PERFORMANCE ANALYSIS OF MWOOC AND OCFHC/OOC

OPTICAL ORTHOGONAL CODES

Thesis submitted in the partial fulfillment of requirement for the award of degree of

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NEW DELHI, INDIA

DECLARATION

I hereby certify that the work which is being presented in this thesis entitled **"PERFORMANCE ANALYSIS OF MWOOC AND OCFHC/OOC OPTICAL ORTHOGONAL CODES"** by me in partial fulfillment of the requirements for the award of degree of Master of Technology in Electronics and Communication Engineering from Delhi Technological University, is an authentic record of my own work carried out under the supervision of Dr.Yogita Kalra

The matter presented in this thesis has not been submitted in any other university for the award of any other degree.

Date: **Tarun Singh Hayaran**

(2K13 / MOC / 14)

It is certified that the above statement made by the student is correct to the best of my knowledge and belief.

Date: **Dr. Yogita Kalra**

Department of Applied Physics

ABSTRACT

With the rising challenges of coping up with the effective utilization of bandwidth due to increasing number of users in communication system, it is our utmost requirement to reduce the probability of bit error i.e. bit error rate as far as possible.

The large bit error rate degrades the signal to noise ratio at the receiver end. The bit error rate arises due to the fact that when various user communicate using a single channel, there arises significant amount of interference and crosstalk in channel which are responsible for the reason of degradation of signal to noise ratio at receiver.

Here we are introducing couple of coding techniques which reduce the bit error rate by using optical CDMA techniques. These techniques are MWOOC and OCFHC / OOC codes. The bit error rate of the system employing these coding techniques are evaluated and then there performance and their impact on decreasing in effective bit error rate of the system is evaluated for several users communicating over a channel.

Their mathematical analysis and simulation is done which reveals the effectiveness of these coding techniques in reducing the bit error rate of systems.

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TARUN SINGH HAYARAN

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CHAPTER 1

INTRODUCTION

1.1 Code Division Multiple Access (CDMA)

Code division multiple access (CDMA) is a kind of multiplexing and also a method of multiple access to a medium such as frequency channel, where different users employ the medium at the same time using various unique code sequences. In CDMA, every user is allocated the entire spectrum all the time and CDMA uses unique codes to spread the baseband data for transmission. In optical CDMA, each user is identified by different codes or addresses. In a particular technique, a CDMA user puts its codes in each data bit and initiates transmission [1]. In Optical CDMA, the optical signal carrying the data exhibits a set of signal processing operation. This modifies it's time and/or frequency, in a way recognizable only by the receiver.

1.2 Optical Code Division Multiple Access

This OCDMA combines the large bandwidth of optical with the flexibility of the CDMA technique to achieve high speed connectivity. In long haul optical fiber transmission links and networks [2], the information consists of a multiplexed aggregate data stream originating from many individual subscribers and normally is sent in a well-timed synchronous format. The design goal of the Time Division Multiplexing (TDM) process is to make maximum use of the available optical fiber bandwidth for information transmission, since the multiplexed information stream requires very high-capacity links. To increase the capacity even further, Wavelength Division Multiplexing (WDM) techniques that make use of the wide spectral transmission window in optical fibers are employed. As an alternative to these techniques in a local area network (LAN), Optical Code Division Multiple Access (OCDMA) has been examined. WDM and TDM system imposes higher cost and complexity in LAN therefore; OCDMA finds its place to conceal the data content in LAN [3]. For long haul, high speed LAN and MAN networks, this OCDMA system is an essential part of the digital communication system [4]. The challenge with optical CDMA system is to maintain the performance of the system and offer high bandwidth in case of high number of users at minimum cost. On the other hand, In OCDMA system the BER degrades by the multiple access interference which comes from all other active users. This in turn ultimately limits the number of active users in a given OCDMA networks.

Table 1.1 Comparison of Optical CDMA with Wireless CDMA

Parameters	Wireless CDMA	OCDMA
1) Carrier	Micro-& millimeter wave Limited availability	Lightwave 4000-70000 GHz
2) Spread/Despread	Frequency Domain	Time Domain
3) Code	Direct Sequence SS Frequency Hopping	Direct Sequence SS Wavelength Hopping
4) Encoding/Decoding	RF Domain	Optical Domain
5) Transmission Medium	Free Space (Air), Non-Dispersive Large Attenuation Linear	Closed-Spaced(Optical Fiber) Dispersive Low attenuation Nonlinear
6) Problems in Propagation	Far-near effect Multipath effect	Dispersion effects Nonlinear effect Interferometric effects

An OCDMA system may be defined by a data source, containing the data that will be sent, followed by an encoder and a laser which maps the signal from electrical domain to an optical pulse. At the receiver, an optical correlator is used to extract the encoded data. Many subscribers transmit data simultaneously. Each user has its own codeword, which is approximately orthogonal to all other code words. The data which is encoded is send to the Nx1 star coupler, from where the optical channel carries the signal through the optical fiber and couples to a 1xN coupler and broadcast to all nodes. All users encoded data are then added together chip by chip and the result, which is called the superposition, is sent over the channel. The individual receivers consisting of optical correlator continuously observe the superposition of all incoming pulse transmission and recover the data from the corresponding transmitter. This is done by correlation between the incoming signal and stored copies of that user unique sequence. The correlator will give a peak, if the incoming stream of optical pulses contains the unique sequence and the presence of other users will be considered as noise. The decoding process is accomplished by using optical correlation. The receiver performs a time correlation operation to detect only the specific desired codeword. All other code words appear as noise due to de-correlation. For detection of the message signal, the receiver needs to know the codeword used by the transmitter. Each user operates independent with no knowledge of the users [5]. The presence of the light pulse represents the binary bit 1 and the absence of the light pulse represents the binary bit 0.

