STUDY AND IMPLEMENTATION OF CODES IN OPTICAL CDMA SYSTEM

Submitted in partial fulfillment of the Degree of
Bachelor of Technology

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CERTIFICATE

This is to certify that the work titled "PERFORMANCE OF OPTICAL CDMA IN TRANSMISSION SYSTEMS AND ANALYSIS OF PERFORMANCE OF DIFFERENT OCDMA CODES " submitted by "RAHUL SHARMA" in partial fulfillment for the award of degree of B.Tech of Jaypee University of Information Technology, Waknaghat has been carried out under my supervision. This work has not been submitted partially or wholly to any other University or Institute for the award of this or any other degree or diploma.

Signature of Supervisor ……………………

Name of Supervisor …………………….

Date ……………………..

ACKNOWLEDGEMENT

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Signature of the student ……………………..

Name of Student ……………………..

Date ……………………..

SUMMARY

CDMA (Code Division Multiple Access) has been extensively studied in the context of microwave communications as it allows users to access any shred channel randomly at any arbitrary time. Its use in optical fiber networks has attracted considerable attention since 1985. In long-haul optical fiber transmission links and networks, the information consists of a multiplexed aggregate data stream originating from many individual subscribers and normally is sent in a well-timed synchronous format.

OCDMA is a technology to realize multiplexing transmission and multiple access by coding in the optical domain, which supports multiple simultaneous transmissions in the same time slot and the same frequency. It is another technology of multiplexing and multiple access that is potentially promising technique for optical networks in the future, and especially, due to its easy access and flexible network structure, it is very applicable to the access network.

In this project , we have studied different codes(both 1D and 2 D) that helps to analyse the performance of an OCDMA system.

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1.4 Objective

The objective of our project is to study and analyze the basic functioning and working of an OCDMA system and understand various codes like Prime Codes(PC's), Quadratic Congruence Codes(QCC's) , Multi Wavelength Optical Orthogonal Code(MWOOC) that are used to measure the performance of such system. We will study their construction algorithms and will generate them in MATLAB. Finally we will compare the performance of codes studied, in terms of number of users a code can support for a particular BER and for a given prime number.

CHAPTER 1

INTRODUCTION

1.1 Optical Fiber Communication Systems

Optical fiber communication is a communication approach to transport information from one point to another using light as a carrier and optical fibers as transmission media. Initially the optical fibers exhibited very high attenuation (i.e., 1000dB/km) and were therefore not competitive with the coaxial cables which they were to replace (i.e., 5 to 10dB/km).In 1970, the Corning Company in America manufactured a fiber-optic with attenuation of 17dB/km, and the optical fiber losses at 1310 nm wavelength were reduced to 0.3dB/km.

The optical fiber communication operate in the 800-1600 nm wavelength band.

1.1.1 Advantages of optical fiber communication:

Communication using an optical carrier wave guided along a glass fiber has number of extremely attractive features, over more conventional electrical communications.

1. **High potential bandwidth**

   The optical carrier frequency in the range 10^{13} to 10^{16} Hz yields a far greater potential transmission bandwidth than metallic cable systems.

2. **Small size and weight**

   Optical fibers have very small diameters. Hence, even when such fibers are covered with protective coatings they are far smaller and much lighter than corresponding copper cables.

3. **Electrical isolation**

   Optical fibers which are fabricated from glass or sometimes a plastic polymer are electrical insulators and therefore unlike their metallic counterparts, they do not exhibit earth loop and interface problems.

4. Immunity to interference and crosstalk

Optical fibers form a dielectric waveguide and are therefore free from electromagnetic interference (EMI), radiofrequency interference (RFI). Hence the operation of an optical fiber communication system is unaffected by transmission through an electrically noisy environment and the fiber cable requires no shielding from EMI. Also crosstalk is negligible, even when many fibers are cabled together.

5. **Low transmission loss**

   Fibers have been fabricated with losses as low as 0.2db/km and this feature has become a major advantage of optical fiber communications. It facilitates the implementation of communication links with extremely wide repeater spacing, thus reducing both system cost and complexity.

6. **Ruggedness and flexibility**

   Optical fibers may be manufactured with very high tensile strengths. They can also be bent to quite small radii or twisted without damage. Taking the size and weight advantage into account, the optical fiber cables are generally superior in terms of shortage, transportation, handling and installation than corresponding copper cables .

7. **Potential low cost**

   The glass which generally provides the optical fiber transmission medium is made from sand. So, in comparison with copper conductors, optical fibers offer the potential for low cost line communication.

1.2 CODE DIVISION MULTIPLE ACCESS (CDMA):

CDMA is a form of multiplexing, which allows numerous signals to occupy a single transmission channel, optimizing the use of available bandwidth. The technology is used in ultra-high-frequency (uhf) cellular telephone systems in the 800MHz and 1.9GHz. This uses the concept of multiple access which is to allow several transmitters to send information simultaneously over a single communication channel and thus allows several users to share a band of frequencies. Thus it is called as a channel access method.

CDMA technology was developed based on spread spectrum (SS) techniques and has become one of the most important multiple access technologies. SS techniques provide a means to extend the bandwidth of transmitting signals to obtain some advantages, which may not be possible if using only a bandwidth comparable to that spanned by the original information signals.

The major attractive features of CDMA technologies are :

• multiple access capability

• protection against multipath interference

• privacy

• anti-jamming capability

• low probability of interception

• possibility to overlay with existing radio systems

• low transmit power emission, which is important to reduce health risks.

CDMA, in contrast to FDMA and TDMA is a multiple access technology that divides users based on orthogonality or quasi-orthogonality of their signature codes (CDMA codes). There are three primarily different types of CDMA technologies:

1. Direct sequence (DS) CDMA : This is the simplest and most popular CDMA scheme among the three. Each user in a DS-CDMA system should use a code to spread its information bit stream directly by multiplication or modulo-2 addition operation.
2. Frequency hopping (FH) CDMA : It uses a multi-tone oscillator to generate multiple discrete carrier frequencies and each user in the system chooses a particular frequency hopping pattern among those carriers that are governed by a specific sequence, which should be orthogonal or quasi-orthogonal to the others
3. Time hopping (TH) CDMA : This type of CDMA is found to be much less widely used than the previous two mainly to its implementation difficulties and the hardware cost associated with it.

1.2.1 CDMA CODES AND THEIR PROPERTIES

One of the most important characteristics of a CDMA system is that it allows all users to send their information at the same frequency band and same time duration simultaneously but using different. codes. Therefore, it is obvious that the orthogonality or quasi-orthogonality among the codes or sequences plays an extremely important role.

There are two important roles of the codes or sequences used in a CDMA system:

1. to act as signature codes (to accomplish code division multiple access)
2. to spread the data bits (to spread signal bandwidth to achieve a certain processing gain).

The properties of CDMA codes play a critical role in a CDMA system since the fundamental principle of CDMA communications demands the use of different codes to separate different users. Therefore, a CDMA system differs from traditional FDMA and TDMA systems in terms of its unique way of separating users or channels in a communication system or network. While FDMA and TDMA systems require ‘different frequency bands’ and ‘different time slots’ to offer good separation among different channels, a CDMA system relies on the ‘orthogonal properties of CDMA codes to separate different users or channels.

1.3 OPTICAL CODE DIVISION MULTIPLE ACCESS (OCDMA):

OCDMA is a technology to realize multiplexing transmission and multiple access by coding in the optical domain, which supports multiple simultaneous transmissions in the same time slot and the same frequency. It is another technology of multiplexing and multiple access that is potentially promising technique for optical networks in the future, and especially, due to its easy access and flexible network structure, it is very applicable to the access network. In an OCDMA network, the transmission signal over a fiber-optic channel is formed by the superimposing of pseudorandom OCDMA signals encoded from multiple channels. The signal is broadcast to each node (subscriber) in the network and a receiver in each node decodes the signal. If the output of the decoder in this receiver is an autocorrelation, the node can detect the information sent to it from the aforementioned pseudorandom signals. Alternatively, if the output of the decoder is a cross-correlation function (no apparent peak value), then the node cannot receive the information.

1.3.1 Advantages of OCDMA

1. Random and simultaneous access protocol.
2. No need for the strict timing synchronization.
3. No need for the strict wavelength control.
4. Effective utilization of bandwidth
5. High tolerance to noises, Inherent security and low cost devices.

The attractive advantages of OCDMA and the widespread use of this technology has motivated us to study this topic in detail and to choose this as the topic of our project.

CHAPTER 2
LITERATURE REVIEW

2.1 FO CDMA SYSTEM:

A typical FO-CDMA communication system consists of

1. information data source : which may be electrical or optical
2. a laser : to convert electrical signal into optical form
3. an optical encoder : to map each bit of the output information into a very high rate optical sequence, that is then coupled into the single-mode fiber channel **.**

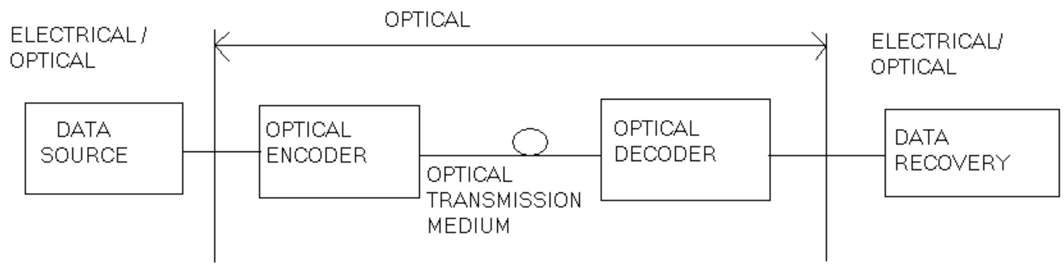


Figure 2.1: Fiber OCDMA communication system

At the receiver end of the FO-CDMA, the correlation process is followed i.e the optical pulse sequence is compared to a stored replica of itself and to a threshold level at the comparator for the data recovery.

In FO-CDMA there are N such transmitter and receiver pairs (users).

