Evaluation the Performance of IP Routing Based OCDMA Networks by using fourth Padded Sequences of MPC Sequences

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Abstract—
The new code namely "Fourth Spreading Code-modified prime code (FSC-MPC)" was introduce through this paper of IP routing schemes over coherent optical code-division multiple-access (OCDMA) network. This code is created by addition pad for the prime code (MPC). The length and weight of the proposed code are equal to (P^2+4P) and (P+4), respectively, where P is a prime number used to generate the code, this proposed to enhance the performance of IP-based OCDMA networks and this code performed by using correlation term. The performance has been analyzed in terms of the users', Bit Error Rate (BER) and received power signal of channel utilization factor in the network, and these results compared with another families codes. The numerical results show that the proposed code to reduces the multiuser interference without affecting the optical receiver sensitivity, and increasing the users with low power Consumption.

الخلاصة—
تم تقديم شفرة جديدة،في هذا البحث والتي تسمى "شفرة التوزيع الرباعية للشفرة التقليدية المعدلة(FSC-MPC)" لبروتكول الانترنيت IP لشبكات التقسيم التشفيري الضوئي (OCDMA).
تم توليد هذه الشفرة عن طريق عمل حشوات متعددة تضاف إلى الشفرة الأساسية التقليدية المعدلة (MPC). إن طول ووزن هذه الشفرة يكونان مساويان ل (P^2+P) و (P+4) على التوالي, حيث إن P هو عدد أولي يستخدم لتوليد الشفرة, ان الشفرة المقترحة تستخدم لتحسين الاداء العام لشبكة التشفير الضوئي على اساس برتوكول الانتر نيت (IP-based OCDM) وانجزت بطريقة التماثل (correlation) term . تم تقيم اداء الشفر للمستخدمين باستخدام معدل خطأ البت(Bit Error Rate (BER) وقدرة الاشارة المستخدمة في خط النقل المستخدم في الشبكة , وتلك النتائج قورنت بعوائل اخرى من الشفرات , والنتائج العددية بينت تقليل تقليل تداخلات المستخدمين وبدون تأثير على المستقبل الضوئي وزيادة المستخدمين مع استهلاك قدرة قليلة.

I. Introduction

The customized and service-orientated all-optical network can implement ultrahigh speed transmitting, routing and switching of data in the optical domain, and has the transparency to data formats and protocols which increases network flexibility and functionality such that future network requirements can be met. OCDMA technology is one of the promising technologies to implement all-optical Networks [1].

Optical CDMA (OCDMA) has for a long time been the subject of research because of its inherent ability to support asynchronous burst communications. Initially it was employed for local area [2], then for access network applications [3] and more recently for emerging networks such as generalized multiprotocol label switching [4]. Optical communication networks are widely reported in the literature, OCDMA offers the same virtual point-to-point topology as wavelength-division multiplexing (WDM), however, using a simpler network configuration. In doing so, WDM requires individual wavelength filters at the user end with associated power loss, while OCDMA requires only the power-splitter and/or correlator. Since WDM systems use multiple wavelengths, the effect of beat noise is very remarkable. Unlike WDM and time-division multiplexing (TDM), OCDMA can accommodate a large number of low and high bit-rate users on the same channel. Such aspects corresponding to access traffic patterns are highly desirable since they eliminate electronic grooming as well as supporting bursty traffics [5]. Finally, OCDMA exhibits higher levels of security due to the optical signal coding.

In general, in the CDMA system implementations, there are two types of codes that can be employed, namely, bipolar codes such as Gold codes and Hadamard codes which are used for (Radio Frequency) RF CDMA systems, and unipolar codes such as orthogonal optical code (OOC), prime codes (PC) and Maximum-Length sequence (ML-sequences) which are used for the optical CDMA. The latter families of codes are known as 1-D optical codes. In the case of an optical incoherent network, the spreading codes are unipolar, not strictly orthogonal. This introduces the so called multiple-access interference (MAI) which is one of the main limitations of the OCDMA system performance [6], a major problem associated with PC families is their code-weight, , which is always fixed to the number of subsequences and must be a prime number P [8]. To accommodatemore users in an OCDMA system, a larger P is required, so is the code-weight, Other major degrading factors are the auto λ_a and cross λ_c correlation constraints, To reduce the effect of MAI, the optical address sequences with minimum λ_c (i.e., the weakest MAI) are desirable for synchronous time-spreading OCDMA networks. we use 2-D unipolar codes [7]. In general, 2-D unipolar codes can be constructed by combining 1-D code and temporal spreading and hopping frequency or by using a spatial/frequencies schema. In this paper,we present some of the interesting features of the optical 2-D codes used in OCDMA systems as the process of generation, the number of sequences that can be reached and the auto-correlation and cross-correlation property use as the criteria to determine actuality of the proposed the new code.

II. Proposed a New Spreading Code

In this paper we proposed a new version of spreading code is called Fourth Spreading Code-modified prime code (FSC-MPC), this a new code based in structure on the(design with respect to the) prime code (PC) families, including PC and modified PCs (MPCs) [8], padded MPC (PMPC) [10], new-MPC (nMPC) [11], and double-PMPC (DPMPC) [12], Enhanced-MPC (EMPC) [9]. Since it is an extension of the enhanced-MPC (EMPC) proposed by Lalmahomed et al. [9].

