A Novel QoS Aware RWA with Dedicated Path Protection Consideration for All Optical Networks

K .RAMESH KUMAR*, R.S.D.WAHIDA BANU**

* Bharat Sanchar Nigam Limited, Vellore, INDIA
krameshkumar@bsnl.co.in

**Department of Electronics and Communication Engineering,
Government College of Engineering, Salem, INDIA

Abstract: - In all optical networks, signals has to travel over long distances and physical layer impairments (PLI) accumulate as regeneration capability is not available. During transmission, Quality of Service (QoS) of signals as measured by their Bit Error Rates (BER) is degraded due to propagation in the fibers, amplifier noise, and crosstalk between channels arising from the switches and demultiplexers which cannot be removed at the physical layer. It is possible to mitigate physical layer effects at the network layer using appropriate QoS aware Routing and Wavelength Assignment (RWA) algorithms. There are only few Offline RWA algorithms that consider dedicated path protection. In this paper an offline RWA Scheme called WpDp-MaMiQ is presented with dedicated path protection consideration that mitigates PLI. Simulations show that the proposed algorithm performs better in terms of blocking rate and BER.

Key-Words: - Routing and Wavelength Assignment (RWA), Physical layer impairments, Optical networks, Dedicated path protection, Cross talk, QoS aware, Blocking probability.

1 Introduction

In the present, opaque optical networks, signals are regenerated at the nodes by electronic devices and they become bottlenecks for the today's increasing traffic demand. (40Gbps per channel and tens of channels per fiber is present status).Thus making it necessary to replace them with all-optical networks (AON) where no electro-optic conversion is used [1]. As discussed in [2–4], deploying all-optical networks is promising but at the same time, its reliability should also be ensured. As the signals in AON travels over long distances (few hundreds to thousands of Kilometers) its QoS measured in terms of BER degrades due to physical layer impairments such as amplifier spontaneous emission (ASE) noise, crosstalk from optical nodes and switches, inter-symbol interference (ISI) due to chromatic dispersion, polarization mode dispersion (PMD), and nonlinear effects (self phase modulation (SPM), four wave mixing (FWM)) [5].

Conventional studies on routing and wavelength assignment (RWA) have proposed many algorithms for establishing Lightpaths (LP) without considering any physical impairments [6-7]. In the recent years, many RWA schemes incorporating the QoS in terms of BER, have been proposed, considering QoS blocking (Call is blocked, if the LP does not meet the minimum QoS threshold, Q_{th}) along with wavelength blocking (Call blocking due to *wavelength continuity constraint*) [2], [8–14].In most of these proposed techniques, QoS criterion is just checked at the last routing step for call admission. If QoS falls below Q_{th}, then call request is rejected. These schemes do nothing to mitigate the effects of PLI. Also as indicated in [15] few works target the offline case compared with the proposed solutions for its online counterpart. In [16], the RWA issues of shared protection in translucent WDM mesh networks with consideration for physical layer impairments is addressed. For transparent optical networks, studies in [17] shows that the CAPEX difference is considerably lower for shared and dedicated path protection schemes, thus making dedicated protection attractive.

In [18], two physical impairments aware RWA schemes namely HQ and MAMIQ were proposed which mainly focuses on cross talk effects. These algorithms incorporate QoS information at both the routing and the wavelength assignment steps. Quality of transmission (QoT) guaranteed FF scheme for networks suffering from transmission impairments was proposed in [19], wherein at the last step, selected route is checked for QoT threshold. In [20], offline version of the routing and wavelength assignment (RWA) problem in transparent all-optical networks were presented

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based on LP relaxation formulation .Later the RWA formulation was extended so as to model the physical layer impairments as additional constraints on RWA. In [21], offline routing and wavelength assignment problem in translucent WDM networks in the presence of physical impairments were considered. Also proposed algorithm considers the 3R regeneration capabilities.

The wavelength preordered version of HQ and MaMiQ were presented in [22], wherein the wavelength preordering was shown as the reason for the BER improvements. The proposed schemes WpO-MaMiQ and WpO-HQ were compared with wavelength preordered version of standard SP technique; WpO-SP.

In [23], offline PLI aware RWA is proposed for dedicated path protected transparent networks. In that paper, set of standard RWA schemes taken form literature were enhanced to incorporate PLI and path protection then compared with the proposed so called "Rahyab IA-RWA" algorithm. The authors concluded, that demand preprocessing reduces blocking probability considerably with standard k-shortest path (SP) routing with Firsfit (FF) wavelength assignment technique for path protected transparent networks. At the last step, QoS (Q factor) is checked for the selected LP, and if it is below threshold, then it is established else call is blocked. There is no mechanism is employed to mitigate the PLI (thereby to enhance QoS), but minimum QoS is ensured. Enhanced QoS in terms of BER have many advantageous, first for network scaling- links and nodes can be added by keeping QoS with in threshold, secondly robustness in the context of hardware aging is improved by operating far from the threshold, lastly lower BERs imply fewer retransmissions at the higher layers (such as TCP) and thus increase the actual information data throughput. Indeed, more reliable paths can forgo Forward Error Correction (FEC) techniques which can be used to relax the QoS (BER) constraint of a path and since FEC is difficult to achieve at very high bit rates, FEC could be used and reserved for paths that exhibit high BER (because of length or high crosstalk for instance)[18].

