Reed Solomon coded NC-MFSK for low power Remote Sensing sensor nodes

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Abstract: Low power consumption and thus less implementation complexity should be the major design goal for RF wireless transceiver circuitry for Remote Sensing sensor nodes. WSNs are deployed to sense one or more parameters concerned to a remote environment i.e. the environment in which Human intervention is not allowed or suggested. Nodes deployed for such applications should prolong their battery life in order to avoid frequent node failure which in turn causes undesired changes in the topology of the network. As these nodes are driven into sleep mode for most of the time so as to conserve the battery power, the modulation scheme used should have quicker transition time from sleep mode to active mode. Otherwise, conservation of battery power becomes useless. As the transceiver consumes its maximum power during data transmission, the modulation scheme should be less complex to implement. Besides these, the data sequence is needed to be robust enough to withstand the interference caused by neighbouring wireless technology or devices with more power factor as well as the harsh behaviour of the channel. In order to fulfil all the requirements as mentioned above, Reed Solomon coded non-coherent M-ary Frequency Shift Keying modulation technique is proposed using Matlab / Simulink. Being Direct Digital Modulation approach, MFSK has faster transition time between sleep mode and active mode. Moreover as it is operated under non-coherent mode, there is no need of carrier phase recovery circuitry. Due to these, the transceiver circuitry becomes less complex and so reduced power consumption. The phase relationship between various signal components are plotted in terms of Eye diagram, Signal trajectory and Scatter plot. The simulation results show that, the phase relationship is clear under multipath Rayleigh and Rician fading channel conditions. But, when additive white Gaussian noise gets added with Rayleigh / Rician fading, the phase relation becomes worse. And this model gives its worst case Bit Error Rate performance around 50 to 60%.

Keywords: Physical layer, Doppler Shift, Bit Error Rate, Rayleigh fading, Rician fading.

I. Introduction

Wireless sensor nodes are suitable to get deployed over the physical environment in which human entry is not advisable or allowed. In such case, most of the applications for which WSNs are deployed is for monitoring / sensing the essential physical parameters concerned to that environment, processing the sensed data and transmitting that data to a remote place i.e. most of the applications are concerned with Remote Sensing. In order to prolong the life of these battery operated nodes so as to avoid frequent changes in the topology, the nodes are preferred to be operated in their sleep mode for most of the time. But the problem is waking up these devices whenever necessary to active mode, which may consume more power besides its conservation.

Transceiver circuitry of sensor nodes is the most power hungry component and thus efforts are needed to consider all the possible ways of keeping this circuitry as less complex as possible. Less complexity not only ensures low power consumption and also quicker transition from sleep mode to active mode.

Modulation scheme keeps the transceiver circuitry not only to consume more power and also drives it to take longer transition time from sleep mode to active mode however the transition time and thus the power consumption during the transition from active mode to sleep mode is comparatively negligible. By comparing the available pass band modulation scheme, due to its Direct Digital Modulation (DDM) approach, M-ary FSK can be the right choice.

Again when comparing its Coherent and Non-coherent counterparts, it is quite obvious that non-coherent scheme can be considered for reduced power sensor applications. Non-coherent scheme requires less complex implementation as the receiver does not require carrier phase recovery circuit. In order to have a fair trade-off between performance and power consumption, the transmitted signal should be made robust enough to withstand the rude behaviour the wireless channel, especially when transmitted over a noisy band like ISM.

In such scenario, it is desired to propose suitable Forward Error Correction (FEC) scheme in the sense that it should also be implemented with less complexity with convincing performance. The most widely used FEC scheme employs Reed-Solomon codes. With the feature of treating the corruption of one or more bits as single error, RS codes are much suited for correcting burst errors. As the sensor nodes are transmitting their data whenever they are driven into active mode, the data will undergo burst error. In order to reduce the implementation complexity of these RS codes, RS (7, 3) code with and without puncturing is considered in this work.