The proposed optical signature sequence FSC-MPC, is generated by concatenating the MPC final sequence stream of the previous MPC sequence rotating in the same group (Extended part in Table I) and finally the last second sequence stream of the Extended part rotating in the same group (see the second row in Table I). The order of the final sequence-streams can be interchanged; however, it is important to maintain the order uniformly throughout the generation of the whole code set; otherwise this would negatively affect (increase) the cross correlation.

In an OCDMA system, each data bit “1” is encoded into a waveform *s(n),* where n ∈ {1, 2, . . ., N}, consisting of a code sequences (or signature sequences) of N chips, which addresses the destination of that bit. Data bits “0” are not encoded. Each receiver correlates its own address *f(n)* with the received signal *s(n)*. The receiver output *r(n)* is [12]

$$r(n) = \sum_{k=1}^{N} s(k).f(k-n) \qquad \text{... (1)}$$

If the signal arrived at the correct destination, then *s(n)* = *f(n)*, and *r(n)* represents an autocorrelation function, however, if the signal arrived at an incorrect destination, then $s(n) \neq f(n)$ and *r(n)* represents a cross correlation function. At the receiver, it is necessary to maximize the autocorrelation function and minimize the cross correlation function in order to optimize the discrimination between the correct (destination address) and all other interfering signals. This can be accomplished by selecting a set of “orthogonal” signature codes . The prime code can be built from multiplication of the Galois Field GP(P) = $\{0, 1, 2, \dots, j, \dots, P-1\}$ and then modulo with P, where P is the prime number. The number of available sequences is P and the length of each code is P2. MPC is the time-shifted version of the prime sequence code. Time-shifting is allowed in an optical synchronous system, and its advantage is an increase in the number of subscribers. Each prime sequence can be a seed to generate $(P-1)$ more modified prime sequences. Thus, the available number of sequences can be extended to P^2 with P code sequences in each P group, while the length of each code is P^2, and the weight (the number of ones) is P. PMPC and nMPC were also introduced in [10] and [11], respectively.

The auto- and cross-correlation function for any pair of the proposed code Cn and Cm is given at each synchronized time T, i.e., equivalent to the bit duration or the code-length, by

$$C_{mn} = c_m . c_n = \begin{cases} P+4, & \text{if } m = n \\ 0, & \text{if } m \neq n, m \text{ and } n \text{ share the same group} \\ 1, & \text{if } m \neq n, m \text{ and } n \text{ are from different groups} \end{cases} \quad \ldots (2)$$

where $m,n \in \{1,2,...P\}$.

The code length is P^2+4P for the proposed code family, which implies an increase in 3P as compared with the nMPC[11], an increase in 2P as compared to DPMPC [12] an increase in P as compared to E-MPC [9]. An implication to this is an increase in the chip rate (processing factor in spreading), which makes the proposed new code more secure (i.e., less or no interception) and enhances the autocorrelation value.

Table 1: Fourth Spreading Code-modified prime code (FSC-MPC),sequences, P=4.

Codes	MPC Part					Extended part			
C_{00}	10000	10000	10000	10000	10000	10000	01000	00100	00010
C_{01}	00001	00001	00001	00001	00001	00001	10000	01000	00100
C_{02}	00010	00010	00010	00010	00010	00010	00001	10000	01000
C_{03}	00100	00100	00100	00100	00100	00100	00010	00001	10000
C_{04}	01000	01000	01000	01000	01000	01000	00100	00010	00001
C_{10}	10000	01000	00100	00010	00001	00001	00010	00100	01000
C_{11}	01000	00100	00010	00001	10000	10000	00001	00010	00100
C_{12}	00100	00010	00001	10000	01000	01000	10000	00001	00010
C_{13}	00010	00001	10000	01000	00100	00100	01000	10000	00001
C_{14}	00001	10000	01000	00100	00010	00010	00100	01000	10000
C_{20}	10000	00100	00001	01000	00010	00010	01000	00001	01000
C_{21}	00100	00001	01000	00010	10000	10000	00010	01000	00001
C_{22}	00001	01000	00010	10000	01000	01000	10000	00010	01000
C_{23}	01000	00010	10000	00100	00001	00001	01000	10000	00010
C_{24}	00010	10000	00100	00001	01000	01000	00001	01000	10000
C_{30}	10000	00010	01000	00001	00100	00100	00001	01000	00010
C_{31}	00010	10000	00001	00100	10000	10000	00100	00001	01000
C_{32}	01000	00001	00100	10000	00010	00010	10000	00100	00001
C_{33}	00100	00100	10000	00010	01000	01000	00010	10000	00100
C_{34}	00001	10000	00010	01000	00001	00001	01000	00010	10000
C_{40}	10000	00001	00010	00100	01000	01000	00100	00010	00001
C_{41}	00001	00010	00100	01000	10000	10000	01000	00100	00010
C_{42}	00010	00100	01000	10000	00001	00001	10000	01000	00100
C_{43}	00100	01000	10000	00001	00010	00010	00001	10000	01000
C_{44}	01000	10000	00001	00010	00100	00100	00010	00001	10000

Hence, the auto- and cross-correlation values for any pair of codes m and n is given by eq. (2), shown at the bottom page(page 3), where m,n $\in \{1,2,...P\}$ Based on this correlation function and example of (FSC-MPC)from Table I, the auto- and cross-correlation values of the (FSC-MPC) for the data stream of "10101" are displayed in Figs. 1–3.

