A New Modified Prime Codes for Higher User Capacity in Smart Synchronous OCDMA Network

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***Abstract*—In this paper, a new technique of transmission, reception of optical codes and a smart computational and decision based bit detection technique has been proposed in Synchronous Optical Code Division Multiple Access network. Here, Modified Prime Codes is used and simple On-Off keying modulation is considered. A simple simulation is run in OptiSystem 9.0 to prove practical applicability of the proposed system. This proposed system can accommodate up to almost maximum users available if the hardware can adjust to it.**

***Keywords*— Optical Code Division Multiple Access, Modified Prime Codes, OptiSystem.**

I. Introduction

In the near future, the user demand for information and communication technology all over the world will be unimaginably high. In this situation a network technology capable of carrying very high rate of traffic is required. Fiber optic communication technology is the solution and Code Division Multiple Access (CDMA) is the most promising technique for optical access network for giving the advantages of accommodating large number of users by utilizing available frequency with no time delay, no centralized control and flexibility over other available access techniques Wave Division Multiple Access (WDMA) and Time Division Multiple Access (TDMA).

In order to have a high performance Optical CDMA (OCDMA) network, the following two main criteria must be achieved- (1) It should be possible to accommodate more subscribers and (2) the receiver should be able to correctly recognize the intended user's information in the presence of the other interfering users' signals [1]. The first criterion depends completely on the optical code and the second criterion depends on encoding/decoding technology. So, we see that, in the design of an OCDMA system, the first and main part of concern is code. The design of code sequences for both asynchronous and synchronous OCDMA networks using optical processing have been the major challenges to many of the researchers since last few decades. The main problem of optical code is that, optical codes are unipolar and nonorthogonal. Here, orthogonality refers to the non-overlapping of the codes. In bipolar environment where the representation of binary '1' and '0' by positive and negative pulses is possible, the cross-correlation between any two codewords in a code set can be made to zero. Thus, perfect orthogonal codes can be achieved only in bipolar environment [2]. In optical environment binary '1' is represented by the existence of light pulse split over a unique code sequence over the time domain or space domain and binary '0' is represented by no pulse (all 0's sequence) because of nonexistence of negative light pulse. Thus, perfect orthogonality cannot be achieved in a unipolar (optical) environment.

So, optical codes are called pseudo-orthogonal codes. Due to the pseudo-orthogonality, when two codewords are transmitted simultaneously, they overlap at certain chip positions. When, the optical pulses in the codeword overlap, the optical power is added. Optical pulses from one codeword can be detected by receivers tuned to other codewords. As a result, receivers may falsely detect their codewords resulting in packet errors. These false positive errors increase with offered load, resulting in throughput collapse.

There are various types of optical codes proposed by many researchers. Among these the most popular codes that are of interest of study are Optical Orthogonal Codes (OOC), Prime Codes, Modified Prime Codes (MPC), Random Diagonal Codes etc. Modified Prime Codes (MPC) is the most popular code, and so, many more codes which are actually variations of MPC are proposed, such as, Double Padded MPC, Partial MPC, New MPC, Modified Prime Hop Codes etc [2-6]. Going through many research papers, we see that, all these existing codes, because of the unipolarity, the Multiple Access Interference (MAI) that is caused, the codes cannot support more than 60-65% subscribers. Even more, the modification to the codes do not give improvement factor more than 5-10% or other side complexities arises.

Another important criterion in the design of a high performance OCDMA system is the encoding/decoding technique. There also have been many researches showing that, modification to the traditional encoding/decoding technique aids in decreasing the effect of MAI and thus improve detection performance [4, 7]. But one thing to mention that, whenever a system with new and complex technique is developed, also other side complexities arises.

In this research paper, the intention was to develop such a code that can be applied using the simplest encoding and decoding technique, to be used in backbone network, because side complexities do not arise. The simpler the network structure will be, the more efficient it will be for long distance backbone network. Access networks are in the hands of third party service providers, where the design has much flexibility and planned on user demands. But, the up-gradation and maintenance is very costly for backbone network. The backbone network should be very strong with the capability of fulfilling infinite user demands. Such a network should be designed on simple strategies, but a very intelligent structure.

After going through many research papers, the first question arose that, is it possible to create such a code that will allow the maximum users available. No, it is not, because of the pseudo-orthogonality. The second question arose is that, is it possible to fully suppress MAI applying any kind of modification to the encoding/decoding technique and bit detection circuitry. No, it is not possible. After that, came the thought of applying smart computational technique.