Code interleaving is another interesting technique to be considered to study the performance of this Simulink model. Numerous data processing, data transmission and data storage applications require Interleaved Reed-Solomon code to overcome burst errors. Permutation of ordinary RS codes provides Interleaved Reed – Solomon codes, which require classical algebraic decoding algorithms to decode the code words independently. Interleaving is an encoding mode that is being instantiated over any family of codes i.e. interleaved codes are not an explicit family of codes. Interleaving leaves the RS codes (IRS codes) to be a subset of parallel code words belong to the set of equal length RS codes. Being a hybrid approach, Interleaved Forward Error Correction (I-FEC) incorporates the robustness of FEC coding to random errors and the survivability of I-FEC to burst errors of higher degree.

Quantitative analysis of signals used in digital transmission can be analysed by using Eye diagram tool. An eye diagram is represented below:

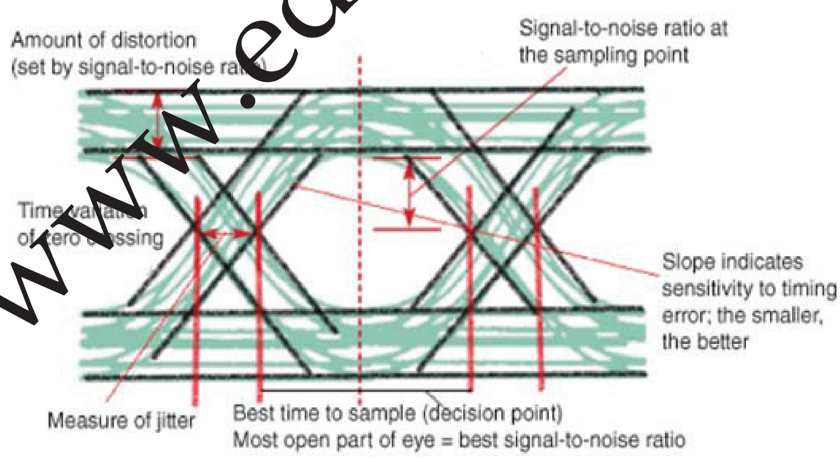

Fig.1 Representation of Eye Diagram

It provides an insight to the channel imperfections during the signal transmission. In the presence of inter symbol interference and noise, the system provides closed eye pattern otherwise i.e. open eye diagram pattern indicates that the signal is transmitted with minimal distortion. Impact of noise added to the signal can be measured from the opening of eye i.e. height and peak-to-peak. Overshoot or undershoot of eye pattern is to measure the peak distortion caused to the signal. Width of the eye is to measure timing synchronization and jitter. The most widely opened point of the eye diagram is the decision point while a demodulated signal is de-mapped to recover the digital message at the receiver.

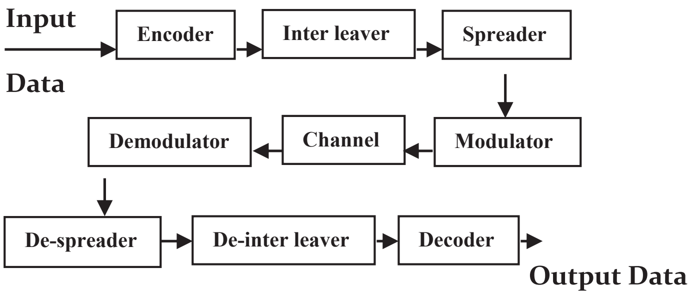

Fig.2 Basic Block Diagram for the proposed scheme

The basic block diagram for this simulation scenario is shown in Fig.2. As shown, the data input is first encoded and the encoded data bits are permutated in a predefined manner by the inter leaver. The spectrum of this interleaved cum encoded gets spreaded using Direct Sequence Spread (DSSS) Spectrum technique. After spreading, the data sequence modulates the carrier. Modulated data is transmitted through the suitable channel. Upon receiving the modulated carrier, the first step at the receiving end is demodulation i.e. detection of modulated carrier so as to filter it out. After demodulation, the data sequence gets despreaded by its spectrum. And then it is deinterleaving so as to arrange the bits in their original order before decoding. Finally, the replica of the original data at the input side was got. As the main objective is low power consumption, the phase relationship between the signal components is much essential together with the bit error rate performance of this model. So it is desirable to compare the finally received replica of originally transmitted data to get the amount of corrupted bits during transmission – reception process. Phase relationship between the components can be observed with suitable display devices.

