Quality Analysis in Phase Modulated Radio over Fiber in WDM/DWDM Network

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Abstract: - There has been increasing demand for connection setup with a higher quality of service (QoS) in WDM/DWDM networks, especially in fields like radio over fibres, where phase modulation affects the link quality. Hence to meet guaranteed QoS in a phase modulated link, the effects of phase modulation on link quality is very much needed. The link quality is termed as quality factor (Q-factor). The primary objective is to use effectively the connections available to optimize the computed number of connections and reduce the blocked connections but at the same time guarantying QoS as per client's need. The analysis has been done by taking care of routing and wavelength assignment (RWA) techniques. The performance analysis is presented in terms of blocking probability.

Key-Words: - Phase modulation, Radio over fiber, Physical layer impairments, Blocking probability, Wavelength division multiplexing.

1 Introduction

WDM/DWDM networks have proven to be the best solution for providing increased throughput and the best Q-factors. Pure optical connections including switches are used thereby removing the need for O-E-O conversions. Ideally, the physical layer is considered to have no noise, signal delay or signal degradation elements. But in practicality physical layer consists of multiple impairments. These Physical layer impairments (PLI) are responsible for the deterioration of the connection. The link quality is mathematically termed as Q-factor. That can be due to many attributes including linear and non-linear PLIs. Linear impairments include chromatic dispersion, polarisation mode dispersion, amplifier spontaneous noise, in-band/out-band crosstalk, insertion loss, fibre concatenation, polarisation dependent loss, etc. Non-linear PLIs include self-phase modulation, cross phase modulation, four wave mixing, stimulated Raman scattering, stimulated Brillouin scattering, etc.

Many previous works have analyzed different considerations of impairments. Ramamurthy et al. [1] calculated bit-error rate (BER) with amplifier spontaneous emission (ASE) noise as impairments. C. Politi et al. [2] studied Q-factor as quality parameter for transmission with four wave mixing (FWM) and cross phase modulation (XPM) as impairments. I. Tomokos et al. [3] calculated Q-factor with ASE, FWM, and XPM as impairments. S. K. Das et al. [4] studied BER as QoT parameter with in-band crosstalk and FWM as impairments. Huang et al. [5] studied ASE noise and polarization mode dispersion (PMD) as impairments and optical signal to noise ratio as quality parameter for transmission. Similarly, N. Sengezer et al. [6] analyzed Q-factor as QoT with ASE, crosstalks and PMD as impairments in consideration.

Radio over fiber (RoF) is a developing innovation as far as dependability, coverage, and security is concerned. RoF advanced during an era when industry fell for the union of wired and wireless communication systems. RoF is an exceptionally encouraging system to upgrade the limit and data transfer capacity for wireless radio signals over long separation. Some of most emerging fields of applications of this technology are broadband wireless access networks, satellite communication, video distribution frameworks, versatile broadband administrations, vehicular correspondences, airplane terminals, shopping centres and so on. In future optical domain processing in RoF could also provide optical mm-wave frequency mixing for up/down conversion of digital subcarrier frequencies without optical-to-electrical (O/E) and electrical-to-optical (E/O) conversions [7]. The mixing setup mostly uses electro-optic modulators but faces degradation due to chromatic dispersion. Phase modulator and dispersive fiber system is used for optical microwave mixing. So, phase modulation even affects link quality in RoF WDM/DWDM networks.

Phase modulation degrades link quality. Particularly in fields like RoF in WDM/DWDM networks which are rapidly growing technology, phase modulation plays a significant role in frequency mixing techniques. So as to meet up to the guaranteed QoS in a phase modulated link, the effects of phase modulation analysis on link Q-factor is very much needed. The motivation behind the work is to use efficiently the connections available to optimize the computed number of connections and reduce the blocked connections but at the same time guarantying QoS as per client's demand.

Following to the introduction presented in Section 1; Section 2 explains system model; Section 3 presents the algorithm and flow charts; Section 4 provides the results, and Section 5 gives the conclusion drawn from the work.

