Performance of Systematic Distance-4 Codes in Free-Space Optical Communication System

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Summary
In this paper, we reconfigured the SD-4 code with both: long and very long code lengths. Firstly, we generated SD-4 code with 15 codeword length that implies SD-4 code 3,900 lengths, secondly, we extended SD-4 code to 32,768 which is very long code length . Our model is based on SD-4 code as an encoding/decoding block cascaded by multiple pulse-position modulations (Q-PPM) in FSO communication environment. Such model performance is evaluated by lognormal atmospheric turbulent fading channels. Furthermore, coding gains are compared with different code lengths and Q-PPM modulations to demonstrate such codes ability of coding with pulse position modulation (Q-PPM). The optimal obtained raw code gain is equal to 0.56 dB for SD-4 at code length (4096) which analyzed with BPPM regarding the other related codewords (channel throughput is not considered). Meanwhile; the real code gain results have been obtained and equal to 3.87 dB at code length (32768) for such channel(channel throughput is considered). Tto demonstrate the SD-4 code ability to be coded with Q-PPM, we analyzed such code utilizing 4PPM and 8PPM. Also, we compared our results with existing results for other techniques namely : Hamming, Reed-Solomon, and Bose-Chaudhuri-Hocquenghem.

Key words:
LDPC, Hamming distance, systematic coding, FSO, PPM. channel throughput.

1. Introduction

To apply the building networking in un-applicable fiber communications areas, Free-space optical communication (FSO) has been proposed. To mitigate the high bit streaming and channel capacity, Unmanned aerial vehicle (UAV) transmission is also investigated. FSO systems provide a transmission capacity with Gbps. Accordingly, high-bit-stream transmissions like images and videos become available for UAVs. The intensity modulation/direct detection (IM/DD) techniques are commonly utilized in FSO modulation and demodulation which are cheap and simple to implement. On–off keying (OOK) and pulse position modulation are important IM/DD techniques used in FSO systems. Similar to Radio frequency (RF) applications, diversity is compatible with FSO system such as multiple-input-multiple-output (MIMO), single-input-single-output (SISO), and single-input-multiple-output (SIMO). Unlike RF system, a line of side (LOS) is necessary to be available in FSO.

The major cause of FSO system degradation is the atmospheric turbulence. Mainly, climate changes (temperature and pressure) or flying objects can greatly degrade the link performance, this degradation is known as scattering/observation which attenuates and fades the optical signal respectively[1]. These turbulence effects are classified into weak, moderate, and strong. A lognormal model is suitable for weak atmospheric turbulence effect in FSO channels (link range of 1–5 km). Meanwhile; gamma-gamma model is fit to be used in the moderate and strong turbulence effects for long FSO links, such as satellite applications [2]- [3].

To mitigate atmospheric turbulence degradation, several solutions are proposed [2],[3]. These solutions are; error correcting codes (ECC), cooperative systems[3]-[4] and optical adaptation techniques [5],[6]. Cooperative FSO transmission strategy reduces the atmospheric turbulence effects and enhances the FSO systems performance. Hybrid channel optical/RF is an analysis for Turbo Codes in [7]. For ECC, to provide coding gain superior to uncoded data transmission; a low-density parity-check (LDPC)-coded FSO communication system over an atmospheric turbulence channel is designed [8]-[9].

A systematic distance code is proposed as LDPC code with a constant Hamming distance of 4 (SD-4) [10]. SD-4 codes possess a systematic configuration and consequently enable a simple decoding process. This code obtains different gains in terms of codeword and modulation techniques, such as (16,11,4) and (512, 502, 4). SD-4 codes are affording approximately 6.3 dB and 4.6 dB coding gains in Rician channel respectively, SD-4 code yields approximately coding gain at a bit error rate (BER) of 10-5 with a binary continuous frequency phase-shift keying the list of gain with different codewords as radio frequency (RF) modulation is summarized in[11]. They developed SD-4 with encryption/decryption with a RF domain [12]. Accordingly, SD-4 has never utilized before with FSO communication system, which is the main contribution to apply our study.
In this study, our contribution is categorized into two parts; study and analysis parts. In study part, firstly we design a new codewords of length 15 which do not exist before in previous studies of SD-4. This implies SD-4 code length

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4,096 and illustrated clearly in appendix A. Secondly, we extended the previous result in appendix A to generate SD-4 code length up to 32,1768.

In analysis part; we tend to find firstly, the optimal raw gain (channel throughput is not considered) for SD-4 at different code lengths, and then secondly, find the optimal actual gain (channel throughput is considered) for SD-4 at such code lengths, where the actual code gain is obtained

To clarify the powerful of our study, we compare our results with another traditional coding techniques, Reed-Solomon (RS), Hamming, and Bose-Chaudhuri-Hocquenghem(BCH) at different modulation techniques, OOK and Q-PPM.

The remaining parts of this paper are organized as follows: Section 2 introduces the model of encoded/decode as SD-4 coded with Q-PPM FSO systems; Section 3 designing code SD-4 for long code length Section 4 describes the mathematical model Bits detection and correction for SD-4-Q-PPM of the FSO system coded; Section 5 presents the simulation results and discussion, and Section 6 concludes the paper.

2. System Performance

As we mentioned before, using coding reduces the degradation of performance in FSO communication that caused by atmospheric turbulence, based on this fact, we proposed a system based on long SD-4 code with Q-PPM to reduce this bad effect. The obtained performance is signal-to-noise ratio with 3.87 dB gain for SD-4 code at length of 32,768 bit as throughput of FSO channel with BPPM.

SD-4 codes can be used to generate a constant Hamming distance of 4 binary linear block codes [10]. The following steps are employed to generate SD-4 code. The systematic generator matrix of an SD-4 code is constructed [10] as follows:

The full rate (max.) of SD-4 code can be obtained with the C (n, k, d) = (128, 120, 4) code length, where n and k are matrix dimensions of the code generator. The size of the identity matrix I for this code is (120×120), which contained 120 rows and 120 columns. The size of the generator matrix (G), which is a systematic generator matrix, (G) is (120×8), (i.e.120 rows, 8 columns). Therefore, the length of generator codewords (GC) that will be formed is 8, and each codeword can be used to produce seven codewords by cyclic shifting. The first GC (GC1(16,8,4)$_{)}$ is formed by sequentially placing three of the binary codes as (3+0) as G. C1(16,8,4) = (1, 1, 1, 0, 0, 0, 0, 0). After the last circulation with one shifting is completed, the last codeword can be obtained as G. C1(16,8,4) = (1, 1, 1, 1, 1, 1, 1, 0), and the full description can be found in previous studies [10]- [12]. In next paragraph we will extend SD-4 (128, 120, 4) up to several tens of thousands code length, this will be done by two steps, in the first one, we will generate codeword with length 15, and GC has been extended from GC15 to GC250. In the second step, we will formulate GC250 to generate thousands of code lengths.

