Application and Analysis of Performance of DQPSK Advanced Modulation Format in Spectral Amplitude Coding OCDMA

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ABSTRACT

SAC (Spectral Amplitude Coding) is a technique of OCDMA (Optical Code Division Multiple Access) to encode and decode data bits by utilizing spectral components of the broadband source. Usually OOK (ON-Off-Keying) modulation format is used in this encoding scheme. To make SAC OCDMA network spectrally efficient, advanced modulation format of DQPSK (Differential Quadrature Phase Shift Keying) is applied, simulated and analyzed. m-sequence code is encoded in the simulated setup. Performance regarding various lengths of m-sequence code is also analyzed and displayed in the pictorial form. The results of the simulation are evaluated with the help of electrical constellation diagram, eye diagram and bit error rate graph. All the graphs indicate better transmission quality in case of advanced modulation format of DQPSK used in SAC OCDMA network as compared with OOK.

Key Words: **Optical Code Division Multiple Access Network, Spectral Amplitude Coding, m-sequence, Differential Quadrature Phase Shift Keying.**

1. INTRODUCTION

Spectral efficiency is an important measure of the performance of the networks [1]. It can be described as the density of the information bits in spectral domain, i.e. bits/ Hz. [2]. Because of the cost involved in transmitting information bits, it is considered important to send the data in a cost effective manner. Spectral efficiency is an assessment of cost efficiency of the information transmission [3].

It can be defined by the relation [1]:

$$\eta = \frac{N_{ber} R_b}{B} \tag{1}$$

Where η is the spectral efficiency, N_{ber} is the number of simultaneous users emitting at a bit rate R_b at a certain BER and B is the optical bandwidth occupied by the system.

In optical communication systems, lower order modulation format of OOK is normally used. This results in lower efficiency of the networks [4-6]. To improve the spectral efficiency of OCDMA networks advanced modulation formats are required to be adopted such as DPSK and DQPSK [7]. In this article DQPSK format is taken for achieving better spectral efficiency as compared with OOK.

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In OCDMA networks, an important source of noise is MAI (Multi Access Interference) [8]. It is the type of signal degradation. It occurs when signals from neighboring users are simultaneously transmitted and cause interference in the information signal for the intended subscriber. In this environment, all users at receiving end receive all the signals from the all active users from the transmitting end. The signal for the intended receiver is matched and recovered by the decoder. In this process of sifting the signals, all the other undesired signals become noise producing MAI.

In OCDMA networks, spectral amplitude coding scheme is considered as an effective mechanism to reduce the effects of MAI when it employs the OCDMA codes with good cross-correlation properties [9].

In this article, scheme of SAC used in OCDMA is described briefly. Then a small description about m-sequence codes is presented. After that DQPSK modulation format is narrated and its application in SAC-OCDMA is described. In the next section, simulation setup is detailed. In the last part, results and conclusion are given.

1.1 Spectral Amplitude Encoding

In SAC, the number of the frequency bins are made equal to the length of the code. The code is said to have ideal in-phase cross-correlation if cross-correlation $\lambda=1$. In this encoding technique, spectral codes are spread in the wavelength domain as shown in Fig. 1.

A spectral code (N, w, λ) is expressed as $\{c_1, c_2, \ldots, c_N\}$ where $c_j \in \{0,1\}$. N is the code length, w is the weight of the code and λ is the in-phase cross correlation. The properties of SAC codes are described below:

- All the SAC codes have w pulses and therefore w wavelengths. The (N-w) wavelengths have no pulses.

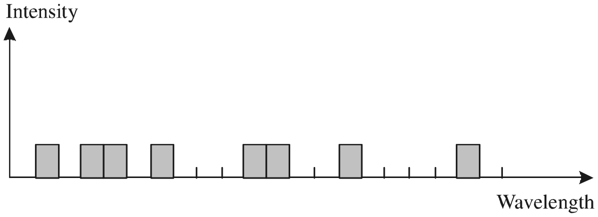


FIG. 1. SCHEME OF SPECTRAL AMPLITUDE CODING

For any two codes of the SAC family, there are only λ common elements. For example two code words $c_a=\{c_a(0), c_a(1),\ldots,c_a(N-1)\}$ and $c_b=\{c_b(0), c_b(1),\ldots,c_b(N-1)\}$ have only λ common elements as per following relation:

$$\Phi_{C_a,C_b} = \sum_{i=0}^{N-1} C_a(i)C_b(i) = \begin{cases} w & if\ a=b \\ \lambda & if\ a \neq b \end{cases} \quad (2)$$