2 System Model

In this work, impairments based on phase modulation is considered. A microwave signal with continuous wave directly modulates a laser diode with a wavelength of 1500 nm at a frequency of f_{RF}. At the yield of the laser diode, direct modulation causes frequency and intensity Modulation simultaneously. The waveform from the laser diode is added into a phase modulator obsessed with an electrical signal with a frequency of f_{LO} which has continuous waveform. A dispersive single mode fibre gets the signal at the output of the phase modulator as input but with a 17 ps/(nm.km) dispersion coefficient. The signal is detected by a photodetector with a bandwidth of 20-GHz at the output of the optical fibre link. Block diagram of phase modulation in optical network is as shown in Fig.1 with laser diode (LD) at frequency, f_{RF}, phase modulator (PM) at frequency, f_{LO}, single mode fibre (SMF) and photo diode (PD).

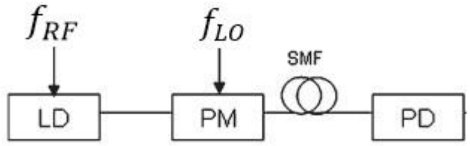


Fig.1 Phase modulation in optical Network

The optical field, $E_{LD}(t)$, at the output of Laser diode can be written as [7],

$$E_{LD}(t) = \sqrt{1 + m\cos(2\pi f_{RF}t)}\, e^{j\beta\sin(2\pi f_{RF}t)} e^{j2\pi f_0 t} \quad (1)$$

where, m is the intensity modulation index, β is the frequency modulation index at a frequency f_{RF}, and f_0 is the frequency of the carrier.

LD characteristics in the linear portion of equation (1) can be estimated as,

$$E_{LD}(t) = (1 + \frac{m}{2}\cos(2\pi f_{RF}t)) e^{j\beta\sin(2\pi f_{RF}t)} e^{j2\pi f_0 t} \quad (2)$$

Light of the output laser diode is mixed with the phase modulator. So optical field strength at the phase modulator output, $E_{PM}(t)$, is expressed as,

$$E_{PM}(t) = E_{LD}(t) e^{j\frac{\pi V}{V_\pi}\cos(2\pi f_{LO}t)} \quad (3)$$

where, V is voltage at frequency f_{LO} applied to the phase modulator and V_π is the half-wave voltage of the modulator.

Simplifying equation (2) and (3), using following Jacobi-Anger Expansions:

$$cos(z\,cos(\theta)) = J_0(z) + 2\sum_{l=1}^{\infty}(-1)^l (J_{2l}(z)\,cos(2l\theta)) \quad (4)$$

$$sin(z\,cos(\theta)) = -2\sum_{l=1}^{\infty}(-1)^l (J_{2l-1}(z)\,cos((2l-1)\theta)) \quad (5)$$

$cos(z\,sin(\theta))$=$J_0(z)+2\sum_{l=1}^{\infty}(J_{2l}(z)\,cos(2l\theta))$ (6)

$sin(z\,sin(\theta))$=$2\sum_{l=1}^{\infty}(J_{2l-1}(z)\,sin((2l-1)\theta))$ (7)

We get,

$$E_{PM}(t)=\sqrt{1+m\,cos(2\pi f_{RF}t)} \times e^{j\beta\,sin(2\pi f_{RF}t)}e^{j2\pi f_0 t}e^{j\frac{\pi V}{V_\pi}cos(2\pi f_{LO}t)} \quad (8)$$

On further simplification,

$$E_{PM}(t)=(1+\frac{m}{2}cos(2\pi f_{RF}t))\,e^{j2\pi f_0 t}\ \times$$

$$[J_0(\beta)+2\sum_{k=1}^{\infty}(J_{2k}(\beta)\,cos(2\pi 2kf_{RF}t))\ +\ 2j\sum_{k=0}^{\infty}(J_{2k+1}(\beta)\,sin(2\pi(2k+1)f_{RF}t))]\ \times$$

$$[J_0\left(\left(\frac{\pi V_{LO}}{V_\pi}\right)\right)+ 2\sum_{k=1}^{\infty}(-1)^k\left(J_{2k}\left(\frac{\pi V_{LO}}{V_\pi}\right)cos(2\pi 2kf_{LO}t)\right)+ 2j\sum_{k=0}^{\infty}(-1)^k\left(J_{2k+1}\left(\frac{\pi V_{LO}}{V_\pi}\right)sin(2\pi(2k+1)f_{LO}t)\right)] \quad (9)$$

