Design Implications of the Add/Drop Ratio in Transparent Photonic Networks


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ABSTRACT
Using the Engset traffic model, we demonstrate conflicting effects of add/drop ratio on performance of the access networks and that of the core networks. This will have important design implications to future transparent photonic networks.

Keywords: Fiber optics and optical communications, circuit-switched networks, add/drop ratio, access network, Engset model, blocking probability.

1. INTRODUCTION
In many situations, different parts of the networks are managed and operated by different entities where each entity is responsible for minimizing the costs and meeting the Quality of Service (QoS) requirements in its part. One consequence of this is that decisions made by one entity in one part of the network may affect QoS in another part and such effects require understandings and careful considerations. To gain insight into such effects, we consider the connection blocking probability as the QoS of interest. For simplicity, we consider the optical network to be divided into two parts: the access and the core. Given the importance of the add/drop ratio as a key cost factor of an Optical Cross-Connect (OXC) [1], in this paper, we focus on the behavior and relationship of the blocking probabilities in the different parts of the networks and the end-to-end blocking probability.

We define the add/drop ratio at an OXC as the ratio of the total number of add/drop ports to the total number of bypassing wavelength channels at this OXC. A larger add/drop ratio implies a larger number of add/drop ports. The latter is equal to the number of transmitters/receivers (transponders) in the node, which incurs significant cost. Therefore, it may not be cost effective to allow all the wavelengths to be added/dropped at an OXC node. On the other hand, when the number of add/drop ports is smaller than the total number of wavelength channels at an OXC, it may not be possible to establish a lightpath between two nodes, even if there are free wavelengths between them.

Previously published results for the effect of add/drop ratio on the network blocking performance [2]-[5] considered only the end-to-end blocking probability over one network. In [2]-[4], it was assumed that the connection request arrivals follow a Poisson process and the connection holding times are exponentially distributed. The study in [5] also assumed the Poisson arrival process and the exponentially distributed holding times, but considered two additional arrival processes where the inter-arrival times are constant and lognormal. The NSFNet topology was used in [2]-[4], and while [2,3] used also the ARPA2 network topology, in [4], a ring topology was used in addition. The study in [5] considered the topologies of the German backbone network and the Italy backbone network. Similar results are observed under these different topologies and modeling assumptions. When the add/drop ratio is small, the blocking probability is reduced significantly as the ratio increases. However, once the add/drop ratio reaches a certain threshold value, increasing it further does not reduce the blocking probability significantly.

Here we also assume exponentially distributed connection holding times, and the traffic generated by each individual source is based on on-off model with exponential on and off times. Then, subject to availability of add-drop ports and core network wavelength resources, these traffic streams are then transported by the access and the core networks. This on-off modelling enables us to accurately study and explain the effects and relationships between the various blocking probabilities, from which we reach an important conclusion that optimizing exclusively the core network may have adverse effects on the end-to-end blocking probability.

2. NETWORK MODEL
We consider a circuit-switched core network described by a graph $G = (N, E)$ where $N$ is a set of $n$ core (OXC) nodes and $E$ is a set of $e$ arcs that connect the nodes. Each arc corresponds to a trunk carrying $C$ wavelengths. The $n$
nodes are designated \{1, 2, 3\ldots, n\}, each of which has circuit switching capabilities. For each node \(i \in N\), the degree is \(d_i\), and the add/drop ratio is \(\delta\), so the total number of add/drop wavelengths of node \(i\) is both \(d_iC\delta\).

Let \(\psi\) be a set of directional Origin-Destination (OD) pairs. Every directional OD pair \(m \in \psi\), is defined by its end nodes. Thus, \(m = \{i, j\} \in \psi\) represents the directional OD pair \(i\) to \(j\).

We assume no internal blocking in the access network except blocking that occurs at the interface with the core network. Therefore, we model the access network as a multiplexer of multiple sources connected to each node in the core network. This simplified model of the access network is illustrated in Fig. 1 (a). For each node \(i \in N\), the input traffic is modeled by the finite source Engset traffic model [6]. Accordingly, for each node \(i \in N\), the number of sources is \(M_i\), and the time until an idle source attempts to make a connection is exponentially distributed with mean \(1/\lambda\). The holding times of connections are assumed to be exponentially distributed with mean \(1/\mu\). For each node \(i \in N\), letting \(K_i\) be the average number of active sources observed by a Poisson inspector, the total offered load is obtained by

\[
A = (\lambda/\mu) \sum_{i \in N} K_i.
\]

If the number of connections that are generated is \(q_{\text{total}}\) and the number of connections that are blocked is \(b_{\text{total}}\), then we define the ratio of the connections that are blocked to those that are generated as the total blocking probability \(B_{\text{total}} = b_{\text{total}}/q_{\text{total}}\). A connection can be blocked because there is no available add wavelength at the source node or drop wavelength at the destination node \((b_{\text{access}})\), or because there is no available wavelength to establish a lightpath in the core network \((b_{\text{core}})\). Therefore, \(b_{\text{total}} = b_{\text{access}} + b_{\text{core}}\). We define the blocking probability due to the former as the access blocking probability \(B_{\text{access}} = b_{\text{core}}/q_{\text{total}}\) and due to the latter one as the core network blocking probability \(B_{\text{core}} = b_{\text{core}}/(q_{\text{total}} - b_{\text{access}})\), then the access blocking probability can be obtained by

\[
B_{\text{access}} = (B_{\text{total}} - B_{\text{core}})/(1 - B_{\text{core}}).
\]

Also, the core network offered load is

\[
a = A(1 - B_{\text{access}}).
\]

In this paper, the blocking probabilities \(B_{\text{total}}\) and \(B_{\text{core}}\) are obtained by a discrete event simulation based on the Engset traffic model.

