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A novel analytical model for dynamic waveband switching

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ABSTRACT

We present a novel framework to analytically model dynamic waveband switching in a multi-granular optical network. The scalable solution consists in modeling each potential carrier of waveband tunnels independently by a Markov chain while modulating the rate of critical transitions, i.e. reserving a new waveband tunnel, by the waveband setup availability computed from the solution of other potential carriers. An iterative procedure is repeated to obtain a consistent numerical solution all over the network. To get an accurate solution we present a novel method to solve the problem of link load correlation in the analysis of circuit-switched networks. Analytical and simulation results are presented to show the effectiveness of the proposed model. The model is also applied to evaluate the performance of waveband cross-connects when introducing waveband conversion.

1. Introduction

Cutting-edge applications, demanding enormous network bandwidth, will result in a huge increase in the number of ports of an optical cross-connect (OXC). Multi-granular OXCs (MG-OXCs) using different switching granularities can reduce the number of ports while enhancing the lack of flexibility resulting from bulk switching. In a survey paper [1], a review of the state of the art shows the challenge of MG-OXCs and the need, in this field, to further R&D in technology development, network design and network control.

Few works are done to study the performance of MG-OXC networks in the dynamic context, where lightpaths and waveband tunnels are set up and torn down depending on demand arrivals. This is a crucial problem, since waveband switching highly modifies the logical topology of the network and a bulk switching decision at consecutive hops builds a long tunnel and must be carefully taken in order to have a good throughput.

Most performance evaluations of waveband switching are done by simulation. Only a few works present analytical methods; for instance, in [2] an analytical model for dynamic waveband switching considers a condition to set up a waveband-route and the problem is treated based on this assumption.

The framework presented in this paper proposes a generic solution. It allows us to define the basis to analyze different architectures and can be extended to model multi-granular optical networks.

This paper is organized as follows. In Section 2, we present the analysis method after describing the principle of operations and defining used terms. In Section 3, we present the model based on a Markov chain and we study its scalability. Section 4 is devoted to finding out the probability distribution of used wavebands in each port. We thoroughly describe in Section 5 the method of deriving the setup availability of a given connection (that modulates some transitions of the Markov chain) first by assuming link load independence and then by taking into account the link load correlation. Analytical and simulation results are presented in each part of the discussion to introduce the next part and hence to compare different approaches and to prove the validity of the model. An application on waveband conversion, with numerical results, is presented in Section 6. Finally, we conclude in Section 7.

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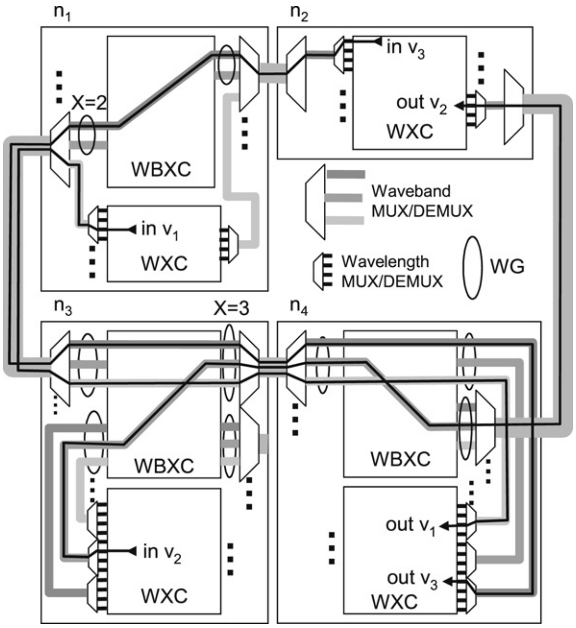

Fig. 1. Multi-granular nodes and waveband tunnels.

2. Analytical model

2.1. Principle of operations

Setting up a lightpath by passing through one or several consecutive waveband cross-connects (WBXC) creates a tunnel between the ingress of the first one and the exit of the last one [3]. This means that all included wavelengths are constrained to follow the same path. Wavelength cross-connects (WXC) can form the access points to these waveband tunnels. An access point (ingress or exit) is where wavebands are demultiplexed to a finer granularity (e.g. wavelengths). During data transfer, rearrangement and reassignment are not usually allowed (since they give rise to traffic interruption) therefore, waveband tunnels are torn down only when data transfer ceases in all included lightpaths before a new demand arrival. Now lightpath demands arrive independently and have different service times, therefore the first lightpath that has established a given waveband tunnel, even though torn down, may leave a significant trace on the logical topology of the network.

We show in Fig. 1 (where only interesting elements are shown) three waveband tunnels v_1, v_2 and v_3 and four nodes n_1, n_2, n_3 and n_4. Note that different node architectures are shown; for instance, node n_1 is a muli-granular but non hierarchical cross-connect and nodes n_3 and n_4 are hierarchical ones.

2.2. Definitions

We define the following:

- *Waveband channel*: the set of contiguous wavelength channels that can be treated in bulk. Two waveband channels don't share any wavelength channel.
- *Waveband group (WG)*: the set of wavebands applied to the WBXC and belonging to the same physical port. All included wavebands are supposed to have different waveband channels. A WG can be the set of wavebands applied to the WBXC and belonging to the same fiber. It can be also the set of different waveband channels coming from other switching fabrics dealing with different granularities (like, for instance, the WXC of a multi-layer hierarchical cross-connect).
- *WG granularity (X)*: The number of waveband channels in a WG applied to a WBXC. Let X be this number.
- *Waveband granularity (G)*: the number of wavelengths per waveband. Let G be this number.
- *End-to-end tunnel (ETE-tunnel)*: Any path through consecutive WBXCs that can potentially carry up to X waveband tunnels (WG capacity) having the same access points and different waveband channels. A waveband tunnel belongs to an ETE-tunnel t if, and only if, it has the same ingress and exit as t. Let T be the total number of ETE-tunnels in the network.
- *Waveband in an ETE-tunnel*: Since there is no possible confusion we shall also refer to a waveband tunnel in an ETE-tunnel as a waveband in an ETE-tunnel.

We consider in this paper that X is the same all over the network. While in Fig. 1, to show the difference, we consider a WG with $X = 2$ and a WG with $X = 3$ at the output of WBXCs of node n_1 and node n_3, respectively. G is also supposed to be the same all over the network.

2.3. Analysis method

To ensure a scalable and tractable solution, we model each ETE-tunnel independently by a Markov chain while modulating the rate of critical transitions, i.e. reserving a new waveband, by a probability representing the waveband setup availability and computed from the solution of other ETE-tunnels. Starting from arbitrary waveband setup availability, a successive iterative solution method is applied where, at each iteration, Markov chains are solved and this probability is recalculated until having a consistent numerical solution for all ETE-tunnels and where the waveband setup availability converges.

3. The ETE-tunnel model

3.1. Model based on a Markov chain

First we need to estimate the number of wavebands used in a given ETE-tunnel t and also the number of used wavelengths in each of these wavebands.

Let β_t be the maximum number of wavebands allowed to be used in ETE-tunnel t $(0 \leq t < T)$, $\beta_t \leq X$ and is equal to X when there is no restriction on the number of used wavebands in t. Once used, a waveband is exclusively reserved by t until all included wavelengths are freed.

To setup a new wavelength in t, we try first to use the most but not the fully filled waveband already used in t (note that the model can be easily modified to carry other policies). If there is no such waveband, a new waveband is allowed to be set up if the number of already used wavebands in t is less than β_t and if there are available