

Quasi-Dynamic Network Design Considering Different Service Holding/Contract Terms

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Abstract: We present a quasi-dynamic multi-layered photonic network design algorithm that achieves cost-effective incremental network expansion to accommodate future broadband services. It is demonstrated that service holding/contract times are key parameters in developing cost-effective networks.

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1. Introduction

Internet traffic has been exploding throughout the world, and this is being spurred by the rapid penetration of broadband access such as ADSL and FTTH. In addition to the increase in the amount of traffic, new broadband services will be developed such as streaming video service, lambda-leased line service, optical VPN service, and broadband connections for e-science and so on [1]. Their service contract terms or holding times will range from hours/days to months/years, quite different from existing network services. Therefore, novel network designs must be developed so as to handle these new services. Conventional studies on designing photonic networks for existing and envisaged applications fall into two categories; static network design [2], and dynamic network design [3] that supposes future switched (optical) services. The target of the static design, for a given fixed traffic pattern, is typically to minimize the network (hardware) cost needed to accommodate the given traffic. In dynamic design, the amount of traffic is assumed to change on the order of second or minutes and its objective is to minimize the blocking probability against service demand. Few works have been done, however, on network designs that consider traffic expansion and future service uncertainty, for example, handling the traffic of new services with different holding times or contract terms.

In this paper, we develop quasi-dynamic multi-layered photonic network design algorithms that can cost-effectively accommodate such incremental traffic growth. For traffic with uniform contract terms (or holding times), we first analyze the variation of network cost in terms of incremental expansion frequencies. The relation between the cost variations and the contract term is investigated, and we find that the parameter “Age” is one key to defining network cost changes. We then discuss the network cost variations with further generalization to traffic with non-uniform contract terms.

2. Quasi-dynamic network design

Hereafter we assume a multi-layered photonic network to create broadband networks cost effectively. It consists of hierarchical paths consisting of higher order path, optical paths (OPs), and lower order paths, electrical paths (EPs) such as LSPs and digital paths (Fig. 1). EPs are accommodated within OPs and are classified into two major groups: (1) those accommodated within an OP that connects directly the end nodes of the EPs, and (2) those accommodated within concatenated multiple OPs. The former does not require expensive hardware such as O-E-O converters or electrical routing at intermediate nodes. On the other hand, concatenated OPs generally achieve higher OP utilization and may reduce total hardware cost in particular when the total capacity of the EPs between each node pair is not enough to fulfill an OP. Both of these different OP configurations are utilized in the network to minimize total cost.

We expand a recently proposed quasi-dynamic network design algorithm [4] that can periodically (every quarter or half year) expand the network so as to accommodate incremental traffic growth (Fig. 2). Upon network expansion, routes for existing network traffic (or routes of the EPs/OPs) are left unchanged in order to minimize service disruption and any impairment or processing complexity stemming from path rerouting or from human-oriented errors. This is particularly important for mission-critical services. In this paper, we employ the following two algorithms for incremental design, Min-hop algorithm and Max-pack algorithm.

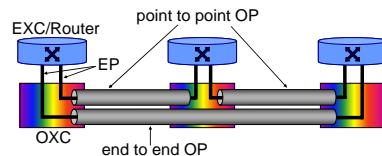


Fig. 1 Hierarchical path

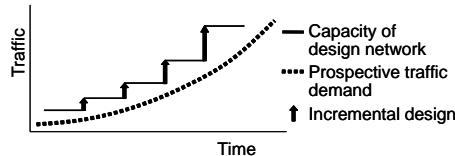


Fig. 2 Traffic growth and incremental design

Min-hop algorithm All the EPs are accommodated, one by one, within direct OPs that connect the end nodes of the EPs with the fewest hops possible. Even if there is only one EP demand between a pair of node, this algorithm tries to set up a new OP. The usage of OPs, therefore, tends to be lower in the early network design stages where traffic volume is small. In subsequent steps, however, the spare capacity is used more effectively.

Max-pack algorithm This algorithm tries to minimize the total network cost at each design step by making the best use of the spare capacities of the existing OP network. The advantage of the Max-pack algorithm is that OP usage can be maximized. The disadvantage is that the average EP length becomes longer.