In this paper for dedicated path protected transparent networks, a novel QoS aware RWA called WpDp-MaMiQ is presented that mitigates PLI. The proposed algorithm not only ensures the minimum QoS requirement, but also mitigates the effects of the PLIs at network layer thereby improving QoS in terms of BER performance. QoS is enforced both at wavelength assignment step and routing step.

In [23], the standard FF wavelength assignment (WA) scheme is employed. However, it is seen from [5] and [8] that QoS blocking depends significantly on the choice of WA algorithm used. Further crosstalk effects are stronger when the participating signals are on closer channels and when channel separation is tighter. In the proposed technique, wavelengths are pre ordered by spectral differences in such a way that assigning of spectrally closer wavelengths on links can be minimized. During routing phase, amongst possible lightpaths, paths having higher Q value and least loaded (For QoS enhancement), are tried as candidate paths to maintain minimum optical power interactions, which will help reducing cross talks and non-linear effects. For better BP performances, call requests are pre-ordered based on hop counts in a demand set.

In this paper a novel RWA algorithm called W*p*D*p*-MaMiQ is proposed in which given wavelengths are pre-ordered in a wavelength set while the demands are preordered in a demand set based on certain criteria. The proposed RWA algorithm is compared with the so called "Rahyab IA-RWA" presented in [23] and Wp-MaMiQ presented in [22] by assuming similar network conditions and topology. Also the proposed algorithm is applied to the NSFNET network topology and results are presented separately. This result is compared with the standard QoS aware version of FF-Shortest path RWA scheme (SP-FF-Q).

This paper is organized as follows. Section 2 describes the transmission path model and physical layer impairment model used in this work. In section 3, the proposed QoS aware routing and wavelength assignment algorithm is presented. Section 4 explains the simulation, assumed network parameters and finally the results are presented. At the last section 5 a brief conclusion is given.

2 System Description and PLI Model

In this work, a network of bidirectional links with C equally spaced wavelengths in each direction are considered. Physically, the links consist of one or several spans; each span in turn consists of single mode fiber, an optical amplifier (EDFA) that compensates for the fiber linear attenuation, and a dispersion compensation fiber (DCF) that compensates for the fiber chromatic dispersion. Links are separated by Optical cross connects (OXC) where switching and demultiplexing takes place. Wavelength conversion is not available; hence a call must use the same wavelength from source to destination. The legitimate signal is shown in bold line in Fig.1.The ASE noise arise form

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optical amplifiers, Non linear cross talk arise from optical fiber due to non linear effects, node crosstalk form nodes are shown in dotted lines in the model shown in Fig.1.

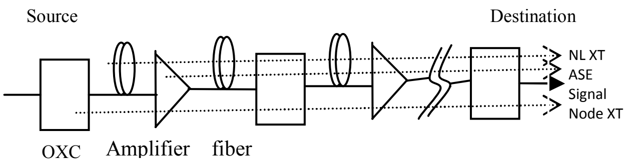

Fig. 1.Transmission path model used

The receiver is modeled by an optical filter (for demultiplexing purposes), followed by a photo detector per channel (a square-law device, a time sampler and a narrow electrical filter). A sample lightpath is shown in Fig. 1. A centralized network management system is assumed to perform entire call process and typically, a low-speed control channel is reserved to manage the network operations.

There are two types of crosstalk, node crosstalk and nonlinear fiber crosstalk. The strongest node crosstalk originates from two sources: *fabric crosstalk* due to power leaking of in-band signals traversing the switch, and *adjacent-port crosstalk* from imperfect power isolation in the demultiplexers of network nodes. The strongest nonlinear fiber crosstalk also comes from two sources, FWM and XPM. The severity of the crosstalk in both cases depends partly on the spectral spacing of the interfering signals [24].All these four crosstalks have been considered in this work.

There are two kinds of PLI; static and dynamic. Static impairments are independent of network state and only depend on topology and in this paper the following static impairments are considered: ASE noise form optical amplifiers filter concatenation, and ISI. PMD is negligible at 10 Gbps, hence it is ignored here. (But however, it should be incorporated at higher data rates (40 Gbps/channel)).The dynamic effects node crosstalk, XPM and FWM are considered.

