Comparison of Static and Dynamic WDM Networks in Terms of Energy Consumption

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Abstract: The benefit of migrating from static to dynamic WDM networks is evaluated, for the first time, in terms of energy consumption. Results show a clear benefit of dynamic operation for traffic loads < 0.5.

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1. Introduction

Currently, telecommunication networks have been reported to account for 1-10% of the world's energy consumption [1]. Given the ever increasing demand for Internet traffic, this figure is expected to keep growing [2]. As a result, taking into account energy consumption is key in the design of next-generation networks [3].

Core networks are at this moment migrating from static to dynamic WDM networks. Dynamic networks allocate network resources only when and where necessary, such that more users may use the same network with reduced resources. This effect is clearly observed in networks with wavelength conversion [4]. In networks without wavelength conversion, the benefits of dynamic operation appear only at low traffic loads (<0.3-0.4) [4].

In this paper, we evaluate the potential benefit of migrating from static to dynamic WDM networks in terms of energy consumption. By activating the network equipment only when required and therefore reducing the number of active wavelengths, dynamic operation could lead to a lower energy consumption compared to the static case. The energy saving would come from devices with reduced port-count (due to the lower wavelength requirements) and because of the fact that network equipment could be switched to a low-energy consumption mode (or: stand-by mode) when not used. The results in this paper show that energy consumption of dynamic networks employing wavelength conversion is lower than that of the static approach for traffic loads up to 0.5. To the best of the author's knowledge it is the first time that such comparison is made.

2. Network and traffic models

Let us assume a mono-fiber network with N nodes, L uni-directional links (adjacent nodes are connected by two unidirectional links, one for each direction), and W_l that denotes the number of wavelengths required by link l.

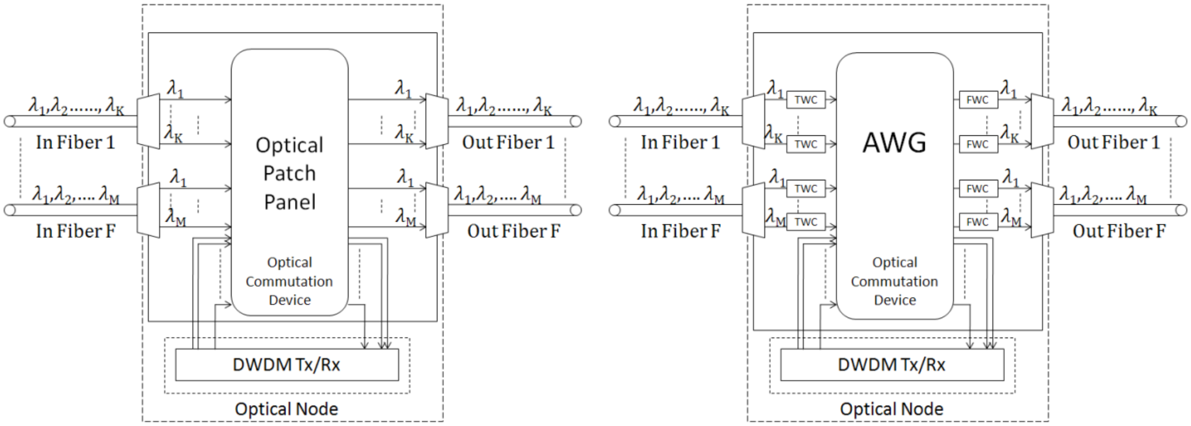
In the static case, one lightpath must be established for each pair of nodes communicating in the network. In the dynamic case, lightpaths are established (and released) on demand. Accordingly, an ON-OFF process is assumed to create and release the lightpaths between source and destination nodes. The mean duration of ON (OFF) periods is denoted by t_{ON} (t_{OFF}). Thus, the traffic load offered to the network by each connection is given by $\rho = t_{ON}/(\ t_{ON}+\ t_{OFF})$. Wavelength conversion is assumed in the dynamic case, since the best benefits of dynamic operation is shown in such kind of networks with respect to the static counterpart