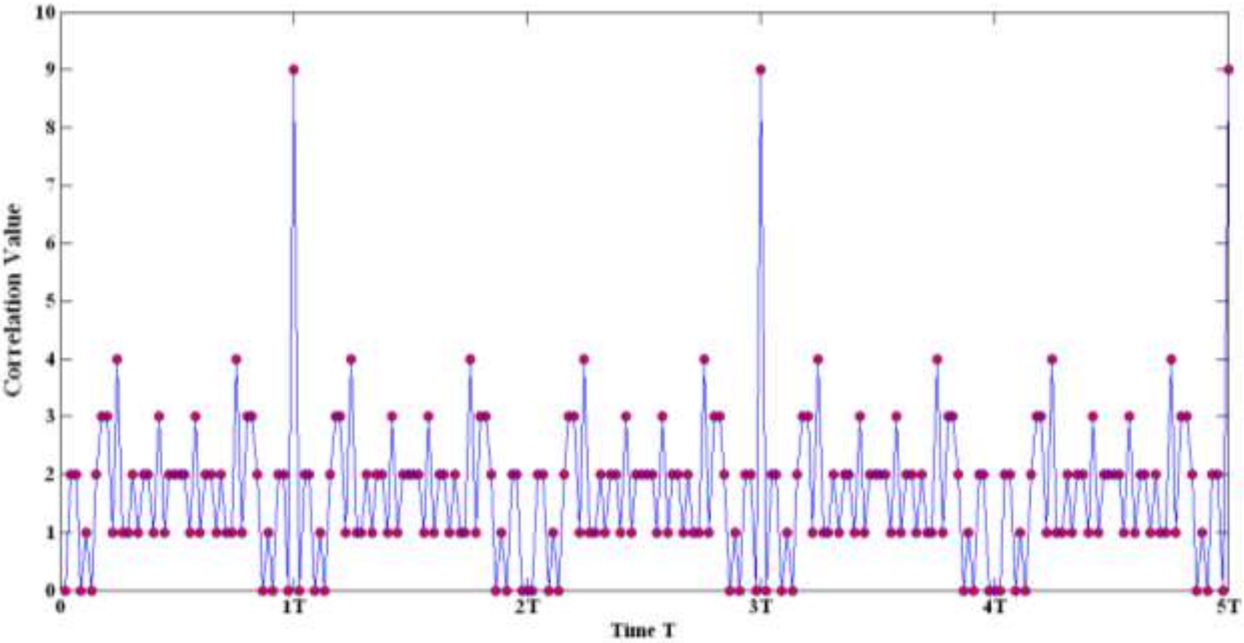

Fig. 1. Autocorrelation of (FSC-MPC) of C_{30} for the data stream of 10101(T is synchronization time equal to the code length)

In Fig. 1, the autocorrelation values of C_{30}at every chip synchronous position T, which is equivalent to the code length are displayed. As expected, the peak value is at 9, i.e., P+4.

In Fig. 2, it can be seen that the value of the cross correlation of two sequences from the same group, e.g., C_{30} and C_{31} , at every synchronized time T is “0,” which implies perfect orthogonality.

Two other sequences from different groups, e.g., C_{30} and C_{40} are presented in Fig. 3 yielding a value of “1” for the same data stream at every synchronized time T . It can be seem from Figs. 1–3 that the sequences follow the data stream as a result of CDMA encoding.

For comparison purposes the auto- and cross-correlation values of MPC, DPMC, and EMPC are calculated and the results are reported in table 1. The comparison reveals that

(i) The auto-correlation of the (FSC-MPC) is enhanced remarkably as its value increases by 5, 4, and 3 when it compared with the MPC, DPMPC, and EMPC, respectively. Accordingly, this will make the detection by the intended receiver easy and more accurate, see table 1.

(ii) Due to its high auto-correlation peak, (FSC-MPC) enhances the system security and lessens MAI compared with other codes.

*(iii)*The cross-correlation between codes from different groups of (FSC-MPC) decreases to 1 compared with 2 for DPMPC. This makes the optical decoder more efficient in extracting the required signal.

