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Performance of Turbo Coded CDMA System with PPM Modulation on Optical Fiber

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Abstract: Pulse Position Modulation (PPM) is a power efficient scheme that is used with IM/DD.In this paper, performance of an optical code division multiple access (CDMA) system with Turbo coding is analyzed and simulated. Turbo coding is applied on an optical channel with PPM and direct detection of the received optical signal then the performance is evaluated. From the simulation results, it is demonstrated that performance of the optical CDMA system can be improved by increasing the interleaver length and the number of iterations in the decoding process for a fixed code rate.

Keywords: Turbo Codes, Pulse Position Modulation (PPM), Code Division Multiple Access (CDMA).

1. INTRODUCTION

CODE division multiple access (CDMA) is an alternative to the wavelength division multiple access (WDMA) and time division multiple access (TDMA) techniques in optical fiber communication system [1], [2]. By applying CDMA to an optical communication system, the following benefits can be obtained: (i) Accurate time of arrival measurements, (ii) Security against unauthorized users,(iii) Protection against jamming, (iv) Flexibility of adding users, (v) Asynchronous access capability,(vi) Ability to support variable bit rate and bursty traffic etc. [3], [4].

A turbo code can be thought of as a refinement of the concatenated encoding structure plus an iterative algorithm for decoding the associated code sequence. The substantial coding gain by turbo coding has been confirmed for a CDMA system in an AWGN channel as well as in a wireless channel. We consider the optical CDMA packet network which can be modeled as a discrete Markov process. The performance of this network is evaluated by turbo coded BER performance in terms of packet throughput delay characteristics.

The rest of the paper is organized as follows: In Section II, structures of encoder and decoder of turbo code and system model of an optical network are described. In Section III, packet throughput and delay are derived. In Section IV, Simulation results are presented and conclusions are drawn in section V.

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2. SYSTEM MODEL

2.1. Turbo Encoding/Decoding

The block diagrams of turbo encoder and decoder are shown in Fig.1 (a) and (b).The fundamental turbo code encoder is built using two identical recursive systematic convolutional (RSC) codes with parallel concatenation [5]. An RSC encoder is typically r = 1/2 and is termed a component encoder. An interleaver separates the two component encoders. Only one of the systematic outputs from the two component encoders is used, because the systematic output from the other component encoder is just a permuted version of the chosen systematic output. Figure 1 shows the fundamental turbo code encoder.

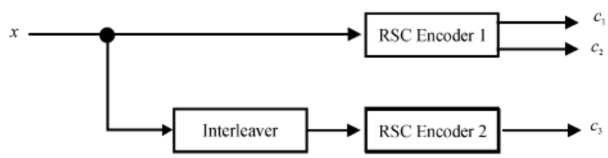

Figure. 1(a): Fundamental Turbo Code Encoder

Systematic $c1$ and recursive convolutional $c2$ sequences while the second RSC encoder discards its systematic sequence and only outputs the recursive convolutional $c3$ sequence.

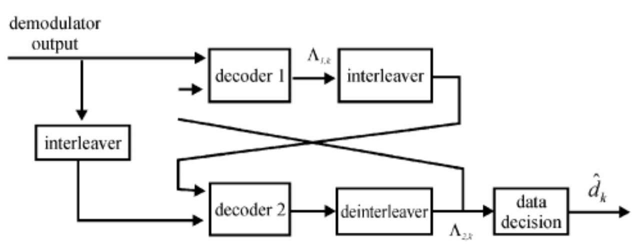

Figure. 1(b): Turbo Code Decoder

The turbo code decoder is based on a modified MAP (maximum a posteriori) algorithm that incorporates reliability values to improve decoding performance [6], [7]. Interleavers in a structure similar to that of the encoder link two component decoders. The MAP decoder computes a posteriori probability conditioned on the received sequence. The iterative turbo decoder makes use of a posteriori probability (APP) in the form of a log likelihood ratio given by [8], [9].

$$L(u) = \log \frac{\Pr\{u = 1 \mid x\}}{\Pr\{u = 0 \mid x\}} \tag{1}$$

$$= \Lambda_e^m + \Lambda_r + \Lambda_s \tag{2}$$

Where x is received sequence, Λ_e^m is extrinsic information from m^{th} decoder (m = 0 or 1), Λ_r is a priori log likelihood ratio of the systematic bit u and Λ_s is log likelihood ratio of the a posteriori probabilities of the systematic bit. The iteration process continues until a desired performance is achieved at which point a final decision is made by comparing the final log likelihood ratio to the threshold 0.

