Optical CDMA: Performance of Spectral-Amplitude Coding with New Direct Recovery Scheme using Vector Combinatorial (VC) Code

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Abstract: *In this paper, a new code structure with ideal in-phase cross-correlation for the Spectral-Amplitude-Coding Optical Code-Division Multiple-Access (SAC-CDMA) system called Vectors Combinatorial (VC) code is proposed. VC code is constructed using Euclidian vectors and a simple algebraic way for any positive integer number based on the relationship between the number of users N and the weight W. We have also studied the performance of OCDMA systems using a newly proposed Direct Recovery Scheme (DRS) under various link parameters. The impact of the detection techniques and data rate effects on the Multi-User Interference (MUI) is reported using a commercial optical systems simulator, Virtual Instrument Photonic (VPI^{TM}). The VC code is compared mathematically with other codes which use similar techniques. We analyzed and optimized the data rate, fiber length, and channel spacing in order to reduce the BER effect. A comparison between complementary and DRS techniques for theoretical and simulation results taken from VPI^{TM} is demonstrated. It is verified that, for a high data rate (higher than 2.5 Gb/s), even if dispersion compensated devices are not deployed, the BER can be significantly improved when the VC code with desired parameters are selected using DRS technique. Also, it is found that as the channel spacing width goes from very narrow to wide, the BER decreases and best performance occurs at a spacing bandwidth between 0.8 and 1nm. In addition, we have shown that the proposed new DRS technique utilizing VC code significantly improves the performance compared with the conventional SAC Complementary subtraction technique.*

Keywords: *VC, MUI, SAC-OCDMA, BER, DRS.*

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1. Introduction

In information era, we are seeing increasing demand for networks with higher capabilities at low cost. This demand is fueled by many different factors. Multimedia services promise to integrate moving images, statistic images, text, and sound in an interactive environment. At the same time, businesses are relaying increasingly on internet. The tremendous growth of internet has brought huge amount of users consuming large amount of bandwidth since data transfers involving video, database queries, updates and image [10, 11, 12, 15]. The conventional bandwidth, such as twisted wire pairs and coaxial cables is limited and for this reason it will not be able to integrate these broadband services sufficiently. To solve this problem the advanced development in fiber optics over the last few years has made it possible to use optical fiber as a transmission medium or channel in modern communication systems [12, 13]. Code-Division Multiple-Access (CDMA) was invented and used as the first technique for wireless communication. It gives best results compared to other wireless multiple access techniques. This fact led the researchers to study if the advantages of CDMA could also be utilized in optical communication systems. Optical CDMA is the latest multiple access technique that has been proposed during the last twenty years after studies of drawbacks of previous multiple access technique [11, 12, 13, 14]. Optical fiber offers a much larger transmission band width and in CDMA every user is differentiated from the others by his unique code address and hence can use the whole band width of the fiber optic media. The key advantage of using OCDMA is that, it can be encoded and decoded in optical domain without converting to electronic signal unless it is needed to be. In an incoherent OCDMA system, each user is assigned a unique code sequence as its address signature based on the spectral amplitude only. When a user wants to transmit data bit "1", it sends out a code sequence matching the address signature of the intended receiver. At the receiver, all the code sequences from different users are correlated. If correct code sequences arrive, an autocorrelation function with a high peak results. For incorrect code sequence, cross correlation functions and crosstalk are generated and they create Multiple-User Interference (MUI) [8, 11, 12]. In OCDMA, the MUI is the ultimate limit in system performance [16]. MUI increases with the number of simultaneous users and severely limits the capacity of the system. Although, MUI can be cancelled by balance detection scheme, inherent problem of noise labelled as Phase Induced Intensity Noise (PIIN) still remains arising from spontaneous emission of broad band source. In particular, intelligent design of codeword is important to reduce the effect of MUI and PIIN on the total received power [5, 8, 9, 10, 17].

