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DESIGN OPTIMIZATION OF OPTICAL COMMUNICATION SYSTEMS USING CARBON NANOTUBES (CNTs) BASED ON OPTICAL CODE DIVISION MULTIPLE ACCESS (OCDMA)

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ABSTRACT

This paper presents optimized design performance of incoherent OCDMA as well as coherent OCDMA using carbon nanotubes (CNTs) based devices with reference to increased Data Rate (R) and reduced Bit Error Rate (BER) which is far enhanced in comparison to Silicon based Optical Devices. The carbon nanotubes (CNTs) based devices are having optical properties as well as brings in miniatured dimension. Besides, it has been observed that a CNT – based FET switches reliably use less power than silicon based optical devices, specifically in traditional t – gate multiplexer, which is a fundamental logic block, carbon nanotubes based optical devices can have a wide range of applications in a wide variety of miniaturized circuits. The carbon nanotubes with OCDMA system supports ultrahigh speed network with data rate up to Tb/s and exceptional BER performance in the system. The OOK/OCDMA formats provide better performance in comparison to PPM/OCDMA formats because in the OOK formats the numbers of code length is much more than PPM formats, and also less complex hardware from PPM formats. As observed and presented in this paper, the carbon nanotubes brought in the improved performance OCDMA system network with highest data rate and lowest bit error rate.

KEYWORDS: OCDMA System, Carbon Nanotubes, OOK Formats, PPM Formats, BER Performance

INTRODUCTION

The performance of any communication system is fundamentally limited by the available bandwidth, the signal to noise ratio of received signal, and the codes used to relate the original information to the transmitted signal. These limits inevitably lead to increased errors and corresponding loss of information [1]. An OCDMA network is expected to be able to accommodate many subscribers and simultaneous access users, and to have high date rate for each user and low bit error rate [2]. However, since they are strongly associated with each other, optimized performance analysis of network becomes an issue of multiple target function description, which is very complex. For example of subscribers and simultaneous access users allowed are related to a set of address codes chosen and the requirement of system bit error rate. Meanwhile, the performance of the address – code set again influences the user’s data rate as well. Next generation of optical communication system may preferably incorporate carbon nanotubes based devices so as to achieve much higher data rate up to Tb/s in comparison to present systems using silicon optical devices giving data rate up to Gb/s. Besides, such systems with advanced energy source power realize in much longer life Nevertheless, future requirements of ultrahigh speed internet, video, multimedia, and advanced digital services, would suitably be met with incorporation of carbon nanotubes based devices providing optimal performance . In the following, they commence with the system performance analysis from the viewpoint of the system BER as a function of data rate, the address – code parameters, such as code length and code weight, the number of subscribers and the decision – threshold of receiver. The inherent relationship among these parameters will be revealed, which acts as a theoretical basis for the optimized design of practical network. At the same time, two approaches to effectively reduce MAIs will be introduced, here, one approach is silicon optical devices micro- technology, and another approach is carbon nanotubes nano-technology in optical decoder. The silicon optical devices have refractive index $n_2 = 2 * 10^{-20} m^2/w$ and the band gap energy is 1.12 e V, at temperature 300K the system can work normal in this temperature, while the carbon nanotubes have refractive index $n_2 = 1.55 * 10^{-8} \frac{m^2}{w}$, and the band gap energy is 2.9 e V , at temperature for carbon nanotubes is 973 K, so that we can use it for more applications. Standard values of band gap are 1.12 e V for silicon, 0.67e V for germanium, 1.43e V for GaAs, and 2.9e V for carbon nanotubes given $E_{g\,,} d_t$ can be determined and of course (n,m) Hadmade integers [3],[4]. Two mechanisms of contact between metal (source/drain) and semiconducting SWNTs interface lead to two types of carbon nanotubes field effect transistors CNTFET, and conventional CNTMOSFET. The carbon nanotubes support optical properties by three main parameters very important to develop work in optical system application such as Electronics structure of carbon nanotubes, saturable absorption, and third order nonlinearity [5]. The OCDMA encoder and decoder are the key components to implement OCDMA systems. In order to actualize the data communications among multiplier users based on OCDMA communication technology, one unique codeword – waveform is focus here is to use carbon nanotubes to work with OCDMA for improving the performance of optical system application integrated circuit devices based on carbon nanotubes next generation to support high speed data rate for communication networks [5]. The demonstration of the first functional laser [7], and the development of an optical waveguide [8], marked the beginning of modern optical communication networks. From these demonstrations came the first generation of optical communication networks with the development of a GaAs semiconductor laser operating at 0.8μm and low – loss optical devices [9]. These networks operated at data rates of 45MB/s with repeated spacing of large distance as 10Km. It was quickly realized that the transmission distance between repeaters in these first generation optical networks could be increased by operating in the wavelength region near 1.3μm. The reason for this was due to the low device loss and minimum dispersion experienced in silicon optical device at these wavelengths. Hence, world wide effort was undertaken to develop In GaASP semiconductor devices operating at 1.3μm eventually resulting in second – generation lightwave systems operating at data bit rates of up to 1.7 Gb/s with repeater spacing of about 50Km. The third generation networks shifted the operational wavelength once again, this time to 1.55μm to take advantage of the low 0.2dB/Km loss in silicon devices at this wavelength. While dispersion is a problem at this wavelength, a solution could be found through the use of dispersion – shifted fiber or a single – mode laser transmitter. As a result, third generation optical networks operating at 2.5Gb/s were available by 1990. The next major breakthrough occurred with the advent of optical amplification and optical multiplexing techniques. By 1990, commercially available optical amplifiers allowed for repeater spacing of (60-80)Km with optical multiplexing techniques pushing data rates of fourth generation networks into the 40Gb/s [9]. The next generation optical system will now use carbon nanotubes with enhanced performance increasing data rates to Tb/s, less bit error rates (BER), besides, reduced power consumption in the system.

Carbon Nanotubes Multiplexers

Two novel types of carbon nanotubes (CNTs) based multiplexers are introduction as shown in figure 1 (a). The new device is a solid – state transmission gate (t-gate) multiplexer that uses carbon nanotube as channel in the Field Effect Transistor (FET) of both n- FET and p- FET type's as shown in as figure 1 (b). Because it has been shown that carbon nanotubes – based FET switches are reliable and ultrafast responsivity using much less power than a silicon optical – based devices, and thus support ultrahigh data rates to Tb/s for ultrahigh speed application networks. The new device will consume less power than traditional t – gate multiplexer [10]. Nanotechnology is new field of Research that cuts across many fields of electronics, chemistry, physics, and biology, that analyzes and synthesize objects and structures in the nano-scale (10^{-9}) such as nano particles, nanowires, and carbon nanotubes (CNTs). Carbon nanotube is one of several cutting- edge emerging technologies and very wide range of applications in many different streams of science and technology [11-18].

