The Impact of Number of Transceivers and Their Tunabilities on WDM Network Performance

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***Abstract*—For all-optical WDM networks, we study the impact of the number of transceivers and their tunabilities on network performance. Results have been obtained through simulations for networks with different topologies. We find that a network with a limited number of transceivers in each node and limited transceiver tunability can still perform close to one equipped with a full number of fully tunable transceivers.**

***Index Terms*—Number of transceivers, tunability, VWP, WDM, WP.**

I. INTRODUCTION

RAPID development of all-optical wavelength division multiplexing (WDM) networks is currently being anticipated [1]. By transmitting a large number of distinct wavelengths in an optical fiber, a WDM network provides features such as high data-capacity, low bit cost and protocol and bit-rate transparency. Wavelength routing WDM networks with dynamic traffic loading are being widely investigated [2]. In these studies, a common assumption made is that there are enough fully tunable transceivers equipped in each node—the number and tunability of these transceivers are typically ignored. For a practical system, the above assumption may not be suitable as both the number of transceivers and their tunabilities will be limited in realistic situations. Network designers may not be able to provide separate transceiver for all wavelengths at the nodes, as this may be very costly in a large-scale network. Moreover, considered from the viewpoint of performance improvement, full transceiver provisioning (i.e. one separate transceiver per wavelength) may even be somewhat inefficient. This is because there may be situations where a light-path passes through intermediate nodes without any add/drop processes being required.

Some initial related studies on the impacts of the number of transceivers and their tunabilities at nodes have been conducted. These are for the wavelength routing network with static traffic loading [3] and for a local optical star network [4]. Our study provides new results for these issues for a wavelength routing network with dynamic traffic loading. The objective of this study is to provide insight into the impact of the number of transceivers and their tunabilities on network performance in terms of the light-path blocking probabilities. Simulation studies for this have been done for both irregular and regular networks.

II. ASSUMPTIONS

The following assumptions are made in our study:

Traffic Assumptions: 1) Call arrivals follow independent Poisson processes at each node. 2) Call holding times have a negative exponential distribution with unity means. 3) Calls that cannot be established in the network are blocked and rejected. 4) Dijkstra's shortest path algorithm is used to find the fixed light-paths between different node pairs. 5) The maximum number of available wavelengths is the same for every link. 6) *First-fit* method of [4] is applied to assign a wavelength in the wavelength path (WP) network. (In a WP network, the same wavelength is assigned on all the links of a light-path.) Note that for a virtual wavelength path (VWP) network, where each node has full wavelength conversion capability, no distinction is made between different wavelength assignment methods. 7) Connections are considered to be duplex in nature.

Node Assumptions: 1) The transceivers in each node are placed in a common pool and any unused transceiver may be utilized. 2) A node with higher connectivity is equipped with more transceivers, e.g. a node connected to N links is equipped with TN transceivers if the network transceiver density is T transceivers per link. 3) By controlling the optical switches, the optical signal from any transmitter/input-link can be switched to any output-link/receiver. 4) The tunabilities of all transceivers (lasers) are assumed to be identical in the whole network.

III. NETWORKS WITH LIMITED NUMBER OF TRANSCEIVERS AND LIMITED TRANSCEIVER TUNABILITY

In order to establish a light-path between a pair of nodes, both spare capacities (i.e., wavelengths) on the related links and unoccupied transceivers in the source and destination nodes are required. To study the impact of the number of transceivers and their tunabilities on the network performance, simulations have been conducted for both the 14-node NSFNET backbone network (irregular) and a 15-node bi-directional ring network (regular).

A. Impact of the Number of Transceivers

We first study the impact of number of transceivers on the network performance with the assumption that each transceiver is either fully tunable or nontunable. For the fully tunable case, the transceiver is assumed to be able to tune to any wavelength

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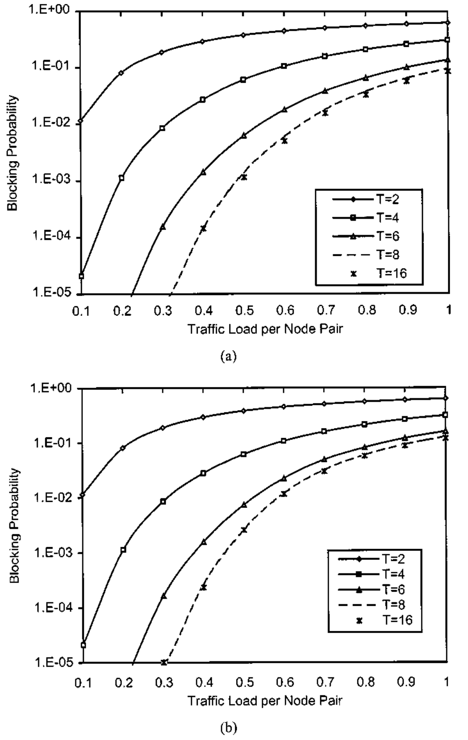