Most commonly, QoS for a signal is measured by its BER, and Q factor for a lightpath is related to the signal's Bit-Error Rate (BER). For an On-Off modulated signal, assuming Gaussian distributions for the '0' and '1' samples after photo detection, the Q factor is given by [24]

$$Q = \frac{\mu_1 - \mu_0}{\sigma_0 + \sigma_1} \tag{1}$$

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where $\mu 0$ and $\mu 1$ are the means of the '0' and '1' samples, respectively, and $\sigma 0$ and $\sigma 1$ are their standard deviations. BER and the Q factor of a signal are related by

$$BER = \frac{1}{2} erfc\left(\frac{Q}{\sqrt{2}}\right) \tag{2}$$

A BER of 10^{-9} corresponds to a Q factor of 6 and in this work, every established lightpath is expected to have of a minimum Q value of 6. The ISI, ASE, and node crosstalk are accounted in Q factor through its noise variances σ_i^2 , σ_n^2 and σ_x^2 respectively. The non linear effects XPM and FWM are modelled as in [25-26] and they are accounted through the noise variance termσ_{nx}^2. Incorporating these effects, Q factor of a lightpath can be written as,

$$Q = \frac{\mu_1 - \mu_0}{\sigma_0 + \sqrt{\sigma_i^2 + \sigma_n^2 + \sigma_x^2 + \sigma_{nx}^2}} \tag{3}$$

Since node crosstalk, XPM and FWM are dynamic effects that depend on the network state they have to be computed on-line.

3 QoS Aware RWA with Dedicated Path Protection Consideration

In this section the proposed RWA algorithm is described. In [23], simple FF technique was employed for wavelength assignment, ignoring the power of wavelength assignment in improving blocking performance and BER performance. In this paper, wavelengths are pre ordered in a wavelength matrix, based on its spectral differences in decreasing order before serving any requests. Routing is performed separately by a routing engine considering PLI effects. During routing phase, candidate LP matrix is computed by picking wavelengths form pre ordered wavelength matrix using FF method by incorporating Q factor calculations.

3.1 Wavelength Pre Ordering

WA techniques play an important role in network performance. For example, FF technique has a smaller wavelength blocking than Random pick (RP) technique. But BER performance of RP is better, as it tend to spread the wavelength use geographically across the network [5]. The dominant sources of BER degradation are noise and crosstalk. As indicated in [24], crosstalk is severe when participating interfering signals are spectrally close. Therefore if spectrally close wavelengths are avoided on the links, the corresponding BER performance will improve. In this offline wavelength ordering technique, the given C wavelengths are ordered in a wavelength set λ before network operations begins. The wavelengths that are spectrally far away are placed first and spectrally closer wavelengths are placed at last. Then these wavelength set is tried as FF technique. For protected demands, two successive wavelengths are tried; one for main path and another for backup path.

3.2 Demand Pre Ordering

The call demands are processed in a pre defined order unlike conventional offline RWAs where requests are processed in the order as it arrives. The order in which the demands are considered plays an important role in the performance of the proposed algorithm. To define the order of demands, the a-priori distance between source nodes and destination node is assessed by the length of the shortest path between them in terms of hops. Then, the demands are ordered according to this shortest distance in decreasing order (demands with longer path are placed first) in a demand set $\mathcal{D}$

The rationale behind this is, due to the wavelength continuity constraint, it is more difficult to establish a path between a source and a destination that are far away from one another in terms of hops. If we also account for noise and crosstalk impairments, establishing paths between distant sources and destinations is even more difficult because of the many sources of noise and crosstalk that may exist between the end nodes. Therefore, more resource-consuming requests are accommodated first, otherwise, which could easily be blocked by less resource-consuming requests. The demands may be protected or unprotected. *Demand pre-ordering* orders the static demand set in decreasing expected resource consumption, that is, protected demands have higher priority over unprotected ones.