The rest of this paper is organized as follows:

Section II elaborates the simulation model. Section III details the simulation setup, parameters. Section IV gives the detailed simulation results. Section V concludes this paper.

II. Simulation Model

MATLAB / SIMULINK is used to develop the simulation model as it is convenient to convert it into its equivalent VLSI architecture.

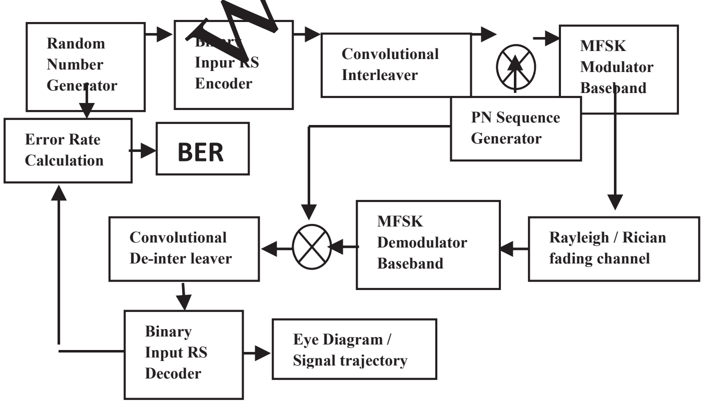

Fig.3 Block Diagram for Simulation Setup

The randomly generated data from Random Number Generator is encoded by the Binary Input Reed Solomon Encoder. This encoded data sequence is multiplied with a randomly generated pseudo-random noise sequence from PN sequence generator so as to spread its spectrum. After spreading, the data sequence modulates the local carrier generated inside the MFSK Modulator Baseband block. This modulated data is transmitted via either a multipath Rayleigh fading or Rician fading channel. The data received gets demodulated, de-spreaded, de-interleaved and finally decoded. The decoded data sequence is compared with the original data sequence to calculate the number of erroneous bits or corrupted points using Error Rate Calculation block. Error rate with reference to the number of bits transmitted, number of erroneous bits is displayed. This displayed result is used to analyze the performance of the proposed scheme in terms of Bit Error Rate. The data being transmitted is displayed using separate scopes for Eye Diagram, Signal Trajectory and Scatter Plot so as to get the phase relationship between In-phase and Quadrature in-phase components.

III. Simulation Setup and Parameters

Except for the AWGN channel, the set of values for M-ary number is {2, 4, 8 and 16} i.e. for either under AWGN only channel or under AWGN along with Rayleigh / Rician fading channel condition, the value of M is restricted to 2 as the phase relationship becomes worse for higher values of M. Even under either Rayleigh fading only or Rician fading only, the phase relationship gets disturbed which becomes much severe for M=16 i.e. the eye diagram gets closed which indicates that the inter symbol interference goes high. This is due to the increase in the order of signal constellation with the increase in M value.

Randomly generated output from the Random Integer Generator block is set to Frame-based mode with the value of Samples per frame varying in terms of power of 3, which is the length of message in RS (7, 3) code. Each integer output from this block is represented by 3 bits and fed into the Binary input RS encoder block by the integer to bit converter. Binary input RS (7, 3) encoder block is set with primitive polynomial,

$$P(p) = p^3 + p + 1 \qquad (1)$$

and default generator polynomial. The bits in this encoded data sequence are permutated in a predefined manner defined for Convolutional interleaver. Then the output from RS encoder is multiplied with PN sequence so as to spread the spectrum of encoded cum interleaved data sequence. The generator polynomial along with suitable initial conditions is,

$$G(x) = x^6 + 1 \qquad (2)$$

The carrier of MFSK Modulator Baseband block is being modulated by this data sequence. The modulator block is set with Integer input type, 'Continuous' phase continuity, 12 samples per symbol and frequency separation between different modulated components as 534 Hz.

Rayleigh fading channel block is set with the lowest value for Maximum Doppler Shift i.e.1, Doppler Spectrum type as Bi-gaussian and the relevant standard deviation, centre frequency values.

