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Comparative Analysis of the Performance of Reed-Solomon Code on the Bit Error Rate (BER) of MIMO-GMSK and MIMO-MSK in a Noisy Multipath Rayleigh Fading Channel

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Abstract- In this paper, the comparative analysis of the performance of Reed-Solomon code on BER of MIMO-GMSK and MIMO-MSK in a noisy multipath Rayleigh fading channel has been achieved. A Model-based design methodology was employed in this research using Simulink; it involved the design and simulation of a MIMO-GMSK and MIMO-MSK digital Modulation system with Reed-Solomon forward error correction method. The results obtained show that the Bit Error Rate (BER) increases as the error correction capability of the RS code decreases for the same E_b/N_o value. It was observed that a lower code word symbol RS code is more effective in correcting bit error and produces lower BER in MIMO-GMSK than MIMO-MSK in a noisy multipath Rayleigh channel. It was also observed that the BER decreases as the code word symbol increases for different E_b/N_o values in the MIMO-MSK system. However, the RS code performed better in correcting bit errors resulting from the effect of a noisy multipath Rayleigh fading channel in the MIMO-GMSK system than in the MIMO-MSK system.

Keywords- *MIMO, MSK, GMSK, Reed-Solomon Code*

I. Introduction

The primary consideration of digital high speed communication system is to achieve modulation with power spectrum of acceptable bandwidth and constant amplitude of the modulated signal [1] MSK and GMSK/GFSK (members of the Continuous Phase Frequency Shift Keying (CPFSK) modulation family with a constant envelope) are some of the most efficient digital modulation techniques [1] GMSK is an improved version of MSK in the sense of bandwidth and spectral efficiency. The bandwidth of a GMSK system is defined by the relationship between the pre-modulation filter bandwidth B and the bit period T_B. Thus the decision of value of BT and data rate is crucial in the sense that there has to be a trade-off between the BER and out of band interference as the narrow filter will result in provocation of Inter Symbol Interference (ISI) which on the other hand will reduce the signal power enormously. The major disadvantage of GMSK is its high susceptibility to ISI at higher data rates due to narrow symbol shape [1]

MSK is a modified form of continuous phase FSK, with a major advantage of having out of band power significantly lower than QPSK. However, the basic demerit of MSK modulation technique is that the spectrum is not enough compact for the realization of higher data rates. The connection of data rate with BER is crucial to the performance of a communication system. High BER results in low data rate. Hence, the inability to realize high data rates with MFSK is a trade-off for acceptable BER due to its limited spectrum capability. Larger bandwidths are required to obtain higher data rates. The emerging multiple-input multiple-output (MIMO) communication technologies exploit spatial diversity by employing multiple antennas at either side of the communication and this has the potential to improve the performance without increasing the bandwidth or transmitted power [2] The objective of this paper is to analyze the impact of Reed-Solomon forward error correction method on the BER of a MIMO (multiple-input and multiple-output) -MSK and MIMO-GMSK systems in a noisy multipath Rayleigh fading channel.

This paper is organized as follows. The next section presents a summary of related works. A description of GMSK and MSK modulation techniques and Reed-Solomon codes are presented in Section 3. Simulation steps and overview of the model are presented in section 4. Simulation results for GMSK, MSK modulation schemes with different Reed-Solomon coding rates are presented in Section 5 and the conclusions are given in Section 6.

[3] Examined the performance of coded GMSK systems in AWGN using RS channel coding under a constant bandwidth constraint. Results showed that when the code rate decreases to a certain value, the system performance decreases. For this reason the optimal code rate was found to be a function of the total system bandwidth.

[4] Analyzed the performance of Gaussian Minimum Shift Keying (GMSK) modulation with several combinations of coding strategies using various analysis metrics such as Bit Error Rate (BER), energy consumption. Results show that GMSK scheme with Golay FEC achieves significant gains and that energy consumption can be greatly minimized.

II. THEORETICAL REVIEW

[1] Both modulations, MSK and GMSK/GFSK, are derived from the ordinary Frequency Shift Keying (FSK) modulation scheme, which is a digital version of frequency modulation (FM). An FM signal is defined as:

$$u_{FM}(t) = U_m \cos[\omega_c t + \varphi(t)] \quad (1)$$

Where U_m is the amplitude, ω_c is the carrier frequency, and $\varphi(t)$ is the phase of FM signal.

