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Analysis And Modeling Of GSM/EDGE Mobile Communication System

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ABSTRACT: In this study, Enhanced Data rate for GSM Evolution (EDGE) mobile communication system is analyzed and modeled assuming to operate in both Additive White Gaussian Noise (AWGN) channel and Rayleigh fading channel. A MATLAB software package is developed to simulate extensively the EDGE system. The system analysis takes into account channel coding, modulation type, interleaving and burst building, multipath channel effect, channel estimation, and detection process. The modeled system is simulated and tested for AWGN channel and 6-path of Rayleigh fading channel and the simulation results indicate clearly that the eye opening of the received signal decreases as the Signal to Noise Ratio SNR decreases and this effect is more pronounced in the presence of fading channel. It is also noted that, to obtain the same eye diagram for both transmitted and received signals, the SNR values needed at the receiver are 40 dB and 60 dB when the system is operating in AWGN channel and Rayleigh fading channel respectively.

KEYWORDS: *EDGE, GMSK, GSM, MCS.*

I. INTRODUCTION

Global System for Mobile (GSM) has been and is by far the most widely used and most successful communications system of all time, enabling, over four billion subscribers to communicate in just about every single country of the world, just about everywhere (including airplanes) and with virtually everyone. Of all the active digital mobile subscriptions worldwide, more than 80% are GSM [1]. The existing time-division multiple access (TDMA)-based global system for mobile (GSM) is a second cellular standard with worldwide success. While speech is still the main service of this mobile system, support for data communication over the air interface is rapidly improving. Standard products provide data services with bit rates up to 9.6kbits/s. The forthcoming steps in the evolution of GSM are phase 2 and phase 2+ standards which define [2]: 1) High bit-rate, circuit–switched modes (high–spread circuit switched data, (HSCSD)); 2) Packet services (general packet radio service, GPRS). HSCSD and GPRS achieve high bit rates through multislot operation. But because these techniques are based on original Gaussian minimum shift keying (GMSK) modulation, they yield only a moderate increase in bit rate per time slots. Recently, there is increasing interest in using high–level modulation to provide enhanced data rate for GSM evolution (EDGE) [3, 4]. This technique improves spectral efficiency by applying the modulation format 8-ary phase shift keying (8-PSK) instead of binary GMSK which is used in conventional GSM. By extending the signal space from 2 to 8, each symbol contains three times more information [3].

Although EDGE reuses the GSM carrier bandwidth and time-slot structure, it can also be used with other cellular systems. It can be regarded as a generic air interface for efficiently providing high bit rates thereby facilitating the evaluation of cellular systems toward third–generation capabilities [3]. In 2002, Wolfgang and Schober [3] have shown an equalization concept for EDGE by which high performance can be obtained at moderate computational complexity. It has been shown that delayed decision-feedback sequence estimation (DDFSE) and reduced-state sequence estimation (RSSE) are promising candidates. Arslan and Hui [4] have proposed RSSE for EDGE system. A significant issue associated with soft information generation for the RSSE receiver has been discussed in detail. Several practical algorithms that calculate soft values efficiently have been reported. The performance of these algorithms has been evaluated through computer simulation and compared with the performance of more complex decision feedback sequence estimation (DFSE) receiver. Atdo et al. [5] have presented a new method to perform channel estimation. It has been shown that accurate estimation can be obtained when a training sequence is actually arithmetically added to the information data as opposed to being placed in a separate empty time slot.

Al-Hasson [6] has implemented a baseband model for the GMSK modulation with the GSM standard coding and interleaving schemes. Loat and Bidan [7] have introduced a low complexity receiver scheme where equalization and channel decoding are jointly optimized in an iterative process. Majeed [8] has introduced a new detection method with minimum computational complexity for the GSM/EGDE mobile communication system.

The aim of this study is to analyze and model GSM/EDGE systems. Comprehensive MATLAB simulation models are to be developed for the studied system to assess the key role played by each part of the system.

II. DESCRIPTION OF GSM/EDGE SYSTEM

GSM/EDGE system uses eight Phase Shift Keying (8-PSK) modulations with filter in addition to GMSK. This means that three bits are sent for every symbol instead of only one single bit. Therefore, three times higher bit rates are theoretically possible. EDGE supports transmission rates ranging from 8.8 kbps to 59.2 kbps per channel. GMSK modulation can still be used when a more robust modulation is needed. One idea is to use 8PSK/GMSK for downlink communication, where the demand for high bit rates is larger, and use only GMSK for uplink communication, which results in less complex transmitters in the terminals [9]. To optimize the throughput for all radio conditions link quality control (LQC) is used to dynamically adapt the modulation and code rate with respect to the current link quality. EDGE has nine different Modulation and Coding Schemes MCS , (MCS-1 to MCS-9) as shown in Table 1.

Table 1: Coding parameters for the EDGE coding schemes.

Data rate kbit/sec	Raw data within one data block	Modulation	Scheme
59.2	148	8-PSK	MCS-9
54.4	136		MCS-8
44.8	112		MCS-7
29.6	74		MCS-6
22.4	56		MCS-5
17.6	44	GMSK	MCS-4
14.8	37		MCS-3
11.2	28		MCS-2
8.8	22		MCS-1

The first four use traditional GMSK and the last five used the new 8PSK modulation scheme. The MCS's also have different code rates and are therefore suitable for different radio conditions. If the conditions are very good, no coding is necessary and high bit rates can be achieved. Bad conditions require more robust coding, which results in less payload and lower bit rate [9]. Fig. 2 shows the blocks of the EDGE system. All the transmitter blocks are standard and they are certified by the ETSI [10, 11]. The first block in the transmitter is the convolutional encoder, which is the same for all the modulation and coding schemes (MCS's) (except for MCS-9, no coding is used). When the data is received from the higher layers it must be encoded using the convolutional encoder to make it possible for the receiver to detect and correct some (or all) the errors that are introduced in the channel. After the convolutional encoder, the encoded data is passed through a puncturing block. This block deletes some of the coded bits from transmission and this increases the throughput and also reduces the complexity of the decoder. The puncturing block structure depends on the used MCS.