The same way correlation between complementary of c_a with c_b can be defined as:

$$\Phi_{\overline{C_a},C_b} = \sum_{i=0}^{N-1} \overline{C_b}(i)C_b(i) = w - \Phi_{C_a,C_b} = \begin{cases} 0 & if\ a=b \\ w-\lambda & if\ a \neq b \end{cases} \quad (3)$$

The ratio (α) between the optical signals at the two receiving branches at the receiving end is set in such a manner that the MAI is eliminated. The ratio can be defined as $\lambda/(w-\lambda)$. The cancellation can be given by the following expression:

$$(\Phi_{C_a,C_b}) - \alpha(\Phi_{\overline{C_a},C_b}) = \lambda - \frac{\lambda}{w-\lambda}(w-\lambda) = 0 \quad (4)$$

The SAC scheme was implemented by Kavehrad and Zaccarin [10]. They used balanced receiver and m-sequence and Hadamard codes were utilized for encoding and decoding.

Commonly used SAC structure is depicted in Fig. 2.As shown in this diagram (Fig. 2), spectral encoder receives broadband signal to slice it into spectral components and a pulse with a particular combinations of wavelengths is sent when data bit "1" is received. On "0" bit nothing is sent because OOK is used in general. But this modulation has the main drawback of lower spectral efficiency. After passing through transmission media, the received signal is divided into the ratio of 1:α by the splitter placed before the spectral decoder and complementary decoder. The divided signal is branched out to the both decoders. Complementary decoder receives the complement set of wavelengths for the data bit "1". Theoretically, this arrangement is considered effective in eliminating the MAI as already stated above.

Because of these characteristics, SAC is gaining interest and is considered to be part of the future access networks. Several SACs are designed and their encoding is done through this technique. Some of these codes are studied in the next chapter. Their construction details are given. Also analysis of the performance in terms of SNR (Signal to Noise Ratio) and BER (Bit Error Rate) of these codes makes the core part of the study.

The oldest codes applied in spectral amplitude coding scheme are m-sequence and Hadamard codes. Here m-sequence will be considered and applied in the DQPSK-SAC to prove the practicality and effectiveness of this scheme by using this code that is considered as performing below than the newly designed spectral amplitude codes. This will prove the point that higher order modulation will be aiding in boosting the performance and spectral efficiency of the SAC OCDMA.

1.2 m-Sequence

It is a pseudorandom sequence widely used in coding and error correction techniques. It can be generated by using feedback shift registers [11]. This is a cyclic sequence and hence it has a certain period called maximal period. Therefore, this sequence is called m-sequence. The no. of stages (r) in the feedback shift register determine its period and length of the sequence. The primitive polynomial defining its relationship with number of stages in the linear feedback shift registers is:

$$f(x) = \sum_{i=0}^{r} c_i x^j \qquad (5)$$

Where f(x) is an irreducible polynomial that can be decomposed into further factors.

In this simulation, m-sequence chosen is 100010011010111 (n=15). The 4-stage feedback shift register is used to generate this sequence and primitive polynomial is $f(x) = x^4+x+1$.

Signal to ratio for the m-sequence is given by the following formula [12]:

$$SNR_m = \frac{2\Delta v}{K^2(1+R_c(N-2))B} \qquad (6)$$

Using this relation, performance of m-sequence was determined. For computing BER, Gaussian distribution is assumed and under this assumption, BER and SNR are related as follows:

$$BER = \frac{1}{2} erfc\sqrt{(SNR/8)} \qquad (7)$$

For different lengths of sequence. BER displaying curves are drawn as shown in Fig. 3. The sequence with the smallest length performs much better than the sequences having longer lengths. The curve on the right most is drawn using m-sequence of length of 31. This curve has the lowest BER when the number of simultaneous users are increasing. On the contrary, m-sequence with N=255, lags in performance as compared to others as shown in the left most.