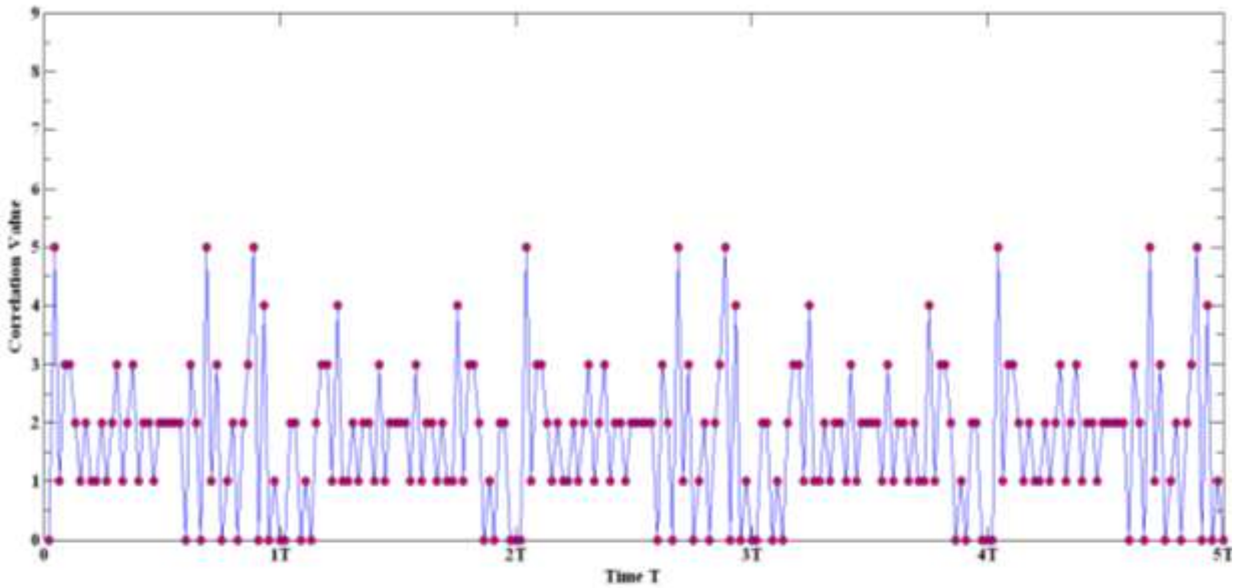

Fig. 2. Cross correlation of (FSC-MPC) sequences of C_{30} and C_{31} (same group) for the data stream of 10101 (T is synchronization time equal to the code length).

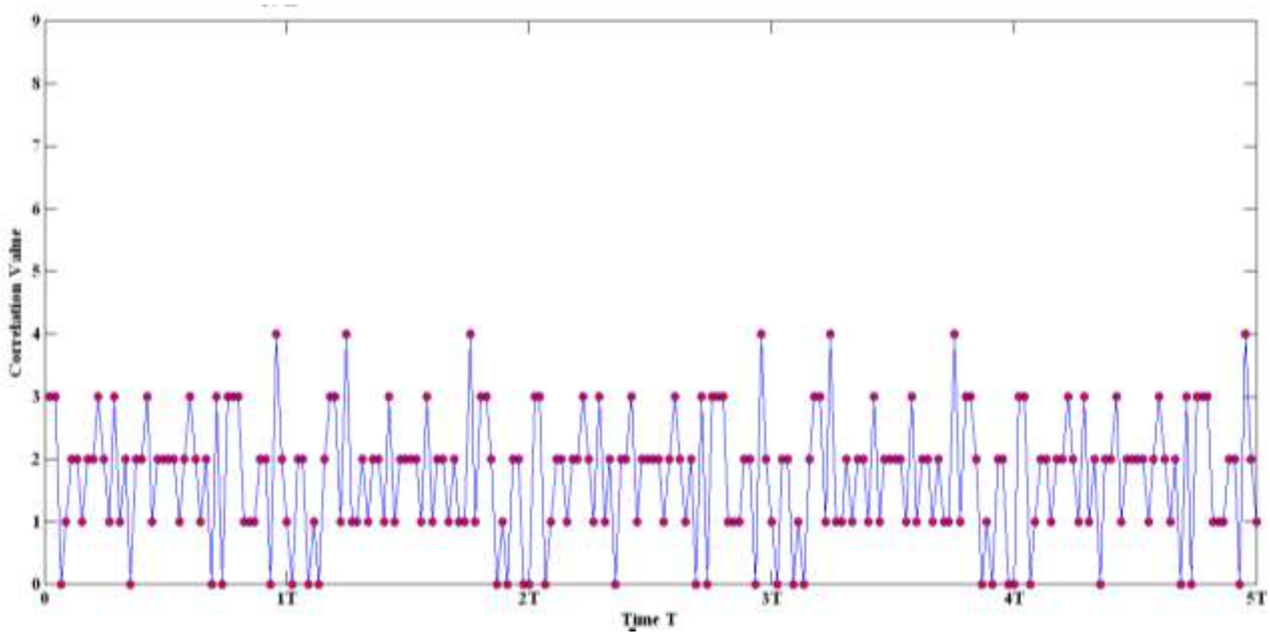

Fig. 3. Cross correlation of (FSC-MPC) sequences of C_{30} and C_{40} (different group) for the data stream of 10101 (T is synchronization time equal to the code length).

The main parameters of prime codes used here are listed in Table 2 for comparison purposes. Parameters values corresponding to P=4 are listed in Table 3. Note that the (FSC-MPC) gives the highest auto-correlation among the codes.

Table 2: Main parameters of various prime codes.

Parameters	Prime Codes			
	MPC	DPMPC	EMPC	FSC-MPC
Code length	P^2	$P^2 + 2P$	$P^2 + 3P$	$P^2 + 4P$
Code weight	P	P + 2	P + 3	P + 4
Auto-correlation	P	P + 2	P + 3	P + 4
Cross-correlation (same group)	0	0	0	0
Cross-correlation (different group)	1	2	1	1
Code cardinality	P^2	P^2	P^2	P^2

Table 3: Parameters values corresponding to P=4

Parameters	Prime Codes			
	MPC	DPMPC	EMPC	FSC-MPC
Code length	25	35	40	45
Code weight	5	7	8	9
Auto-correlation	5	7	8	9
Cross-correlation (same group)	0	0	0	0
Cross-correlation (different group)	1	2	1	1
Code cardinality	25	25	25	25

III. Theoretical Analysis of (FSC-MPC) and IP Routing in OCDMA Network

Figure (4) illustrates the encoder/decoder structure for OCDMA system employing optical modulation in the transmitter and heterodyne detection in the receiver. Usually, optical binary phase shift keying (BPSK) is used since it offers high receiver sensitivity compared with other coherent optical modulation schemes.

