A Modular Encoder Design Scheme for Turbo-encoded BPPM-OCDMA System

Muralidhar Kulkarni

Abstract**—** A Turbo-encoded Optical Code division Multiple Access(OCDMA) system has been simulated and an application specific design process has been proposed to implement a Turbo-encoded OCDMA modulated using Binary Pulse Position Modulation (BPPM) for transmission over optical fiber channels. The design process follows a modular approach and consists of four distinct modules RSC (Recursive Systematic Code) encoder, Pseudorandom Interleaver, Parallel to Serial Converter, BPPM circuit. A reference system has been designed for a frame size of 16 bits. Bit error rates were calculated for this reference design, assuming 10 simultaneous users using 5 iterations of the MAP decoding algorithm at various values of SNR for the two obtainable code rates (1/2; 1/3).

Keywords**—**Turbo Codes, OCDMA, BPPM, RSC Encoder.

I. INTRODUCTION

Optical CDMA (OCDMA) systems have attracted interest in recent years, due to their asynchronous access capability, accurate time of arrival measurements, flexibility of user allocation, ability to support variable bit rate/ bursty traffic and security against unauthorized users [1]. Further from a practical point of view, OCDMA is interesting since it requires minimal signal processing and is virtually delay free. However, OCDMA suffers from multi-user interference, which degrades both the bit error probabilities and data rates, as the number of users is increased. The performance improvement of optical communication systems with turbo coding has been examined in several works [2-4].

Fig.1 depicts a standard turbo encoder. A turbo encoder consists of two binary encoders separated by an N-bit interleaver or permuter, together with an optional puncturing mechanism. Clearly, without the puncturer, the encoder is rate 1/3, mapping N bits to 3N code bits. We observe that the encoders are configured in a manner reminiscent of classical concatenated codes. However, instead of cascading the encoders in the usual serial fashion, the encoders are parallel concatenated. It is observed that the constituent convolution encoders are of the recursive systematic variety. Because any non-recursive non-catastrophic convolution encoder is equivalent to a recursive systematic encoder in that they possess that same set of code sequences, there was no compelling reason in the past for favoring recursive encoders. However, recursive encoders are necessary to attain the exceptional performance provided by turbo codes. Without any essential loss of generality, we assume that constituent codes are identical.

In this communication, we focus on a design methodology to implement a turbo-encoder for Binary Pulse Position Modulation–OCDMA (BPPM-OCDMA) systems as described in [5-6]. We consider a centralized slotted OCDMA network, supported by an intensity modulated/direct detected (IM/DD) optical system employing BPPM. In general, the BPPM scheme improves the receiver sensitivity and power efficiency as compared to on off keying, at the expense of a wider signaling bandwidth. The turbo encoded BPPM-OCDMA scheme is suitable for systems where the transmitted power is severely restricted such as inter-satellite links and long-haul optical fiber transmission.

II. SIMULATION OF A TURBO-ENCODED OCDMA SYSTEM

Before designing the modular encoder scheme, we analyzed, simulated and compared the performance of uncoded OCDMA systems (without error control coding) and Turbo-coded OCDMA (TC-OCDMA) systems. The conclusions derived were entirely based on the results of the simulations carried in MATLAB for 20 active users. It is assumed that errors introduced are due to OMAI only because the effects of thermal or quantum noise on the BER can be reduced by increasing the transmitter power or using optical amplifiers while the OMAI results are unaffected. Figure. 2 shows the block diagram of the turbo encoder used in the simulation. The turbo decoder used in the simulation employs decoding algorithms viz. MAP algorithm and Max-logarithmic-MAP algorithm 16,19,20] although SOVA algorithm could have been used[23].