The SAC system gained more attention due to its ability to recover the original signals by using complementary detection technique with fixed cross-correlation [9]. However, the Modified Quadratic Congruence (MQC) and Modified Frequency Hopping (MFH) [3, 12] codes have a cross correlation that always equals to one and therefore the complementary detection scheme can be used to give accurate results. The new proposed code is a family of [0, 1] which is characterized by (L, N, W, λ_c). The length L, number of users N, weight W (number of marks) and cross correlation λ_c. However, in order to increase the number of users for VC code a mapping technique must be applied [2]. Therefore, when applying the mapping technique, the cross correlation is no longer fixed to 1. Consequently, the complementary detection technique cannot be used to obtain accurate results. To solve the stated problem, a new detection technique called Direct Recovery Scheme (DRS) is proposed.

The most common subtraction techniques are the complementary and AND subtraction techniques [9, 7]. Based on the construction of Vector Combinatorial (VC) code, the new detection technique is used to recover the original signal by using direct proposed technique. In this paper, we will compare the complementary technique with the new detection technique known as direct recovery scheme technique. It will be shown that VC code using direct recovery scheme reduces the receiver complexity and provides a better performance than other codes using the same Spectral Amplitude Coding (SAC) complementary subtraction technique.

The rest of this paper is organized as follows: The family of newly constructed codes is described in section 2. Section 3 presents the analytic results of system performance using newly proposed detection technique. Section 4 shows simulation analysis of proposed detection and complementary detection techniques. Theoretical analysis and simulation results are drawn in section 5. Finally, we have the conclusion in section 6.

2. Code Construction and Properties

- *Definition:* In mathematics, the standard basis of the W-dimensional Euclidean space R^W is obtained by taking the W (code weight) basis vectors as $\{v_i\!:\!1\leq i\leq W\}$, where v_i is the vector with a 1 in the i^{th} coordinate and 0 elsewhere.

For example, the standard basis for R^5 (i.e., W=5) is given by the five vectors as follows:

$$\boldsymbol{v}_1 = \begin{pmatrix} 1\\0\\0\\0\\0 \end{pmatrix} \quad \boldsymbol{v}_2 = \begin{pmatrix} 0\\1\\0\\0\\0 \end{pmatrix} \quad \boldsymbol{v}_3 = \begin{pmatrix} 0\\0\\1\\0\\0 \end{pmatrix} \quad \boldsymbol{v}_4 = \begin{pmatrix} 0\\0\\0\\1\\0 \end{pmatrix} \quad \boldsymbol{v}_5 = \begin{pmatrix} 0\\0\\0\\0\\1 \end{pmatrix}$$

The design of new proposed code family which is referred to as VC code, can be constructed by dividing the code construction into three steps; vector construction, vectors combination and mapping technique.

In vector construction which is based on the standard basis, we first construct a column vector having only two "1" which will make the cross-correlation exactly equal to 1. Let $V_{(i,\, i+1)}$ be a column vector whose i^{th} element is one and the others are zeros and its length equals N as follows:

$$V_{(i,\, i+1)} = \begin{pmatrix} 1\\0\\.\\.\\1 \end{pmatrix} \tag{1}$$

In Vectors combination in order to make the in-phase CC exactly equal to 1 in each column while maintaining the weight value in the row (code word for each user), every vector in the matrix as shown in Figure 1 is indexed as $V_{(i,\ i+1)}$ for i fixed to user arrangement and $i+1$ shifts down by one up to N to make the CC with N-1 exactly equal to 1 (i.e., for N=5 (vector length), the maximum value of i= N-1 is 4. Therefore for N=4, the corresponding values of i will be calculated as: i=1; $V_{(i,\ i+1)}$=V_{12}, V_{13}, V_{14}; for i=2, $V_{(i,\ i+1)}$=V_{23}, V_{34} ; for i=3, $V_{(i,\ i+1)}$=V_{34} which means i represents number of row (user).

