

sequence CDMA (DS-CDMA) in mobile wireless communications [1, 2], that has been shown to have superior performance to single carrier CDMA in multipath fading. The attractive features derived from the CDMA-OFDM combination makes MC-CDMA a firm candidate for the next generation of wireless system [3, 4]. Since 1993, MC-CDMA rapidly has become a topic of research. Wireless mobile communication systems present several design challenges resulting from the mobility of users throughout the system and the time-varying channel (Multi-path fading). There has been an increasing demand for efficient and reliable digital communication systems. To tackle these problems effectively, an efficient design of forward error coding (FEC) scheme is required for providing high coding gain. To obtain high coding gains with moderate decoding complexity, concatenation of codes with iterative decoding algorithms has proved to be an attractive scheme. In iterative decoding, instead of extracting all information from the received symbols and the knowledge about the code in a single run, it is done during several iterations with successively better reliability of the result. On the contrary, iterative decoders only extract little new information during every iteration which is added to the previously extracted information.

MC-CDMA SYSTEM DESCRIPTION

The generation of an MC-CDMA signal can be described as shown in Figures 1 and 2, a single data symbol is replicated into N parallel copies. Each branch of the parallel stream is multiplied by one chip of a spreading code of length N [5]. The resulting chips are then fed to a bank of orthogonal subcarriers. As is commonly done in MC-CDMA, it is assumed that the spreading sequence length N equals the number of subcarriers. However, this scheme can be generalized to the case where the number of carriers is a multiple of the spreading sequence length allowing in this way the simultaneous transmission of several symbols from the same user. Carrier modulation is efficiently implemented using the inverse fast Fourier transform (IFFT) [3].

After parallel-to-serial (P/S) conversion, a cyclic prefix (CP) is appended to the resulting signal to minimize the effects of the channel dispersion. It is assumed that the CP length exceeds the maximum channel delay spread and therefore, there is no interference among successively transmitted symbols (i.e. there is no interblock interference).

The transmitted signal corresponding to the k^{th} data bit of the m^{th} user ($a_m[k]$) is given by [5]

$$S_m = \sum_{i=0}^{N-1} c_m[i] a_m[k] \cos(2\pi f_c t + 2\pi i \frac{F}{T_b} t) p_{T_b}(t - kT_b) \quad [1]$$

$$c_m[i] \in \{-1, 1\}$$

where $c_m[0], c_m[1], \dots, c_m[N-1]$ represents the spreading code of the m^{th} user and $p_{T_b}(t)$ is defined to be an unit amplitude pulse that is non-zero in the interval of $[0, T_b]$. The input data symbols, $a_m[k]$, are assumed to takes on values of -1 and 1 with equal probability.

At the receiver side, opposite operation to that done at the transmitter are done. These operations are the OFDM demodulation, despreading, MPSK demodulation, demapping and the PCCC decoding.

Parallel and Serial Concatenated Convolutional (PCCC and SCCC) Encoding

The convolutional turbo coder consists of a parallel concatenation of recursive systematic convolutional RSC encoders separated by a pseudo-random interleaver [6]. The main aim of RSC is to produce more high weight codes even though input contains more number of zeros [7]. The stream of input bits is fed to the first encoder without any modification and is randomly interleaved for the second encoder. A natural rate for such a code is 1/3 (one systematic bit and two parity bits for one data bit). The rate can be relatively easy increased by puncturing the parity bits but reducing the rate below 1/3 is more difficult and may involve repetition of some bits [6]. The structure of such a parallel concatenated convolutional code (PCCC) is shown in Figure (3).

One important feature of turbo codes is the iterative decoding which uses a soft-in/soft-out (SISO) like MAP (Maximum A Posteriori) decoding algorithm which was first applied to convolution



codes by Bahl Cocke, Jelinek and Raviv also known as (BCJR) algorithm [8]. In iterative decoding, there are two SISO decoders where the extrinsic information obtained from decoding process is exchanged between them [6]. MAP algorithm gives optimal estimate of information symbols given the received data sequence. In MAP decoding scheme the fact that it gives the maximum MAP estimate of each individual information bit is crucial in allowing the iterative decoding procedure to converge at very low SNR's although soft output Viterbie algorithm SOVA can also be used to decode turbo codes but a significant improvements can be obtained with MAP algorithm. This algorithm requires a forward and backward recursion and is therefore suitable for block oriented processing since turbo code is a block oriented process this algorithm. The MAP algorithm calculates the posterior probability (APP) of each state transition message bit. The log-MAP algorithm is the most complex of the algorithms used when implemented in software, but generally offers the best bit error rate (BER) performance. The max-log-APP decoding scheme is an approximation of the log-APP decoding and is widely used in practice because of its reduced computational complexity [8].

