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Performance evaluation of DSSS – RS code using non-coherent MFSK under multipath Rayleigh and Rician fading channels

Artee Kumari Vats[1], Kuldeep Pandey[2]

1. Research Scholar, Dept. of ECE, Bhabha College of Engineering, Bhopal, India, Email: arteevats@outlook.com
2.Assistant Prof., Dept. of ECE, Bhabha College of Engineering, Bhopal, India, Email: kuldeeppandey23@gmail.com

Abstract

In order to fulfil the two critical design constraints – transmit power and reliable wireless link for any wireless network, it is mandatory to consider not only the FEC scheme with less computation complexity, but also some of its key parameters, specifically for low data rate, low power and low duty cycle scenarios. Even though Reed-Solomon codes provide appreciable coding gain over other FEC schemes, it is desirable to choose other influential code parameters those can extend good support over energy efficient burst error correction. This paper is an analysis of simulated Bit Error Rate (BER) performance of RS code with Direct Sequence Spread by using non-coherent M-ary FSK. Being the appropriate channel conditions for WPANs and WSNs, multipath Rayleigh and Rician fading effects are taken into consideration. The simulations were run using a generic model developed using Matlab / Simulink. The simulation results show that, the model with Rayleigh fading channel provides comparatively better BER performance over Rician fading channel.

Key words: FEC, BER, RS code, DSSS, MFSK

1. INTRODUCTION

As the nodes in a sensor network are operated with battery power which is however limited, it is desirable to find all the possible means and ways to extend the lifetime of the battery by the way of driving the sensor nodes with least possible power consumption. Among the three important functions performed by sensor nodes – sense, communicate and process the signal, communication forces the node consume the maximum power. Because of this the sensor nodes drive their transceiver circuitry into sleep mode for most of the time and of course this idea can further be strengthened by considering some of the modulation schemes like non-coherent M-FSK as it helps the transceiver circuitry to have quicker transition between sleep mode and active mode of transceiver, less hardware complexity. Non-coherent M-FSK very well supports the goal of energy conservation of sensor nodes.

The performance of above mentioned scheme is severely affected by the conditions of channels used by the sensor nodes in the network. Any receiving node in the network keeps waiting for retransmissions after employing an ARQ procedure whenever the data packets received by it got corrupted either as a whole or a part of it. This also enforces the nodes to waste their battery power.

By the way of incorporating appropriate FEC schemes, energy conservation in sensor nodes [3] and thus in the network can get increased appreciably. The codes that are expected to provide excellent error correction performance requires much complex hardware for their implementation which also consumes high power than conserving it.

The information bits should be provided with redundancy whenever any error correcting coding scheme is incorporated[6,7] i.e to a sequence 's' of data bits with length 'l', parity bits are added with various possible combinations of bits in 's'. This forms a codeword of 'x' of length 'n_c'. Now the redundancy extended by these additional n_c - l parity bits enable the decoder to decode the received information bit sequence much close to correctness when compared to decoding the data sequence without adding redundancy. Forward Error Correction over the information bits with redundancy enables to get the same BER performance as that of uncoded data sequence but with much reduced SNR.

In order to improve the reliability of wireless link between nodes in a wireless sensor network, besides Forward Error Correction [4], the encoded data can also get its spectrum spread over the channel. Direct Sequence Spread Spectrum technique creates a wideband signal through phase-shift-keying of RF carrier modulated by added data sequence and pseudo random noise sequence (with high pulse rate than that of data sequence). When the receiver "de-spreads" the received signal, narrowband interfering signals are spread out such that only a little fraction of their power falls within the bandwidth of recovered sequence of data bits. In comparison to FH/SS system, the performance of DSSS system against partial-band disturbances is much appreciable together with the advantage of spectrum with low probability-of-intercept.

By combining both spread-spectrum (SS) and forward error correction (FEC) any digital communication system can very well overcome the Narrow Band Interference (NBI) provided sufficient trade-off between these two schemes is maintained. The block diagram represents the combined coded - spread spectrum in which the spectrum of the encoded data spreads before transmission after it is multiplied with a pseudo random spread signal which has wider bandwidth by nature.