The issues of IP routing and traffic analysis in coherent OCDMA networks have been addressed carefully by Karbassian and Ghafouri-Shiraz [5] and their results are summarized here.

The performance of the system shown in Fig.(**4)** is analyzed when a based on coherent BPSK signaling is used. When a heterodyne detection is employed, the system operates under shot noise limited regime. Now assume the signal comes from the intended user.

According to this system, the signal is heterodyne detected, thus the decoder output contains both unwanted optical signal and required intermediate frequency (IF) signal which is selected through the lowpass filter shown in the figure. The IF signal level is proportional to the phase shift of the incoming signal, the higher the difference in phase between the two states the higher will be the difference between the two output voltage levels from the receiver. Decisions are taken by the IF receiver, from this system the basis of the IF signal level achieved from the following variable *V (T)* [13]

$$V(T) = \frac{\Re}{2N}\left[N \,.\, d_i + \sum_{i=1, i\neq l}^{K} d_i \,.X_{l_i}\right] + n_B\,(T) \qquad ..(3)$$

where

K= Number of simultaneous active users.

N= Length of the spreading sequence.

d_i= Transmitter information (data) bits.

n_B= Adaptive noise contains thermal noise and photo-detectors shot noise.

X_{l_i} = A random variable represents the cross-correlation between the code sequences used by the *l*th and the *i*th transmitters.

$\Re$ = PD responsivity.

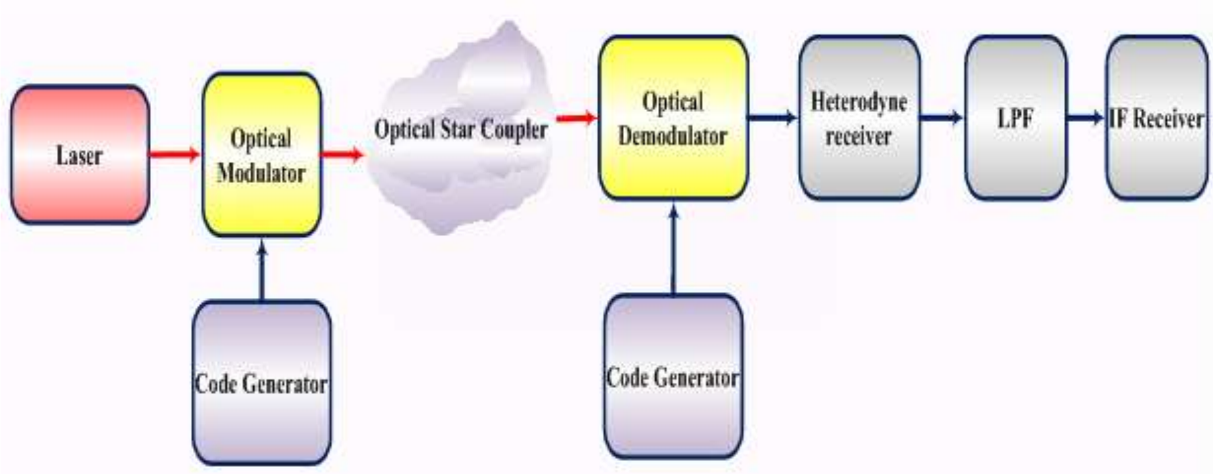

Fig. 4: OCDMA encoder/decoder structure.

If we define the new random variable, as

$$S = \sum_{i=1, i\neq l}^{K} d_i \, . X_{l_i} \qquad ..(4)$$

Its probability density function (PDF) can be obtained from the PDF of the random variable, X_{l_i}. Referring to eqns. (1,2), the in-phase cross-correlation values are either zero or one depending on whether the intended user shares the channel with either the same or the different groups respectively. Obviously, the zero value does not cause the interference due to perfectly orthogonal sequences, while the one value causes the interference which is just among intended user and $P^2 + P$ users from different groups (i.e., P^2 all users and P users from the same group of the intended user which are orthogonal). Therefore, cross-correlation values are uniformly distributed among interfering users, thus the PDF of S is derived as [12]

$$P\,(S = i) = \frac{i}{P^2 - P} \qquad ..(5)$$

Where *P(S = i)* is the probability that *S* assumes the value *i* (the number of actively involved users in the transmission). Based on the modulation scheme and knowledge of the interference PDF, the decoder probability of error, *Pdec(K)* denoting the BER, can be obtained as the following expression, conditioned to a number of simultaneous transmissions, *K* [12]

$$P_{dec} = \frac{1}{2}\sum_{i=0}^{s_m} erfc\,\left[\frac{N-i}{N}.\sqrt{r}\right].P(S=i) \qquad ..(6)$$

Where s_m is the largest value assumed by the random variable which depends on the number of active users, and *r* is the signal-to-noise ratio, *Eb/No*, defined by

$$r = \frac{E_b}{N_0} = \frac{\eta P_r}{2hfB_{IF}} \qquad ..(7)$$

where
η = Quantum efficiency of the PD.
P_r = Power of the received signal.
h = Planck's constant.
f = Optical frequency.
B_{IF} = The IF bandwidth.
E_b = One bit signal energy.

