

# Cost Study of Dynamically Transparent Networks

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**Abstract:** The network equipment cost benefit of dynamic wavelength routing is compared with point-to-point IP networks and static wavelength routing in a simple ring topology with variable network traffic loading.

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## 1. Introduction

Internet routing cost, power consumption, and footprint per gigabit of data has been identified as a key bottleneck to the development of high-bandwidth services. Techniques for bypassing the IP layer have been proposed in order to redirect part of the traffic load currently handled by the IP router towards lower layers. In [1] it was demonstrated, for example, that bypassing IP traffic using SONET switches could bring significant cost savings on network expenditure. The introduction of transparent or photonic fiber switches and wavelength selective switches in recent years, has promoted the idea of bypassing part of the IP traffic at the optical level and led to the rapid adoption of reconfigurable optical add drop multiplexing (ROADM) technologies in commercial systems. The economic effectiveness of optical bypass has been demonstrated in [2, 3], showing a cost benefit that increases with the traffic demand. Transparent switching also reduces overall power consumption and system footprint. In addition to the benefits of optical bypass, ROADM-based networks promise to enable in-service wavelength reconfiguration.

Although many technological hurdles must be resolved in order to implement these capabilities in the physical layer, such dynamic transparency would enable optical flow switching, in analogy with IP flow switching. Recent cost studies have shown that optical flow switching is an effective approach to reducing router loads [8]. Additional savings, however, may be realized due to the efficient use of reconfiguration to reduce over-provisioning. We present a first step toward quantifying this important aspect of optical flow switching by taking into consideration the variation of traffic demand in the network.

In the absence of reconfiguration capability the network needs to be provisioned with additional equipment to ensure that variations in the traffic demand do not degrade the quality of service below service level agreements (SLAs). The more variable the traffic demand, the greater the needs for over-provisioning, leading to higher equipment cost (in terms of number of lightpaths, line cards, transceivers, etc.). A key advantage of a reconfigurable optical network is that the lightpaths can be modified to adapt to the traffic demand; therefore the network equipment can be used to provision bandwidth where it is required without the need for abundant over-provisioning. This represents a novel approach to traffic engineering: instead of "moving traffic where the bandwidth is available", following the legacy approach to IP/MPLS traffic engineering, optical re-configurability allows one to create bandwidth where it is required.

## 2. Network model

Three reference architectures are examined in this analysis: point-to-point IP routing, static wavelength provisioning, and dynamic optical provisioning. Point-to-point routing represents the opaque legacy IP-over-WDM architecture, in which data packets are routed at the IP layer at every node. The advantage of this model is the capability of routing traffic at the packet granularity; whereas, the main disadvantage is that it requires a high number of expensive IP line cards. The static wavelength model is based on the provisioning of dedicated optical links that allow optical bypass of the IP layer for end-to-end traffic demands that are large enough to justify the use of dedicated lightpaths. Lightpath provisioning in this case is implemented assuming global knowledge of the traffic demand. Since the lightpaths are statically provisioned, optical links and transceivers cannot be re-directed to create different paths when the traffic demand varies. The dynamic optical provisioning model, finally, is based on the optical IP switching (OIS) architecture introduced in [4], in which lightpaths are dynamically and automatically adapted to the changing traffic demand. Instead of considering end-to-end demands, the OIS nodes analyze traffic locally, provisioning optical paths in a distributed fashion.

The purpose of this analysis is to examine the network equipment cost increase for the three reference architectures due to the network over-provisioning necessary to satisfy variable traffic conditions. Other benefits of dynamic wavelength routing, such as physical layer survivability, are not considered here. A physical ring topology of 11 add-drop nodes is used both due to its inherent simplicity and to avoid topology and wavelength routing algorithm dependent results (lightpaths connect nodes either clockwise or counter-clockwise). Wavelength blocking

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is also considered, although the capacity of WDM links is automatically upgraded when more lightpaths are needed, so that links are never exhausted in this baseline study.

The analysis starts by considering an arbitrary traffic demand and calculating the solution (in terms of network equipment used) for the three network models described above. We have then modified the demand matrix by randomly scrambling its elements, with the constraint that the amount of traffic added and dropped at each node remains constant (an approach known as the 'hose model' [5]). In our case, for simplicity, we also consider that all the nodes add and drop the same amount of traffic. After modifying the demand matrix, a new solution is calculated for each of the three models.