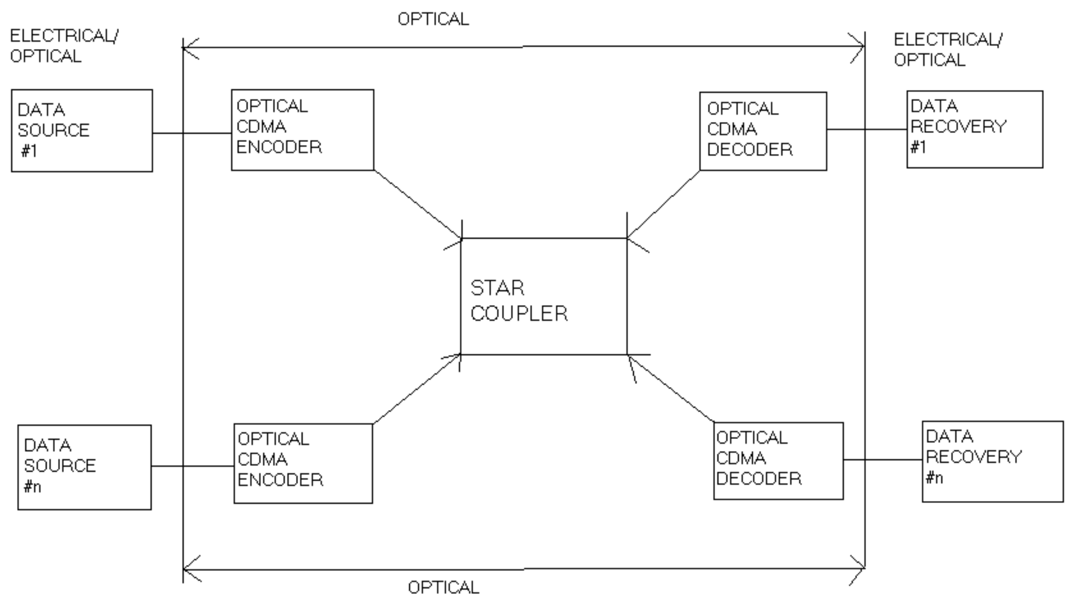


Figure 2.2: OCDMA system in star configuration

Each optical pulse is assigned a sequence known as address code or signature sequence. If we want to send information from user A to B then the address code for receiver B is impressed upon the data by the encoder at A.

The primary purpose of FO CDMA is to recognize the desired optical pulse sequence in presence of all others and extract data from it.

Therefore, sequences should be defined such that they satisfy two conditions :

1. each sequence can be distinguished from the shifted version of itself
2. each sequence can be distinguished from every other sequence.

2.2 PROPERTIES OF CDMA CODES

Auto-correlation and Cross-correlation are two very important parameters to assess interference and performance of signals. The process of assigning different codes to different users for transmission of signal depends on these two parameters.

1. **Auto-Correlation Function :**

   The ACF is defined as the result of chip-wise convolution, correlation or matched-filtering operation between two time-shifted versions of the same code, which can be further classified into two subcategories: periodic ACF and aperiodic ACF, depending on the same and different signs of two consecutive bits.

2. **Cross-Correlation Function :**

The cross-correlation function (CCF) is defined as the result of a chip-wise convolution operation between two different spreading codes in a family of codes. There are also two different types of CCF, i.e. periodic and aperiodic CCF. The former is mainly found in synchronous transmission channels, such as downlink channels in a wireless system, and the latter can appear in either synchronous (if MI is present) or asynchronous channels. In contrast to out-of-phase ACF, which will contribute to MAI only under multipath channels, the CCF always contributes to MAI, no matter whether or not multipath propagation is present. On the other hand, the out-of-phase ACF will become harmful if and only if a multipath channel is present; otherwise it will never yield MAI at a correlator receiver. MAI is one of the most serious threats to jeopardize detection efficiency of a CDMA receiver using either a correlator.

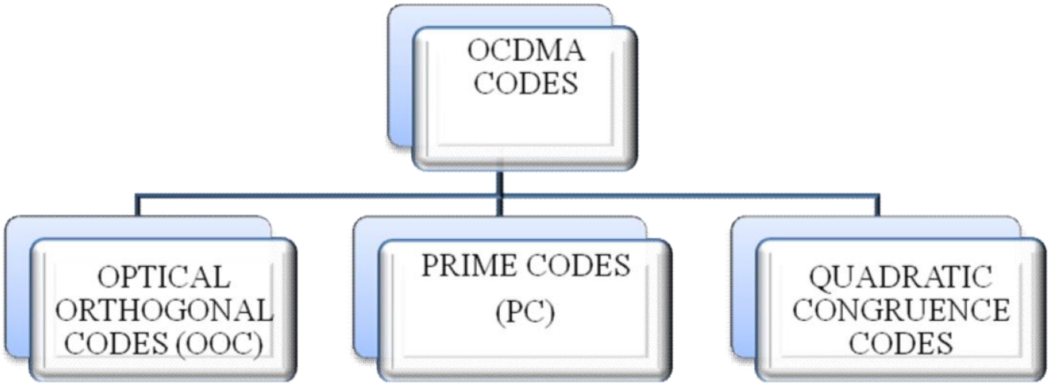
The ACF and CCF determine the time domain characteristics of a CDMA code family or set. The ACF governs the performance of a CDMA system against the ISI caused by multipath propagation, while the CCF determines the capability of a CDMA system to mitigate MAI.

2.3 Code Parameters

1. Code Length (L) - It is the total no of 1’s and 0’s in a binary sequence in a given code.
2. Code Weight (w)-Also known as the Hamming weight, it is the no of 1’s in a given code.
3. No of Users supported-It is the maximum number of users that can be supported in a system for a given Bit Error Rate (BER).
4. Bit Error Rate (BER)-The bit error rate is the number bit errors divided by the total number of transferred bits during a studied time interval. BER is performance measure expressed as a percentage number.

2.4 TYPES OF OCDMA CODES

Ocdma codes can broadly be described in 3 categories:



2.4.1 PRIME CODE FAMILY

The congruence techniques make use of the congruence operations in the finite field to construct the prime codes for users. The congruence techniques have strong regularity and are simple in comparison with the constructions of OOC. However, the correlation properties of the congruence codes are not as good as those of OOC. In terms of the different congruence operations, the congruence codes can be classified into Linear Congruence Codes (LCC), Quadratic Congruence Codes (QCC), Cubical Congruence Codes (CCC) and Hyperbolic Congruence Code (HCC) and so on.

The basic idea of constructing the congruence codes is as follows. Firstly choose a prime number p and produce a group of sequences $y_i(j)$, $-1<i<p$, using galois field GF(p)={0,1,2,…,p-1}. Then, according to a certain algorithm, map this group of sequences into a group of binary sequences and $y_i(j)$ corresponds to the 1's position of jth chip (called the slot) of ith codeword.

2.4.1.1 1-D PRIME CODES:

A. BASIC PRIME CODES

Prime code is a typical linear congruence code. Prime Code is a family of (0, 1) sequences with good auto and cross-correlation properties with the help of Galois Field. Construction of codes is as follows :

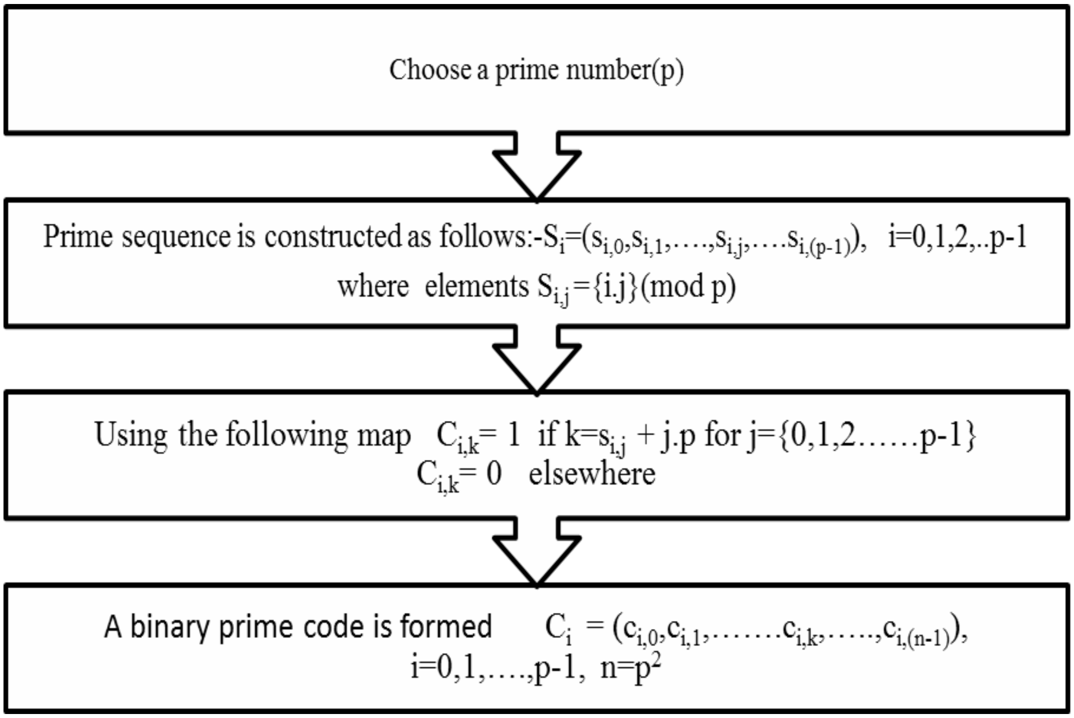


Figure 2.3: Basic Prime code construction

We illustrate an example below that shows how a prime code is developed.

Example

Selected prime number is p=5

Prime sequences S_i constructed for p=5

Galois Field developed for p=5

Elements of GF(5)	**0**	**1**	**2**	**3**	**4**
S_0	0	0	0	0	0
S_1	0	1	2	3	4
S_2	0	2	4	1	3
S_3	0	3	1	4	2
S_4	0	4	3	2	1

Table 2.1: *Prime sequences constructed for p= 5*

Prime sequence S_i	**Prime code C_i**				
S_0=(00000)	10000	10000	10000	10000	10000
S_1=(01234)	10000	01000	00100	00010	00001
S_2=(02413)	10000	00100	00001	01000	00010
S_3=(03142)	10000	00010	01000	00001	00100
S_4=(04321)	10000	00001	00010	00100	01000

Table 2.2: Prime codes constructed for p = *5*

B. Modified Prime Code (MPC):

These sequences were developed to overcome the limitation of PCs. These optical sequences have the ability to support more users simultaneously transmitted in the system with the lower MAI.