Helpful articulations of complex envelopes of the spectral lines SL_f at the optical recurrence *f* can be obtained from equation (9)

$$SL_{fo}=J_0(\beta)J_0\left(\left(\frac{\pi V_{LO}}{V_\pi}\right)\right) \quad (10)$$

$$SL_{fo+\mathcal{E}(f_{RF}+f_{LO})}=\mathcal{E}jJ_1(\beta)J_1\left(\left(\frac{\pi V_{LO}}{V_\pi}\right)\right)+j\frac{m}{4}J_0(\beta)J_1\left(\left(\frac{\pi V_{LO}}{V_\pi}\right)\right) \quad (11)$$

$$SL_{fo+\mathcal{E}f_{RF}}=\mathcal{E}J_1(\beta)J_0\left(\left(\frac{\pi V_{LO}}{V_\pi}\right)\right)+\frac{m}{4}J_0(\beta)J_0\left(\left(\frac{\pi V_{LO}}{V_\pi}\right)\right) \quad (12)$$

$$SL_{fo+\mathcal{E}f_{LO}}=jJ_0(\beta)J_1\left(\left(\frac{\pi V_{LO}}{V_\pi}\right)\right) \quad (13)$$

with $\mathcal{E}=\pm 1$.

The regular beatings of $SL_{fo+f_{LO}}$, with SL_{fo} (noted $SL_{fo}\times SL_{fo+f_{LO}}$) and $SL_{fo}\times SL_{fo-f_{LO}}$ create the yield force of the stage modulator at a recurrence of f_{LO} . Both beating terms have the same abundancy, however they are out of stage seen in equation (10) to (13). It provides no detected power at the output at f_{LO}.

The yield power of the phase modulator at recurrence of f_{RF} results from the prevailing beating terms $SL_{fo+f_{RF}}\times SL_{fo}$ and $SL_{fo}\times SL_{fo-f_{RF}}$. This time, both beating terms do not counteract each other because of the nearness of IM at the LD yield. As a result, power at f_{RF} can be detected with the output power expressed as,

$$P(f_{RF})=\eta m^2{J_0}^2(\beta){J_0}^2(\frac{\pi V_{LO}}{V_\pi}) \quad (14)$$

where, η is Photo diode responsivity , V_{LO} *is* voltage at the given frequency f_{LO}, and V_π is the half wave voltage for the modulator

The bit error probability for phase modulation, $P_{be}(PM)$ is expressed as [4],

$$P_{be}(PM)=0.5erfc(SNR_{PM}) \quad (15)$$

where, the signal to noise ratio due to phase modulation, SNR_{PM} can be expressed as [8],

$$SNR_{PM}=\rho_s=\frac{P_r}{S_{ns}\beta_d} \quad (16)$$

where, P_r is the received signal power, S_{ns} is the spectral density, and β_d is bandwidth of single polarization.

The received power P_r, can be expressed as,

$$P_r=\eta m^2{J_0}^2(\beta){J_0}^2(\frac{\pi V_{LO}}{V_\pi}) \quad (17)$$

Bandwidth, β_d can be expressed as [5],

$$\beta_d=\frac{\delta}{D_{PMD}\sqrt{L}} \quad (18)$$

where, δ is the pulse broadening factor, D_{PMD} is the fiber PMD parameter, and L is the length of the link.