1.3 DQPSK SAC

The greatest benefit of QPSK modulation is that two bits can be coded in one phase shift. The same bit rate is secured in QPSK at the reduced bandwidth as compared to BPSK. It is preferable transmission technique in the areas where high spectral efficiency is needed and high data rates are required to be transmitted. There are 4 levels of modulation and also it maintains a constant intensity envelope. Due to these factors, DQPSK offers great resilience in the face of nonlinear effects among other things and provides better performance. It has higher receiver sensitivity as compared to the conventional OOK modulation used in SAC schemes. Also it can perform better than OOK because it has a balanced receiver structure that will be helpful in eliminating MUI [13].

In this transmission technique, signal is sent for converting serial data into parallel data. Parallel data is then forwarded to precoding section. The principle precoding is explained in the following subsection.

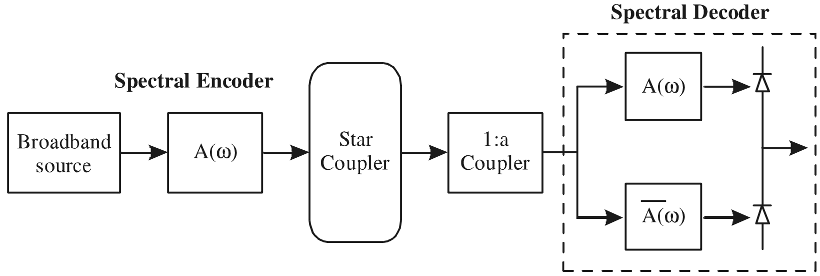


FIG. 2. SPECTRAL AMPLITUDE CODING

Precoding component is used in DQPSK to evade iterative decoding. Iterative decoding can be defined as a decoder performing decoding on each encoder by taking turns. This iterative process is done to estimate the probabilities of the signal decoded. These probabilities are called extrinsic probabilities and encoders pass these to the other decoder. When received by the decoder, these probabilities are used as prior probabilities. The decoder sends back and forth these to the other decoders. In this iterative process of some iterations, the decoder estimates the codeword.

However precoding component is used to avoid this complexity of iterative algorithm and also ensure the transmission of correct data. Consider that after serial toparallel conversion, two input data streams are A and B as shown in Fig. 4. Two Equations (9-10) determine the output of precoding.

$$I_i = \overline{(Q_{i-1} \oplus I_{i-1})(A_i \oplus I_{i-1})} + (Q_{i-1} \oplus I_{i-1})\overline{(B_i \oplus I_{i-1})} \quad (9)$$

$$Q_i = \overline{(Q_{i-1} \oplus I_{i-1})(A_i \oplus I_{i-1})} + (Q_{i-1} \oplus I_{i-1})\overline{(A_i \oplus I_{i-1})} \quad (10)$$

After this stage of precoding, input signals are divided into two In-phase and Quadrature components I and Q. Both components offer four possible outputs (00, 01, 10, 11) that are related to four phases (0, π/2, π, 3π/2) or (π/4, 3π/4, 5π/4, 7π/4). In this simulation, two phase modulators in series are used with phase shifts of 0 and π/2 respectively, as given in Fig.4. After this DQPSK modulated signal is spectrally encoded and sent on the fiber. At the end of transmission through fiber, spectrally decoding and complementary decoding are carried out. At the DQPSK receiver, received signal is divided and MZDI (Mach-ZehnderDelay

