Performance Analysis of RS Encoded and Self-Synchronizing RS Encoded PPM through a Gamma Gamma Channel

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***Abstract*—RS encoded PPM proves to be the best suited encoding scheme in terms of its efficiency and robust nature for terrestrial FSO links. Self-synchronizing RS codes are superior to RS codes in terms of their synchronizing ability but they have not been put to proper experimental use. In this paper, we have tried to conduct a comparative study between RS (n, k) and self-synchronizing RS (n, k) when used with M-ary PPM. We considered the use of RS (255,223) and self-synchronizing RS (255,223) along with 16-PPM through a gamma-gamma channel. The bit error rate for both models was plotted against the signal to noise ratio. The results indicated their similar behavior with no visible difference in their performances except at higher noise variation values. It can be concluded that increase in the value of noise variation along with the use of higher states of PPM can lead to better performance of self-synchronizing codes.**

Keywords—Reed Solomon codes (RS codes), Self-synchronizing Reed Solomon codes (SSRS codes), Pulse Position Modulation, styling, Gamma-gamma channel, Free Space Optics (FSO)

I. INTRODUCTION

Free Space Optical (FSO) communication systems have gained a lot of popularity during the past few years because they provide an enormous amount of bandwidth leading to high data rates [1]. Apart from this, some other advantages behind the widespread use of FSO systems are cost efficiency, less signal losses, transmission efficiency, no electromagnetic interference and zero crosstalk. [1]

Forward Error Correction (FEC) plays an important role in FSO communications and Reed Solomon (RS) codes are the most common type of FEC codes used in such kinds of transmissions because of their ability to correct bit as well as burst errors. Reed Solomon codes belong to the class of non-binary codes that operate over Galois Field or GF (2^m) most frequently GF (8). A typical RS (n, k) can correct up to t errors through the use 2t parity for sending a k bit message such that t corrupted bits or fewer than t corrupted bits in the received message can be detected and corrected. Here n represents block length of the code and k represents dimensions.

$$2t=n-k \qquad (1)$$

The complexity of RS codes is the function of their block length. Different values of n and k lead to various RS code combinations giving rise to codes with distinct error correcting capabilities. Self-synchronized Reed Solomon codes (SSRS) are the upgradation to the original RS codes proposed by Reed and Solomon in 1968.The basic idea behind these codes is to obtain additional coma freedom while preserving the error correcting capability of the original RS codes [2]. A self-synchronized code or a comma free code can be defined as a binary block code having length n such that if overlapping between two adjacent codewords occur, it will not result into a legitimate coded sequence. Comma free codes have an advantage of synchronization of codewords at both bit and block level. A very commonly used approach for synchronization is the insertion of synchronization markers in between the codewords but sometimes typically in noisy channels this technique causes jumbling of the actual data and the synchronization markers and it becomes quite complicated to differentiate between them. This kind of problem can be mitigated through the use of self-synchronizing codes by completely eliminating the need of sync- markers in between codewords. The self-synchronized RS codes lead to the possible correction of mis synchronized codewords through the inspection of code itself. RS codes have 2^m-1-2k degree of comma freedom while the self-sync RS (n, k) is supposed to have degree of comma freedom greater than 2^m-1-2k [2].

Most of the FSO systems employ Pulse Position Modulation (PPM) as a modulation scheme because of its high-power efficiency [3].The use of multi-pulse PPM or M-PPM can improve the power efficiency of the system. For an RS encoded FSO environment, PPM is the best suited modulation scheme because RS codes and PPM have one to one correspondence with each other. The alphabet size of the RS codes can be easily matched with PPM [3].

Our approach is to gain an insight into the use of self-synchronized RS codes in terms of their efficiency. Since their introduction they have not been in much use in the research area as well as practical systems. The reason behind it may be the difficulty in implementation or maybe they do not show improved performance in comparison to simple RS codes. Our research uses RS (255,223) combination to compare both channel coding schemes in terms of their efficiency by passing RS encoded and self-synchronized RS encoded PPM modulated optical data through a gamma-gamma channel model and observing their bit error rate (BER). According to the theoretical assumptions, a self -synchronized Reed Solomon encoded system should give enhanced results based upon its ability to deal with mis-synchronization of coded sequences. The remainder of this paper is organized as follows: Section II contains some necessary background information regarding RS and self-synchronized RS codes. Section III we discuss our proposed approach. Section IV analyzes the performance of both coding schemes to draw useful conclusions.