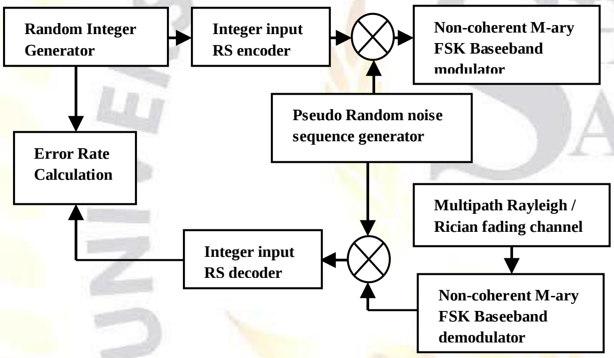


Fig.1 Block diagram of DSSS – RS coded non - coherent MFSK

Due to this multiplication, the bandwidth of the encoded data approximately spreads to the bandwidth of the spreading signal. By multiplying the received data with the same pseudo random spreading signal at the receiver end, the information can be reconstructed.

The rest of the paper is organized as follows: Section 2 briefs the suitability and effectiveness of RS codes. Section 3 explains the simulation setup and the parameters used for the simulations. Section 4 elaborates the simulation results. Section 5 concludes this paper.

2. SUITABILITY AND CAPABILITY OF RS CODES

Because of high code rate and less computation complexity[7], RS code is much popular in well known traditional applications like Compact Disks (CD), Digital Versatile Disks (DVD), Digital Video Broadcasting (DVB), Mass Storage Devices, Wireless Communication and Satellite communication and also stands as an industry-standard for considerably longer duration. Finite field or Gallois Field is the fundamental arithmetic behind the construction and decoding of Reed- Solomon codes. Gallois field with any 'e' elements can be denoted as GF (e) such that the elements are of the form 'a^i' with 'a' as a prime integer and 'i' as any positive integer.

Conceptual shortening of RS code is possible by making certain number of data symbols equal to zero at the encoder itself and thus avoiding them not to get involved with the transmission. Due to this the required bandwidth gets reduced considerably, less interference in the transmission medium, much less complex encoding-decoding algorithm with sufficient amount of coding gain, error correcting capability. These omitted zeroes are reinserted at the decoder.

RS codes are much capable to correct any n-k symbols within the code block. There is no limit on the redundancy assigned for RS codes. They do effective error correction over channels with memory. While considering a RS (n,k) code with n = 255 and k = 247 i.e. RS(255,247) code where each symbol is of n-k = 8 bits (or) 1 byte, it is capable to correct any four symbol errors [(n-k)/2] in a code block with a length of 255 bits. Irrespective of whether it is a single bit error or symbol error, the RS decoder replaces that symbol completely while correcting the errors in the received data.

For the above mentioned RS code, the key parameters are,

Length of code block, n = 255

Length of each message, k = 247

Rate of the code, k/n = 247/255 = 0.97

Symbol length for parity-check = n - k = 8

Minimum code distance, $d_{min.}$ = n-k+1 = 9 symbols

Error correction capability, t = (n – k) / 2 = 4 symbols

Block or average message correction capability = (n – k) / 2n = 1.6%

Order of Galois Field, q = n + 1 = 256 symbols

Additionally, RS code has the capability to detect simultaneous errors i.e. decoder error and decoder failure. Whenever a received code word differs only by fewer coordinates, the RS decoder concludes it as a 'decoder error' i.e. the received code word has unacceptable level of errors. Whereas if the received code word differs from all code words lie in t+1 and additional coordinates, then it is concluded as decoder failure. Retransmission of encoded data is requested by the receiver when decoder failure is concluded.