In general, the combined design method will attain higher performance, however, the improvement achieved depends on the actual traffic characteristics. Details and benefits are demonstrated in Sec. 3.2.

3. Results and Evaluations

3.1 Estimation of long term network cost changes with parameter Age

The incremental traffic growth can be characterized with two parameters, a : new service contract rate and b : service cancellation rate; the traffic growth rate is given as $a - b$. For different values of a and b such that $a-b=25\%$, we designed a network using the two algorithms given in Sec. 2. The network tested was a 7x7 polygrid. For details of other parameters, please refer to [4]. We assume the same conditions as in [4] in performing our numerical experiments. The costs of the obtained networks are normalized by those calculated using a static zero-based design with the Max-pack algorithm that requires complete traffic reconfiguration but provides the ideal cost. Here we introduce the *Age* parameter [4], which represents the average life of the existing traffic in the network. *Age* is expressed as

$$Age := \frac{1-b}{a} \left\{ 1 - \left(\frac{1-b}{1-b+a} \right)^n \right\} \xrightarrow{n \rightarrow \infty} \frac{1-b}{a} =: Age^*.$$

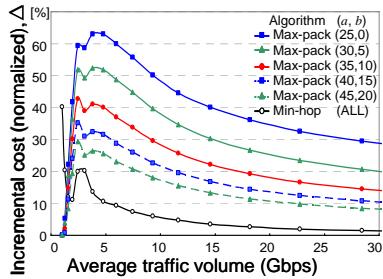


Fig. 3 Network cost with different contract/cancellation rates

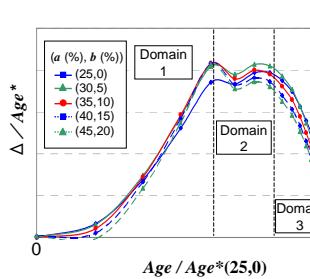


Fig. 4 Cost characterized with Age parameter

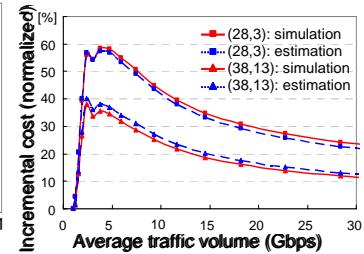


Fig. 5 Estimation of network cost using Age

Figure 3 plots incremental cost versus average traffic volume with the parameter of net traffic growth, $a - b$. Each data point represents normalized incremental cost after incremental design. The result in Fig.3 was originally given in [4], and we provide further analysis here. As for the Min-hop algorithm, the result only depends on the net traffic growth rate $a - b$, thus we can easily estimate the cost change for the Min-hop algorithm for different combinations of (a, b) . On the other hand, since the cost behavior of the Max-pack algorithm strongly depends on parameters a and b , estimating the network cost variation is not straightforward. It was found, however, that utilizing *Age* allows the estimation to be simplified further.

Figure 4 is a re-plot of Fig. 3 for the Max-pack algorithm. The horizontal axis corresponds to the frequency of network re-design relative to that of $(25, 0)$. The normalized costs (Δ/Age^*) for the Max-pack algorithm are found to be almost the same regardless of the (a, b) value. This means that we can easily estimate the cost variations for the Max-pack algorithm from the result of one (a, b) by simply calculating *Age* without performing intensive simulations using various combinations of (a, b) . Indeed, it is proved in Fig. 5 that the network cost changes for $(28, 3)$ and $(38, 13)$ are well estimated using the results for $(25, 0)$. The *Age* parameter, thus, enables us to effectively estimate the network cost change for quasi-dynamic network design.

3.2 Network design for multiple types of traffic

In the previous section, we assumed uniform traffic. However, this assumption is not always valid for the future broadband service environment. In this section we generalize the assumption to a case where two different traffic types exist. One, traffic T_L , has long service contract terms, and the other, T_S , has short service contract terms. These types are accommodated by different EPs, and the EPs may be accommodated within same OP(s). In this situation we propose an extended method, Combined algorithm, which applies the Min-hop algorithm for T_S and the Max-pack algorithm for T_L .