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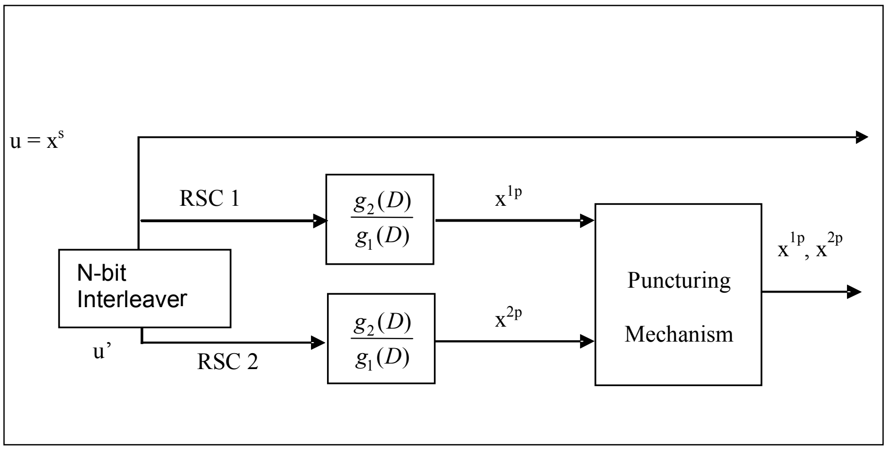


Figure. 1. Diagram of a standard turbo encoder with two identical recursive systematic encoders (RSC's)

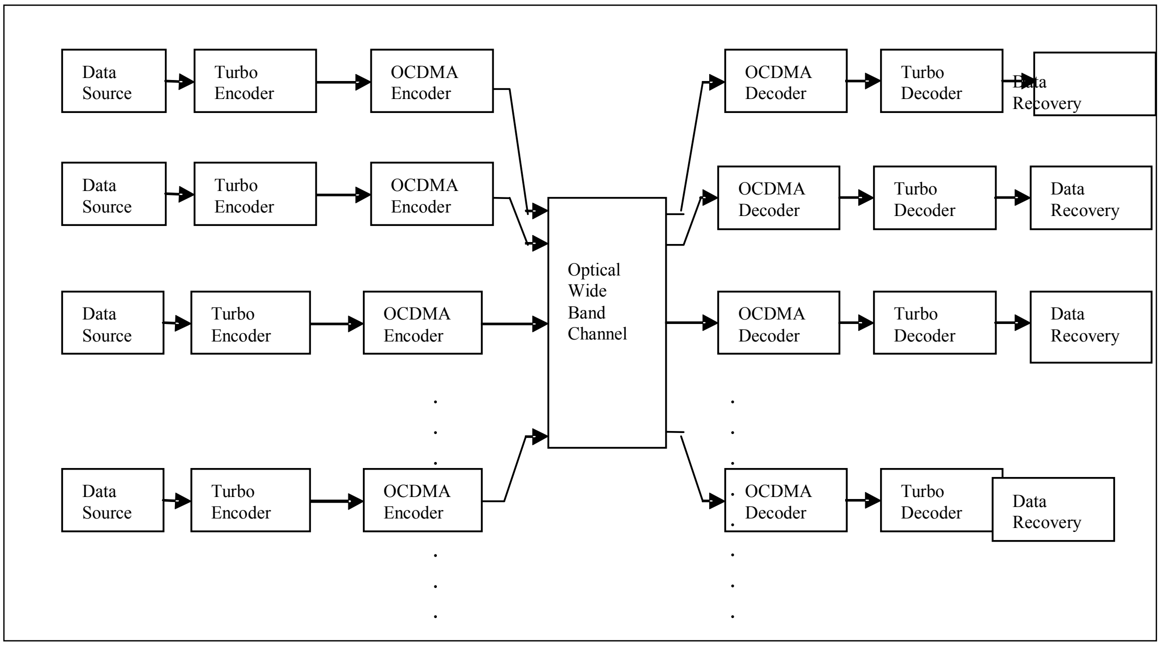


Figure. 2. Turbo-coded OCDMA system.

The simulation was carried out under the following assumptions:

- The communication between the transmitters and receivers is pair wise.
- All other users send data bits that are randomly generated. Thus, the OMAI effect of all other users on transmitter-receiver pair # 5 is considered.
- The effects of thermal noise and quantum noise are neglected.
- The various transmitter-receiver pairs send data asynchronously with respect to each other.
- The asynchronism between various pairs is always an integral number of chips.

