavers = Π^K. Where, Π^K is defined as $\Pi^1 = \Pi$, $\Pi^2 = \Pi\ (\Pi)$ etc. User specific Interleaver is orthogonal to interleaver related to other user[15]. This method of generation improves the performance in the terms of information that has to be send by the base station to the mobile station.

3.3 Prime Interleavers

Prime Interleaver is very simple to generate and is superior than the random and any other interleavers in terms of bandwidth

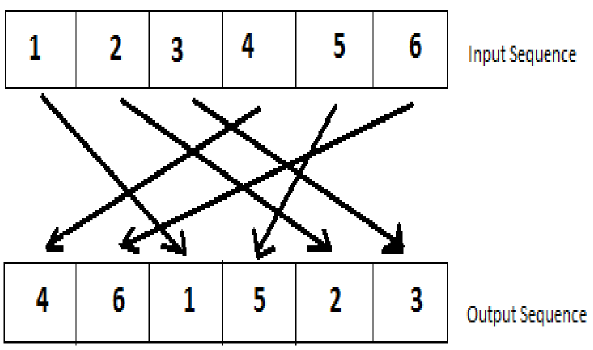

Figure 2. Random interleaving of data sequence.

utilization. The Prime interleaver is better than master random interleaver in terms of computational complexity. With tree based interleaver, the proposed interleaver seems to be having little bit more complexity. However entertaining the other issues including BER, memory and bandwidth requirements, and the proposed interleavers can take the place of any other interleaver techniques without performance loss. In generation of prime interleaver the prime numbers are used as seed of interleaver[11,13]. Here, user-specific seeds are assigned to different users. For understanding the generation mechanism of prime interleaver, consider a case of interleaving n bits with seed p. First, we consider a gallois field GF(n). Now, the bits are interleaved with a distance of seed over GF(n).

$$n \Rightarrow \left(1+(n-1)\,p\right) \bmod n \tag{20}$$

The bandwidth required by the Prime Interleaver (PI) is smaller than other available interleavers as only seed is to be transmitted[11].

3.4 Tree Based Interleavers

The Tree Based Interleavers (TBI) is basically proposed to optimize the problems of computational complexity and memory requirement which occurs in MRI and RI respectively. In TBI generation mechanism, two randomly generated master interleavers Π_1 and Π_2 are taken initially[6].

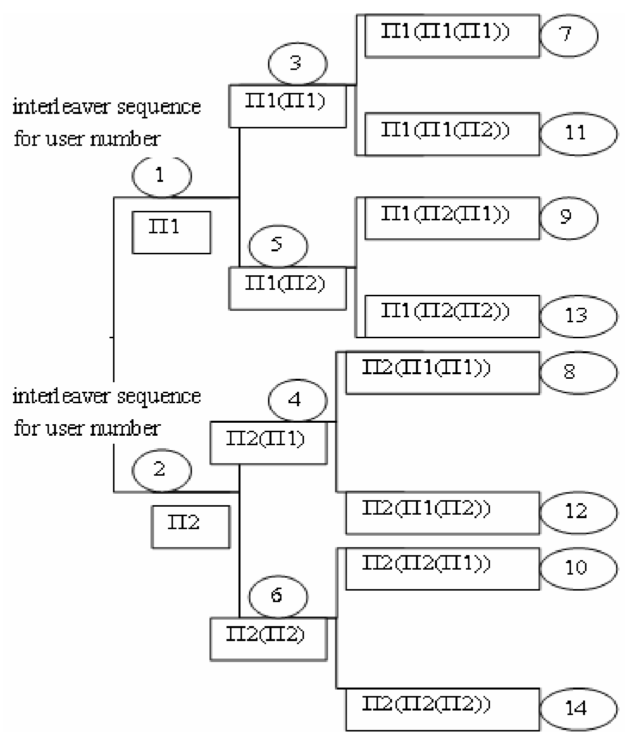

Figure 3. Interleaving strategy for Tree Based Interleaving scheme.

The allocations of the interleaving masks follow the tree format as shown in Figure 3 representing tree based interleaver mechanism[6]. The interleaver masking diagram is shown upon fourteen users only for the simplicity. For obtaining the interleaving sequence of the 14th user, the TBI mechanism needs only 2 cycles of clock, as compared to several more cycles needed in case of master random interleaver method.

$$\Pi_{14} = \Pi_2\left(\Pi_2\left(\Pi_2\right)\right) \quad (21)$$

4 Comparison of Interleavers

The Table 1 below show comparison between different interleavers used in wireless optical IDMA system on the basis of memory requirement, bandwidth, complexity, bite error rate and also on the basis of user cross correlation for RI, MRI, PI and TBI.

5 Simulation Results

The simulation of optical IDMA for indoor wireless channel model presented in this section has been performed using MATLAB software.