The amount of over-provisioning required (in terms of router cards, optical transceivers, link capacity and optical regenerators) in order to satisfy the different traffic demands is calculated as follows. For the point-to-point and OIS models we consider the union of the sets of equipment needed at each node for each traffic pattern considered. The flexibility at the routing and optical layers in fact allows us to consider over-provisioning at the level of the routing or switching port (because the same ports can be re-used over different routing and optical paths). For the static wavelength provisioning, optical ports cannot be reconfigured to re-provision different paths and the over-provisioning is applied at the level of the end-to-end path; in this model we have therefore considered the union of the end-to-end paths, rather than the union of the ports on each node.

The values used in the cost model (illustrated in Table 1) for the routing equipment was taken from [8], those related to the optical equipment from [7], while the cost of the 9-port WSS and OXC switching matrix was obtained directly from equipment vendors. For the 20-port WSS, we have considered a 20% cost increase over the 9-port, and a similar increase for the 40-port model. Although these devices are not yet commercially available, we have considered that the future development in WSS technology will maintain similar relative pricing as today.

In the static and dynamic wavelength models, dedicated optical paths are only considered for demands equal to the channel rate (10 Gbps). The demand matrix is constructed such that most of the traffic is exchanged between 3 nodes. The length of each link is 800 km; however the transparent architectures make use of a longer reach transceiver (2500 km), and signal regenerators are used for dynamic transparent paths over 2500 km.

Table 1. Base cost structure.

Device	Cost (in units)	Device	Cost (in units)
IP card (10G, core router)	120	WSS 9-port 80 wavelengths	10
IP core router (per 160G traffic)	50	WSS 20-port 80 wavelengths	12
Short reach transceiver	1	WSS 40-port 80 wavelengths	15
Long reach transceiver	2	OXC port	2
Signal regenerator	3	link cost (short reach)	50
WDM multiplexer 40 wavelengths	4	link cost (long reach)	70
WDM multiplexer 80 wavelengths	7		

### 3. Results

The results of the cost analysis are reported in Figure 1, expressing the network cost as a function of the variability of the traffic pattern for 100 Gbps (Fig. 1a) and 400 Gbps (Fig. 1b) of added and dropped traffic at each node. The values reported in the y axis show the network costs (expressed in percentage) relative to the cost of the IP-over-WDM architecture under static demand. The absolute values for the IP-over-WDM model are 52495 and 204225 units, respectively for the 100Gbps and 400Gbps cases. The variation in the traffic pattern is expressed as the number of different traffic demand configurations that the network can carry (in the x axis); the higher the number of different demands configurations, the higher the amount of over-provisioning needed, the more expensive the overall network cost.

The point-to-point model presents the highest cost compared with the transparent optical architectures. This result is the well-known benefit of optical bypass [2, 3]. The cost for the static wavelength architecture is the most dependent on the traffic pattern, because of its inability to reconfigure optical paths. The dynamic optical architecture, being highly reconfigurable, does not show a significant cost increase for traffic variations.

Another aspect we notice comparing the plots in Figure 1 is that the difference between the static and dynamic wavelength provisioning models is more pronounced in the 100 Gbps add-drop case compared with the 400 Gbps. This is a consequence of the fact that the optical IP switching architecture for dynamic provisioning uses a distributed approach to lightpath creation based on local traffic observation, which allows better traffic aggregation capability compared to end-to-end provisioning. When traffic increases, however, this advantage disappears, and, for static traffic demand, we see that the static-wavelength model is slightly more cost-effective than OIS. With higher traffic in fact, global knowledge of the demand matrix (assumed for the static wavelength provisioning model) allows for better exploitation of the network equipment. Moreover the static model deploys less expensive non-reconfigurable equipment, which constitutes an advantage when the demand is considered static. As we assume traffic variation however, the cost of over-provisioning sharply increases in the static wavelength model.