N_0 = Power spectral density of $n_B(T)$.

In order to minimize the laser phase noise or chirp, the bandwidth of the IF receiver should be practically wider than a matched filter whose noise bandwidth would be generally equal to the bit-rate [5].

In case of widening the matched filter bandwidth itself, to avoid the phase noise, the IF bandwidth still should be at least equal to the matched filter bandwidth, however this inherently increases the noise levels. Therefore, the bandwidth of identical to the chip-rate (wide enough regarding to the bitrate) has been considered for the IF bandwidth as an optimum bandwidth. On the other hand, when the bursty IP traffic is implemented to the OCDMA concept, to obtain the acceptable performance without overload, the designed transmission rate for each user should be larger than the average traffic arrival rate. Hence each "code channel" cannot be fully utilized. It is easy to see that the average number of active users in the network changes when different channel utilizations are applied. Since the performance of an OCDMA network is a function of the number of active users, the channel utilization will have a significant effect on the network performance. For this impact analysis, all users (i.e., ONUs) are assumed to have the same channel utilization in the network as defined by [5]

$$B = \frac{\text{Average Output Bitrate}}{\text{Maximum Transmission Bitrate}} \qquad ..(8)$$

Taking into account that the data bits are equiprobable then the probability of each transmitted bit is 0.5. Besides, user activity is only referred to sending data bit one thus the probability of sending bit one is 1/2. Since the users are sending data independently, the distribution of K active users out of the total number of users accommodated in the network (*U*) is *K/U*. Consequently, as each process is independent, the probability of *K* active users (P_{ac}) equals the probability of a transmitted data bit (i.e., data bit one) times the probability of *K* number of users out of *U*, involved in the transmission, times the ration of the occupied channel (i.e., channel utilization, *B*). This can be expressed as:

$$P_{ac} = \frac{1}{2} \times \frac{K}{U} \times B \qquad ..(9)$$

As being active (i.e., sending IP packet) has the binomial behavior, the active users among all users can be treated as a binomial distribution. Thus, the PDF of *K* active users are sending IP packet is obtained as [5]:

$$P_{IP}(K) = \binom{U}{K} P_{ac}^{K} (1 - P_{ac})^{U-K} \qquad ..(10)$$

The error PDFs of coherent CDMA encoding regarding the modulation scheme, eqn. 6, and the IP routing, eqn. 10, are independent processes, accordingly, the total probability of error, function of the number of active users *K*, $P_T(K)$, denoting BER, can be expressed by the decoder error PDF times IP traffic error PDF. It is then derived as:

$$P_T(K) = \sum_{k=1}^{K} P_{IP}\ (k).P_{dec}(k) \qquad ..(11)$$

IV. Operation Analyses of OCDMA Network

This section presents operation analyses of OCDMA network incorporating (FSC-MPC). The system under investigation is shown in Fig 4 which describes IP routing over OCDMA network node architecture. Figure 5 illustrates details of the optical encoder/decoder blocks introduced in Fig 4. Here a coherent modulation, namely, binary phase shift keying, is employed with heterodyne detection.

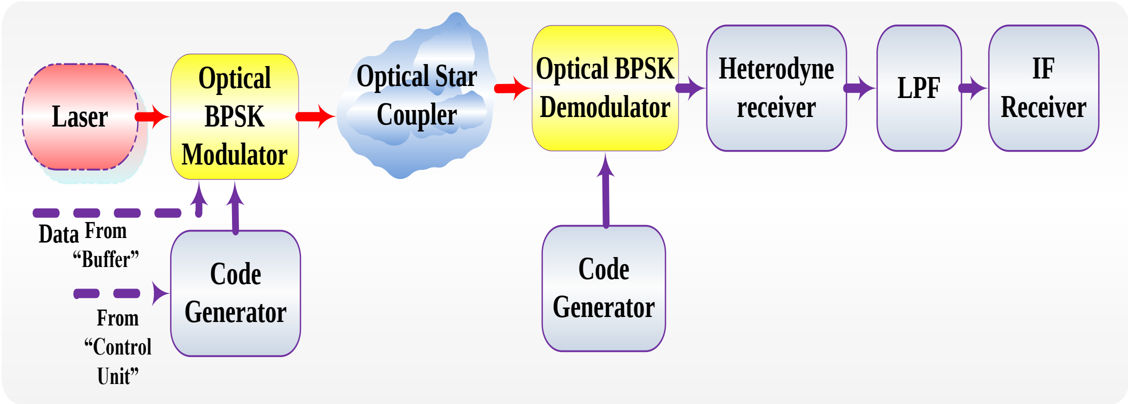

Fig.5 OCDMA encoder/decoder scheme.

The following steps describe the principles of operation for the encoder/decoder system

(i) In the transmitter side, each incoming data bit is encoded by means of the spreading code, i.e., (FSC-MPC) sequence. The sequence identifies the target receiver.