1.3 Fundamental Concept of Optical CDMA

High speed can be achieved in optical CDMA by combining large bandwidth of the optical medium with the flexibility of CDMA. CDMA was originally investigated in the context of radio frequency (RF) communications systems and was first applied to the optical domain in the mid 1980 by Prucnal and Salehi [6]. They tried to use the excess bandwidth in single-mode fibers to modulate low-information rate electrical signals into high rate optical pulse sequences to achieve random, asynchronous operation without the need for a centralized network controller.

This is done by correlation between the incoming signal and stored copies of that user unique sequence. The correlator will give a peak, if the incoming stream of optical pulses contains the unique sequence and the presence of other users will be considered as noise. The decoding process is accomplished by using optical correlation. The receiver performs a time correlation operation to detect only the specific desired codeword. All other code words appear as noise due to de-correlation. For detection of the message signal, the receiver needs to know the codeword used by the transmitter. Each user operates independent with no knowledge of the users. The presence of the light pulse represents the binary bit 1 and the absence of the light pulse represents the binary bit 0.

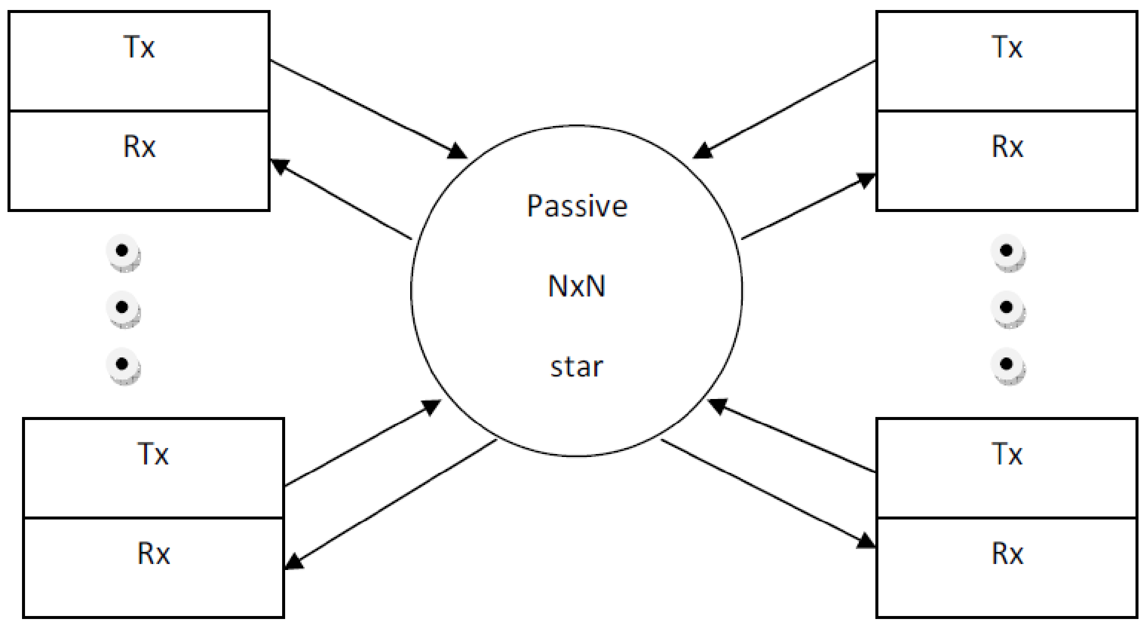

Figure 1: A Fiber optic CDMA network using a passive N x N Coupler

In an OCDMA system, every bit is divided into "n" number of time periods known as chips. On sending short optical pulse during some chip intervals, represented as 1 and no pulse represented as 0, an optical sequence is created. Each user has a unique sequence i.e. each user is assigned one signature sequence called codeword. When this sequence is sent, it represents that user with that unique has sent the information bit"1". If the information bit is 0, means that user sends the corresponding length of zeroes i.e. no light pulses during that interval. Since each data bit is represented by high rate sequence, the bandwidth of the data stream increases. Therefore O-CDMA is spread–spectrum technology.

1.4 Principle of OCDMA

The principle of OCDMA employs spread-spectrum techniques, which are widely used in mobile-satellite and digital-cellular communication systems. Its spreads the energy of the optical signal over a frequency band much wider than the minimum bandwidth required to send the information. This spreading is done by a code independent of the signal. Thus, an optical encoder is used to map each bit of information into a high rate (longer code length) optical sequence. In SS transmission, the input signal is coded in a way that its spectrum spreads over a much wider range than the original signal. At the receiver, the spreaded signal is decoded and its original form is restored. While de-spreading the input signal, unwanted noise or intentional jamming signals are spreaded, i.e. though input signal and distortion might carry the same power, the power spectral density of the distortion covers a wider area, thus, enabling the receiver to detect the input signal and noticing some additional, but only weak noise. Furthermore a de-spreading of the input signal is impossible without exact knowledge of the code sequence, thus increasing the security of the transmission.