3. Developing SD-4 Code Length (Long and Very Long)

Since SD-4 with codewords length up to 10 is demonstrated in [10]that allows generating SD-4 code with maximum length of 512 lengths, furthermore, since our goal is developing the performance of SD-4 with Optical communication which is required encoder/decoder with high-speed bit stream, therefore; we will reconfigure SD-4 for code length equal to 32,768 to achieve the compatibility between the encode/decode data and FSO transceiver which is required high-speed data coding as following:

The codewords GC_1 - GC_{15} of length 8 that described in the introduction, are limited to generate SD-4 code with a maximum length of 120 (120 rows, 8 columns). For example, the new codeword GC_{16} (after G. C_{15}) will be generated from 110000010 and so on. Therefore, for codeword length 10, the codewords will be extended up to GC_{52} and length of Code SD-4 becomes (52× 10 = 520). To reach code length in thousands; we need to use code length up to 15, therefore the codewords for such length becomes GC_{250} and code length will be 3,750. The GC_1-GC_{250} can be seen in table III (appendix A). In this table, we generated codewords with length (i) equal to 15. For simplicity and since in [10]they generated 50 codewords with length 10, therefore we reused it but with length 15 and we labeled it from GC_1- GC_{50} in table III. While GC_{51} to GC_{250} has created which is our first contribution to the paper. In the Following steps we summarize our procedure that used to generate GC_{51} to GC_{250} of table III:

1- Since the minimum number of ones in a codeword of SD-4 is 3, also, the last position in the codeword should be zero which is mean the position of 10^{th} is zero (see [10]). Therefore, we set_ones at this position 10^{th} for codeword with length 15. For example, GC_{51}= [1 1 0 0 0 0 0 0 0 1 0 0 0 0 0]. We will refer to GC_{51} as (2+1) situation concerning the location of binary ones. This is beneficial to observe the cyclic versions of the codeword.

Since the SD-4 code is generated the next codeword by cyclic shifted, therefore to avoid similarity in produced codewords, we don’t use (1+2) since it produced the same GC_{51} during the cyclic.

2- Since we used code length 15, therefore we can produce codewords that avoided in [10], for example GC_{52} $_{=}$ [1 0 0 1 0 0 0 0 0 1 0 0 0 0 0] which is can’t be used in case length 10, because it was [1 0 0 1 0 0 0 0 0 1] which is similar to (2+1) during the cyclic.

3- We emphasized that we produced new versions that never existing before, in following are some examples (not all) of these versions: GC_{74} (1+1+2), GC_{148} (2+1+1), GC_{123} (1+1+2), GC_{148} (2+1+1).

Another emphasizing, we produced four places of ones that has never exist before, like; GC_{124}[1 0 1 0 0 1 0 0 0 0 0 1 0 0 0], GC_{141} (1+1+3+3), GC_{143} (1+1+4+1), GC_{144} (1+2+3+2), GC_{146} (1+2+3+3) and so on.

Now we configured the code SD-4 for length 3,900, to implement code SD-4 for long code length (ex. 8,192; 16,384 and 32,768) and for simplicity, we added zeros for all codewords GC1 - GC250, therefore to generate any codeword with j length we proposed to use the following equation:

$$G.C_j = \begin{vmatrix} G.C_1 \\ \vdots \\ \vdots \\ G.C_{250} \end{vmatrix} |Z_i| \qquad (1)$$

Where Z_i is the zeros rows with length i, and i is the integer number to represent codeword and given by:

$$i = \left\lceil DC_{SD-4} / L_{\max} \right\rceil \qquad (2)$$

Where DC_{SD-4} is the desired code length for SD-4 and L_{max} is the maximum number of the codeword that can be generated with codeword length. For example, to produce code lengths equal to 4,096 and 8,192; the values of i in

this case are equal to 17 and 32 respectively. In transmitter side of FSO system, the information bit stream has been encoded with SD-4 code, the input must be framed with respect to rows of SD-4(i.e. identify), that is,

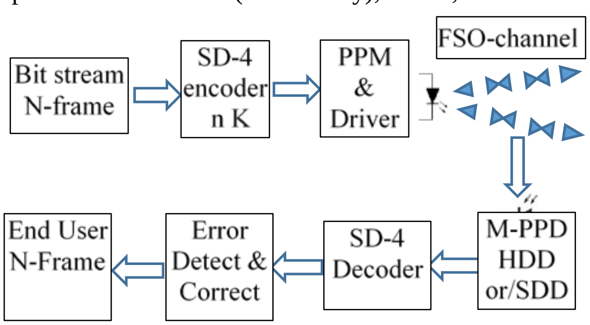

Figure 1: an illustration of SD-4 with Q-PPM for FSO communication system.

N frame = n, and the output of SD-4 is codeword with a constant Hamming distance of 4. Therefore, the codeword length is C (n, k, 4). The code word then has been mapped and modulated using Q-PPM. The modulation size is $\log_2(Q)$ and will be send through the optical channel, as shown in Figure (1).The statistical FSO channel model can be considered as follows:

$$y = \eta I x + n \qquad (3)$$

where η is the diode responsivity, x is the average power-modulated PPM signal, n is the noise that assumed as white Gaussian noise with zero mean and variance $N_0/2$, and I is the FSO channel gain which satisfies both attenuation (I_a) and fading (I_f) of the signal which expressed as $I = I_f I_a$. The fading under weak turbulence assumption is lognormal distribution with random variable (z) given by $I_f = e^z$, where z is a Gaussian random variable with mean μ_x and variance σ_x^2. The variance is affected by atmospheric parameters and obtained by $\sigma_R = 1.23 c_n^2 K^{7/6} d^{11/6}$, where c_n^2 is the refraction structure parameter index, d is the FSO channel length and K is the optical wave number expressed as $K = 2\pi/\lambda$, where λ is the wavelength.