A. MSK Modulation Basics

MSK is a continuous phase modulation scheme. The modulated carrier does not contain phase discontinuities and frequency changes at carrier zero crossings. It is typical for MSK that the difference between the frequency of logical 0's (f_0) and 1's (f_1) is equal to half the data rate. MSK modulation makes the phase change linear and limited to $\pm(\pi/2)$ over the symbol interval. Due to the linear phase change effect, better spectral efficiency is achieved. That means that MSK is ordinary FSK with the modulation index set to 0.5, and it is defined as:

$$m = \Delta f T_b \quad (2)$$

where peak frequency deviation Δf is given by

$$\Delta f = |f_1 - f_0| \quad (3)$$

The MSK modulator can be realized by using a direct MSK approach or the I-Q based concept. In both types of modulators the straightforward means of reducing the Out Of Band (OOB) energy is pre-modulation filtering or pulse shaping. Direct MSK modulation can be realized by direct injection of NRZ data into the frequency modulator with the modulation index set to 0.5. The spectrum of the direct MSK modulator output is not compact enough to realize common data rates for the RF channel bandwidth (*B*). Because of that, pulse shaping is of particular interest. Data input sequence is forwarded to a shaping filter whose output pulse shape is given by (4).

$$g_{RECT}(t) = \begin{cases} U_m \cos\left(\frac{\pi t}{T_b}\right), -\frac{T_b}{2} \le t \le \frac{T_b}{2} \\ 0 \qquad otherwise \end{cases} \quad (4)$$

The resulting pulse shaped sequence is then applied to the FM modulator whose output is a constant amplitude continuous phase FM signal (MSK signal $u_{MSK}(t)$). The phase of the MSK signal is given by (5):

$$\varphi_{MSK}(t) = 2\pi \frac{m}{T_b} \int_o^t \sum_{i=0}^{\infty} b_i g_{MSK}(\tau - iT_b)\, d\tau \quad (5)$$

The input data stream, which arrives to the modulator at the rate of $R_s = 1/T_b$bits/sec, separates into two data streams $b_I(t)$ and $b_Q(t)$, containing odd and even bits respectively, with the rate $R_p = 1/(2Tb)$. Offset Quadrature Phase Shift Keying (OQPSK) is obtained by delaying the odd bit stream by a symbol interval Tb with respect to the even bit stream (I and Q streams). If these two streams are offset by one symbol interval, amplitude fluctuations become minimized since the phase always changes by $\pm 90°$. The MSK signal is derived by replacing the OQPSK rectangular data streams pulses used in QBPSK with half sine pulses. In that way I and Q components of the MSK signal $u_I(t)$ and $u_Q(t)$ become:

$$u_I(t) = b_I(t) g_{MSK}(t) \ , \\ u_Q(t) = b_Q(t) g_{MSK}(t - T_b) \quad (6)$$

and the MSK signal is defined as:

$$u_{MSK}(t) = b_i(t) g_{MSK}(t) \cos(\omega_c t) \\ + b_Q(t) g_{MSK}(t) \sin(\omega_c t) \quad (7)$$

1) GMSK Modulation Basics

GMSK/GFSK modulation can be realized by both parallel and serial synthesis. It differs from the ordinary MSK by using the Gaussian LP filter or Gaussian shaper on the input of the I-Q or FM modulator**.** Minimization of the spectral bandwidth of the output signal $u_{GAUSS}(t)$ for the NRZ input sequence can be realized by filtering with the Gaussian LP filter, whose name came from impulse response function $h_{GAUSS}(t)$. Impulse response of the Gaussian pulse shaping filter is given by:

$$h_{GAUSS}(t) = K\sqrt{\frac{2\pi}{ln(2)}} B e^{-2\frac{(B\pi)^2}{\ln(2)} t^2} \quad (8)$$

Gaussian shaped bit stream $g_{GAUSS}(t)$, which is equal to convolution of $g_{RECT}(t)$ and $h_{GAUSS}(t)$ becomes:

$$g_{MSK}(t) = \\ -\frac{K}{2\sqrt{\ln(2)}} \left[Erf\left(2B\pi \frac{t - \frac{T_b}{2}}{\sqrt{\ln(4)}}\right) - Erf\left(2B\pi \frac{t + \frac{T_b}{2}}{\sqrt{\ln(4)}}\right)\right] \quad (9)$$

where$Erf(t)$is error function envelope (Švedek, Herceg, and Matić, 2009) given by

$$Erf(x) = \frac{2}{\sqrt{\pi}} \int_0^x e^{-t^2}\, dt \quad (10)$$

The main characteristic of the Gaussian filter is a BT_b product, where *B* is a −3 dB bandwidth of the Gaussian filter, and T_b is a previously defined symbol interval. The Product BT_b determines the pulse shape of the output bit stream. A lower BT_b product implies lowering amplitude and increasing the pulse width. The Gaussian shaped pulse sequence has better base-band spectrum performance (low OOB energy). The resulting Gaussian pulse shaped sequence $g_{GMSK}(t)$ is then applied to the FM modulator, resulting by data phase $\varphi_{GMSK}(t)$:

$$\varphi_{GMSK}(t) = 2\pi \frac{m}{T_b} \int_o^t \sum_{i=0}^{\infty} b_i g_{GMSK}(\tau - iT_b)\, d\tau \quad (11)$$