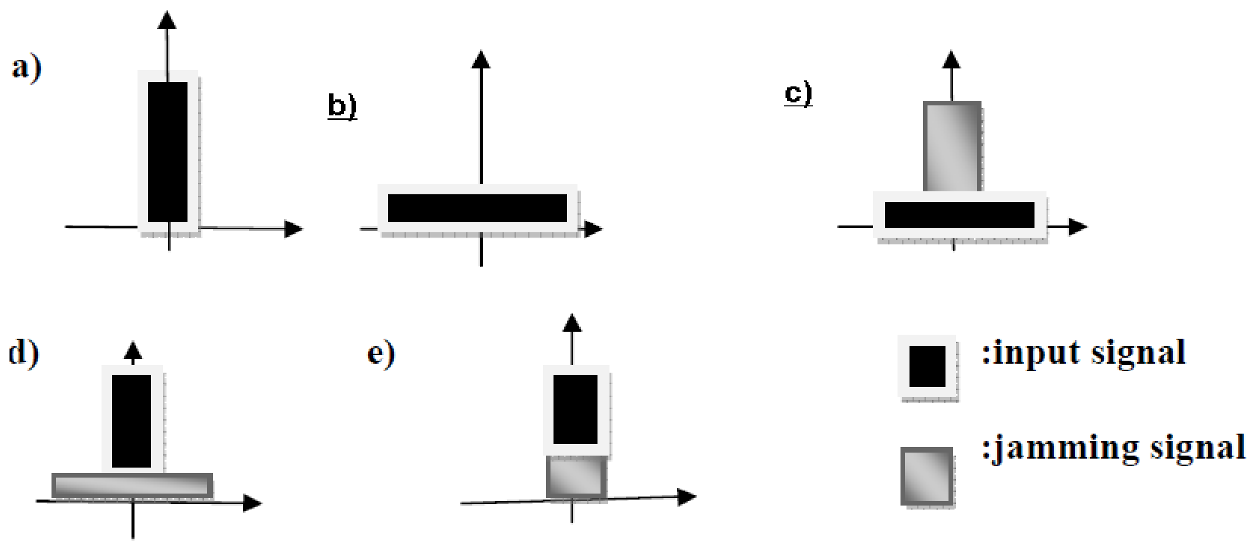

Fig 2: OCDMA

1.6 Advantages of OCDMA

1. All Optical Processing: The coding operations are performed all optically in OCDMA that is desirable for the entire PON requirement.

2. Full asynchronous access: OCDMA network can work with fully asynchronous access without the requiring of complex and expensive electronic equipment and protocols.

3. Fair division of bandwidth: Dynamic allocation of bandwidth makes the adding of new subscribers or removing unsubscribed users from the network much easy.

4. Latency access: OCDMA could also provide low delay of access as the coding operations are performed all optically and passively. Multiple logical topologies can be supported simultaneously on the same physical network.

5. Flexibility: OCDMA systems have the potential to be very flexible.QOS guarantees could be managed in physical layer by assigning different code in OCDMA networks.

6. Network Control and Management: If the optical codes are designed such that the non-shifted autocorrelation peak is large and the shifted autocorrelation peak is minimized, each receiver is able to operate asynchronously without the need for a global clock signal. Since the number of unique codes is equal to the number of stations on the network, there is no need for a centralized node to arbitrate channel contentions. Adding a new user on an OCDMA system is as easy as assigning a new code. Unused codes are provided to the new user. If no free codes were available, the system could be upgraded to support more users by increasing the amount of time or wavelength domain spreading. The amount of coding overhead could also be increased if it were being violated.

7. Service Differentiation: CDMA offers the possibility of offering differentiated service or QOS at the physical layer. Through the use of multirate OCDMA codes different service classes for multimedia traffic can be defined.

8. Security: Finally, optical CDMA would offer an advantage that current access networks do not offer: inherent security. Sophisticated encryption is not required because OCDMA is already encoded and does not suffer from the same type of adjacent –channel crosstalk as DWDM.

1.7 Disadvantages of OCDMA

Inspite of being a promising technology, there are still many drawbacks that limit its wide scale deployment. Following are some major disadvantages:

1. Basic limitation: A basic limitation of OCDMA using a coded sequence of pulses is that as the number of user‟s increases, the code length has to be increased in order to maintain the same performance .Since this leads to shorter and shorter pulses, various ideas for solving this problem have been proposed. Alternatively, frequency domain methods based on spectral encoding of broadband incoherent sources e.g. LEDs or Fabry Perot Lasers have been proposed [18].

2. Cost: The biggest barrier to the wide scale deployment of OCDMA is "cost". Cost not only affects OCDMA rather other multiple access technologies like WDMA also suffers from the same problem. They are also constrained by the need for expensive optical hardware. The need for all optical encoding/decoding hardware and broadband light source for OCDMA makes it much expensive.

Remedy to cost problem

If an array of tunable lasers could be integrated on the same substrate as a Waveguide based encoder and modulator costs as well as size would drop rapidly, while reliability and robustness would also improve. Install a single broadband light source at the head-end. The multi-wavelength light could be distributed by fiber to all nodes on the network for use in encoding data on the return path. So each node requires only encoding/decoding hardware and not a dedicated broadband source.

3. Multiple Access Interference (MAI): The optical CDMA systems suffer from other simultaneous users. As the number of simultaneous users increases, the bit error rate (BER) degrades because the effect of MAIs increases. A critical limitation of OCDMA networks is the reduction of throughput when many users are simultaneously trying to transmit over common medium, thus producing extreme congestion at high network loads [7]. In addition, even if the received optical power is large enough i.e. if the effect of noise is small, the effect of MAIs is constant because the power of the transmitted pulse is equal among all users.

Light pulses transmitted by different users may overlap. As the light source in each transmitter is assumed to be total intensity at a chip is the sum of the intensities of the individual light pulses existing in that chip. The codes are designed to be sufficient different that the probability of mistaking one code for another is very low. However, when many users are transmitting simultaneously, many overlaps may occur. A receiver may then conclude that its target code was sent. As a result, a receiver may incorrectly detect other users codewords, resulting in packet transmission error, this phenomenon is known as an error due to multiple access interference (MAI). As more users share the channel simultaneously, the effect of MAI becomes more significant. MAI increases the level of a pulse by integer multiple of the original pulse level. When pulse power is high and the photo detectors are of low noise, MAI is the dominant cause of performance degradation in OCDMA systems.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Prior to starting of my thesis, it is important to have a deep understanding on the existing pages of optical OCDMA and its various types of codes used in this OCDMA. The main sources of the information for the dissertation are books, journal, thesis and the internet.

2.2 Literature Survey

Sangwook Han examined optical CDMA communication techniques with optical orthogonal codes. Simulations that show the desired properties of theses codes and their use in optical CDMA also reported and demonstrated this OCDMA for two user synchronous channels, for two user asynchronous channels and for K-user synchronous channel. Based on the simulations, they investigate the properties of optical CDMA and probability of error was also evaluated.