The Max-Log-MAP (MLMAP) algorithm is a good compromise between performance and complexity [9]. It is very simple and, with the correction operation, also very effective [10]. Compared to the MAP/Log-MAP algorithm no SNR-information is necessary and the critical path within the add-compare-select (ACS) unit is shorter because of the maximum operation without the correction term [11]. The performance is better than the standard SOVA algorithm and reaches nearly the optimal performance results of the MAP/Log-MAP algorithm.

The decoding is done for each inner code vector. The decoded bits are then decoded again according to the outer code used [12]. It consists of two soft input soft output SISO [14] modules connected in a ring.

The Turbo decoding process is done in an iterative manner. SISO decoding of the convolutional subcodes is done with the use of a-priori information of previous decoding steps. Here only relevant formulas of the used Max-Log-APP MLMAP algorithm are given.

Like other methods max-log-APP algorithm calculates approximate log-likelihood ratios LLR's for each input sample as an estimate of which possible information bit was transmitted at each sample time[10].They are calculated according to[10,11]

$$L_i = \max_m [A_i^m + D_i^{0,m} + B_{i+1}^{f(0,m)}] - \max_m [A_i^m + D_i^{1,m} + B_{i+1}^{f(1,m)}] \quad [2]$$

where i is the sample time index, $m \in \{0, \dots, N_s-1\}$ is the present state, N_s is the number of encoder states, $f(d, m)$ is the next state given present state m and input bit $d \in \{0,1\}$, A_i^m is the forward state metric for state m at time i , B_i^m is the reverse or backward state metric for state m at time i , and $D_i^{d,m}$ is the branch metric at time i given present state m and input bit $d \in \{0,1\}$. The forward state metrics are calculated starting at the first sample received in the block and moving forward in time to the last sample received. The reverse state metrics are calculated starting at the last sample received and moving backward in time to the first sample received. More formally, the state and branch metrics are given by

$$A_i^m = \max [A_{i-1}^{b(0,m)} + D_{i-1}^{0,b(0,m)}, A_{i-1}^{b(1,m)} + D_{i-1}^{1,b(1,m)}] \quad [3]$$

$$B_i^m = \max [D_i^{0,m} + B_{i+1}^{f(0,m)}, D_i^{1,m} + B_{i+1}^{f(1,m)}] \quad [4]$$

$$D_i^{d,m} = \frac{1}{2} (x_i d^d + y_i c^{d,m}) \quad [5]$$

where $b(d,m)$ is the previous state given present state m and previous input bit $d \in \{0,1\}$, x_i is the i^{th} systematic sample, y_i is the i^{th} parity sample, d is a systematic bit, $c^{d,m}$ is the corresponding coded bit given state m and bit d , $d^{d,m} = 1 - 2d$, and $c^{d,m} = 1 - 2c^{d,m}$. The state metrics provide a measure of the probability that state m is the correct one at time i , while the branch metrics are a measure of the probability that each possible combination of encoder outputs is the correct one given the channel outputs x_i and y_i .

Note that in contrast to the true-APP or log-APP algorithms, no estimate of the channel signal-to-noise ratio (SNR) is required. It is apparent that metric combining involves adding up all of the metrics associated with a given branch in the trellis, with each sum being an input to one of the $\max[\cdot]$ operations in (2).