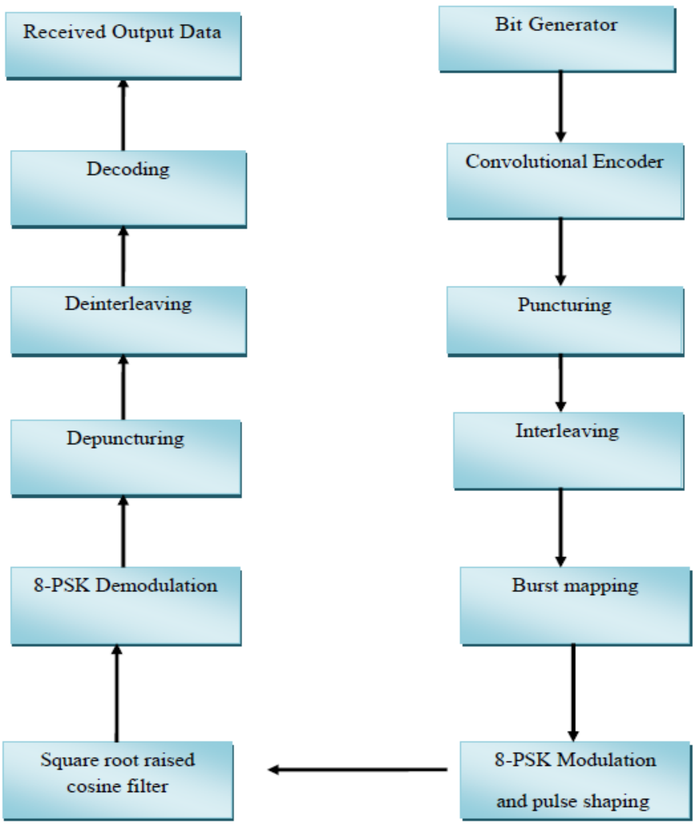


Fig.2: A schematic block diagram for EDGE system

The third block is the interleaver which interleaves the punctured data to increase its immunity to noise. This block also has different structures depending on the MCS used. When the data are encoded and interleaved, it will be arranged to form the transmitted frames, by inserting the header bits and the training sequence bits (used for channel estimation). All the MCS's have the same number of bits in each frame, but each MCS has a special frame arrangement. When the frame arrangement is completed, the frames are now modulated (mapped) into either GMSK (for MCS-1 to MCS-4) or 8-PSK (for MCS-5 to MCS-9). After the modulation, and before the transmission, a transmitter filter is used to limit the bandwidth of the transmission. For EDGE system a Gaussian filter is used to limit the bandwidth of the transmitted signal, and make it fit in the same bandwidth specified for GSM.

III. EDGE MODELING AND SIMULATION

This section describes briefly the modeling and simulation of GSM/EDGE systems. Both MCS-1 and MCS-7 modulation coding schemes are considered for the studied system. In this study only the downlink is considered, i.e., the data transmission from BTS to the MS, where high data rates are needed, unlike the uplink where low data rates are sufficient for its needs. The EDGE system is simulated using developed software written in MATLAB environments. The present study includes the modeling of the followings.

Channel Coding: The baseband model has the same structure for all MCS's. As shown in Fig. 3, the output bits generated by the encoder depend on the current input bit as well as the state of the encoder [11]. The convolutional encoder has a code rate 1/3 and a constraint length k=7. This means that for each data bit additional seven consecutive bits are used to calculate the output three bits. Block size of 196 and 468 bits are used for MCS-1 and MCS-7 respectively. The flow chart for the conventional encoder is shown in Fig. 4. Here g represents the number of bits in the data block that enters the convolutional encoder and its value depends on the MCS (e.g. for MCS-1, g=196 and for MCS-7, g=468)[15].

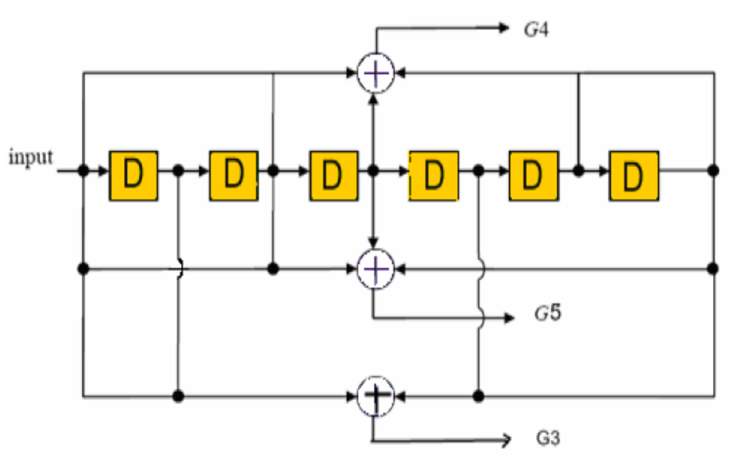


Fig. 3: Convolutional encoder in EDGE system .

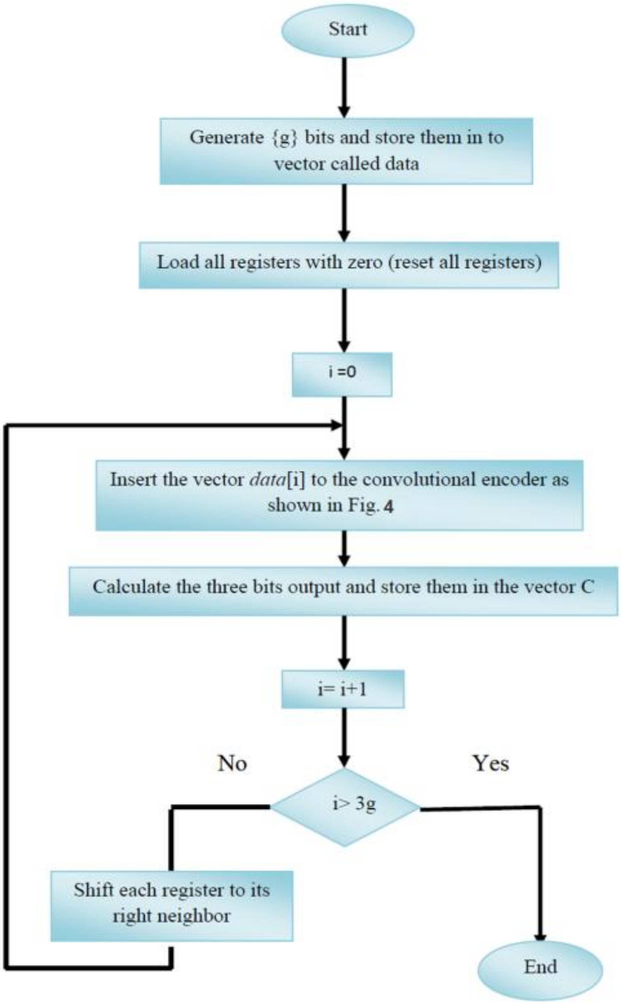


Fig. 4: Flowchart of the convolutional encoder.

Puncturing: This block is placed after the convolutional encoder [10]. Puncturing is to delete some bits from the transmitted bit stream, to reduce the redundancy bits added by the encoder thus increasing the throughput. This also reduces the complexity of the decoder at the receiver. Each MCS has a different puncturing scheme. As an example the encoded data is punctured in MCS-1 using the following puncturing scheme, {C(2+21j), C(5+21j), C(8+21j), C(10+21j), C(11+21j), C(14+21j), C(17+21j), C(20+21j) for j = 0,1,...,27} are not transmitted except {C(k) for k = 73, 136, 199, 262, 325, 388, 451, 514} which are transmitted. The flowchart of Fig.5 shows the puncturing program structure for the MCS-1, as an example of the puncturing in the nine MCS's. The other MCS's differ in the equation to find the value of *j*, and also what to do with this *j* value (transmit or not transmit). The value of *k* is also variable depending on the MCS used.