István Frigyes showed that as spectrum spreading and CDMA proved themselves as very efficient in radio communication CDMA application in optical communication seems to be reasonable as well. Research in this field started two decades ago or so and is still flourishing. In this paper – after giving a brief listing of relevant concepts in optical communications – concepts of optical spectrum spreading, techniques of temporal and spectral coding was described, possibilities of long-haul application and some networking issues were also discussed.

Jawed A. Salehi derived the bit error rate of the proposed FO-CDMA system as a function of data rate, code length, code weight, number of users, and receiver threshold; and they discuss the performance characteristics for a variety of system parameters. Furthermore, they discuss a means of reducing the effective multiple-access interference signal by placing an optical hard-limiter at the front end of the desired optical correlator. They calculate the performance of the FO-CDMA with an ideal optical hard limiter, and they show that using an optical hard-limiter would, in general, improve system performance.

Here we are introducing couple of coding techniques which reduce the bit error rate by using optical CDMA techniques. These techniques are MWOOC and OCFHC / OOC codes. The bit error rate of the system employing these coding techniques are evaluated and then there performance and their impact on decreasing in effective bit error rate of the system is evaluated for several users communicating over a channel.

Their mathematical analysis and simulation is done which reveals the effectiveness of these coding techniques in reducing the bit error rate of systems.

CHAPTER 3

MULTI-WAVELENGTH OPTICAL ORTHOGONAL CODES

(MWOOC)

3.1 Introduction

It is our utmost requirement in any wavelength hopping time spreading codes to keep the cardinality as high as possible and cross correlation value should be low. Low value of cross correlation value offers us to distinguish desired signal from the interfering signal more efficiently.Also there is requirement of high spectral efficiency. It must be kept in mind two dimensional codes thus employed should not increase bit error rate on increasing number of users.

MWOOC are another type of two dimensional codes which offers the independent selection of number of wavelengths and the corresponding code lengths so as to increase the system capacity because the various time slots available are very limited and system capacity depends upon number of active users(or the number of wavelengths selected or employed) in system.

MWOOC are new types of codes which meet the above mentioned requirement criteria and fall in the category of two dimensional codes so as to improve the system performance by improving the code efficiency and increasing the signal to noise ratio. It offers high coding efficiency which corresponds to high speed and high spectral efficiency. Due to low cross correlation value multi user intereference is kept as low as possible.

MWOOC are types of codes which employs two dimension i.e. wavelength and time so as to increase the number of users at same time with low multi user interference.

Mathematical Analysis-

$M \times N$ matrices are taken where M corresponds to number of waveleghths (rows) and N corresponds to number of time slots (columns).

The format of an two dimensional optical orthogonal code is $(n, w, \lambda a, \lambda c)$ where

n= code length,

w= code weight’

λa= autocorrelation function,

λc= cross correlation function.

1. A two dimensional code where an OOC was used as time spreading code and it corresponds to N=Nooc and prime code was used as wavelength hopping code and it corresponds to M=p^2 such that

$$M \times N = Nooc \times p^2$$

And where,

p^2 = length of prime sequence

Nooc = length of OOC

The Nooc comes out to be

$$Nooc = [p(p-1) \times Øooc] + 1$$

Where

Øooc = cardinality of OOC.

Thus the overall cardinality of code is-

$$Ø! = Øooc \times Nooc \times p$$

And cross correlation value is choosen to be 1.

Drawback- Even though the cross correlation value is minimal but cardinality is too low.So we have to move onto another technique.

2**.** The next technique employs only prime sequence codes both for wavelength hopping and time spreading such that N = p and M = p^2.

Now M×N = p × p^2 and overall cardinality Ø! = p(p-1) with $\lambda c = 1$.Here also cardinality is low even if $\lambda c = 1$.

3. Next coding employs Extended Quadratic Congruence Codes (EQC) for time spreading and prime sequence codes for wavelength hopping such that,

$$M \times N = p \times p \times (2p-1)$$

And overall cardinality

$$Ø! = p \times (p-1)^2$$

With $\lambda c = 2$.

Here we are met with the higher cardinality value as overall cardinality is quadratic equation but here cross correlation value is large i.e. it is equal to 2,which will increase the multi user interference and degrade the system performance.So we move on to next scheme.

4. It uses prime sequence for time spreading and EQC for which is vice versa of above scheme.

$$M \times N = p \times p^2$$

And overall cardinality is

$$Ø! = p^2 \times (p-1)$$

With $\lambda c = 2$.

Hence we can see that by implementing this technique the problem of above schemes is not resolved by this method as cardinality is higher but at cost of higher cross correlation.

5. Finally a new two dimensional code came into existence called as MWOOC, which uses OOC codes for time spreading and prime sequence for wavelength hopping.

Thus,

$$M \times N = p \times N_{ooc}$$

And overall cardinality

$$Ø! = Ø_{ooc} \times p^2$$

With $\lambda c = 1$.

Where,

$Ø_{ooc}$ = cardinality of OOC codes alone.

CONCLUSION- Thus, MWOOC overcomes all previous drawbacks and meets our requirement of low cross correlation and high cardinality as overall cardinality is quadratic and $\lambda c = 1$.

3.2 Performance Analysis of BER of MWOOCs-

The performance analysis starts with the consideration of average probability ‘q’ to line up (or hit) with one of the pulses in a multi wavelength codeword with a pulse in other code.’Th’and ‘k’ are the decision threshold of the receiver and the total number of simultaneous users.

The error probability with hard limiting (wavelength aware detector) is

$$\mathbf{Pe} \quad = [\frac{1}{2}] \sum_{i=0}^{Th} \binom{w}{i} (-1)^{i} (1 - \frac{qi}{w})^{k-1}$$

Where usually Th = w for optimal operation.