The probability density function of I_f is shown in the following equation[1]:

$$p(I_f) = \frac{1}{h_f \sqrt{2\pi}\sigma_X} \exp\left(-\frac{1}{2\sigma_X^2}\left(\ln(h_f)+\mu_x\right)^2\right). \qquad (4)$$

To avoid the signal amplifying, we normalized the fading amplitude that implied $\mu_x = -\sigma_X^2$. The lognormal module is valid when the scintillation index (σ_I) is less than one(i.e. $0 \le \sigma_I < 1$), this assumption is true at weak turbulence [1]

4. Bits Detection and Correction for SD-4- Q-PPM

At the receiver side, the signal is faded by I_f and attenuated by I_a, the received signal is detected and demodulated (Q-PPD) by two techniques named hard and soft decisions. The hard decision for Q-PPM is as following [13]:

$$PPD_i \begin{cases} 1 & y_i > \frac{1}{2} \\ 0 & y_i < \frac{1}{2} \end{cases} \qquad (5)$$

In the soft decision, the Q-PPDM output is a block of bit sequence with length Q×N frame (reshape), and it will be decoded with SD-4 to obtain N frame that represents the information bit sequence. Log-likelihood ratios (LLR) has employed to search for the signaling endpoint [14]. For the MIMO case, N receivers are responsive to symbol q denoted as $\boldsymbol{r}_{n,m}$ (n=1,2,…,N; m=1,2,…,M), which are handled to decide the symbol reliabilities (q), (m=1,2,…,M) specified by the following [14]:

$$\lambda(m) = -\frac{\sum_{n=1}^{N}\left(r_{n,m} - \frac{\sqrt{E_s}}{Q}\sum_{q=1}^{Q} I_{n,q}\right)^2}{\sigma^2} - \frac{\sum_{n=1}^{N}\sum_{l=1,l\neq m}^{M} r_{n,l}}{\sigma^2} \qquad (6)$$

where Es is the symbol's energy of non-coded symbol in the electrical domain (no fading), (hence $Es = E_b \log_2 Q$, where E_b is bit energy). In case of point-to-point FSO connection is present, the FSO system becomes SISO. Therefore (N=Q=1), and Equation (6) can be simplified as follows:

$$\lambda(m) = -\frac{\left(r_m - \sqrt{E_s}I\right)^2 - \sum_{l=1,l\neq m}^{M} r_l}{\sigma^2} \quad (7)$$

The BER and bit reliabilities are determined from these symbol reliabilities by the following [15]:

$$L(c_i) = \log \frac{\sum_{c:c_i=0} \exp[\lambda(m)]\exp\left(\sum_{c:c_j=0,j\neq i} L_a(c_j)\right)}{\sum_{c:c_i=1} \exp[\lambda(m)]\exp\left(\sum_{c:c_j=0,j\neq i} L_a(c_j)\right)}. \quad (8)$$

After detection and decision steps in the demodulation with Q-PPM, the signal has been decoded by SD-4 decoder then it has corrected and delivered to the users.

Generally, there are two techniques for signal correction, one and two error correction. In case of two error correction, the system is complex therefore, one error correction is easy to perform by multiplying the received codeword by the transpose check parity matrix (H^T) of SD-4 decoder. The result is known as syndrome (S) and expressed as follows:

$$S(i) = C_i \otimes H^T \quad (9)$$

Where the error location determination is based on the identified location of ones of S(i) with respect to H^T,therefore, the correction is easily performed as follows:

$$r_{i,j} = 1 \otimes r_{i,j} \quad (10)$$

if and only if S(i) = H^T

Since our goal is developing then improving SD-4 code with a specific optical modulation technique ,namely, Q-PPM which is commonly used in FSO communication, therefore SD-4 code with different code lengths have been reconfigured.

Since the coding gain is an improvement in SNR of coded data with respect to uncoded data of such code length, therefore, this coding gain is defined as raw gain ($gain_{-rw}$) because the bandwidth (B.W) has not considered. Therefore, normalizing this coding gain ($gain_{-rw}$) with respect to B.W is referred as actual SNR gain ($gain_{-act}$) of code length i (i.e. throughput).

To find $gain_{-act}$ for each code length with index i of code SD_i-4, we used Shannon limit spectral efficiency b/s/HZ [16], and we reformulated it to be as follows:

$$gain_{i-act} = \frac{gain_{i-rw}}{2^{\eta_i} - 1} \quad (11)$$

where η is bandwidth (B.W) efficiency of the channel coding and defined as the ratio of information rate over B.W (i.e. Shannon limit on rate b/s) and in our case is given by:

$$\eta_i = R_i \frac{\log_2 Q}{Q}. \quad (12)$$

where $R_i = Rc_i BW_i$ Rc_i is the code SD-4 rate for length i, $B.W_i$ is the normalized B.W of code length i with respect to B.W of optimal code SD-4 gain in such channel.

5. R*esults and* discussion

We used MATLAB to simulate code SD-4 with FSO system**.** The used parameters in our results are listed in Table I. The analytic results are obtained by equations (11) and (12). Our results are obtained by analyzing the performance of different code lengths designed by code SD-4. To check (evaluate or test) our development; We compared the performance of the FSO communication system with and without using SD-4 code for different schemes Q- PPM. To approve our development; we compared the performance of SD-4 code with other coding techniques at FSO communication system. The simulation results for coded/uncoded data with Q-PPM is obtained from equations (5), and (8) for hard decision respectively. The error detection and correction are obtained by equations (9) and (10), respectively.

Table I: System Parameters used in computations

Parameter Name	***Type /Range***
Modulation	PPM
Order of PPM	2, 4, 8
Channel Type	Log-Normal
scintillation index (σ_I)	0.2, 0.5
Encoder/decoder	SD-4
Code length	1,024| 2,048| 4,096| 8,192| 16,384| 32,768

In Figure 2., we illustrate the FSO system performance with SD-4 code for different schemes modulation of pulse position modulation Q-PPM at a targeted bit error probability of BER = 10^{-6} with SD-4 code length 1024. The optimal code gain is obtained at BPPM and equal to 0.56 dB. For modulation scheme 4PPM, the coding gain is 0.45 dB, meanwhile, at scheme 8PPM the code gains slightly decreased and becomes 0.4 dB.