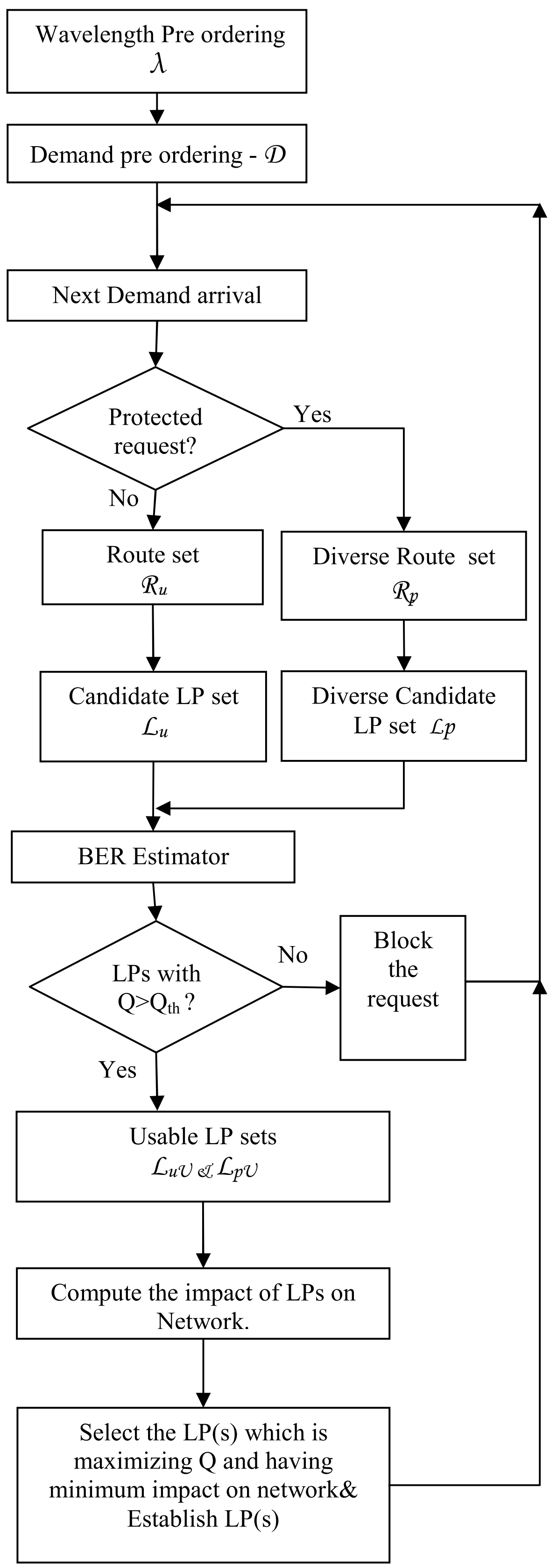

Fig.2.QoS aware RWA (WpDp-MaMiQ)

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3.3 QoS Aware RWA

For each request, the routing engine performs the routing function for each source destination pairs and thus computes the route set $\mathcal{R}_u$. For protected request, it computes diverse route set $\mathcal{R}_p$. When a new request arrives, wavelength from λ, is tried to form a candidate lightpath set $\mathcal{L}_u$ using $\mathcal{R}_u$ for unprotected request and diverse candidate lightpath set $\mathcal{L}p$ using $\mathcal{R}_p$ for protected request by enforcing QoS constraint. If LPs with $Q>Q_{th}$ found then these LPs used to form usable LP set $\mathcal{L}_{uU}$ and $\mathcal{L}_{pU}$ for unprotected and protected requests respectively. If no LP is found with $Q> Q_{th}$ then request is blocked. The impacts of each elements form $\mathcal{L}_{uU}$ and $\mathcal{L}_{pU}$ on network is computed. Finally the member form L_{uU} and $\mathcal{L}_{pU}$ having least impact on network, and maximizing Q is selected and LP is established. This algorithm is shown in Fig.2.

Paths are selected such that it maximises the minimum Q factor among paths affected by the establishment of the call. If a call is established, it injects crosstalk and modifies the Q factor for all paths used by previously established calls it crosses in the network, which conversely inject crosstalk on the considered path. The proposed path selection policy retains the path that will yield the maximum (among all possible wavelengths) of minimum (among all paths crossed by the tentative path, including itself) Q factor considering crosstalk effects. This policy tries to spread the crosstalk over the network such that all established paths are as far away from the QoS threshold as possible. Again, this policy may lead to waste of physical resources as non-shortest paths may be chosen. In this work, not only the topological state of the network is considered at the routing time, but it also incorporates QoS information in terms of crosstalk and other PLIs.

4 Simulations and Results

A network model as explained in section II is assumed for simulation. The DTNet topology was used for ease of comparative studies with [23] and is shown in Fig.3.This network has 14 nodes and 23 bidirectional links. The characteristics of DTNet topology is shown in table 2.The same work is repeated for NSFNET topology assuming same network parameters. This network has 14 nodes and 21 bidirectional links. This NSFNET network topology is shown in Fig.4. Also it is assumed that physical layer impairments of node and link architectures are having different impacts and contributions. The various physical parameters used in the simulation are listed in Table 1. These are standard parameters for a regional area network.