Where,

q^0 = [(w^2) (Øooc × p -1)] ÷ [(2) (Nooc) (Øooc × p^2 -1)]

q^i = [{(w^2) (Øooc × p-1)} + (w-1)^2] ÷ [(2) (Nooc) (Øooc × p^2 -1)]

3.3 Analysis of (7, 3, 1, 7) MWOOC-

Coding and Simulation-

```
w=3
n=7
phi=1
p=7
k1=[w^2*[phi*p-1]]
k2=2*n*(phi*(p^2)-1)
q0=k1/k2
k3=[w^2*(phi*p-1)]+(w-1)^2
qi=k3/k2
k=[0:5:40]


pe1=[1-[q0./3]].^[k-1]
pe2=[1-[qi./3]].^[k-1]
p1=0.5*[pe1-pe2]

plot(k,p1)
```

```
w=3
n=7
phi=1
p=7
k1=[w^2*[phi*p-1]]
k2=2*n*(phi*(p^2)-1)
q0=k1/k2
k3=[w^2*(phi*p-1)]+(w-1)^2
qi=k3/k2
k=[0:5:40]


pe1=[1-[q0./3]].^[k-1]
pe2=[1-[qi./3]].^[k-1]
p1=0.5*[pe1-pe2]

plot(k,p1)
```

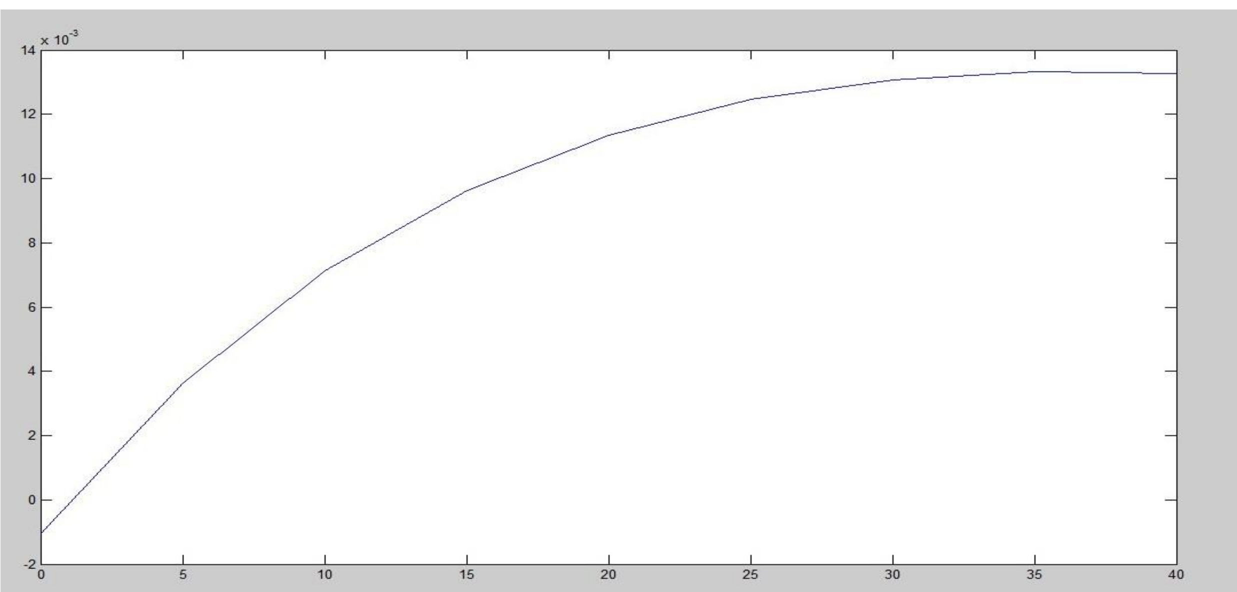

Figure 3: Pe vs No of users of (7, 3, 1,7) MWOOC

3.4 Analysis of (31, 4, 2, 7) MWOOC-

Coding and Simulation-

```
w=4
n=31
phi=2
p=7
k1=[w^2*[phi*p-1]]
k2=2*n*(phi*(p^2)-1)
q0=k1/k2
k3=[w^2*(phi*p-1)]+(w-1)^2
qi=k3/k2
k=[0:5:40]


pe1=[1-[q0./4]].^[k-1]
pe2=6*[1-[qi./4]].^[k-1]
pe=0.5*[pe1-pe2]
plot(k,pe)
```