The $gain_{-rw}$ appeared first time for BPPM at SNR =9 dB, for 4PPM at SNR = 7dB and for 8PPM at SNR = 5 dB. However, the $gain_{-rw}$ of BPPM is found at the highest SNR of the above values, this $gain_{-rw}$ is growing up rapidly more than others at 4PPM and 8PPM toward BER = 10^{-6}. Therefore, the $gain_{-rw}$ of BPPM becomes the optimum among 4PPM and 8PPM at BER = 10^{-6} and below. Because the SD-4 code gain is the highest in BPPM among the other different schemes Q-PPM; therefore; the next analysis will based on BPPM.

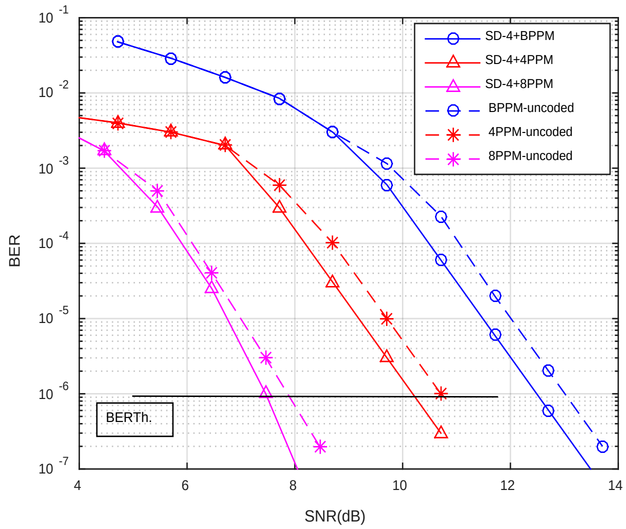

Figure 2: SD-4 code with 1024 code length and σ_I = 0.2 at different scheme Q-PPM

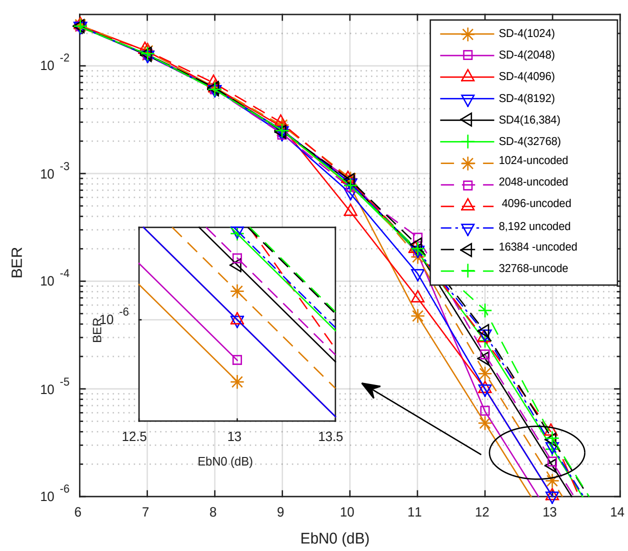

Figure 3: SD-4 code with different code length 1024 - 32,768 with BPPM and σI = 0.5.

In Figure 3, we illustrate the performance of SD-4 for different code lengths between 1,024 up to package lengths of SD-4 code which is 32,768, then analyze it to find the real (or actual) gain (gain$_{-act}$) in next steps. We analyze the code gains at targeted bit error rate probability of BER = 10^{-6}. The coding gain has been increased in direct proportion with respect to code length up to 4,096 and the code gain$_{-rw}$ has been maximized and to be equal to 0.56 dB at code length 4,096. After the code length 4,096 has been maximized up to max.code length 32,768, the gain$_{-rw}$ has been decreased compared with gain$_{-rw}$ at code length 4,096. Since this coding gain doesn't take into account the throughput of such channel of package code lengths, therefore, in next step we will normalize and analyze the coding gain (gain$_{-rw}$) with respect to the throughput of such channel, therefore the gain will be gain$_{-act}$.
In Table II, we normalized the throughput code gain of encoded data using Eq. (11) as following:
Since the LSD-4$_{(i+1)}$ throughput increases to double of LSD-4$_{(i)}$ (i=1,2) of such frequency (bit/s/Hz), furthermore, the optimum LSD-4 code gain is existing at code length 4096, therefore, to compare code gain for different code lengths (1024, 2048, 4000, 8,192, 16,384 and 32,768) with respect to code length 4096, the bandwidth efficiency in eq. (12) has been affected by factors (1/4,1/2,1, 4, 16 and 32) for each code length mentioned above respectively. Therefore, the normalized code gain (i.e. gain$_{-rw}$) with respect to the throughput of such channel is calculated by using eq. (11 &12) and the gain becomes gain$_{-act}$ and shown in table II.

Table II: The normalization of coding gain of SD-4 for all code lengths

Code length	**Code gain dB**	**gain$_{-act}$ bit/s/Hz**
SD$_{1024}$-4	0.47	0.031
SD$_{2048}$-4	0.53	0.18
SD$_{4096}$-4	0.56 (max.)	1
SD$_{8192}$-4	0.52	1.26
SD$_{16384}$-4	0.43	2.3
SD$_{32768}$-4	0.35	3.87 (max.)

In Figure 4, we illustrated the gain$_{-act}$ for code lengths SD$_{1024}$-4 until SD$_{32768}$-4. We found gain$_{-act}$ by analyzing the simulation results of Fig.3 and table II. This analysis has been done using eq. (11,12). In this figure, we calculated the gain$_{-act}$ with respect to optimum SD-4 code gain$_{-rw}$ in table II (i.e. SD$_{4096}$-4). Since the code SD$_{4096}$-4 has optimum gain$_{-rw}$, therefore we normalized all other gain$_{-rw}$ with respect to gain$_{-rw}$ of SD$_{4096}$-4. Accordingly, the gain$_{-act}$ of SD$_{32768}$-4 becomes the highest among all gain$_{-act}$ in our package of code lengths. This because the throughput of SD$_{32768}$-4 code is the highest even though the gain$_{-rw}$ is the lowest. Therefore, the SD$_{32768}$-4 code gain becomes 3.81 times more than the SD$_{4096}$-4 code which has optimum gain$_{-rw}$ and as shown in Figure 4. Clearly, the SD$_{i+1}$-4 code gain is higher than SD$_{i+1}$-4 code gain with respect to the throughput of such channel.Therefore, SD$_{i}$-4 code has been developed to very long code length.

For more affirmation, detailed comparisons have been accomplished by authors. These comparisons have clearly depicted in Figures 5 and 6.