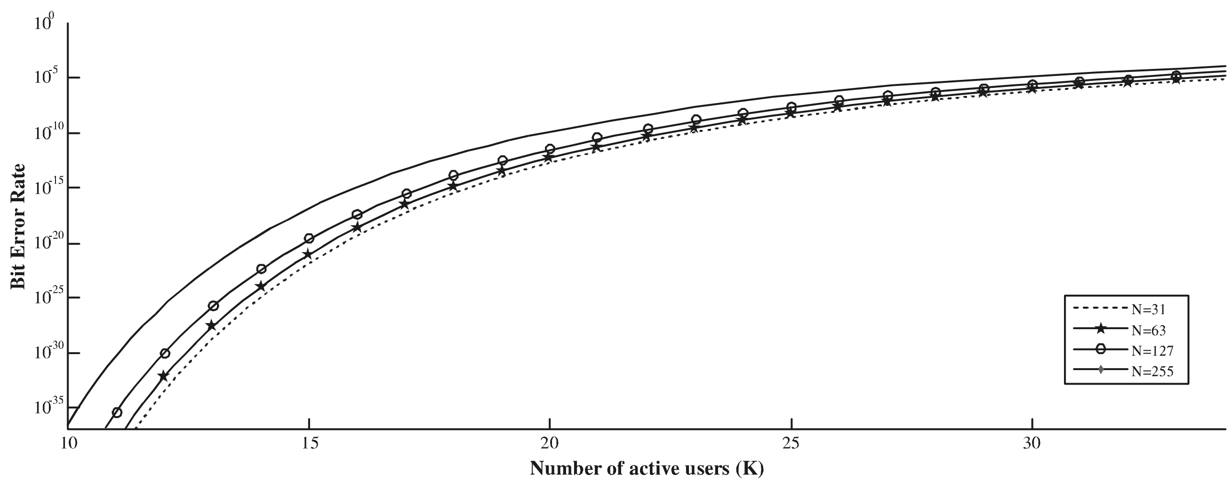


FIG. 3. PERFORMANCE CURVES OF M-SEQUENCE

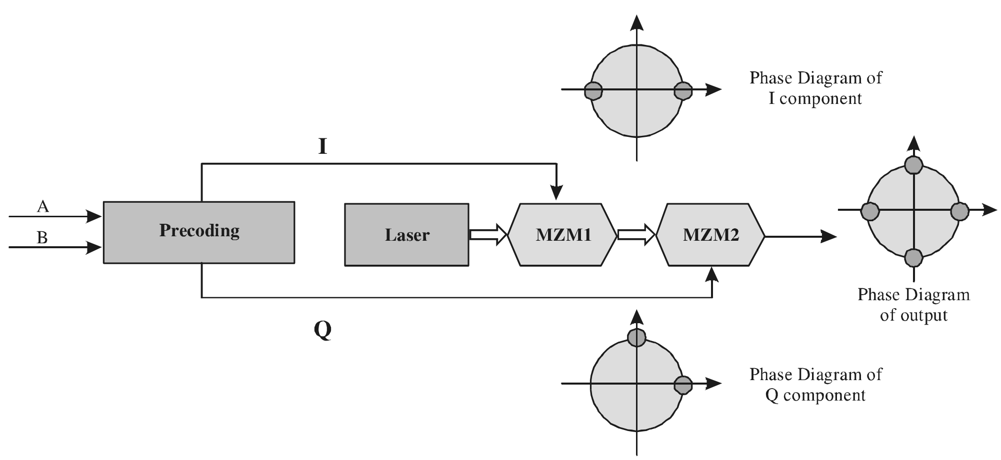


FIG. 4. I AND Q COMPONENTS

Interferometers) are utilized to with delay T and phase shifts of $\pi/4$ and - $\pi/4$. Delay is set as T=2/B, where B is the data rate. This delay is helpful in producing two I and Q components. For the detecting each component, balanced or complementary detection is used and for both components four photodiodes are employed as shown in Fig. 4. Further details regarding simulation are given in the coming section.

2. SIMULATION SET UP OF DQPSK SAC

Simulation set up of proposed DQPSK SAC OCDMA network is shown in Fig. 5. For this simulation, Optisys 7 [14] is used. In this simulation, m-sequence has been used for spectrally encoding and decoding with balanced detection.In the transmitter side (CO), 2.5-Gbps PRBS (Pseudorandom Bit Stream) data of order 2^7-1 is used in downstream transmission, having launch power 0 dBm employing DFB (Distributed Feedback) laser source. Parameters used in this simulation are summarized in Table 1. Before transmitting the signal via optical fiber spectral amplitude coding of the signal is performed. At the other end of the optical medium, signal is split into two components for forwarding to two branches of decoders receiving side, balanced or complementary detection is applied in order to cancel out the MAI. Four photodiodes are required for dual detection in both arms.