Construction Principle

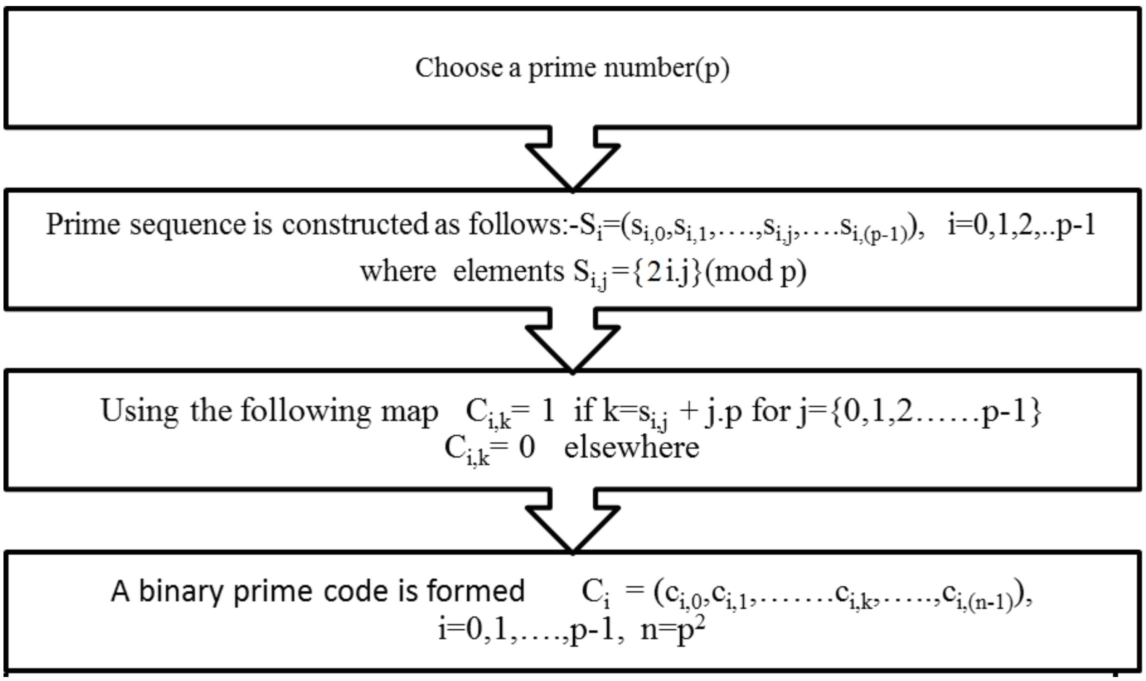


Figure 2.4 : Modified Prime code construction

<u>Example</u>

Selected prime number is p=5; Code Weight chosen w=4

Prime sequences S_i constructed for p=5

a_k	a_0	a_1	a_2	a_3	**Modified Prime Sequence**
(i)	0	1	2	3	
0	0	0	0	0	S_0`
1	0	1	2	3	S_1`
2	0	2	4	1	S_2`
3	0	3	1	4	S_3`
4	0	4	3	2	S_4`

Table 2.3: Modified prime sequences constructed for p= *5 and* w= *4*

(i)	A_0	a_1	a_2	a_3	Prime Sequence			Prime codes		
	0	1	2	3						
0	0	0	0	0	S_0`	10000	10000	10000	10000	00000
1	0	1	2	3	S_1`	10000	01000	00100	00010	00000
2	0	2	4	1	S_2`	10000	00100	00001	01000	00000
3	0	3	1	4	S_3`	10000	00010	01000	00001	00000
4	0	4	3	2	S_4`	10000	00001	00010	00100	00000

Table 2.4: Modified prime codes constructed for code length $n=p^2=25$, p *= 5 and* w= *4*

MPC Correlation Properties

The auto- and cross-correlation functions for any pair of code sequences Cn and Cm in a discrete manner are as follows:

$$R_{CmCn}\quad \begin{cases} P, & \text{if } m=n \\ 0, & \text{if } m\neq n,\ m \text{ and } n \text{ share the same group} \\ 1, & \text{if } m\neq n,\ m \text{ and } n \text{ are from different groups} \end{cases}$$

where m,n=(1,2,...,P ^2).

Advantages of MPC Sets:

1.It can accommodate greater number of subscribers.

2.Since code length is greater it improves the system's performance in terms of SNR, BER and MAI.

C. new-Modified Prime Code (n-MPC)

Construction Principle

The n-MPC is generated through repeating the last sequence stream of the previous MPC sequence and rotating in the same group with the aid of a sub-sequence of length P. This kind of code has P groups, each of which has P code sequences. The length of each code is P^2+P and the weight is P+1. The total number of available sequences is P^2.

n-MPC Correlation Properties

The auto- and cross-correlation function for any pair of codes Cn and Cm is given by

$$R_{CmCn} = \begin{cases} P+1, & \text{if } m=n \\ 0, & \text{if } m\neq n,\ m \text{ and } n \text{ share the same group} \\ 1, & \text{if } m\neq n,\ m \text{ and } n \text{ are from different groups} \end{cases}$$

where m,n=(1,2,...,P^ 2).

D. Double-Padded Modified Prime Code (DPMPC)

Construction Principle

The DPMPC is generated after one more step padding of n-MPC by repeating the final sequence-stream of the previous MPC sequence. Finally, the two sequences are padded into each MPCs and hence the code enlarges by 2P as compared with MPC and by P as compared with n-MPC. This code-family has also P groups, each of which has P sequence codes. The length of each code is P^2+2P and the weight is P+2 with the total number of available sequences of P^2.

DPMPC Correlation Properties

The auto- and cross-correlation function for any pair of codes Cn and Cm is given by:

$$R_{C_m C_n} = \begin{cases} P-2, & \text{if } m=n \\ 0, & \text{if } m \neq n, \text{ m and n share the same group} \\ 1, & \text{if } m \neq n, \text{ m and n are from different groups} \end{cases}$$

where m,n =(1,2,...p^2)

Advantages of DPMPC Sequences:

•Excellent correlation property

•Improved system performance.

2.4.1.2 2-D PRIME CODES

2-D PC/PC codes can be obtained by using PC for both wavelength-hopping and time-spreading. Any two codewords either have different wavelength-hopping or possess different time-spreading. The maximal value of cross-correlation function of the 2-D PC/PC code is one and the sidelobes of its autocorrelation are zero.

Construction :

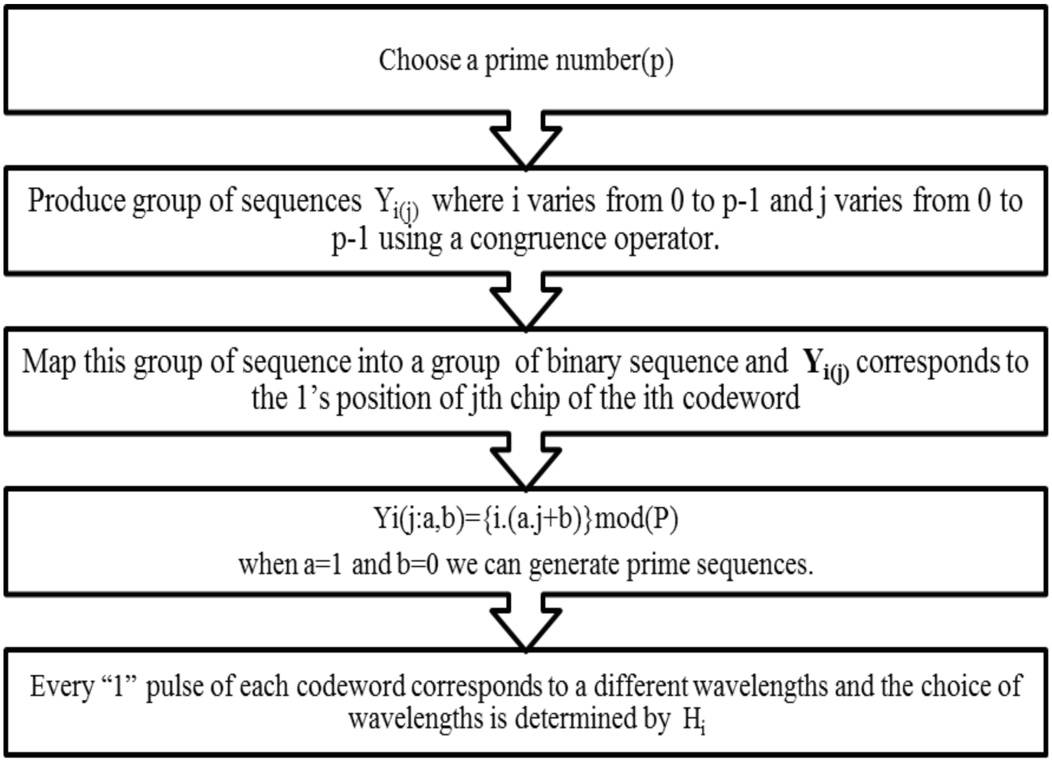


Figure 2.5 : Construction of 2D prime codes

- **Advantages of 2-D PC/PC Codes**

1. Properties of autocorrelation and cross-correlation of this code have been considerably improved.

- **Disadvantages of 2-D PC/PC Codes**

2. Cardinality is smaller than the cardinality of 1-D OCDMA+WDMA hybrid system.

<u>Example</u>

Prime number p=5

Prime sequences

S_0= (00000) S_1= (01234) S_2= (02413) S3= (03142) S4= (04321)

Wavelength H_1= (01234) H_2= (02413) H_3= (03142) H_4= (04321)

S_i is employed as time spreading and H_i is deployed to determine wavelength-hopping

(i) j		**0**	**1**	**2**	**3**	**4**	**Prime**	**Code**		**S_i**	
0	S_0	0	0	0	0	0	10000	10000	10000	10000	10000
1	S_1	0	1	2	3	4 (H_1)	10000	01000	00100	00010	00001
2	S_2	0	2	4	1	3 (H_2)	10000	00100	00001	01000	00010
3	S_3	0	3	1	4	2 (H_3)	10000	00010	01000	00001	00100
4	S_4	0	4	3	2	1 (H_4)	10000	00001	00010	00100	01000

Table 2.5: Prime codes obtained for the prime number p *= 5*

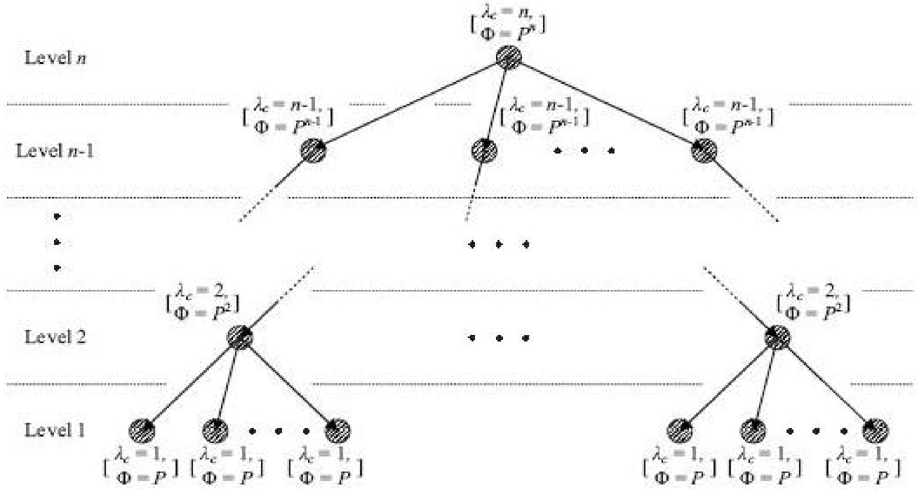
S_0H_1	**λ_0 0000**	**λ_1 0000**	**λ_2 0000**	**λ_3 0000**	**λ_4 0000**
S_0H_2	λ_0 0000	λ_2 0000	λ_4 0000	λ_1 0000	λ_3 0000
S_1H_1	λ_0 0000	0λ_1 000	00λ_2 00	000λ_3 0	0000 λ_4
S_2H_2	λ_0 0000	00λ_2 00	0000λ_4	0λ_1 000	000λ_3 0

Table 2.6: 2-D PC/PC codes

2.4.2 MULTILEVEL PRIME CODE

A new class of two-dimensional codes called multilevel prime codes, with expanded code cardinality by relaxing the maximum cross-correlation function to any arbitrary positive integer. Multilevel prime codes can be partitioned into a tree structure of multiple levels of subsets of code matrices. In each level, the number of subsets, the number of code matrices per subset, and the cross-correlation function of each subset are related to the level number. This partition property allows the selection of code matrices of certain cardinality and maximum cross-correlation functions in order to meet different system operating requirements.