II. BACKGROUND

Free Space Optical systems need to employ forward error correction techniques in order to improve the quality of communication while keeping the bandwidth requirements and average transmitted power in check.RS codes are the best possible choice for this kind of transmission as they have the ability to transmit high speed data. The use of Reed Solomon codes as a channel coding scheme in relatively low fades improves the bit error rate performance making it almost identical to a fading free channel [4].

Most of the papers discussed the use of PPM along with RS codes because PPM symbols can be altered to fit the RS code symbols. M-PPM uses one pulse per M slots to transmit binary data and in general the total number of bits transmitted per slot are represented by $\frac{\log_2 M}{M}$. Reed Solomon codes RS (n, k) are defined over Galois Fields GF(q) and by using n=q-1one to one correspondence between PPM symbol and RS code symbols can be achieved. However, S.S Muhammad et.al noticed that matching the code structure with PPM order promises no extra coding gain[4]. The use of RS codes can enhance the receiver's efficiency for attenuations ranging up to 6dB but in cases where the attenuations start exceeding 10dB, RS codes become unable to correct single block errors as they fall above their error correcting capability. [4] employed RS (225,127) along with16-PPM and 256-PPM for short range terrestrial links under ambient light conditions and discovered a gain of 25 dB as compared to the uncoded modulation schemes.

According to Shu-Ming Tsend et.al ,keeping in mind the computational efficiency along with exceptionally good error correcting capacities and good synchronization properties RS and convolutional codes are the only error correcting codes that should be considered with PPM. They proposed joint symbol synchronization and decoding schemes with reduced complexity in photon limited optical channels using convolutional codes after considering RS codes as an option[5].

In Self-synchronizing codes or comma free codes no two adjacent codewords resulting from either from a misaligned window or noisy channel should result in a valid decodable codeword [6]. Reed and Solomon proposed the idea of self-sync RS codes as a unified approach to solve the synchronizing issues between codewords and increase the error tolerance at the same time while successfully maintaining their compatibility with existing modulation schemes also. According to Reed and Solomon loss of synchronization between two codewords can occur leading to the misinterpretation of the first (n–r) symbols of the successive codeword with the last r symbols of the previous codeword. In such circumstances the possibility of mistaking c as a codeword when it is actually not a codeword increases. The deployment of self-sync RS codes in recent FSO systems can help in avoiding such situations .

Some papers discussed joint sync schemes [6] and slot synchronization in optical systems but self-sync RS codes were not discussed very clearly. The need of self-synchronizing codes arises in noisy channels where the insertion of synchronization markers between codewords can give rise to complications in communication systems. Zero symbol sync errors are still not guaranteed in a completely noiseless channel assuming an ideal scenario because it is possible that exactly one pulse or M pulses are present in a misaligned window and they go undetected. Self-synchronizing RS codes can also have the advantage of offering synchronization support to PPM in FSO environments as it is vulnerable to loss of synchronization resulting from inter symbol interference or environmental noise [7].

The topic of self-synchronizing RS codes remained untouched for several years despite of the fact that FSO communications have gained massive popularity in those years. The reason behind it can be their questionable practicality. Our research focuses on the comparison of RS codes and self-sync RS codes in terms of their bit error rate. The BER of both coding schemes is plotted against the signal to noise ratio in a gamma gamma channel.This comparison will help in understanding about the use of both the schemes in FSO systems.

III. DESIGNS AND METHODS

Our research focuses on the comparative performance analysis between RS encoded PPM and self-synchronized RS encoded PPM. The design uses a modular approach and all the individual modules are connected with each other in such a way that input to one module is output of previous module. All the simulations are done using MATLAB. Fig. 1 gives a rough insight into our model.