As Rician fading channel block is with additional parameters relevant to line-of-sight components, Doppler Shift of LOS component (in terms of Hz.), initial phase of LOS components (in terms of radians) and Maximum diffuse Doppler shift (in terms of Hz.) are set with the minimum value as 1. The key parameter, k-factor, the ratio between LOS component and diffused component is set as 0.1 i.e. LOS component is 10 times more in quantity than the diffused component. After being transmitted via either Rayleigh or Rician fading channel with above mentioned parameters, the data received is appropriately demodulated, de-interleaved and decoded.

IV. Simulation Results

Besides its best BER performance 0% and worst performance ranging over 50 – 60%, this model provides the phase relationship between In-phase (I) and Quadrature in-phase (Q) component as represented in the following Figures under different channel conditions. Fig.4 is the eye diagram display between I and Q components without interleaving the

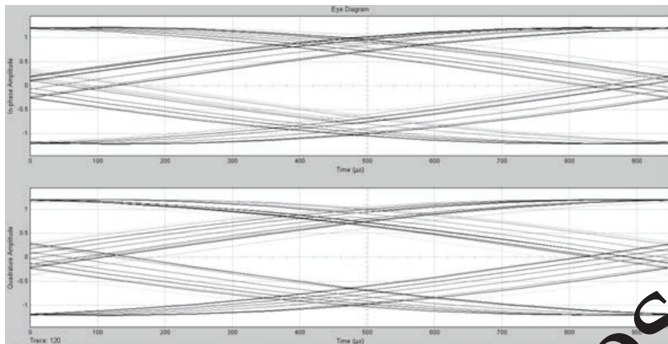

Fig.4 Eye diagram for I- and Q-components under Rayleigh fading for RS (7, 3) code

R-S code. Fig.5 is the signal trajectory plot i.e. continuous plot of signal components; correspond to the eye diagram plot shown in Fig.4.

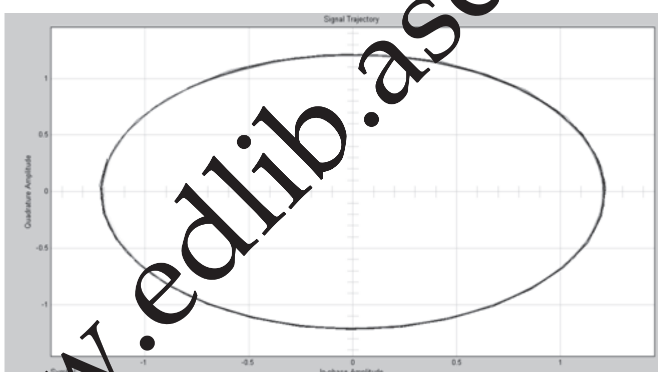

Fig.5 Signal trajectory between I- and Q-components under Rayleigh fading for RS (7, 3) code

As shown in Fig.4, the eye diagram is wide enough in the sense that the set simulations parameters enable the Simulink model to undergo appreciably lower inter symbol interference. Fig.5 is the corresponding signal trajectory plot for Fig.4.

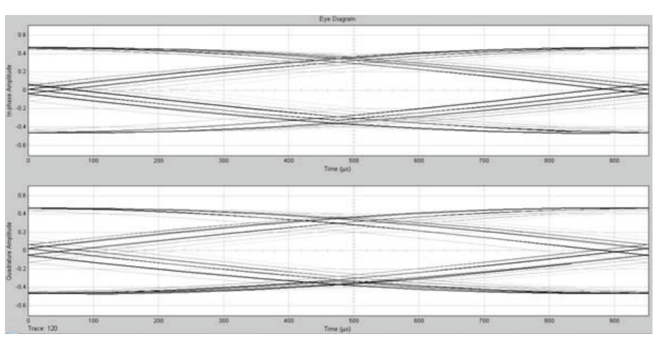

Fig.6 Eye diagram for I- and Q-components under Rayleigh fading for RS (7, 3) code

Fig.6 is the eye diagram pattern for interleaved RS code under Rayleigh fading channel. As shown, this eye diagram is comparatively wider than that obtained for non-interleaved RS code. With reference to the corresponding signal trajectory shown in Fig.7 for Fig.6, it is observed that there is a small reduction in peak value of the signal components i.e. Simulink model with interleaved RS code requires reduced peak power factor. So, this model provides fair enough trade-off between power and hardware complexity of transceiver circuitry.