2.2. Optical CDMA Network

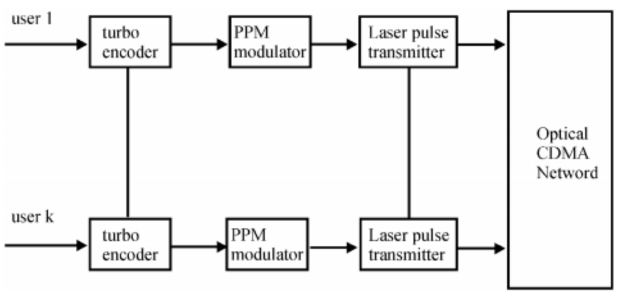

Figure. 2(a): Optical CDMA Transmitter

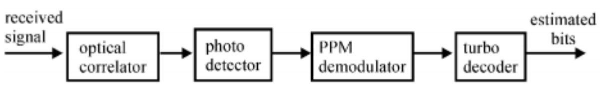

Figure. 2(b): Optical CDMA Receiver

The optical CDMA network consists of K users, each transmitting its own message. Each user is assigned a unique optical pulse sequence for its address. The optical CDMA network has the advantages of being able to use simple pulsed lasers without wavelength control and standard photo detectors without wavelength control and standard wideband photo detectors without narrow optical filters. All of the users operate independently, and no common clock is needed to synchronize the transmitters of the users.

In Fig. 2(a) the information bits of each user is fed in to the turbo encoder. The turbo encoded bit stream is modulated at the PPM modulator where transmitter sends its pulse sequence in one of the two time slots to represent each data bit.

In Fig. 2(b), the received signal is first processed at the optical correlator. When the desired signal passes through optical correlator, the correlator output is converted in to the electrical signal at the photo-detector. In the PPM demodulator, the highest output of two slots is selected as the transmitted symbol, and then it passes through the turbo decoder to estimate the transmitted information bits.

3. PERFORMANCE ANALYSIS

In the performance analysis, the following are assumed: 1) Optical components for each user are identical, 2) synchronization between the transmitters and the intended receiver is perfect in a chip and a bit levels, 3) constituent codes of turbo encoder are identical.

And, as a simple example for application of the turbo coded performance analysis to an optical CDMA network, the following are assumed: 1) an optical network is modeled as a slotted CDMA Network, 2) a packet has a packet size of L bits, 3) finite K terminals are in the network, 4) each terminal transmits with same intensity, 5) timing information for synchronization is perfect, and 6) each packet consists of one codeword of turbo code.

In the slotted optical CDMA network, at the beginning of each slot, each terminal is either blocked or unblocked, depending on whether its previous packet was successfully transmitted or not. Only the unblocked terminal can generate a new packet with probability P_n and the blocked terminal retransmit its backlogged packet with probability P_r in each slot, the central receiver broadcasts feedback messages to all the terminals simultaneously.

The dynamics of this network can be modeled by a multidimensional Markov chain. The number of blocked terminals can be modeled by a Markov chain where a state represents the number of blocked terminals. The state space of this Markov chain is {0, 1, …, K} where K is the number of terminals in the network. The transition from one state to another is determined by the difference between the number of new successful transmissions and retransmissions. The successful new transmission and the successful retransmissions have no influence on the system state.

