RoFSO System Based on BCH and RS Coded BPSK OFDM for 5G Applications in Smart Cities

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RoFSO System Based on BCH and RS Coded BPSK OFDM for 5G Applications in Smart Cities

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Abstract In recent years, the radio over free space optical (RoFSO) communication system has become a popular research topic in the field of 5G communication. Atmospheric turbulence typically degrades the performance of RoFSO system. Multiple input multiple output, aperture averaging, error correcting codes, and robust modulation are common mitigation techniques used to reduce the effects of atmospheric turbulence. In this paper, a Reed Solomon (RS) and Bose-Chaudhuri-Hocquenghem (BCH) coded binary shift keying (BPSK) orthogonal frequency division multiplexing (OFDM) based RoFSO system is proposed for 5G applications in smart cities. The average bit error rate (ABER) of the proposed system is investigated for various turbulence, weather, and pointing error cases. The ABER results for uncoded, BCH, and RS coded cases are compared. The results show that the BCH coded system outperforms the RS coded and uncoded systems in all turbulence regimes, weather conditions, and pointing error scenarios.

Keywords RoFSO · OFDM · BCH · RS · WOC

1 Introduction

One of the most important areas of research in wireless communication is radio over free space optical (RoFSO) communication. It offers huge data rate
(100Mb/s-10Gb/s) of communication over shorter ranges (few Kms) [1][2]. Other features include license-free spectrum, large bandwidth, electromagnetic interference immunity, and less power requirement [3][4]. Remote sensing, deep space networking, backhaul for wireless cellular networks, and disaster recovery are all major RoFSO applications. In recent times, the research has been focused on utilizing the RoFSO link as a resort for last mile problem, especially in urban and semi-urban areas.

The message signal is transmitted via the atmosphere in the RoFSO communication system. Thus, it led to different types of distortions in the optical signal. There are broadly three adverse effects on the RoFSO Communication system which are namely attenuation, scintillation, and scattering. Atmospheric attenuation mainly depends on the weather conditions. The scintillation effect is also known as turbulence-induced fading. Variation of pressure and temperature happens randomly in the atmosphere and due to that, air masses known as atmospheric turbulence formed. The optical beam that passes through the atmosphere comes in contact with these air masses and random fluctuations got introduced to it, this phenomenon is called the scintillation effect which degrades the system to large extent. Another aggravating factor is pointing error, which occurs when the transmitter and receiver in the system are misaligned.

The atmospheric turbulence effect has been defined using a variety of statistical models, including Lognormal, Negative exponential, GammaGamma [5], K-distribution, and M-distribution [6]. We have considered the M-distribution for atmospheric turbulence modeling in this paper.

Different mitigation methods, such as diversity, relay, multiple input multiple output, aperture averaging, modulation techniques, and error correcting codes (ECCs), are used to mitigate atmospheric turbulence and pointing error [7].

Earlier different modulation schemes have been used in RoFSO communication to mitigate the effect of atmospheric turbulence such as pulse position modulation (PPM), On-Off Keying (OOK), digital pulse interval modulation (DPIM), and pulse width modulation (PWM). The OOK modulation is most commonly used because of its simplicity and low cost [8], but it requires an appropriate adaptive threshold for optimal performance. PPM is used in [9] for FSO communication but it has low spectral efficiency. PWM requires lower peak power for transmission as compared to PPM and also has better spectral efficiency [10]. But PWM requires higher average power in comparison to PPM. DPIM has variable symbol length thus, categorized as an asynchronous modulation scheme [11]. DPIM has high possibility of error propagation during signal demodulation at the receiver. Also, Subcarrier intensity modulation (SIM) is employed in the FSO system, but this modulation scheme is limited by poor power efficiency [12]. To overcome these shortcomings Orthogonal frequency division multiplexing (OFDM) can be used, which we have considered in this paper. By combining with other modulation schemes binary phase shift keying (BPSK) also provides better performance [13].
To bring signals parallelly together in OFDM, mutually orthogonal sub-carriers separated at a specific frequency in the frequency domain are used. Using Fast Fourier Transformation at the transmitter terminal, orthogonality of sub-carriers is achieved. The effect of co-channel interference and intersymbol interference is eliminated by using OFDM with RoFSO links [14]. In [15], the bit error rate (BER) performance of OFDM based RoFSO is investigated. Here authors have used quadrature amplitude modulation (QAM). The effect of pointing error is also analyzed. To increase the data-carrying capacity of the FSO link multiplexing in intensity [16], phase [17], code [18], polarization [19], and wavelength [20] have been explored by researchers. In Ref. [21], the author investigates the performance of a Bose-Chaudhuri-Hocquenghem (BCH) coded FSO link with a Gamma-Gamma turbulence model. A bit error rate performance of a convolutional coded OFDM-based FSO system over a Gamma-Gamma turbulence channel is analysed in [22].