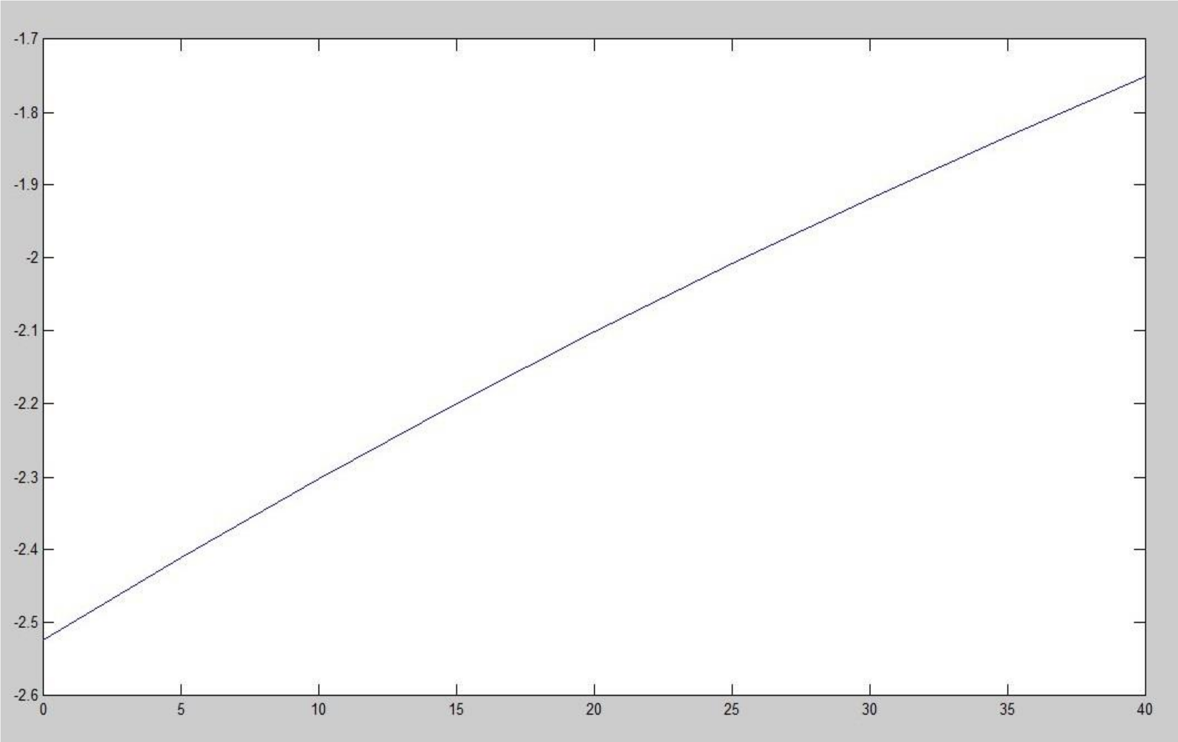

Figure 4: Pe vs No of users of (31, 4, 2, 7) MWOOC

3.5 Analysis of (41, 4, 3, 11) MWOOC-

Coding and Simulation-

```
w=4
n=41
phi=3
p=11
k1=[w^2*[phi*p-1]]
k2=2*n*(phi*(p^2)-1)
q0=k1/k2
k3=[w^2*(phi*p-1)]+(w-1)^2
qi=k3/k2
k=[0:5:40]


pe1=[1-[q0./4]].^[k-1]
pe2=6*[1-[qi./4]].^[k-1]
pe=0.5*[pe1-pe2]
plot(k,pe)
```

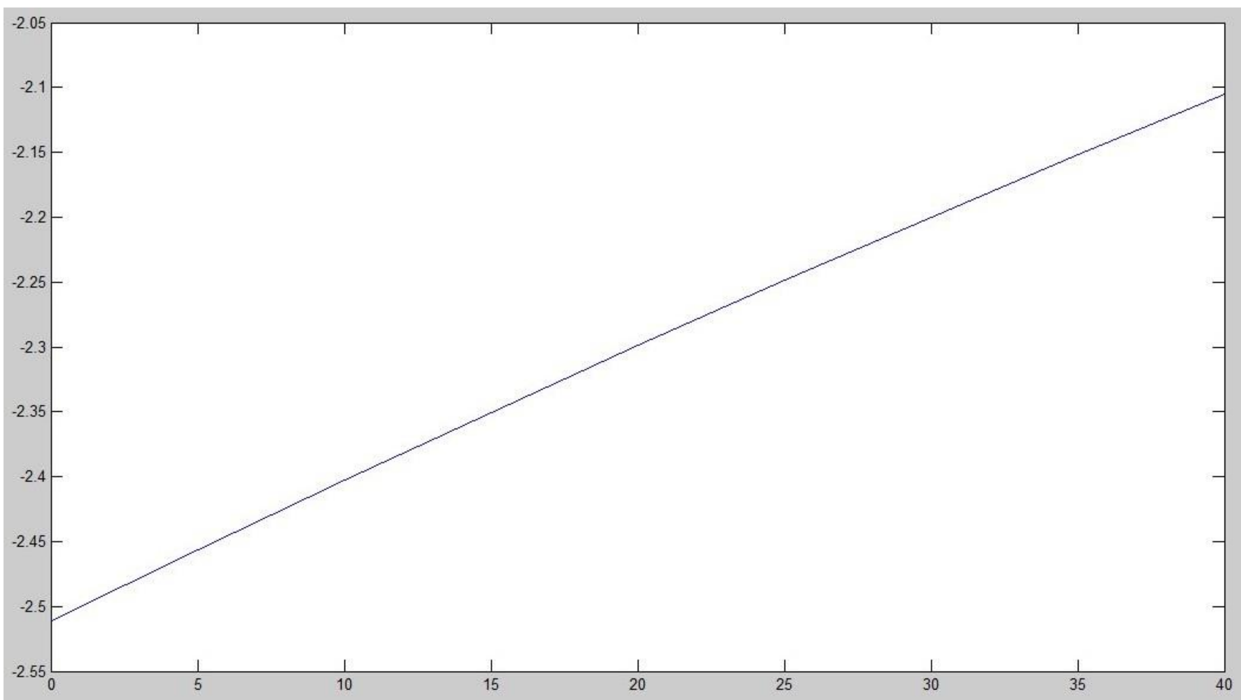

Figure 5: Pe vs No of users of (41, 4, 3, 11) MWOOC

3.6 Analysis of (41, 5, 2, 13) MWOOC-

Coding and Simulation-

```
w=5
n=41
phi=2
p=13
k1=[w^2*[phi*p-1]]
k2=2*n*(phi*(p^2)-1)
q0=k1/k2
k3=[w^2*(phi*p-1)]+(w-1)^2
qi=k3/k2
k=[0:5:40]
pe1=[1-[q0./5]].^[k-1]
pe2=[1-[qi./5]].^[k-1]
pe=0.5*[pe1-pe2]
plot(k,pe)
```