Now, $P_{be}(PM)$ can be expressed as,

$$P_{be}(PM)=0.5\ erfc\ (\frac{\eta m^2{J_0}^2(\beta){J_0}^2\left(\frac{\pi V_{LO}}{V_\pi}\right)}{S_{ns}\frac{\delta}{D_{PMD}\sqrt{L}}}) \quad (19)$$

Now, the Q-factor due to phase modulation, $Q-factor_{PM}$, can be expressed as,

$$Q-factor_{PM}=\frac{1}{P_{be}(PM)} \quad (20)$$

Equation (19) is valid because $P_{be}(PM)$ and $Q-factor_{PM}$ are inversely proportional.

3 Proposed Algorithm and Flowchart

It shows the sequence of algorithms and flow charts used to analyse the accepted connection requests and blocking probability with respect to the number of wavelengths used and connections requested.

Generally, in RWA with guaranteed QoS, lightpath request is considered first. Then depending on routing technique and wavelength assignment (WA) technique used, lightpath is assigned. But to get the guaranteed QoS, the assigned lightpath undergoes the quality test. The quality test can be anything depending on client demands like BER, Q-factor, etc. If the lightpath passes the quality test then it is accepted, else the next available lightpath is checked. If no connections are available, then the connection request is blocked. The corresponding flow chart is represented in Fig. 2. Here quality factor is driven by phase modulation as mentioned in equation (20).

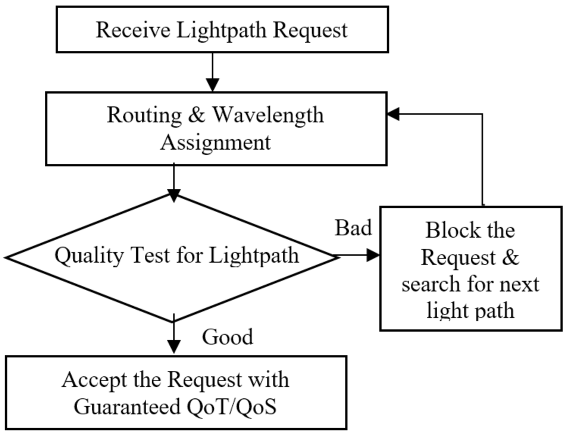
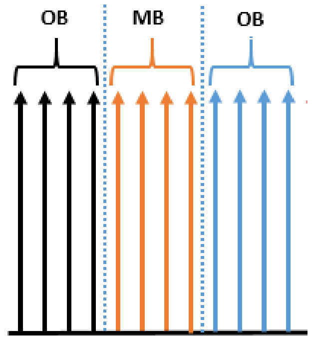
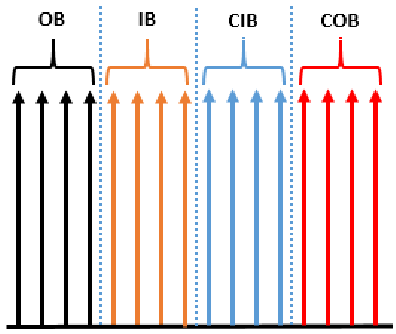


Fig.2 Flow chart of general quality routing and wavelength assignment

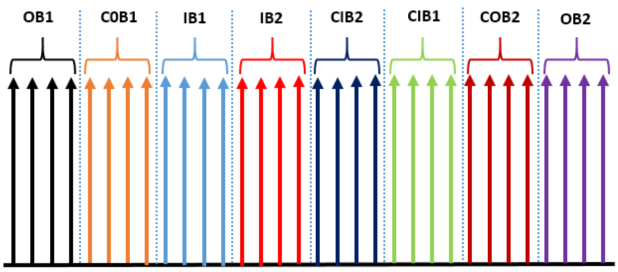
For wavelength assignment, 4 Band /8 Band complimentary inner outer band wavelength assignment (CIOBWA) is implemented where transmission window is divided into four bands or eight bands respectively. In 4 Band CIOBWA outer band (OB) is as proposed by S. K. Das et al. in [4], the complimentary outer band (COB), the inner band (IB) and complimentary inner band (CIB). Here CIB and IB are used for lower distance whereas COB & OB are used for longer distance connections. 8 Band IOBWA is similar to that proposed by S. K. Mahapatra et al. in [9]. In this WA technique, transmission window is divided into eight bands with two of each IB, CIB, OB, and COB. Adhya et al. [10] proposed middle outer band random wavelength assignment technique (MOBRWA). It consists of 3 bands namely middle band & two outer bands and wavelength which was assigned randomly to the bands of the transmission window. Transmission windows for all these WA techniques are presented in Fig. 3 (a, b, c).