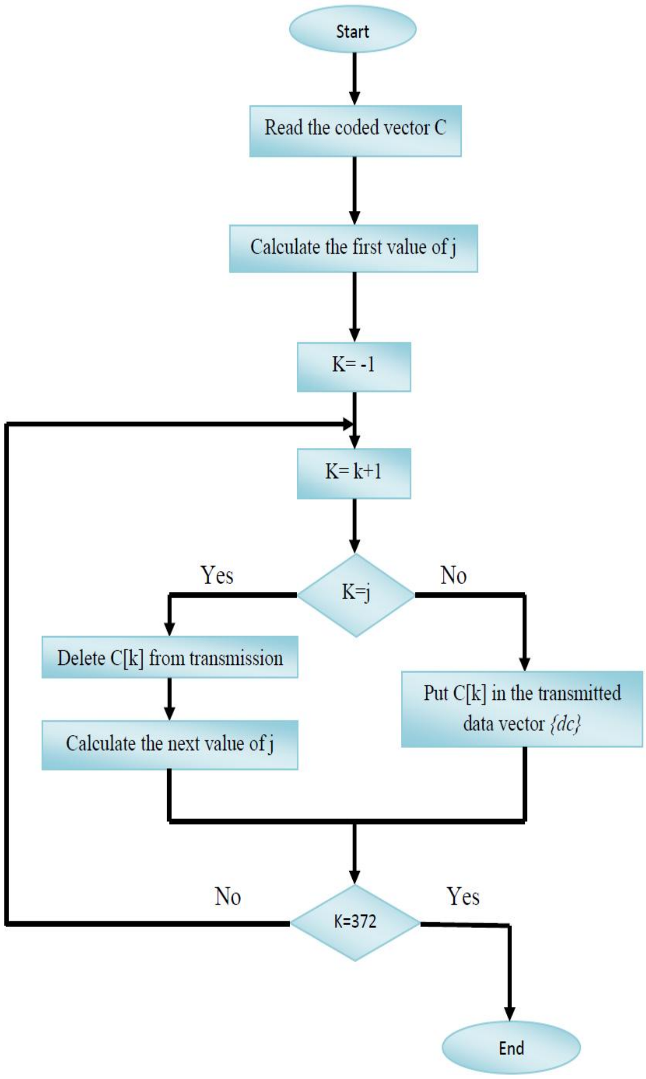


Fig. 5: Flowchart of the MCS-1 puncturing.

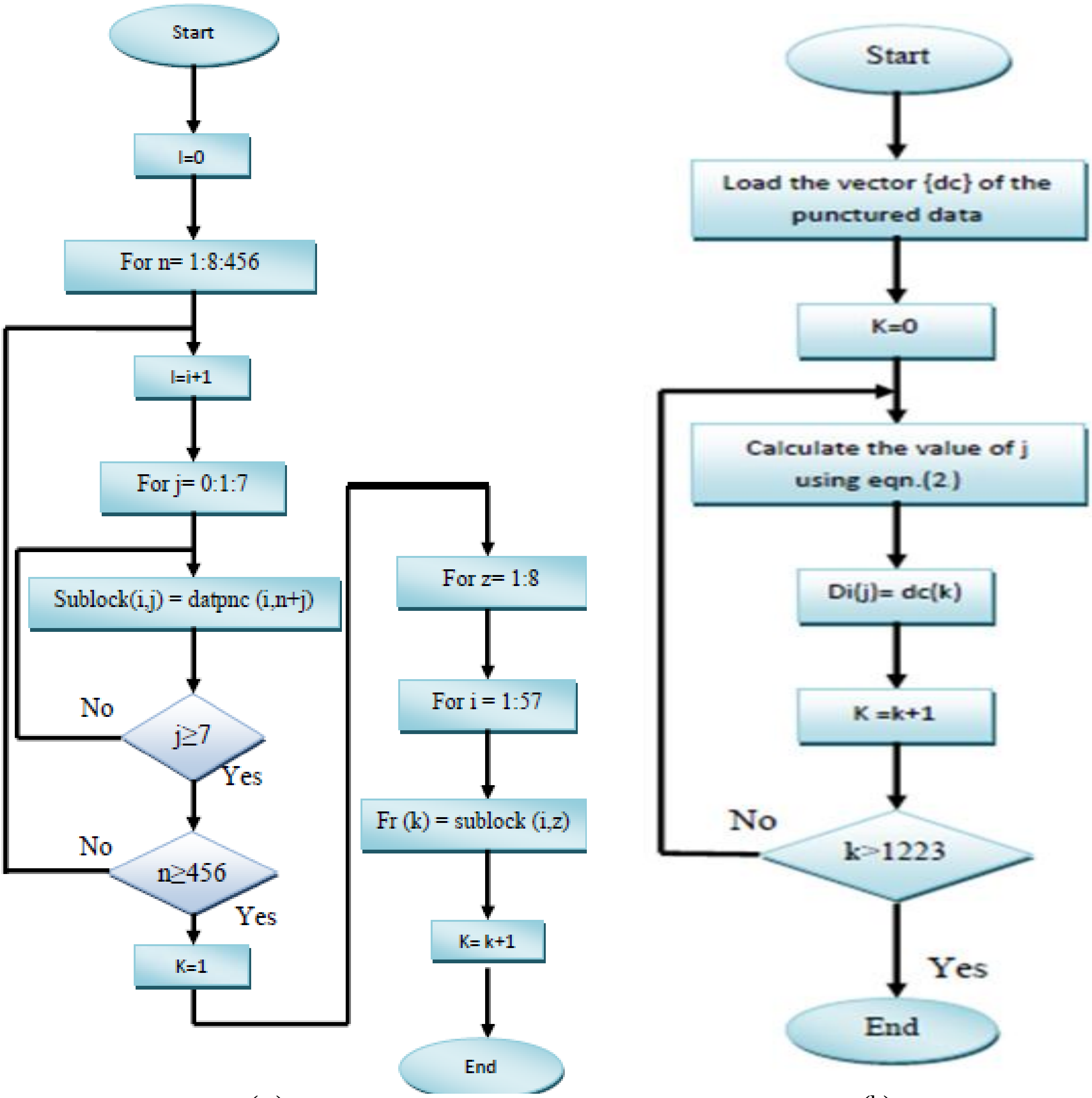
Interleaving: Different interleaving schemes are used; each MCS has its own scheme. For example the interleaver for MCS-7 interleaves a block of 1224 bits and for MCS-1 interleaves a block of 456 bits according to the the following rule [10]:

$$d_i'(k) = d_c'(j) \quad \ldots\ldots\ldots\ldots\ldots (1)$$

Where k=1, 2, 3, …………., 456 and

$$j = 306\,(k \bmod 4 + 3((44k) \bmod 102 + (k \ \mathrm{div}\ 4) \bmod 2 + \left(k + 2 - (k \ \mathrm{div}\ 408)\right) \bmod 3 \quad \ldots\ldots (2)$$

where 'a div b' is the quotient of a/b and 'a mod b' is the reminder of a/b. Fig.6 a and b shows the flowchart for the block interleaver of MCS-1 and MCS-7. Each MCS has a different number of bits in the input data vector and its own equation to find the value of j, where the datpnc represents the puncturing data and sublock represents the division bits.



