# Quality of Transmsision Aware Routing and Wavelength Assignment Algorithm for Blocking Minimization in Translucent Optical Networks

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*Abstract*— **In Optical Transport networks, the optical reach is defined as the maximum distance (number of hops) a lightpath connection can span before the intelligence of the signal it is carrying to unrecoverable state as a result of the degradation in the signal to noise power ratios. When the signal to noise ratio has degraded below a certain acceptable threshold, regeneration is necessary. Optical Transport networks will normally incorporate optical repeaters throughout to facilitate signal reach for all the lightpath connection establishments. Such networks are classified as being Translucent. The role of the sparsely spaced optical repeaters is to refresh the degraded optical signals so that an acceptable quality of transmission (QoT) can be guaranteed by the network operator. The deployment of such units where necessary throughout the network leads to an escalation to both capital as well as operational expenditures. It is however necessary that network designers strike a balance between the network operating costs versus renderable quality of service (QoS) to end users. In light of this challenge, in this paper we propose and analyze a QoT-Aware routing and wavelength assignment algorithm (QARWA) that seeks to minimize blocking of data bursts traversing the network. The QoT blocking considers the effects of various linear as well as nonlinear impairments. The proposed model can be infused with other algorithms that attempt to calculate wavelength blocking per route and also per available layer. We also further enhance the same algorithm's efficacy by introducing its QoT aware guaranteed RWA (QGRWA) equivalent. The novelty of the scheme is in taking into account physical layer impairments, as well as signal quality when computing candidate routes for a given source to destination pair. The proposed algorithm's overall promising performance is validated via analytical and simulation means.**

***Keywords— Transparent optical networks, QoT aware, blocking probability, optical repeaters***

## I. Introduction

The ever increasing global data volumes has led to demands for matching transmission as well as switching capacities in existing backbone networks, hence the emergence of all optical backbone networks that utilize both reconfigurable optical switching fabrics and adaptable tuneable lasers to achieve the required speeds as well as scalabilities. Such network infrastructures will be expected to provision multiples of simultaneous end-to-end lightpath connections in a cost-effective manner. In this regard, proper dimensioning of the available networking resources is a key challenge that requires addressing. Notably, when selecting an end-to-end lightpath connection (path and wavelength), the a routing and wavelength assignment (RWA) algorithm being implemented has to take into consideration the unavoidable presence of physical layer impairments under a wavelength continuity constraint. The impact of physical layer impairments on the general quality of transmission end-to-end has been studied by various authors Overall, the consensus appears to be in adopting the two general models , that will take into account the effects of physical layer impairments when designing transparent all optical transport networks. RWA algorithms [1]. These are the analytical and hybrid models. With the earlier closed-form formulae are relied upon in computing the effects of physical impairments whereas in hybrid models the analytical approach is further validated with the aid of simulation runs. A quality of transmission (QoT) parameter. Is proposed in [2] for the evaluation of overall signal levels and quality in all optical networks that take into account such impairments. The authors in [3] propose the decomposing of physical impairments aware RWA by considering the individual wavelengths as a stratified integral system. In this case a typical RWA algorithm implemented in a network with several links, where each has a set $\Lambda$ of active (usable) wavelengths can be decomposed into a set of $\Lambda$ stratified distinct networks. Each individual network maintains the original base topology with each link operating a single wavelength.

The network load is offered on each layer, starting with layer 1. The spill traffic load is passed on to the next layer and the pattern recursively repeats for all available layers. Note that at each network layer $\Lambda$ , the spilled traffic is a measure of the blocked traffic portion hence the overall blocking probability can be computed using accordingly.