In this paper, a new transmission/reception technique of optical codes and bit detection technique is proposed. Here, Modified Prime Codes is used in synchronous OCDMA. The simulation shows that, this new system can efficiently detect the intended user's code even at very high interference and can allow more than 90% subscribers.

This paper is organized as follows: Section II presents details of the optical code used in this network. Section III gives the proposed new techniques. In section IV a simple OptiSystem simulation of the proposed new system is shown. Finally the study is concluded.

II. MODIFIED PRIME CODES

Modified Prime Codes are generated from prime codes, hence named after prime codes. For a prime number P, Galois Field GF(P) = {0, 1, 2……P-1} is taken. Multiplying this GF(P) with each of the elements of itself one by one, P number of sequences are constructed $S_x=\{S_0, S_1, S_2 \ldots\ldots S_{p-1}\}$. Binary coding these sequences using the formula mentioned below, we get the prime code sequences $C = \{C_0, C_1, C_2 \ldots\ldots\ldots C_{p-1}\}$.

$$C_{x\,i} = \begin{cases} 1, & \text{for } i = S_{x\,j} + jP \quad j = 0, 1, \ldots. P-1 \\ 0 & \text{otherwise} \end{cases}$$

TABLE I. PRIME CODES OF P=5

Group x	i 0 1 2 3 4	Sequence S	Equivalent Binary Sequences
0	0 0 0 0 0	S_0	C_0 = 10000 10000 10000 10000 10000
1	0 1 2 3 4	S_1	C_1 = 10000 01000 00100 00010 00001
2	0 2 4 1 3	S_2	C_2 = 10000 00100 00001 01000 00010
3	0 3 1 4 2	S_3	C_3 = 10000 00010 01000 00001 00100
4	0 4 3 2 1	S_4	C_4 = 10000 00001 00010 00100 01000

The prime sequences are of code length P^2, if P=5, then we will get 5 prime codewords of code length 25 and weight 5, which is shown in the above table.

Now, for constructing modified prime codes, each of the prime sequence $S_x= \{S_0, S_1, S_2 \ldots\ldots S_{p-1}\}$ is left rotated (or right). Then, the new time shifted sequences will be $S_{x,t} = \{S_{x,0}, S_{x,1}, S_{x,2} \ldots\ldots\ldots S_{x,P-1}\}$. Here, t represents the number of times S_x is left rotated. Binary coding these sequences $S_{x,t}$, the code sequences $C_{x,t} = \{C_{x,0}, C_{x,1}, C_{x,2} \ldots\ldots\ldots C_{x,P-1}\}$ using the formula mentioned below is created [7].

$$C_{xt\,i} = \begin{cases} 1 & \text{for } i = S_{xtj} + jP, \quad j = 0,1,\ldots\ldots..P-1 \\ 0 & \text{otherwise} \end{cases}$$

For example, from the above table, $S_{1,0}$ = {0 1 2 3 4}. Left shifting this sequence becomes $S_{1,1}$ = {1 2 3 4 0}. Again, left shifting it becomes, $S_{1,2}$ = {2 3 4 0 1}. This way, from each prime sequence, P numbers of shifted sequences are generated. Then, the total codewords will be P.P = P^2, of code length P^2 and weight P. The modified prime code sequences of P=5 are shown in the following table [2].