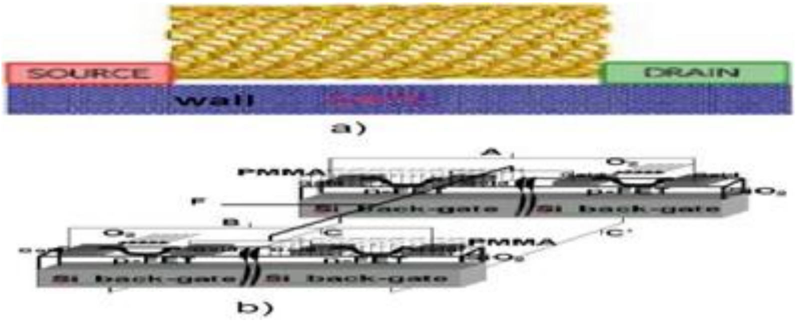

Figure 1: (a) The Carbon Nanotubes as Channel in FET and (b) The Carbon Nanotubes Structures Multiplexer (CNTs MUX)

The biggest challenge with optical CDMA system is to maintain the performance of the system and offer high bandwidth in case of higher number of users at minimum cost [19]. Here, we determine some of important parameter in this system as data rate (R) with Pulse Position Modulation (PPM) formats, and bit error rate (BER) and also for On- OFF Keying (OOK) formats on Incoherent OCDMA 2-D wavelength – hopping / time spread technique and coherent OCDMA spectral phase encoding and temporal phase encoding for analysis and computing BER for silicon optical devices and carbon nanotubes. Multiplexing technique is to increase the capacity of an optical link beyond the limit available for serial transmission, a service provide can either install an additional fiber or to use some form of multiplexing. Multiplexing allows multiple channels to be transmitted simultaneously over a single optical fiber giving network provides access to the large bandwidth capabilities of single fiber which can lead to increased throughput in the network without laying additional fiber. Optical multiplexing can be achieved through multiplexing either in the time domain, wavelength, or hybrid of both. Due to the large bandwidth (5GHz) and associated high bit rates, the multiplexing process is beyond the capabilities of pure electronic methods and has to be implemented optically as well. Code division multiple access (CDMA) is strong candidate for creating effective multiple methods for the optical subscriber access network because of its asynchronous access and code multiplexing [23]. OCDMA system has attracted increasing attention in recent years due to the following advantages: asynchronous access capabilities, accurate time of arrival measurements, and flexibility of user allocation, ability to support variable bit rate, busty traffic and security against unauthorized users. Moreover, the OCDMA method is preferable for multiplexing in the optical domain because it uses broad bandwidths in optical devices for the electrical CDMA method and the Electrical to Optical E/O conversion in transmitter optical system to send through optical fiber as transmission media after that the Optical to Electrical O/E conversion in receiver in optical system to recover original information [24].

ASSUMPTION SYSTEM AND SIMULATIONS

In the present study, OCDMA scheme has bee nan increasing interest for optical system because it allows multiple users to access the system asynchronously and simultaneously. OCDMA is expected for further ultrahigh speed and real time computer communications where there is strong demand for the systems to support several kinds of data with different traffic requirements [19]. We have analyzed the improved performance in OOK and PPM formats through some of parameters as bit error rate (BER), data rate (R), the transmitted signal power, the received signal power, the threshold system (Ths), and the code weight in OCDMA techniques with silicon optical devices and carbon nanotubes.

General Block Diagram of Tx/Rx OCDMA Communication System

Code division multiple access (CDMA) scheme has been an interesting fiber optic network because it allows multiple users to access the network asynchronously and simultaneously. Optical code division multiple access (OCDMA) is expected for further ultrahigh speed and real time computer communications where there is strong demand for the systems to support several kinds of data with different traffic requirements. As shown figure 2 that data are coming into the data conversion unit which converted the data in electrical form. This converted data is driving the laser driver. This laser light is passing through the optical fiber. Temperature controller controls the temperature of optical devices [22].

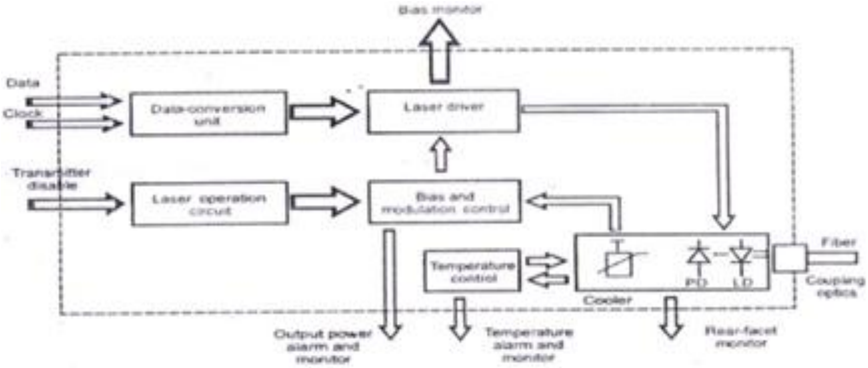

Figure 2: Transmitter Optical Code Divisions Multiple Access (OCDMA) Communication System

Figure 3 shows that signals are received in photo detector block, preamplifiers amplify signal because it may be weaken during transmission time. Then it goes through an element noise filter. Finally, we get result for the OCDMA system with fabricated carbon nanotubes devices or silicon optical devices, but with carbon nanotubes. OCDMA, system works much more satisfactorily [19].

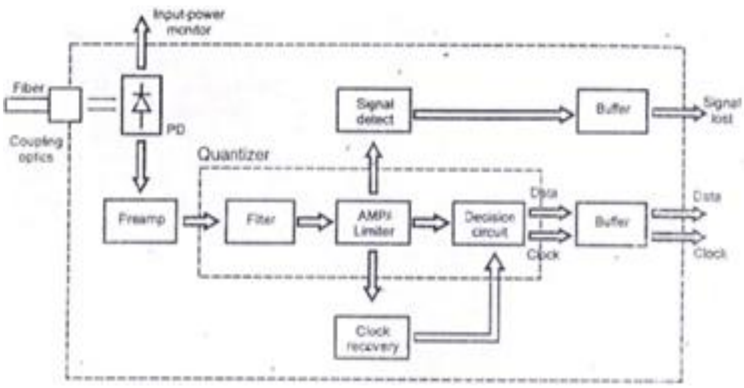

Figure 3: Receiver Optical Code Division Multiple Access (OCDMA) Communication System

The Performance Analysis of OCDMA System with Chip Level Receiver

There are other types of receivers for OCDMA communication system, called chip receivers [20], which are in turn categories into the On – Off keying (OOK) OCDMA chip level received and Pulse Position Modulation (PPM) OCDMA chip level receiver. Since the multiple access interference received by the receiver increases with the increasing of the number of simultaneous subscribers, the performance of the correlation receiver degrades with the increasing of the number of users. The performance of chip level receiver is asymptotically optimal and nevertheless the complexity of the receiver is independent of the number of subscribers. The block diagram of OOK/PPM OCDMA system is shown in figure 4.

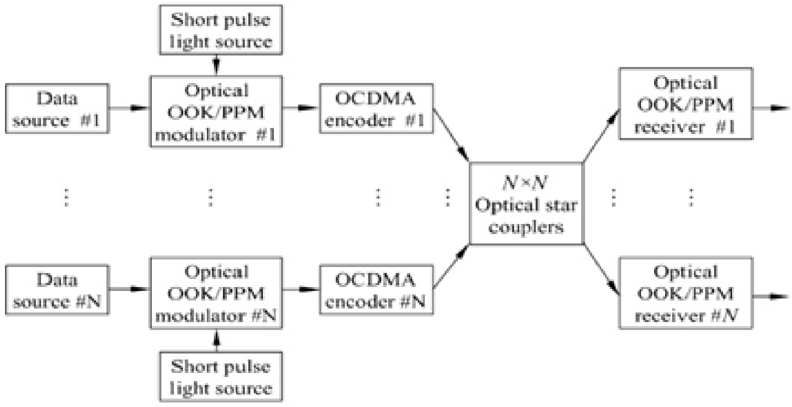

Figure 4: Direct – Detection OOK/PPM OCDMA Models [1]

At the transmitting end, the narrow optical pulse signal from light source is firstly modulated by data information through OOK/PPM optical modulator. The output signal of the optical modulator is transmitted to the optical network after encoded by the optical encoder. Figure 5 shows the schematic diagram of OOK/PPM OCDMA signal corresponding to databit.

