# Comparison of PCCC and SCCC for an Optical CDMA System

**Jin Young Kim**

*Central Research and Development Center*
*SK Telecom*
*9-1, Sunae-dong, Pundang-gu, Sungnam City*
*Kyunggi-do 463-020, Korea*

## ABSTRACT

In this paper, performance of an optical CDMA system with PCCC and SCCC is simulated and compared. It is assumed that optical channel is an intensity modulated (IM) channel and direct-detection scheme is employed to detect the received optical signal. The modulation scheme used is pulse-position-modulation (PPM). The performance is evaluated in terms of bit error probability. From the simulation results, it is shown that turbo coding offers considerable coding gain with reasonable encoding/decoding complexity.

## Ⅰ. INTRODUCTION

CDMA (code-division-multiple-access) based on spread-spectrum technology is one of the promising techniques, by which multiple users can be multiplexed on the same frequency bands and time slots through unique signature codes. The optical medium is very well suited to the CDMA technique in that it can provide extremely large bandwidth [1].

As a modulation format for optical communications, OOK (on-off-keying) and PPM (pulse-position-modulation) have primarily been employed [2]. For power-limited optical channels such as wireless optical channels, PPM is preferable to OOK because the PPM is more power-efficient than the OOK. In PPM, a laser pulse is shifted into one of a set of possible pulse locations for data transmission. Each pulse position corresponds to a different PPM symbol.

Recently, in the channel coding community, there has been much interest on turbo codes (also termed as PCCC (parallel concatenated convolutional codes)) introduced by Berrou *et al.* in 1993 [3]. The substantial coding gain of turbo coding has been confirmed for CDMA systems in the wireless channels as well as in AWGN channels [4]. However, there has not yet been an attempt to evaluate the performance of optical CDMA systems with SCCC (serially concatenated convolutional coding).

The PCCC and the SCCC is a kind of concatenated convolutional code, and performs decoding in an iterative manner. The encoder is formed by concatenation of two constituent codes in parallel and in serial, respectively, and by separating the codes with an interleaver. This interleaver permutes the information sequence and then uses this as the input to the second component encoder. It is known that the decoding complexity is proportional to the block length, the number of decoding iterations, and the constraint length of the constituent codes. The decoding is not maximum likelihood (ML) decoding, but tries to approach ML decoding in an iterative way. At every iteration, a single decoding is performed using the observation as well as reliability information delivered by the other decoders which were acting before. For the decoding of the PCCC and the SCCC, the MAP (*maximum a posteriori*) algorithm is known to be the optimal choice [5]. There are many suboptimal algorithms such as SOVA (soft output Viterbi algorithm) or Max-Log-MAP that are less complex than the MAP algorithm at the cost of lower performance [6].

In this paper, the performance of an optical PPM/CDMA system with the PCCC and the SCCC is compared and simulated for both shot noise-limited and thermal noise-limited systems. It is assumed that the optical channel is an intensity modulated (IM) channel and direct-detection scheme is employed to detect the received optical signal. The performance is evaluated in terms of bit error probability. The optical CDMA system with direct-detection requires code sequences of 0's and 1's with desirable correlation properties. For the smallest multiple access interference (MAI), the codes with the smallest cross-correlation is necessary. In this paper, it is assumed that a low weight optical orthogonal code (OOC) is assigned to each user [7].

The rest of this paper is organized as follows. In Section II, system model of an optical CDMA system and structures for PCCC are described. In Section III, the SCCC is described. Simulation results are presented in Section IV, and conclusions are drawn in Section V.

## II. PCCC

### II. 1. Overall System Description

In Fig. 1. (a) and (b), block diagrams of the transmitter and receiver for the optical PPM/CDMA system are shown. The information bits of each user are fed into the turbo encoder. The turbo encoded bit stream is modulated at the PPM modulator where the coded bit stream is first blocked into a symbol of length $\log_2 M$ data bits. In a PPM modulator, a transmitter sends its pulse sequence in one of the M time slots (symbol positions) to represent a block of $\log_2 M$ data bits. Each symbol is encoded into M-ary PPM signaling format. In a laser pulse transmitter, the laser is pulsed on at the first chip position corresponding to the symbol. In

The received signal is first processed in the optical correlator which is a set of optical delay lines matched to the pulse duration. The optical signals of the users are additive in intensity because the laser lights are assumed to be noncoherent. When the desired signal passes through optical correlator, the correlator output is converted into the electrical signal at the photodetector. Then, in the PPM demodulator, the highest output is selected as the transmitted symbol. The output of the PPM demodulator is decoded at the turbo decoder to estimate the transmitted information bits.