The calculations in (3) and (4) are exactly the Viterbi algorithm without history and will therefore find the same winning path through the decoding trellis given the same inputs and initial conditions. The max-log-APP algorithm is sub-optimum due to the approximations involved. However, most of the performance loss associated with this suboptimality can be recovered by applying a simple scale

constituent decoder. The so-called extrinsic information may be calculated as follows:

$$L_{ex}^n = sf \cdot (L_{out}^n - L_{in}^n) \quad [6]$$

where $n \in \{1,2\}$ denotes one of the constituent decoders, L_{out}^n represents the set of LLRs produced by the max-log-MAP decoder, L_{in}^n represents the set of input LLRs, and sf is an appropriate scale factor. Corrected LLRs are then calculated according to

$$L_{cor}^n = L_{in}^n + L_{ex}^n \quad [7]$$

These corrected LLRs are the systematic input to the next constituent decoder, while the extrinsic information L_{ex}^n is fed back to be subtracted off on the next iteration. It has been found that setting $sf = 5/8 = 0.625$ typically yields performance within 0.1 dB to 0.2 dB of a true-APP decoder given the same number of iterations. At the same time, using this method vastly reduces the amount of computation required.

While in SCCC, only the inner code must be recursive systematic convolutional RSC. The information bits are encoded by the outer encoder and the resulting code bits are interleaved by the bit wise random interleaver and become the information bits of the inner encoder. The outer code with a rate $R_o = k/p$ and the inner code with rate $R_i = p/n$ joined by an interleaver of length N bits, generating an SCCC with rate $R_c = k/n$. Note that N must be an integer multiple of p [14]. For more details about the SCCC decoding refer to [15].

SIMULATION RESULTS

The proposed system is illustrated in Figure [5]. A 20 Mbps was transmitted over the system. Since the channel for the 4th generation is not developed yet, therefore, the 3.5 G channel specifications was used in the simulation process. These channels are AWGN and frequency selective fading channels. The modulation schemes are the MPSK with $M=2, 4$ and 16. The simulation was performed using Matlab program version R2008b.



First, a simulation of MC-CDMA system that utilized the parallel concatenated coded data PCCC was achieved with AWGN channel and for multipath fading channel. First, the input binary data generated at the transmitter side is encoded with the parallel concatenated convolutional coder with both the upper and lower coder of a generator polynomial of $[1\ 0\ 1\ 1; 1\ 1\ 0\ 1]$ polynomial generators and a constraint length of (4). With the MAP decoding algorithm which is an iterative decoding algorithm. The performance of the concatenated convolutional code system depends upon the number of iteration of the decoder.

The same work was repeated with the serially concatenated convolutional code with the outer coder of a generator polynomial in octal of (3, [7 5], 7) while the inner one has a ([3 3], [7 0 5; 0 7 6], [7 7]) generator polynomial. The random interleaver length was 1024 in both cases.

Table [1] summaries the system specifications for the AWGN and frequency selective fading channels [16] while figure (6) shows the flow chart of the proposed system.

The performance characteristics of the proposed system shown in figures (7, 8, 9 and 10) for binary, 4, 8 and 16 PSK modulation techniques respectively. The figures also contain comparison of the system with the PCCC data with that uses serially concatenated code and uncoded data.

Table 1-Simulation parameters for the AWGN channel

Available bandwidth	5 MHz
FFT sampling rate	5 MHz
Spreading code	Hadamard Walsh
Spreading factor	32
FFT size	512
Subcarrier spacing	2.4414 kHz
Effective symbol duration	409.6 μ s
Guard time duration	102.4 μ s
MC-CDMA symbol duration	128 μ s
Modulation technique	BPSK, QPSK, 8PSK & 16PSK
No. of iterations	6

Figures (11, 12 and 13) show a comparison of the BER versus symbol signal power to the noise power) E_s/N_o for MC-CDMA system with PCCC, SCCC and uncoded data with multipath fading channel and 2,4,and 8 PSK modulation techniques respectively.

Table [2] summarizes the obtained results as a comparison of SNR in dB for the selected channels; AWGN channel, Multipath fading channel for modulation techniques of BPSK, 4 PSK and 16 PSK with uncoded, serially concatenated convolutional coded (SCCC) data and parallel concatenated convolutional coded (PCCC) data.

Table [2]: A comparison of SNR in dB for Uncoded, SCCC and PCCC data for BER of 10^{-4} .

MPSK	SNR/dB for AWGN channel			SNR/dB for multipath fading channel		
	Uncoded	SCCC	PCCC	Uncoded	SCCC	PCCC
2 PSK	21	16.5	12	24	15	8
4 PSK	25	18.1	16	28	21.5	11.2
8 PSK	29	23	17	-	-	-
16 PSK	34	27	22.5	-	-	-

CONCLUSION:

The use of the parallel concatenated convolutional coded (PCCC) technique in conjunction with the MC-CDMA system improved the performance of the system over that which uses the uncoded or serially concatenated convolutional coded (SCCC) data. It can be noticed that there is an improvement in the results of the use of the PCCC data over the others as summarized in table 3.