In this paper, we have considered the OFDM based RoFSO communication system with BPSK modulation having ECCs. We have compared the BER performance of BCH and Reed-Solomon (RS) coded RoFSO communication links with uncoded RoFSO links. We analyzed the performance of the proposed system over various weather, turbulence, scattering, and pointing error conditions.

The remainder of this work is structured as follows: The system model is presented in Section 2. The atmospheric channel model with pointing errors is described in Section 3. In Section 4, both ECCs BCH code and RS code details are discussed. The average bit error rate (ABER) of the proposed BPSK OFDM RoFSO system is derived for coded and uncoded cases in Section 5. In section 6 numerical results are presented and compared for uncoded, BCH coded and RS coded system with different turbulence conditions, weather conditions, scattering conditions, and different misalignments. The work’s conclusion has been outlined in Section 7.

2 System Model

OFDM is a multicarrier modulation scheme that breaks large data streams into smaller data streams and transmits them synchronously over narrowband subcarriers in the OFDM-FSO communication system. It uses other modulation schemes as its baseband, such as quadrature phase shift keying (QPSK), BPSK, QAM, and so on, and is transmitted at a high frequency. In this paper, we have used the BPSK modulation scheme with OFDM RoFSO communication. Here the coding technique is added to improve the reliability of the system. We have considered the BCH and RS codes as ECCs for RoFSO communication. After conversion at the transmitter, the OFDM signal can be expressed as [23].

$$S_{OFDM}(t) = \sum_{j=0}^{N-1} X_j e^{j(w_n + 2\pi f_c) t}$$  \hspace{1cm} (1)
Where \( w_n \) is the OFDM frequency, \( N \) is the total number of subcarriers, \( f_c \) is the carrier frequency, \( X_j \) is the complex transmitted data symbol, and \( T \) is the OFDM duration. The M-distributed FSO channel is used to transmit the \( S_{OFDM} \). Since the OFDM-based optical signal is transmitted through free space, it is attenuated and has noise added to it as it passes through the medium. The received power is given as \([24]\) at the receiving end.

\[
P_r(t) = P_t(t)I(t) + n(t)
\]  

Here \( I \) denote the channel attenuation due to path loss, atmospheric turbulence, and misalignment fading. Here \( n(t) \) is the additive white Gaussian noise (AWGN) which gets added while traveling.

The instantaneous carrier to noise plus distortion ratio (CNDR) for a specific OFDM subcarrier is measured at the receiver’s output as follows \([24]\).

\[
CNDR_n(I) = \frac{(m_n \rho P_0 I)^2}{2(N_0/T + \sigma_n^{2,IMD})}
\]

\( m_n \) represents the optical modulation index for each OFDM subcarrier and \( \rho \) is the photodetector responsivity.

Considering the IMD noise as Gaussian distributed \([24]\) then Eq. \([3]\) can be expressed as

\[
CNDR_n(I) \approx \frac{m_n^2 \rho^2 P_0^2 I^2}{2[(N_0/T)_{AV} + (\sigma_n^{2,IMD})_{AV}]}.
\]
Table 1 Different attenuation coefficients at 1550 nm [26]

| Weather condition | Attenuation $\sigma$ (dB/KM) |
|-------------------|-----------------------------|
| Very clear air    | 0.0647                      |
| Haze              | 0.7360                      |
| Light fog         | 4.2850                      |

Here the AV stands for the average value. From Eq. (4) the expected value of $CNDR_n$ can be expressed as

$$CNDR_n(I) \approx \frac{m_n^2\rho^2P_0^2(E[I])^2}{2[(N_0/T)_{AV} + (\sigma^2_{n,IMD})_{AV}]}$$  \hspace{1cm} (5)

Here $E[I]$ is the expected value of $I$.

3 Channel Model

We have considered the overall channel $I$ which includes the atmospheric path loss $I_l$, atmospheric turbulence $I_a$, and pointing error $I_p$.