$V_{(i,i+1)}$	V_{12}	V_{13}	V_{1N}	V_{23}	V_{24}	V_{2N}	$V_{(N-1)N}$
User# 1	1	1	1	0	0	0	0
User# 2	1	0	0	1	1	1	0
.	0	1	0	1	0	0	0
.	0	0	.	0	1	.	.
.	0	0	.	0	0	.	.
.	0	0	.	0	0	.	1

Figure 1. A general matrix of VC when N=W+1.

In Figure 1, we have shown the procedure for generating (0,1) sequence after combining all columns vectors. To be more precise from the figure we can observe that each column vector contains two "1"s; W represents number of "1"s per row; N are number of rows (number of users). Thus, the sequence (V_{12}, V_{13},…,V_{1N}) (V_{23}, V_{24},…,V_{2N}) …, $V_{(N-1)N}$) gives a code having ideal in-phase CC (λ=1) called Ideal Case (IC). In a mapping technique although the IC can be constructed easily using a column vector, the requirement that N-1=W must be satisfied limits the number of users. To overcome this problem, a mapping technique must be applied as shown in

Figure 2. The mapping technique is a mechanism used in [13], in order to increase the number of users beyond the basic number of users offered by the basic matrix for a specific weight. Therefore, N can be written:

$$N=P\,(W+1)+R \tag{2}$$

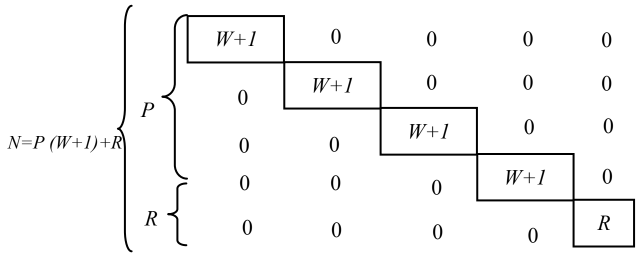


Figure 2. A graphic representation of mapping techniques for $N=P(W+1)+R$.

Where P and R are positive integer numbers representing number of ($W+1$) repeating in diagonal fashion, and the remaining users after module division for N respectively, and R can be expressed as:

$$R=N \bmod P\,(W+1) \tag{3}$$

To clarify equations 2 and 3 where *mod* represents modulo division, let us consider the example N=8, W=2. Substituting these values in equation 2, gives 8=2×(2+1)+2, which means P=2 and R=2. For N=9, W=2, gives 9=3×(2+1)+0 which means P=3 and R=0. In order to increase the number of users in VC code family, a mapping technique must be applied. The mapping technique as shown in Figure 2 operates diagonally by repeating the IC for the (W+1) users P-times and filling the empty spaces with zeros.

The length of that part is $p.\frac{W(W+1)}{2}$. Consequently, an IC with the parameters (W, R) must be added if $R<W+1$ is to be satisfied (i.e., $R=N \bmod P\,(W+1) \neq 0$) as shown in Figure 2. The length of that second part of the code is $\frac{R(2W-R+1)}{2}$. Finally, the whole length L is given by:

$$L=\frac{WN+R(W+1-R)}{2} \tag{4}$$

For example, for W=4 and N=5, the following columns vectors represents the IC.

$$v_{12}=\begin{pmatrix}1\\1\\0\\0\\0\end{pmatrix}, v_{13}=\begin{pmatrix}1\\0\\1\\0\\0\end{pmatrix}, v_{14}=\begin{pmatrix}1\\0\\0\\1\\0\end{pmatrix}, v_{15}=\begin{pmatrix}1\\0\\0\\0\\1\end{pmatrix} v_{23}=\begin{pmatrix}0\\1\\1\\0\\0\end{pmatrix}, v_{24}=\begin{pmatrix}0\\1\\0\\1\\0\end{pmatrix} v_{25}=\begin{pmatrix}0\\1\\0\\0\\1\end{pmatrix} v_{34}=\begin{pmatrix}0\\0\\1\\1\\0\end{pmatrix} v_{35}=\begin{pmatrix}0\\0\\1\\0\\1\end{pmatrix} v_{45}=\begin{pmatrix}0\\0\\0\\1\\1\end{pmatrix}$$