The structure of multilevel prime codes can be modelled as a tree, as illustrated in Figure.



Figgure 2.6 : Multilevel Prime Code generation Tree structure

Tree structure of multilevel code

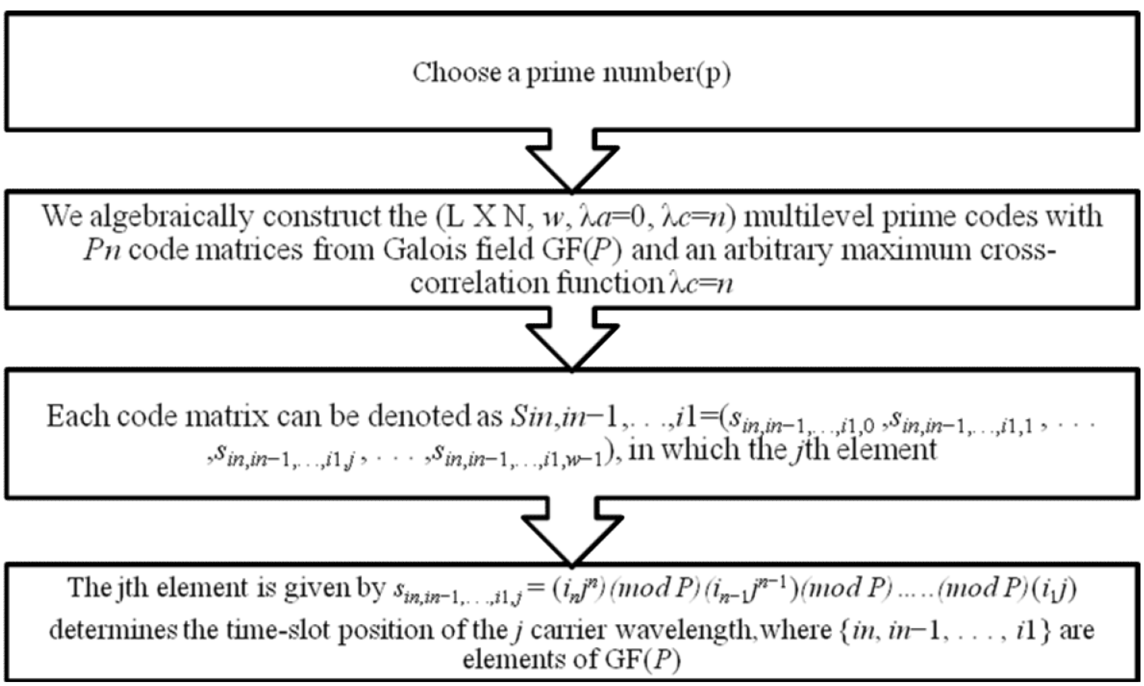


Figure 2.7: Multilevel prime code generation

Advantages of Multilevel Prime Codes

1. Provides a great flexibility in usage. According to the number of users codes can be selected from various codesets based on the value of (λc).

2. Increase in number of users since a large value of (λc) can be used.

2.4.3 QUADRATIC CODE-FAMILY

2.4.3.1 1-D QUADRATIC CONGRUENCE CODE

A. Basic QCC

The length and the weight of the quadraric congruence code are n= p^2 and w=p respectively. Its cardinality is |C|=p-1. The term OCC, the quadratic congruence code is a quasi- OOC with the parameters (n,w, a, c)= (p^2, p, 2, 4).

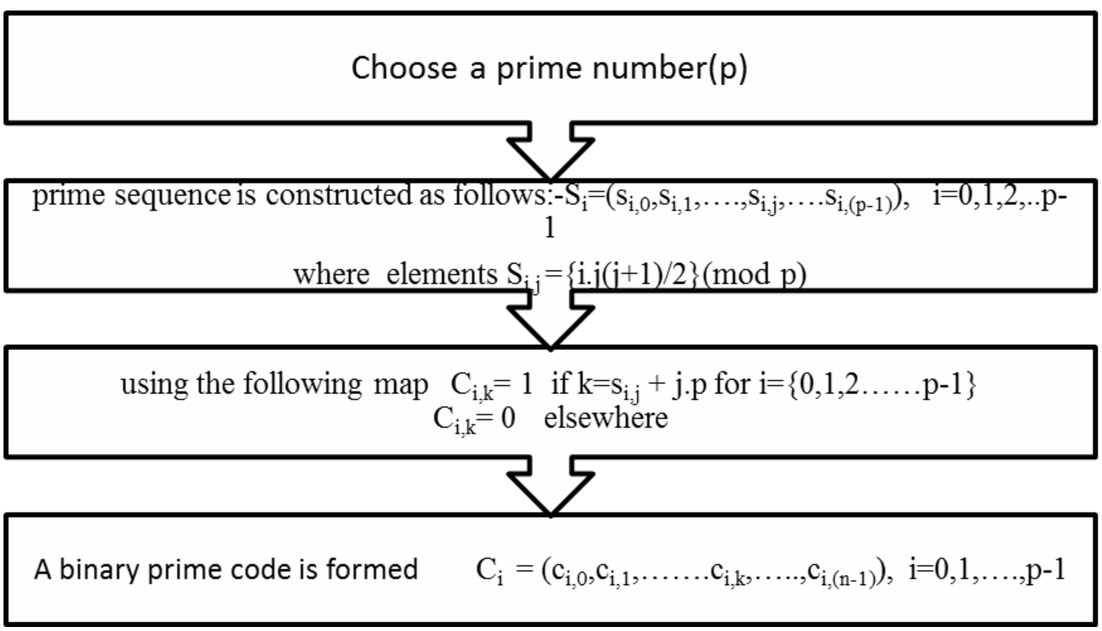


Figure 2.8: Construction of 1D Quadratic congruence code

B. EXTENDED QUADRATIC CONGRUENCE CODE

In order to improve the properties of auto-correlation of the quadratic congruence code. The extended congruence code (EQCC) is proposed. The construction of EQCC is basically same as that of EQCC. The mapping equation of EQCC is different from QCC.

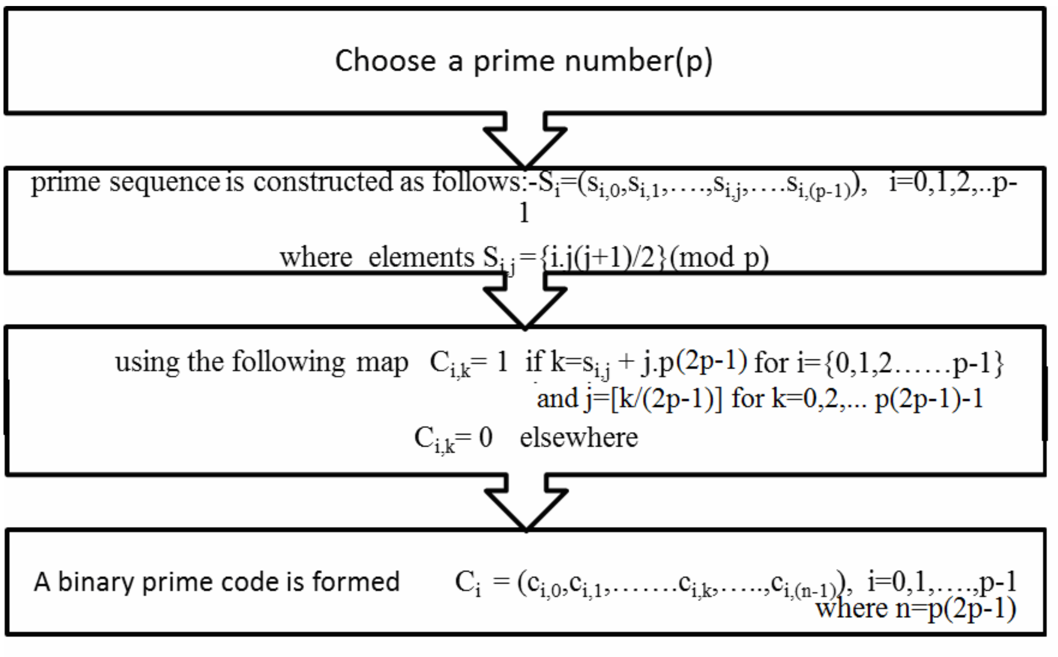


Figure 2.9: Construction of 1D Extended Quadratic Congruence Code

2.4.3.2 2-D CODES

A. 2-D QUADRATIC CONGRUENCE CODE

Construction flowchart is as follows :

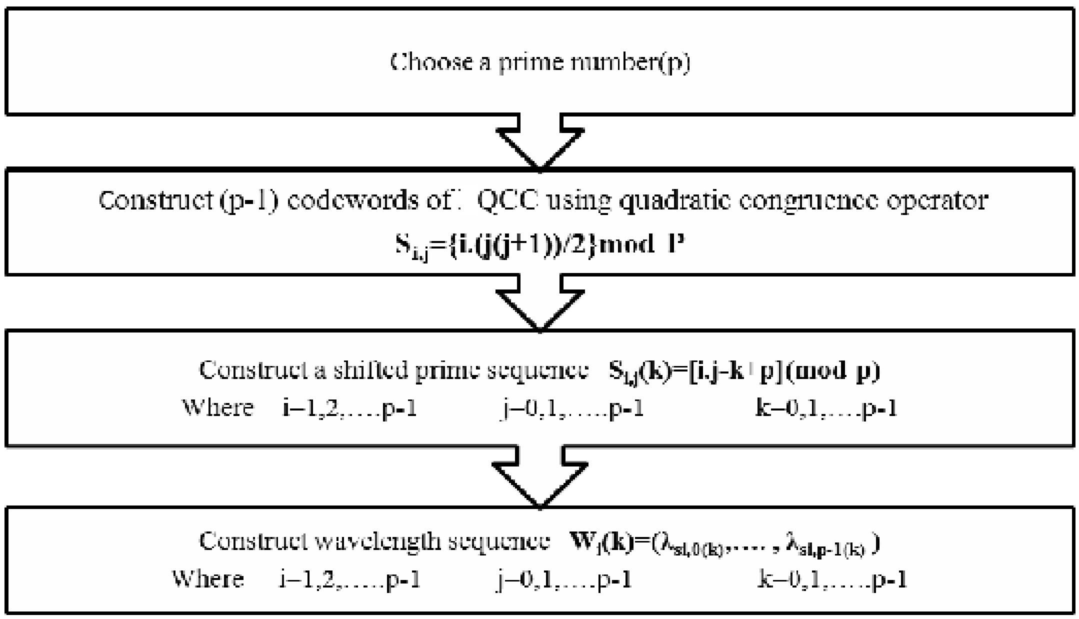


Figure 2.10: Construction of 2-D QCC

B. 2-D EXTENDED QUADRATIC CONGRUENCE CODE

2-D PC/EQCC code is constructed by using prime codes and their cyclic shifts for wavelength-hopping and extended quadratic congruence codes for time-spreading. Because every “1” pulse in each codeword uses a different wavelength, the constraint of its autocorrelation is zero and the maximal value of cross-correlation constraint of 2-D PC/EQCC code is two.