Fig. 1. Blocking probability versus traffic load under different number of transceivers per link for 16-wavelength NSFNET network [(a) VWP; (b) WP; T: Number of transceivers per link].

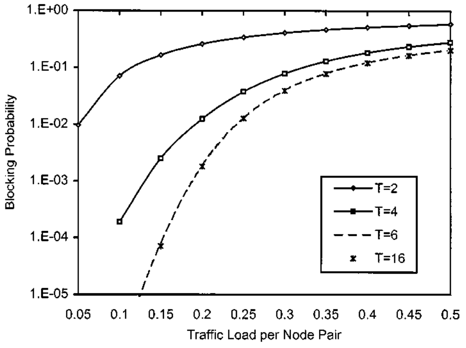

Fig. 2. Blocking probability versus traffic load under different mumber of transceivers per link for 16-wavelenth 15-node WP ring network (T: Number of transceivers per link).

on the link. Based on this assumption, the simulation results for a 16-wavelength NSFNET backbone network are shown in Fig. 1(a)–(b) for a VWP network and a WP network, respectively. As expected, with increasing number of transceivers, the blocking probabilities decrease correspondingly. Moreover, we also observe a threshold for the number of transceivers versus the network blocking probabilities for both the VWP and WP networks. This implies that when the number of transceivers in each node exceeds its threshold level, the performance improvement obtained by adding more transceivers will be marginal. For the NSFNET network, the threshold typically observed is approximately 8, i.e. half the number of wavelengths (16) on a link. In addition, the results of Fig. 1(a)–(b) may also be compared. Although the VWP network has wavelength conversion capability, the results for the two networks are very close in this example. The reason for this may be explained as follows. Both the number of wavelengths on each link and the number of transceivers in each node affect the network blocking probabilities. Initially, when there are few transceivers in each node, the blocking probability is primarily determined by the number of transceivers. Thus, the results for VWP and WP when $T = 2$, $T = 4$ and $T = 6$ are very close to each other. However, with increasing number of transceivers in each node, the effect of having a limited number of transceivers reduces and the impact of having a limited number of wavelengths on each link goes up. In this situation, the capability of wavelength conversion progressively improves the blocking probability performance of the VWP network, as compared to that of the corresponding WP case. We have also conducted a similar study for the ring topology. As an example, Fig. 2 shows the result for a 15-node bi-directional WP ring network with 16 wavelengths on each link. A similar threshold has been found for the ring network. The threshold observed for this is 6, which is somewhat smaller than the value of 8 for the earlier NSFNET example. We therefore conclude that the impact of the number of transceivers and their tunabilites on network performance will also be a function of the network topology. However, we believe that this effect is marginal, as we have also examined other topologies with similar parameters and observed that the thresholds range marginally between the values of 6 and 8. We also conclude that the above results for a network with fully tunable transceivers are also applicable for a network equipped with fixed-wavelength transmitter arrays, as such an array will also function like a fully tunable transmitter.

In a network with nontunable transceivers, each transceiver can only transmit a fixed wavelength. In such a network, some inefficiency may arise. Consider the situation where the wavelengths of the free channels on a link and the wavelengths of the unoccupied transceivers in a node are different. In this case, a light-path starting from this node and going through this link cannot be established even though there are both free transceivers and free channels available. To better utilize the network resources (i.e. transceivers and channels) and avoid situations like the above, we should keep the wavelengths of the transceivers in each node as different as possible. Given that there are M transceivers in a node and W wavelengths on each link, we will first assign $\lfloor M/W \rfloor$ transceivers for each wavelength; we then distribute the remaining $M - (W \times \lfloor M/W \rfloor)$ transceivers uniformly over the different wavelengths. Based on this proposed transceiver-wavelength-assignment approach, simulations have been done and the corresponding results for the 16-wavelength WP NSFNET network are shown in Fig. 3. Note that results for the VWP network are not relevant for this case as here wavelength conversion will prevent the above mentioned inefficiency from arising. Unlike the fully tunable case, no threshold in the number of transceivers per node is observed in Fig. 3. However, we do find that adding extra transceivers greatly improves the network performance when the initial number of transceivers in each node is small (e.g. from $T = 2$ to $T = 4$). We may also conclude that the performance of a WP network without transceiver tunability (Fig. 3) is to some extent poorer than that of the corresponding network with fully tunable transceivers [Fig. 1(b)].