2) REED-SOLOMON CODES

Basically, Reed-Solomon codes are non-binary systematic cyclic linear block codes [4]. They are cyclic because each valid code produces another valid code when it is circularly shifted. They are linear because a new code word with the same length can be generated by adding any two valid code words. As the RS encoder processes each block of message symbols, represented as a sequence of m-bits with m as any positive integer which is greater than 2, these codes are referred as Block codes. And each R-S (N, K) code, where 'N' represents length of each block, and 'K' represents the number of original message symbols, on m-bit symbols exist for all N and K such that $0 < K < N < 2^m + 2$. As the error correction is on symbol level, these codes are suitable for correcting burst errors. Suitable reversible mathematical function is applied to the message symbols by the RS encoder so as to generate redundant or parity symbols such that the number of parity digits $N - K = 2t$. Then these redundant symbols are appended on to the message symbols to form the code word. The minimum distance between two different codes is, $d = 2t + 1$. Due to the availability of sufficient and efficient encoding techniques, cyclic codes are used in several applications. Reed-Solomon codes are much useful for burst-error correction as they deal with symbols or they are block level codes. They are very much effective for channels with memory [5].

R-S code has an interesting feature that any amount of two information symbols can be added with any R-S code with length 'N' while the minimum distance between codes is maintained. Now, the new R-S code will have a length of 'N+2' with equal amount of parity check symbols as the original code. According to the concept of R-S codes, encoding of 'K' message symbols is done by viewing them as coefficients of any polynomial *m(x)* of highest degree K1 over a finite field of order *'x'*. After this, the polynomial is evaluated at N > K distinct points. When this polynomial with degree K - 1 is sampled at more than K points, an over-determined system is created. But in real-time scenario, rather than transmitting sampled values of a polynomial, these encoded symbols are viewed as the coefficients of an output polynomial *C(x)* which is constructed after the multiplication of message polynomial *m(x)* of maximum degree K - 1 by a generator polynomial *g(x)* of degree t = N – K - 1. When a generator polynomial *g(x)* can be defined with its roots $\alpha, \alpha^2, \ldots . \alpha^t$ i.e. $g(x) = (x + \alpha)(x + \alpha^2) \ldots . (x + \alpha^{2t})$then the transmitter will send the x - 1 coefficient of $C(x) = m(x)g(x)$ [2]. There are two basic classifications of R-S decoding algorithms – frequency domain, time domain. Due to the need of additional error value transformation block, inverse transformation block and delay block for syndrome polynomial, implementation of frequency domain algorithm requires more chip area which leads to more power dissipation than time domain algorithm.

The RS (N, K, t) code parameters can be represented as follows [6].

Code word symbols: $\mathrm{N} = 2^m - 1$

Information symbols: $\mathrm{k} = 1, 3, \ldots, \mathrm{n} - 2$

Code minimum distance: $d_{min} = \mathrm{n} - \mathrm{k} + 1$ and

The error-correction capability symbols: $t = \frac{(d_{min}-1)}{2} = \frac{(n-k)}{2}$

III. SIMULATED DESIGN - STEPS

The model used in this paper was achieved using Simulink.

i. Select *Random integer Generator block* from the *Channels sub library* of the Communications System Toolbox. Configure the block as shown in Fig 1.

ii. Select *Communications system toolbox→Error Detection and correction →* Block →*Integer-input RS encoder, and decoder* blocks. Configure the selected blocks as shown in Fig 2.

iii. Select *Communications system toolbox→Utility Blocks→Bit to Integer, and Integer to Bit* blocks. Configure the selected blocks as shown in Fig 3.

iv. Select *Communications system toolbox→Modulation →* Digital Baseband Modulation →*CPM → GMSK Modulator Baseband, GMSK Demodulator Baseband, MSK Modulator Baseband, and MSK Demodulator Baseband* blocks. Configure the selected blocks as shown in Fig 4.

v. Select *Communications system toolbox→MIMO→MIMO Channel, OSTBC Combiner, and OSTBC Encoder* blocks. Configure the selected blocks as shown in Fig 5

vi. Select *Communications system toolbox→Channels→AWGN* block. Configure the selected block as shown in Fig 6 below.

vii. Select *Communications system toolbox→Comm Sinks→Error Rate Calculation* block.

viii. Select *Sinks* Sub library →*Display* Block.