### II. 2. PCCC Encoding/Decoding

In Fig. 2 (a) and (b), the block diagrams of turbo encoder and decoder are shown. The turbo encoder consists of two recursive systematic convolutional codes that are usually called *constituent codes*. Since the turbo code is a kind of linear block codes, the encoding operation can be viewed as the modulo-2 matrix multiplication of an information matrix with generator matrix. The encoder 1 encodes the input data sequence directly, and the encoder 2 encodes the data sequence permuted by pseudorandom interleaver with length N. The encoder outputs are composed of the systematic bit, $d_k$, and parity bits of the constituent codes, $x_{p1,k}$ and $x_{p2,k}$. In this encoding process, a very large effective constraint length is generated through interleaving and concatenation. So, the conventional Viterbi decoding algorithm is not feasible for turbo decoding. Turbo decoding is typically performed in an iterative manner. Each constituent code is separately decoded using the most recent decoding information from the other constituent code. The decoding process continues until some stopping criterion is met. After iteration, the data bit decision is made based on the final decoder output.

## III. SCCC

A concatenated coding scheme has been proposed by Forney as a class of codes which have an exponentially decreasing probability of error with an algebraically increasing decoding complexity. The conventional concatenated code typically consists of the cascade of an inner code and an outer code. In most of the applications, the inner code is a relatively short code (typically convolutional code) admitting simple maximum likelihood decoding, whereas the outer code is a long high-rate algebraic (typically, nonbinary Reed-Solomon code) equipped with a powerful algebraic error-correction algorithm. The concatenated code is appropriate for the systems which require high coding gain such as deep space communications.

As an alternative for the conventional concatenated code, concatenation two convolutional codes in a serial and a parallel manners has been proposed. The turbo codes are parallel concatenated convolutional codes (PCCC) where the information bits are first encoded by a recursive systematic convolutional code, and then, after passing through an interleaver, are encoded by a second systematic convolutional encoder. The PCCC encoded sequences are formed by the information bits and parity bits generated by the two constituent encoders. The other approach using the two encoders and an interleaver is serially concatenated convolutional code (SCCC) which has been shown to yield performance comparable, for some cases, superior to the PCCC [8].

The block diagrams shown in Fig. 3. (a) and (b) show the encoder and decoder of the SCCC. The SCCC encoder shown in Fig. 3. (a) consists of an inner encoder with code rate of 2/3 and an outer encoder with code rate of 1/2. An interleaver permutes the output codewords of the outer encoder before passing them to the inner encoder. The SCCC decoder shown in Fig. 3. (b) consists of an outer decoder, an inner decoder, and an interleaver and deinterleaver. The inner decoder employs a soft-output decoding algorithm to provide soft-input decisions to the outer decoder. An interleaver is employed between two decoders to separate bursts of errors produced by the inner decoder. The major difference between decoder structure of SCCC and PCCC is that in the SCCC decoder, the outer decoder does not have input from the demodulator.

## IV. SIMULATION RESULTS

For simulation examples, 8-ary PPM, OOC (optical orthogonal code) with length F = 500 and weight w = 5 were assumed. For the 8-ary PPM, every 3 encoder bits are mapped to one of the 8 possible PPM symbols because the cardinality of the turbo encoder is set to be the same as that of PPM modulator.

The upper bound on the turbo-coded bit error probability can be obtained by weight distribution of the code. However, it is difficult to compute the weight distribution of a turbo code with a particular interleaver. Therefore, it is assumed that uniform interleaver is empoyed. In the uniform interleaver, the average of weight distributions over all possible interleavers is taken, which corresponds to mapping an input sequence into its all distinct permutations with equal probability.