RS encoder takes 'k' data symbols each of 'b' bits mentioned in any RS (n,k) code and parity bits are added to these symbols so as to make their length equal to 'n'[1]. For this, the following is the flow of arithmetic operations at the encoder side:

1. Finite or Galois field arithmetic – Fundamental arithmetic operations are performed on these field elements such that the result is also available within that field. These fields are of order defined by 'n+1' symbols.
2. Generator Polynomial – This polynomial is for generating code words such that all the code words are divisible by it. The generator polynomial is of the form[2],

$G_p(x) = (x\text{-}a_i)\ (x\text{-}a_i + 1)........(x\text{-}a_i + 2t)$ .... (1)

and the codeword is constructed using

$C_w(x) = G_p(x) * D_b(x)$.. (2)

where $D_b(x)$ is the data block and 'a' is a primitive element of Galois Field. For an example, the generator polynomial for RS (255,247) code is

$G_p(x) = (x - a_0)(x - a_1)(x - a_2)(x - a_3)(x - a_4)$
$(x - a_5)(x - a_6)(x - a_7)$.......................... (3)

(or)

$G_p(x) = x_7 + G_{p6}\,x_6 + G_{p5}\,x_5 + G_{p4}\,x_4 + G_{p3}\,x_3 +$
$G_{p2}\,x_2 + G_{p1}\,x_1 + G_{p0}$.............................. (4)

The added '2t' parity symbols are decided based on

$P_s(x) = D_b(x)\ xn\text{-}k \bmod(G_p(x))$ .... (5)

The arithmetic operations needed to decode the received code word,

$R_{cw}(x) = C_w(x) + e(x)$.......................... (6)

where, $C_w(x)$ is the actual code word and $e(x)$ is the added error during transmission of the code word, are as follows:

1.Calculation of Syndrome – This is equivalent to finding parity symbols i.e. any RS code word will have 2t syndromes depend only on the number of errors. By substituting the 2t roots of $G_p(x)$ into $D_b(x)$, the syndromes can be calculated.

2. Locating the Symbol Errors – By solving simultaneous equations with't' unknowns, symbol errors can be located. The complexity involved in this step is very much reduced due to the unique matrix structure of RS codes.

3. Finding Error Locator Polynomial - This can be done using the Berlekamp-Massey algorithm or Euclid's algorithm is used. In particular, because of its simplicity in implementation, Euclid's algorithm is preferred even though Berlekamp – Massey algotrithm needs much complex hardware and software implementation.

4. Finding the roots of Error Locator Polynomial - By Chien search algorithm, the roots of error locator polynomial can be found.

5. Finding the Symbol Error Values - Finally, by using a faster and because of that most-widely preferred Forney algorithm, the values of symbol errors can be found.

3. SIMULATION SETUP

By picking up the necessary individual blocks from Simulink Library, a simulation model as shown in Fig.1 is created. But, in addition to this, which is optional and not shown in Fig.1, necessary conversions are done for both generated cum decoded data and PN sequence i.e. as these two sequences are in unipolar form by generation, it may need to convert them into their corresponding bipolar form so as to enable signal multiplication in order to spread the spectrum of the data sequence before it modulates the high frequency carrier at the non-coherent MFSK modulator. There may be a need to convert the encoded data sequence from its bipolar form to its original unipolar form before modulating the carrier as it is baseband modulation. The simulations were run with the lowest value of M-ary numbe i.e. 2. After transmitting the modulated carrier over the realistic channel conditions for wireless environment i.e. either multipath Rayleigh or Rician fading, the received data is converted back to the required polarity before further processing. Finally, the received data sequence is compared with the originally transmitted data sequence so as to find how much degree of variation is between them and finally Bit Error Rate (BER) is calculated. Here, various RS codes with differing code rate, error corrections capability and order of Galois field are used. The response of the systems under both Rayleigh and Rician fading channels are recorded by varying the Average Path Gain Vector. The simulation model is operated in non-coherent mode of demodulation by setting Phase Continuity parameter both in the modulator and demodulator block to Discontinuous. The Maximum Doppler Shift is taken as 10Hz and Frequency Separation between different modulated components as 100 Hz. Even though higher values of Frequency Separation gives much improved BER, it may require wider bandwidth and hence it is limited the value of 100 Hz. And as the signal already undergoes severe multipath Rayleigh and Rician fading, it is not preferable to have higher Doppler shift in the frequency of the received signal. And this leads to the lowest value as 10 Hz. In the Random Integer generator, the Samples per frame is chosen such that it matches either with the value of 'k' or its multiples. Even though Samples per frame with multiples of 'k' gives much improved BER, it requires much complex hardware and thus by increasing the power consumption. And so Samples per frame is made equal to message length 'k' of any RS code. The simulations were run with the following two options:

1.Constant Code Rate, in which the code rate was maintained at a value equal to 4.