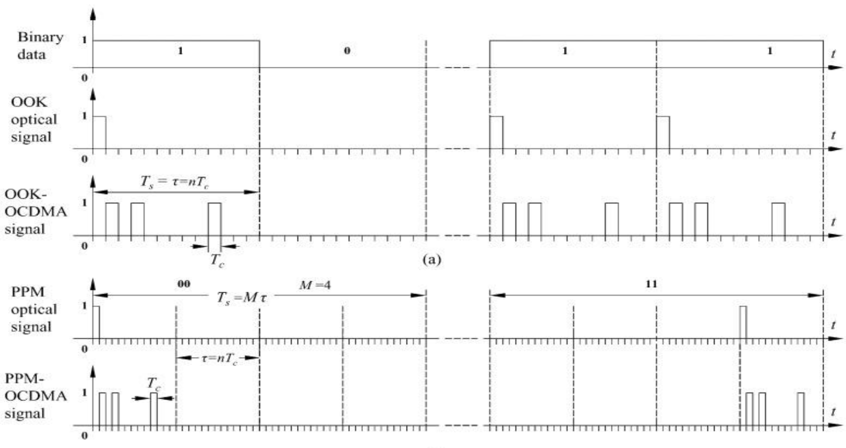

Figure 5: Schematic Diagrams of OOK and PPM OCDMA

As to the OOK modulation manner, there are only two binary symbols and each symbol corresponds to one data bit. When data bit is "1", the optical encoder sends an optical pulse code sequence to the network. Otherwise, when data bit is "0", the optical encoder doesn't send any optical signal [2]. In M-ary PPM signaling format, there are M symbols possible. Therefore, each symbol represents log_2M bits of data information as example M=4 are shown in this figure 5 where each represents two bits of data information. In PPM modulation format, the different symbol is expected by the distinct position where the pulse locates, for example, the pulse at the first slot represents the first symbol; the pulse at the second slot represents the second symbol, etc. Then, an optical encoder encodes the optical pulse and there would be an optical pulse code sequence within the corresponding slot. The temporal sequence corresponding to each symbol is called one frame whose length is represented byT_b. Each frame is divided into M slots and the length of each slot is denoted by$\tau = T_b$. Furthermore, each slot is composed of n chips and the time width of chip is indicated by $T_c = 5.181 * 10^{-17} second$, where n corresponds to the code length of the optical orthogonal code. Thus, there exists $T_b = 3.33 * 10^{-10}$ sec, and power source is $35.99 * 10^{-3} watt$ in silicon optical devices, and also$T_b = 2.58 * 10^{-13}\ sec$, and power source $214.8 * 10^{-3} watt$ in carbon nanotubes devices. For OOK modulation format, the slot length is equal to the length of a frame. Assuming that both the chip time $T_c = 5.181 * 10^{-17} sec$ and throughput are held fixed, the code length is given by equation (1) [20] [37].

$$n = \begin{cases} \frac{1}{R_o} & for\ OOK \\ \frac{log_2 M}{M R_o} & for\ PPM \end{cases} \tag{1}$$

Where M indicates the number of possible slots within a PPM time frame and $R_O = 1.0 * 10^{-3}$ denotes the throughput in bits/chip time. At the receiving end, the data are restored by the OOK/PPM chip – level optical receiver. Since the chip – level receiver are dependent on the number of photons (optical energy) per chip in the received frame when it uses silicon optical devices the optical source power is $35.99 * 10^{-3} watt$, whereas when it uses carbon nanotubes the optical source power is $214.8 * 10^{-3} watt$. That means when we use the carbon nanotubes devices the consumed power is very low. Here, the time duration of time slot $T_b = 3.33 * 10^{-10}$ sec or nanosecond in silicon optical devices, but the time duration $T_b = 2.58 * 10^{-13}\ sec$ or femtosecond in carbon nanotubes, therefore, the carbon nanotubes ultrafast switching based system, are formulated to attain optimized performance of OCDMA technology. Parameters as indicated in table 1 are assumed for achieving enhanced performance of carbon nanotubes based OCDMA in comparison to silicon optical devices based devices which would in turn consume lesser power, miniaturized in dimension and withstand higher temperature.

Table 1: Parameters Assumed in Simulated OCDMA System

Parameters	Silicon Optical Devices	Carbon Nanotubes
Time duration (T_b)	$3.33 * 10^{-10}$sec	$2.58 * 10^{-13}$sec
Data rate (R_b)	$3.00 * 10^9\ bits/sec$	$7.7519 * 10^{11} bits/sec$
Code weight (w)	W=3,5,7	W=3,5,7
Load resistance (RL)	$50 * 10^3 \Omega$	$12.9 * 10^3 \Omega$
Temperature for material	300K	973 K
Refractive index (n_2)	$2 * 10^{-20} m^2/watt$	$1.55 * 10^{-8} m^2/watt$
Source power laser (P_{ook})	$35.99 * 10^{-3} watt$	$214.8 * 10^{-3} watt$
Recharge electron (e)	$1.6 * 10^{-19}$	$1.6 * 10^{-19}$
Light of speed	$3 * 10^8$	$3 * 10^8$
Threshold value (Th)	$1 * 10^{-3}\ watt$	$1 * 10^{-3}\ watt$
Boltzmann's constant (K_b)	$1.38 * 10^{-23} J/K$	$1.38 * 10^{-23} J/K$
Area of devices	$m2.5 * 10^{-5}$	$m2.5 * 10^{-5}$
Length of code for OOK formats	n=1000	n=1000
Length of code for PPM formats	n=375	n=375
Throughput in bits/chip timeR_o	$1.0 * 10^{-3}$	$1.0 * 10^{-3}$
Noise for MAI	$6.5 *\ 10^{-5}\ watt$	$6.5 *\ 10^{-5}\ watt$
Band gap energy (E_t)	$1.12\ e\ V$	$2.9\ e\ V$
Time chip (T_c)	$5.181 * 10^{-17} sec$	$5.181 * 10^{-17} sec$
Wavelength center (λ_c)	$1550 * 10^{-9} m$	$1550 * 10^{-9} m$

RESULTS AND DISCUSSIONS

In this paper, we have investigated the transmission analysis of OCDMA communication systems using silicon optical devices and carbon nanotubes under the set of the wide range of operating parameters as shown in table 1. It is aimed to improve the performance of the incoherent OCDMA systems by OOK formats and PPM formats using carbon nanotubes (CNTs), and silicon optical devices. Figure6 illustrates that the data rate is decreased when the number of users are increased in the PPM format for OCDMA system given by equation (2) [1].

$$\boldsymbol{R = \frac{K\ log_2 M}{M * n * T_b}} \tag{2}$$

Where K is the number of simultaneous users, T_b is the signaling period “symbol interval”, n is the code of length, where each user is assigned a set of M codes, each corresponding to a particular “digit”. In the M-ary system with M=8 [1].

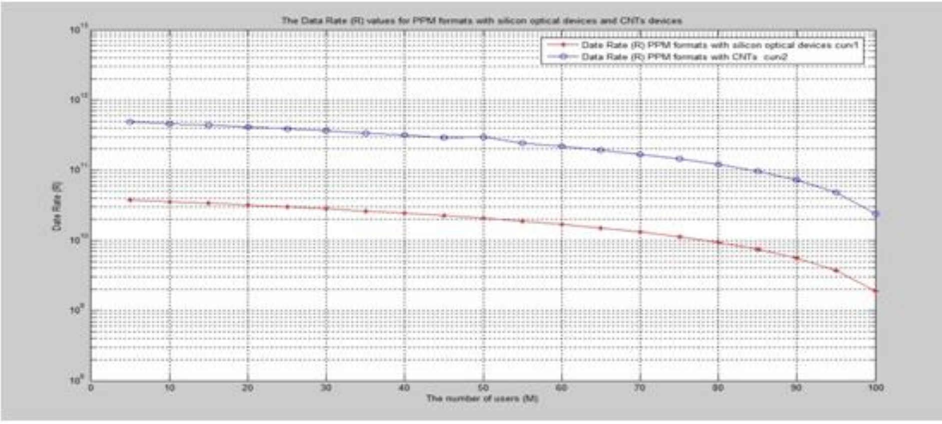

Figure 6: Represented the Data Rate (R) in the Incoherent OCDMA by PPM Format with Silicon Optical Devices and Carbon Nanotubes