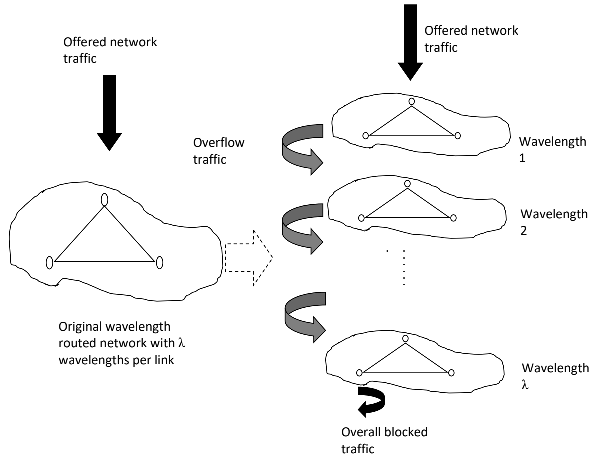


Fig. 1. Illustration of the decomposed multi-layered network model

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Accordingly, the mandatory wavelength continuity constraint, which requires that a connection be assigned the same wavelength end-to-end, is thus accordingly implemented in this perspective. The approach also enables appraisal of each individual wavelength and its blocking probability is only affected by data arrival rates and patterns. Other related approaches are discussed in [5],[6]-[13]. The paper looks at path and wavelength blocking computations before discussing the proposed algorithm. Finally both analytical and simulation results are discussed.

## II. WAVELENGTH BLOCKING PROBABILITY COMPUTATION

The section summarily narrates the steps towards computing a wavelength's blocking probability in the wavelength sublayer. As defined in the introductory section. Wavelength blocking results when the continuity constraint cannot be achieved end-tend.

### A. *Single Wavelength Blocking Probability case*

A lightpath connection can span a total of $n$ hops and mathematically the wavelength state $(\lambda)$ at any arbitrary time $t$ associated with the chosen path may be expressed as an $\frac{n(n+1)}{2}$ dimensional process:

$$\left(\beta_{0,1}^{\lambda}(t), \beta_{0,2}^{\lambda}(t), \dots, \beta_{n-1,n}^{\lambda}(t)\right), \quad (1)$$

where,

$$\beta_{i,j}^{\lambda} + \beta_{j,m}^{\lambda} \leq 1, \ \forall r(i,j) \cap r(l,m) \neq 0, 0 \leq l < m \leq n \quad (2)$$

This process is typically a time-reversible Markov process with a static probability vector $\pi^{\lambda}$ expressed as;

$$\pi^{\lambda}\left(\beta_{0,1}^{\lambda}, \beta_{1,2}^{\lambda}, \dots, \beta_{n-1,n}^{\lambda}\right) = \frac{1}{G_r^{\lambda}(0,n)}\left[\left(\left(a_{0,1}^{\lambda}\right)^{\beta_{o,1}^{\lambda}}, \left(a_{1,2}^{\lambda}\right)^{\beta_{1,2}^{\lambda}}, \dots, \left(a_{n-1,}^{\lambda}\right)^{\beta_{n-1,n}^{\lambda}}\right)\right] \quad (3)$$

where $G_r^{\lambda}(0,n)$ represents the recursively computed normalization constants:

$$G_r^{\lambda}(0,n) = G_r^{\lambda}(0,n-1) + \sum_{i=0}^{n-1} G_r^{\lambda}(0,i) a_{i,n}^{\lambda}, \ \lambda = 1, \dots, \Lambda \quad (4)$$

Note that $G_r^{\lambda}(0,0) = 1$, $a_{i,j}^{\lambda}$ this denotes the summated equivalent Poisson network traffic from all source-destination (s-) lightpath connections on a given network segment $r(i,j)$ at wavelength $\lambda$. The summate sum can be expressed as:

$$a_{i,j}^{\lambda} = \sum_{\substack{r(i,j) \subseteq r(s,d) \\ r(i,j) \Leftarrow A_{s,d}^{\lambda}, then\ r(m,l) \nLeftarrow A_{s,d}^{\lambda} \\ \forall r(l,m) \subseteq r(0,n)}} \frac{A_{s,d}^{\lambda} \cdot (1-P_{s,d}^{\lambda})}{1-P_{i,j}^{\lambda}}, (5)$$

where, the following expression:

$$r(i,j) \Leftarrow A_{s,d}^{\lambda}, then\ r(m,l) \nLeftarrow A_{s,d}^{\lambda}, \forall r(l,m) \subseteq r(0,n)" \quad (6)$$