The overall channel model $I$ is given by [25]

$$I = I_lI_aI_p$$  \hspace{1cm} (6)

3.1 Atmospheric loss

Beer-Lambert’s law [25] is used to model Atmospheric loss and it is given by

$$I_l = c.exp(-\sigma L)$$  \hspace{1cm} (7)

Here $L$ stands for the link length and $\sigma$ represents the attenuation coefficient. $\sigma$ takes different values depending upon the weather conditions and optical wavelength used. We’ve used a 1550 nm wavelength optical signal in this work. Table 1 [26] shows the various values of attenuation coefficient for different weather conditions. The length of the link is 1 km in this case.

3.2 Atmospheric turbulence induced fading

In this work, atmospheric turbulence in the FSO channel has been considered to be M distributed. According to this model at the receiver, there are three components; line of sight (LOS) contribution $U_L$, coupled to LOS contributions quasi-forward scattered component $U_S^C$, and scattered energy due to off-axis eddies $U_S^G$ [27]. The power of components $U_L$, $U_S^C$ and $U_S^G$ are $\Omega$, $2\rho b_0$ and $2(1-\rho)b_0$ respectively.
Here $\rho$ represents the coupling of power between the scattered component and LOS component. At $\rho = 0$ the coupling is minimum and at $\rho = 1$ it is maximum.

For the M-distribution turbulence model the probability density function (PDF) of the irradiance $I_a$ is given by [25]

$$f_{I_a}(I_a) = A \sum_{k=1}^{b} a_k I_a^{\alpha+1-k} K_{\alpha-k} \left( 2 \sqrt{\frac{\alpha\beta I_a}{\gamma\beta + \Omega}} \right)$$

where

$$A = \frac{2\alpha \frac{2}{\gamma+\frac{\beta}{2} \Gamma(a)}}{\gamma+\frac{\beta}{2} \Gamma(a)} \left( \frac{\gamma\beta + \Omega'}{\gamma\beta + \Omega'} \right)^{\beta+\frac{\gamma}{2}}$$

$$a_k = \frac{(\beta-1)}{(k-1)} \frac{(\gamma\beta + \Omega')^{1-k}}{k-1!} \left( \frac{\Omega'}{\gamma} \right)^{k-1} \left( \frac{\alpha}{\beta} \right)^{\frac{k}{2}}$$

and $\gamma = 2(1-\rho)b_0$

Here $\alpha$ is a scattering process positive parameter associated with the effective number of large-scale cells. $\beta$ is natural number, allowing PDF to follow the realistic observed data, resulting in a closed form representation [28].

The parameter $\Omega' = \Omega + 2\rho b_0 + 2\sqrt{2\rho b_0} \cos(\phi_A - \phi_B)$, which is the average power from the coherent contributions. $\phi_A$ represents the phase of the LOS component and $\phi_B$ represents the phase of coupled-to-LOS scatter components. The difference between $\phi_A$ and $\phi_B$ has been considered to be 90°.

3.3 Pointing Errors

Line of sight (LOS) communication is used by the FSO. As a result, the transmitter and receiver must be aligned. The performance of the FSO communication system is strongly affected by this alignment. Building sway, thermal expansion, and wind loads are some of the reasons for the misalignment between transmitter and receiver in this system [29], [30], [31]. Beckmann and Rayleigh’s distributions have been used to model the pointing errors. For pointing error the irradiance PDF distribution is given as [32]

$$f_{I_p} = g^2 A_0^2 I_p^2 \text{, for } 0 \leq I_p \leq A_0$$

Where $A_0 = [\text{erf}(\nu)]^2$ is the fraction of total received optical power. $\nu$ is given by, $\nu = \sqrt{\frac{2}{\pi}} \frac{a}{w_z}$. Here $a$ is the radius of the receiver. The transmitted optical signal has a beam width of $w_z$ at the distance $L$.

Effective beam width at the receiver is given by

$$w_{zeq} = \left[ \frac{\sqrt{\pi \text{erf}(\nu)} w_z^2}{2e^{-\nu^2}} \right]^{\frac{1}{2}}$$
Here $g = \frac{w_{\text{ave}}^2}{\sigma}$ is the ratio between the effective beam width and the jitter standard deviation $\sigma$.

3.4 Combined Channel model

The overall channel model for $I$ is given as [25]

$$f_I(I) = \int f_{I/I_a}(I/I_a)f_{I_a}(I_a)dI_a$$  \hspace{1cm} (11)

Here $f_{I/I_a}(I/I_a)$ is conditional probability for considered turbulence state $I_a$.