(a) (b)

Fig.6: Flowchart of block interleaving
(a) MCS-1 and (b) MCS-7

Burst Building: This block is responsible for arranging the bits (data bits, header bits, training sequence) in form of a burst depending on the MCS used. All the MCS's have the same basic burst structure and the same number of bits in each burst. The EDGE MCS-1 to 4 structures has the same burst builder as in GSM system. Eight different training sequences are used in normal burst for MCS-1 to 4 (see Table 2) for normal burst structure. When a user requests an access, the base station allocates him one of the eight time slots that this user will use during the entire communication. Also for MCS-5 to 9, eight different training sequences are used in normal burst. The burst builder in GSM system is used to match the output dimension which contains 57 bits. Then 3 tail bits are added and 2 stealing flags are combined with the 26 bits training sequence along with the guard bits to obtain the normal burst. This burst consists of four parts having the same dimension (4x148 bits).

Table 2: Normal burst GMSK training sequence

Training Sequence code (TSC)	Training sequence bits
0	00100101110000100010010111
1	00101101110111100010110111
2	01000011101110100100001110
3	01000111101101000100011110
4	00011010111001000001101011
5	01001110101100000100111010
6	10100111110110001010011111
7	11101111000100101110111100

Mapping: The GSM/EDGE (MCS-1 to 4) uses GMSK modulation. The differential encoder block encodes the binary input signal. The output is the logical difference between the present input and the previous output. The GMSK modulator baseband block modulates the carrier using the Gaussian minimum shift keying method. The output is a baseband representation of the modulated signal. The BT product parameter represents bandwidth multiplied by time. This parameter is a nonnegative scalar 46 and it's equal to 0.3. It is used to reduce the bandwidth at the expense of increased intersymbol interference. The remains MCS's of EDGE system uses 3 offset 8-PSK as illustrated in Fig.7. Equations (A_1), (A_2), (A_3), and (A_4) that are seemed in flow chart of Fig. 7 are given in Appendix of this paper.

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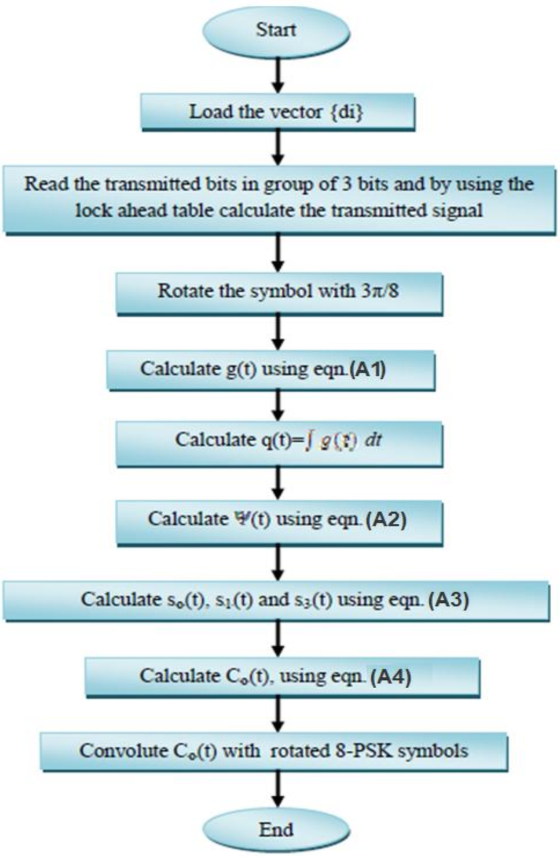


Fig.7: Flow chart for EDGE 8-PSK modulator

Channel Estimation and Symbol Detection: This can be divided into two parts [8]. The first part estimates the channel impulse response, and the second part detects the transmitted symbols using the estimated values of the channel parameters. The receiver first limits the received signal with a band pass filter to a cutoff frequency which depends on the carrier frequency and a bandwidth of 200 kHz. This filter is here replaced by a low pass filter with a cutoff frequency of 100 kHz because of the baseband model conditions. The filter used here is a square root raised cosine filter with a normalized bandwidth of 1 and a roll-off of 0.5. A number of channel estimators have been tested; all of them use the gradient channel estimator that uses the minimum phase filter in front of the gradient estimator. The minimum phase filter that is used here to minimize the impulse response of the mobile channels is a linear feed forward transversal filter introduced by Clark and Hau to work in HF channel [12]. To reduce the complexity of the filter, new starting points set has been selected from the old nine starting points. Also the maximum iterations have been tested to see if it can be reduced. These new settings of the filter can speed up the iteration method and hence reduce the complexity of the receiver. The GSM/EDGE receiver first limits the received signal with a band pass filter to a cutoff frequency which depends on the carrier frequency and a bandwidth of 200 kHz. This filter is here replaced by a low pass filter with a cutoff frequency of 100 kHz because of the baseband model conditions. The filter used here is a square root raised cosine filter with a normalized bandwidth of 1 and a roll-off of 0.5. The detection procedure of the transmitter symbols needs calculating the nearest point and the second nearest and sometimes the third and so forth to nearest points. This is done by first dividing the constellation of the 8-PSK into eight parts as shown in Fig. 8. Then the angle of the received symbol is calculated and tested in what part it lays. For example, if the angle of one of the transmitted symbols lay in part number 1 then the angle of the nearest point will be π/4.

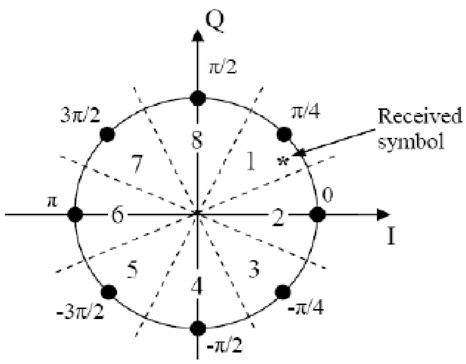


Fig.8: Calculations of the nearest points in near maximum detection.