Figure 4 shows BER performance of various Interleavers on Wireless Optical IDMA with different numbers of simultaneous users. During the simulation, the spreading length is chosen to be 16, and the iterative number is set to be 10. The variation in user count has been selected as parameter for performance comparison of various interleavers over uncoded Wireless Optical IDMA system. For simulation purpose, the input data length for each user is assumed to be same i.e. 2048 bits. The laser has been operated with 155nm wavelength with maximum bit rate of 1Gbps capability. The transmitted power is chosen to be 1mW, while the nature of channel is selected to be AWGN. The responsivity and efficiency is 0.65, 0.80 has been taken respectively. The transmitted signal is a Gaussian waveform and ON-OFF Keying (OOK) is used for pulse transmission. The simulations have been performed using random interleavers, master random interleavers and prime interleavers. Simulation results shown in Figure 5 demonstrates

Table 1. Comparison between RI, MRI, PI and Tree Based Interleaver

Parameters	RI	MRI	PI	TBI
Memory requirement	High	Low	Lowest	Low
Bandwidth requirement of Interleaver (30 users)	1.5×10^6	0.01×10^6	0.0001×10^6	0.02×10^6
Complexity	High	Very high	Low	Low
Bite error rate for $E_b/N_o = 9$ (20 users) with Datalength–**2048**	6.1890×10^{-4}	3.0762×10^{-4}	6.5186×10^{-4}	4.2969×10^{-4}
Bite error rate for $E_b/N_o = 9$ (20 users) with Datalength–**1024**	8.1787×10^{-4}	0.0009	0.0011	0.0013
Specific user cross correlation	Low	Low	High	High

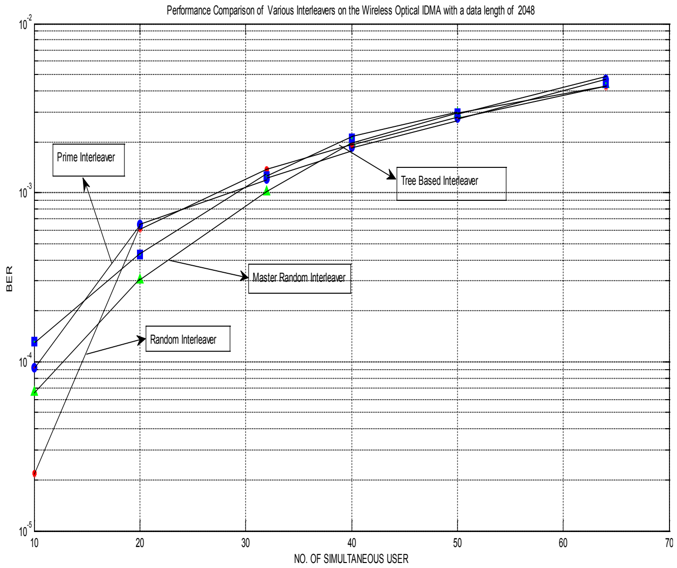

Figure 4. Comparison of BER performance of Various Interleavers On Uncoded Wireless Optical IDMA for various users with data length 2048.

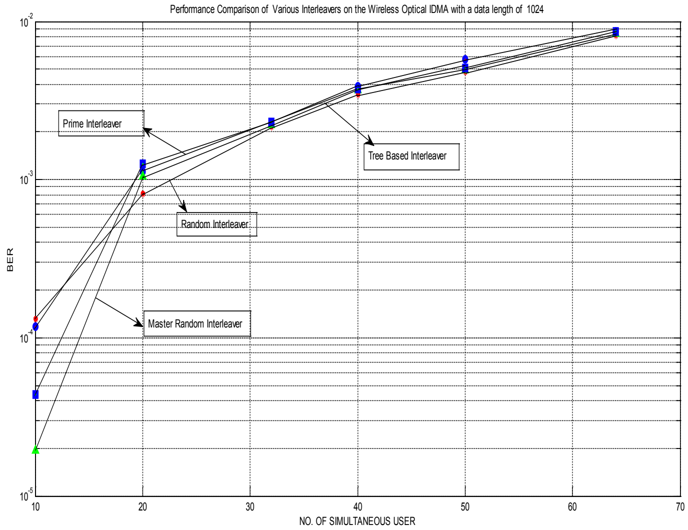

Figure 5. Comparison of BER performance of Various Interleavers On Uncoded Wireless Optical IDMA for various users with data length 1024.

the performance of various interleavers over uncoded wireless optical IDMA for different number of users with a data length of 1024. The BER degrades with the increasing number of users.

6 Conclusion

In this paper, comparison between various Interleavers have been made on the basis of parameters like complexity, Bit Error Rate (BER), memory requirement etc. Among all the comparisons discussed so far, the features of Master random interleavers shows their precision for the Wireless Optical IDMA technology for fourth generation wireless communication. On the basis of above comparisons shown in table 1, we can see that Master random interleavers and Tree based interleavers perform better than other interleavers. But if we consider 32 users and calculate the bit error rate then we find that these all interleavers have almost identical performance as shown in Figures 3 and 4. Tree based interleaver has low complexity than other interleavers in consideration.

Further, it has to be noted that the performance of the system can be observed employing tree based interleavers with convolutional coding[6]. Further the performance of Optical IDMA systems can also be observed with diversity schemes[14].

7 References

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