In Fig. 4, bit error probability vs. average number of photons/nat is compared for serial and parallel concatenations of constituent encoders with the number of users K = 10, interleaver size N = 100, average number of noise photons $K_b$ = 50, and the MAP algorithm. The interleaver size of the PCCC and the SCCC is assumed to be the same for a fair comparison. The PCCC with code rate 1/3 is employed, and it is formed by two identical four-state recursive convolutional codes with generator polynomial $1+D^2$ and $1+D+D^2$. The SCCC encoder consists of two identical four-state recursive convolutional codes with an inner encoder of code rate 2/3 and an outer encoder of code rate 1/2. Both the PCCC and the SCCC have overall code rate of 1/3. The performance of the SCCC is comparable to that of the PCCC. The BER performance is significantly enhanced as the number of iterations used in the decoding process increases.

## V. CONCLUSIONS

The performance of an optical CDMA system with the PCCC and the SCCC was analyzed and simulated for the PPM modulation. From the simulation results, it is confirmed that both the PCCC and the SCCC offer considerable coding gain with reasonable encoding/decoding complexity. From this coding gain, the required laser pulse power is reduced, which leads to the longer life expectancy for the laser system [9]. And, the SCCC achieves the comparable performance compared to the PCCC. The results of this paper can be applied, for example, to optical CDMA wireless LAN systems operating in indoor environments.

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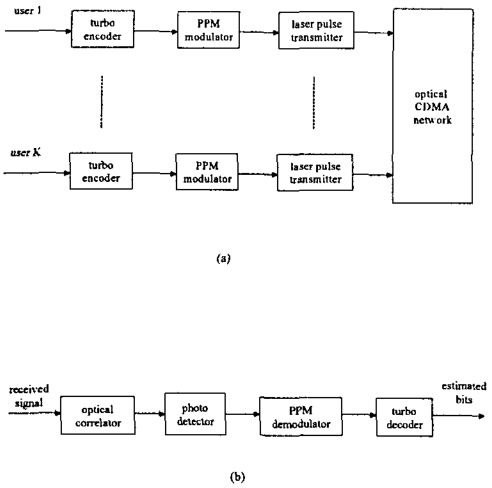

Fig. 1. Block diagram of optical CDMA system.
(a) Transmitter. (b) Receiver.

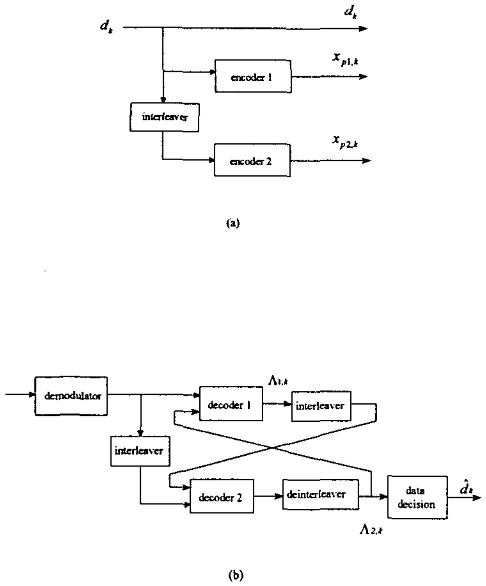

Fig. 2. Encoder and decoder of PCCC.
(a) Encoder. (b) Decoder.

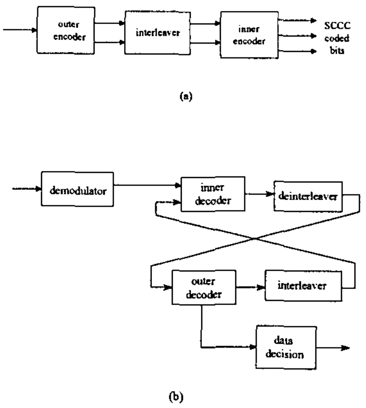

Fig. 3. Encoder and decoder of SCCC.
(a) Encoder. (b) Decoder.

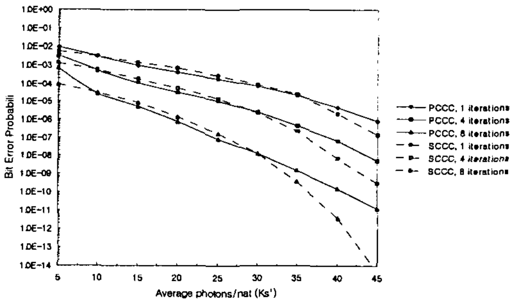

Fig. 4. Comparison of bit error probability.