3. SIMULATION RESULTS

As discussed above, Fig. 1 (a) illustrates our access network model. Fig. 1(b) represents our core network topology, which is an NSFNet with 14 nodes and 42 unidirectional trunks, where each link represents two trunks in opposite directions and all the nodes do not have wavelength conversion capability. We choose all possible OD pairs with shortest path routing, where a tie is broken randomly. The number of wavelengths in each link is 20 and the wavelengths are assigned randomly. We obtain by discrete event simulation the core network blocking probability and the total blocking probability for various cases.

\[\text{Fig. 1 (a) An access network; (b) A core network: NSFNet topology with 14 transparent photonic nodes and 42-unidirectional links.}\]

Fig. 2 (a) illustrates the effect of add/drop ratio on core network blocking probability \((B_{\text{core}})\), as a function of the core network offered load. Here, the number of sources to each node is equal to its number of add wavelengths. This implies that a source can always find a free add wavelength but finding a drop wavelength at the destination core node is not necessarily guaranteed. We consider add/drop ratios of 25% and 50% for each core node. Clearly, the number of sources in the case of 25% add/drop ratio is half the number of sources in the case of 50% add/drop ratio. We observe that when the add/drop ratio is 25%, the core network blocking probability is much lower than that when...
the add/drop ratio is 50%. This trend and behavior is consistent with the classical Engset model, in which smaller number of sources leads to lower blocking probability while keeping the total offered load constant [7].

In Fig. 2 (b), we present results for the total blocking probabilities when the add/drop ratio of each node in the core network is 50% and 25%, respectively. As discussed, since the number of sources to each node is equal to its number of add wavelengths, the blocked connections are either blocked in the core network, which contributes to increase core network blocking probability ($B_{\text{core}}$), or blocked because there is no available drop wavelengths, which contributes to $B_{\text{access}}$ and $B_{\text{total}}$. We observe in Fig. 2 (b) that when the add/drop ratio is 25%, the total blocking probability ($B_{\text{total}}$) is slightly higher than that when the add/drop ratio is 50%. The reason is that when the add/drop ratio is 25%, the number of drop wavelengths is half of when it is 50%, which leads to larger number of connections blocked at the destination core node because of unavailability of drop wavelengths. Therefore, although the core network blocking probability of 25% add/drop ratio is lower than that when the add/drop ratio is 50%, the total blocking probability is still higher. This implies that lower add/drop ratio can result in lower cost and lower blocking probability in the core network, but may cause unacceptable blocking probability at the access and end-to-end.

![Fig. 2 Core network blocking probabilities and total blocking probabilities in NSFNet. The number of sources to each node is equal to its number of add wavelengths.](image)

Fig. 3 (a) and (b) show the core network blocking probabilities and total blocking probabilities when we use the First Fit wavelength assignment scheme. We observe similar behaviors and trends with Fig. 2, which demonstrates that the wavelength assignment scheme may not affect significantly these behaviors and trends.

![Fig. 3 Core network blocking probabilities and total blocking probabilities in NSFNet. The number of sources to each node is equal to its number of add wavelengths. Wavelength assignment scheme is First Fit.](image)

Fig. 4 (a) and (b) show the core network blocking probability and the total blocking probability when we fix the number of sources to each node in the core network to 40. This implies that the number of sources is always larger than or equal to the number of add wavelengths for all the nodes in the core network. Therefore, when the add/drop ratio is reduced from 50% to 25%, the access blocking probability ($B_{\text{access}}$) and the total blocking probability ($B_{\text{total}}$) will increase. We observe in Fig. 4 (a) that the core network blocking probability when the add/drop ratio is 25% is still lower than that when the add/drop ratio is 50%. A closer look reveals that the core network blocking probability
curves in Figs. 2 (a) and 4 (a) are close to each other, for the cases of both 50% and 25% add/drop ratio. This implies that the performance of the core network stays almost the same with a larger number of sources due to the “bottleneck” effect of limited add/drop ports.

In Fig. 4 (b), we observe that compared with Fig. 2 (b), the total blocking probability is slightly higher when the add/drop ratio is 25%. Unlike the case in Fig. 2, where connections can only be blocked in the core network or at the destination core node, in the case of Fig. 4, connections can also be blocked because there is no available add wavelength at the origin core node. This leads to a higher blocking probability at the origin core node and therefore a higher total blocking probability. Therefore, in this case, reducing add/drop ratio may not be optimal because the improvement in the core network blocking probability is marginal while the deterioration of the end-to-end performance is bigger than in the case of Fig. 2.

4. CONCLUSION

We have introduced a new modeling approach to study the effect of add/drop ratio on blocking probabilities in the core network and end-to-end using an Engset traffic model. We have compared core network blocking probability when the add/drop ratio is 25% and 50% and demonstrated that the behavior of the core network blocking probability is consistent with that of the classical Engset system when the number of sources is equal to the number of add wavelengths for each core node. When the number of sources of each core node is fixed at 40 (which is higher than or equal to the number of add wavelengths of each node in the core network), we have demonstrated that 25% add/drop ratio does not improve core network blocking probability significantly, but it leads to a higher total blocking probability (end-to-end). This demonstrates that optimizing one’s network, e.g. core (or metropolitan), can lead to unacceptable end-to-end blocking probability and therefore, core (or metropolitan) network operators should always consider end-to-end QoS perceived by the end users.

REFERENCES