In a given slot, there are $N = N_n + N_r$ packets where N_n and N_r are the number of new and backlogged packets , respectively. Then the N_n and N_r are independent Bernoulli random variables with distributions.

$$Q_n(l \mid i) = \Pr\{N_n = l \mid X_k = i\} = \binom{K-i}{l} P_n^l (1 - P_n)^{K-i-l} \tag{3}$$

$$Q_r(l \mid i) = \Pr\{N_r = l \mid X_k = i\} = \binom{i}{l} P_r^l (1 - P_r)^{i-l} \tag{4}$$

where X_k denotes the number of blocked terminals at the beginning of slot k. Thus, the total number of packets in a slot has a distribution given by

$$Q_r(l \mid i) = \Pr\{N_t = l \mid X_k = i\} = \sum_{m=0}^{l} Q_n(m \mid i) Q_r(l-m \mid i) \quad (5)$$

One–step transition probability of this Markov chain at the given time slot k, $P_{i,j} = \Pr\{X_{k+1} = j \mid X_k = i\}$, is given by

$$P_{i,j} = \begin{cases} 0, \; j < i-1 \\ Q_n(0/i)\sum_{l=1}^{j} Q_r(l \mid i) P_s(l), \; j = i-1 \\ Q_n(k+1 \mid i)\sum_{l=1}^{j} Q_r(l \mid i) P_s(l+k+1) \\ +Q_n(k \mid i)\sum_{l=1}^{j} Q_r(l \mid i)[1-P_s(l+k)], \; j \geq i \end{cases} \quad (6)$$

The Markov chain has a limiting distribution denoted by

$$f = [f(0), f(1), \ldots\ldots, f(K)], \quad (7)$$

Where

$$f(j) = \Pr\{X_\infty = j\} = \lim_{n\to\infty} \Pr\{X_{k+n} = j \mid X_k = i\} \quad (8)$$

Since the above Markov chain has finite population and is irreducible, a steady –state distribution exists. The steady-state probabilities are found by solving the linear system of equations

$$f = fP, \quad (9)$$

with constraint

$$\sum_{j=0}^{K} f(j) = 1, \quad (10)$$

Where $P = [P_{i,j}]$ is a state transition matrix. The above two equations, (9) and (10), involves solution a set of $N + 1$ simultaneous equation.

Packet throughput in a steady state is defined as the average number of successfully transmitted packets per slot, and given by

$$T_p = \sum_{j=1}^{K} jS(j)\left[\sum_{m=0}^{K} f(m)\xi(j \mid m)\right] \quad (11)$$

Where $S(j)$ is the probability of a successful packet transmission at the state j and given by

$$S(j) = \sum_{k=0}^{e} \binom{L}{m} [P_b(j)]^m [1-P_b(j)]^{L-m} \quad (12)$$

e is error correcting capability in a block of length L and $\xi(j|m)$ is composite (newly generated and retransmitted) packet arrival distribution function (newly and retransmitted) and given by

$$\xi(j \mid m) = \sum_{i=\max(j-m,0)}^{\min(j,K-m)} B(i, K-m, p_n), B(j-i, m, p_r) \quad (13)$$

for binomial distribution, $B(i, j, \rho) = \binom{j}{i} \rho^i (1-\rho)^{j-i}$

Average delay in a steady state is defined as the average number of time slots required to successfully transmit a data packet. From the Little's formula, the average delay is given by

$$D_{av} = \frac{B_g}{T_p} + 1, \quad (14)$$

Where B_g is expected channel backlog and given by

$$B_g = \sum_{j=0}^{K} jf(j) \quad (15)$$

4. SIMULATION RESULTS

For simulation examples, the code length $F = 500$, the weight of optical orthogonal code $w = 5$, packet size $L = 1024$ bits and two identical four–state recursive systematic convolution codes with code generator polynomials $(1 + D^2, 1 + D + D^2)$ and memory size $V = 2$ are assumed. The overall code rate is chosen as 1/3 where every source data bit is mapped into 3 coded symbols, respectively. In a turbo code with rate 1/3, the 3 bits at the encoder output can be interpreted as the sum of one uncoded bit and two parity bits.

In Fig. 3, packet throughput vs. offered load is shown for 8 iterations, MAP algorithm, interleave length =2000, new packet generation probability $P_n = 0.04$, packet retransmission probability $P_r = 0.8$ with the varying number of iterations. In the decoder, the MAP algorithm is adopted because it achieves better performance than the other algorithms. It is shown that the packet throughput is significantly improved by increasing the number of iterations is the decoding process. The turbo coding improves packet throughput by about more than twice for a wide range of offered traffic load.