The preceding equation (6), indicates the uniqueness of traffic belongings to the segment $r(i,j)$ . The blocking probability of the wavelength $\lambda$ for the segment $r(0,n)$ can be computed using the equation;:

$$P_{0,n}^{\lambda} = 1 - \pi^{\lambda}(0,0,\dots,0) = 1 - \frac{1}{G_r^{\lambda}(0,n)} \quad (7)$$

### B. *Overall Blocking Probability case*

In this section, we briefly explain how each wavelength's blocking probability can be determined by way of the overflow model approach. In section one we did narrate the overall network traffic overflow process in the stratified networks. In short, any blocked traffic in a particular network layer overspills to the next available layer network and so forth. The overflowed traffic is not necessarily Poisson distributed but and its mean less that its variance thus making it bursty in nature [4]. A mathematical characterization of such overflowed traffic is provided by the authors in [4]. In this study the average the average overflowed traffic to incident to a given layer is given by:

$$\bar{A}_{s,d}^{\lambda+1} = A_{s,d}^{\lambda} . P_{s,d}^{\lambda} \quad (8)$$

Its statistical variance $\bar{V}_{s,d}^{\lambda+1}$, is computed using the Riordan's formula as follows:

$$\bar{V}_{s,d}^{\lambda+1} = \bar{A}_{s,d}^{\lambda+1}\left(1 - \bar{A}_{s,d}^{\lambda+1} + \frac{\Phi_{s,d}}{\bar{\Omega}_{s,d}^{\lambda}+1+\bar{A}_{s,d}^{\lambda+1}-\Phi_{s,d}}\right), \quad (9)$$

In the previous equation, $\bar{\Omega}_{s,d}^{\lambda}$ is a measure of the volume of an equivalent single isolated link can be determined from:

$$\Phi_{s,d} . Er\left(\Phi_{s,d}, \bar{\Omega}_{s,d}^{\lambda}\right) = \bar{A}_{s,d}^{\lambda+1} \quad (10)$$

. In equation (10) above, $Er\left(\Phi_{s,d}, \bar{\Omega}_{s,d}^{\lambda}\right)$ is the non-integral capacity calculated with the aid of the Erlang B formula. Its expanded form is given by [5]:

$$Er(x,y) = \frac{x^y e^{-x}}{\Gamma(y+1)[1-\Gamma(x,y+1)]} \quad (11)$$

where, $\Gamma(x, y+1)$ denotes the incomplete Gamma function.

The burstiness factor of the overflowed traffic (i.e. the ratio of the variance to mean value) is:

$$\bar{Z}_{s,d}^{\lambda+1} = \frac{\bar{V}_{s,d}^{\lambda+1}}{\bar{A}_{s,d}^{\lambda+1}} \quad (12)$$

The Fredericks and Hayward's approximation techniques [4] can be used to account for the non-Poisson distribution nature of the overflow traffic as follows:

$$A_{s,d}^{\lambda+1} . P_{s,d}^{\lambda+1} \approx \bar{A}_{s,d}^{\lambda+1} . Er\left(\frac{\bar{A}_{s,d}^{\lambda+1}}{\bar{Z}_{s,d}^{\lambda+1}}, \frac{\Omega_{s,d}^{\lambda+1}}{\bar{Z}_{s,d}^{\lambda+1}}\right) \quad (13)$$

where, $\Omega_{s,d}^{\lambda+1}$ is determined according to:

$$P_{s,d}^{\lambda+1} = Er\left(A_{s,d}^{\lambda+1}, \Omega_{s,d}^{\lambda+1}\right) \tag{14}$$

$\Omega_{s,d}^{\lambda+1}$ also represents the capacity of another equivalent single-link system only for layer $\lambda + 1$ that has a mean arrival rate equaling $A_{s,d}^{\lambda+1}$.