2.Constant order for Galois field and here it is set to 5.

4.SIMULATION RESULTS

The above mentioned first case led to RS codes with improper Galois field even though they were considered for less computation complexity and thus reduced power consumption due to less complex hardware implementation. However, as this idea is against the basic principle or arithmetic of Reed-Solomon codes, it is not wise to be considered and it may a reference for not doing improper coding.

Table – 1 Reference Value in X-axis vs. Actual value of Gain Vector (dB)

Reference value mentioned in X – axis	Corresponding actual value of Average Path Gain Vector (in dB)
0	[0 20]
1	[0 15]
2	[0 10]
3	[0 5]
4	[0 0]
5	[0 -5]
6	[0 -10]
7	[0 -15]
8	[0 -20]

As shown in Fig.2, even though the various codes have their performance get overlapped with each other at the beginning, they are with respect to unstable, non-preferred positive value of gain parameter. However, as the average path gain vector reaches towards it negative values, the Bit Error Rate performance comes down and it is RS(35,31) code with the lowest BER performance. But, as mentioned already its 'n' value doesn't define any eligible order for Galois field and so it could not be considered. In such case, either RS(7,3) or RS(31,27) should be considered and as RS(7,3) provides the least coding gain i.e. the worst error correction capability, it is wise to consider RS(31,27) even though it needs comparatively a much complex hardware

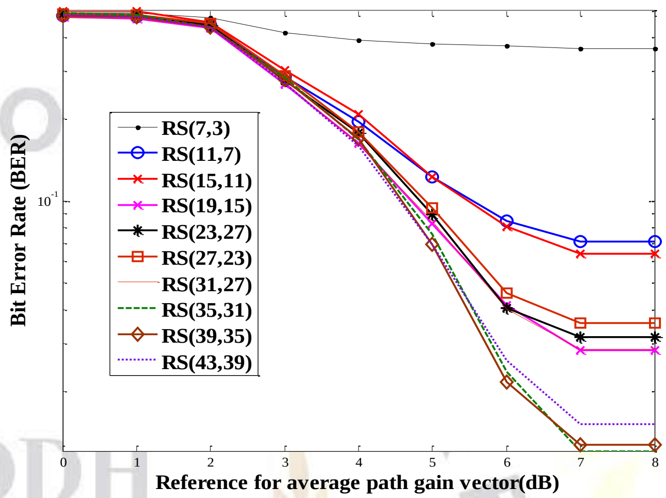


Fig.2 BER performance of RS codes with constant code rate = 4 under Rayleigh Fading Channel

implementation due to the increased order Galois Field. Now, the performance of the same set of RS codes over Rician Fading should be considered, which is shown in the following Fig.

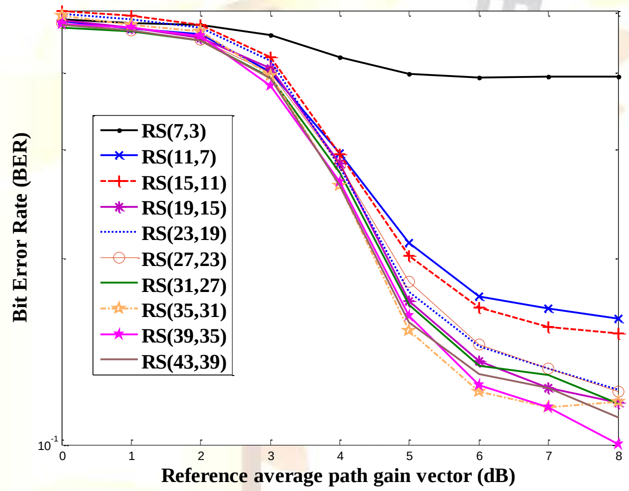


Fig.3 BER performance of RS codes with constant code rate = 4 under Rician Fading Channel

Similar to Fig.2, in Fig.3 also the RS codes have their overlapping performance for the positive, unstable values of Average path gain vector. Here also, the performance of RS(31,27) code is appreciable, even though other codes defining improper order for Galois field performs better.