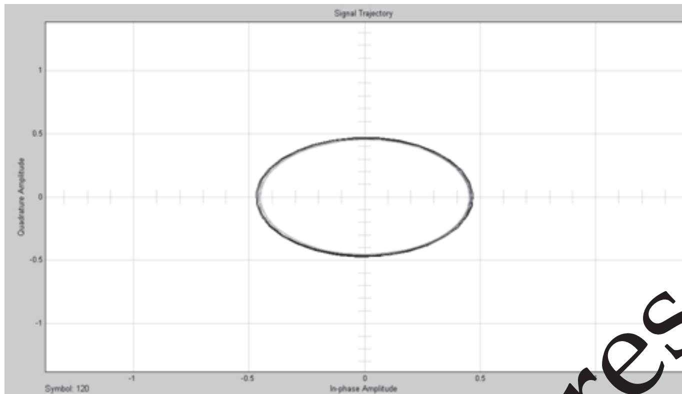

Fig.7 Signal trajectory between I- and Q-components under Rayleigh fading for RS (7, 3) code

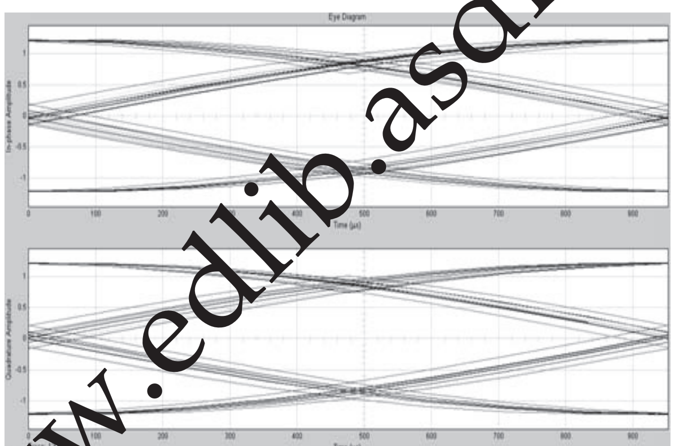

Fig.8 Eye diagram for I- and Q-components under Rician fading for RS (7, 3) code

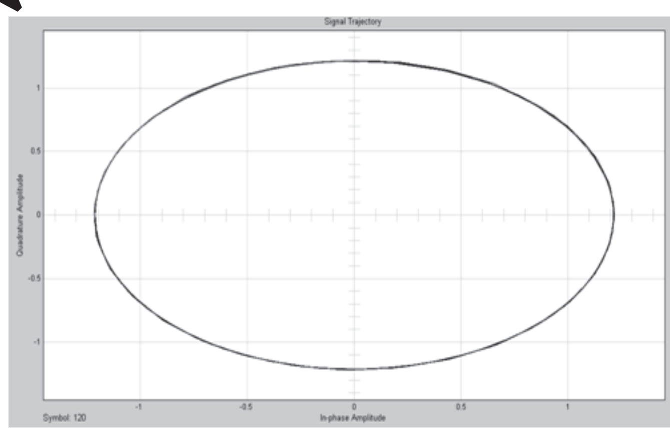

Fig.9 Signal trajectory between I- and Q-components under Rician fading for RS (7, 3) code

Fig.8 and Fig.9 are the respective eye diagram pattern and signal trajectory for the case of non-interleaved RS code under Rician fading channel. As shown, when compared with the eye diagram shown for non-interleaved RS code under Rayleigh fading channel, this eye diagram is widely opened i.e. it is with comparatively less inter symbol interference. The main reason is that, Rician fading deals with LOS components but Rayleigh fading deals with non-LOS components.