The data rate with carbon nanotubes as obtained result represented by curve 2 is better than silicon optical devices as represented curve 1as shown figure 6. It is indicated that in the simulated system with the existing coding technique for PPM/OCDMA system, the bit error rate increases much more with silicon optical devices but the bit error rate is very low with carbon nanotubes used $\tau = T_b = 2.58 * 10^{-3}sec$, source power of laser $P_{OOK} = 214.8 * 10^{-3}watt$, and refractive index $n_2 = 1.55 * 10^{-8}m^2/watt$ from table 1 [1],[5],[6]. Bit error rate in PPM/ OCDMA format is given by equation (3)

$$\boldsymbol{BER} = \frac{1}{2}\left[\sum_{m=N_\lambda}^{M} \frac{n!}{m!(n-m)!}\left\{\frac{E_t N_\lambda \tau}{2*T_c}\right\}^m \left\{\mathbf{1} - \frac{E_t N_\lambda \tau}{2*T_c}\right\}^{n-m}\right]^{E_t} \quad (3)$$

Let M is the number of simultaneous users and τ is the single pulse width used in silicon optical devices and carbon nanotubes, N_λ is code with N_λ =8 different wavelength channel and different values of E_t in silicon optical devices is E_t =1.12 e V, and carbon nanotubes is E_t =2.9 e V. Then, as a function of number of users, the bit error rate (BER) performance codes C is affected by the multiple access interference (MAI). In the limiting case where the noise due to spontaneous emission in optical amplifier, detector dark current, etc., can be neglected as compared to the effect of Multiple Access Interference (MAI). The multiple access interferenceaffects theincoherent OCDAM system. The bit error rate (BER) increases marginally with carbon nanotube as represented by curv2 compared with silicon optical devices represented curv1 as shown figure 7.

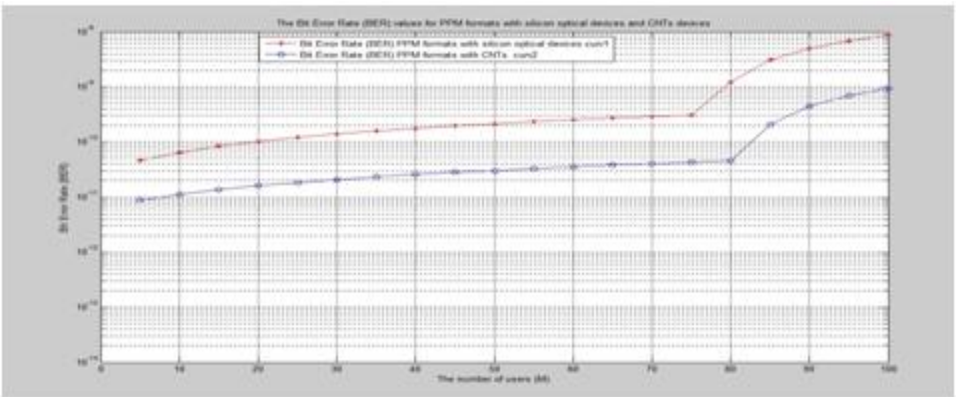

Figure 7: Represented the Bit Error Rate (BER) in the Incoherent for Silicon Optical Devices and Carbon Nanotubes

Therefore, we can say that the Data Rate (R) incoherent OCDMA with OOK/OCDMA format gives better results than PPM/OCDMA with carbon nanotubes (CNTs). In the OCDMA system increasing the number of users decreases the data rate, while increasing the bit error rate enhances the system performance. For the best performance of optical communication with highest data rate and lowest bit error rate, we investigated the optimized OCDMA performance with carbon nanotubes in comparison with silicon optical devices.

The Effect of Temperature on Thermal Noise in OCDMA System

The total noise in OCDMA system with carbon nanotubes and silicon devices is given by equation (4) [2], [20], [25].

$$\boldsymbol{\sigma_n}^2 = \boldsymbol{\sigma_{th}}^2 + \boldsymbol{\sigma_{sh}}^2 + \boldsymbol{\sigma_{MAI}}^2 \tag{4}$$

Where σ_n is the total noise; σ_{th} is the thermal noise, σ_{sh} is the shot noise, and σ_{MAI} is multiple access interference (MAI) equal to $6.5 * 10^{-5}\, watt$ from table 1. Here, we focus on the effect of temperature on the thermal noise on OCDMA system when we used it either with carbon nanotubes or silicon optical devices300K is normal room temperature in silicon optical devices and more effected with rise in roomtemperature but the carbon nanotubes having 973K as normal temperature with continue to work with rise in temperature without effect on the performance. This is observed OCDMA system with carbon nanotubes are less affected with rise in temperature. The thermal noise is expressed by equation (5)

$$\boldsymbol{\sigma_{th}}^2 = \frac{\boldsymbol{4\, k_B T}}{\boldsymbol{R_L}} * \boldsymbol{B} \tag{5}$$

Where k_B is the boltzmann's constant $(1.38 * 10^{-23} J/K)$ from table 1, T is the ambient temperature $(\frac{T}{T_o})$ T_o=300K, B is transmission bit rate for silicon optical devices B= $3.00 * 10^9\, bits/sec$ and for B= $7.7519 * 10^{11} bits/sec$, and load resistance for silicon optical devices is $50 * 10^3 \Omega$,while load resistance for carbon nanotubes $12.9 * 10^3 \Omega$. Figure 8 illustrates temperature effect on thermal noise in OCDMA with carbon nanotubes as represented by curv2 which is observed to far less affected on performance than with silicon optical devices as represented by curv1[20],[26].

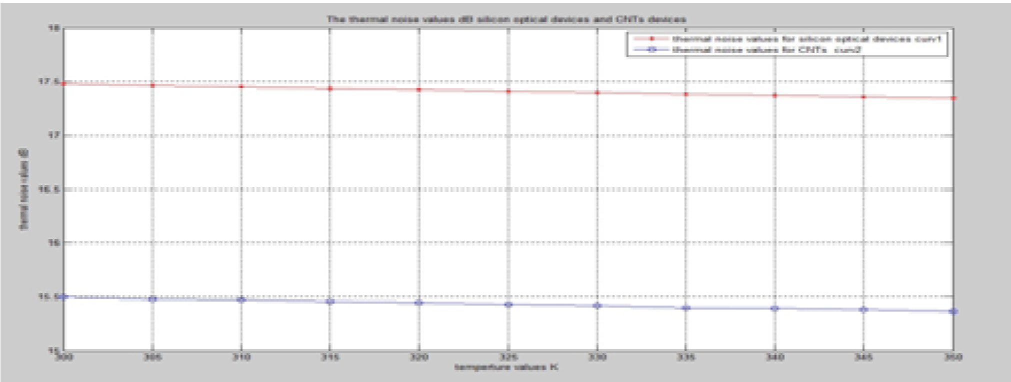

Figure 8: Variations the Temperatures Effect on the OCDMA Performance with Carbon Nanotubes and Silicon Optical Devices

The Variations the Number of Users versus the Code Length and the Code Weight for OCDMA System

The figure 9 indicates that with increase in code weight brings in comparatively lesser increase in the number of users with increase in the number of code length. It is observed with curv1 that with code weight w=3, the number of users increases with code length. However, as indicated by curv2 and curv3, as the code weight increases from weight w=5 and w=7, there is a pronounced fall in the number of users with the similar increase in the code length. The relationship between the number of users, the number of code length and the code weight is given by the equation (6) [20], [27], [28].