Advantages of 2-D PC/EQCC :

Cardinality increases as compared to 1-D EQCC

<u>Example</u>

Prime number p=5

Prime sequences = $S_i(k)$

Wavelength sequences = $W_i(k)$

QC sequence	EQCC	Code			
0 1 3 1 0	100000000	100000000	100000000	100000000	100000000
0 2 1 2 0	100000000	100000000	100000000	100000000	100000000
0 3 4 3 0	100000000	100000000	100000000	100000000	100000000
0 4 2 4 0	100000000	100000000	100000000	100000000	100000000

Table 2.7: Extended Quadratic Congruence Codes for p= *5*

(i)	$S_i(0)$	$S_i(1)$	$S_i(2)$	$S_i(3)$	$S_i(4)$
1	0 1 2 3 4	4 0 1 2 3	3 4 0 1 2	2 3 4 0 1	1 2 3 4 0
2	0 2 4 1 3	4 1 3 0 2	3 0 2 4 1	2 4 1 3 0	1 3 0 2 4

Table 2.8: Prime sequences and their cyclic shift sequences $S_i(k)$

$W_i(0)$	$W_i(1)$	$W_i(2)$	$W_i(3)$	$W_i(4)$
λ_o λ_1 λ_2 λ_3 λ_4	λ_4 λ_0 $\lambda_1\lambda_2$ λ_3	$\lambda_3\lambda_4$ λ_0 λ_1 λ_2	λ_2 λ_3 λ_4 λ_0 λ_1	λ_1 λ_2 λ_3 λ_4 λ_0

Table 2.9: Wavelength Sequences $W_i(k)$ corresponding to $S_i(k)$

1:	Λ_0 00000000	0$\lambda_1$0000000	000$\lambda_2$00000	0$\lambda_3$00000000	λ_4 00000000
. .	. .	. .	. .	. .	. .

20:	$\lambda_1$00000000	0λ_0 0000000	000$\lambda_4$00000	0λ_3 0000000	$\lambda_2$00000000

*Table 2.10: **2**-D PC/EQCC codes for* p *= 5*

2.4.4 Multi Wavelength Optical Orthogonal Codes (MWOOC) :

We describe here the optimal construction of MWOOC based on that of the conventional 1-D OOC and the cardinality of MWOOC constructed by this method achieves the theoretical upper bound.

Constructions of MWOOCs Based on Constructions of 1-D OOCs:

The construction of MWOOC based on the construction is as follows.

First of all, let n be a prime number such that for any given integer w and some integer t. The position blocks of any (n,w,1,1)-OOC constructed are:

$\{[a_{i,0}, a_{i,1}, a_{i,2}, \ldots\ldots, a_{i,j}, \ldots\ldots\ a_{i,w-1}]$: i [0,t-1]}

Where the element $a_{i,j}$in the i[th] block represents the displacement of the j[th] pulse (i.e. a binary "1") in the i[th] codeword.

After modifying these t position blocks of 1-D OOC, the following 2-D position blocks can be obtained:

{[($a_{i,0}$+k(mod n), j$a_{i,0}$(mod n)), ($a_{i,1}$+k(mod n), j$a_{i,1}$(mod n)), ($a_{i,2}$+k(mod n), j$a_{i,2}$(mod n)),….

,($a_{i,j}$+k(mod n), j$a_{i,j}$(mod n))….., ($a_{i,w-1}$+k(mod n), j$a_{i,w-1}$(mod n))]: i [0,n-1], j [0,n-1],

k [0,n-1]}

and thus (n*n, w, 1, 1)-MWOOC is formed, where an ordered pair (v,h) denotes the vertical (v) and horizontal (h) displacements of a pulse from the bottom-leftmost corner of a matrix. Therefore n^2t distinct codewords can be obtained.

2-D Construction of MWOOC using Generalized Multi-Wavelength Prime Codes (GMWPC) with p_1 p_2 p_3...... p_k Codeword:

2-D approaches use the modified frequency-hoppingsequences such as the prime codes and RS codes(Reed-Solomon) codes to construct MWOOC. The 2-D WH/TS codes are constructed with these two methods are called GMWPC. The construction is done as follows

Given an integer c and a set of prime numbers $p_{k,}$ $p_{k-1,\ldots\ldots}$ p_1 such that $p_k \geq p_{k-1\ldots\ldots\ldots\geq}$ $p_{1\geq}c$, then the following 2-D blocks

$\{[(0,0),(1,\ i_1+i_2p_1+\ldots.+\ i_k\ \ p_1\ \ p_2\ldots\ldots\ p_{k-1}),\ldots\ldots.\ i_1 \quad [0,\ p_1\text{-}1],\ i_1 \quad [0,\ p_2\text{-}1],\ldots.,\ i_k \quad [0,\ p_1\text{-}1]\}$

form an (c^* p_1 p_2 $p_{3\ldots\ldots\ldots}$ p_k,c,0,1) GMWPC, C, with the cardinality p_1 $p_{2\ldots\ldots}$ p_k.

CHAPTER 3

PERFORMANCE OF OPTICAL CDMA SYSTEM

Let xi be the DPMPC sequence identifying the ith receiver and call the '1' or '0' symbols forming the DPMPC sequence chips. The signals from all the transmitters are summed up and broadcast to every receiver. The receivers perform a correlation between the received signal and their own prime code sequence (address). All the signals except the properly encoded one, will be decoded as interfering noise, whereas the latter will give rise to a correlation peak. Hence, several simultaneous transmissions, addressed to different receivers are possible. Because the cross-correlation between DPMPC sequences in different groups is not zero (but it is as low as one), the interfering signals will reduce the noise margin of the receivers.

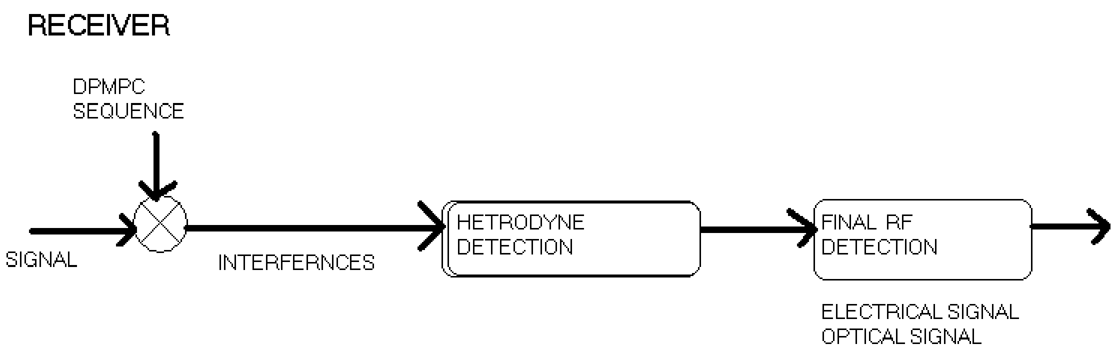


Figure 3.1 Hetrodyne Receiver

The signal from the user is heterodyne detected, thus the receiver output after multiplication contains both unwanted optical signal and required intermediate frequency (IF) signal which is selected through the filter.

$$I = \frac{R}{4}\sum_{n=1}^{N} c(nT_c)\sum_{i=1}^{K}(S_i^0 + d_i(t)c_i(t - nT_c)S_i^1) + n(t)$$

Considering 1st user as the intended user

$$I = \frac{R}{4}\sum_{n=1}^{N} S_1^0 c(nT_c) + R/4 \sum_{i=2}^{k}\sum_{i=1}^{N} c(nT_c)c_i(t-nT_c)d_i(t)S_i^1 + n(t)$$

The first element in the equation is a dc element that needs removal in the balanced detector. The second element considers interference caused by other transmitters and the third element is the noise. SNR of the system is given as

$$\text{SNR} = \frac{\left(\frac{R}{4}\sum_{n=1}^{N} c(nT_c)c_1(t-nT_c)d_1(t)S_1^1\right)^2}{\left(\frac{R}{4}\sum_{i=2}^{K}\sum_{n=1}^{N} c(nT_c)c_1(t-nT_c)d_1(t)S_1^1\right)^2 + \sigma_{n(t)}^2}$$

As per the DPMPC property :

$\sum_{n=1}^{N} c(nT_c)c_i(t-nT_c) = P+2$

Defining variable X as the DPMPC autocorrelation value

$X_{li} = \sum_{n=1}^{N} c(nT_c)\, c_i(t-nT_c)$

The in-phase cross correlation value is either zero or one depending on whether the codes are the same group or from the different groups. The zero value does not cause the interference due to perfectly orthogonal sequences, while the one value causes the interference which is only among intended user and (P2-P) users from the different groups (i.e., P2 whole sequences and P sequences from the same group of intended user which are orthogonal). As the cross correlation values are uniformly distributed among interfering users, thus, the pdf of w realization of Xli, is

$P(w=i) = \frac{i}{P^2-P}$

The system SNR is given by:

$$SNR(k) = \frac{1}{\left(\frac{(k+2)(k-1)}{2(P^2-P)(P+2)}\right)^2 + \frac{16\,\sigma_n{}^2}{R^2 d_1{}^2 S_1{}^2 (P+2)^2}}$$

where

K = number of users

P = code length parameter

σ_n^2= total noise

R = load resistance

$S_1 = R_d P_r$= signal current

EQUATION FOR BER:

$$BER = 0.5 erfc\left[\frac{SNR}{\sqrt{2}}\right]$$

3.1 Relation between SNR and Number of Users

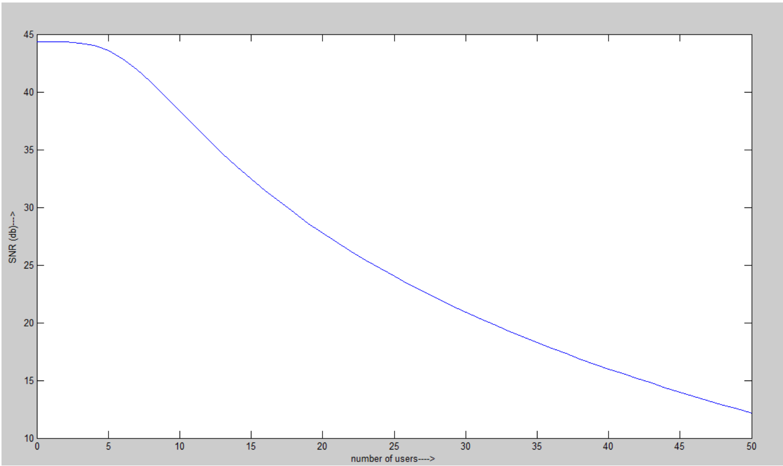


Figure 3.2: plot between SNR and Number of Users

This shows the plot of SNR (dB) vs. Number of Users. In the figure we plot the number of user to the X-axis and the signal to noise ratio (SNR) to the Y-axis.We observe that the curve is decreasing which implies SNR and Number of users are indirectly proportional to each other. This is because when we increase number of users noise level increases which decreases SNR