The transmitter consists of an encoder and a PPM modulator. A random bit generating source produces bit stream of data at the input which passes through the encoder and gets encoded into RS codewords using RS (255,223) where n=255 referring to the block length of code and k=223 represents the total number of information bits. RS (255,223) can detect and correct up to 16 errors in 255 bits while using 32 bits as parity.

$$t=\frac{n-k}{2} \qquad (2)$$

The addition of parity bits in k number of information bits yields the total block length (n) of the code. The block length n of the RS code is given by:

$$n=2m-1 \qquad (3)$$

Here m refers to the number of bits that are kept in mind while choosing the order of GF(q). The message bits are refashioned into a message polynomial at the transmitter. The encoder works by generating a generator polynomial in GF(q) of degree 2t upon detecting the entry of message polynomial. The degree of generator polynomial is decided depending upon the number of errors (t), a certain RS (n, k) combination can correct. The message and generator polynomial perform a process of convolution with each other giving rise RS codewords.

Figure 1. FSO system model

M-PPM is used as modulation scheme with M=16.On-Off keying (OOK) is also a very popular modulation approach used along with RS codes.But for any M greater than 2 less optical power is required contributing to efficient transmission of data especially in systems with severe peak power constraints. Although M-PPM is a power efficient modulation scheme but, on the downside, it has a poor bandwidth efficiency but the abundance of bandwidth in FSO communications makes this of little concern. Although increasing the value of M increases the power efficiency of the system but we selected 16-PPM keeping in mind the systems amplitude constraints while making sure that power and bandwidth efficiency targets are met. Generally, M-PPM transmits $\frac{\log_2 M}{M}$ bits per slot. Each symbol interval of duration T is divided into M sub-intervals. The transmitter sends an optical pulse during one of these sub intervals using only one slot per symbol out of 16 available slots for the transmission of data.

A gamma-gamma channel model is used because of its the simplicity and tractability. Apart from gamma gamma model other options may include log normal and exponential models. Log normal is the most widely used channel model dealing with weak turbulence conditions while exponential model is used to cater strong turbulence environments. Gamma-gamma model is based on doubly stochastic theory of scintillation. In gamma-gamma distributions $K_v(x)$ is a Bessel function and the parameters α and β are directly related to large scale and small scale scintillations of the optical wave. Generally, gamma-gamma channels are preferred over log normal channels because log normal channels can be challenging under certain conditions and may not fit the experimental data properly. The gamma-gamma PDF is not only valid for all kinds of turbulence regimes from weak to strong in an environment but also provide a good fit to the experimental data. It assumes large scale and small scale fuctuations governed by gamma distributions and attains the uncoditional irradiance distribution through averging of the conditional PDF.

$$f(I) = \frac{2(\alpha\beta)^{\alpha+\beta/_2}}{\tau(\alpha)\tau(\beta)}\, I^{\frac{\alpha+\beta}{2}-1} K_{\alpha-\beta}(2\sqrt{\alpha\beta I}\,)\text{ , I>0} \quad (4)$$

$$\alpha=[\,\exp\left(\frac{0.49\delta}{\left(1+1.11*(\delta)^{\frac{6}{15}}\right)^{\frac{7}{6}}}\right)-1]^{-1} \quad (5)$$

$$\beta=[\,\exp\left(\frac{0.51\delta}{\left(1+0.69*(\delta)^{\frac{6}{15}}\right)^{\frac{5}{6}}}\right)-1]^{-1} \quad (6)$$

$$\delta=((1.23*e^{-14}((2*\pi/_\lambda)^{\frac{7}{6}}))^{\frac{11}{6}} \quad (7)$$

The receiver consists of a demodulator and decoder. The RS decoder uses Brelekamp algorithm to decode the demodulated bits. Noisy bits from the decoder are retrieved to their original values by comparing the symbol values from the modulator with those received from the channel. This comparison helps in calculating the bit error rate.

The self-synchronizing RS encoder and decoder have the ability to synchronize the bitstreams on their own without any external help. Except that the encoder and the decoder work exactly in the same fashion as they do for original RS model. To achieve this kind of synchronization a vector C is added to each codeword individually. The addition of vector $C= \{x^m\}= \{1, \beta^m, \beta^{2m}\}$ to each codeword gives them an additional degree of comma freedom equal to at least $2^k - l - 2m$ while keeping their error correcting capability same. This vector C is generated using the primitive element for a typical Galois Field.