(a) Conventional MOBWA technique



(b) Four band CIOBWA technique



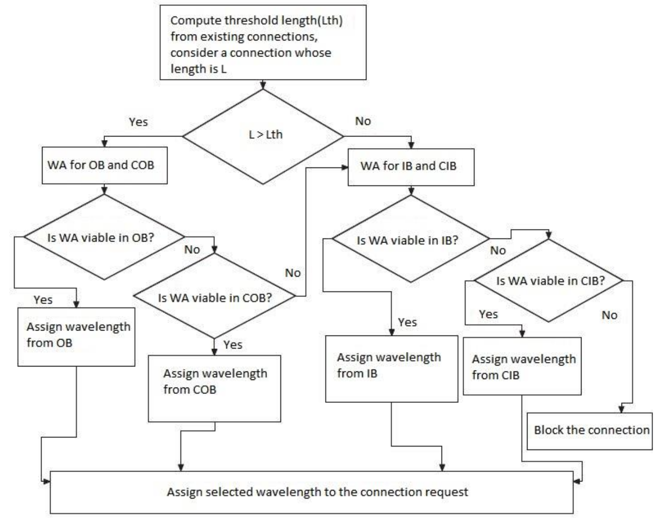
(c) Eight band CIOBWA technique

Fig. 3 Band division of transmission window in MOBWA, four band CIOBWA and eight bands CIOBWA

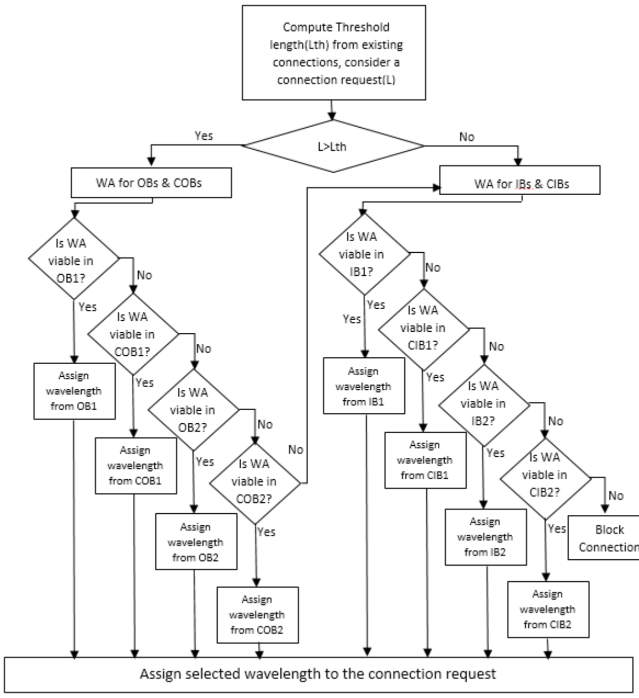
L_{th} decides whether the distance of given connection request is shorter or longer so as to be included in IB/CIB or OB/COB.

$$L_{th} = \frac{\sum \forall_{\, s-d\, pairs}\, connection\ lengths}{Number\ of\ connections} \qquad (20)$$

The flowchart of wavelength assignment in four bands and eight bands CIOBWA is presented in Fig. 4 (a,b). Flow chart of quality aware RWA used in this work is presented in Fig. 5.