3.2 RELATION BETWEEN BER AND NUMBER OF USERS

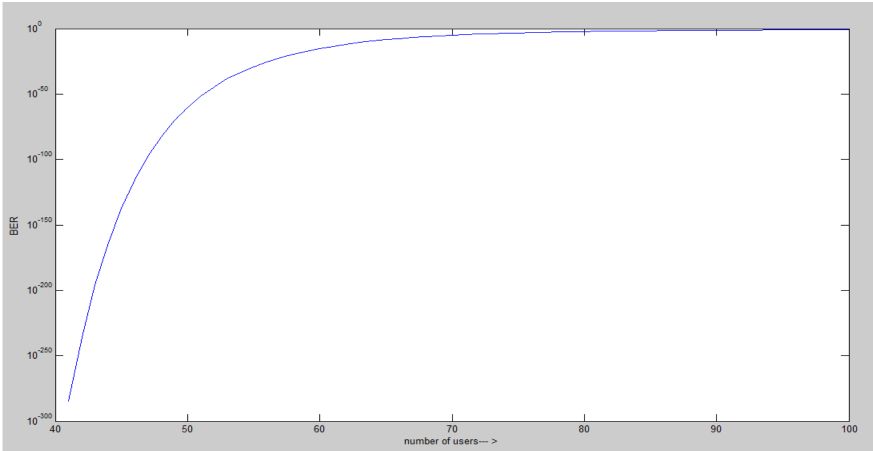


Figure 3.3: plot between BER and Number of users

This graph shows the plot of bit error rate vs. number of users. In the figure we plot the number of user to the X-axis and the Bit error rate (BER) to the Y-axis. We observe that the curve is increasing which implies BER and number of users are directly proportional to each other. Here also we vary our number of user range from 0-100 and see the variation in BER accordingly. The graph signifies that if we increase number of user the bit error increases highly and after a certain number of time BER become almost constant irrespective of number of users where as for less number of user bit error rate is less hence improving received signal.

3.3 RELATION BETWEEN SNR AND BER

Graph 3.4 Shows the plot of bit error rate vs. signal to noise ratio. In this we have plotted SNR on the X-axis and BER on the Y-axis. From the graph we see that this graph is decreasing. SNR and BER are indirectly proportional to each other. We plot this graph with the help of above given eq. This graph implies that for a low SNR ratio BER is high and for high SNR ratio BER is low

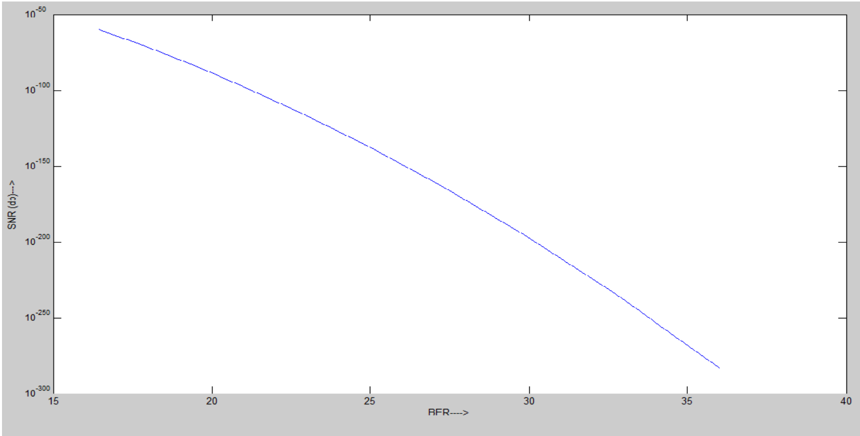


figure 3.4: plot between SNR and BER

CHAPTER 4

IMPLEMENTATION OF CODES

4.1 MATLAB

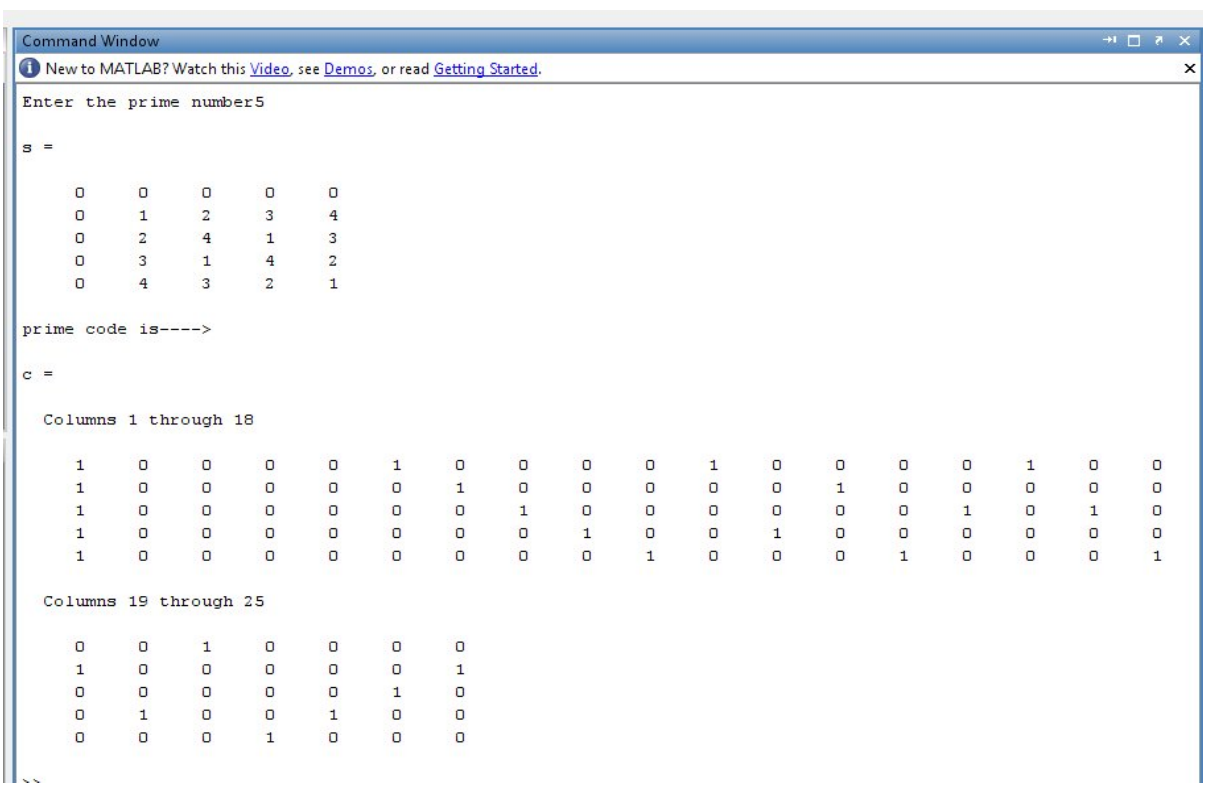
MATLAB is a programming environment for algorithm development, data analysis, visualization, and numerical computation. Using MATLAB, you can solve technical computing problems faster than with traditional programming languages, such as C, C++, and Fortran. MATLAB is used in a wide range of applications, including signal and image processing, communications, control design, test and measurement, financial modeling and analysis, and computational biology.

Here, we are implementing various codes of optical cdma using MATLAB.

4.2 PRIME CODE

4.2.1 1-D Prime Code

For prime number p=5, we are obtaining following code in MATLAB. For p=5 code length is equal to 25, weight is eaual to 5 and cardinality is equal to 5.

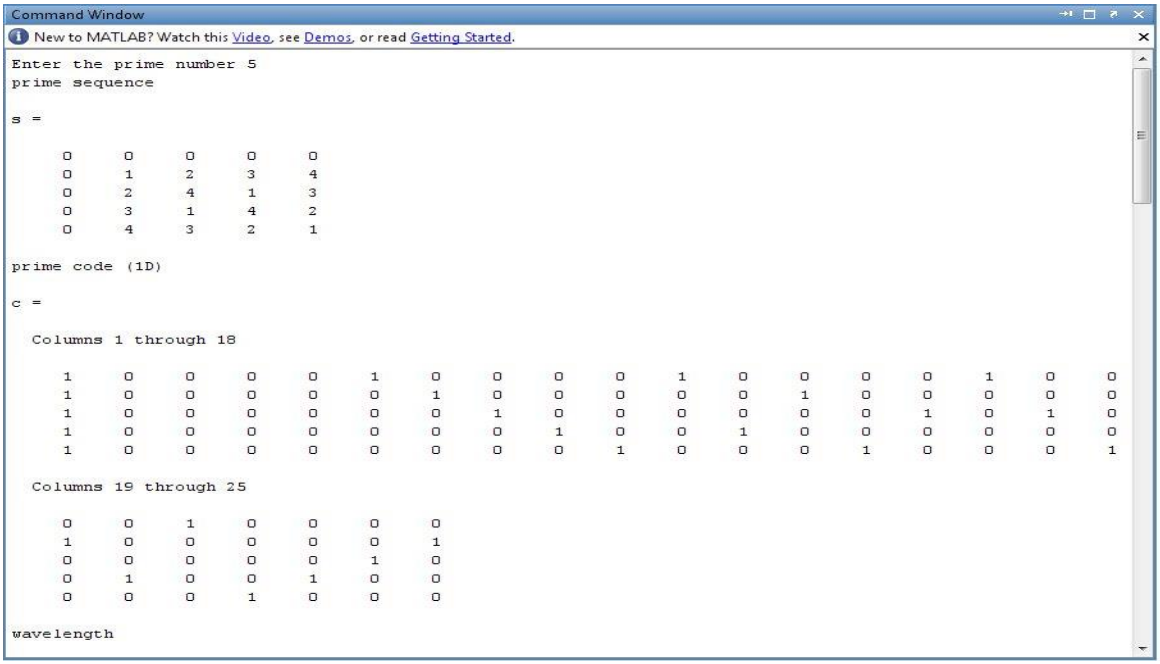


```
Command Window
New to MATLAB? Watch this Video, see Demos, or read Getting Started.
Enter the prime number5

s =

     0     0     0     0     0
     0     1     2     3     4
     0     2     4     1     3
     0     3     1     4     2
     0     4     3     2     1

prime code is---->

c =

  Columns 1 through 18

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

  Columns 19 through 25

     0     0     1     0     0     0     0
     1     0     0     0     0     0     1
     0     0     0     0     0     1     0
     0     1     0     0     1     0     0
     0     0     0     1     0     0     0
```