The bit error rate (BER) is recorded for each model and plotted against signal to noise ratio (SNR) in decibels to carry out an extensive performance analysis between both models.

IV. RESULTS AND DISCUSSIONS

We carried out performance analysis of both models by plotting their BER and SNR against each other. SNR in decibels (dB) ranging from 0 to 40 dB is plotted on x-axis whereas bit error rate is plotted along y-axis.

Normally for an RS encoded FSO system using M-ary PPM as a modulator, when SNR and BER are plotted against each other they exhibit an inverse relationship. The increase in SNR of the system will lead to the decrease in the BER of the system. This kind of behavior gives rise to waterfall curves.

In the first stage, it is important to verify that either our system is working accurately or not. Results and curves obtained by simulations showed the typical nature of RS encoded PPM system. It established the fact that our systems are working perfectly. The next step led to the most crucial part of this research. The Bit error rate of RS (255,223) and self-synchronizing RS (255,223) using 16-PPM through a gamma gamma channel is evaluated at three various noise std. values which are 0.06 ,0.08 and 0.12 respectively. Figure 1 compares the Bit error rate of Uncoded PPM and RS encoded PPM. Uncoded PPM exhibits higher BER than RS (255,223) specially at increased values of SNR. However, a negligible difference between the Bit error rates of both schemes can be seen at lower SNR levels. Similar trend can be observed at all the noise std. values. The highest value of noise std. used is 0.12. At this value, RS codes show the lowest possible Bit error rate indicating that Reed Solomon codes can work better under greater noise variations. Similarly, Figure 2 compares the Bit error rate of Uncoded PPM and self

synchronizing RS encoded PPM. The self-synchronizing RS (255,223) show exactly the same trends. The results shown in figure 3 clearly indicate that RS (255,223) and self-synchronizing RS (255,223) show the same performance.

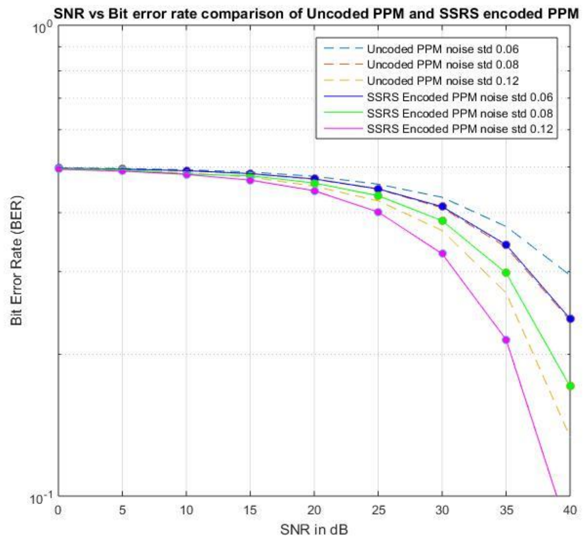

Figure.2 SNR vs BER of Uncoded PPM and SSRS Encoded PPM

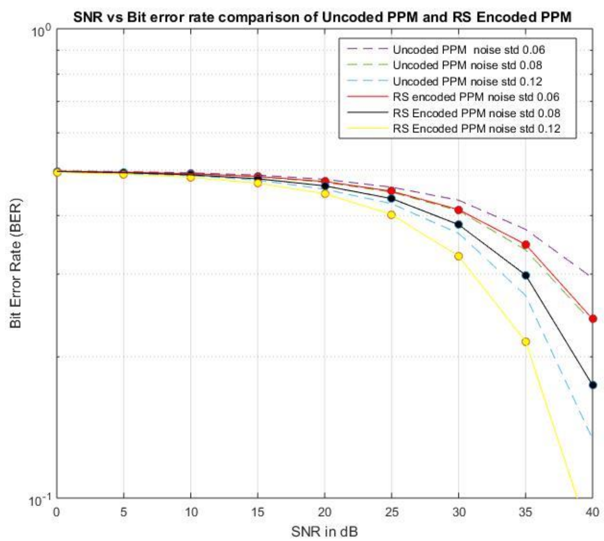

Figure 3. SNR vs BER of Uncoded PPM and RS Encoded PPM

Both systems exhibit almost negligible in their bit error rates. However, it can be seen that for larger values of noise std. the bit error rates of self-synchronizing RS (255,223) show some improvement over RS (255,223) as soon as the SNR exceeds 25 dB. It is quite evident from the results that self-synchronizing RS codes are compatible with M-ary PPM in the same manner as their counterpart. Although significant improvements in the bit error rate are not seen but may be the use of higher orders of PPM can give progressive results.