Finally, equations (9) to (14) to determine both the wavelength blocking probability and the path arrival rate for the individual layers as follows:

The path's overall blocking probability is approximated by:

$$\hat{P}_{s,d} = \frac{A_{s,d}^{\Lambda} \cdot P_{s,d}^{\Lambda}}{\Phi_{s,d}} = \frac{\bar{A}_{s,d}^{\Lambda+1}}{\Phi_{s,d}} \tag{15}$$

From which the overall wavelength blocking probability for the overall network is determined from:

$$\hat{P} = \frac{\sum_{(s,d)\epsilon Z} \bar{A}_{s,d}^{\Lambda+1}}{\sum_{(s,d)\epsilon Z} \Phi_{s,d}} \tag{16}$$

The overall network and path wavelength blocking probabilities are computed according to Algorithm I. The algorithm assumes the *first fit wavelength assignment* (FF WA) and is subject to the following conditions:

$\lambda_0 = 1$, $\bar{A}_{s,d}^{1} = \Phi_{s,d}$, $\bar{V}_{s,d}^{1} = \Phi_{s,d}$ , $\bar{Z}_{s,d}^{1} = 1$ for all $(s,d) \in Z$.

According to the same algorithm, should the relative difference of the blocking probabilities between two successive iterations differ by a magnitude less that equal to $\epsilon$ per path, the current layer will be deemed stable enough to allow may be viewed as stable and thus iterations for the next layer will proceed.

## III. ANALYTICAL MODEL FOR QARWA SCHEME

Next we present model for the proposed quality of transmission (QoT) Aware RWA (QARWA) algorithm. Fundamentally QoT blocking takes into account physical impairments such as amplified spontaneous emission (ASE)e, thermal, shot as well as crosstalk (XT) noises. The algorithm can incorporate other existing ones in the calculation of path wavelength blocking per layer.

When the algorithm is applied to small and medium sized networks the volumes of required calculations are fairly modest. However, these become quite extensive as well as complex for large networks.

In order the reduce the computational loads as well as complexes, simplifying techniques can be incorporated in the main algorithm. These include estimation approaches. In this a network blocking estimation tool is proposed for larger networks such as a typical all optical backbone. The entire network decomposed into several cascaded smaller subnets each with 5 or less layers that are interrelated.

**Algorithm I: QRWA**

1. Assume initial values of $A_{s,d}^{\lambda} = \bar{A}_{s,d}^{\lambda}$, and the initial wavelength blocking probability of the path as $\bar{P}'_{s,d} = 0 \; \forall \, (s,d) \in Z$
2. Compute $P_{s,d}^{\lambda}$
3. Obtain $\Omega_{s,d}^{\lambda} \; \forall \, (s,d) \in Z$
4. Compute the equivalent Poisson traffic $A_{s,d}^{\lambda}$ for layer $\lambda \; \forall \, (s,d) \in Z$
5. **if** $\frac{\left|P_{s,d}^{\lambda} - P'_{s,d}\right|}{P'_{s,d}} > \epsilon, \forall (s,d) \in Z$ **then**
6. $\bar{P}'_{s,d} = P_{s,d}^{\lambda}$
7. go to step 2
8. **else**
9. $\lambda = \lambda + 1$
10. Calculate $\bar{A}_{s,d}^{\lambda}$, $\bar{V}_{s,d}^{\lambda}$, and $\bar{Z}_{s,d}^{\lambda}$
11. **if** $\lambda \leq \Lambda$, **then**
12. go back to step 1
13. **else**
14. Compute the net path and network wavelength blocking probabilities
15. **return** $\hat{P}$ and $\hat{P}_{s,d}$ for all $(s,d) \in Z$
16. **end if**
17. **end if**