Both uncoded OCDMA and TC-OCDMA systems were implemented assuming 20 users. All the users except one were considered dummy users. The data being sent by all the users other than one user is assumed to be truly random. The Various models were designed to gather the following data for different configurations:

1) Number of bits transmitted.
2) Number of erroneous bits received.
3) Bit error rate (BER).

In order to arrive at a generalized value of bit error rate for an OCDMA system with a particular set of specification, number of simulations was carried out and average results taken into consideration.

The correctness of the simulations was tested thoroughly by checking user data and user code words for each bit transmitted. Testing was also done by simulating systems whose results were expected. For example: if all other users except one user sent only the data bit ‘0’, there will be zero OMAI and number of erroneous bits received should be zero and hence, BER would be zero. All the users are chip synchronous with respect to each other. We concluded that for a fixed weight, the TC-OCDMA system performs better than uncoded OCDMA system. The improvement in BER performance can be interpreted as the coding gain by turbo coding. We can see that the BER performance of the TC-OCDMA system is better than that of the uncoded system. We also showed that the BER performance of TC-OCDMA systems with lower weight OOCs at threshold level becomes comparable with that of the uncoded OCDMA systems with higher weight OOCs.

III. SYSTEM CONFIGURATION

The block diagrams for the network configuration, transmitter chain in an OCDMA-BPPM system and the proposed design scheme are shown in Fig.3 (a), (b), (c).

Fig.3 (a) depicts the typical configuration of an OCDMA network with K terminals. Each terminal transmits its message at the beginning of a time slot and waits for the acknowledgement from the central station. At the physical level such a network is typically a passive optical network with a star topology, while at the logical level it is a type of broadcast and select network.

Fig.3 (b) shows the transmitter chain. The information bit stream of each user is fed into a turbo encoder. The turbo encoded bit stream is then modulated using a BPPM modulator via which the transmitter sends each of its pulses in one of two time slots to represent one data bit. Our design scheme obviates the need for a separate PPM modulation block, and laser pulse transmitter. The entire transmitter chain is embedded in a single system and the user inputs may be simply fed in and the output fed to the optical CDMA network. Hence a complete system wide deployment may consist only of the proposed design block and the optical CDMA network. This reduces the system complexity and is easier to maintain.

Fig.3(c) shows the proposed design scheme, which utilizes a Parallel Concatenated Convolutional Coding (PCCC) scheme as proposed in [8] and utilizes two identical recursive systematic convolutional codes separated by an interleaver. The upper encoder generates a parity bit stream P1 and the lower encoder generates a parity bit stream P2.The interleaver is used to permute the time order of the bits so that the two encoders are working on the same set of input bits, but on different input sequences (i.e. the sequences differ in the time order). The interleaver ensures the statistical independence of the parity bits of encoder 1 and encoder2, which is an important property for the iterative decoding process. Thus if the input bit is S and the encoders1 and 2 produce the output pairs (S, P1) and (S, P2), the overall code rate is reduced to 1/3. We may utilize a puncturing mechanism to adjust the code rate as desired.