In Table 1, for W=3 and N=10 by using equation 2, gives 10=2×(3+1)+2, resulting in P=2 and R=2 which means we have to repeat the IC two times (P=2) in diagonal fashion resulting in 8 users and add two more user (R=2) after user# 8 in diagonal fashion as well. By using (4) L=10×3+2(3-1+2)/2, the code length will be 17. In Table 1, there are three groups, the first group of the code (the first six columns) is the VC with the parameters (3, 4) which means W=3 and N=4 having CC equal to 1; the second group (the columns from 7 to 12) is a replica from the first group with the parameters (3, 4); the third group (the columns 13 to 17) is the VC with the parameters (3, 2) which means W=3 and N=2 (i.e., R=N) since the condition $R<W+1$ (2<4) is satisfied having CC equal to 1.

Table 1. VC Code for N>W+1(N=10, W=3).

1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0
0	1	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0
0	0	1	0	1	1	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0
0	0	0	0	0	0	1	0	0	1	1	0	0	0	0	0	0
0	0	0	0	0	0	0	1	0	1	0	1	0	0	0	0	0
0	0	0	0	0	0	0	0	1	0	1	1	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0	0
0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	1

3. Performance Analysis of the VC Code using Direct Recovery

3.1. SAC Direct Recovery Scheme

The setup of the proposed VC system using direct recovery scheme is shown in Figure 3. This figure demonstrates the implementation of the VC code using direct recovery scheme thereby only one pair of decoder and detector is required as opposed to two pairs in the complementary subtraction techniques. There is also no subtraction process involved. This is achievable for the simple reason that, the information is assumed to be adequately recoverable from any of the chips that do not overlap with any other chips from other code sequences (λ_2, λ_3) for user# 1 (Green chips) and (λ_4, λ_5) for user# 2 (Red chips). The chips that have overlap are not filtered (Black chips). Thus the decoder will only need to filter through the clean chips at the code sequence; these chips are directly detected by a photodiode as in normal intensity modulation/ direct recovery scheme. This technique has successfully eliminated the MUI because the only wanted signal spectral chips at the sequence in the optical domain will be filtered. This is possible because, the code properties possess more than one clean signal chips for each of the channels with the mapping technique. Consequently, the PIIN is suppressed at the receiver, thus the system performance is improved. Codes which possess non overlapping spectra such as VC code can normally be supported by this detection scheme. It is also important to note that the whole code's spectra still need to be transmitted to maintain the addressing signature.

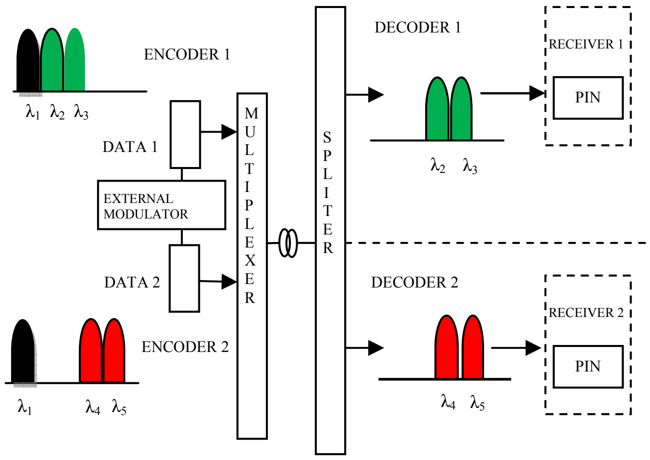


Figure 3. Implementation of VC code using direct recovery scheme.