In Figure5, to compare our results with other coding techniques results at FSO channel, we used the same

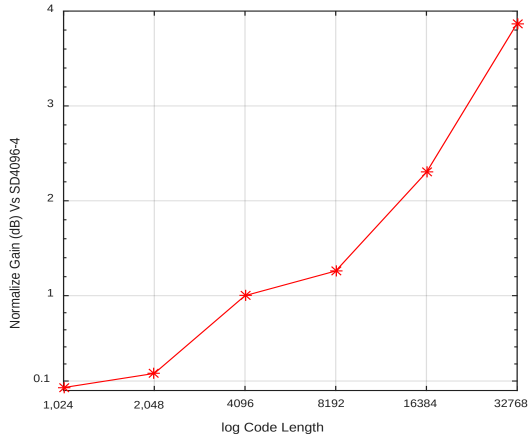

Fig 4: Normalized code gain with respect to code SD4096-4 gain using equations (11,12)

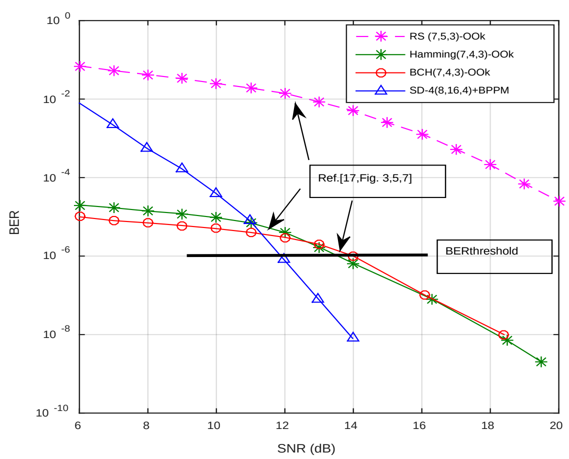

Fig 5: SD-4 normalization with respect to length code 7 compared with Hamming (7,4,3), BCH (7,5,3) and R-S codes.

values of FSO channel parameters that mentioned in [17], which has: turbulence induce fading C_n^2 = 3×10^-14 and 5 Km link distance which produces turbulence scintillation index equal 1.03. Since our goal is using the SD-4 at at high-speed data rate the Performance of code SD-4 at BER_{th} is better than the other codes like Reed-Solomon (RS), Hamming codes, and Bose, Chaudhuri, Hocquenghem (BCH) under lognormal channel of turbulence conditions. This performance of SD-4 code has0.8-1 dB advanced gain at $BER_{th}=10^{-6}$ compared with other coding techniques gains that mentioned previously.

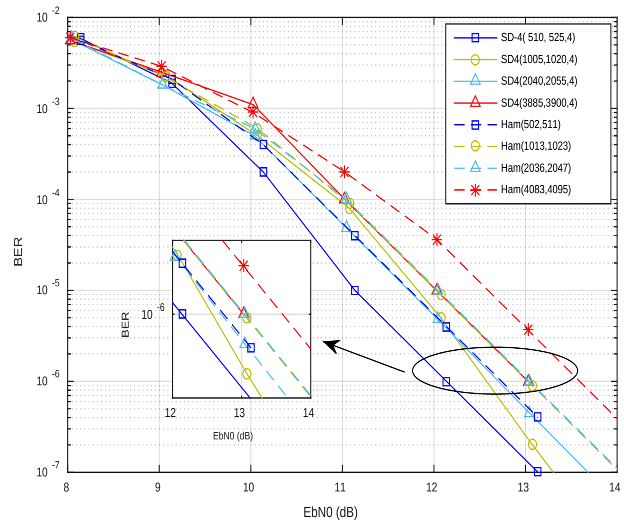

Figure 6: different code lengths comparison at BPPM between SD-4 and Hamming code

Finally, in Figure 6, we compared SD-4 with Hamming code at different code lengths. Our comparison between SD-4 and Hamming codes is based on threshold BER = 10^{-6} with BPPM modulation. The performance of SD-4 is better (higher) than Hamming code at all code lengths (512, 1020, 2055, and 3900) that utilized. The SD-4 code becomes worthier in gain and equal to 0.70, 0.55, 0.40, and 0.38 compared with Hamming code gain at each code lengths mentioned before and as shown in Figure 6.

6. Conclusion

In this study, we reconfigured code SD-4 from short code length to become very long code length. Our reconfiguration has been applied mainly in two steps; where long SD-4 code has accomplished with codeword length 15 in the first step and tabled in Appendix A, the very long code SD_{32768}-4 is obtained in the second step included formulas, code SD_{32768}-4 which is necessary to accommodate the requirement of LDPC coding. The SD_{32768}-4 code mitigates the high-speed encoding/decoding with Q- PPM modulation for an optical communication system with different varsions of PPM namely: BPPM, 4PPM, and 8PPM. At SD_{4096}-4 code of 4096 length, the optimum gain has been obtained and equal to 0.56 dB.

The SD-4 codes performance based on OOK modulation has superior gain (0.8-1) dB compared with the other coding techniques; RS, Hamming and BCH coding. In this paper, additional comparison has been done between different lengths of SD-4 codes based on BPPM which produced advanced net gains equal to 0.70, 0.55, 0.40, and 0.38 dB.

Authors' information

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Appendix A: table III to generate GC_1- GC_{250} codewords for length 15, Then generate code SD-4 length with 32,186 by using eq. (1 &2)