It can be noticed that with 8 and 16 PSK modulation schemes with the multipath fading channel a convergence of the BER to 10^{-4} cannot be obtained and it remains fluctuating around BER of 10^{-2} .

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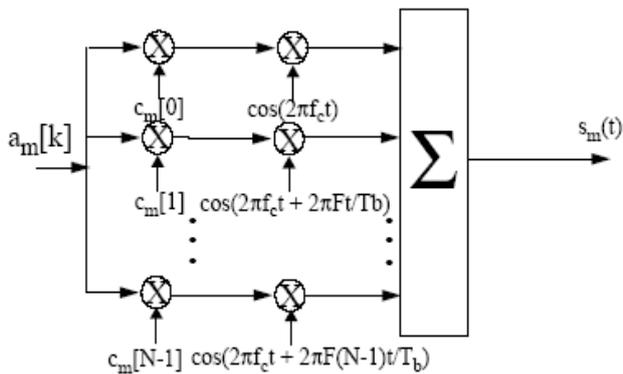


Figure (1) MC-CDMA transmitter

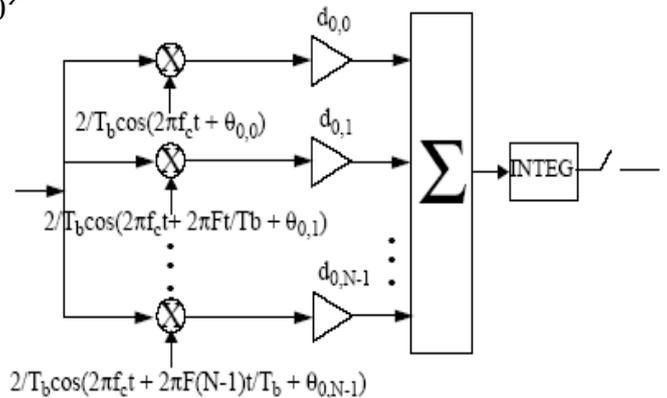


Figure (2) MC-CDMA receiver