Demapping : *(a) GMSK Demapping in MCS-1:* Each data symbol is represented by $J^{A_{n,o}}$ and thus the data symbol can take one of the four values 1, j, -1 and *–j*. The data symbol takes one of these values by following the phase vector. Since *J* is equal to exp ($j\frac{\pi}{2}$) and $A_{n,o}$ take one of the four possible values {0, 1, 2, and 3}, then a phase vector can be defined by [8]:

$$J^{A_{n,o}} = I_n = j\alpha_n \, I_{n-1} \qquad \text{………………….. (3)}$$

Since $\alpha_n \epsilon${1, -1}, then can take one of the four possible values {1, j, -1, -j}. If, for example, I_{n-1} = 1 and α_n = 1 then I_n= *j*. if α_{n+1} =1 then I_{n-1}= -1. Thus if I_n represents a complex phase vector of unity magnitude, then its rotation direction is determined by α_n . Fig. 9 shows the phase vector [8], if α_n equals 1, the phase vector will rotate 90 degree anticlockwise, while if α_n is equal to -1 the phase vector will rotate 90 degree clockwise. To remove the modulator effect, the demodulator does simple phase calculations to extract the value of α_n from the transmitted phase vector. This is done by storing two values of phase vector that are I_n and I_{n-1} and by testing simple conditions about the previous value I_{n-1} and the current value I_n of the phase vector, the value of α_n can be found.

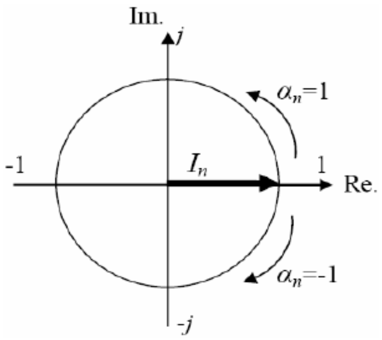
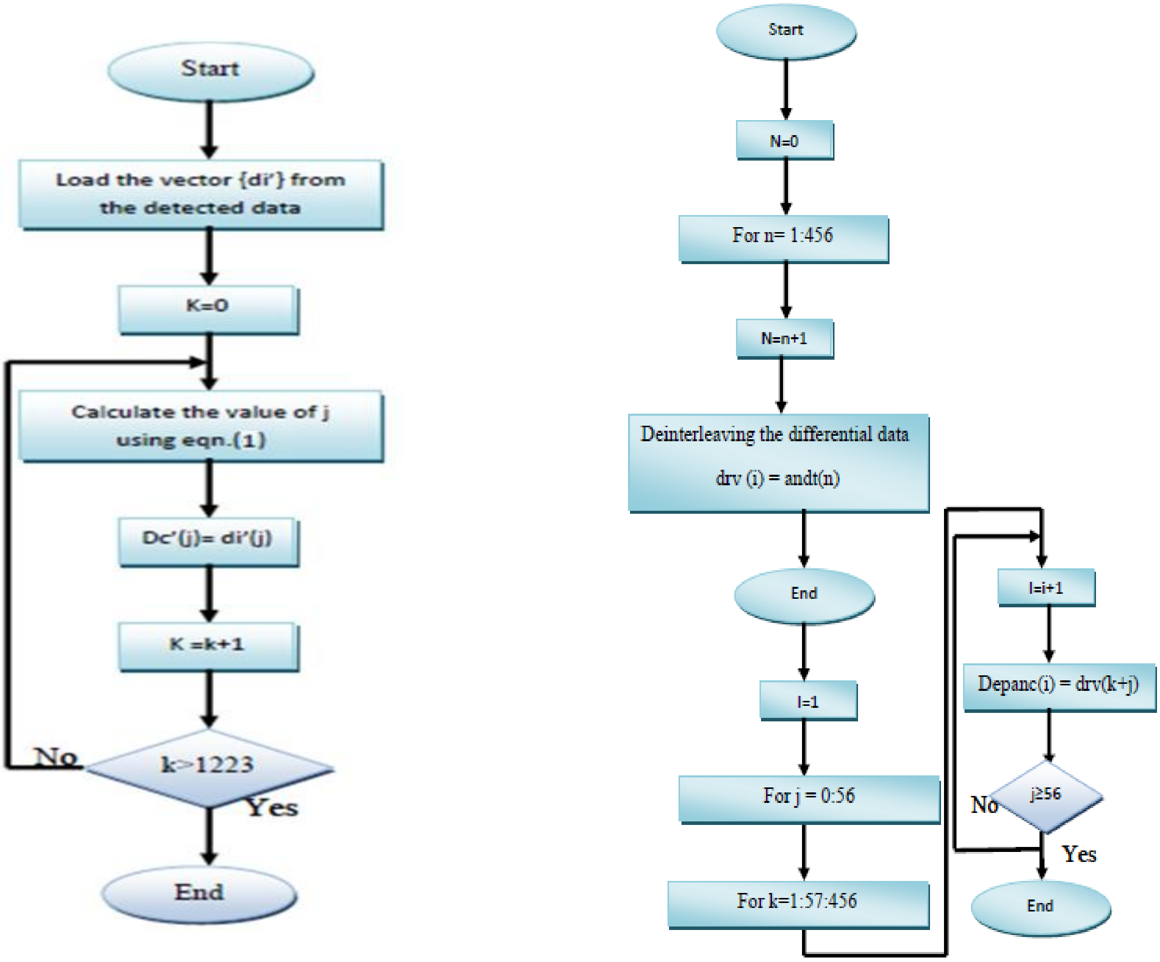


Fig. 9: The phase vector.

(b) 8-PSK Demapping in MCS-7: For the 8-PSK modulation, there are eight different transmitted symbols; each transmitted symbol represents three bits. After the detection of the transmitted symbols, the demapper will substitute each symbol with the equivalent transmitted three bits using a lock a head table.

Deinterleaving : The deinterleaving process in MCS-1 is reverse to its interleaving process. It's similar to the conventional GSM systems. The deinterleaving results in MCS-7 are also based on eqation (1) that mentioned in sec.3.3. Fig. 10 shows the flowchart of the deinterleaving for MCS-1and MCS-7.



(a) (b)

Fig.10: Flowchart of block deinterleaving for (a) MCS-7 and (b) MCS-1

Depuncturing : This block substitutes each punctured coded data bits in a manner that each location of a punctured bit will be filled with a new value that is different from the data values. For example if the data bits $\alpha_n \in \{0,1\}$ (as in our case) then the filled value will be 2, which doesn't belong to the data values. This is done to make the convolutional decoder (which uses the Viterbi algorithm) be able to distinguish the punctured bit; so this bit will not affect the calculations of the vector costs for the decoder that simplifies the decoder. Fig.11 shows the flowchart depuncturer block for the MCS-1 as an example of the other MCS's.