Figure 4.1 MATLAB 1-D generation

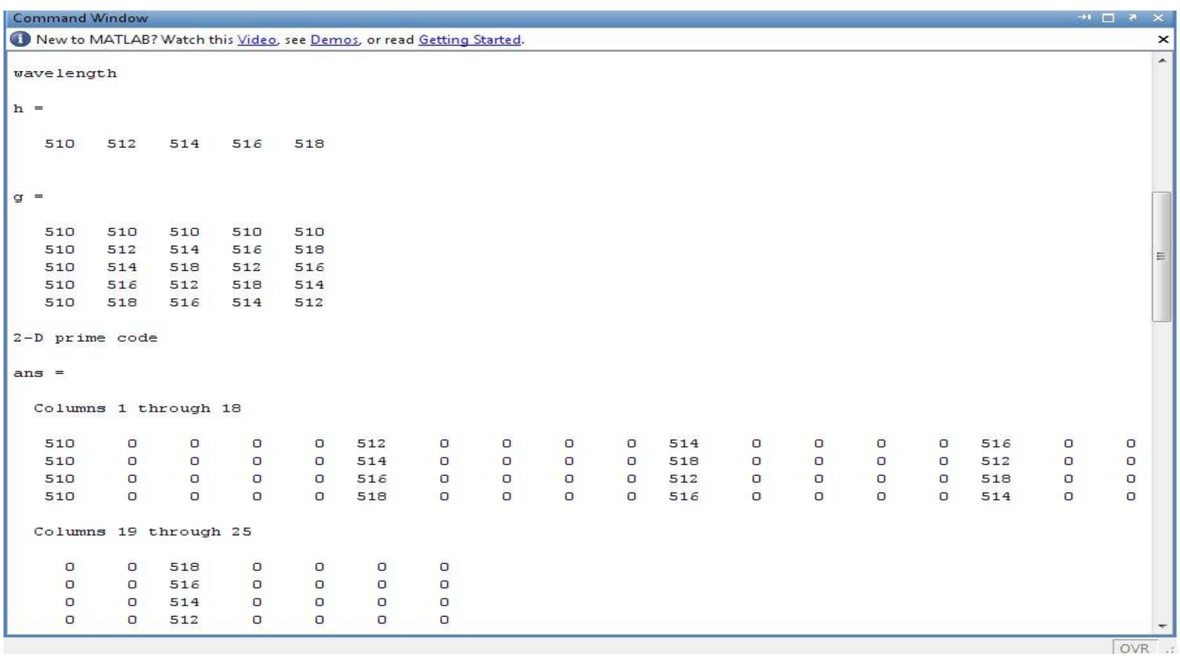
4.2.2 2-D Prime Code

For prime number p=5, we are obtaining following code in MATLAB



```
Command Window
New to MATLAB? Watch this Video, see Demos, or read Getting Started.
Enter the prime number 5
prime sequence

s =

     0     0     0     0     0
     0     1     2     3     4
     0     2     4     1     3
     0     3     1     4     2
     0     4     3     2     1

prime code (1D)

c =

  Columns 1 through 18

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

  Columns 19 through 25

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

wavelength
```

figure 4.2a: MATLAB 2D prime code generation



```
Command Window
New to MATLAB? Watch this Video, see Demos, or read Getting Started.
wavelength

h =

   510   512   514   516   518


g =

   510   510   510   510   510
   510   512   514   516   518
   510   514   518   512   516
   510   516   512   518   514
   510   518   516   514   512

2-D prime code

ans =

  Columns 1 through 18

   510     0     0     0     0   512     0     0     0     0   514     0     0     0     0   516     0     0
   510     0     0     0     0   514     0     0     0     0   518     0     0     0     0   512     0     0
   510     0     0     0     0   516     0     0     0     0   512     0     0     0     0   518     0     0
   510     0     0     0     0   518     0     0     0     0   516     0     0     0     0   514     0     0

  Columns 19 through 25

     0     0   518     0     0     0     0
     0     0   516     0     0     0     0
     0     0   514     0     0     0     0
     0     0   512     0     0     0     0
OVR
```

figure 4.2b: MATLAB 2D prime code generation

4.3 QUADRATIC CONGRUENCE CODE

4.3.1 1-D QCC

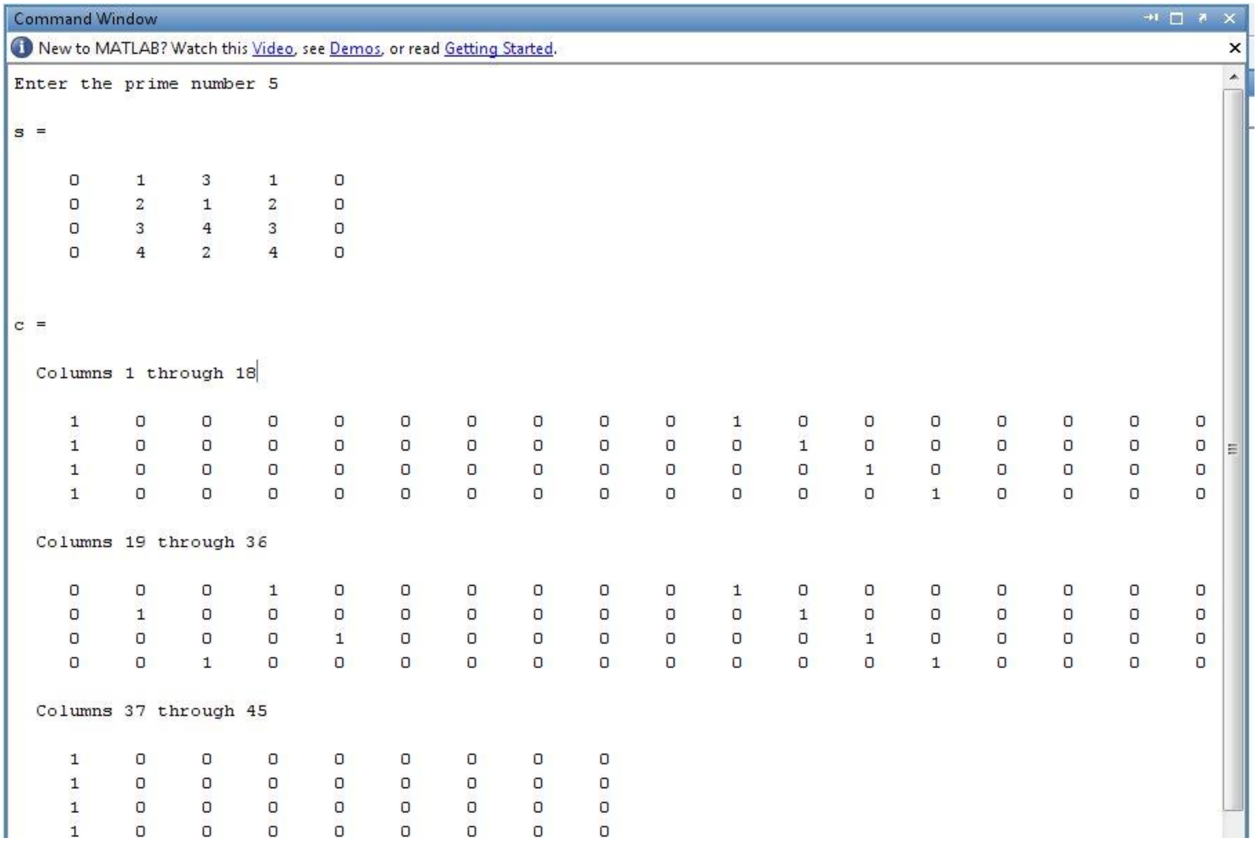
For prime number p=5, we are obtaining following code in MATLAB. For p=5 code length is equal to 25, weight is equal to 5 and cardinality is equal to 4. that means its can support less number of user as compared to 1-d prime code.

```
Command Window
New to MATLAB? Watch this Video, see Demos, or read Getting Started.

Enter the prime number 5

s =

     0     1     3     1     0
     0     2     1     2     0
     0     3     4     3     0
     0     4     2     4     0

Quadratic Congurence Code

c =

  Columns 1 through 18

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

  Columns 19 through 25

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

>> |
```

figure 4.3: MATLAB 1-D QCC generation

4.3.2 1-D Extended Quadratic Congruence Code

For prime number p=5, we are obtaining following code in MATLAB. For p=5 code length is equal to 45, weight is eaual to 5 and cardinality is equal to 4. It can support less number of user as compared to 1-D prime code at cost of it better correlation properties. It's code length is also long as compared to both the above codes. Hence, complexity increases.



```
Command Window
New to MATLAB? Watch this Video, see Demos, or read Getting Started.
Enter the prime number 5

s =

     0     1     3     1     0
     0     2     1     2     0
     0     3     4     3     0
     0     4     2     4     0


c =

  Columns 1 through 18

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

  Columns 19 through 36

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

  Columns 37 through 45

     1     0     0     0     0     0     0     0     0
     1     0     0     0     0     0     0     0     0
     1     0     0     0     0     0     0     0     0
     1     0     0     0     0     0     0     0     0
```

figure 4.4: MATLAB 1D EQCC generation

4.3.3 2-D Extended Quadratic Congruence Code

```
Command Window
New to MATLAB? Watch this Video, see Demos, or read Getting Started.
quadratic congruence sequence

s =

     0     1     3     1     0
     0     2     1     2     0
     0     3     4     3     0
     0     4     2     4     0

extended quadratic congruence code

c =

  Columns 1 through 18

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

  Columns 19 through 36

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

  Columns 37 through 45

     1     0     0     0     0     0     0     0     0
     1     0     0     0     0     0     0     0     0
     1     0     0     0     0     0     0     0     0
     1     0     0     0     0     0     0     0     0
Start
```

figure 4.5a: MATLAB 2D EQCC generation

```
Command Window
New to MATLAB? Watch this Video, see Demos, or read Getting Started.
  Columns 37 through 45

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

wavelength

h =

   510   512   514   516   518


g =

   510   510   510   510   510
   510   512   514   516   518
   510   514   518   512   516
   510   516   512   518   514
   510   518   516   514   512

2D PC-EQCC code

ans =

  Columns 1 through 18

   510     0     0     0     0     0     0     0     0     0   512     0     0     0     0     0     0     0
   510     0     0     0     0     0     0     0     0     0   514     0     0     0     0     0     0     0
   510     0     0     0     0     0     0     0     0     0   516     0     0     0     0     0     0     0
   510     0     0     0     0     0     0     0     0     0   518     0     0     0     0     0     0     0
Start
```

figure 4.5b: MATLAB 2D EQCC generation

```
Command Window
New to MATLAB? Watch this Video, see Demos, or read Getting Started.
g =

   510   510   510   510   510
   510   512   514   516   518
   510   514   518   512   516
   510   516   512   518   514
   510   518   516   514   512

2D PC-EQCC code

ans =

  Columns 1 through 18

   510     0     0     0     0     0     0     0     0     0   512     0     0     0     0     0     0     0
   510     0     0     0     0     0     0     0     0     0   514     0     0     0     0     0     0     0
   510     0     0     0     0     0     0     0     0     0   516     0     0     0     0     0     0     0
   510     0     0     0     0     0     0     0     0     0   518     0     0     0     0     0     0     0

  Columns 19 through 36

     0     0     0   514     0     0     0     0     0     0   516     0     0     0     0     0     0     0
     0     0     0   518     0     0     0     0     0     0   512     0     0     0     0     0     0     0
     0     0     0   512     0     0     0     0     0     0   518     0     0     0     0     0     0     0
     0     0     0   516     0     0     0     0     0     0   514     0     0     0     0     0     0     0

  Columns 37 through 45

   518     0     0     0     0     0     0     0     0
   516     0     0     0     0     0     0     0     0
   514     0     0     0     0     0     0     0     0
   512     0     0     0     0     0     0     0     0
```

figure 4.5c: MATLAB 2D EQCC generation

CHAPTER 5

RESULT AND DISCUSSIONS

The performance of all these above codes is analyzed to support various number of active users for the permissible BER of 10^{-9}.The performance is evaluated by using MATLAB simulations.