The following simulation results shown in Fig.4 and Fig.5 are run as per the second condition mentioned previously.

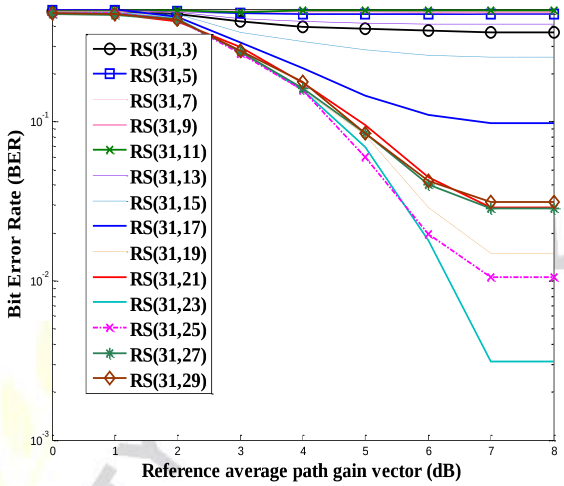
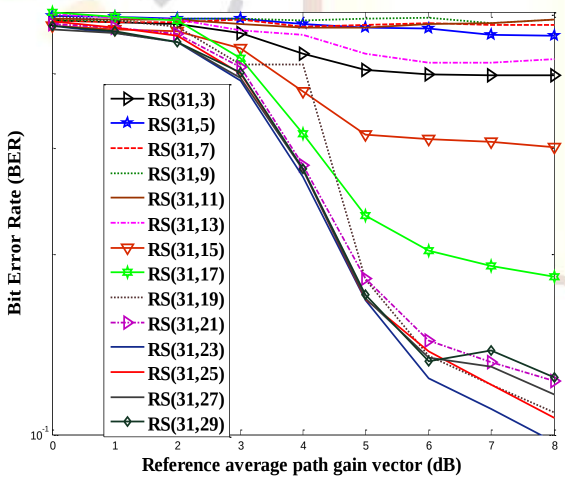


Fig.4 BER performance of RS codes with constant Galois Field Order = 5 under Rayleigh Fading Channel

As shown in Fig.4, BER performance of various RS codes with Galois Field of order 5 is compared. As like previous Fig.s 2 and 3, here also the codes have their overlapping performances for unstable and positive values of average path gain vector. But, as the gain vector reaches towards its stable negative value, RS(31,23) code provides the best BER performance. As its error correction capability is not appreciable, the performance of RS(31,27) can be considered as it has 100% error correction capability i.e. it corrects 2 block errors which perfectly matches with its error correction capability parameter.

Now, Fig.5 shows the BER performance of the same set of codes as used in Fig.4 under Rician Fading.



Even though it is similar to previous simulation cases, considerable amount of performance difference exist between the different RS codes. As per this simulation, it is RS(31,23) code that provides the lowest BER performance. However, crystal clear decision cannot be made on any particular RS code as like the case under Rayleigh fading channel. Anyhow, Rician fading is a supplementary channel condition along with Rayleigh fading and hence it can be concluded that the same RS code that gives the lowest BER performance under Rayleigh fading channel can very well be considered for Rician Fading scenario also.

5. CONCLUSION

Even though the complete analogy on the BER performance of Reed-Solomon codes for energy efficient sensor nodes cannot be described completely in a single paper, it can further be divided into sub themes and after all the modules are over they can be integrated suitablty to get the complete picture on the performance of RS codes i.e. this paper may just be a small part of the entire scenario and may get further extended by using more sophisticated simulink models as it is much convenient the works verified with simulink platform can very well easily be ported over FPGA or Cadence environment for verification of the design towards the development of a dedicated hardware of course without adding much complexity to it.

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