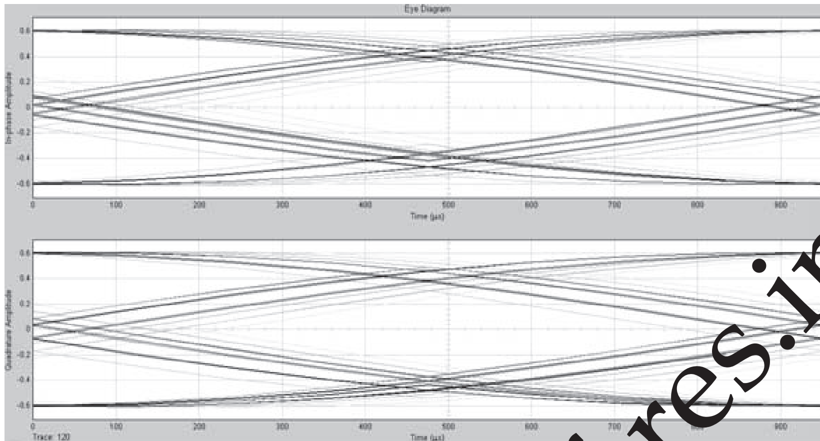

Fig.10 Eye diagram for I- and Q-components under Rician fading for RS (7, 3) code

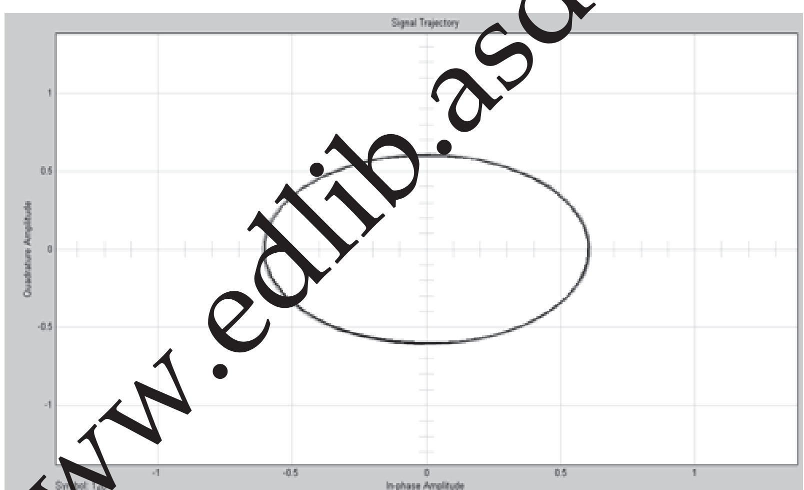

Fig.11 Signal trajectory between I- and Q-components under Rician fading for RS (7, 3) code

Fig.10 and Fig.11 are the respective eye diagram pattern and the corresponding signal trajectory for interleaved RS code under Rician fading channel. The eye diagram pattern is much clear than that shown for non-interleaved code scenario. (Fig.8) i.e. interleaved RS code enables this Simulink model to deliver its signal with the lowest inter symbol interference over the wireless channel with multipath Rician fading.

The next simulation scenario is for higher values of modulation order, M. As its value increases from its default lowest possible value of 2, the phase relationship gets affected in the sense that, the best time to decode the data is not clear and so it becomes much difficult to recover the information. Fig. 12 shows one such eye diagram for M = 16. The corresponding signal trajectory is shown in Fig.13. The point to be considered here is that, the model gives its modulated signal with minimal inter symbol interference for the least possible value of M i.e.2, which is preferred for low power scenario, as it helps to design the modulator – demodulator with less hardware complexity.

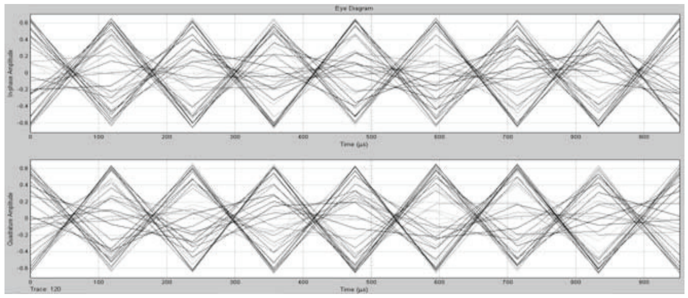

Fig.12 Eye Diagram of I- and Q- components under Rayleigh / Rician fading for RS (7, 3) code with M=16