TABLE II. MODIFIED PRIME CODES OF P=5

Group x	i 0 1 2 3 4	Sequence S	Code Sequences
0	0 0 0 0 0	$S_{0,0}$	$C_{0,0}$ = 10000 10000 10000 10000 10000
	4 4 4 4 4	$S_{0,1}$	$C_{0,1}$ = 00001 00001 00001 00001 00001
	3 3 3 3 3	$S_{0,2}$	$C_{0,2}$ = 00010 00010 00010 00010 00010
	2 2 2 2 2	$S_{0,3}$	$C_{0,3}$ = 00100 00100 00100 00100 00100
	1 1 1 1 1	$S_{0,4}$	$C_{0,4}$ = 01000 01000 01000 01000 01000
1	0 1 2 3 4	$S_{1,0}$	$C_{1,0}$ = 10000 01000 00100 00010 00001
	1 2 3 4 0	$S_{1,1}$	$C_{1,1}$ = 01000 00100 00010 00001 10000
	2 3 4 0 1	$S_{1,2}$	$C_{1,2}$ = 00100 00010 00001 10000 01000
	3 4 0 1 2	$S_{1,3}$	$C_{1,3}$ = 00010 00001 10000 01000 00100
	4 0 1 2 3	$S_{1,4}$	$C_{1,4}$ = 00001 10000 01000 00100 00010
2	0 2 4 1 3	$S_{2,0}$	$C_{2,0}$ = 10000 00100 00001 01000 00010
	2 4 1 3 0	$S_{2,1}$	$C_{2,1}$ = 00100 00001 01000 00010 10000
	4 1 3 0 2	$S_{2,2}$	$C_{2,2}$ = 00001 01000 00010 10000 00100
	1 3 0 2 4	$S_{2,3}$	$C_{2,3}$ = 01000 00010 10000 00100 00001
	3 0 2 4 1	$S_{2,4}$	$C_{2,4}$ = 00010 10000 00100 00001 01000
3	0 3 1 4 2	$S_{3,0}$	$C_{3,0}$ = 10000 00010 01000 00001 00100
	3 1 4 2 0	$S_{3,1}$	$C_{3,1}$ = 00010 01000 00001 00100 10000
	1 4 2 0 3	$S_{3,2}$	$C_{3,2}$ = 01000 00001 00100 10000 00010
	4 2 0 3 1	$S_{3,3}$	$C_{3,3}$ = 00001 00100 10000 00010 01000
	2 0 3 1 4	$S_{3,4}$	$C_{3,4}$ = 00100 10000 00010 01000 00001
4	0 4 3 2 1	$S_{4,0}$	$C_{4,0}$ = 10000 00001 00010 00100 01000
	4 3 2 1 0	$S_{4,1}$	$C_{4,1}$ = 00001 00010 00100 01000 10000
	3 2 1 0 4	$S_{4,2}$	$C_{4,2}$ = 00010 00100 01000 10000 00001
	2 1 0 4 3	$S_{4,3}$	$C_{4,3}$ = 00100 01000 10000 00001 00010
	1 0 4 3 2	$S_{4,4}$	$C_{4,4}$ = 01000 10000 00001 00010 00100

Here, given the correlation properties of modified prime codes.