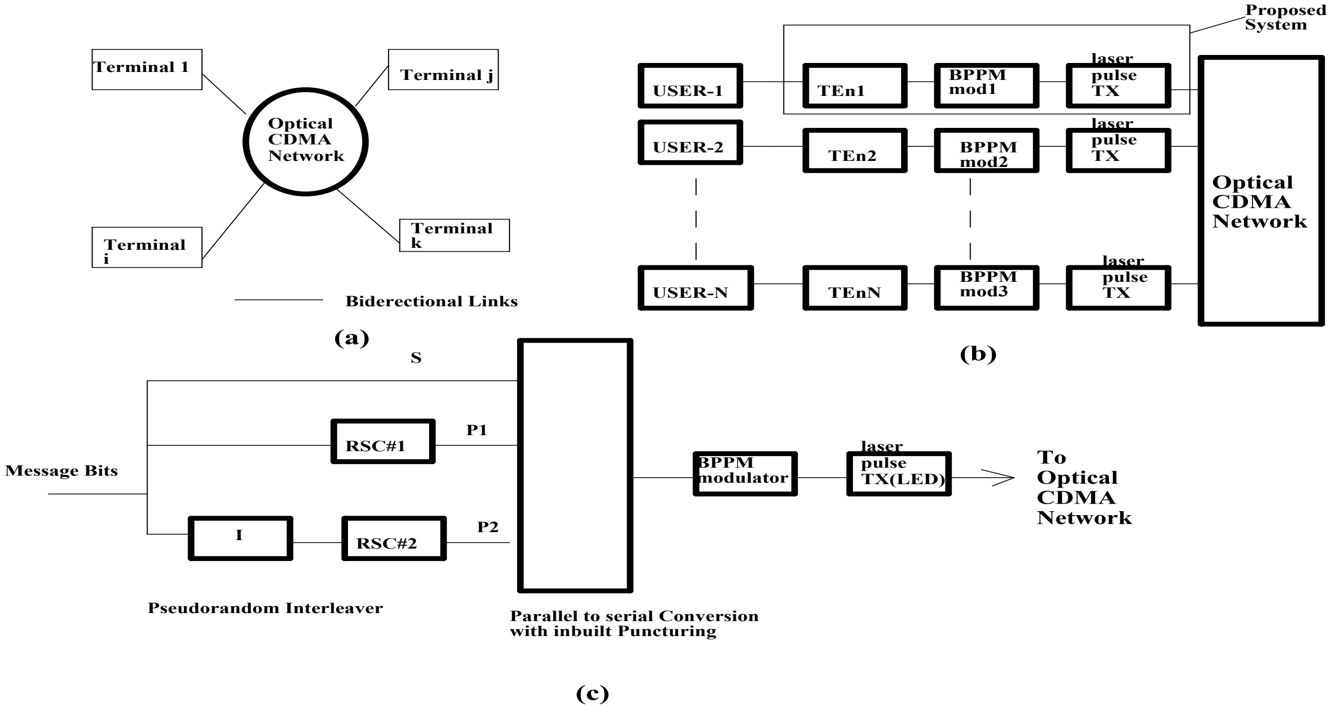


Figure. 3.(a) Typical OCDMA network Configuration **(b)** Transmitter chain **(c)** Proposed design configuration

IV. DESIGN DESCRIPTION

The various modules employed in the design of the system are shown in Fig.4.