3. RESULTS AND ANALYSIS

The analysis of the proposed scheme was carried out using the electrical constellation chart, BER values and eye diagram.

In the constellation diagram, a higher order digitally modulated signal is represented. It is made in the complex plane using sampled symbols in the two-dimensional scatter plot. From this diagram (Fig. 6), scale of distortion of the received data and inter-symbol interference is determined. It is given in Fig. 6. The diagram displays better positioning of the sampled symbols and indicates high quality of transmitted signal and better shape of the received signal.

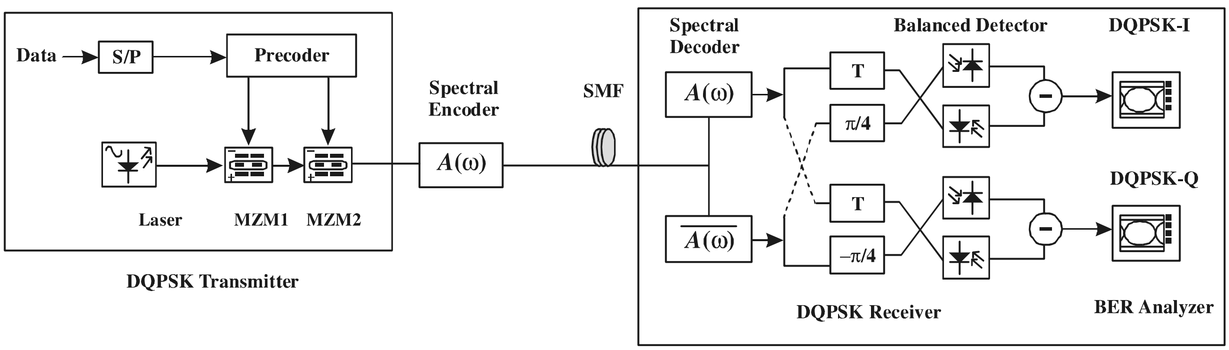


FIG. 5. DQPSK TRANSMITTER AND RECEIVER WITH SAC ENCODER AND DECODER

TABLE 1. PARAMETERS USED IN THE SIMULATION

Parameter	Value
SMF length	30 km
Dispersion parameter of SMF	16.75 ps/nm/km
Attenuation Coefficient of SMF	0.2 dB/km
Non Linear index-coefficient of SMF	2.6×10^{-20} m^2/W
Responsivity of Photo detector	1 A/W
Dark current of photo detector	10 nA
Spectral width	0.8 nm
Data Rate	2.5 Gbit/s

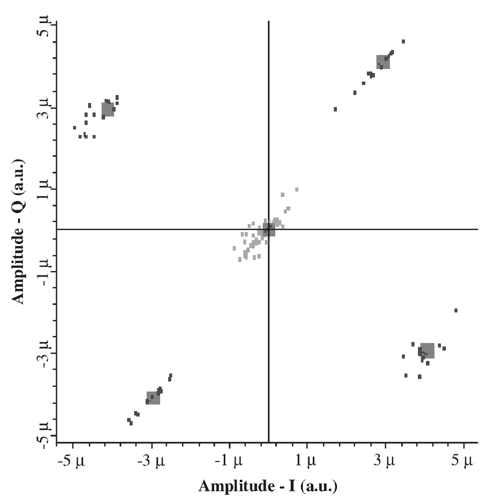


FIG. 6. ELECTRICAL CONSTELLATION DIAGRAM OF DQPSK

Eye diagrams for this simulation for the both DQPSK-I and DQPSK-Q are shown in Fig. 7. Eyes are widely open indicating the minimal distortion of the signal and better reception at the receiver side. This diagram confirms the feasibility of the simulated setup of DQPSK-SAC scheme. Further, BER calculated for both DQPSK and OOK modulated scheme to give a comparative analysis and establish the supremacy of the higher order modulation format.