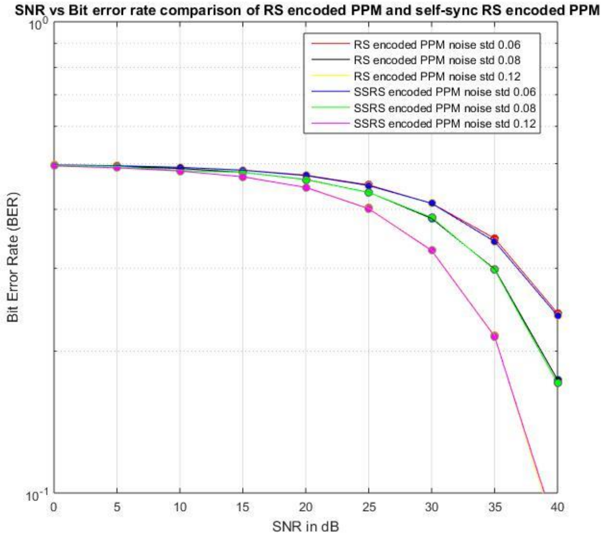

Figure 4. SNR vs BER of RS and SSRS Encoded PPM

Theoretical analysis of self-synchronizing codes predicted that they perform better than original RS codes because they provide additional degree of comma freedom ≥ 2^k–1–2m yet the practical implementation of both models resulted in their similar behavior. One of the reasons for not so improved perforamnce of SSRS encoded PPM can be the the use of lower states of PPM. The channel model also plays a significant role in the behaviour of Forward Error Correction codes, although we made the best possible choice for a channel model but it resulted in a similar behviour between both encoding schemes.Nonetheless, it becomes quite evident that for the systems having increased noise variance levels self-synchronizing RS codes are the best possible form of forward error correcting codes which can be employed. Our basic purpose was to put the efficiency of self-synchronizing codes to test by comparing them with original idea of Reed Solomon codes. Furthermore, to improve the results, time and slot synchronization techniques can be applied in harmony with higher states of M-PPM and using channels known statistics to decode the codewords at all the possible distances[8].

V. CONCLUDING REMARKS

In this paper we presented a comparison between Reed Solomon and Self-synchronizing Reed Solomon codes performance on a gamma-gamma turbulent FSO link. The use of RS (255,223) and self-synchronizing RS (255,223) along with 16 PPM through a gamma-gamma channel model is considered. Gamma-gamma model is chosen because of its tractable design and its ability to cater all types of turbulence conditions.The channel coded schemes in FSO systems show enhanced performance than their uncoded counterparts. The experimental results clearly indicate the closely similar behavior of RS and self-synchronizing RS codes when implemented under the same noise conditions. According to the theory Self-synchronizing RS codes should exhibit an improved bit error rate because they have greater degree of comma freedom than original RS codes [9]. However, our results practically show a little performance improvement. The chances are that SSRS codes can show improvement if used with higher PPM orders and increased noise variations. Further efforts to get finer results may include changing channel models along with the use of different RS (n, k) combinations.

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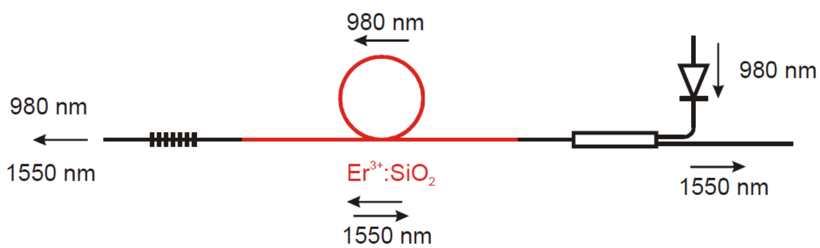

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