Table 1

Various parameters used in the simulation

Description	**Value**
Span length	100 km
Signal peak power	2 mW
Pulse Shape	NRZ
Bit duration	100 ps (10 Gbps)
Fabric crosstalk	-40 dB
Adj. port crosstalk	-30 dB
Non adj. port crosstalk	-60 dB
Fiber loss	0.25 dB/km
Nonlinear coefficient	2.2 $(\text{W km})^{-1}$
Linear dispersion	17 ps/nm/km
Dispersion compensation	100% post DC
Noise factor	2
Receiver electrical bandwidth	7 GHz
Channel Spacing	50 GHz
Minimum Q factor	6 (BER 10^{-9})

Table 2

DTNet topology characteristics

Parameter	**Value**
Number of Nodes:	14
Number of links:	23
Node degree:	3.29 (min.2,Max. 6)
Link length (km):	186 km (min.37, Max.353 km)
Hop count:	2.35 (min.1, Max.5)
Path length (km):	410 km (min.37, Max.874)

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QoS constraint is enforced in such a way that, any call, at any time, should use a path with a Q factor at least equal to $Q = 6$, which corresponds to a BER of 10^{-9}. All links were made of one or more 100 Km long spans.
At the end of each link a DCF is used which exactly compensates for the dispersion. Offered load in the network is defined as the ratio between the numbers of lightpath demands divided by the number of pairs of nodes in the network.

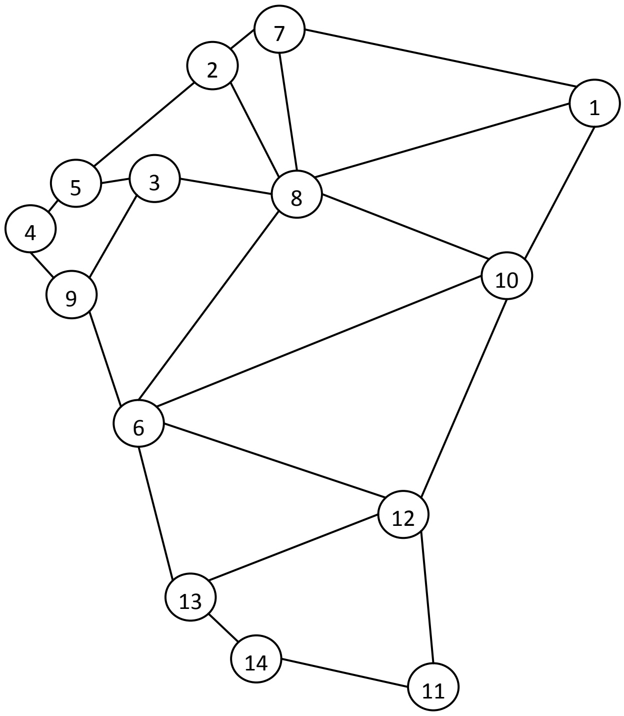

Fig.3 DTNet Topology

The unit traffic load corresponds to the demand set where there is a lightpath request between each distinct pair of source and destination nodes. At random 25 demand sets were generated for every load value. Out of total requests, 20% and 30% requests were assumed to be protected request and dealt separately. The wavelength usage against blocking rate for DTNet topology is given in Fig.5 for 20% protected request and in Fig.6 for 30% protected demands, both for DTNet topology. It is seen that blocking rate for 30% protected demands seems higher compared to 20% protected demands. It is due to the fact that, as the protected demand increases, resource consumption also increases and this leads to resource blocking of future requests. Also it is observed that the proposed algorithm outperforms Rahyab and SP-FF. Blocking rate against network load for DTNet is shown in Fig.7 for 20% protected demands.

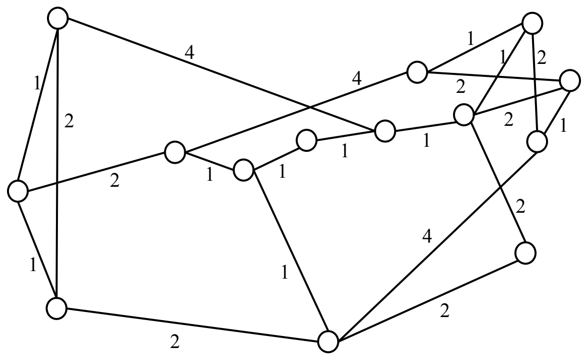

Fig.4. A downscaled 14 node NSF net topology. The link weights on the figure correspond to the number of fiber spans

It is seen that at 70% load, the proposed algorithm WpDp-MaMiQ performs better by 47% compared to Rahyab. This is due to wavelength pre ordering which reduces QoS blocking due to crosstalk reduction.In Fig.8, blocking rate against network load is shown for 30% protected request. Blocking rate is higher for 30% protected request compared to 20% protected request, It is because, 30% protection requires more resources in terms of wavelengths and links and hence blocking rate for 30% protection is higher. In both the 20% and 30% protection cases, Wp-MaMiQ performs similar to Rahyab since Wp-MaMiQ lacks Demand pre processing.
The average BER Vs network load for 20% protected request is shown in Fig.9 and for 30% protected requests, it is shown in Fig.10, both for DTNet topology. It is seen that for the proposed algorithm, there is only a slight variation in the BER performance of the 20% and 30% protected requests cases. It is because QoS criterion is same for both the cases. However at 30% protection case, Wp-MaMiQ performs close to the proposed one. This is because both the algorithms employs wavelength pre-ordering which is causing low BER.