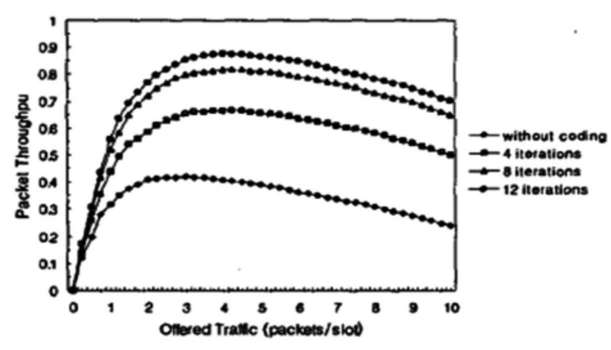

Figure. 3: Packet Throughput for the Different no. of Iterations

In Fig. 4, packet throughput vs. offered load is shown for 8 iterations, MAP algorithms, $P_n = 0.04$ and $P_r = 0.8$ with the varying interleave size. It is confirmed that the larger interleave size, the higher packet throughput. So, we can find a tradeoff between a system complexity due to the interleaver size and the packet throughput. And, it can be noted that the long interleaver may not be applicable for the optical CDMA network because the high speed (>Mbps) data is transmitted in an optical network.

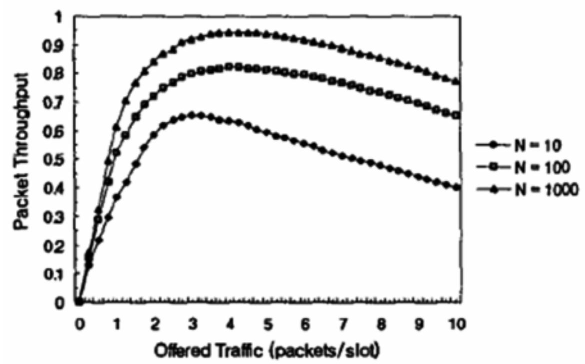

Figure. 4: Packet throughput for the Different Interleaver Sizes

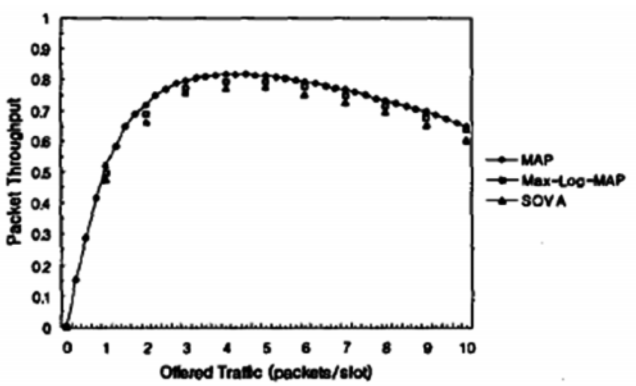

Figure. 5: Packet throughput for the Different Decoding Algorithms

In Fig. 5, Packet throughput vs. offered load is shown for 8 iterations, MAP algorithm, K = 8, P_n = 0.04 and P_r =0.8 with varying the turbo decoding algorithms. The MAP algorithm accomplished the best packet throughput among three algorithms. However, throughput difference between the MAP and the Max-Log-MAP algorithms is not significant.

5. CONCLUSION

The performance of an optical direct-detection CDMA with turbo coding was analyzed and simulated for the BPPM modulation. From the simulation results, it was confirmed that turbo coding offers considerable coding gain compared to the uncoded system with reasonable encoding /decoding complexity. The performance was gradually improved by increasing the interleaver length and the number of iterations for a fixed code rate. As a decoding algorithm, the Max-Log-MAP algorithm is recommendable to be a suitable choice in terms of both performance and complexity. It can be concluded that turbo coding is very effective in improving throughput performance from the viewpoints of network. The extension of BPPM to higher order PPM (>2) is very straightforward from the analysis of this paper. The result in this paper can be applied to an optical CDMA network with power limitation.

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