3. Energy consumption model

The node architecture is shown in Fig. 1.a and b for the static and dynamic scenarios [5,6], respectively. Both node architectures can deal with a different number of wavelengths per fiber. Each node has a pool of transmitters/receivers for add/drop traffic (transmission/reception transponders). In the static node, the passing traffic is demultiplexed and directed to the destination output fiber (along with added traffic) or dropped by means of a passive optical patch panel. In the dynamic node, passing traffic is demultiplexed, converted to a different wavelength if necessary (by means of a tunable wavelength converter, TWC) and then directed to the destination output fiber (along with the added traffic) or dropped by means of a passive arrayed waveguide grating (AWG). At the output of the AWG, the signal is converted by means of a fixed wavelength converter (FWC). Transponders are used as optoelectronic wavelength converters. Assuming that the power consumption of transmission/reception transponders and tunable or fixed wavelength converters is the same (as in [1]), the power consumption of node i, E_{n_i}, is given by:

$$E_{n\_i} = \quad (T_i + R_i + WC_i) \cdot E_t \cdot \Delta + E_{OC} \tag{1}$$

where T_i, R_i and WC_i correspond to the number of transmitters, receivers and wavelength converters in the node i; E_t is the power consumption of transponders; E_{OC} is the power consumption of the optical commutation device (equal to 0 for both types of network nodes considered in this paper, since the switching fabric is passive) and Δ is the fraction of time that devices are in the active state (equal to 1 and ρ in the static and dynamic case, respectively). In this paper we assume that $T_i=R_i=N-1$. Thus, only the impact of wavelength count reduction in energy consumption is studied in this paper.



(a) (b)

Fig. 1 Schematic of a WDM node in a) a static network and b) a wavelength-convertible dynamic network.

The energy consumption of WDM link j is given by:

$$E_{l\_j} = N_{OA\_j} \cdot E_{OA} \tag{2}$$

where N_{OA_j} and E_{OA} are the number of optical amplifiers in link j and the power consumed by an optical amplifier, respectively. Since we assume the use of erbium-doped fiber amplifiers (EDFA), the span length depends on the number of amplified wavelengths, which may be different on each link. For the topologies studied in this paper (section 4), $N_{OA\_}$ does not significantly change in the static and dynamic cases, because the numbers of wavelengths per link in both cases are in the same order of magnitude. For instance, in the topology with the largest difference (Eurolarge), 5 and 16 wavelengths are required in the dynamic and static case, respectively. Consequently, the difference in power consumption is negligible in both types of networks.

Then, the energy consumption of the core of optical network, denoted by E_{net}, can be written as:

$$E_{net} = \sum_{i=1}^{N} E_{n\_i} + \sum_{j=1}^{L} E_{l\_j} \tag{3}$$

In terms of energy consumption, a migration from static to dynamic operation is justified only if the value of (3) for the dynamic case ($E_{net}^{dynamic}$) is lower than the value of the same equation for the static case (E_{net}^{static}), that is:

$$\sum_{i=1}^{N}([2(N-1)+WC_i]\cdot E_t \cdot \rho) + \sum_{j=1}^{L}(N_{AO\_j}\cdot E_{OA}) \quad < \quad \sum_{i=1}^{N}([2(N-1)]\cdot E_t) + \sum_{j=1}^{L}(N_{AO\_j}\cdot E_{OA}) \tag{4}$$

After simplifying and grouping terms of (4) the power consumption of dynamic networks is lower than that of the static approach only if the ratio R is lower than 1:

$$R = \frac{WC}{2N(N-1)} \cdot \frac{\rho}{1-\rho} < 1 \tag{5}$$

where WC= $\sum_{i=1}^{N} WC_i$ is the total number of wavelength converters in the dynamic networks case. This number is equal to the total number of wavelength requirements in the network namely $\sum_{i=1}^{L} W_l$. Eq. (5) constitutes a simple design rule as to evaluate whether a dynamic network consumes less power than the static counterpart

4. Numerical results

The condition set by (5) was verified for 5 different network topologies, namely: Eurocore (N=11, L=50), NSFNet (N=14, L=42), EON (N=20, L=78) UKNet (N=21 , L=78) and Eurolarge (N=43, L=180).