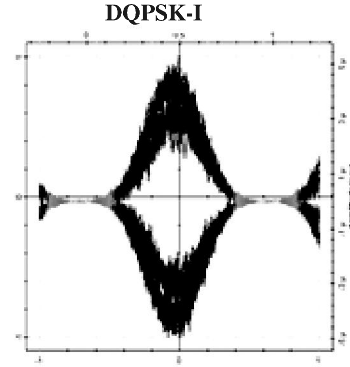
Fig. 8 portrays the bit error rate values plotted against received power in dBm for both modulation formats. The diagram also gives a pictorial comparison of the receiver sensitivity for the two cases. From Fig. 8, it can be seen that receiver sensitivity of DQPSK is in the range of -30 dBm while in the case of OOK, it is much lower and it is around -22 dBm. It means that in OOK, reception of the weak signal below the power of level of -22 dBm is not possible. That however can be achieved in the case of DQPSK for the lower power levels because of various losses like MAI, shot noises, thermal noises and phase induced intensity noise. These BER values are taken for the distance of 30km transmission.

As for as power penalty is concerned, it is around 8dB. It means that DQPSK modulation format improves the receiver sensitivity by 8dB as compared with OOK. It can be concluded that the modulation format of DQPSK along with SAC-OCDMA improves the spectral efficiency as well transmission efficiency of the network. For higher data rates and for longer distances, this setup is preferable due to lower power penalties and higher performance.

4. CONCLUSIONS

In this article, higher order modulation format of DQPSK is studied and applied in SAC-OCDMA network. Its working principle is discussed in details including precoding method.
A well-known SAC code m-sequence is also discussed. The code is used in this simulated setup. Its performance regarding various lengths of the sequence is also studied and displayed in the pictorial representation.

DQPSK-I



DQPSK-Q

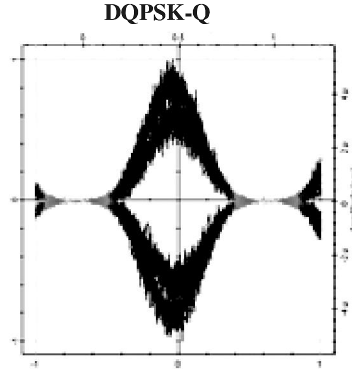


FIG. 7. DQPSK EYE DIAGRAMS

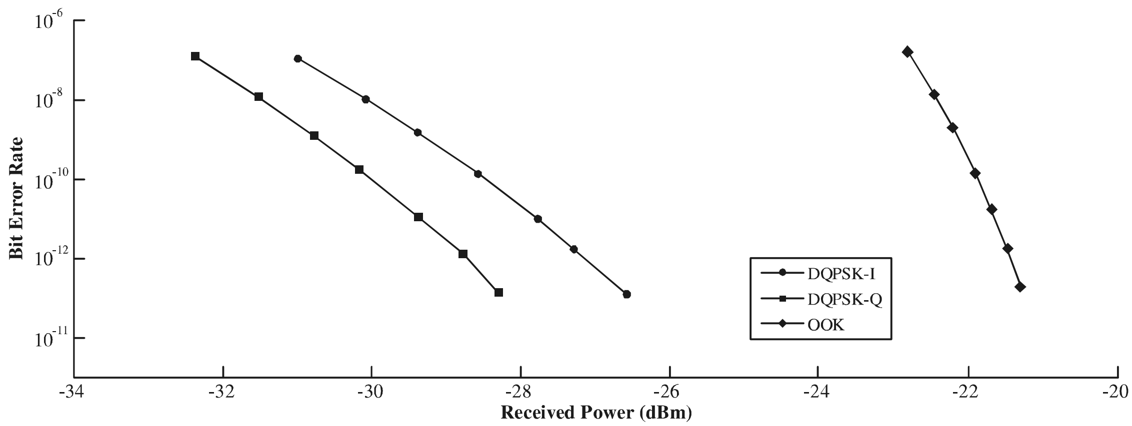


FIG. 8. BER VERSUS RECEIVED POWER

The results of the simulation are analyzed with the help of electrical constellation diagram, eye diagram and bit error rate graph. All the graphs indicate high transmission quality in case of advanced modulation format of DQPSK used in SAC OCDMA network.

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