$$M = \frac{(n-1)}{w(w-1)} \quad (6)$$

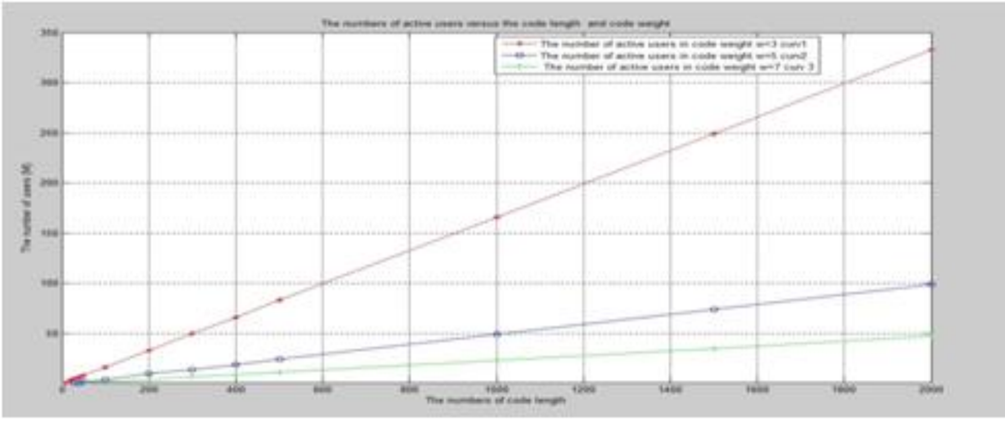

Figure 9: Variations of the Number of Users against Variations of Both Code Length and Weight Code

Analysis of the Transmitted Power Performance in OCDMA System

The transmitted power in OCDMA system with source power (P_{ook}) for silicon optical devices is $P_{ook} = 35.99 * 10^{-3} watt$, while it is $214.8 * 10^{-3} watt$ for carbon nanotubes to give result as shown in figure 10 which illustrates that in silicon optical devices. The curv1shows that the transmitted signal power provides lowest values with code weight w=3, whereas curv2 represents values with code weight w=5 higher from curv1 but lower than curv3 wherein the code weight w=7. These result are obtained by equation (7)

$$P_T = \frac{w}{n} P_{ook} \quad (7)$$

Where P_T the transmitted power is for OCDMA system, w is weight of the code, and n is the length of the code [20], [29].

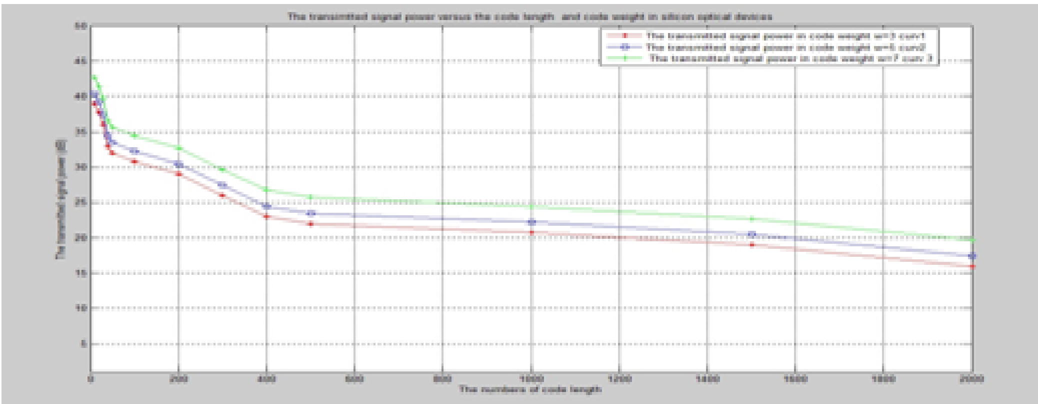

Figure 10: Variations of the Transmitted Signal Power against Variations of Both Code Length and Weight for OCDMA System with Silicon Optical Devices

Figure 11 illustrates the transmitted signal power with carbon nanotubes in the simulated signal curv1shows the transmitted signal power when the code weight w=3, and is observed to be lower than curv2 when the code weight w=5, and the curv3 represented the highest transmitted power with code weight w=7. Figure 9 and figure 10 illustrate that the transmitted power in simulated system is less with carbon nanotube than with silicon optical devices this leads us to the observation that power consumption in OCDMA transmitter with carbon nanotubes is lower than with silicon optical devices which provides the net result that OCDMA systems based on carbon nanotubes are basically power to be low voltage source power.

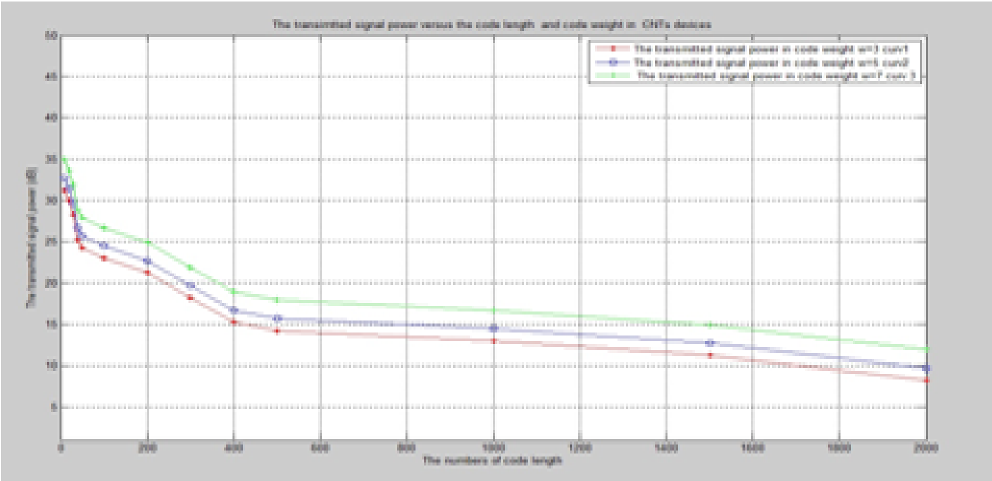

Figure 11: Variations of the Transmitted Power against Variations of Both Code Length and Code Weight for OCDMA System with Carbon Nanotubes

The Received Power in OCDMA Receiver

The received power can be estimated for simulated OCDMA receiver with carbon nanotubes and silicon optical devices as shown figure 12. It is observed that the received power with silicon optical devices represented by curv1 indicates that the received power is decreased as the number of code length is increased. However, it is farther observed that with code weight w=3 curv1 the received power is lower than with code weight w=5 and w=7 as represented by curv2 and curv3 respectively. It is shown that corresponding to code weight w=7, highest received power is obtained as represented by curv3.

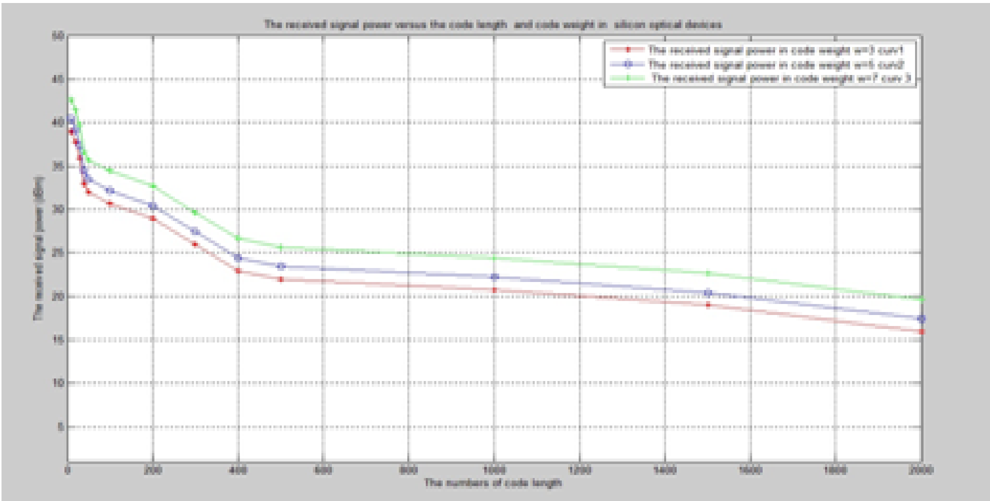

Figure 12: Represented the Received Signal Power in Relation to Both Code Length and Code Weight for Silicon Optical Devices

Figure 13 illustrates the variation of the signal power received with the similar increase in the number of code length in simulated OCDMA with carbon nanotubes. In this design, the received signal power is observed to be much lower than in case of simulated OCDMA with silicon optical devices as depicted in figure 11, but in similar fashion as regards the code weight that is the received power with code weight w=3 is lowest whereas with code weight w=7 it is the highest. Thus, it is observed that with simulated OCDMA, the energy saving with carbon nanotubes is much more pronounced than with silicon optical devices, saving the way to adopt lower energy sources resulting into longer lifetime of the devices using carbon nanotubes.