The same work is repeated for NSFNET topology with 20% and 30% protected demands using the proposed RWA. The results are compared with the QoS aware standard First Fit, Shortest path RWA scheme (FF-SP-Q) and Wp-MaMiQ. For protected demands first shortest path and second shortest paths were considered. BER performance against load is shown in Fig.11 for 20% protected demand and in Fig.12 for 30% protected demand. It is found that for both the cases, BER performance is almost similar. The proposed WpDp-MaMiQ out performs FF-SP-Q at good margin but however performs closer to Wp-MaMiQ as both these employs wavelength preordering. The blocking rate Vs load is given in Fig.13 and Fig.14 for 20% and 30% protected demands respectively. As in DTNET topology, for NSFNET also, blocking rate performance for 20% protected demand is better compared to 30% protected demand because 30% protected demand consumes more resources and cause resource blocking (links, wavelengths) for future demands.

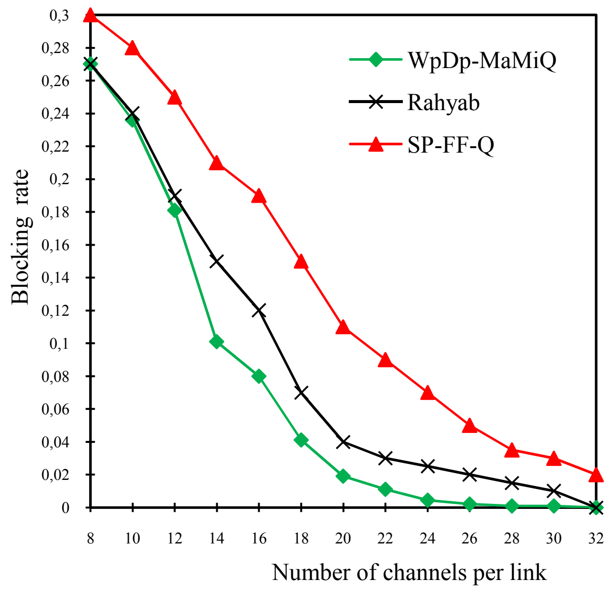

Fig.5. Call blocking rate Vs Number of channels per link (Load =70%) for 20% protected demand for DTNet

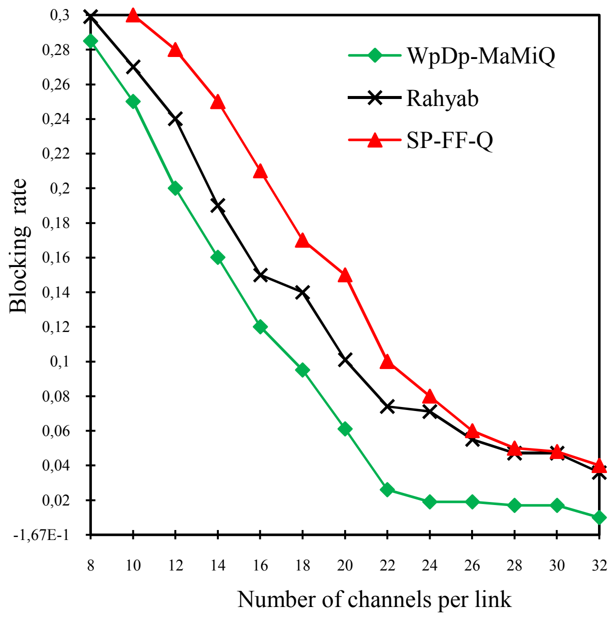

Fig.6. Call blocking rate Vs Number of channels per link (Load =70%) for 30% protected demand for DTNet