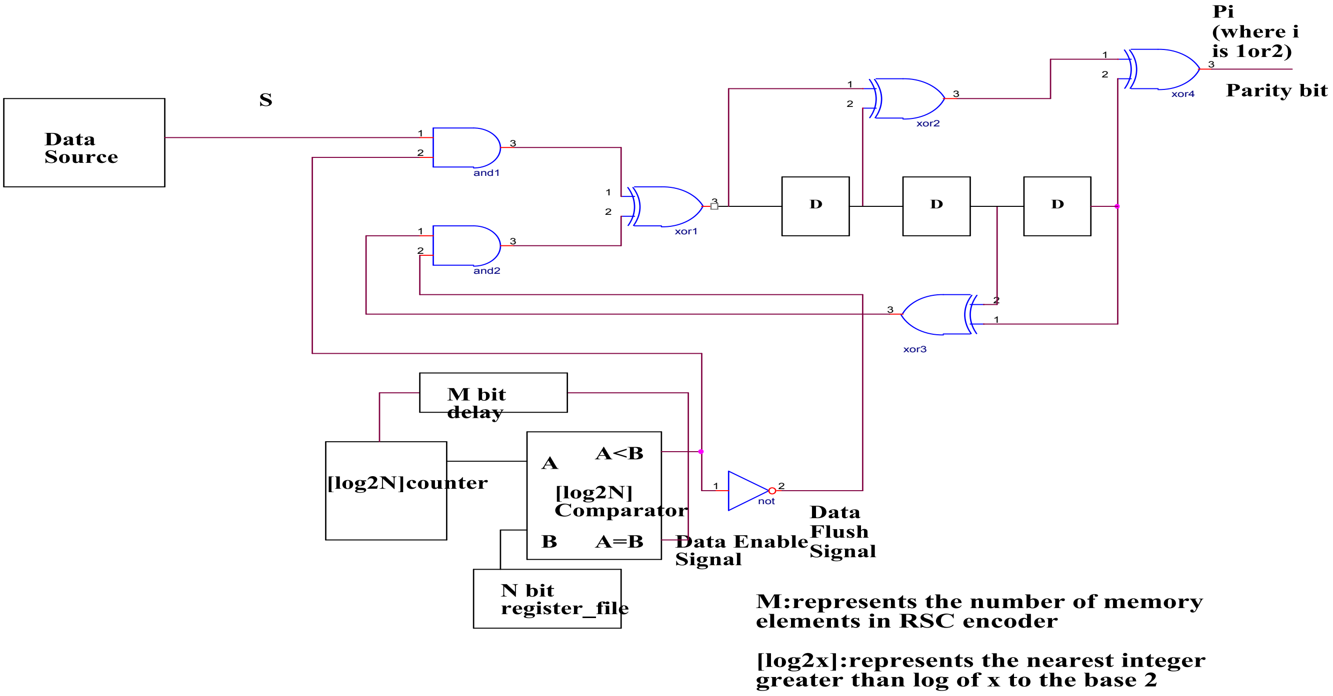
Fig. 4 (a) shows the RSC encoder employed, which confirms to the IS-2000 CDMA standard [9] and the generator connection matrix employed is $G(D)=[1,1+D+D^2/1+D^2+D^3, 1+D+D^2+D^3/1+D^2+D^3]$ (only the second output generated is used as parity bit).The system constraint length C is 4 and the number of memory elements employed is M=(C-1)=3.The RSC module contains a tail bit flush circuit and data switch circuit to reset the RSC to a known initial state by appending M zero bits at the end of each frame i.e. after N bits have been transmitted.

Fig. 4(b) shows the Pseudo-random Interleaver (PI) module, which improves the BER performance by ensuring statistical independence between the two-encoder outputs and ensuring generation of high weight code words essential for good noise performance.

A pair of N*1 SRAMs are connected in parallel having a storage capacity equal to frame length. At any given instant, one SRAM is receiving (writing in) data in the correct order and the other SRAM is transmitting (reading out) data in a permuted order in a pseudorandom manner. A control circuit that contains a counter, comparator, flip-flop and programmable LFSR (to generate the pseudorandom number sequence) and associated logic circuitry provides the address for the bits written in and read out from the SRAM cells.

Fig. 4(c) shows the Parallel to Serial conversion and Puncturing Module (PSSM) circuit with bit puncturing capability to vary the code rate. The module serializes the incoming parallel bits sets (S, P1, P2). A bit puncturing circuit is employed for selective removal of bits from the parity bit streams and hence improves the code rate. The module consists of a bit latch circuit, AND gates and select signals to select between the systematic and the two parity bit streams and to set the desired code data rate 1/k. where k is either 2 or 3 achieved by deleting specific bits from the two parity bit streams.

Fig. 4(d) shows the BPPM Modulator and Electro Optical Conversion module. The serialized turbo encoded data stream is fed into a BPPM modulator circuit that generates the corresponding chip sequence corresponding to each input encoded data bit. The mapping employed is “01” for “0” and “10” for “1” with time period that is half of the original input bit, hence generating the BPPM data sequence. The modulated output is then converted to the optical domain by feeding it to a coherent light source such as LED and may be then coupled to any optical fiber channel for transmission. The detection of the received optical signal in the optical BPPM system can be simulated using Avalanche Photodiodes(APD) as in [22].