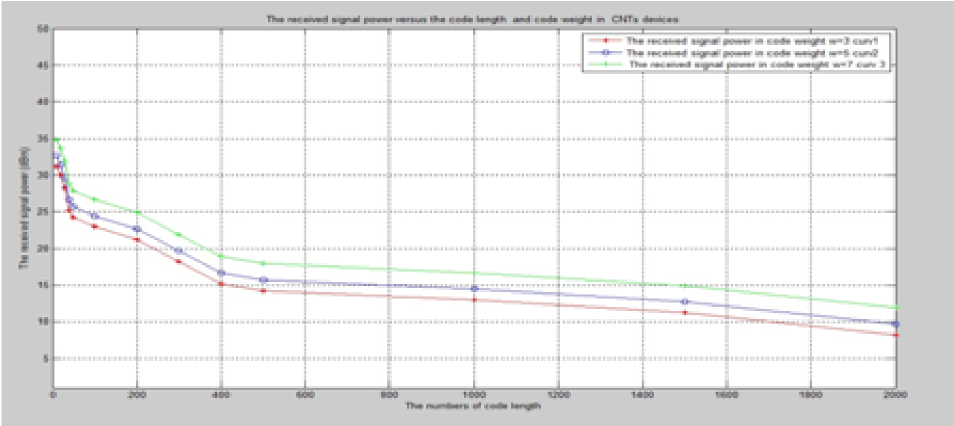

Figure 13: Variations of the Received Signal Power in Relation to Both Code Length and Code Weight for Carbon Nanotubes

The received signal power is given by equation (8)

$$\boldsymbol{P_{received} = P_T * e^{-\sigma_n * A}} \tag{8}$$

Where P_T is transmitted power of transmitter for OCDMA system, σ_n is total noise comprising of thermal noise, shot noise, multiple access interference noise as in table 1, as the dark current noise can be neglected in photo detector [20], [30].

The Threshold OCDMA Systems

Threshold system (Th) can be computed for OCDMA system with carbon nanotubes ($P_{ook} = 35.99 * 10^{-3} watt$), and with silicon optical devices ($P_{ook} = 214.8 * 10^{-3} watt$) which is given by equation (9)

$$\boldsymbol{Threshold\ System(Th) = P_{ook} * Th * \frac{w}{n}} \tag{9}$$

Where Th is threshold value$1.0 * 10^{-3}$watt, w is the code weight, and n the codes of length. Figure 14 illustrates that the threshold system values decrease as the number of code length increases [20], [31], [30].

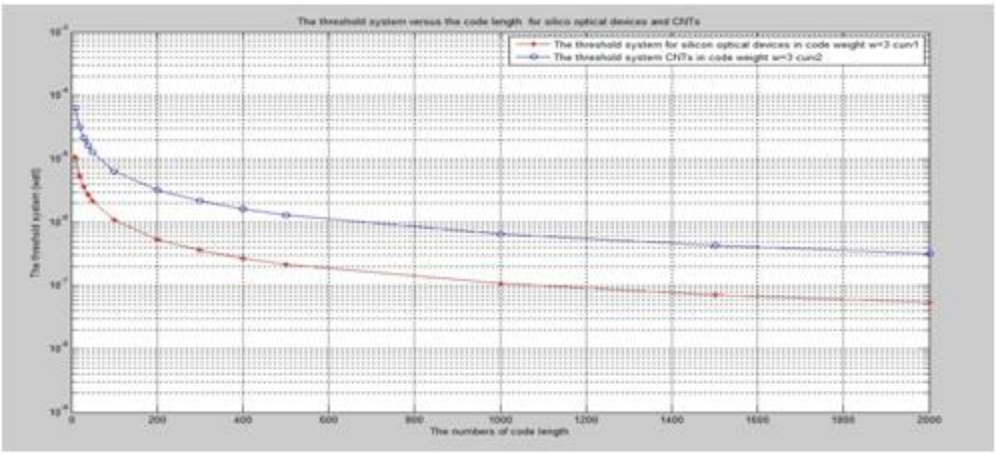

Figure 14: Variations of Threshold System in Relationship to Code Length and Code Weight for Silicon Optical Devices and Carbon Nanotubes

The OOK/ OCDMA Chip – Level Receiver and its Performance Analysis

In the OOK/ OCDMA system uses the (n, w, 1), the signature with optical pulse is sent for data bit “1” while nothing is sent for data bit “0”. Hence, we focus the Bit Error Rate (BER) for OOK/OCDMA chip level receiver with carbon nanotubes less than BER with silicon optical devices and we got result when the number of code length n=1000 is given by equation 1, resulting in BER with carbon nanotubes as represented by curv2 very less than silicon optical devices represented by curv1 as shown figure 15. T the BER can be given by equation (10) and equation (7).

$$\boldsymbol{P_b} = \frac{\mathbf{1}}{\mathbf{2}}\left\{\sum_{i=1}^{w}(-\mathbf{1})^{i}\binom{w}{i}\left(\mathbf{1}-\boldsymbol{i}\,\frac{w}{2n}\right)^{M-1}\right\} \tag{10}$$

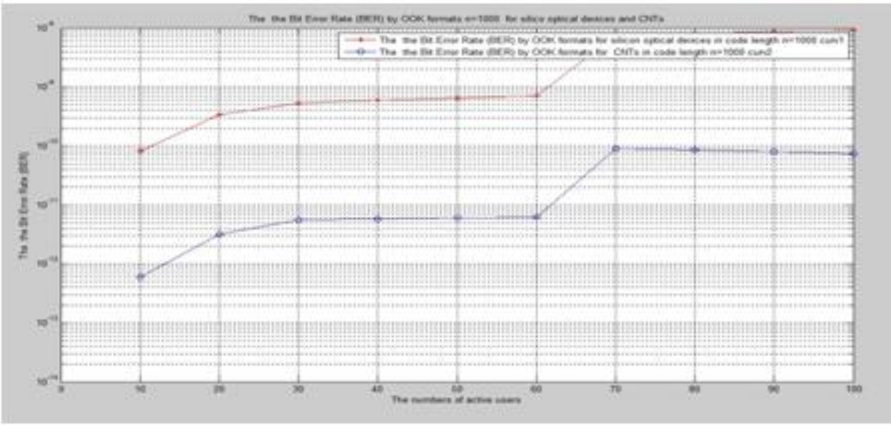

Figure 15: Represented the Bit Error Rate (BER) by OOK/OCDMA Formats for Silicon Optical Devices and Carbon Nanotubes

The PPM/ OCDMA Chip – Level Receiver and its Performance Analysis

In M-ary PPm signaling format the j^{th} symbol, j∈ M={0,1,…,M-1} is represented a signature sequence at the j^{th} slot and otherwise, there is not any pulse within all other slots the result bit error rate can be given by equation (11) and equation (6)

$$\boldsymbol{P_d} = \frac{M/2}{M-1}\left\{(\boldsymbol{M}-\mathbf{1})\sum_{i=0}^{w}(-\mathbf{1})^{i}\binom{w}{i}\left[\mathbf{1}-(\boldsymbol{i}+\boldsymbol{w})\,\frac{w}{Mn}\right]^{N-1}-\binom{M-1}{2}\left[\frac{(N-1)w\,e}{Mn}\right]^{2w}\right\} \tag{11}$$

OCDMA system with PPM receiver can enhance the security of information transmission. However, in the hardware implementation OCDMA system with PPM chip – level receiver is more complex than OOK chip level receiver system. Figure 16 illustrates the result for PPM/OCDMA format with carbon nanotubes as represented by curv2 which is observed to be better than silicon optical devices represented curv1. The result can be given by equation (11) and equation (6).