(a) Four bands CIOBWA technique



(b) Eight bands CIOBWA technique

Fig. 4 Flow charts of WA in 4 band CIOBWA and eight bands CIOBWA

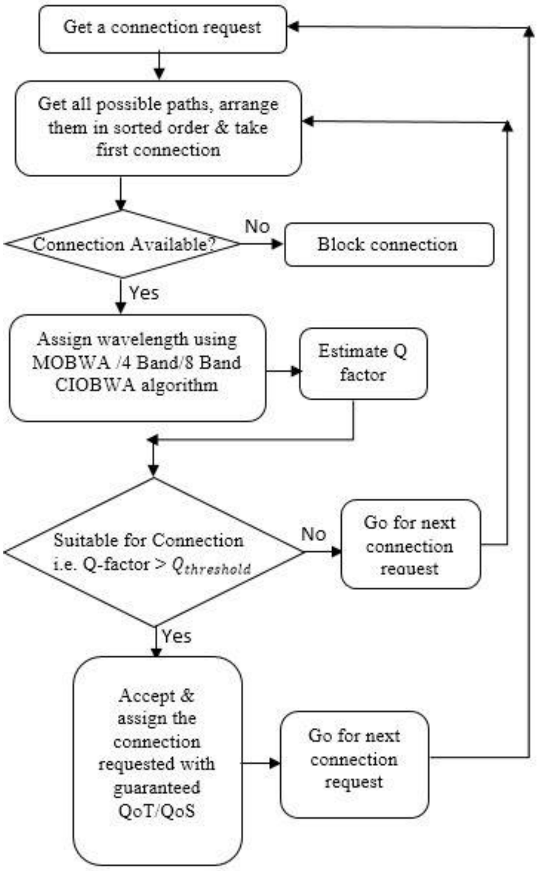


Fig.5 Modified routing and wavelength assignment flowchart

4 Analytical Results and Discussions

NSFNet topology of 16 links and 10 nodes is considered for demonstration of our proposed algorithm as shown in Fig. 6.

This section tells about the (1) blocking probability at different wavelength values, (2) guaranteed connections calculation, and (3) blocking probability at various wavelengths and connection requests (loads). There are some assumptions considered: (1) in the considered topology all nodes are of same type, (2) links have equal number of wavelengths, (3) shot noise and thermal noise are considered to be absent, (4) all interfering signals have same in band cross-talk levels, (5) all links follow wavelength constraint, and (6) any source–destination pairs have no connections prior to the study.

Here central wavelength of 1500 nm, the quantum efficiency of 90% and responsivity η=1.13 A/W are assumed. Other values considered are:

β=FM index at f_{RF}=0.6, V_{LO}=100, V_{π}=50, D_{PMD}=0.5, δ=0.1 and IM Index m in the range 0.1 to 0.4 [4].

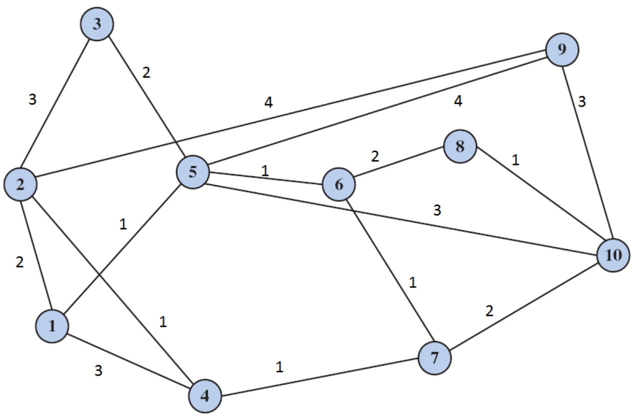
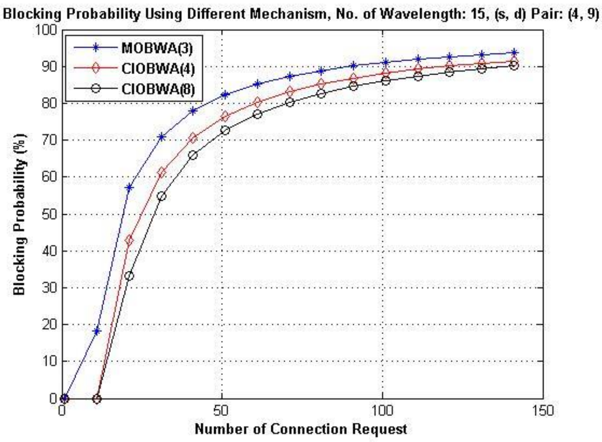
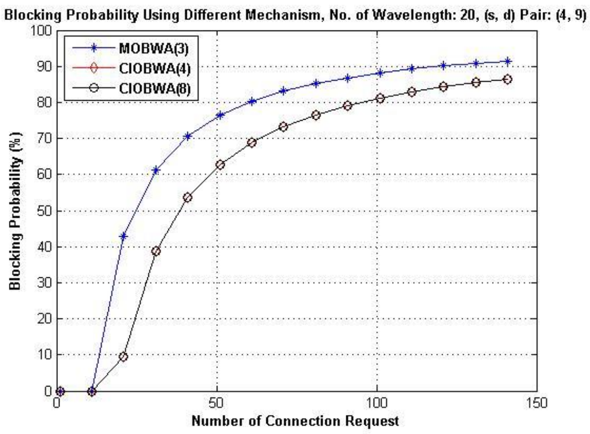