In the dynamic case, three different lightpath allocation algorithms were studied: SP-FF (Shortest-Path First Fit), 3-SP-FF (alternated routing, 3 first shortest paths and First Fit) and AUR-E (Adaptive Unconstrained Routing Exhaustive [8]). For each lightpath allocation algorithm, the wavelength requirement per link (W_l) to obtain a maximum blocking per connection of 10^{-3} was calculated by means of the simulation technique proposed in [4]. In this way, the value of WC was calculated for each network topology and traffic load. Fig. 2 shows the value of *R* as in (5) for the 5 topologies studied for the a) SP-FF, b) 3-SP-FF and c) AUR-E algorithms.

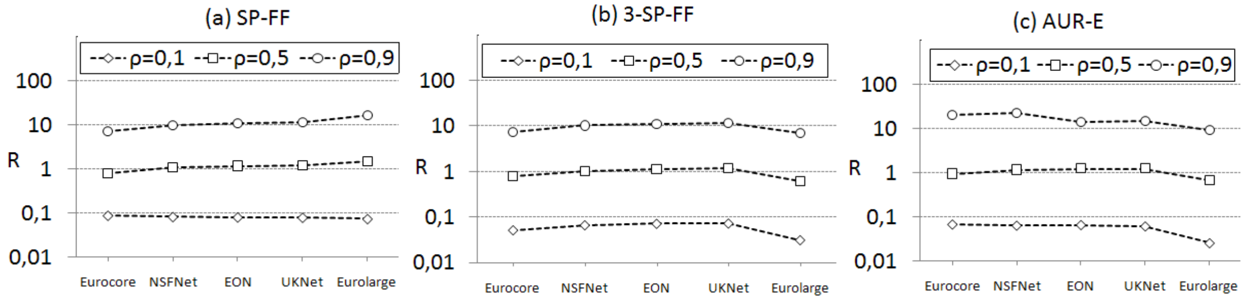


Fig. 2: R as function of the 5 topologies for a) SP-FF, b) 3-SP-FF and c) AUR-E algorithms.

From the figures it can be seen that in terms of power consumption, dynamic networks are attractive only for traffic loads lower than 0.5. This result is in contrast to the results obtained in [4] where dynamic operation saved resources in terms of wavelengths requirements in a large range of traffic loads for FF-based algorithms. The high number of wavelength converters is the main reason for the higher power consumption of dynamic networks with respect to the static ones (where there are no wavelength converters). Eliminating wavelength converters in the dynamic node would lead to higher wavelength requirements and the need of introducing an active switching element, showing a trade-off between the functionalities of the dynamic node and the wavelength requirements, both affecting the power consumption. This is part of future research work.

For traffic loads below 0.5, dynamic networks allow a reduction in the OPEX with respect to the static networks, due to the lower power consumption. Given that current networks operate at traffic loads well below 0.5 [9], dynamic operation brings benefits in the operation regimen of real networks.

The use of different lightpath allocation algorithms did not lead to significant differences in the value of the traffic load at which dynamic operation is not longer attractive in terms of power consumption (about 0.5), since for traffic loads under 0.5 the difference in wavelength requirements among the different algorithms was very small (a few tens) in all the network topologies, except Eurolarge where a difference between SP-FF and the remaining algorithms is observed.

Summary

In this paper static and dynamic WDM networks were compared in terms of energy consumption. Results show that energy consumption of dynamic networks is lower than that of the static approach for traffic loads up to 0.5. Further research is needed in evaluating the energy consumption of alternative dynamic node architectures.

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