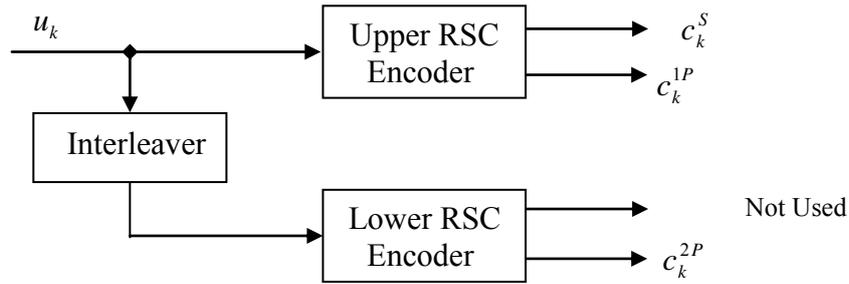


Figure (3) Parallel concatenation convolutional code (PCCC) Encoder

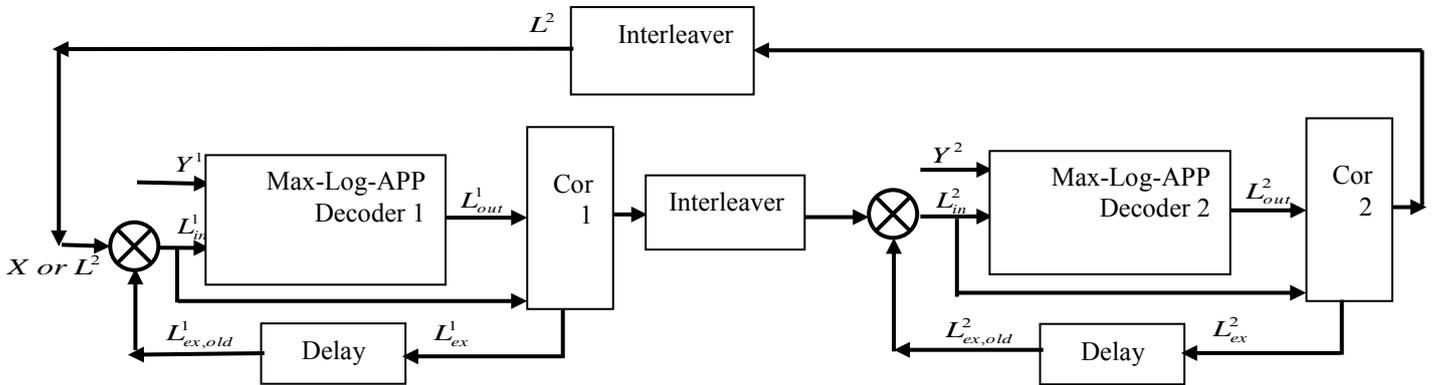


Figure (4): block diagram of the Max-Log-MAP decoding for the PCCC scheme and scale factor correction.

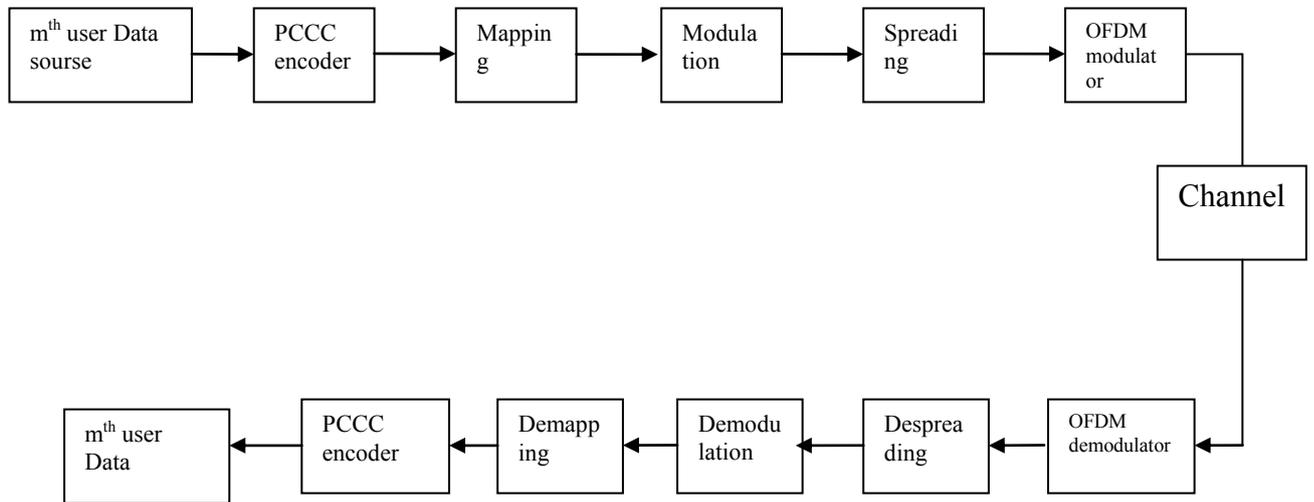


Figure (5) block diagram of the serially convolutional coded MC-CDMA system.