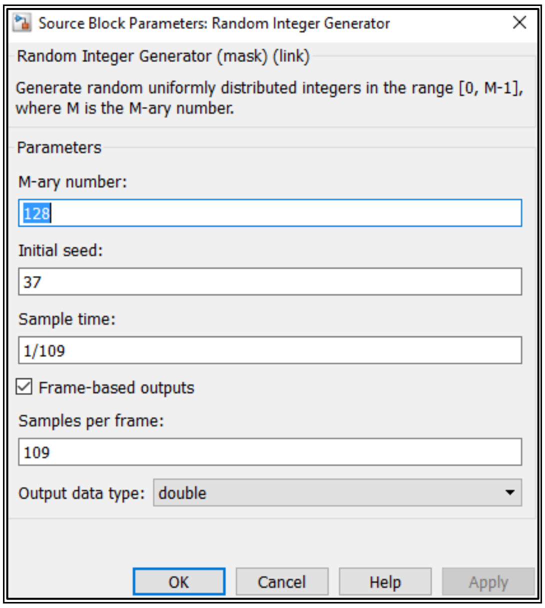

Figure 1. Configuration parameters for the Random integer generator

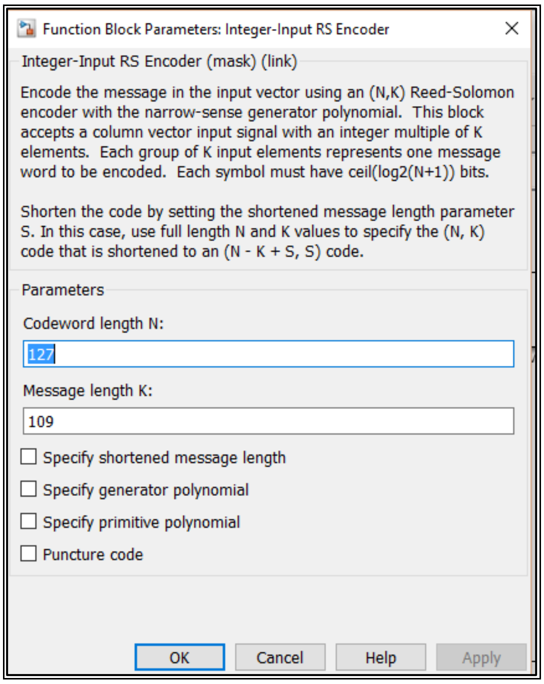

Figure 2. Configuration Parameters for the Integer-input RS encoder & Integer-output RS decoder

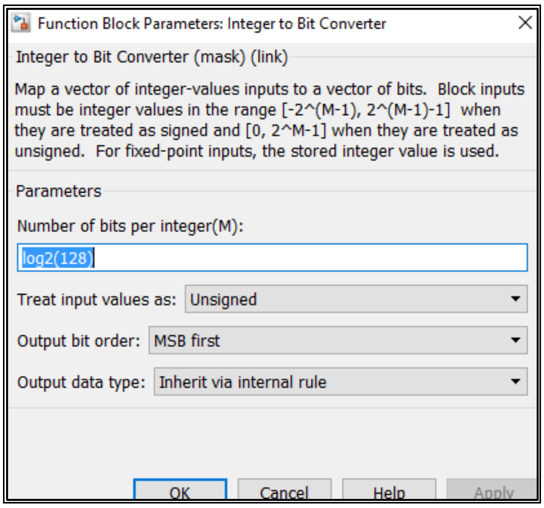

Figure 3. Configuration parameters for the Bit to Integer, and Integer to Bit blocks