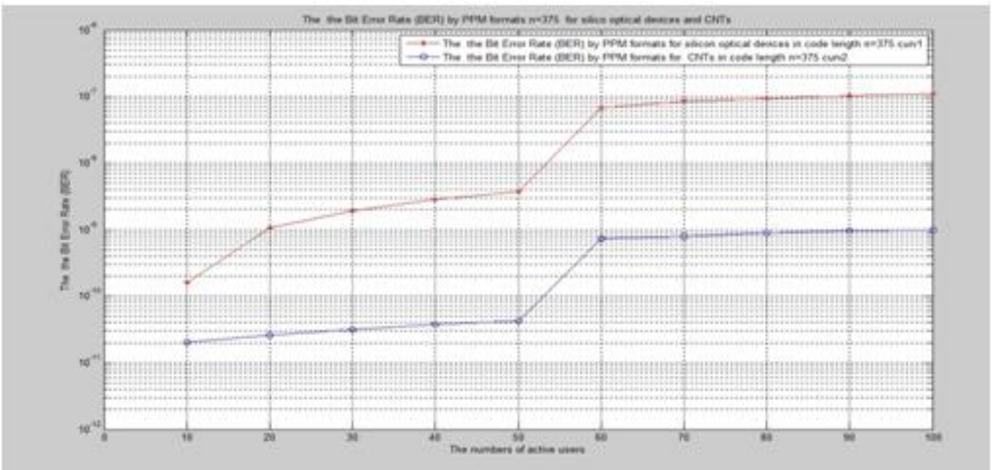

Figure 16: Variations of the Bit Error Rate (BER) PPM Format for Silicon Optical Devices and Carbon Nanotubes (CNTs)

Optical overlapping pulse position modulation (OPPM) chip level receiver [1],[2], [36], whose difference from PPM chip level OCDMA is that it allows partial superposition of two adjacent modulated signals or two adjacent slot with width τ and the overlapping depth index γ, it's hardware is more complex than that of PPM – chip level OCDMA system.

Performance Analysis of Two – Dimensional Wavelength Hopping/ Time Spread Incoherent OCDMA System

Comparative analysis is made for BER performance of 2-D incoherent OCDMA system with carbon nanotubes and silicon optical devices. Figure 17 illustrates that the BER performance OCDMA system with carbon nanotubes represented by curv2 is better than silicon optical devices which represented curv1. Because, carbon nanotubes have high optical power$P_{ook} = 214.8 * 10^{-3} watt$, band gap energy E_t =2.9 e V, high refractive index $n_2 = 1.55 * 10^{-8} m^2/watt$, and duration time $T_b = 2.58 * 10^{-13}$sec ,resulting in ultrafast switches performance better than in case of silicon optical devices which has low power optical source $P_{ook} = 35.99 * 10^{-3} watt$, band gap energy E_t =1.12 e V, low refractive index $n_2 = 2 * 10^{-20} m^2$/watt, and duration time $T_b = 3.33 * 10^{-10} sec$. The result is given by equation (12) and equation (6) [1], [2], [33], [37].

$$\boldsymbol{P_b = \frac{1}{2}\sum_{i=w}^{w(m-1)} \binom{w(m-1)}{i} \left(\frac{w}{2k}\right)^i \left(1 - \frac{w}{2k}\right)^{w(m-1)-i}} \quad (12)$$

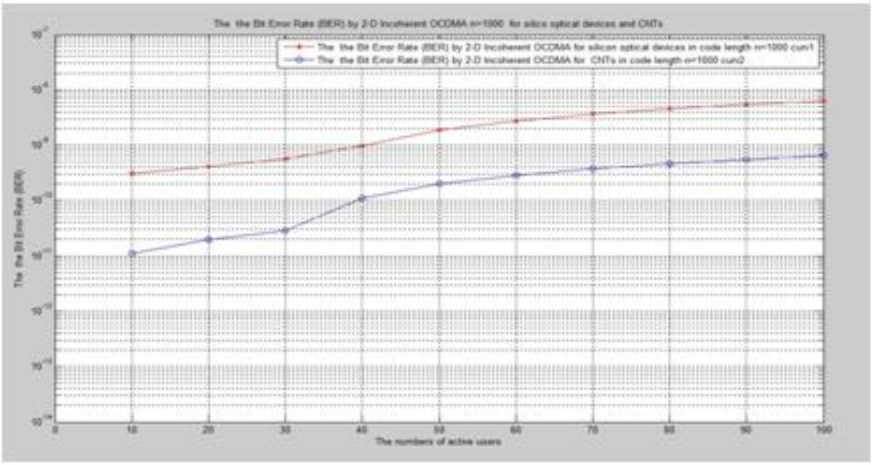

Figure 17: Represented the BER Performance by 2-D WH/TS Incoherent OCDMA for Silicon Optical Devices and Carbon Nanotubes (CNTs)

Performance Analysis of Spectral Encoding Coherent OCDMA System

For the On – Off Keying format; when the data is "1", the ultrashort pulse is fed into the spectral phase encoder. The spectral phase encoder imposes a specific phase shift on each spectral component of the ultrashort pulse. Otherwise, when the data is "0", the output of the spectral encoder. This encoding process is implemented through a spectral phase code generator multiplying each spectral component of the ultrashort pulse. Since the phase code generated by the spectral phase code generator of each subscriber is unique, the solely spectral phase encoding (C) of data from each user is implemented. The spectral phase code can employ the binary codes with good properties which are widely applied to the electrical wireless CDMA, such as m- sequences, Gold codes, etc.

The optical signal with spectral phase encoded in time domain. The optical signal with spectral phase encoded in time domain looks like a low intensity pseudo – noise burst (D), which is fed into the optical communication network. Figure 18 illustrates the BER performance in spectral phase coherent OCDMA with carbon nanotubes more better than silicon optical devices, we can say the spectral phase encoding in OCDMA system is best among other types in OCDMA system, BER is given by equation (13) and equation (6)

$$P_b = \frac{1}{2}\left\{\sum_{I=1}^{M-1}\binom{M-1}{I}\left(\frac{1}{2K}\right)^{I}\left(\mathbf{1}-\frac{1}{2K}\right)^{M-I-1}\left(\mathbf{1}-\gamma(I)^{B-1}(\gamma(I)-P(I))\right)\right\} \tag{13}$$

Where $K = \frac{T_b}{T_c}$, and is the number of simultaneous subscribers in the network, B is solid lines, I is number of interfering subscribers, P(I) is a random variable and satisfies a binomial distribution, and $\gamma(I)$ represented the probabilities of false alarm and missed detection. The result obtained BER performance with carbon nanotubes much better than silicon optical devices [2], [34].