In this case both the path and network blocking probabilities for QARWA are computed with the aid of the main equations presented in the preceding section. However, the quantity $\bar{A}_{s,d}^{\lambda+1}$ now includes the blocking traffic QoT. This is illustrated by Algorithm II in which, $\bar{A}_{s,d}^{1} = \Phi_{s,d}$, $\bar{V}_{s,d}^{1} = \Phi_{s,d}$, and $\bar{Z}_{s,d}^{1} = 1 \; \forall \, (s,d) \in Z$. Both traffic arrival rates as steady state probabilities without taking impairments into consideration are computed in step 2, The obtained values in step 2 are then used for QoT estimation initialization .The traffic flow then proceeds to the QoT blocking sublayer, and then after the traffic flow rate $\bar{A}_{s,d}^{\lambda} = A_{s,d}^{\lambda} \cdot \left(1 - \rho_{s,d}^{\lambda}\right)$ reaches the wavelength blocking sublayer. The arrival rates as well as blocking probability are determined for the respective sublayer in step 4. The next step computes layer 2 overflowed traffic flow, which equals the aggregate of the overflow due to wavelength blocked and QoT blocked requests. Updating of the arrival rates for layers 2 to $\Lambda$ is done at this stage but without taking into account the QoT. The process is requested and ultimately after computing requests for the last layer, the results are returned subject to the overall blocking probability converging, otherwise, the algorithm again from layer 1.

In order to further enhance the efficacy of the proposed algorithm another version called the QoT-Aware guaranteed RWA (QGRWA) is also suggested. Its distinct feature being that portion of the traffic is blocked out of the flow per every layer, and the rate of the traffic flow that exits the flow per layer is approximated by:

$$\mathbb{A}_{s,d}^{\lambda} = A_{s,d} \rho_{s,d}^{\lambda} \left(1 - P_{s,d}^{\lambda}\right) \tag{17}$$

Ultimately, overall path blocking probability $(\bar{P}_{s,d})$ is computed from:

$$\bar{P}_{s,d} = \frac{\bar{A}_{s,d}^{\Lambda+1} + \sum_{\lambda=1}^{\Lambda} \mathbb{A}_{s,d}^{\lambda}}{\Phi_{s,d}} \tag{18}$$

The aggregate (total) blocking probability for the entire network is given by:

$$\bar{P} = \frac{\sum_{(s,d)\in Z} \Phi_{s,d} \bar{P}_{s,d}}{\sum_{(s,d)\in Z} \Phi_{s,d}} \quad (19)$$

**Algorithm II: QGRWA**

1. Set $\boldsymbol{\lambda = 1}$.
2. Use the previous algorithm to calculate the wavelength blocking probabilities $\boldsymbol{P^{\lambda}_{s,d}}$ and rates of arrival $\boldsymbol{A^{\lambda}_{s,d}}$ for every path from $\boldsymbol{\lambda}$ **to** $\boldsymbol{\Lambda}$. Set $\boldsymbol{\bar{P}'_{s,d} = \hat{P}_{s,d}}$
3. Calculate the QoT blocking probability $\boldsymbol{\rho^{\lambda}_{s,d}}$, $\boldsymbol{\forall z = (s,d) \in Z}$.
4. Re-compute the rate of arrival for the wavelength sublayer as $\boldsymbol{\bar{A}^{\lambda}_{s,d} = A^{\lambda}_{s,d}.\left(1 - \rho^{\lambda}_{s,d}\right)}$ for every path. Obtain $\boldsymbol{\bar{V}^{\lambda}_{s,d}}$ , and $\boldsymbol{\bar{Z}^{\lambda}_{s,d}} \; \forall \; \boldsymbol{(s,d) \in Z}$. Re-compute the wavelength blocking probability $\boldsymbol{\rho^{\lambda}_{s,d}}$, to get the sublayer corresponding Poisson traffic estimate for all paths.
5. Compute the traffic overflow rate $\boldsymbol{\bar{A}^{\lambda+1}_{s,d} = A^{\lambda}_{s,d}.\left(1 - \rho^{\lambda}_{s,d}\right) + \hat{A}^{\lambda}_{s,d} P^{\lambda}_{s,d}}$ for every s-d pair and revise $\boldsymbol{\bar{V}^{\lambda+1}_{s,d}}$ , and $\boldsymbol{\bar{Z}^{\lambda+1}_{s,d}}$ for all $\boldsymbol{(s,d) \in Z}$. Set $\boldsymbol{\lambda = \lambda + 1}$
6. **if** $\boldsymbol{\lambda \leq \Lambda}$, **then**
7. go to step 2
8. **else**
9. Compute the overall path blocking probabilities $\boldsymbol{\bar{P}_{s,d}}$.
10. if $\frac{|P_{s,d} - P'_{s,d}|}{P'_{s,d}} > \epsilon, \forall (s,d) \in Z$ **then**
11. return to step 1
12. **else**
13. Compute the total path blocking probabilities $\boldsymbol{\bar{P}}$.
14. **return** $\bar{P}$ and $\boldsymbol{\bar{P}_{s,d}}$ for all $\boldsymbol{(s,d) \in Z}$
15. **end if**
16. **end if**