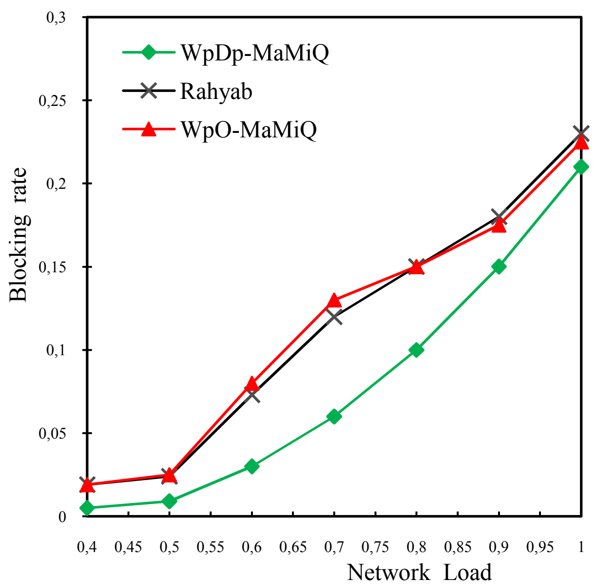

Fig.7.Blocking rate Vs Network Load for 20% protected demand for DTNet

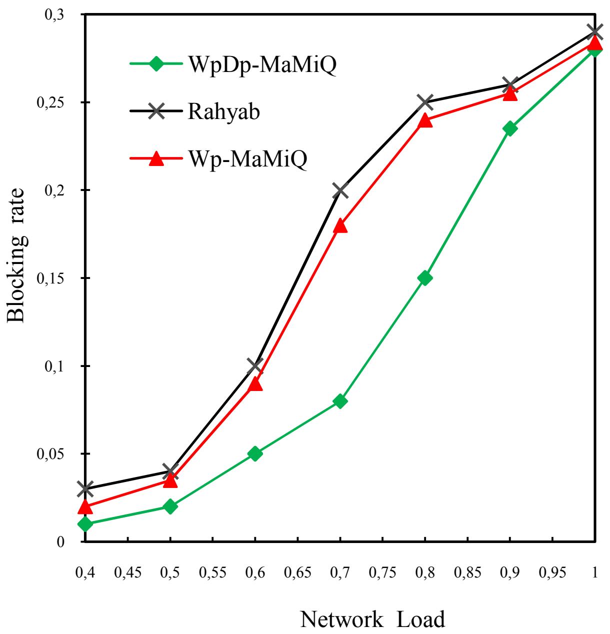

Fig.8.Blocking rate Vs Network Load for 30% protected demand for DTNet

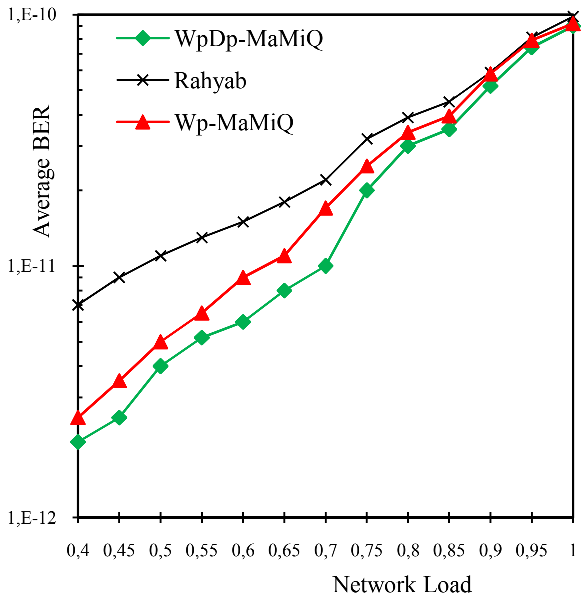

Fig.9.Average BER Vs Load for 20% protcted demand for DTNet

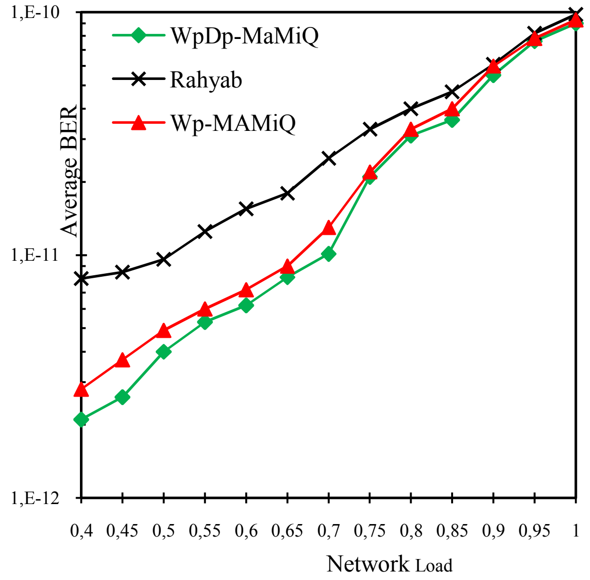

Fig.10. Average BER Vs Load for 30% protected demand for DTNet

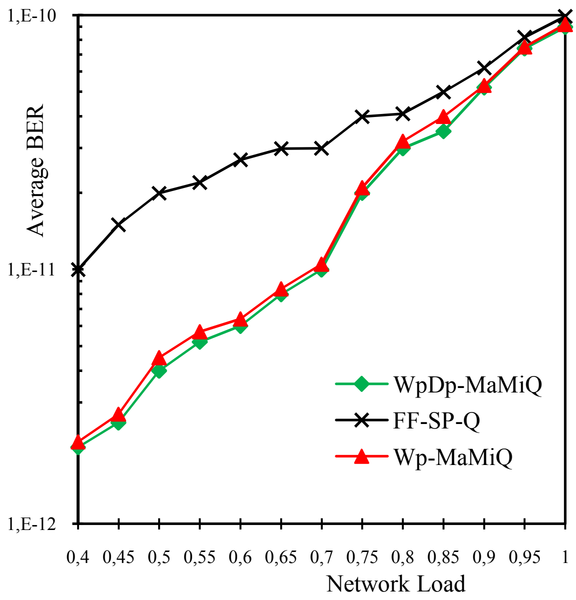

Fig.11.Average BER Vs Load for 20% protcted demand for NSFNET

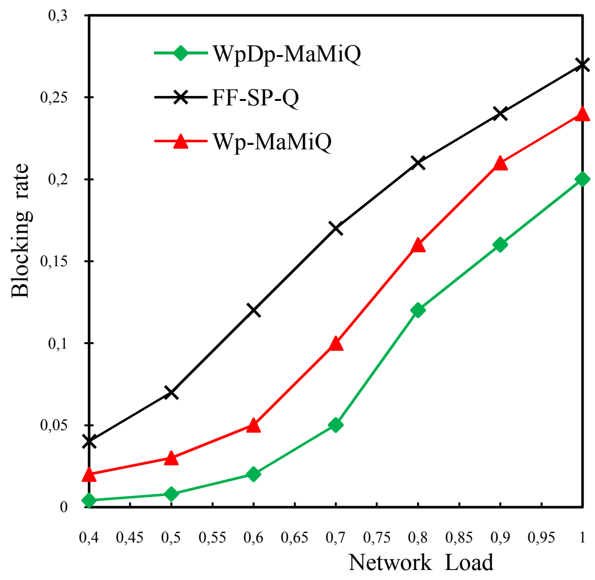

Fig.13.Blocking rate Vs Network Load for 20% protected demand for NFSNET

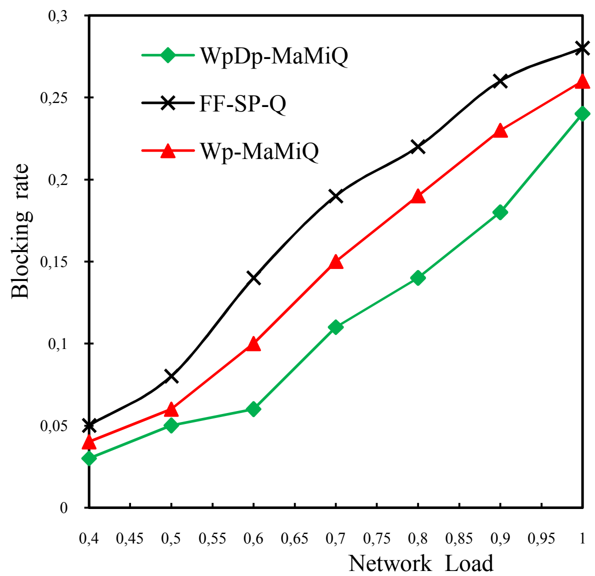

Fig.14.Blocking rate Vs Network Load for 30% protected demand for NFSNET

5 Conclusion

In this work a novel QoS aware RWA incorporating physical layer impairments called WpDp-MaMiQ was presented and shown that physical layer impairments can be mitigated at network layer. Wavelength pre ordering technique based on its spectral differences was used to minimise crosstalk effects and thus improved QoS in terms of BER to minimize QoS blocking. At the routing stage, the path that maximises the Q factor was chosen. This enables the network to operate away from QoS threshold rather than merely close to it and this in turn allows for more LP establishments and thus reduces blocking rate. The proposed algorithm was compared with the so called 'Rahyab" algorithm and Wp-MaMiQ for DTNET topology and it is found that the proposed algorithm performs better. At 70% load, there exists s