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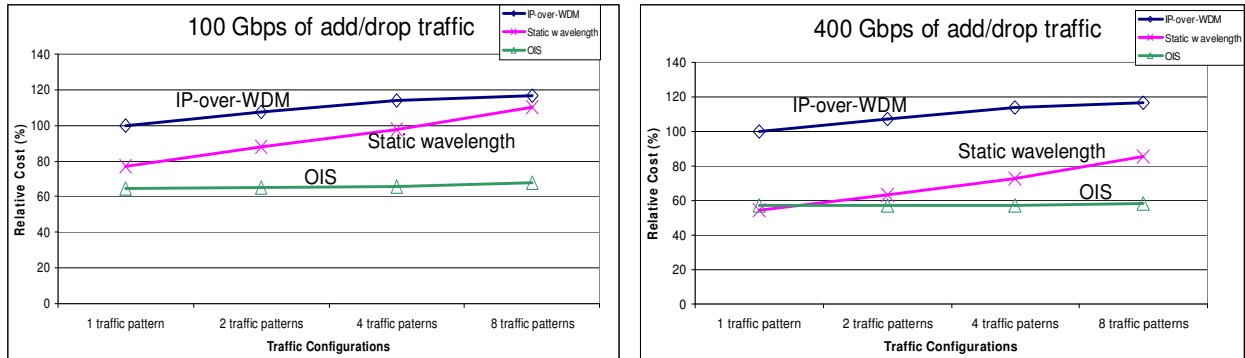


Figure 1. Equipment cost (relative to the IP-over-WDM architecture under static demand) as the number of different traffic patterns increases, for 100Gbps (a) and 400 Gbps (b) of add/drop traffic per pattern.

Simulations were also run considering higher levels of traffic and different traffic patterns (generated by a uniformly distributed random variable). The results obtained showed that larger traffic leads to the same behavior illustrated for the 400Gbps case, and the different traffic demand does not influence considerably the results. Clearly many factors such as the network topology and structured traffic patterns are expected to have a strong impact on the relative cost benefit, both positive and negative, and are beyond the scope of this baseline study.

In Figure 2, the network cost sensitivity to the costs of the IP cards and the WSS's are shown for the 400 Gbps case. In Fig. 2a, the router costs are decreased by half and the WSS equipment is doubled. In Fig. 2b, the cost of IP line cards are further decreased by half and that of WSS doubled again. The overall cost decreases for all three models. Although the cost variation depicted is a highly unfavourable scenario for optical dynamic reconfiguration, the dynamic provisioning architecture remains the most cost-effective under variable traffic demand.

By analyzing the number of IP ports used by the different models, we noticed that in general, the cost curve reflects very closely the trend of the IP port usage. The sensitivity analysis helped us understand that it is not the high cost of the IP cards, but its high number that mostly delineates the cost difference between the three models.

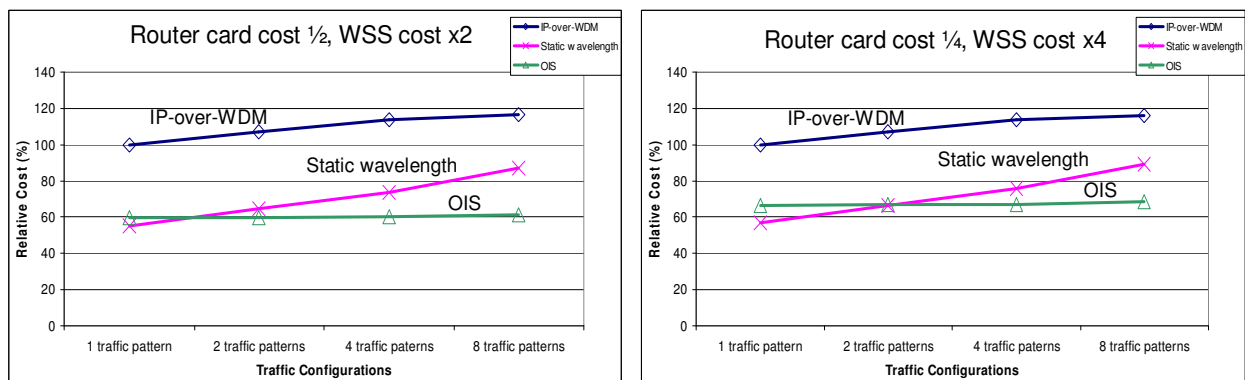


Figure 2. Sensitivity analysis corresponding to Fig. 1b in which the cost of all router cards are reduced and the cost of all WSS's are increased by a factor of 2 (a) and 4 (b).

This initial exploration has shown the potential for cost savings in spatially reconfigurable networks. The cost sensitivity analysis indicates that benefits persist even considering equipment costs that are substantially unfavourable to transparent switching.

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