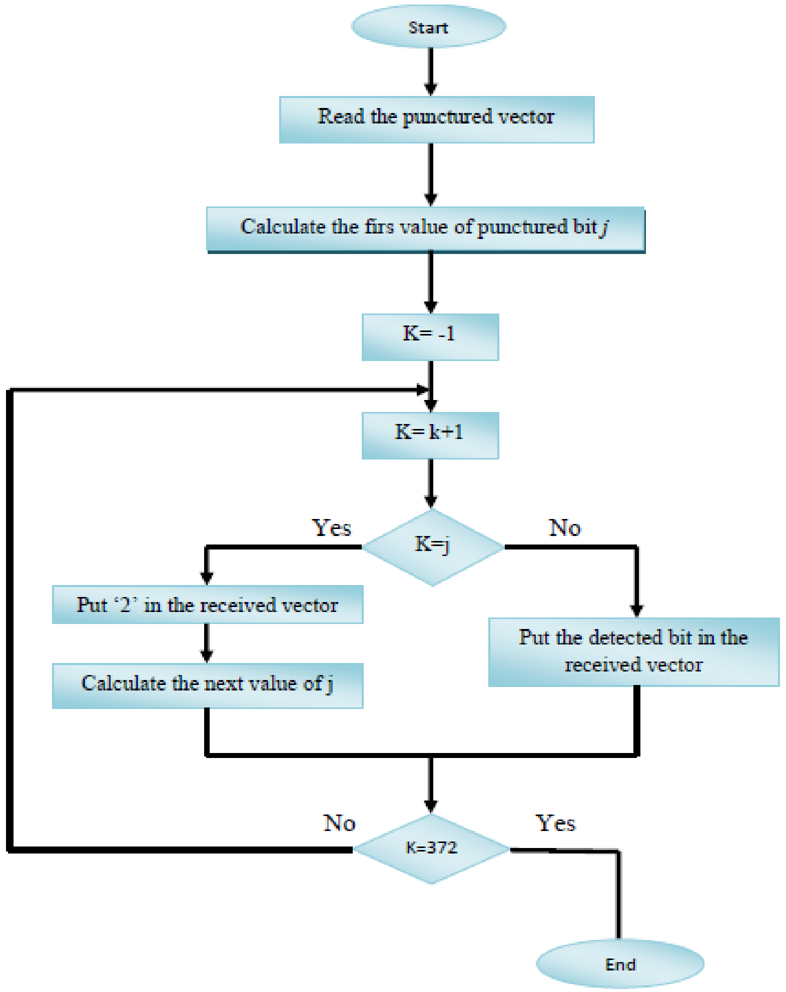


Fig.11: Flowchart of the MCS-1 depuncturing.

Simulation of Convolutional Decoder : It is based on the Viterbi decoding algorithm that is a maximum likelihood decoding method for the convolutional codes wit short constraint length [6]. The algorithm involves calculating the hamming distance between the received bits, at time t_i, and the entire trellis path segment (bits). In EDGE, two path segments enter each of the 64 trellis states. Each path segment consists of three bits. The decoder computes the hamming distance between the received bits and its corresponding bits of each of the two path segments. Each hamming distance is then added to the hamming distance of the path each segment which belongs to the total hamming distance is then assigned to the path of that segment. At each state, the path that has a smaller hamming distance is chosen and the other is removed [8]. This is repeated for all the 64 states and when this is done, the decoder takes the next three received bits and computes the hamming distance with all the corresponding new paths segments. Each computed hamming distance is added to the hamming distance of the path, each path of the 64 paths grows longer and this depends on the decoder depth (the number of segments kept in memory for each path).

IV. RESULTS AND DISCUSSION

This section represents the results of the simulation for 3π/8 – 8PSK EDGE System GSM/EDGE system. Simulation results are reported and assuming the studied system is operating in AWGN transmission channel and 6-path Rayleigh fading channel. The simulation results are related to MCS-7 of the EGDE/GSM system. This MCS uses 8PSK modulation format with 3π/8 phase rotator and operates with 44.8 kbps data rate. Fig. 12 shows the eye diagrams corresponding to the modulated signal observed at three points in the transmitter. Parts a-c of the Fig. 12 corresponds, respectively; to the outputs of the 8PSk modulator, 3π/8 phase rotator, and Gaussian pulse shaping filter. The simulations are also repeated to extract signal constellation and signal trajectory at these points and results are displayed in Figs. 13 and 14, respectively. The trajectory plot represents all possible transitions between symbols.

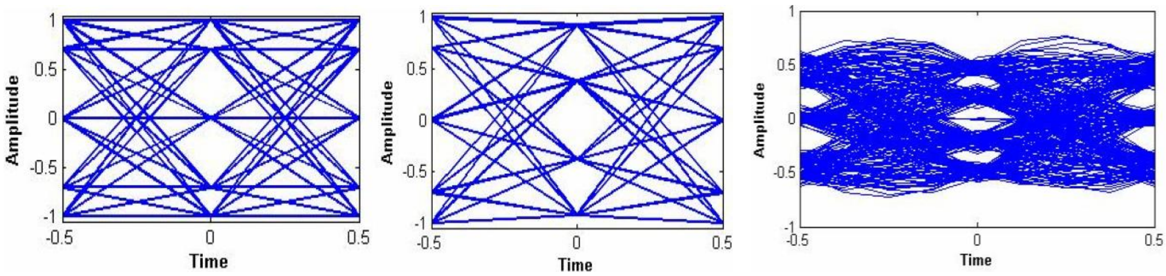
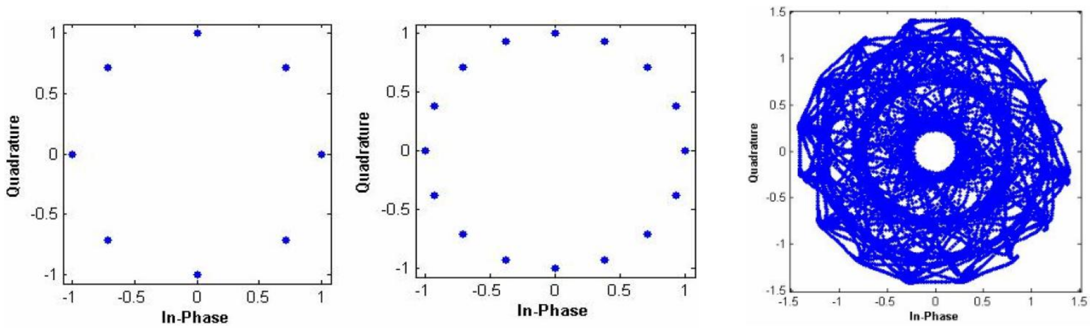
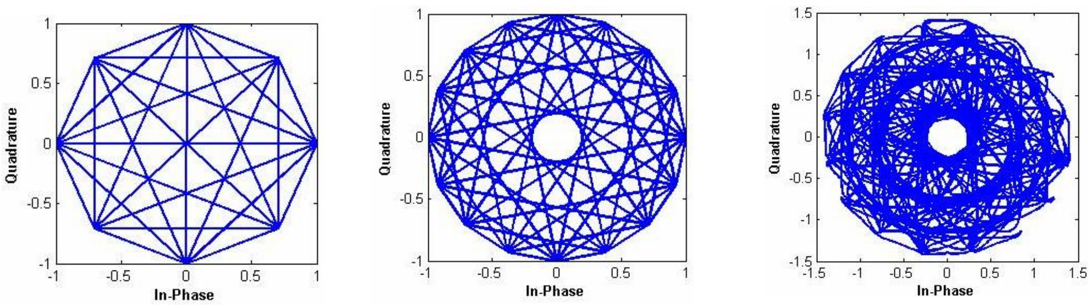


Fig. 12: Eye diagrams observed at three points in the transmitter for MCS-7 system (a) Output of the 8PSK modulator , (b) Output of the 3π/8 phase rotator and (c) Output of the Gaussian pulse shaping filter.