It is given as

$$f_{I/I_a}(I/I_a) = \frac{1}{I_aI_l} f_{I_a/I} \left(\frac{I}{I_aI_l}\right)$$

$$= g^2 \frac{A}{A_0^2 I_a I_l} \left(\frac{I}{I_aI_l}\right)^{g^2-1}$$ \hspace{1cm} (12)

for $0 \leq I \leq A_0 I_a I_l$

by substituting Eqs. (8) and (12) in Eq. (11) we have

$$f_I(I) = g^2 A \left(\frac{I}{A_0 I_l}\right)^{g^2-1} \times$$

$$\sum_{k=1}^{b} a_k \int_{I/I_aI_0}^{\infty} I_a^{n+k-1-g^2} K_{n-k} \left(2 \sqrt{\frac{\alpha \beta I_a}{\gamma \beta + \Omega}}\right) dI_a$$ \hspace{1cm} (13)

Overall channel model $f_I(I)$ obtained as below [25]

$$f_I(I) = g^2 A I_l^{-1} \frac{\beta}{2} \sum_{k=1}^{b} a_k B^{\frac{n+k}{2}}$$

$$G_m^0,0 \left( I \left| BA_0 I_l \frac{1+g^2}{g^2, \alpha, k} \right. \right)$$ \hspace{1cm} (14)

where $B = \frac{\Omega + \gamma \beta}{\alpha \beta}$ and $G_p^m,n[.]$ is meijer G function

4 Error correcting codes

An appropriate channel code must be used to identify and correct errors caused by the channel. In this paper, we looked at the BCH code and the RS code.
4.1 BCH Code

BCH codes come under the category of binary cyclic ECCs which is defined over the Galois field (GF). It can correct multiple bits in error [34].

It is a type of linear block code that increases the signal’s redundancy. In this case, k information bits are converted into an n-bit codeword with n-k redundant bits. The code rate (R), which is given by k/n, defines redundancy. In our work, we used a code rate (R) of less than one-third. We used the BCH code \( n = 31, k = 11 \). These BCH codes are ECCs with t bits. These codes have a bit length of \( n = 2^m - 1 \) in the GF \((2^m)\), where m is a positive integer \((m \geq 3)\). The field components are represented by \( \{0, 1, \alpha, \alpha^2, \ldots, \alpha^{2m-2}\} \). Here \( \alpha \) is the basic element in the field GF \((2^m)\) [35] [36]. There are different conjugacy classes in which these elements are segregated. A minimal polynomial is associated with every conjugacy class. A BCH code’s generator polynomial is realised by finding the least common multiple of the minimal polynomials associated with the elements \( \alpha^b, \alpha^{b+1}, \ldots, \alpha^{b+\delta-2} \), where \( b \) is an integer \( \geq 1 \) and \( \delta \) is design distance, which equals \( 2t+1 \). The generator polynomial is computed as follows,

\[
g(x) = \text{LCM} \{M_b(x), M_{b+1}(x), \ldots, M_{b+\delta-2}(x)\} \tag{15}
\]

Here \( M_i(x) \) represents the minimal polynomial of the \( i^{th} \) conjugacy class. Components of a particular conjugacy class have the same minimal polynomial. Various conjugacy classes consist of different minimal polynomials which are presented in Table 2 [33]. By computing the product of minimal polynomial we get the generator polynomial as

\[
g(x) = 1 + x^2 + x^4 + x^6 + x^7 + x^9 + x^{10} + x^{13} + x^{17} + x^{18} + x^{20} \tag{16}
\]
Using the generator polynomial \( g(x) \), the generator matrix \((G_{11 \times 31})\) is estimated. The operation \( c_{1 \times 31} = s_{1 \times 11}G_{11 \times 31} \) is used to encrypt the data. This BCH-encoded data is modulated with an optical signal before being sent through the atmosphere.

The BCH encoder/decorder is shown in Figure 2. The message bits are encoded using the BCH encoder and sent via the RoFSO channel as \( m \). The BCH decoder receives the received message bits \( y \) and evaluates them as \( m' \). As shown in Fig 2 [21], there are three steps involved in decoding BCH code. The syndrome is computed first, and then the error position polynomial from the syndrome polynomial is developed using the Berlekamp-Massey algorithm. We get the error locations by finding the roots of the error location polynomial. After correcting the errors, an estimated information word is generated [34].