(a)

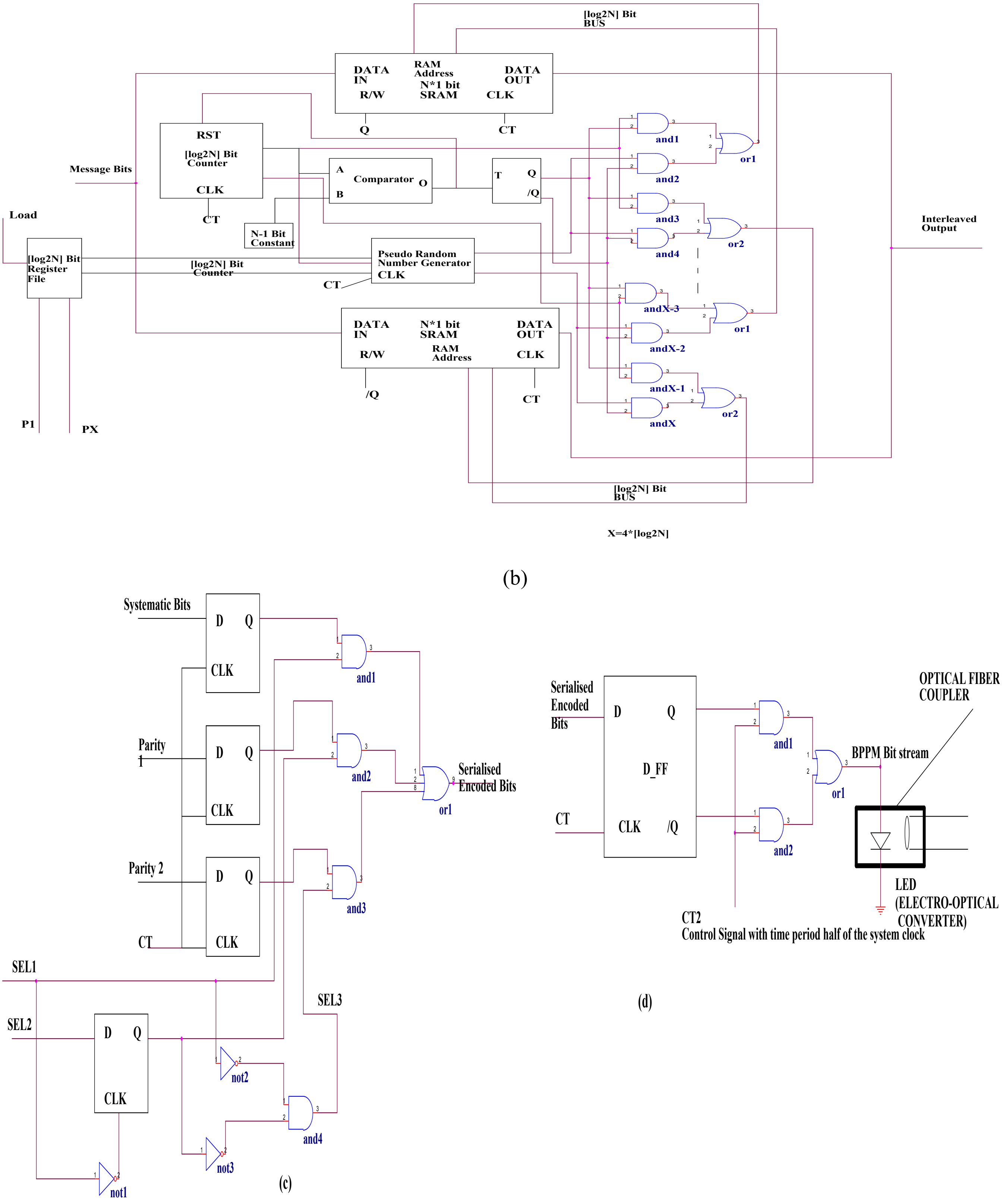


Figure. 4.(a) **RSC** Module **(b)** Pseudorandom Interleaver Module **(c)** Parallel to serial conversion with Puncturing **(d)** BPPM Circuit

V. REFERENCE SYSTEM DESIGN AND SIMULATION RESULTS

A reference system has been designed for a frame length of 16 bits (N=16). Hence the values of [$\log_2 N$] =4, M=3 are used in the reference design as shown in Fig.5, based on the design modules discussed in the above section. The design was simulated using ORCAD software to test the validity of signals generated. Simulation and modeling of a generalized communication system as given in [24] can also be used.