GC1:[1 1 1 0 0 0 0 0 0 0 0 0 0 0 0]	GC64:[1 1 0 0 1 0 1 0 0 1 0 0 0 0 0]	GC127:[1 1 0 0 1 0 0 0 0 1 0 0 0 0 0]	GC190:[1 1 1 0 1 1 1 0 0 0 1 0 0 0 0]
GC2:[1 1 0 1 0 0 0 0 0 0 0 0 0 0 0]	GC65:[1 1 1 1 1 1 0 0 0 1 0 0 0 0 0]	GC128:[1 1 0 0 0 1 0 0 0 0 1 0 0 0 0]	GC191:[1 1 1 0 1 1 0 0 1 0 1 0 0 0 0]
GC3:[1 1 0 0 1 0 0 0 0 0 0 0 0 0 0]	GC66:[1 1 1 1 1 0 0 1 0 1 0 0 0 0 0]	GC129:[1 1 0 0 0 0 1 0 0 0 0 1 0 0 0]	GC192:[1 1 1 0 1 1 0 0 1 0 0 1 0 0 0]
GC4:[1 1 0 0 0 1 0 0 0 0 0 0 0 0 0]	GC67:[1 1 1 1 0 0 0 1 1 1 0 0 0 0 0]	GC130:[1 1 0 0 0 1 0 0 0 0 0 1 0 0 0]	GC193:[1 1 1 1 1 1 1 1 0 1 0 0 0 0 0]
GC5:[1 1 0 0 0 0 1 0 0 0 0 0 0 0 0]	GC68:[1 1 1 1 0 0 1 0 1 1 0 0 0 0 0]	GC131:[1 1 0 0 0 0 0 1 0 0 0 1 0 0 0]	GC194:[1 1 1 1 1 1 1 1 0 0 1 0 0 0 0]
GC6:[1 1 0 0 0 0 0 1 0 0 0 0 0 0 0]	GC69:[1 1 1 1 0 1 0 0 1 1 0 0 0 0 0]	GC132:[1 0 1 0 0 0 1 0 0 0 0 1 0 0 0]	GC195:[1 1 1 1 1 1 1 1 0 0 0 1 0 0 0]
GC7:[1 1 1 1 1 1 0 0 1 0 0 0 0 0 0]	GC70:[1 1 1 0 1 1 1 0 0 1 0 0 0 0 0]	GC133[1 0 1 0 0 0 0 1 0 0 0 1 0 0 0]	GC196[1 0 0 0 1 0 0 0 0 1 0 0 0 0 0]
GC8:[1 0 1 0 0 1 0 0 0 0 0 0 0 0 0]	GC71:[1 1 1 0 1 1 1 0 1 1 0 0 0 0 0]	GC134[1 0 1 0 0 0 0 0 0 0 1 1 0 0 0]	GC197[1 0 0 0 0 0 1 0 1 0 0 0 0 0 0]
GC9:[1 0 1 0 0 0 1 0 0 0 0 0 0 0 0]	GC72:[1 1 1 1 1 1 1 1 1 1 0 0 0 0 0]	GC135:[1 0 1 1 1 0 0 0 1 0 1 1 0 0 0]	GC198:[1 1 1 0 0 0 0 1 0 1 0 0 0 0 0]
GC10:[1 1 1 1 1 0 0 0 1 0 0 0 0 0 0]	GC73:[1 0 0 1 1 1 1 0 1 0 0 1 0 0 0]	GC136:[1 1 1 1 1 0 0 0 1 1 0 0 0 0 0]	GC199[1 1 0 0 0 0 1 1 0 0 0 1 0 0 0]
GC11:[1 1 1 1 1 1 1 1 1 0 0 0 0 0 0]	GC74:[1 0 0 1 0 0 0 0 1 1 0 0 0 0 0]	GC137:[1 1 1 0 1 1 0 1 0 0 1 1 1 0 0]	GC200[1 1 0 0 1 0 0 1 0 1 0 0 0 0 0]
GC12:[1 1 0 1 1 0 0 0 1 0 0 0 0 0 0]	GC75:[1 0 1 0 0 1 0 0 0 1 0 0 0 0 0]	GC138:[1 1 1 1 1 0 0 0 0 0 0 1 0 0 0]	GC201:[1 1 0 0 0 1 0 0 1 0 1 0 0 0 0]
GC13:[1 1 1 1 1 0 0 0 0 0 0 0 0 0 0]	GC76:[1 0 1 0 0 1 0 0 0 0 1 0 0 0 0]	GC139:[1 0 0 0 1 1 1 1 1 1 1 0 0 0 0]	GC202:[1 1 0 0 0 0 1 0 0 1 0 1 0 0 0]
GC14:[1 1 1 1 0 1 0 0 0 0 0 0 0 0 0]	GC77:[1 1 0 1 0 0 1 0 0 0 0 0 0 0 0]	GC140:[1 0 0 1 1 1 1 0 0 0 1 1 1 0 0]	GC203:[1 1 1 1 1 1 0 0 0 0 1 0 0 0 0]
GC15:[1 1 1 1 0 0 1 0 0 0 0 0 0 0 0]	GC78:[1 1 0 0 1 0 0 1 0 0 0 0 0 0 0]	GC141:[1 0 1 0 1 1 1 0 0 0 1 1 1 0 0]	GC204:[1 1 1 1 1 0 0 0 1 0 1 0 0 0 0]
GC16:[1 1 0 0 0 1 1 0 1 0 0 0 0 0 0]	GC79:[1 1 0 0 0 1 0 0 1 0 0 0 0 0 0]	GC142:[1 0 1 0 1 1 1 1 0 0 0 1 1 0 0]	GC205:[1 1 1 1 1 0 0 0 0 1 0 1 0 0 0]
GC17:[1 1 1 1 0 0 0 0 1 0 0 0 0 0 0]	GC80:[1 1 0 0 0 0 1 0 0 1 0 0 0 0 0]	GC143:[1 0 1 0 1 1 1 1 1 0 0 0 1 0 0]	GC206:[1 1 1 1 0 0 1 0 0 1 1 0 0 0 0]
GC18:[1 1 1 0 1 1 0 0 0 0 0 0 0 0 0]	GC81:[1 1 0 0 0 1 0 0 0 1 0 0 0 0 0]	GC144:[1 0 1 1 0 1 1 1 0 0 0 1 1 0 0]	GC207:[1 1 1 1 0 0 0 1 0 0 1 1 0 0 0]
GC19:[1 1 1 0 0 1 1 0 0 0 0 0 0 0 0]	GC82:[1 1 0 0 0 0 0 0 1 0 1 0 0 0 0]	GC145:[1 1 1 1 1 0 1 1 0 0 0 1 1 0 0]	GC208:[1 1 1 0 0 1 1 1 0 1 1 0 0 0 0]