4.2 Reed-solomon coding and decoding

RS code has great burst error correcting capability [37]. Sometimes in FSO communication, we encounter burst errors [38]. So, this RS ECC has been proposed to improve the integrity of information transmission.

The generator polynomial of RS-code having \( n\)-length over Galois Field GF\((q)\), with error correcting capabilities \( t \) symbol is given by, \( g(x) = (x-a^b)(x-a^{b+1})... (x-a^{b+\delta-2}) \), where \( \alpha \) is a primitive element of the GF\((P^m)\), \( b \geq 0 \) is any real positive integer and \( \delta = 2t + 1 \). The code-word of \( n\)-length is depicted in polynomial as \( c(x) = c_0 + c_1x + c_2x^2 + ...c_{n-1}x^{n-1} \) and it has one to one correspondence to the message polynomial \( s(x) = s_0 + s_1x + s_2x^2 + ... + s_{k-1}x^{k-1} \).

In this work, we have taken \( n=63 \) and \( k=51 \) RS code over the field GF \((2^6)\) for error detection/correction. Each symbol of the polynomial codeword is converted into 6 tuples of binary bits and transmitted via the FSO channel. At the receiving end, the incoming bits are converted into 6-bit symbols lying in the field GF \((2^6)\). For ascertaining the location of induced errors Berlekamp-Massy and Chien algorithm is used and for finding error magnitudes, Forney's algorithm is used.

5 Analytical BER Evaluation

Average bit error rate (ABER) for BPSK OFDM FSO system is given as [39]

\[
ABER = \int_0^\infty P_I(I)f_I(I)\,dI \tag{17}
\]

Conditional BER for BPSK OFDM system is given by [40]

\[
P_I(I) = \frac{1}{2}erfc\left(\frac{E_b}{\sqrt{N_0}}\right) \tag{18}
\]
Eq. 18 can be approximated as [22]

\[
P(I) = \frac{N-1}{\log_2(2)} \sum_{j=0}^{N-1} erf c \left( \sqrt{CNDR_j(I)} \sin \left( \frac{\pi}{2} \right) \right) \tag{19}
\]

Here \( N \) is number of subcarriers, \( CNDR_j \) is carrier to noise plus distortion ratio, \( E_b/N_0 \) is bit energy to noise ratio. After substituting Eq. 14 and Eq. 19 in Eq. 17, we get ABER as

\[
ABER = \frac{N-1}{\log_2(2)} \sum_{j=0}^{N-1} \int_0^{\infty} \left[ erf c \left( \sqrt{CNDR_j(I)} \right) \right] \times
\]

\[
\frac{g^2 A}{2} \sum_{k=1}^{\beta} I^{-1} \left( a_k B^{\alpha+k} \right) \times
\]

\[
G_{1,3}^{3,0} \left( \frac{I}{BA_0 I_l} \right) \left| 1 + g^2, \alpha, k \right) dI \tag{20}
\]

In Eq. 20 replaced the erf c(.) with the suitable Meijer G function as given in [22]. After solving finally we get ABER as

\[
ABER = \frac{N-1}{\log_2(2)} \sum_{j=0}^{N-1} \frac{1}{\sqrt{\pi}} \frac{g^2 A}{2} \sum_{k=1}^{\beta} \left( a_k B^{\alpha+k} \right) Z \tag{21}
\]

Where

\[
Z = G_{4,3}^{2,3} \left( \sqrt{CNDR_j BA_0 I_l} \right) \left| \begin{array}{c} 1 - g^2, 1 - \alpha, 1 - k, 1 \\ 0, 1/2, -g^2 \end{array} \right)
\]

5.1 BCH Code

The upper bound on the probability of decoding error \( p_d \) with a \((n,k,t)\) BCH code over GF(\(2^m\)) having \( t \) symbol error correcting capability is given by [33].

\[
P_d \leq \sum_{i=t+1}^{n} \binom{n}{i} P^i (1 - P)^{n-i} \tag{22}
\]

Where \( n \) is the block length, and \( P \) is the binary symmetric channel transition probability.
5.2 RS Code

An error occurs when the decoded codeword is not same as the transmitted codeword. The probability of error for RS code is given by [37]

\[
P_d \leq \sum_{i=t+1}^{n} \binom{n}{i} P_s^i (1 - P_s)^{n-i} \tag{23}
\]

Here \( P_d \) is the upper bound BER associated with non-binary RS code, \( t \) is the symbol error correcting capability. \( P_s \) is symbol error probability and, code rate \( r=k/n \).