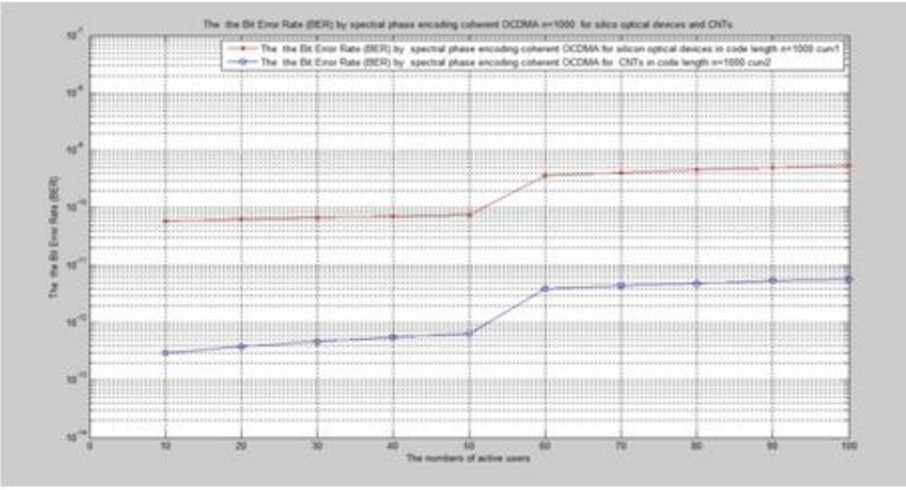

Figure 18: BER Performance by Spectral Phase Encoding in Coherent OCDMA with Silicon Optical Devices and Carbon Nanotubes (CNTs)

Performance Analysis of Temporal Encoding Coherent OCDMA System

The temporal phase encoding coherent OCDMA system is a type of Time – Spreading OCDMA, whose model is shown in figure 19. Four kinds of noises are presented in this model, which are the MAI noise from the OCDMA network, the multiplied beat noise and additive shot noise from photodetector, and the thermal noise of receiver. In the temporal phase encoding coherent OCDMA, the coherence of the optical signal has to be maintained within the chip duration and thus the coherent beat noise becomes critical. It has been shown from investigation that the BER performance of the incoherent OCDMA system mainly confined by the MAIs from the network and otherwise, the BER performance of the coherent OCDMA system is limited by the beat noise [1], [2].

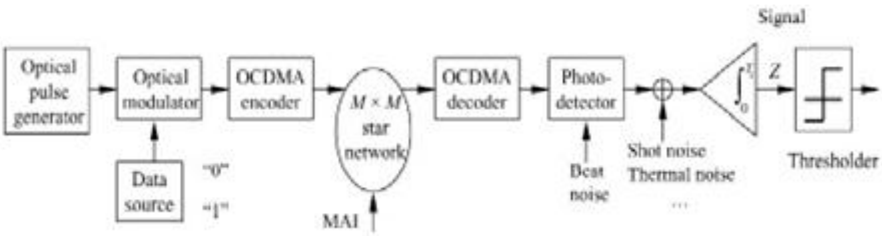

Figure 19: Model of Temporal Phase Encoding OCDMA System with Various Noises

The BER performance in temporal phase encoding OCDMA system with carbon nanotubes represented by curv2 gives better result than silicon optical devices represented by curv1and analyzed by equation (14) and equation (6) [2], [20]

$$P_b = \sum_{I=0}^{M-1} P(I)P_b(I) \tag{14}$$

Where P(I) indicates the probabilities that subscribers among M-1 interfering subscribers, and $P_d(I)$ is the bit error rate with I.

$$\boldsymbol{P(I)} = \binom{\boldsymbol{M-1}}{\boldsymbol{I}}\boldsymbol{2^{-(M-1)}} \quad (15)$$

And

$$\boldsymbol{P_b} = \frac{1}{2}\left\{\left[\boldsymbol{2} - \frac{\boldsymbol{T_c}}{\boldsymbol{T_b}}\right]\boldsymbol{P_e(I)} + \frac{\boldsymbol{T_c}}{\boldsymbol{T_b}}\boldsymbol{P_e(I)}\right\} \quad (16)$$

Where $P_e(I)$ indicates the probabilities of chips 0 and 1 respectively.

$$\boldsymbol{P_e(I)} = \frac{1}{2}\boldsymbol{erfc}\left(\frac{\boldsymbol{P_d(Th-I\varepsilon)}}{\sqrt{2}\boldsymbol{\sigma_n}^2}\right) \quad (17)$$

Where $\boldsymbol{\sigma_n}^2 = \boldsymbol{\sigma_{th}}^2 + \boldsymbol{\sigma_{sh}}^2 + \boldsymbol{\sigma_{MAI}}^2$ equation (4) and (5)

We can get shot noise by equation (18)

$$\boldsymbol{\sigma_{sh}}^2 = \boldsymbol{2} * \boldsymbol{e} * \boldsymbol{B} * \boldsymbol{I_p} \quad (18)$$

Where e is charge of electron, B is data rate, I_p the current of photodetector for carbon nanotubes and silicon optical devices. The BER performance in temporal phase encoding OCDMA system with carbon nanotubes is much better than silicon optical devices as shown figure 20. All types of coherent OCDMA and all types of incoherent OCDMA with carbon nanotubes provides comparativelyimprovedperforming system by way of getting highest data rate (Tb/s) and lowest bit error rate (BER) than silicon optical devices.

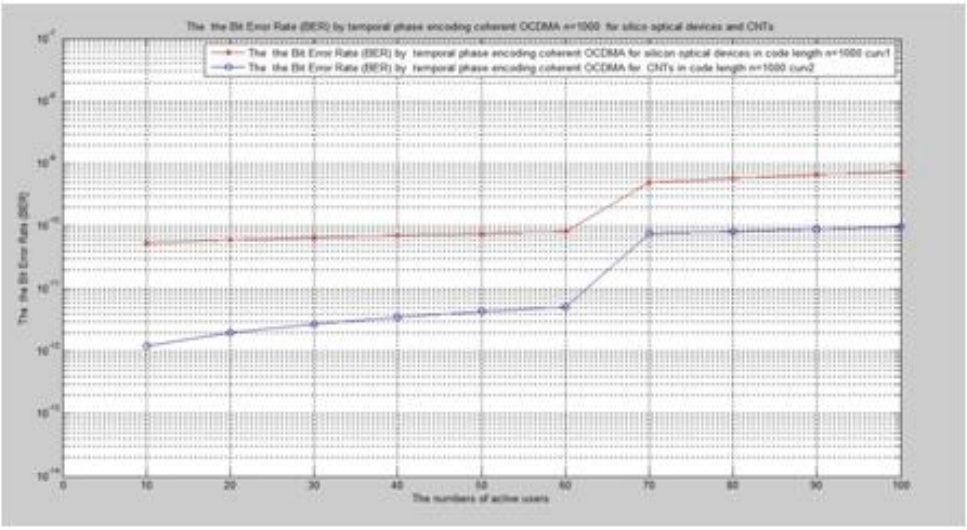

Figure 20: Represented the BER Performance by Temporal Phase Encoding Coherent OCDMA for Silicon Optical Devices and Carbon Nanotubes (CNTs)

CONCLUSIONS

Optimized design performance of OCDMA with carbon nanotubes (CNTs)based devices have been observed providing highest data rate (R) and lowest bit error rate (BER) incorporating techniques like OOK/OCDMA and PPM/OCDMA in Coherent as well as Incoherent OCDMA system. Firstly, the incorporation of carbon nanotube, based devices result in improved system performance in comparison to silicon optical devices, with increased data rate upto Tb/s and much reduced bit error rate between $10^{-13} to\ 10^{-10}$ bits/sec. This has brought in considerable saving in energy of sources in transmitter side, besides bring in better sensitivity of photo detectors in receiver circuit due to reduced effect of total noise on the system. Secondly, it has been observed that number of users would be increased by increase in code length and decrease in code weight. Next generation of optical communication system may preferably incorporate carbon nanotubes based devices so as to achieve much higher data rate up to Tb/s in comparison to present systems using silicon optical devices giving data rate upto Gb/s. Besides, such systems with reduced energy source power realize in much longer life Nevertheless, future requirements of ultrahigh speed internet, video, multimedia, and advanced digital services, would suitably be met with incorporation of carbon nanotubes based devices providing optimal performance.

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