3.2. Mathematical Analysis of VC Code using Direct Recovery Scheme

Let $a=(a_1, a_2,..., a_L)$ and $b=(b_1, b_2,..., b_L)$ be two different code sequences, let their mutual CC be defined as:

$$V_{a,b} = \sum_{i=1}^{L} a_i b_i \tag{5}$$

To analyze the system with transmitter and receiver as shown in Figure 3 for VC code, assume user# (f, g) is the desired user and user# (z, t) is the undesired user, the correlation functions of each user is given by:

$$PD1_{(0)}(f,g,z,t) = \begin{cases} W, f=z, g=t \\ 1, f \neq z, g=t \quad for\ N=(W+1) \\ 0, g \neq t \quad for\ N=P(W+1)+R \end{cases} \tag{6}$$

and

$$PD2_{(1)}(f,g,z,t) = \begin{cases} 0, \quad f=z, g=t \\ W-1, f \neq z, g=t\ for\ N=(W+1) \\ 0, g \neq t \quad for \quad N=P(W+1)+R \end{cases} \tag{7}$$

thus

$$PD1_{(0)}(f,g,z,t) - \frac{PD2_{(1)}(f,g,z,t)}{W-1} = \begin{cases} W, f=z, g=t \\ 0, \quad else \end{cases} \tag{8}$$

The Signal to Noise Ratio (SNR) of the VC code is calculated by using the same method described in [1, 8, 9, 10, 11, 12, 13]. The phase-induced intensity noise, the photodiode shot noise and the thermal noises are taken into account. Therefore, the SNR of the VC code family is given by:

$$SNR = \frac{\Re^2 P_{sr}^2 W^2}{\frac{P_{sr} e B \Re}{L}[(N-1)+W] + \frac{P_{sr}^2 B \Re^2 N}{2\Delta V L^2}[(N-1)+W+(N-1)/P+R] + \frac{4K_b T_n B}{R_L}} \tag{9}$$

where $\Re$ is the photodiode responsivity, P_{sr} is the effective power of a broad-band source at the receiver, e is the electronic charge, B is the electrical equivalent noise band-width of the receiver, K_B is the Boltzmann's constant, Tn the absolute receiver noise temperature, R_L is the receiver load resistor, ΔV is the optical source bandwidth, W, N, L, P and R are the code weight, the number of users, the code length, the number of mapping and the remaining users after modulo operation respectively as being the parameters of VC itself . The Bit Error Rate (BER) is computed from the SNR using Gaussian approximation as [5, 6, 11, 12, 15].

$$BER = P_e = \frac{1}{2} erfc\left(\sqrt{\frac{SNR}{8}}\right) \tag{10}$$

4. Simulation Analysis of Direct Recovery Scheme and Complementary Detection Techniques

The setup of the proposed VC code system using direct recovery scheme with four users is shown in Figure 3. As stated previously, the main difference of this technique compared to the complementary subtraction is at the decoder. With direct recovery scheme, no subtractors are needed at the receivers, thus the number of filters is significantly reduced. This technique will improve the system performance such as in the signal-to-noise ratio and probability of error.

As illustrated in Figure 4, a simple schematic block diagram consists of four users. The performances of VC, MQC, MFH families are simulated by using the simulation software, Virtual Photonic Instrument (VPI^{TM}) version 7.1. Each chip has a spectral width of 0.8 nm (100 GHz). The tests were carried out at a data rate of 10Gb/s for different distances with the ITU-T G.652 standard Single Mode Fiber (SMF).

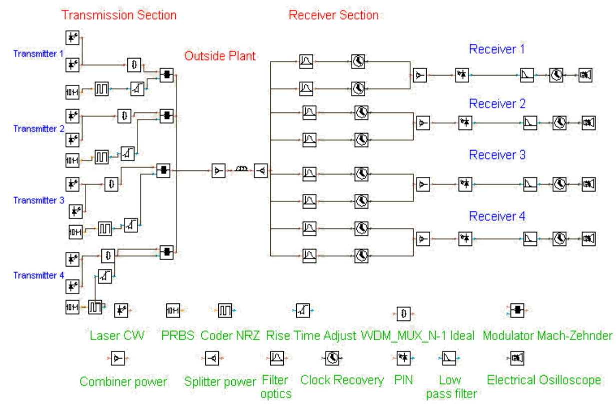


Figure 4. Simulation setup of proposed system.