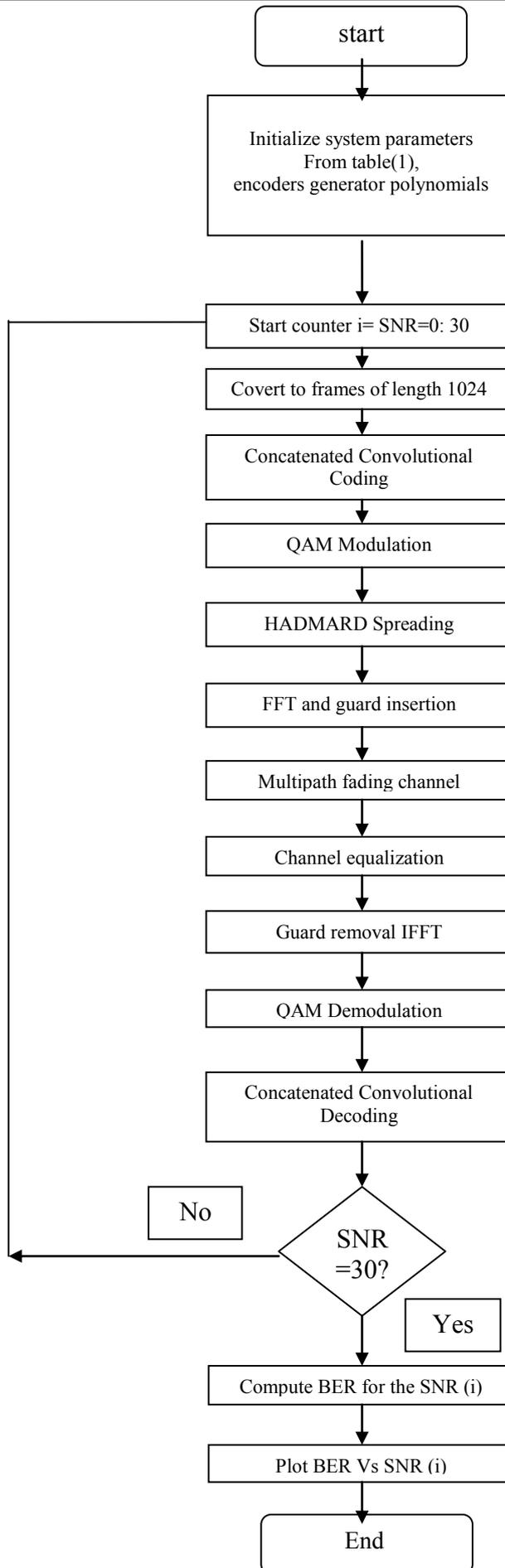


Figure (6): flow chart of the proposed system

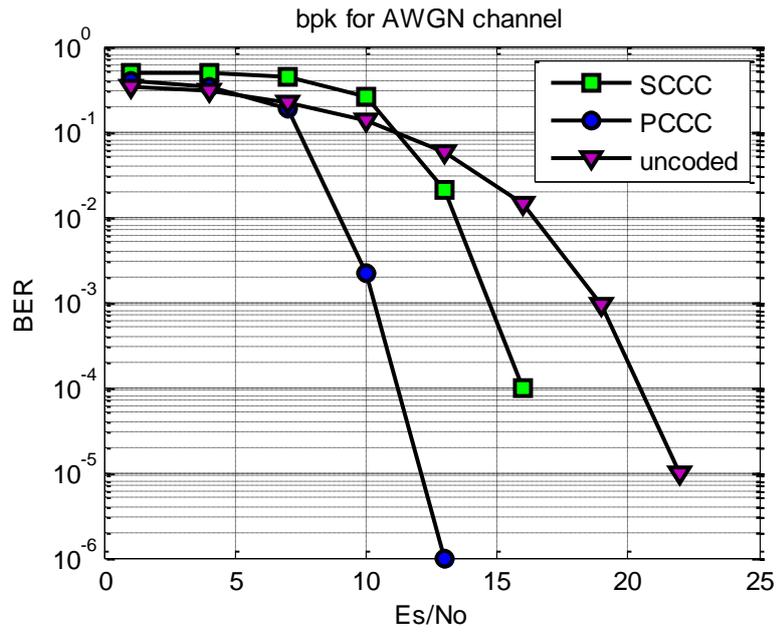


Figure (7) BER Vs SNR for AWGN channel with M=2

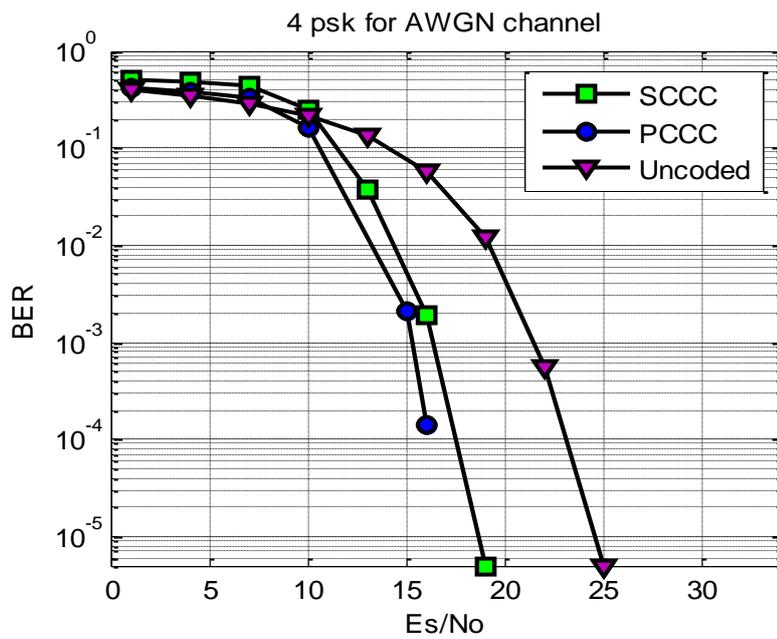


Figure (8) BER Vs SNR for AWGN channel with M=4