(ii) Let x_i is the used AE-MPC sequence, then either x_i or $\overline{x_i}$ is transmitted depending on whether a logic ONE or a logic ZERO data bit is to be sent. In binary notation $S = \overline{x \oplus d}$

Where

x = Spread sequence

d = Data

S = Encoded data

(iii) The optical modulator rotates the phase of the optical carries generated from the semiconductor laser during each chip interval (i.e., during each symbol forming the code sequence) by 0 or 180° depending on the state of the encoded data.

(iv) The decoder performs a correlation between the received signal and its own sequence (address). All the signals except the properly encoded one will yield interfering distortion where the latter will give rise to a correlation peak.

(v) The optical heterodyne receiver employed here uses a local semiconductor laser (i.e., optical local oscillator). The fields of the local oscillator and the incoming optical signal are mixed by the photodiode and yields an intermediate frequency (IF) electrical signal. An optical frequency recovery circuit is used here to keep the difference between the transmitter optical carrier frequency and the local oscillator frequency (i.e., IF frequency) constant.

V. DISCUSSION OF RESULTS

The numerical results are presented based on the above analysis. The parameters used for the simulation are listed in Table 4.

Table:4 Parameters values used in the simulation.

Parameter	Value
Optical Wavelength, λ	1.550 μm
PD Quantum Efficiency, η	0.9
IF Bandwidth	100 GHz
Chip-rate	100 Gchip/s
Prime Number, P	19
Received Signal Power, Pr	-34 dBm

Figure (6) displays the dependence of BER on number of active users when (FSC-MPC) is used. The results are shown for three values of channel utilization, B=1, 0.5 and 0.2, when the received signal power is -34 dBm. Investigating the results in this figure highlights the following findings

(i) The BER increases with number of active users K till a saturation level is achieved.

(ii) A BER<10^{-9} cannot be achieved when B= 1 and K> 6.

(iii) The BER is an increasing function with B. For example, a BER = 5.015×10^{-9}, 2.251×10^{-10} and 3.66×10^{-11} is is achieved when B=1, 0.5, and 0.2 assuming K=30 users.

The calculations are carried further to investigate the effect of received signal power on BER characteristics when (FSC-MPC) is used. The results are depicted in Fig. (7) when K= 100. As expected, the BER performance is enhanced with increasing the level of the received signal power. For example, a BER of 10^{-9} and 10^{-12} are achieved when Pr= -33.5 and -32.0, -34.5 and -33.5 and -35.5 and -34.0) when B= 1, 0.5 and 0.2 respectively. Note that the BER almost decreases linearly with increasing received power measured in dBm.

Tabel 5 lists the received signal power required to achieve a BER of 10^{-9} for IP-based OCDMA network for different values of channel utilization B and number of active users, K. The results are reported for different types of codes for comparison purposes. Investing the calculated results of fig 5 reveals that the proposed (FSC-MPC) code doesn't affect the level of received signal power required to achieve the desired BER as compared with the other existing codes.

Table 5:Received signal power required to achieve a BER of 10^{-9} for IP-based OCDMA network operating with different codes.

Code	Received Signal Power, Pr (dBm)								
	K=10			K=30			K=60		
	B=1	B=0.5	B=0.2	B=1	B=0.5	B=0.2	B=1	B=0.5	B=0.2
MPC	-33.77	-34.48	-35.17	-33.47	-34.47	-35.17	-33.44	-34.47	-35.17
DPMPC	-33.78	-34.48	-35.17	-33.50	-34.47	-35.17	-33.47	-34.47	-35.17
EMPC	-33.78	-34.48	-35.18	-33.51	-34.48	-35.18	-33.48	-34.48	-35.18
FSC-MP	-33.4	-34.1	-34.7	-33.2	-34.1	-34.7	-33.44	-33.9	-34.7