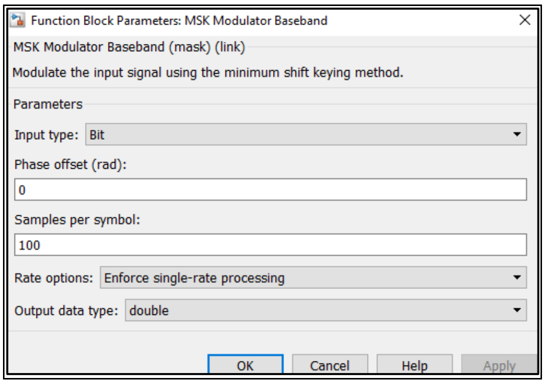

Figure 4. Configuration parameters for the GMSK & MSK modulator baseband blocks

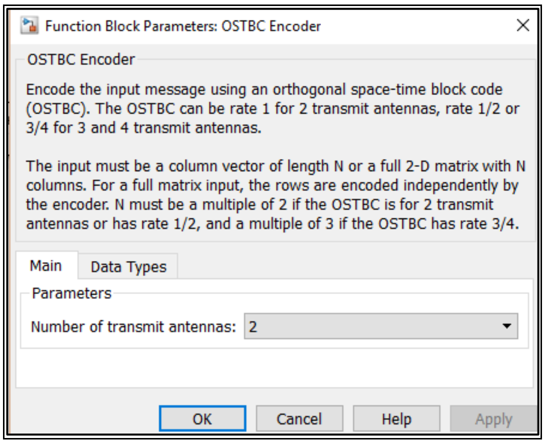

Figure 5. Configuration parameters for the MIMO Channel, OSTBC Combiner, and OSTBC Encoder blocks.

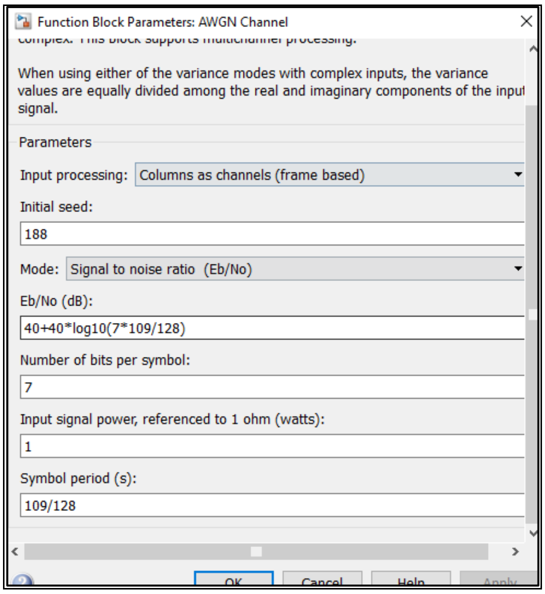

Figure 6. Configuration parameters for the AWGN block

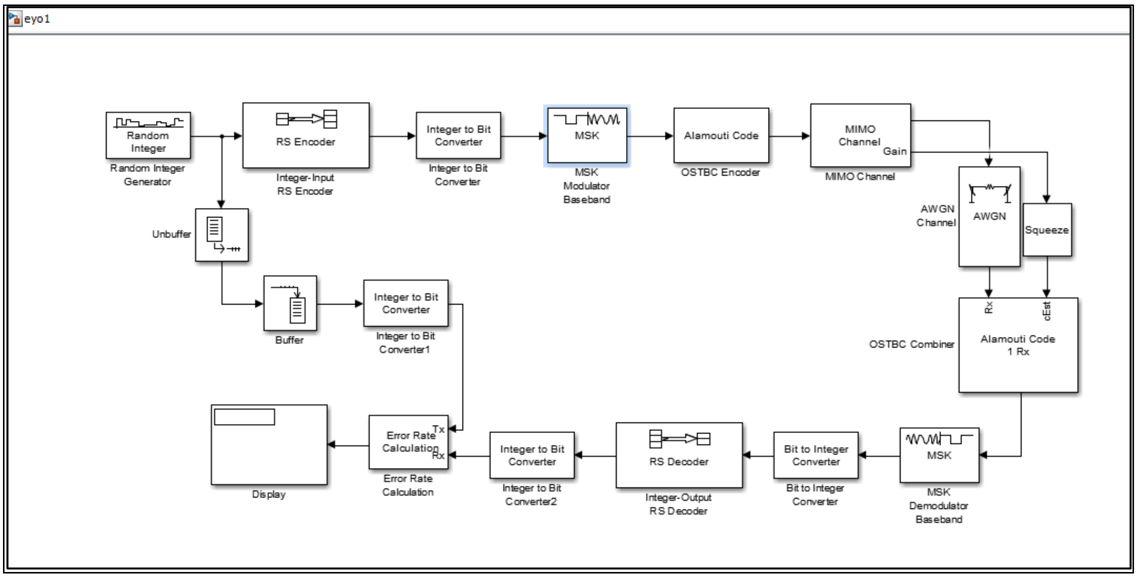

Figure 7. Simulink model for 2X1 MIMO-GMSK system with RS code in a noisy multipath Rayleigh channel