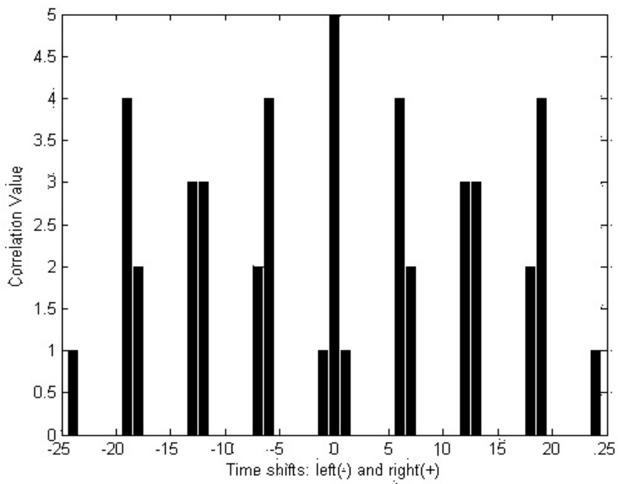

Fig 1: Auto-correlation of MPC $C_{1,0}$

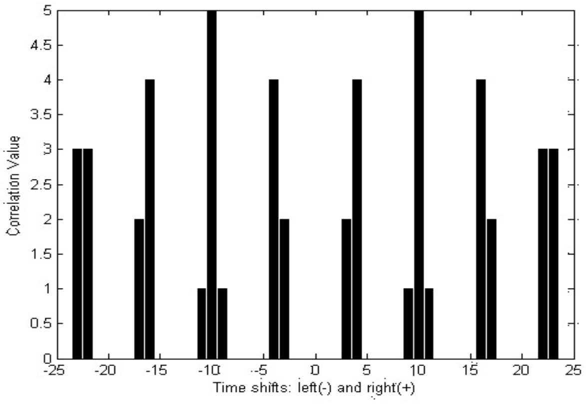

Fig 2: Cross-correlation of MPC $C_{1,0}$ and $C_{1,2}$ of same group

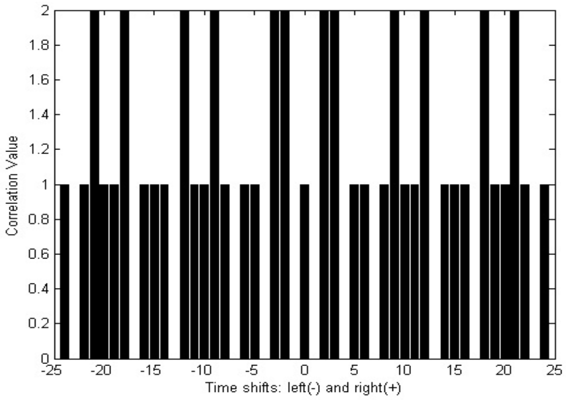

Fig 3: Cross-correlation of MPC $C_{1,0}$ and $C_{2,2}$ of different groups

III. PROPOSED NEW SYSTEM

The proposed new system of synchronous OCDMA network is explained here in two parts:

1. Transmission
2. Reception and Bit Detection.

1) Transmission:

In the table of modified prime codes, we see that, there are five groups of codes. Usually, all the transmitters in the optical fiber communication technology transmit these codes in the same power level. But, in the proposed new system, the codes of each group will be transmitted in different power levels. Assume that, the transmitters using 5th group codes will transmit in a fixed power level. The transmitters using the 4th group codes will transmit in a power level double of the 5th group transmitters. The transmitters using the 3rd group codes will transmit in a power level triple of the 5th group transmitters and so on. All that matters here is the parameter transmission power. The power need not be chosen as double or triple, but, such that, the difference is clear at the receiver. Here, a theoretical representation of the modified prime codes is given based on the transmission power according to the new transmitting scheme.

TABLE III. MODIFIED PRIME CODES OF NEW SYSTEM

New Code Sequences
$C_{0,0}$ = 50000 50000 50000 50000 50000
$C_{0,1}$ = 00005 00005 00005 00005 00005
$C_{0,2}$ = 00050 00050 00050 00050 00050
$C_{0,3}$ = 00500 00500 00500 00500 00500
$C_{0,4}$ = 05000 05000 05000 05000 05000
$C_{1,0}$ = 40000 04000 00400 00040 00004
$C_{1,1}$ = 04000 00400 00040 00004 40000
$C_{1,2}$ = 00400 00040 00004 40000 04000
$C_{1,3}$ = 00040 00004 40000 04000 00400
$C_{1,4}$ = 00004 40000 04000 00400 00040
$C_{2,0}$ = 30000 00300 00003 03000 00030
$C_{2,1}$ = 00300 00003 03000 00030 30000
$C_{2,2}$ = 00003 03000 00030 30000 00300
$C_{2,3}$ = 03000 00030 30000 00300 00003
$C_{2,4}$ = 00030 30000 00300 00003 03000
$C_{3,0}$ = 20000 00020 02000 00002 00200
$C_{3,1}$ = 00020 02000 00002 00200 20000
$C_{3,2}$ = 02000 00002 00200 20000 00020
$C_{3,3}$ = 00002 00200 20000 00020 02000
$C_{3,4}$ = 00200 20000 00020 02000 00002
$C_{4,0}$ = 10000 00001 00010 00100 01000
$C_{4,1}$ = 00001 00010 00100 01000 10000
$C_{4,2}$ = 00010 00100 01000 10000 00001
$C_{4,3}$ = 00100 01000 10000 00001 00010
$C_{4,4}$ = 01000 10000 00001 00010 00100

2) Reception and Bit Detection:

We know that, the cross-correlation between any two codewords in the same group is 0, i.e. no interference occurs in the transmission of same group codewords. Again, the cross-correlation between any two codewords of different group is 1, i.e. in the transmission of two codewords of different group, at one chip position interference will occur. Due to the difference of transmission power of the different group codes, the receiving power will also be different for each code. When multiple user's code will access the shared medium through multiplexer, the optical powers will add in the corresponding chip positions also creating byproduct noises. In the usual OCDMA system, the correlation receiver correlates the incoming signal with the intended user's code, it simply matches the corresponding chip position of the intended user's code. If at any lit chip position it gets a signal, then it counts 1. This way at all the lit chip positions the match number is counted, and if it is equal to or greater than the preset correlation threshold value, then the receiver accepts the signal, otherwise, rejects it.