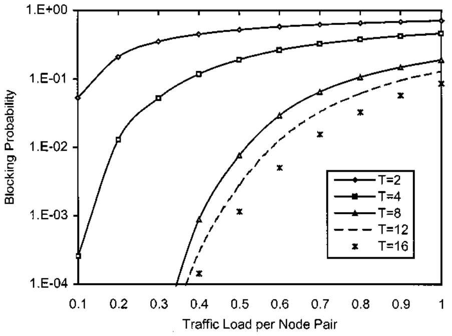

Fig. 3. Blocking probability versus traffic load under different number of transceiver per link for 16-wavelength WP NSFNET network (T: Number of transceivers per link).

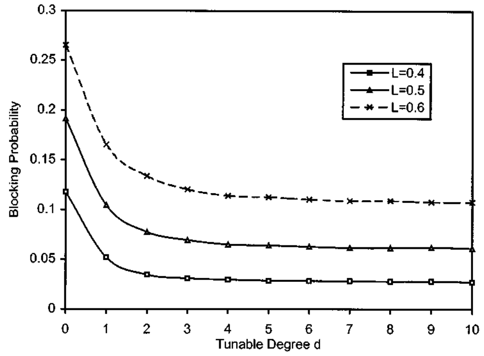

Fig. 4. Blocking probability versus transceiver tunable degree under different traffic loads for 16-wavelength WP NSFNET network with 4 transceivers per link at each node (L: load per node pair; T: Number of transceivers per link).

B. Impact of Transceiver Tunability

The tunability of a transceiver may be represented by its tunable degree, d. Accordingly, this kind of transceiver will be able to tune to $(2d + 1)$ neighboring wavelengths—these are the upper d neighboring wavelengths, the lower d neighboring wavelengths and the central wavelength. We now consider how this transceiver tunability affects network performance. We keep the wavelengths of the transceivers in each node as different as possible using the transceiver-wavelength-assignment method of Section III-A above. Based on this, simulations were done for the 16-wavelength WP NSFNET network. Fig. 4 shows the results of this as plots of network blocking probability versus tunable degree d for the case where there are four transceivers per link at each node; these results have been shown for different values of the load L per node pair. Note that, in this case, a threshold effect in the value of the tunable degree d is observed when the network's blocking probability performance is considered. This threshold is observed to be about $2 \sim 3$ for the NSFNET network. A similar threshold was also observed (Fig. 5) for a 15-node WP ring network with 16-wavelengths on each link and four transceivers per link at each node. Based on these results we conclude that for a network with limited number of transceivers, full tunability of transceivers will actually not be needed. Moreover, tunability beyond the threshold value (which is itself small, i.e. $2 \sim 3$) will not significantly improve the performance of the network. Note that since VWP networks have full wavelength conversion capabilities, transceiver tunability will not be a consideration for these networks.

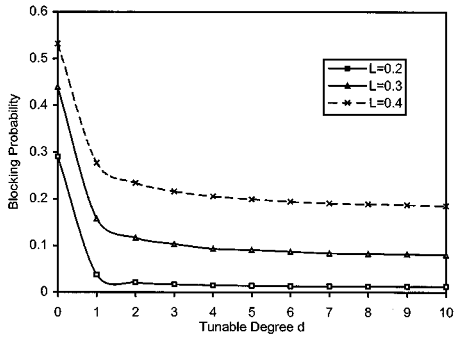

Fig. 5. Blocking probability versus transceiver tunable degree under different traffic loads for 16-wavelength 15-node WP ring network with 4 transceivers per link at each node (L: load per node pair; T: Number of transceivers per link).

IV. CONCLUSIONS

We study the impact of the number of transceivers and their tunabilities on network performance. This has been done through simulations for various kinds of networks. We find that even with a limited number of transceivers and limited transceiver tunability the performance obtained is close to that for a system with a full number of fully tunable transceivers. We therefore conclude that equipment with full number of transceivers and full transceiver tunability is not necessary in wavelength routing WDM networks.

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