5.1 Comparison of BER performance for1-D Extended PC for different prime numbers

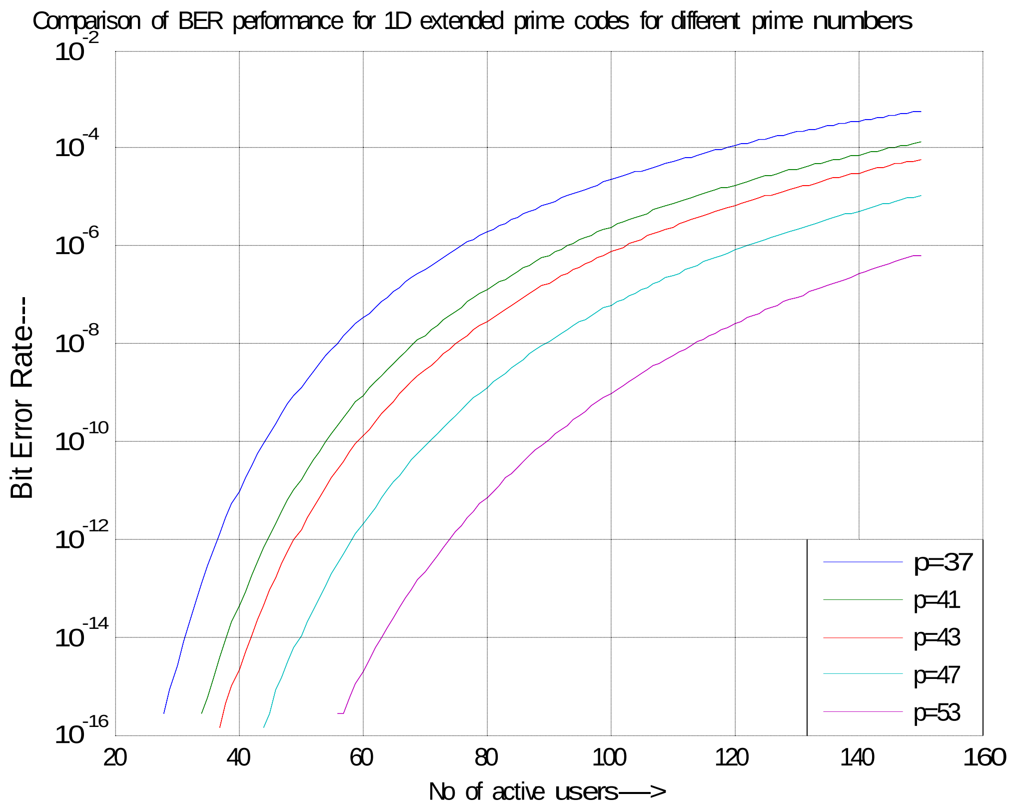
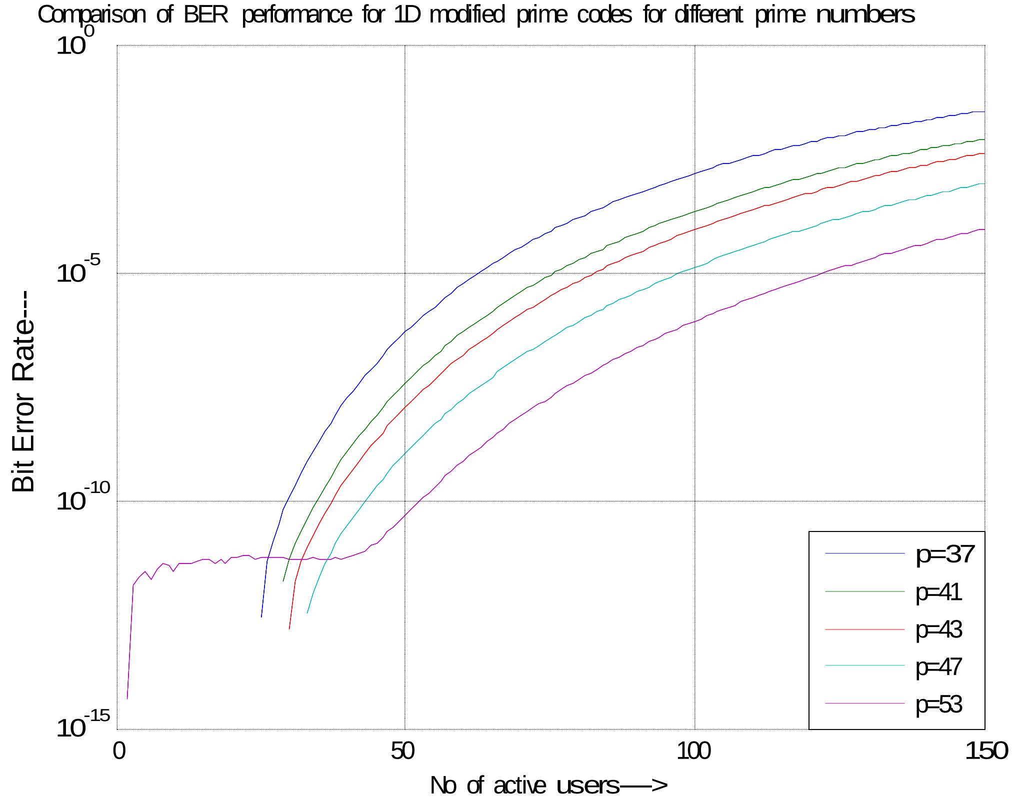


figure 5.1: comparison of BER performance for1-D Extended PC for different prime numbers

Results shown in figure 5.1 compares the Bit Error Rate (BER) performance of the (n, w, λ_a, λ_c) 1-D extended prime codes for prime number p = {37 41 43 47 51} . Here code length (n) is taken as prime number (p).In general larger value of p supports larger number of active users. Prime number 37 supports 28 users whereas prime numbers 47 and 51can support 45 and 58 active users.

The code length and code weight of the prime code are n = p(2p-1) and w = p respectively. Maximum autocorrelation side lobe and maximum cross-correlation function are λ_a=p-1 and λ_c=1 respectively. The theoretical upper bound of cardinality (n, w, λ_a, λ_c) is as follows

5.2 Comparison of BER performance for1-D Modified PC for different prime numbers



In order to reduce the code length 1-D modified prime codes were analysed. Results shown in figure 4.2 compares the Bit Error Rate (BER) performance of the (n, w, λ_a, λ_c) modified prime codes for p= {37 41 43 47 51} In this weight is selected w= {30} and code length (n) is taken as prime number (p).In general large value of p supports larger number of active users. Prime number 37 supports 25 users and whereas prime numbers 47 and 51, can support 32 and 48 number of active users respectively. Modified prime code provides efficient design for OCDMA networks due to which resulting cost and optical power losses can be reduced.

The deviation in the graph can be explained as , when number of users are very less BER is also low. As the number of users increase considerably, BER also increases.

The code length and code weight of the prime code are n and w (w< p) respectively. Maximum autocorrelation side lobe and maximum cross-correlation function are λ_a=w-1 and λ_c= 2 respectively. The theoretical upper bound of cardinality (n, w, λ_a, λ_c) is as follows

Thus modified prime codes have an advantage of a shorter code length by removing redundant bits .

5.3 performance comparison of 1-D extended PC and Modified PC :

Prime Number	1-D extended PC	Modified Prime Code
	λ_c=1	λ_c=2
73	**190**	**129**
79	**222**	**156**
83	**245**	**170**
89	**281**	**194**
97	**334**	**230**

Table 5.1 Comparison of codes in terms of numbers of users

The table 5.1 shows that for the same number of prime number , the number of users supported by 1-D extended prime codes is greater than Modified prime codes.

5.4 FUTURE SCOPE:

As we look more to all-optical networks and less to pure transport, these are salutary observations. Today IP routers offer multiple outputs directly formatted at 10Gbit’s rates that lend themselves to direct optical transport, and this is expected to stretch upwards to 40Gbit's and perhaps 100Gbit’s so the necessity to operate at the discrete packet level in an optical transport core seems unclear.

i. Increase the TDM rate up to the electronic limit (10-40Gbit’s)
ii. Move to the optical domain to achieve higher per fiber transport
    a. using multiple wavelength channels (DWDM)
    b. using optical TDM.

REFERENCES:

1. Hsiao-Hwa-Chen,National Cheng University,Taiwan, “The next generation CDMA technologies” ,John Wiley & Sons Ltd, ed.2007.

2. Hongxi Yin, David J. Richardson, “Optical code division Multiple access Communication Networks : Theory and Applications” , 2007 Tshingua University Press , Beijing and Springer-Verlag GmbH Berlin Heidelberg.

3. Jawad A. Salehi, ” Code division multiple-access techniques in optical fiber networks-part 1: fundamental principles”, IEEE TRANSACTIONS ON COMMUNICATIONS, VOL. 37, NO. 8, pp. 824-826 AUGUST 1989.
4. M. M. Karbassian and H. Ghafouri-Shiraz, “Performance analysis of heterodyne detected coherent optical CDMA using a novel prime code family,” *J. Lightw. Technol.*, vol. 25, no. 10, pp. 3028–3034, Oct. 2007.
5. Kerim Fouli and Martin Maier, “OCDMA and Optical Coding : Principles, Applications and challenges”, Instiut National de la Researche Scientifique (INRS),IEEE Communications Magazine, August 2007.
6. Optical Fiber Communication,”Gerd Keiser”,Mc Graw Hill ,ed. 1991.

7. M. M. Karbassian and H. Ghafouri-Shiraz, “Fresh prime codes evaluation for synchronous PPM and OPPM signaling for optical CDMA networks,” *J. Lightw. Technol.*, vol. 25, no. 6, pp. 1422–1430, Jun. 2007.

8. Jawad A. Salehi , member IEEE and Charles A. Brackett, member, IEEE, “Code division Multiple Access Techniques in Optical Fiber Networks-Part 2: Systems perforamnec analysis”, IEEE TRANSACTIONS ON COMMUNICATIONS, VOL. 31, NO. 8, pp 834-835 ,AUGUST 1989.