All the attenuation α (i.e., 16ps/nm km) and nonlinear effects such as four-wave mixing, the cross phase modulation, and the group delay were activated and specified according to the typical industry values to simulate the real environment as close as possible.

At transmitter side, we have a Pseudo Random Bit Sequence (PRBS) generator as the input data of each user followed by a coder jitter to generate an NRZ sample ended by a rise time to adjust the rise time of the pulse. After that a Mach-Zehnder modulator is used to modulate the laser output. As shown in Figure 4 after transmission, we used a filter optics spectral phase decoder that operates to decode the coded sequence. After that we used a clock recovery ideal to synchronize incoming optical signal with original transmitted signal. The decoded signal was decoded by a Photo-Detector (PD) followed by a 0.7GHz Low Pass Filter (LPF) and error detector, respectively. The transmitted power used was -10dBm out of the broadband source. The noise generated at the receiver was set to be random and totally uncorrelated. The dark current value was 5nA and the thermal noise coefficient was 2.5×e-23W/Hz for each of the photo-detectors.

Figure 5 shows the complementary technique used by other various codes utilizing spectral amplitude coding technique such as MFH, and MQC codes. The main principle behind the proposed technique is no subtraction process is needed, in contrast a complementary needs two photo-detectors compared to one for direct recovery scheme.

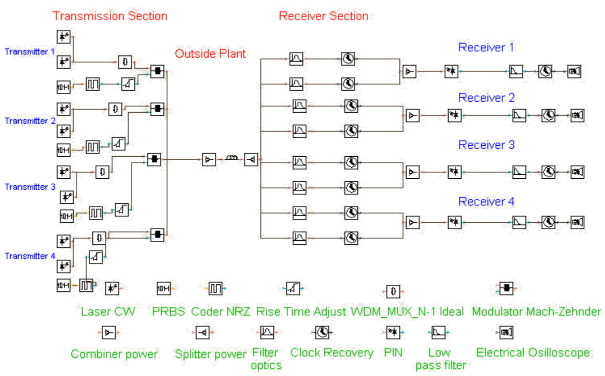


Figure 5. Simulation setup of other spectral amplitude coding system using Complementary technique.

5. Results and Discussion

Dispersion impact on the system performance as a function of the number of users N is illustrated in Figure 6. In order to minimize the MUI impact, the optimum decision threshold is set to S=2×Pcen [4].

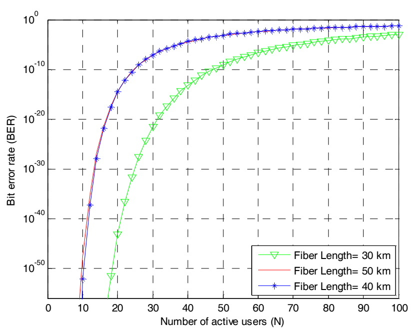


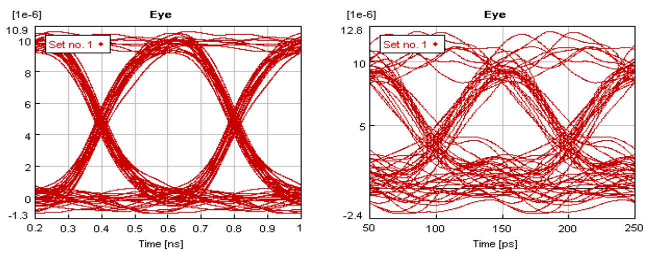
Figure 6. Variation of BER as a function of the number of users and fiber length for VC code when data rate=10Gb/s.