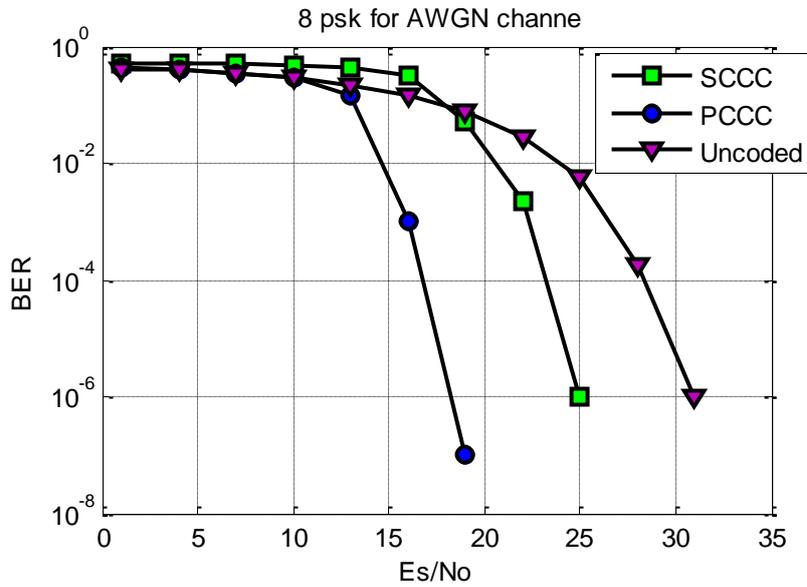


Figure (9) BER Vs SNR for AWGN channel with M=8

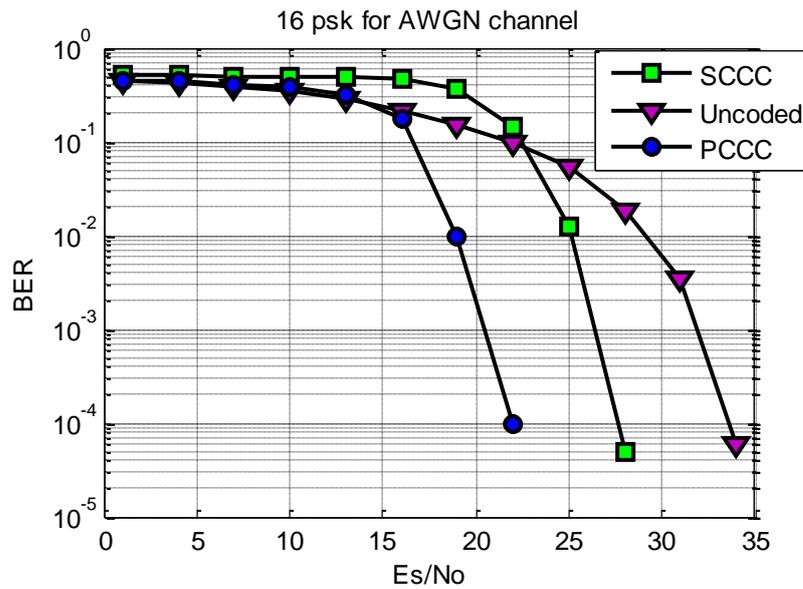


Figure (10) BER Vs SNR for AWGN channel with M=16

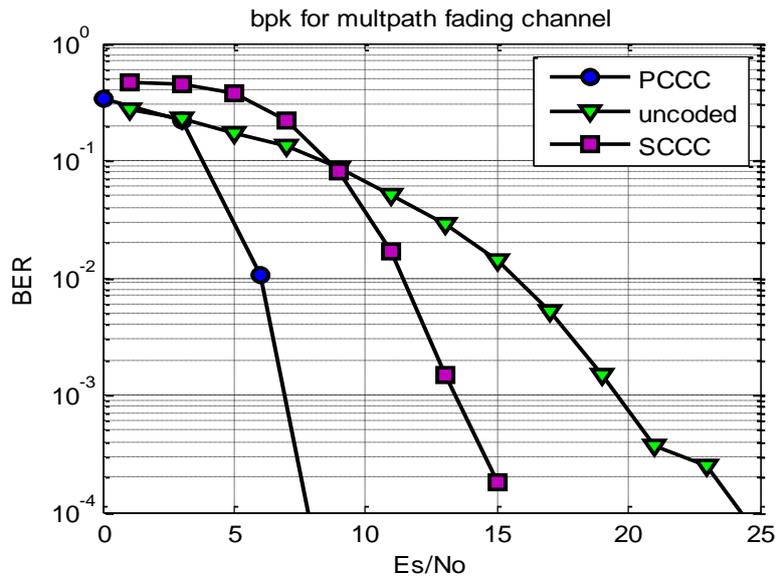