GC20:[1 1 1 0 0 0 1 1 0 0 0 0 0 0 0]	GC83:[1 0 1 0 0 0 1 0 0 1 0 0 0 0 0]	GC146:[1 0 1 1 0 1 1 1 0 0 1 1 1 0 0]	GC209:[1 1 1 0 0 0 0 1 1 1 0 1 1 0 0]
GC21:[1 1 1 0 0 0 0 1 1 0 0 0 0 0 0]	GC84:[1 0 1 0 0 0 0 1 0 0 1 0 0 0 0]	GC147:[1 1 1 1 0 0 1 0 0 0 0 1 0 0 0]	GC210:[1 1 1 1 1 1 1 1 1 0 1 0 0 0 0]
GC22:[1 1 1 0 1 0 1 0 0 0 0 0 0 0 0]	GC85:[1 0 1 0 0 0 0 0 1 1 0 0 0 0 0]	GC148[1 1 0 1 0 0 0 0 0 0 0 1 0 0 0]	GC211:[1 1 1 1 1 1 1 1 1 0 0 1 0 0 0]
GC23:[1 1 1 0 1 0 0 1 0 0 0 0 0 0 0]	GC86:[1 1 1 1 1 0 1 0 0 0 0 0 0 0 0]	GC149:[1 1 1 1 0 0 0 0 1 0 0 1 0 0 0]	GC212:[1 1 1 0 0 0 0 1 1 0 0 1 0 0 0]
GC24:[1 1 1 0 1 0 0 0 1 0 0 0 0 0 0]	GC87:[1 1 1 1 1 0 0 1 0 0 0 0 0 0 0]	GC150:[11 1 1 0 0 0 1 0 0 0 1 0 0 0]	GC213:[1 0 0 0 0 0 1 0 0 0 0 1 0 0 0]
GC25:[1 1 1 0 0 1 0 1 0 0 0 0 0 0 0]	GC88:[1 1 1 0 1 1 1 0 1 1 1 0 0 0 0]	GC151:[1 1 1 1 0 1 0 0 0 0 0 1 0 0 0]	GC214:[1 0 1 0 0 0 0 0 0 0 0 1 0 0 0]
GC26:[1 1 1 0 0 1 0 0 1 0 0 0 0 0 0]	GC89:[1 1 1 1 1 0 0 0 0 1 0 0 0 0 0]	GC152:[1 1 1 1 0 0 1 1 0 0 0 1 0 0 0]	GC215:[1 0 0 0 0 0 0 1 0 0 0 1 0 0 0]
GC27:[1 1 1 0 0 0 1 0 1 0 0 0 0 0 0]	GC90:[1 0 1 1 1 1 1 1 1 0 0 0 0 0 0]	GC153:[1 1 1 0 0 0 0 0 0 1 1 0 0 0 0]	GC216:[1 1 1 0 0 0 0 1 0 0 0 1 0 0 0]
GC28:[1 1 0 1 1 0 1 0 0 0 0 0 0 0 0]	GC91:[1 0 0 1 1 1 1 0 1 1 1 0 0 0 0]	GC154:[1 1 1 1 0 0 0 0 0 0 1 1 0 0 0]	GC217:[1 1 1 0 0 0 0 0 1 0 0 1 0 0 0]
GC29:[1 1 0 1 1 0 0 1 0 0 0 0 0 0 0]	GC92:[1 0 1 0 1 1 1 0 1 1 1 0 0 0 0]	GC155:[1 1 1 0 0 1 0 0 0 1 1 0 0 0 0]	GC218:[1 1 1 0 0 0 0 0 0 1 0 1 0 0 0]
GC30:[1 1 0 0 1 1 0 0 1 0 0 0 0 0 0]	GC93:[1 0 1 0 1 1 1 1 0 1 1 0 0 0 0]	GC156:[1 1 1 0 0 0 0 1 1 0 1 1 0 0 0]	GC219:[1 1 0 0 1 1 0 0 0 0 1 0 0 0 0]
GC31:[1 1 0 0 1 1 0 1 0 0 0 0 0 0 0]	GC94:[1 0 1 0 1 1 1 1 1 0 1 0 0 0 0]	GC157:[1 1 0 0 0 0 0 1 1 0 1 1 0 0 0]	GC220:[1 1 0 0 0 0 1 1 0 0 1 0 0 0 0]
GC32:[1 1 0 0 0 0 0 0 1 0 0 0 0 0 0]	GC95:[1 0 1 1 0 1 1 1 0 1 1 0 0 0 0]	GC158:[1 1 0 0 0 0 1 1 0 1 1 0 0 0 0]	GC221:[1 1 0 0 0 0 0 1 1 0 1 0 0 0 0]
GC33:[1 1 0 1 0 0 1 0 1 0 0 0 0 0 0]	GC96:[1 1 1 1 1 1 1 1 0 1 1 1 0 1 0]	GC159:[1 1 0 0 0 1 1 0 1 1 0 0 0 0 0]	GC222:[1 1 0 0 0 1 1 0 0 0 0 1 0 0 0]
GC34:[1 1 0 1 0 1 0 1 0 0 0 0 0 0 0]	GC97:[1 0 1 1 0 1 1 1 0 0 1 1 0 0 0]	GC160:[1 1 0 1 0 1 0 0 0 0 1 1 0 0 0]	GC223:[1 1 0 1 0 0 0 1 0 0 0 1 0 0 0]
GC35:[1 1 0 1 0 1 0 0 1 0 0 0 0 0 0]	GC98:[1 1 0 0 0 0 0 0 0 0 1 0 0 0 0]	GC161:[1 1 0 1 0 0 1 0 0 0 1 1 0 0 0]	GC224:[1 1 0 1 0 0 0 0 0 1 0 1 0 0 0]
GC36:[1 1 1 1 0 1 0 1 1 0 0 0 0 0 0]	GC99:[1 1 0 0 0 0 0 0 0 0 0 1 0 0 0]	GC162:[1 1 0 0 1 0 1 0 0 1 1 0 0 0 0]	GC225:[1 1 0 1 0 0 0 1 0 0 1 0 0 0 0]
GC37:[1 1 0 0 1 0 1 0 1 0 0 0 0 0 0]	GC100[1 0 0 1 0 0 0 0 0 0 1 0 0 0 0]	GC163:[1 1 1 1 1 1 0 1 1 0 0 0 0 0 0]	GC226:[1 1 0 1 0 0 0 0 1 0 1 0 0 0 0]
GC38:[1 1 1 1 1 1 1 0 0 0 0 0 0 0 0]	GC101:[1 0 0 1 0 0 0 0 0 0 0 1 0 0 0]	GC164:[1 1 1 1 1 1 0 0 1 1 0 0 0 0 0]	GC227:[1 1 0 0 1 0 0 1 0 0 0 1 0 0 0]