Fig. 6 NSFNet topology used for simulation; length of link=number on link x 70 Km

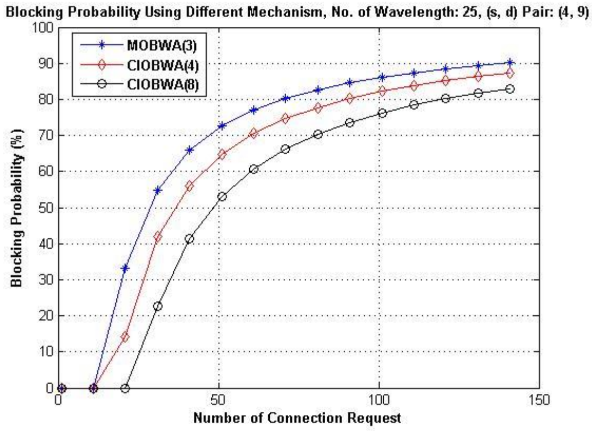
Simulation results of blocking probabilities using MOBWA, four bands/ eight bands CIOBWA with assigned wavelength being 15, 20 and 25 for source-destination node pair as (4, 9), are presented in Fig. 7 (a, b, c).



(a) No. of wavelengths assigned: 15



(b) No. of wavelengths assigned: 20

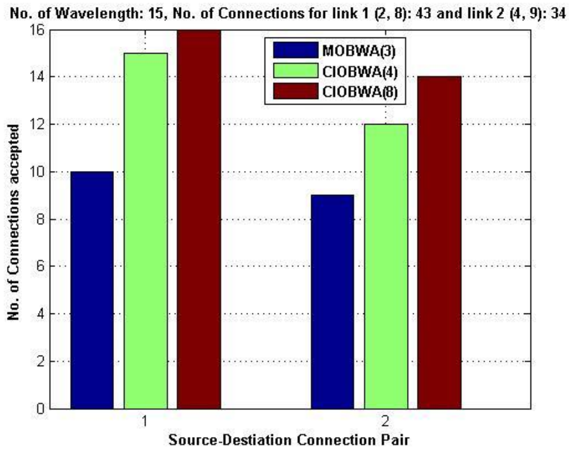


(c) No. of wavelengths assigned: 25

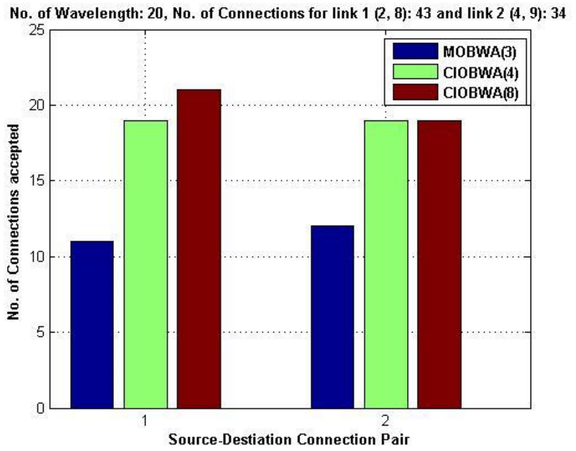
Fig. 7 Blocking probability (%) vs number of connection request at different number of assigned wavelengths: (a) 15, (b) 20, (c) 25

Observation from graph validates that the blocking probability is higher in MOBWA algorithm than blocking probability using four bands CIOBWA algorithm and blocking probability of four bands CIOBWA is still greater than eight bands CIOBWA. It can also be deduced that assigning more number of wavelengths decreases the blocking probability.