## IV. EVALUATION

Our proposed algorithm is evaluated by means of both analytical and simulation techniques. Analytical results are obtained using the 7 node network of Figure 2.

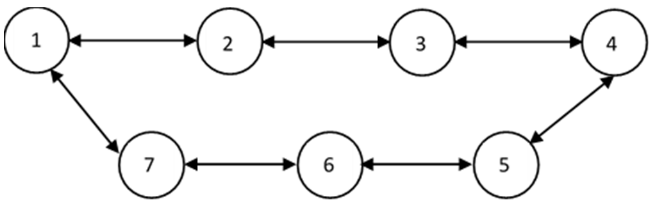

Figure 2. 7 Node network

The necessary physical parameters used for both analytical and simulation evaluations are provided in table 1. We also assume a value of , $\epsilon = 10^{-2}$, A further assumption is that crosstalk (XT) does not have a noticeable effect on the switching network and that the offered load is uniform. Because the proposed wavelength blocking model is regarded to be fairly accurate for the first few network layers, we thus confine ourselves to the use of fewer numbers of wavelengths for the subnet topologies used in the validation process. In the core evaluation, the performance of both the two versions of the of QoT aware RWA algorithm namely QRWA and QGRWA t is carried out.

Table 1. Simulation parameters

| Parameter | value |
| --- | --- |
| Wavelength spacing | 50 GHz |
| Data rate per channel | 10 Gbps |
| ASE factor | 1.5 |
| Laser source power | 0 dBm |
| Receiver responsivity | 0.95 A/W |
| BER threshold | $10^{-12}$ |
| Q-factor threshold | 7 |
| Optical bandwidth | = wavelength spacing |
| Input EDFA gain | 22 dB |
| Output EDFA gain | 16 dB |
| Centre wavelength | 1550 nm |

. Emphasis is on the key parameters such as wavelength and path blockings. WE also consider the blocking probability under various RWA assignments such as first-fit with ordering (FFwO)[3], [4] and FF WA .

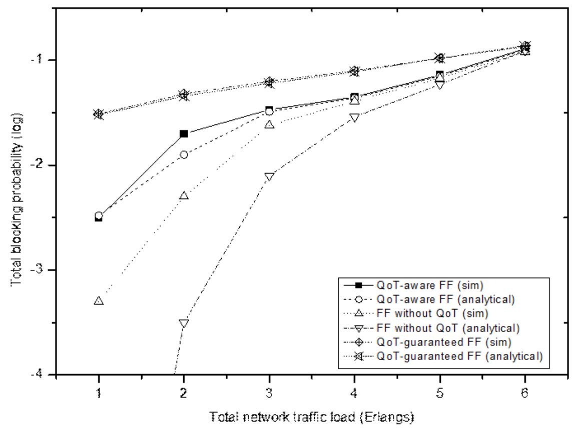


Fig. 3 .FF WA blocking probabilities computed using the analytical technique and simulations for the 7-node network