In the proposed new system, the receiver will first measure the power of the incoming signal at the corresponding lit chip positions of the intended user's code. A single-purpose very high speed processor will be set parallel at the lit chip positions. Then the processor will take the information and from a database that is stored or collected, will check and decide either its binary '1' or '0'. The database will contain the power records of all bit combinations of all codes for the intended user's code. If the number of counts of '1' at all lit chip positions is equal to or greater than the preset threshold value, then the processor will let the receiver accept the signal, otherwise not.

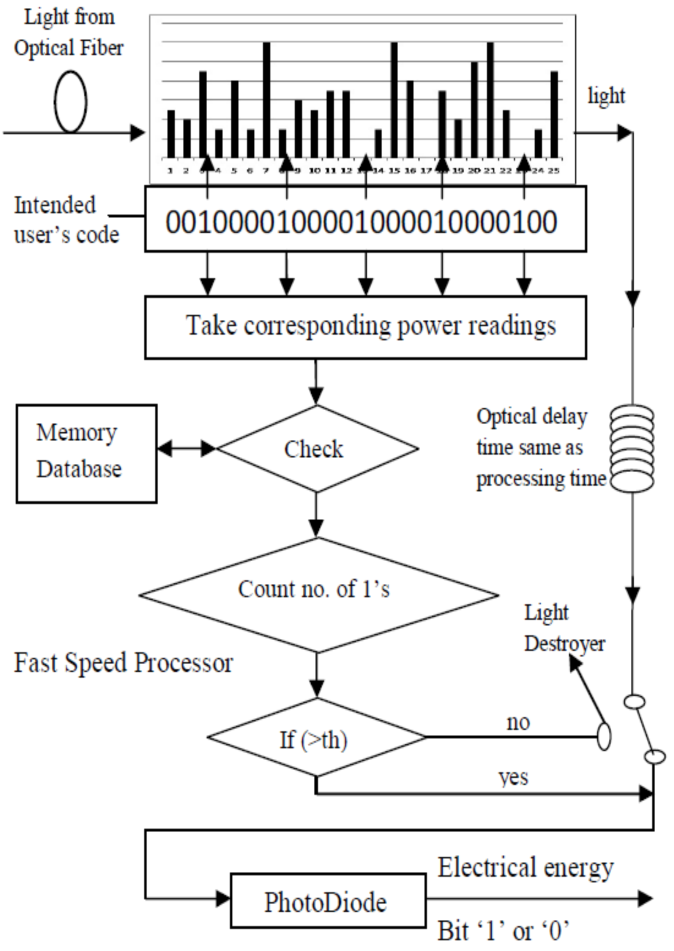

Fig 4: Schematic and Flow Diagram of Receiving Technique

Advantages of this new system:

1) If the optical power meter can measure the optical power very subtly and requirement of fast speed processor is fulfilled, then almost 100% user accommodation is possible.
2) Very simple encoding and decoding technique can be applied and there are no other side complexities.

Disadvantage of this new system:

1) Very subtle measurement and fast processing is required.
2) The receiver needs to be trained up before communication and database of record has to be stored in a memory of receiver. So, for a network that is most often changeable, this system is not appropriate.

IV. Simulation and Results

In the proposed new system, the main challenge is, is it possible to receive signals with variations of power. So, a small simulation is run in OptiSystem 9.0 to see if this scheme is practically possible. We know that, for any codeword of one group at one chip position, there is only one codeword from another group that creates one interference. So, in the simulation, instead of taking one full code, we take only one bit for simplicity.