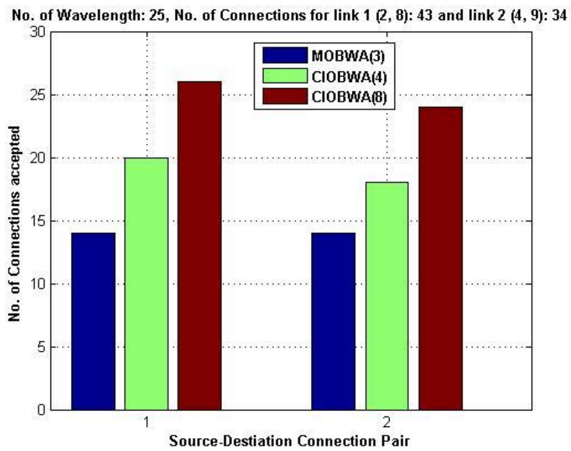
Simulation results of connections accepted versus source-destination (s, d) pairs using MOBWA, four band/8 band CIOBWA with assigned wavelength being 15, 20 and 25 considering (2, 8) and (4, 9) as source-destination pairs, are presented in Fig. 8 (a, b, c).



(a) No. of wavelengths assigned: 15



(b) No. of wavelengths assigned: 20



(c) No. of wavelengths assigned: 25

Fig. 8 Number of Connections accepted vs (s, d) connection pair at different number of assigned wavelengths: (a) 15, (b) 20 and (c) 25

The number of accepted connections is higher for eight bands CIOBWA than for four bands CIOBWA, which in turn has higher accepted connections than MOBWA. It can be clearly concluded about how with increased assigned wavelengths; the number of accepted connections has improved for all WA techniques.

Similarly effects of using different WA mechanisms at different wavelengths on blocking probability considering (2, 8) as source-destination pair is shown in Fig. 9.

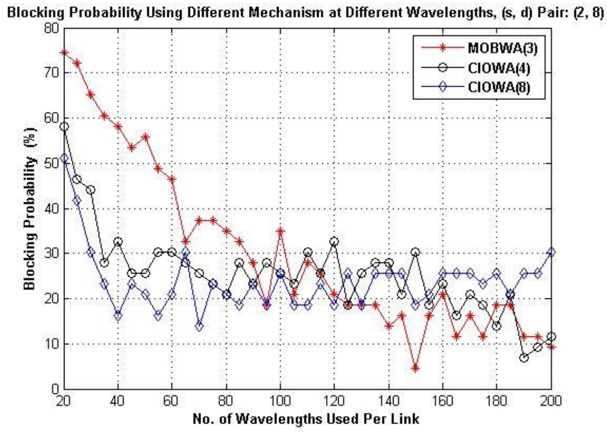


Fig. 9 Blocking Probability (%) versus Number of wavelengths used per single link.

The graphs validate that, with a different number of wavelengths used per link, blocking probability (%) is mostly lower for eight bands CIOBWA than using four bands CIOBWA and also than using MOBWA.

5 Conclusion

In this paper, a system model is presented, which derives the bit-error probability. It is the key factor in the analysis of the proposed algorithm. This work analyses the quality of optical connections with phase modulation as impairment. It also uses various WA techniques such as MOBWA and four bands /eight bands CIOBWA. It analyses accepted connections for a given connection request and blocking probability at different wavelengths and also with various load or requests. Effects of impairments can be seen clearly through the graphs and be used as a basis for future works in this field.

Acknowledgement

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