The BER performance of the chip at various signal to noise ratios was analyzed with and without the use of puncturing i.e. at code rates 1/2 and 1/3 using a MAP decoding algorithm and a frame size N=16 bits is as shown in Fig. 6 (a), (b). For the simulation process, the number of simultaneous users in the OCDMA system is taken to be 10 and the number of iterations in the decoding process is assumed to be 5. As is evident from Fig.3 (b), (c) the system provides good BER performance, though the reference frame size is kept low. During the simulation process, it is postulated that as the frame size increases an increase in throughput of the system may be obtained in a multiple user OCDMA network [4]. From the plots in Fig. 3(b), (c) we can infer that the system offers a competitive BER performance, Furthermore, as expected, the BER rates obtained at code rates 1/3 are lower than those at code rates 1/2 by about an order of magnitude.

Hence from the results it is concluded that the system is suitable for deployment in low SNR OCDMA networks such as long haul optical fiber links.

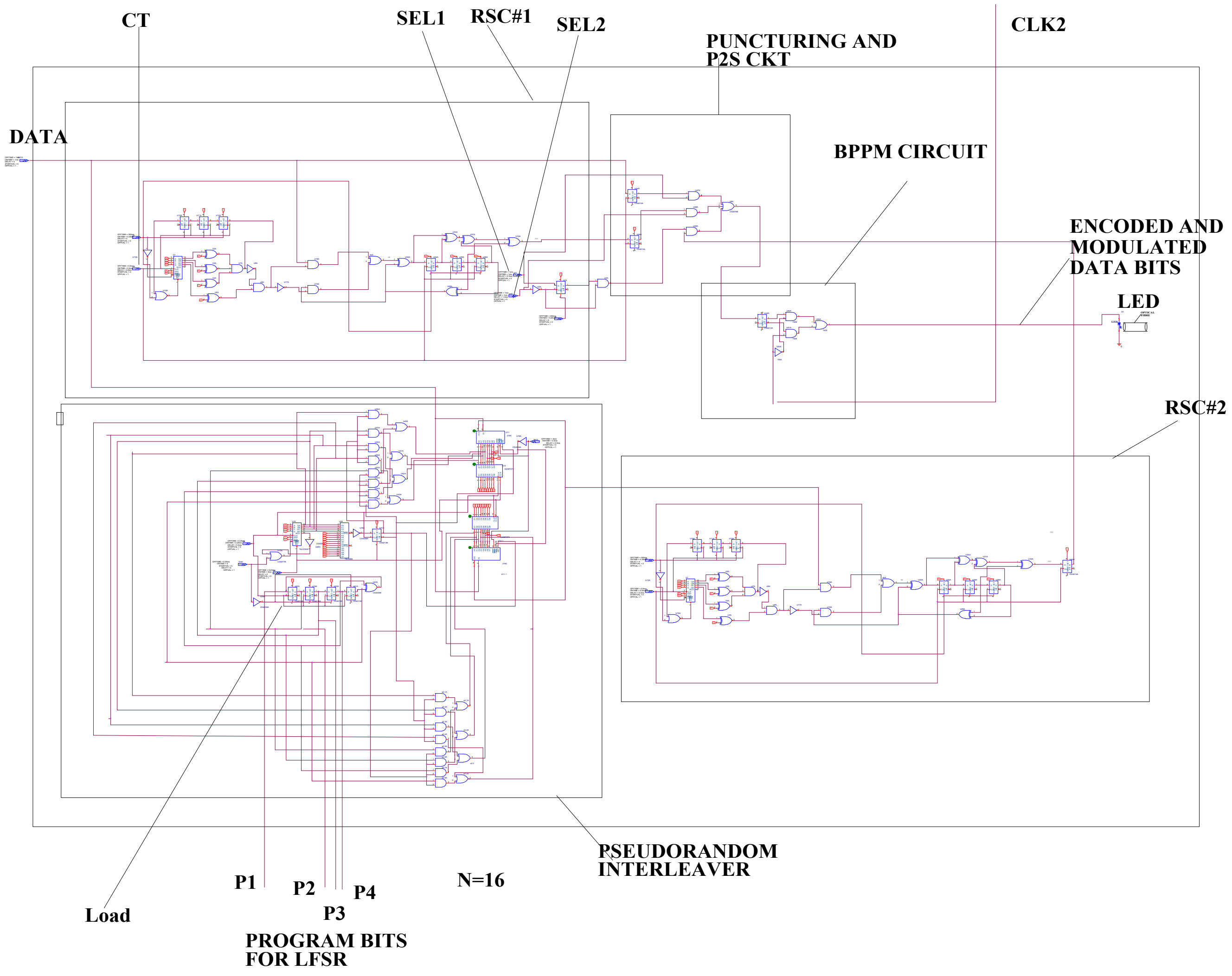
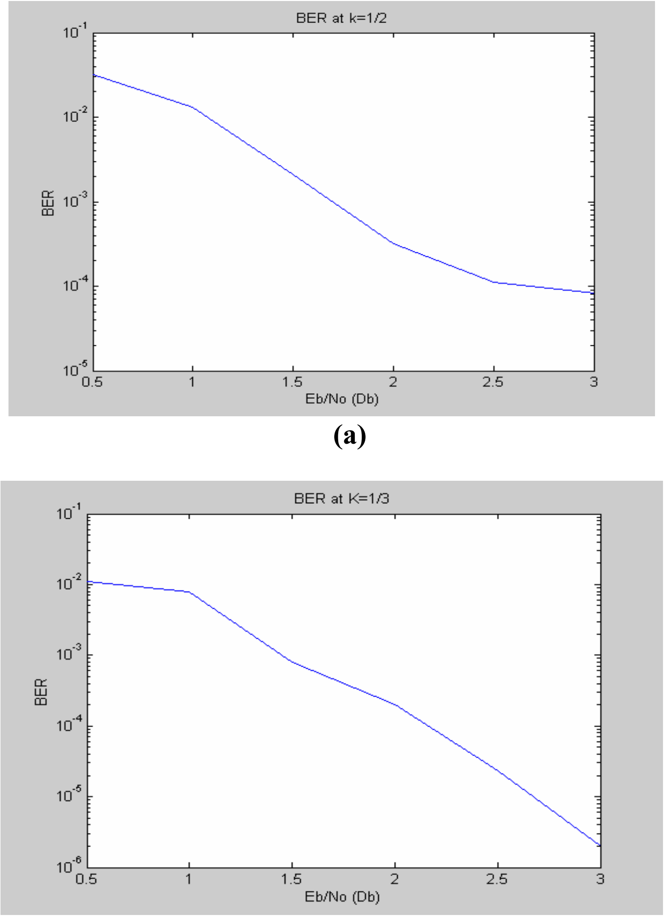