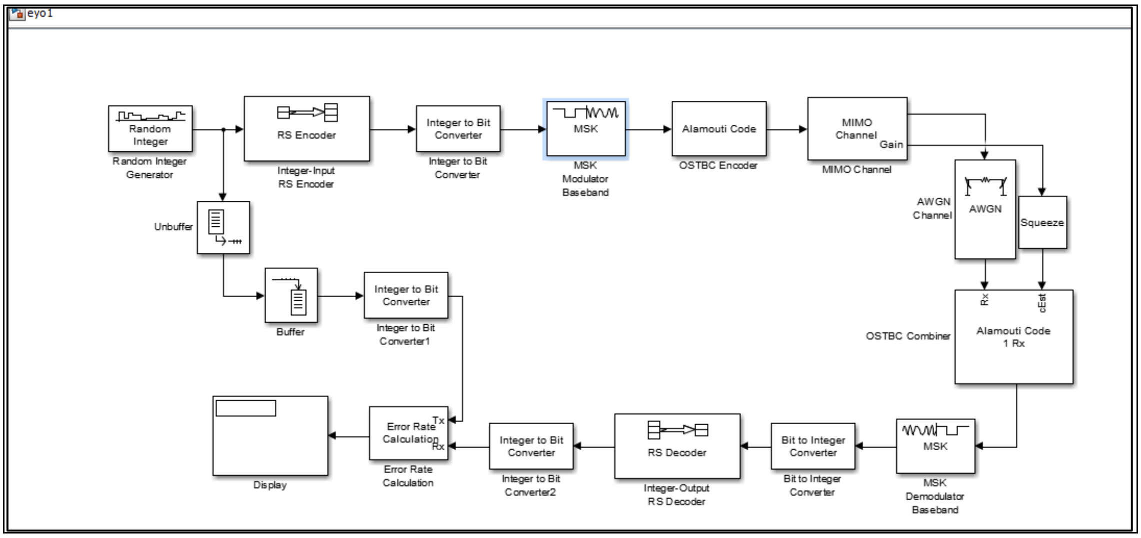

Figure 8. Simulink model for 2X1 MIMO-MSK system with RS code in a noisy multipath Rayleigh channel

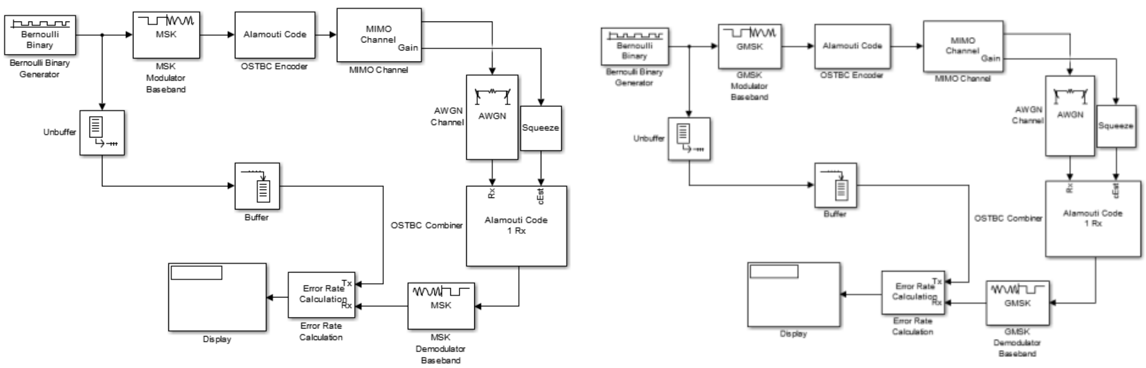

Figure 9. Simulink model for 2X1 MIMO-MSK & MIMO-GMSK without RS code in a noisy multipath Rayleigh channel

IV. SIMULATION RESULTS AND DISCUSSION

Simulation Time: 100 Matlab seconds

Case 1: Coded MIMO-GMSK vs Uncoded MIMO-GMSK, Coded MIMO-MSK vs Uncoded MIMO-MSK

With reference to Table 1, RS(7,4) code was used for error correction for both the MIMO-GMSK and MIMO-MSK systems. It is observed that the Bit Error rates (BER) for the encoded systems are lower than the BERs for the unencoded MIMO-GMSK and MIMO-MSK for different E_b/N_o values:

$E_b/N_o =$ $SNR + SNR \times Log_{10}(n * symbol\ period)$ $where\ n = number\ of\ bits\ per\ symbol.$

Also, the BERs for the MIMO-GMSK are lower than the BERs for the MIMO-MSK system for different E_b/N_o values. It is also observed that the BERs for the unencoded MIMO-MSK remained constant as the E_b/N_o value increases. This may be as a result of the not enough compact spectrum of MSK to realize higher data rates and in extension lower BERs than the results obtained in this simulation even with increase in SNR.