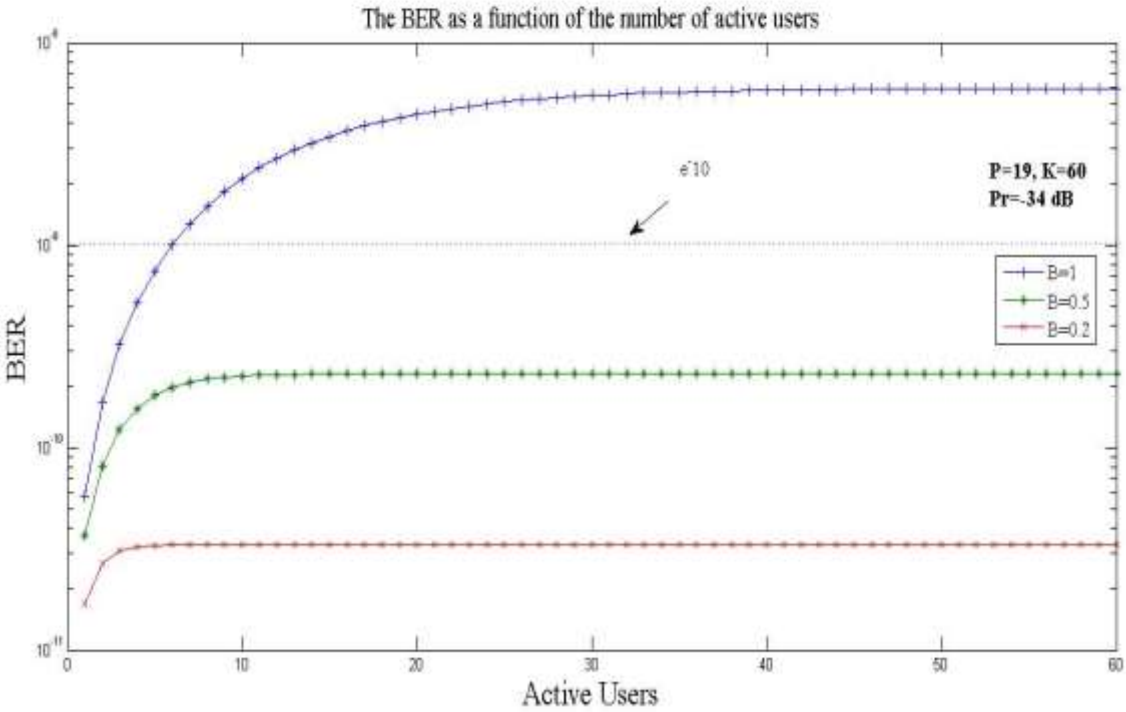

Fig.6 BER for different numbers of active users when (FSC-MPC) is employed in the OCDMA network.

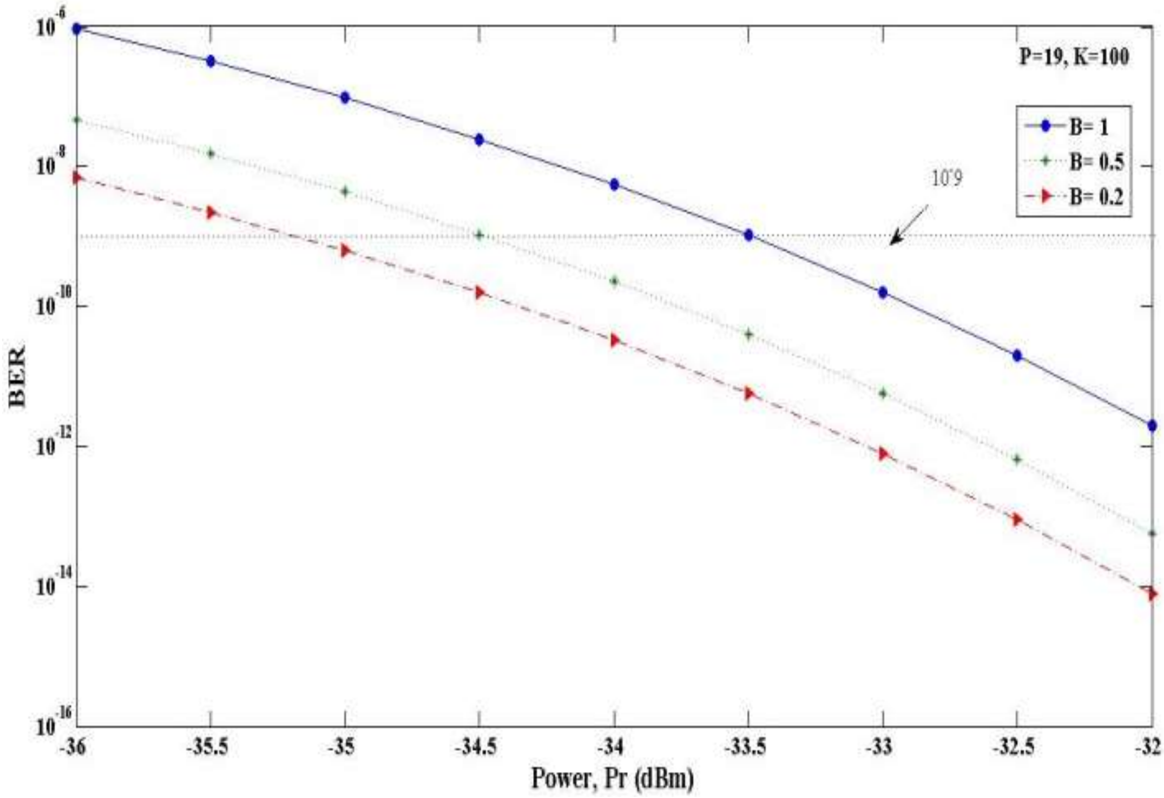

Fig. 7: Effect of received signal power on BER of OCDMA network when (FSC-MPC) is used with K=100.

VI. CONCLUSION

The "FSC-MPC," as a new family of optical spreading sequences, is introduced for optical CDMA systems.The proposed code has a code length of (P^2+4P) and code weight of P+4, where P is the prime number used to generate the code. These values are to be compared with (P^2+3P) and P+3, (P^2+2P) and P+2 and P^2 and P for the enhanced modified prime code (EMPC), double padded modified prime code (DPMPC) and modified prime code (MPC), respectively, reported in the literature. The correlation properties of the new code have been investigated as criteria to test the proposed code. The FSC-MPC applied into IP routing schemes over coherent optical code-division multiple-access (OCDMA) network. IP traffic transmission over this network has also been analyzed.

The BER of the IP-based OCDMA network depends on the error produced by both IP routing and detection processes.The BER increases with the number of active users till a saturation level is achieved. Further, the BER is an increasing function with channel utilization. Finally, the evaluation of these codes can advance the system performance additionally, while increasing multiplicity grows the system complexity

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