Close resemblance is generally noted between analytical and simulation results in Figure 3, for the QoT-aware FF WA and QoT-guaranteed FF WA. In this case the applied traffic intensities ranging from low to medium. In particular we further note that at low traffic intensities, the model presented in [3] becomes inaccurate, and this attributed to the inadequacies of the Fredericks and Hayward's approximation techniques when applied to estimate non-Poisson overflow traffic flows. However, the proposed algorithm appears to fairly maintain its accuracy mainly because of the accuracies in the computations of the QoT blocking. Because QoT blocking dominates in low traffic situations, the traffic flow rate will thus be still close to the actual offered traffic. Furthermore, as expected, more relatively lesser requests are blocked in the QoT-aware case than the QoT-guaranteed, thus further consolidating accuracy as well as validity of the proposed algorithm. This also infers the analytical model more less provides an accurate enhancement for both the QoT-guaranteed and QoT-aware WA. It further provides acceptable approximation to the network performance by factoring in QoT and wavelength blocking.

With regards to the FFwO WA case, we apply static ordering and at the same time assume the following ordering for five wavelengths: {1,5,2,4,3}. The simulated results of the performance of the proposed algorithm are plotted in Figure 4.

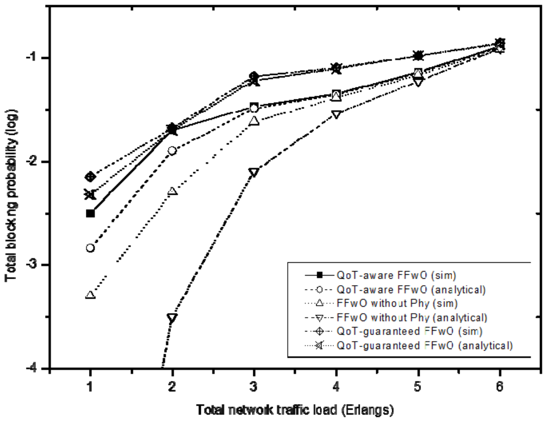


Fig. 4. FFwO WA Blocking probabilities calculated using the analytical technique and simulations for the 7-node network

In this figure, the blocking probabilities were calculated using the analytical technique and simulations for the same 7-node network. The offered traffic intensity is gradually increased from zero to about 6 Erlangs. The graphs plotted indicate an improvement in the capturing of gains attained by implementing the FFwO in comparison to the traditional FF in QoT-guaranteed cases when applying the analytical model... Furthermore, when XT is dominant, then at certain traffic loads the model shows the QoT-aware FF method outperforming the QoT-aware FFwO. This is because the QoT-aware FFwO algorithm initially prefers all channels with low XT levels. The rest of the channels with relatively high XT are reserved for forth coming requests. However, in contrast, QoT-aware FF selects channels based on the wavelength index. Because QoT-guaranteed approaches don't sift through all usable wavelengths, this affords an opportunity for the exploitation of the ordering technique. By further analysis it can be shown that if we take into consideration other additional physical impairments, the FFwO will still outperform the FF solely because of the added complexities of the scenario. Furthermore, it is observed that analytical results are quite close to simulations results for various traffic scenarios as well as mixes hence upholding the accuracy and validity of our proposed model.

## V. CONCLUSION

In this paper proposed as well as and analyzed a QoT-Aware routing and wavelength assignment algorithm (QARWA) that will minimize blocking of data bursts traversing the network. The QoT blocking takes into account the effects of various linear as well as nonlinear impairments. The proposed model can be infused with other algorithms that attempt to calculate wavelength blocking per route and per available layer. We further explored a slightly its modified version called the QoT aware guaranteed RWA (QGRWA) algorithm.

By further analysis it can be shown that if we take into consideration other additional physical impairments, the FFwO will still outperform the FF solely because of the added complexities of the scenario. Furthermore, it is observed that analytical results are quite close to simulations results for various traffic scenarios as well as mixes hence upholding the accuracy and validity of our proposed model.

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