As can be seen from this figure the trend of the BERs with and without dispersion as shown in Figure 6 is the same. One can see that for N=10 active users and 40 km fiber length, the MUI is low. In this case chromatic dispersion is the main limiting factor of the system performance. However, when the number of users is increased to 17, MUI is the main limiting factor, whereas the chromatic dispersion effect is very small. Table 2 shows the system parameters that have been used in calculation part.

Table 2. System parameters.

PD quantum efficiency	η= 0.6
Line-width of the thermal source	V_c 3.75THz
Operation wavelength	λ = 1550 nm
Electrical bandwidth	B=311 MHz
Data bit rate R_b	622 Mb/s
Receiver noise temperature	Tr = 300 K
Receiver load resistor	R_L = 1030 Ω

This is the reason why there is a difference in the value of BERs between the two cases of N=10 and N=17 users. For that reason, the system performance is more subject to dispersion when the number of users is reduced (i.e., low MUI). In turn to upper-bound the dispersion effect, simulations for N=10 are carried out. Also it can be seen from Figure 6 that the systems performance deteriorates when the fiber length is increased. The eye pattern diagrams for VC and MFH codes shown in Figure 7 clearly illustrates in that the VC code using direct recovery scheme gives better performance, having a larger eye opening. The equivalent simulated BER for VC and MFH codes systems are shown in Figure 7. The vertical distance between the top of the eye opening and maximum signal level gives the degree of distortion. Figure 8 shows that the BER increases as the fiber length increases for the different techniques. The number of active users is four at 2.5Gb/s and 10Gb/s bit rates. The effect of varying the fiber length is related to the power level of the received power. A longer length of fiber has higher insertion loss, thus smaller output power. As a matter of fact, when the fiber length decreases, the data rate should increase to recover a similar degradation of the signal form.



a) One of the VC channels using direct detection scheme.

b) One of the MFH channels using complementary scheme.

Figure 7. Eye diagram of a, b at 10Gbit/s.

Thus, in order to design and optimize link parameters, the maximum fiber length should be defined as short as possible, to obtain high data rate and to achieve a desired system performance. This is because in order to reduce the MUI limitations, the data rate should be decreased in OCDMA analysis. For a given code length L, data rate R, the chip rate C_R can be expressed as: C_R=R×L. Hence, as R increases (R>2.5Gb/s) the chip rate increases. Accordingly, the chip duration decreases and as a result the signal would be more subjected to dispersion. In view of that, the optical power contained in the emitted chip "1" causes optical signal broadening, that is then received at several chips. In communication systems, Inter Symbol Interference (ISI) is a result of distortion of a signal that causes the previously transmitted data to have an effect on the received data [8]. The ISI affect results in more chips containing nonzero optical power than expected. As for conventional decisions, we selected the decision threshold level $S=W\times P$cen, where Pcen is the optical power level which corresponds to the chip centre. Thus, the data sent "1" is always well-detected.

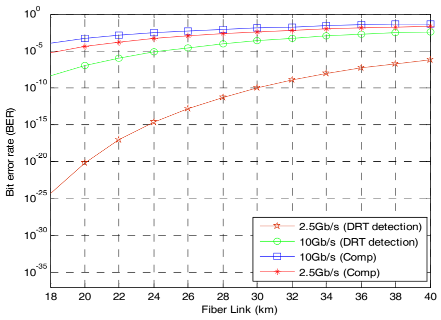


Figure 8. Variation of BER as a function of fiber length using direct recovery (VC code) and complementary techniques (MFH code) at different transmission rates.

The only error that can occur in this situation is when the data sent is "0" as in the ideal case. In terms of fiber length, it should be pointed out that the dispersion effect increases as the fiber length increases. However, for this particular chip duration, the dispersion has no impact on the BER for optical fibers shorter than 18km. However, when the fiber's length is greater than 18km, system performance is deteriorated.