BER improvement of 40% and blocking rate improvement of 47% under similar conditions compared to Rahyab. This work was repeated for NSFNET topology and compared with standard QoS aware version of FF-SP RWA scheme and Wp-MaMiQ. For both the topologies it was found that the proposed RWA performs better in terms of BER and blocking rate compared to Rahyab. Though the BER performances of proposed WpDp-MaMiQ and Wp-MaMiQ are closer, blocking rate performances of the proposed algorithm are impressive. The same work can be extended for online implementation and it is left for future work.

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K.Ramesh Kumar obtained his B.E. degree in Electronics and communication engineering from Bharathiyar University, India in 2001, M.E. degree in Optical communications from Anna University, Chennai, India in 2004 and pursuing Ph.D in Anna University, Coimbatore, India. His areas of interest are Optical networks, Network Reliability and Network scalability. He is currently working as a Junior Telecom Officer at Bharat Sanchar Nigam Limited (BSNL), Tamilnadu circle, India.

R. S. D. Wahidabanu obtained her B.E. degree in 1981 and M.E. degree in 1984 both from Madras University, India and Ph.D in 1998 from Anna University, Chennai, India. Her areas of interest are Network Security, Network scalability and Knowledge Management. She is a life member of IEEE, ISTE, SSI, CSI India and ISOC. She is currently working as a Principal at Government College of Engineering, Salem, India.

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