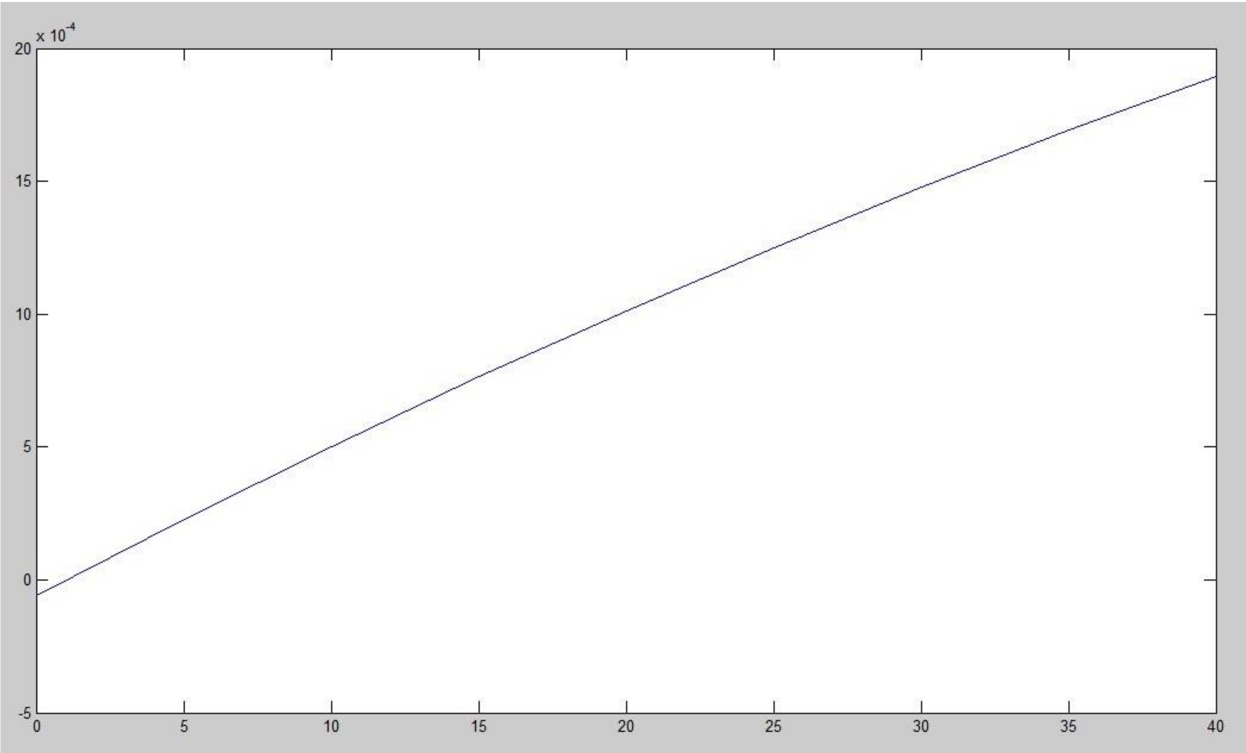

Figure 6: Pe vs No of users of (41, 5, 2, 13) MWOOC

3.7 Conclusion

Pe decreases as number of user k increases, but improves as p, w or N increases. But the decrease in Pe is restricted by the decrease in average hit probability q. The performance of code can be increased or decreased by changing the code length or the number of wavelengths alone.

CHAPTER 4

ONE CONCIDENCE FREQUENCY HOPPING CODE

(OCFHC / OOC)

4.1 Introduction

2-D OCFHC/OOC codes employ one-coincidence frequency hopping code (OCFHC) for wavelength-hopping and OOC used for time-spreading. As the prime code is an exclusive case of OCFHC for k=1, 2-D OCFHC/OOC don't have the limitation on the number of wavelengths to be a prime number. Hence, 2-D OCFHC/OOC codes are more flexible for the choice of the number of wavelengths, and have good correlation properties with their cardinalities asymptotically optimal.

Now, we construct 2-D OCFHC/OOC code and evaluate their performance.

4.2 Construction

OCFHC is used for wavelength hopping and OOC for time spreading. Its format is defined as- ($p^k \times N_{ooc}$, w, λ_a, λ_c) and code consisting of 0 and 1 can be constructed. The parameters are defined as follows-

'p^k' is the number of available wavelengths,

'w' defines code weight,

'N_{ooc}' is the code length.

The autocorrelation sidelobe is at $\lambda_a = 1$ and the cross correlation function is at $\lambda_c = 1$.Thus the code format gets reduces to ($p^k \times N_{ooc}$,w,1,1).Its construction is as follows-

1. We take a prime number 'p' and the number of available wavelengths p^k.

2 .On the basis of 1-D OOC, we construct $Ø_{ooc}$ codewords of an (N_{ooc},w,1) OOC.

3. 'w' elements form a group orderly and circularly from each codeword of the OCFHC. Hence each codeword generates (p^k-1) groups which have 'w' elements each.

4. Each element is regarded as the number of wavelengths to produce [p^k (p^k-1)] wavelength sequences. These wavelengths are now mapped at 1's in codeword.

5. Thus [$Ø_{ooc}$ p^k (p^k-1)] codewords are generated known as 'α' and is given as-

Øooc = [(Nooc-1) / (w (w-1)]

Where 'Øooc' is cardinality.

6. In codeword all 1's are replaced by same wavelength. Thus [Øooc × p^k] codewords can be constructed which are denoted as 'μ'.

The overall cardinality is-

Ø! = Øα + Øμ = [p^k (p^k-1) + p^k] × Øooc

Ø! = p^(2k) [(Nooc-1) / (w {w-1})]

4.3 BER of OCDMA Systems with 2-D OCFHC /OOC Codes

If 'Qi' is the average number of "hits" between a codeword α and μ. Then

Q1 = [{ (w^2) / (2 Nooc) } { p^k × t1 + t2} – {w / (2 Nooc) }] / [Ø! -1]

And

Q2 = [{ (w^2) / (2 Nooc) } { p^k × t1 - 1}] / [Ø! -1]

Where Ω and € are cardinalities of the (Nooc,w,1,1) OOC and the (p^k,w,1,1) OOC respectively and are given as

t1 = [(Nooc – 1) / (w (w-1))]

And

t2 = [(p^k – 1) / (w (w-1))]

Let Q indicate the avg. no. of " hits" between any two codes then

Q = [Øα / Ø!] × Q1 + [Øμ / Ø!] × Q2

The BER is given as

$$\mathbf{P} = \left(\frac{1}{2}\right) \sum_{i=Th}^{k-1} \binom{k-1}{i} q^{i}(1-q)^{k-1-i}$$