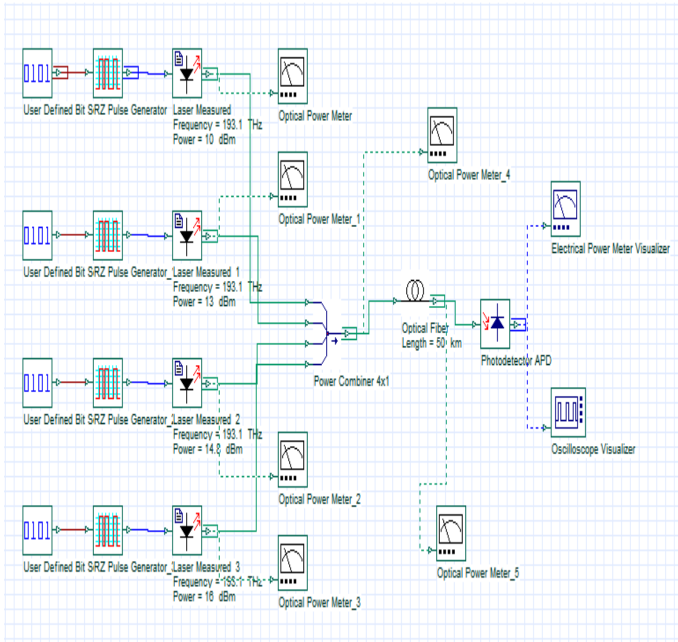

Fig 5: OptiSystem 9.0 simulation

First, any desired bit sequence or bit is generated and passed through the RZ (Return to Zero) pulse generator. These devices are electrical. The signal from the pulse generator is passed to the Laser Diode, where it converts electrical energy into light pulses. With the help of a combiner, 4 such user's bit is added and passed to the optical fiber. Here, optical fiber is taken of length 50 km. Light passing through the optical fiber reaches the photo-detector, where the light energy is converted back into electrical pulses.

At various points power meters are set to record the power levels. The laser diodes that transmit optical pulses according to the user bit sequence are set to different power levels, so that, the optical signals are transmitted at different power levels. As a result, the signals will reach the photo-detector at different power levels. For different combination of the user's bit, the received signal's power will be different. These power values are recorded and stored in a database. On receiving a signal its power value is measured and based on the database the bit is evaluated.

In the figure, 4 users are defined successively from top to bottom. The power values recorded at the laser diodes and at the photo-detector for different bit combinations are given below.

1) Laser 1 set to 0.01 W, 10 dbm.

2) Laser 2 set to 0.02 W, 13 dbm.

3) Laser 3 set to 0.03 W, 14.8 dbm.

4) Laser 4 set to 0.04 W, 16 dbm.

TABLE IV. POWER DETAILS OF TRANSMITTERS

	Transmits bit '1' at		**Transmits bit '0' at**	
Laser 1	$5.503e^{-3}$ W	7.406 dbm	$1.000e^{-3}$ W	0.005 dbm
Laser 2	$10.486e^{-3}$ W	10.206 dbm	$1.000e^{-3}$ W	0.006 dbm
Laser 3	$15.609e^{-3}$ W	11.933 dbm	$997.347e^{-6}$ W	-0.012 dbm
Laser 4	$20.422e^{-3}$ W	13.101 dbm	$1.000e^{-3}$ W	0.002 dbm

TABLE V. POWER DETAILS OF RECEIVER 1 USING CODE 1 FOR ALL OTHER TRANSMITTERS BIT COMBINATION

User 1 bit '1'			**User 1 bit '0'**		
000	$870.527\ e^{-9}$ W	-30.602 dbm	000	$181.507\ e^{-9}$ W	-37.411 dbm
001	$9.524\ e^{-6}$ W	-20.212 dbm	001	$6.181\ e^{-6}$ W	-22.088 dbm
010	$6.042\ e^{-6}$ W	-22.188 dbm	010	$3.928\ e^{-6}$ W	-24.059 dbm
011	$19.514\ e^{-6}$ W	-17.096 dbm	011	$14.518\ e^{-6}$ W	-18.381 dbm
100	$3.328\ e^{-6}$ W	-24.779 dbm	100	$2.216\ e^{-6}$ W	-26.545 dbm
101	$15.1\ e^{-6}$ W	-18.210 dbm	101	$11.516\ e^{-6}$ W	-19.387 dbm
110	$10.903\ e^{-6}$ W	-19.624 dbm	110	$8.414\ e^{-6}$ W	-20.750 dbm
111	$28.896\ e^{-6}$ W	-15.391 dbm	111	$23.568\ e^{-6}$ W	-16.277 dbm

We know that, optical fiber is immune to cross-talk and electrical interference. However, for any reason the power reading may be a little different from the exact value. In such case, the nearest matched value is accepted and the bit is detected.

V. CONCLUSION

Here, a new scheme of transmitting Modified Prime Codes and a new technique of reception and bit detection is proposed in a synchronous Optical Code Division Multiple Access network. The simulation proves that this proposed scheme is practically possible. The main drawback of this scheme is the arrangement of hardware at the receiver. If such a system can be developed, then the system can allow almost the maximum available users, i.e. 100% user capacity.

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