In this particular system, direct recovery scheme can support higher number of users than the conventional technique because no subtractors are needed and the number of filters at the receiver is reduced, leading to smaller power losses. The very low BER values are a measure of the quality of the received signals as calculated by the simulator although they may not be very meaningful from the practical point of view.

The computed BER versus channel spacing width is shown in Figure 9 for different fiber lengths. The pulse duration is fixed to Tc=1/(data rate×code length). As the channel spacing width goes from very narrow to wider, the BER decreases, best performance occurs at spacing bandwidth between 0.8 (100GHz) and 1.2nm. The reason for the BER increasing after the minimum is that the SNR improvement due to the use of wider optical bandwidth is counteracted by an increased crosstalk/overlapping between adjacent frequency bins that yield MUI. Note that, decreasing channel spacing the effects of four-wave mixing on optical transmission and in single mode fiber are appeared, this is noticeable as degradation of optical SNR and the system BER performance.

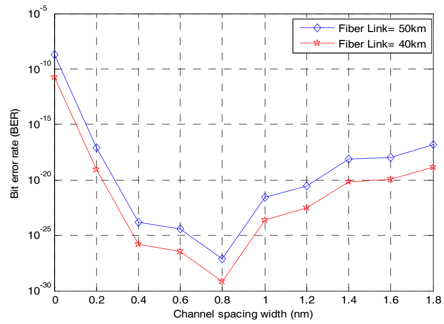


Figure 9. Variation of BER as a function of channel spacing width for VC code.

A variety of direct detection schemes have been proposed in [14, 15], to minimize the effect of MUI; however, the MUI increases with the number of simultaneous users, which severely limits the capacity of the system. MUI also leads to another type of noise, known as PIIN that results from the phase incoherence of the overlapping signals on the same spectra causing fluctuations of the total signal intensity. For comparison purpose, the operations of DRS for VC code and direct detection scheme for RD and EDW codes are drawn in Figure 10. Figure 10 shows the BER variations with Psr when the number of active users is 30 at the data rate 622Mb/s by taking into account the effects of the intensity noise, thermal noise and shot noise for VC, RD and EDW codes, respectively. It has been shown that, the VC using DRS technique has a lower BER than that of direct detection technique; this is due to elimination of MUI effects through DRS technique. It is observed that DRS technique gives a much better performance when the effective received power Psr is large (when Psr>-24dBm). At the lower values of Psr (when Psr<-24dBm), the performance of RD code using direct detection shows slightly better performance than the DRS due to high value of *W*.

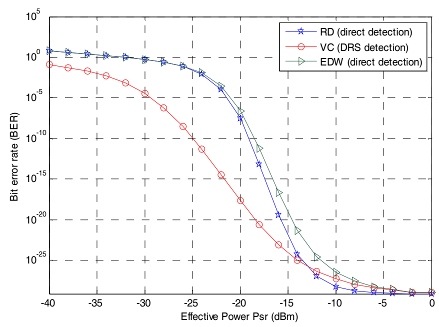


Figure 10. BER versus Psr when number of active users is 30.

6. Conclusions

In this paper, we have proposed a construction method for a new code family with ideal cross correlation value of 1. The properties of this code have been proved and discussed. A new detection technique known as direct recovery scheme has been proposed for SAC-OCDMA systems. The performance was characterized based on VC code. The theoretical and simulation results have shown that the new detection technique provides better performance than the conventional complementary subtraction technique. It is found that for a high data rate, even if dispersion compensated devices are not deployed, the BER can be significantly improved when the VC optimal parameters are carefully selected (even for short fiber length. This is achieved by the elimination of MUI and PIIN. The overall system cost and complexity can be reduced because of the less number of filters used in the detection process. Moreover, we found that as the channel spacing width goes from very narrow to wide, the BER decreases, best performance occurs at a spacing bandwidth between 0.8 and 1 nm. The limitations in using direct recovery scheme is that overall system will have less power than complementary detection scheme when a high span is considered. This is because we select the wavelength by almost $1/W$ less from the whole code weight.

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