Figure (11) BER Vs SNR for multipath fading channel with M=2

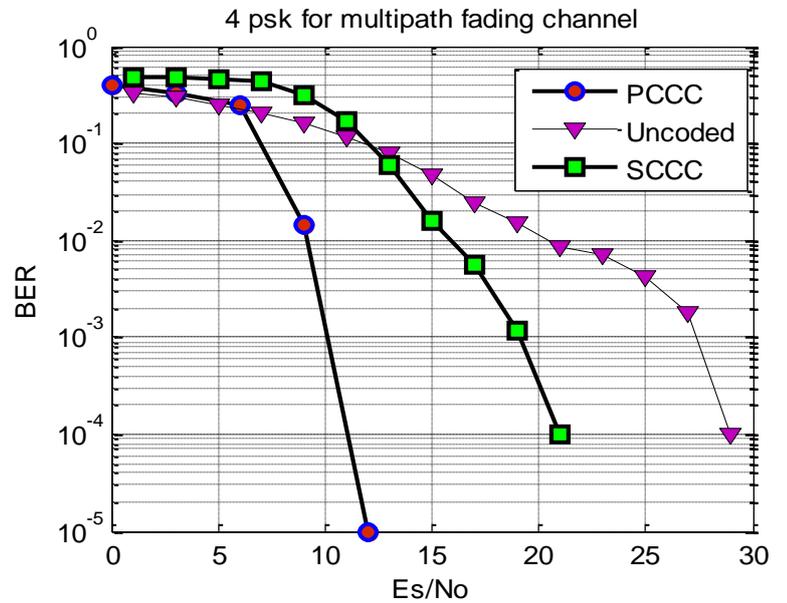


Figure (12) BER Vs SNR for multipath fading channel with M=4

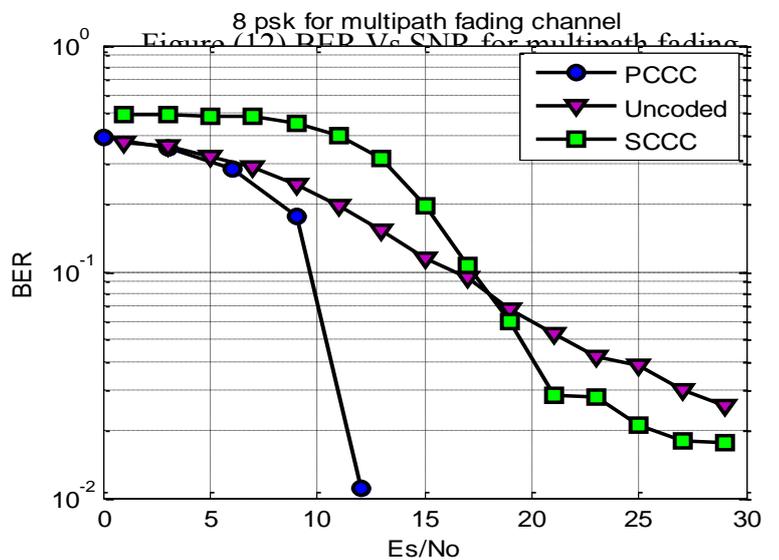


Figure (13) BER Vs SNR for multipath fading channel with M=8.