Case 2: Performance as a function of increasing error correction capability (t) of the R-S code (N, K, t)

The RS code sets used have the same codeword length (N) while the message length (or information symbols) (K) increases. This resulted in different error correction capability (t) 6, 5, and 4 respectively as shown in Table 2. Also, the code rate ($R_c = \frac{K}{N}$) increases: 0.2, 0.33, and 0.47 respectively. It is observed that BER increases as the error correction capability of the RS code decreases for the same E_b/N_o value. It is also observed that BER for MIMO-GMSK system for t = 4, and t = 5 is lower than that of the MIMO-MSK with increasing E_b/N_o value. However, for t = 6, the MIMO-MSK system has a lower BER than the MIMO-GMSK.

With reference to Tables 2 & 3, it is observed that the BER is lower for a lower codeword symbol (N) [that is, the RS (15, k, t) produces better error correction than RS (63, k, t) with exceptions to RS (15, 5, 5) for the MIMO-GMSK system and RS (15, 7, 4) for the MIMO-MSK system] for both the MIMO-GMSK and MIMO-MSK system.

With reference to Table 3, it is observed that MIMO-GMSK system produces better BER than the MIMO-MSK system for higher codeword symbols (N) with increasing error correction capability (t) of the RS code.

Case 3: Performance as a function of increasing codeword symbol (N) with constant error correcting capability (t) of the R-S code (N, K, t)

The RS code sets used has different codeword symbols (N) but the same code minimum distance. This resulted in a constant error correction capability (t = 6) as shown in Table 4. It is observed that the BER increases as the codeword symbol increases while E_b/N_o value is kept constant. It is also observed that the lower codeword symbol produces better BER than the higher codeword symbol for different E_b/N_o values in the MIMO-GMSK system. However, higher codeword symbol (127, 115, 6) produces better BER than lower codeword symbol in the MIMO-MSK system.

A lower codeword symbol RS code is more effective in correcting bit error and produces lower BER in MIMO-GMSK than MIMO-MSK in a noisy multipath Rayleigh channel.

Case 4: Performance as a function of increasing codeword symbol (N) with increasing error correcting capability (t) of the R-S code (N, K, t)

In the simulation results shown in Table 5, the RS code sets used has different codeword symbols (N) with the code minimum distance increasing. This resulted in an increase in the error correction capability (from t = 6 to t = 9). It is observed that the BER increases as the codeword symbol and error correction capability increases while E_b/N_o value is kept constant. It is also observed that the lower codeword symbol produces better BER than the higher codeword symbol for different E_b/N_o values in the MIMO-GMSK system. It is also observed that the BER decreases as the codeword symbol increases for different E_b/N_o values in the MIMO-MSK system. However, the RS code performs better in correcting bit errors resulting from the effect of a noisy multipath Rayleigh fading channelin the MIMO-GMSK system than in the MIMO-MSK system.

TABLE I. BER FOR CODED MIMO-GMSK VSUNCODED MIMO-GMSK, CODED MIMO-MSK VSUNCODED MIMO-MSK

E_b/N_o	BER FOR UNENCODED 2X1 MIMO-GMSK	BER FOR ENCODED 2X1 MIMO-GMSK USING RS(7,4)
	BT = 0.3	BT = 0.3
SNR = 10	0.4851	0.4769
SNR = 20	0.4901	0.4752
SNR =30	0.4901	0.4744
SNR = 40	0.4901	0.4736
SNR = 50	0.4851	0.4752

E_b/N_o	BER FOR UNENCODED 2X1 MIMO-MSK	BER FOR ENCODED 2X1 MIMO-MSK USING RS(7,4)
SNR = 10	0.4975	0.4909
SNR = 20	0.4975	0.4934
SNR = 30	0.4975	0.4934
SNR = 40	0.4975	0.4934
SNR = 50	0.4975	0.4934