(a) (b) (c)

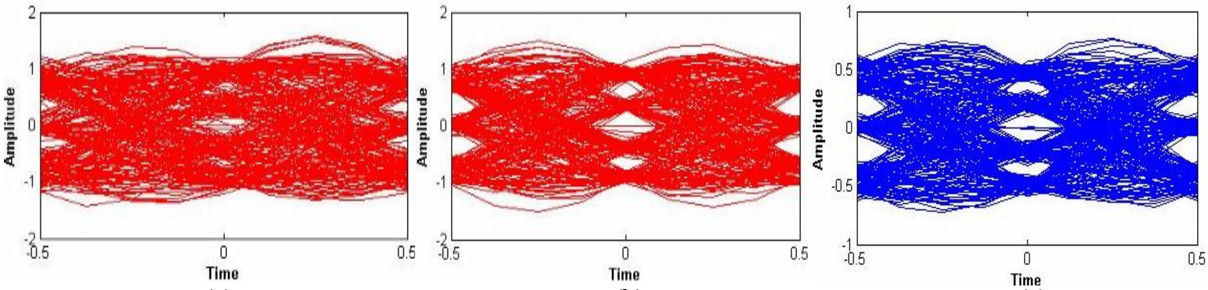
Fig. 13: Signal constellations observed at three points in the transmitter for MCS-7 system (a) Output of the 8PSK modulator, (b) Output of the 3π/8 phase rotator and (c) Output of the Gaussian pulse shaping filter.



(a) (b) (c)

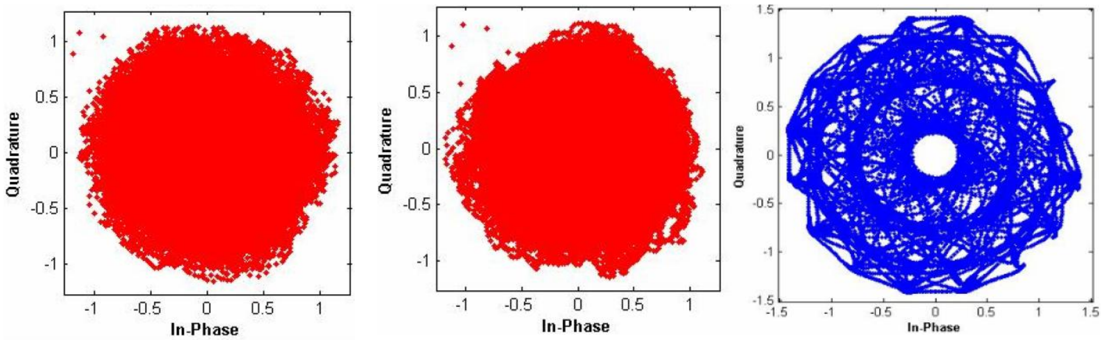
Fig. 14: Signal trajectories observed at three points in the transmitter for MCS-7 system (a) Output of the 8PSK modulator, (b) Output of the 3π/8 phase rotator and (c) Output of the Gaussian pulse shaping filter.

For EDGE, it was decided to use a modified 8-PSK scheme in which the vector diagram trajectory doesn't cross the origin (I and Q signals equal to zero). Indeed zero crossing in the constellation increases the envelope power variation, which increases the distortion when the signal is passed though a power amplifier. In order to avoid zero crossing due to the π radians phase shift the solution that was chosen consists of rotating the constellation by 3π/8 at each symbol period. Note that the effect of 3π/8 phase rotation appears as one has used a 16-PSK modulation format. Note that in 3π/8 – 8PSK signaling, the information contained completely in the signal phase, whereas both the signal amplitude and phase carry information at the output of the Gaussian pulse shaping filter. Fig. 15a-c illustrates, respectively, the eye diagrams corresponding to the received signal and assuming AWGN channel having a signal to noise ratio (SNR) of 10, 15 and 20 dB. The constellations of the received signals for these three cases are depicted in Fig. 16.



(a) (b) (c)

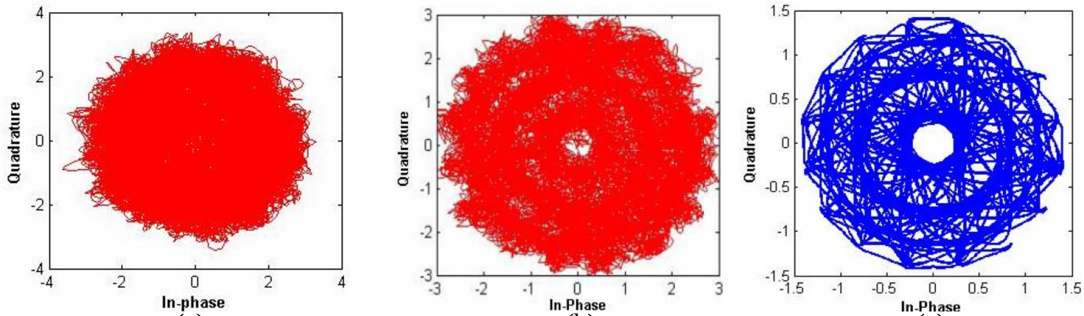
Fig. 15: Eye diagrams of the received signal corresponding to MCS-7 assuming AWGN channel (a) SNR=10 dB, (b) SNR=15 dB and (c) SNR=40dB.



(a) (b) (c)

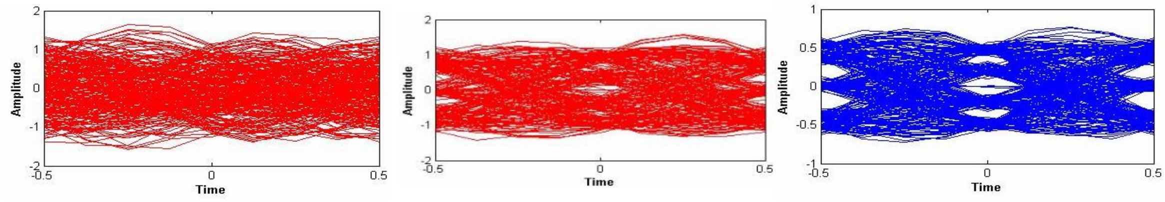
Fig. 16: Constellation plots of the received signal corresponding to EDGE of MCS-7 system assuming AWGN channel (a) SNR=10 dB, (b) SNR=15 dB and (c) SNR=40 dB.