6 Result and Discussion

The analytical BER results of the OFDM RoFSO system as a function of CNDR are described in this section. The optical signal wavelength is considered to be 1.55 \( \mu \)m. We considered 5 cm radius of the aperture of the receiver. We have taken different values of the refractive index structure parameter \( C_n^2 \) for different turbulence conditions. \( C_n^2 \) value is taken as \( 2 \times 10^{-14} \) m\(^{-2/3} \) for
weak turbulence, $4 \times 10^{-14} \, m^{-2/3}$ for moderate turbulence and $8 \times 10^{-14} \, m^{-2/3}$ for strong turbulence. Different misalignment has been taken as in [41].

Fig. 3 illustrates the BER performance comparison between uncoded, BCH coded and RS coded RoFSO system with various turbulence conditions. For plotting Fig. 3 we have considered very clear air condition. In all three turbulence condition, it is clear that the BCH coded RoFSO system outperform the uncoded and RS coded systems. For attaining BER of $10^{-6}$, BCH coded RoFSO system requires 5 dB CNDR in weak turbulence condition but the uncoded RoFSO system requires more than 40 dB CNDR and RS Coded system require 17 dB CNDR. From Fig. 3, we can conclude that for weak turbulence RS coded RoFSO system has performed better than the uncoded system but for strong turbulence condition, RS coded system has performed worse than the uncoded system.

Fig. 4 illustrates the BER performance comparison between uncoded, BCH coded and RS coded RoFSO system with various scattering conditions. For plotting Fig. 4 we have considered very clear air condition and weak turbulence condition. It is visible that the BCH-coded RoFSO system has performed better than the uncoded and RS coded RoFSO system in moderate ($\rho=0.5$) and minimum scattering ($\rho=0.95$) conditions. For maximum scattering ($\rho=0$)

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**Fig. 4** Average BER performance comparison of BCH and RS coded with uncoded OFDM RoFSO communication with different scattering conditions (different $\rho$ values).
condition the BCH coded RoFSO system performed worse than the uncoded system for less than 15 dB CNDR, but if the system’s CNDR is better than 15 dB then BCH coded system performs better than the uncoded system. It is clear from the graph that for moderate ($\rho=0.5$) and maximum scattering ($\rho=0$) RS coded RoFSO system has performed worse than the uncoded system. Only for the minimum scattering ($\rho=0.95$) RS coded RoFSO system performs better than the uncoded system.

Fig. 5 shows the BER performance comparison between uncoded, BCH coded and RS coded RoFSO system with various weather conditions. For plotting Fig. 5 weak turbulence is considered. For all three weather conditions, the BCH coded RoFSO system performs better than the uncoded and RS coded system. For achieving BER of $10^{-6}$ in fog weather condition BCH coded RoFSO system requires 15 dB CNDR but the uncoded system requires more than 40 dB CNDR and RS coded system requires 27 dB CNDR. From the Fig. 5 it is concluded that for clear and haze weather conditions the RS coded RoFSO system performs better than the uncoded system. For the fog weather condition RS coded system performs better than the uncoded system for more than 12 dB CNDR.

Fig. 6 shows the BER performance comparison between uncoded, BCH coded and RS coded RoFSO system with various Pointing error conditions. In
Fig. 6 Average BER performance comparison of BCH and RS coded with uncoded OFDM RoFSO communication with different pointing errors.

Fig. 6 weak misalignment and enhanced misalignment represent weak pointing error and strong pointing error respectively. From Fig. 6 it is clear that for different misalignments BCH coded RoFSO system has performed better than the uncoded and RS coded system. BER of $10^{-7}$ is achieved for the enhanced misalignment of BCH coded RoFSO system with 8 dB CNDR and the same BER, for the uncoded system is achieved with 40 dB CNDR while RS coded system requires 20 dB CNDR for the same BER.

7 Conclusion

In this work, we investigated the BER performance of the BPSK RoFSO system with two coding techniques BCH and RS. The average BER expression is obtained as a closed form equation in terms of the Meijer-G function. BCH is found to be a better coding technique for BPSK OFDM based RoFSO system. we have considered different weather conditions and turbulence conditions for comparing both coding techniques.
Declartation

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Conflict of interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Availability of Data and Material

Not Applicable

Code Availability

Not Applicable

Ethics Approval

Not Applicable

Consent to Participate

Not Applicable

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Not Applicable

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