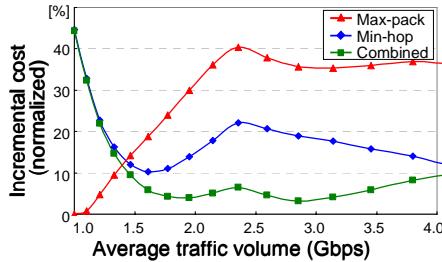


Fig. 6 Network cost for two different traffics
((a, b)= T_L:(10, 0), T_S:(30, 20))

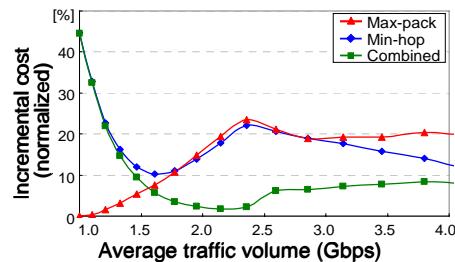


Fig. 7 Network cost for two different traffics
((a, b)= T_L:(10, 0), T_S:(50, 40))

Figures 6 and 7 show the network costs for combinations of the two different traffic types where the Max-pack and Min-hop, Combined algorithms are compared. Both initial values of T_L and T_S are set at 0.5 Gbps (so the total amount of initial traffic is 1.0 Gbps), and service traffic parameter (a, b) of T_L is set to (10, 0), while that of T_S is set at (30, 20), (50, 40) in Fig. 6 and 7, respectively. In Fig 6, the costs obtained by Combined algorithm and Min-hop algorithm show the same value at the initial design step. This is because the initial traffic is not large enough to fulfill an OP (2.5Gbps). Initially, after accommodating T_S within direct OPs, T_L is accommodated within the same direct OPs in the same way as the Min-hop algorithm. The same procedure is then applied in subsequent expansions. The Combined algorithm achieves smaller cost than the Min-hop algorithm after a certain number of incremental design steps. In the 9th design step, the gap between the two algorithms is about 10%. Compared to the Max-pack algorithm, the maximum gap is about 35 %. Figure 7 shows the cost variation when different contract terms are assigned to T_S . Around the 8th design step, the normalized cost becomes almost 1, ideal design, when the combined algorithm is used. The result demonstrates that the contract term of T_S has a substantial impact on the cost variation.

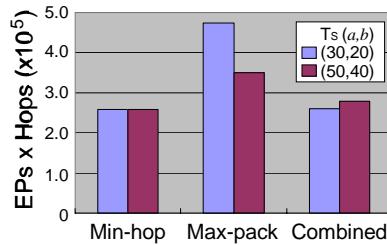


Fig. 8 Total number of EPs x Hops (10th design step)

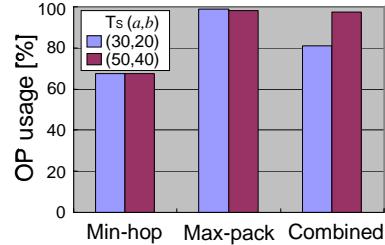


Fig. 9 Average usage of OPs (10th design step)

Total hop counts of all EPs at the 10th design step and average OP usage are given in Fig. 8 and 9, respectively. We can verify that the Min-hop algorithm provides shorter EPs at the expense of OP utilization. On the other hand, the Max-pack algorithm provides much higher OP usage, however, it increases EP length. As for the Combined algorithm, the total number of EPs x Hops approaches that of the Min-hop algorithm while the OP usage is much higher than that of the Min-hop algorithm.

4. Conclusion

In this paper, we proposed a quasi-dynamic network design algorithm that achieves cost-effective expansion of multi-layered photonic networks. The Age parameter, derived from some service traffic parameters, was shown to give one effective way of estimating the cost variations when a single service dominates the traffic volume. When two (or more) service types must be considered, our Combined algorithm, which considers service traffic parameters, realizes more cost effective networks by making the best of the Min-hop and Max-pack algorithms. It should be emphasized that in quasi-dynamic multi-layered photonic network design, service contract terms or holding times is a very important parameter.

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