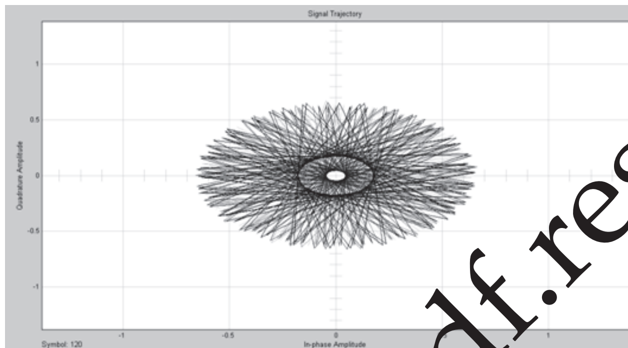

Fig.13 Signal trajectory between I- and Q-components under Rayleigh/Rician fading for RS (7, 3) code with M=16

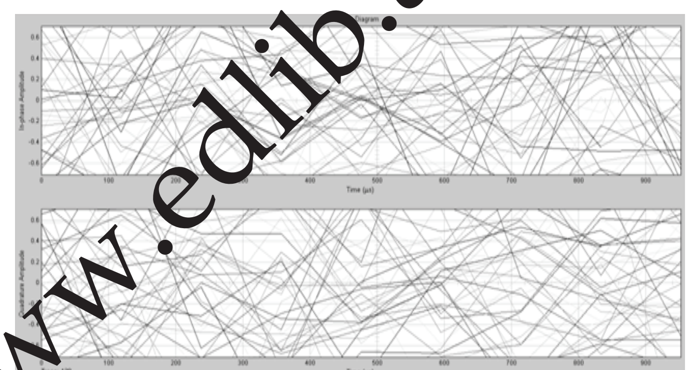

Fig.14 Eye Diagram of I- and Q- components with AWGN + Rayleigh/Rician fading for RS (7, 3) code (M=2)

Even though AWGN channel is very general and not wise to be considered for WSNs and multipath Rayleigh or Rician fading channel is the exact channel condition to be considered, AWGN can be considered just as a reference. In that context, the eye diagram and its corresponding signal trajectory shown in Fig.14 and Fig.15 respectively is the scenario in which the impact of additive white gaussian noise along with multipath Rayleigh or Rician fading channel is observed. It is clear that, it is almost impossible to recover any information from such a transmitted signal. Moreover, this simulation is run just for M=2. The performance goes still worse for higher values of modulation order, M. But a point to be noted is that, AWGN channel with a larger value of signal-to-noise ratio typically in the order of 32 dB and number of bits per symbol as 64, the eye diagram can be made similar to that one got under the channels undergo Rayleigh and Rician fading alone. But such values are practically much difficult to keep, especially in low power scenario.

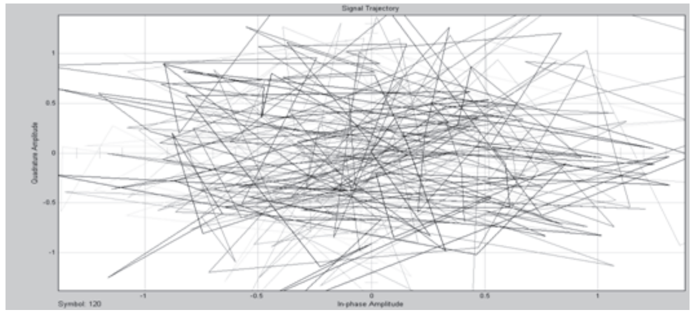

Fig.15 Signal trajectory of I- and Q- components with AWGN + Rayleigh/Rician fading for RS (7, 3) code (M=2)

V. Conclusion

As packet retransmissions are to be avoidable to the possible extent in low power wireless applications, eye diagram is essential performance measures as it clearly indicates the level of inter symbol interference in the transmitted signal. So as to reduce the number of data packet retransmissions, the eye pattern should be as wide as possible. Even though, the eye pattern of this model is sufficiently wide, efforts are needed to reduce the BER performance. In future work, the role of data rate over the BER performance is to be studied.

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