GC39:[1 1 1 1 1 1 0 1 0 0 0 0 0 0 0]	GC102:[1 1 1 1 0 0 0 0 0 0 1 0 0 0 0]	GC165:[1 1 1 1 1 1 0 0 0 1 1 0 0 0 0]	GC228:[1 1 0 0 1 0 0 0 0 1 0 1 0 0 0]
GC40:[1 1 1 0 1 1 1 0 1 0 0 0 0 0 0]	GC103:[1 1 1 1 0 0 0 0 0 0 0 1 0 0 0]	GC166:[1 1 1 1 0 1 1 0 0 0 1 1 0 0 0]	GC229:[1 1 0 0 0 1 0 1 0 0 0 1 0 0 0]
GC41:[1 1 1 1 1 0 1 1 0 0 0 0 0 0 0]	GC104:[1 1 1 0 0 0 0 0 0 0 1 1 0 0 0]	GC167:[1 1 1 1 0 0 0 0 1 1 0 0 0 0 0]	GC230:[1 1 0 0 0 0 0 1 0 1 0 1 0 0 0]
GC42:[1 1 1 1 1 0 0 1 1 0 0 0 0 0 0]	GC105:[1 1 1 0 1 0 0 0 0 0 0 1 0 0 0]	GC168:[1 1 1 0 1 1 1 0 0 1 1 0 0 0 0]	GC231:[1 1 1 1 1 0 0 0 1 0 0 1 0 0 0]
GC43:[1 1 1 1 1 0 1 0 1 0 0 0 0 0 0]	GC106:[1 1 1 0 0 1 0 0 0 0 0 1 0 0 0]	GC169:[1 1 1 0 0 1 1 1 0 1 0 0 0 0 0]	GC232:[1 1 1 1 0 1 0 0 1 0 0 0 0 1 0]
GC44:[1 1 1 1 0 1 1 1 0 0 0 0 0 0 0]	GC107:[1 1 1 0 0 0 1 0 0 0 0 1 0 0 0]	GC170:[1 1 1 1 1 1 1 1 1 1 1 1 0 0 0]	GC233:[1 1 1 1 0 1 0 0 0 1 0 0 1 0 0]
GC45:[1 1 1 1 0 0 1 1 1 0 0 0 0 0 0]	GC108:[1 1 0 1 1 0 0 0 0 0 1 0 0 0 0]	GC171:[1 1 1 1 1 0 1 0 0 1 0 0 0 0 0]	GC234:[1 1 1 1 0 0 1 0 0 0 1 1 0 0 0]
GC46:[1 1 1 1 0 1 1 0 1 0 0 0 0 0 0]	GC109:[1 1 0 0 1 1 0 0 0 0 0 1 0 0 0]	GC172:[1 1 1 0 0 0 0 0 0 0 0 1 0 0 0]	GC235:[1 1 1 1 0 0 0 0 1 0 1 1 0 0 0]
GC47:[1 1 0 1 0 0 0 1 0 0 0 0 0 0 0]	GC110:[1 1 0 0 0 1 1 0 0 0 1 0 0 0 0]	GC173:[1 1 0 0 1 0 0 0 0 0 0 1 0 0 0]	GC236:[1 1 1 0 0 1 1 1 0 0 0 1 0 0 0]
GC48:[1 1 1 1 1 1 0 0 1 0 0 0 0 0 0]	GC111:[1 1 0 1 0 1 0 0 0 0 0 1 0 0 0]	GC174:[1 1 0 0 0 0 0 0 1 0 0 1 0 0 0]	GC237:[1 1 1 0 0 0 1 1 1 0 0 1 0 0 0]
GC49:[1 1 1 0 1 1 0 0 1 1 0 0 0 0 0]	GC112:[1 1 0 1 0 0 1 0 0 0 1 0 0 0 0]	GC175:[1 1 0 0 0 0 0 0 0 1 0 1 0 0 0]	GC238:[1 1 1 0 0 0 0 1 1 1 0 1 0 0 0]
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GC51:[1 1 0 0 0 0 0 0 0 1 0 0 0 0 0]	GC114:[1 1 1 1 1 1 0 0 0 0 0 1 0 0 0]	GC177:[1 1 0 0 0 1 1 0 0 1 0 0 0 0 0]	GC240[1 1 1 0 1 1 0 0 0 1 0 1 0 0 0]
GC52:[1 0 0 1 0 0 0 0 0 1 0 0 0 0 0]	GC115:[1 1 1 1 1 0 0 1 0 0 0 1 0 0 0]	GC178:[1 1 1 0 0 1 1 0 0 0 1 1 0 0 0]	GC241:[1 1 1 0 1 0 1 1 0 0 0 1 0 0 0]
GC53:[1 0 0 1 0 0 0 0 1 0 0 0 0 0 0]	GC116:[1 1 1 1 0 0 0 0 0 1 1 1 0 0 0]	GC179:[1 1 1 0 0 0 1 1 0 0 1 1 0 0 0]	GC242:[1 1 1 0 1 0 0 1 1 0 0 1 0 0 0]
GC54:[1 1 1 1 0 0 0 0 0 1 0 0 0 0 0]	GC117:[1 1 1 1 0 1 1 0 0 0 0 1 0 0 0]	GC180:[1 1 1 1 0 0 0 1 0 0 0 0 0 0 0]	GC243:[1 1 1 0 1 0 0 0 1 1 0 1 0 0 0]
GC55:[1 1 1 0 0 0 0 0 1 1 0 0 0 0 0]	GC118:[1 1 1 1 0 1 0 0 0 0 1 1 0 0 0]	GC181:[1 0 1 1 0 0 1 0 0 0 1 0 0 0 0]	GC244:[1 1 0 1 0 0 0 1 1 0 1 1 0 0 0]
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GC61:[1 0 1 1 0 1 0 0 0 0 1 0 0 0 0]	GC124:[1 0 1 0 0 1 0 0 0 0 0 1 0 0 0]	GC187:[1 1 1 1 0 1 0 1 0 1 0 0 0 0 0]	GC250:[1 1 1 1 1 1 1 0 1 1 1 0 0 0]
GC62:[1 1 0 1 0 1 0 0 0 1 0 0 0 0 0]	GC125[1 0 0 1 0 0 1 0 0 0 0 0 1 0 0]	GC188:[1 1 1 1 0 1 0 1 0 0 1 0 0 0 0]	
GC63:[1 1 0 0 0 0 1 1 0 1 0 0 0 0 0]	GC126:[1 1 0 1 0 0 0 0 1 0 0 0 0 0 0]	GC189:[1 1 1 1 0 1 0 1 0 0 0 1 0 0 0]	