Figure. 5. Reference System Design For Frame Size (N =16)



(a)

(b)

Figure. 6.**(a)** BER at K=1/2 (**b**) BER at K=1/3

VI. CONCLUSION

In this communication, the performance analysis of turbo-coded OCDMA systems was analyzed and simulated. From the results, we observed that it is possible to use lower weight address codes for TC-OCDMA systems that can have the equivalent BER performance of uncoded systems employing higher weight address codes for a fixed number of active users. Further, the use of turbo codes can increase the maximum number of active users in a constant bandwidth OCDMA network for a given BER. Moreover, using a larger w increases the system cost since more optical delay lines are employed in the OCDMA system and optical 1 × w splitter/w × 1 combiner of a higher w are required.

Thus, the Turbo-encoded OCDMA system suggested permits implementation of a cost-effective OCDMA network with reasonable encoding /decoding complexity.

Further, we have postulated a modular encoder design scheme for Turbo encoded BPPM-OCDMA system that simplifies the transmitter chain by combining all blocks into a single stage. The design procedure itself has been considerably simplified and consisting of simple module based design scheme. The system designer can now focus on the design of one module at a time rather than the complete system. The design offers a competitive BER performance and provides a variable code rate transmission capability. The BER offered are agreeably high but these may be improved by employing asymmetric Turbo codes in the design.

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