The trajectories of the received signals for these four cases are depicted in Fig. 17. Note that at SNR=10 dB, the eye diagram of the received signal is almost closed even the effect of Rayleigh fading channel is not included in this simulation. As the SNR increases, the eye opening increases and the interference between the adjacent states in the constellating diagram reduces. The calculations in Figs. 15-17 are repeated for a Rayleigh fading channel and the results are displayed in Figs. 18-20, respectively. The results are reported for a 6-path channel having the parameters values listed in Table 3 [11] and assuming perfect channel estimation is performed at the receiver. Comparison between Figs. 15 and 18 reveals that the presence of fading reduces the eye opening and increases the interference between the adjacent states in the constellation diagram even perfect channel estimation is performed at the receiver.



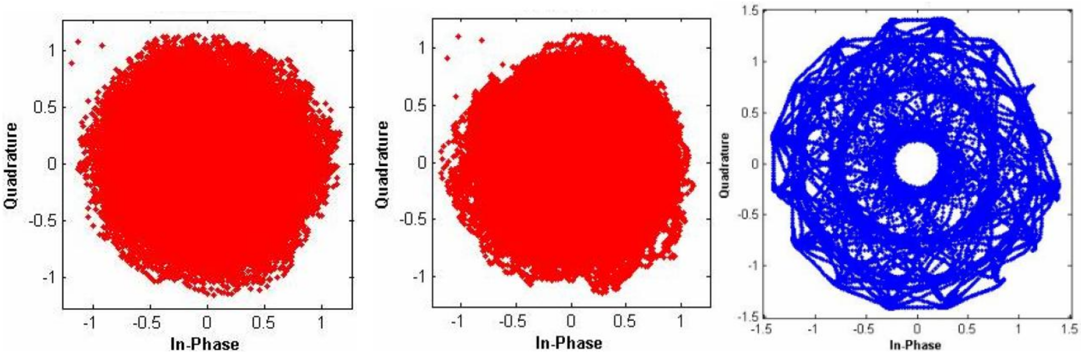
(a) (b) (c)

Fig. 17 Trajectory plots of the received signal corresponding to EDGE of MCS-7 system assuming AWGN channel (a) SNR= 10 dB, (b) SNR=15 dB and (c) SNR=40 dB.



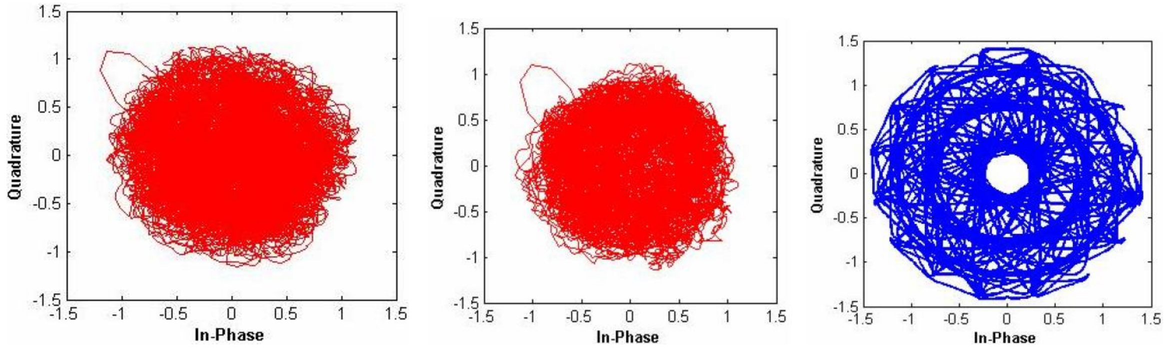
(a) (b) (c)

Fig. 18: Eye diagrams of the received signal corresponding to MCS-7 assuming Rayleigh fading channel (a) SNR=10 dB, (b) SNR=15 dB and (c) SNR=60



(a) (b) (c)

Fig. 19: Constellation plots of the received signal corresponding to MCS-7 assuming Rayleigh fading channel (a) SNR=10 dB, (b) SNR=15 dB and (c) SNR=60 dB.



(a) (b) (c)

Fig. 20 Trajectory plots of the received signal corresponding to MCS-7 assuming Rayleigh fading channel (a) SNR=10 dB, (b) SNR=15 dB and (c) SNR=60 dB.

Table 3: Parameters values used to simulate the 6-path fading channels [11].

Path	Delay factor (μs)	Gain factor(dB)
1	0	-3
2	0.2	0
3	0.5	-2
4	1.6	-6
5	2.3	-8
6	16	-10

V. CONCLUSION

Comprehensive system analysis, modeling and simulation have been carried out for GSM/EDGE systems. The modeled system is simulated and tested and the results indicate clearly that the eye opening of the received signal decreases as the SNR decreases and this effect is more pronounced in the presence of fading channel. The presence of fading increases the interference between adjacent states in the constellation diagram even perfect channel estimation is performed at the receiver.

APPENDIX

Equation (A_1) ***:***

The derivative function of phase response function q(t) is [13, 14] :

$$g_T(t) = \frac{1}{2T_s}\left[Q\left(\frac{2\pi B\left(t-\frac{T_s}{2}\right)}{\sqrt{\ln 2}}\right) - Q\left(\frac{2\pi B\left(t+\frac{T_s}{2}\right)}{\sqrt{\ln 2}}\right)\right]$$

Where $Q(t) = \frac{1}{\sqrt{2\pi}}\int_t^{\infty} \exp\left(\frac{-\tau^2}{2}\right)d\tau$ and B is the 3dB bandwidth of the Gaussian filter and T_s is the symbol period (bit duration).

Equation(A_2)***:***

The phase pulse function can be written as [13, 14]:

$$\psi(t) = \frac{\pi}{2} - \pi q(t - T_s) \quad \text{for } t \geq 3T_s$$

Equation(A_3)***:***

The transmitted analog signal is given by [13, 14]:

$$S_n(t) = \sin\psi(t - nT_s) = S_0(t - nT_s)$$

$S_n(t)$ is thus just $S_0(t)$ shifted n symbol intervals backwards in time.

Equation(A_4)***:***

The $(k+1)^{th}$ component of transmitted analog signal S (t) is represented by [13, 14]:

$$C_k(t) = S_0(t)\prod_{i=1}^{2} S_{i+3\sigma_{k-i}}(t) \quad \text{for } 0 \leq k \leq 3$$

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