TABLE II. BER FOR MIMO-GMSK & MIMO-MSK USING R-S (15, K, T) CODE

		$E_b/N_o = SNR + SNR \times Log_{10}(n * symbol\ period)$			
		SNR = 10	SNR = 20	SNR = 30	SNR = 40
BER FOR ENCODED 2X1 MIMO-GMSK RS(N,K,t)	(15,3,6)	0.4744	0.4761	0.4761	0.4761
	(15,5,5)	0.4896	0.4886	0.4886	0.4886
	(15,7,4)	0.4869	0.4876	0.4876	0.4876
BER FOR ENCODED 2X1 MIMO-MSK RS(N,K,t)	(15,3,6)	0.4554	0.4596	0.4596	0.4596
	(15,5,5)	0.495	0.4931	0.4931	0.4931
	(15,7,4)	0.5067	0.506	0.506	0.506

TABLE III. BER FOR MIMO-GMSK & MIMO-MSK USING R-S (63, K, T) CODE

		$E_b/N_o = SNR + SNR \times Log_{10}(n * symbol\ period)$			
		SNR = 10	SNR = 20	SNR = 30	SNR = 40
BER FOR ENCODED 2X1 MIMO-GMSK RS(K,N,t)	(63,51,6)	0.4878	0.4871	0.4874	0.4874
	(63,55,4)	0.4886	0.4882	0.4882	0.4882
	(63,53,5)	0.4889	0.4884	0.488	0.488
BER FOR ENCODED 2X1 MIMO-MSK RS(K,N,t)	(63,51,6)	0.5016	0.5034	0.5035	0.5035
	(63,55,4)	0.5011	0.5028	0.5028	0.5028
	(63,53,5)	0.5002	0.4973	0.4973	0.4973

TABLE IV. BER FOR MIMO-GMSK & MIMO-MSK USING R-S (N, K, 6) CODE

		$E_b/N_o = SNR + SNR \times Log_{10}(n * symbol\ period)$			
		SNR = 10	SNR = 20	SNR = 30	SNR = 40
BER FOR ENCODED 2X1 MIMO-GMSK RS(K,N,t)	(31, 19, 6)	0.4814	0.4819	0.4818	0.4818
	(63, 51, 6)	0.4878	0.4871	0.4874	0.4874
	(127,115,6)	0.4955	0.4955	0.4957	0.4957
BER FOR ENCODED 2X1 MIMO-MSK RS(K,N,t)	(31, 19, 6)	0.5016	0.5022	0.5022	0.5022
	(63, 51, 6)	0.5016	0.5034	0.5035	0.5035
	(127,115,6)	0.4995	0.4982	0.4982	0.4982

TABLE V. BER FOR MIMO-GMSK & MIMO-MSK USING R-S (N, K, T) CODE

		$E_b/N_o = SNR + SNR \times Log_{10}(n * symbol\ period)$			
		SNR = 10	SNR = 20	SNR = 30	SNR = 40
BER FOR ENCODED 2X1 MIMO-GMSK RS(K,N,t)	(31, 19, 6)	0.4814	0.4819	0.4818	0.4818
	(63, 47, 8)	0.4913	0.4875	0.4874	0.4874
	(127,109,9)	0.498	0.4963	0.4956	0.4956
BER FOR ENCODED 2X1 MIMO-MSK RS(K,N,t)	(31, 19, 6)	0.5016	0.5022	0.5022	0.5022
	(63, 47, 8)	0.4996	0.4961	0.496	0.496
	(127,109,9)	0.4994	0.4969	0.4969	0.4969

V. CONCLUSION

This work has successfully achieved a comparative analysis of the performance of Reed-Solomon code on the Bit Error Rate (BER) of MIMO-GMSK and MIMO-MSK in a noisy multipath Rayleigh fading channel. The BER of a MIMO-MSK and MIMO-GMSK in noisy multipath Rayleigh fading channel without RS code were also compared with the BER of a MIMO-GMSK and MIMO-MSK Reed-Solomon code in a noisy multipath Rayleigh fading channel. It was observed that Bit Error rates (BER) for the encoded systems are lower than the BERs for the unencoded MIMO-GMSK and MIMO-MSK for different E_b/N_o values. It is observed that BER increases as the error correction capability of the RS code decreases for the same E_b/N_o value. It is observed that a lower codeword symbol RS code is more effective in correcting bit error and produces lower BER in MIMO-GMSK than MIMO-MSK in a noisy multipath Rayleigh channel. It is also observed that the BER decreases as the codeword symbol increases for different E_b/N_o values in the MIMO-MSK system. However, the RS code performs better in correcting bit errors resulting from the effect of a noisy multipath Rayleigh fading channel in the MIMO-GMSK system than in the MIMO-MSK system.

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