4.4 Analysis of [13 × (13 × 13),13,0,1] OCFHC / OOC Code-

Coding and Simulation-

```
p=13
k=3
n=13
w=13
K=[100:100:500]

phi=(n-1)/(w*(w-1))
phi1=[(phi)*(p^k)*((p^k)-1)]
phi2=(phi)*(p^k)
phi3=phi1+phi2
t1=[(n-1)/(w*(w-1))]
t2=((p^k)-1)/(w*(w-1))
q1=[[[(w^2)/(2*n)]*((p^k)*t1+t2)]-(w/(2*n))]/[phi3-1]
q2=[[(w^2)/(2*n)]*((p^k)*t1-1)]/[phi3-1]
q=[[phi1/phi3]*q1+[phi2/phi3]*q2]
```

```
q=0.032;
K1=40;
w=13;
n=K1-1;
r=0;
for i=w:K1-1
    r=r+1;
    nCi = nchoosek(n,i);
    terms(r)=nCi.*q.^i.*(1-q).^(n-1);
end
S1=sum(terms)
```

```
q=0.032;
K2=60;
w=13;
n=K2-1;
r=0;
for i=w:K2-1
    r=r+1;
    nCi = nchoosek(n,i);
    terms(r)=nCi.*q.^i.*(1-q).^(n-1);
end
S2=sum(terms)
```

```
q=0.032;
K3=80;
w=13;
n=K3-1;
r=0;
for i=w:K3-1
    r=r+1;
    nCi = nchoosek(n,i);
    terms(r)=nCi.*q.^i.*(1-q).^(n-1);
end
S3=sum(terms)
```

```
q=0.032;
K4=100;
w=13;
n=K4-1;
r=0;
for i=w:K4-1
    r=r+1;
    nCi = nchoosek(n,i);
    terms(r)=nCi.*q.^i.*(1-q).^(n-1);
end
S4=sum(terms)
```

```
q=0.032;
K5=120;
w=13;
n=K5-1;
r=0;
for i=w:K5-1
    r=r+1;
    nCi = nchoosek(n,i);
    terms(r)=nCi.*q.^i.*(1-q).^(n-1);
end
S5=sum(terms)
```

```
K=[K1,K2,K3,K4,K5];
S=[S1,S2,S3,S4,S5];
plot(K,S)
```

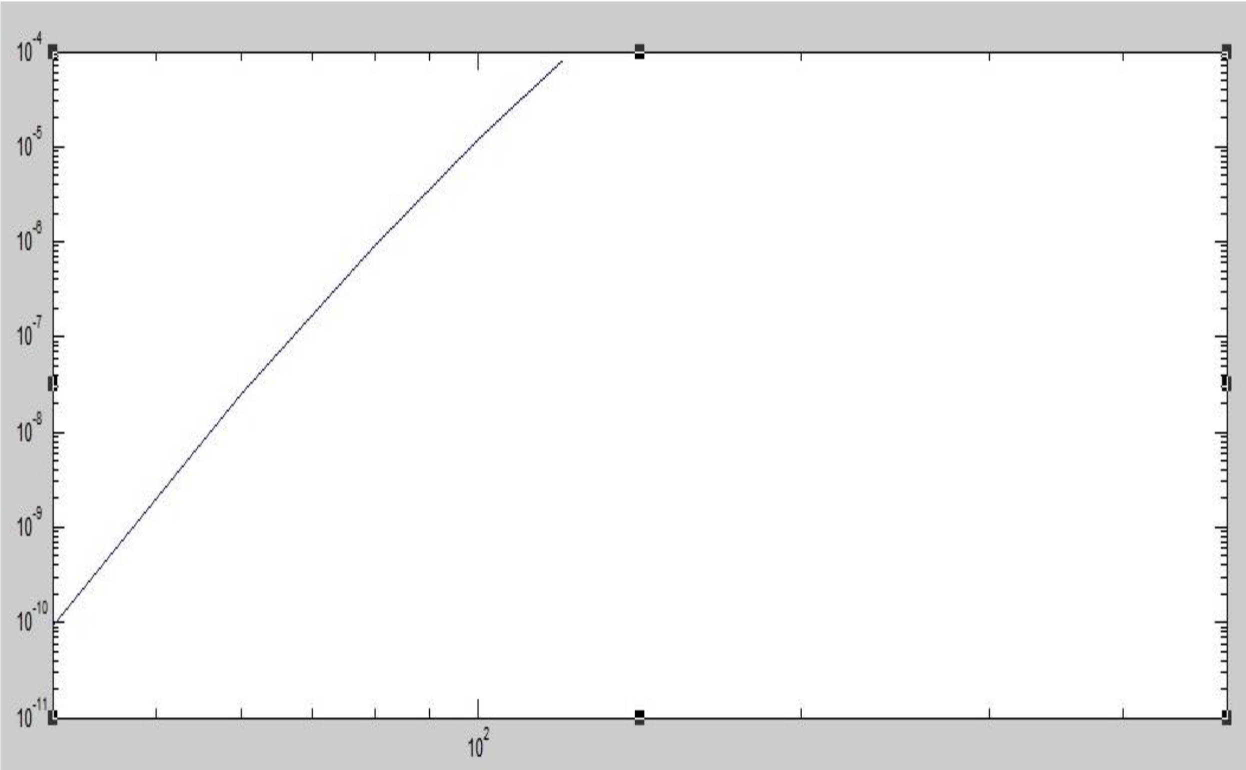

Figure 7: Pe vs K of [13 × (13 × 13),13,0,1] OCFHC/ OOC

CONCLUSION

Thus, we have demonstrated above the performance analysis of optical CDMA opting MWOOC and OCFHC coding techniques. The both techniques offer several advantages as well as disadvantages over each other. Both techniques are quit efficient in reducing the probability of error in transmission.

OCFHC can be used for large number of users giving less probability of error comparison to MWOOC.

Thus both techniques play an important role in reducing the BER of the systems.

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