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Some new load balancing algorithms for single-hop WDM networks

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Abstract

The problem of reconfiguring broadcast and select, single-hop wavelength division multiplexed (WDM) networks to maintain a balanced load when the traffic demand changes is considered. When the load becomes unbalanced the wavelength assignment (WLA) has to be reconfigured. When reconfiguring the WLA according to the new traffic demand, it is important to reduce the number of receivers that need to be retuned to correspondingly reduce the disruption to the network operation. Although it is clear that if the number of retunings is unlimited a better WLA and load balance can be achieved, there is a trade-off between the network load balance and the number of retunings. In this work, two new WLA reconfiguration algorithms are introduced, the One-Directional Transfer (1DT) and the Two-Directional Transfer (2DT) algorithms, and both are shown by simulation to outperform existing algorithms in terms of the trade-off described.
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1. Introduction

Today, two communications technologies are displacing all others: wireless, which can go everywhere, but with limited capacity, and optical fibre, which, although limited to fixed paths, has almost unlimited capacity [1]. The first generation of optical networks employed fibre in traditional architectures. An excellent example of this generation is the upgrade of long-haul trunks in a wide area network (WAN) from copper or microwave radio to fibre connections. The second-generation optical networks are all-optical networks and in these the inherent properties of the fibre are utilized [2]. Wavelength division multiplexed (WDM) lightwave networks can be classified into two categories: broadcast-and-select networks, and wavelength-routed networks. In turn, each of these can be classified as either single-hop or multi-hop networks. In broadcast-and-select architectures, the transmission from each station is broadcast to all of the network stations. At the receiver, the desired signal is then extracted from all the signals. For example, each station can transmit at an optical wavelength different from those of the other stations, and then at each receiver a tunable optical filter can be used to select the desired wavelength for reception. Alternatively, we can have tunable transmitters and fixed-tuned receivers, or have both transmitters and receivers tunable, or have a multitude of fixed-tuned transmitters and receivers at each station [3]. In a single-hop network, a transmitter at the source and a receiver at the destination must operate on the same wavelength for successful packet transmission. This therefore differs from a multi-hop network where

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the transmitter and the receiver may operate at different wavelengths and communicate through other nodes.

The number of channels is a restrictive factor in a WDM network, and usually is less than the number of nodes. Therefore, more than one receiver is assigned to one channel. Since computer network traffic changes rapidly, the load on the channels can become unbalanced and there is thus a requirement for a good mechanism to update the wavelength assignment to maintain a balanced load. This is called the wavelength assignment (WLA) problem.

One of the key features of multi-wavelength optical networks is their ability of rearrangement so that they dynamically optimize a virtual topology to track changing traffic demands. Typical of some early work on reconfiguration in multi-hop lightwave networks is that by Labourdette, Hart and Acampora [4] who present some polynomial time algorithms that minimize overall reconfiguration time. General surveys on virtual topology designs and on routing and wavelength assignment in multi-hop wavelength routed networks can be found in [5,6] and [7] respectively.

Since the evolution of the all-optical networks in the 1990's, many experimental demonstrations and prototypes of single-hop networks have been carried out. Bellcore's LAMBDANET, RAINBOW-I and II, and others showed the practicality and efficiency of the single-hop networks [2]. Many researchers have studied the routing and WLA (RWA) problem but most of the proposed RWA algorithms deal with wavelength-routed networks, either fixed or adaptive [7–9].

In 1998, Baldine and Rouskas introduced an algorithm called the GLPT algorithm [10]. They assumed a single-hop network with dynamic traffic. The algorithm assumes that the number of channels, C, in the single-hop optical network is less than the number of nodes, N. The main idea in the GLPT algorithm is that the current WLA is taken into account when calculating the new WLA after the traffic demand in the network has changed. The average number of retunings for the GLPT algorithm is $N/2$. In 2003, Alfouzan and Jayasumana introduced another algorithm called the MLLCB algorithm [11]. In the MLLCB algorithm, a single node assigned to the highest loaded channel is selected to be exchanged with a single node assigned to the lowest loaded channel. Therefore, the number of retunings is always two. The latter authors claimed that the MLLCB algorithm performs better than the GLPT algorithm in terms of the trade-off between network load balance and number of retunings required to take the network from its current WLA to the new WLA. However, each of the algorithms has a weakness which makes it inefficient. The main weakness for the GLPT algorithm is the high number of retunings required to give a good load balance. The main weakness for the MLLCB algorithm is the relatively poor load balance achieved due to the restricted number of retunings. By taking a middle path between these two algorithms, two new algorithms have been developed, the One-Directional Transfer (1DT) and the Two-Directional Transfer (2DT) algorithms with the aim of giving a better trade-off between load balance and the number of retunings.

The 1DT algorithm transfers nodes from a specific group of channels consisting of the K_H highest loaded channels to a second specific group of channels consisting of the K_L lowest loaded channels, while the 2DT algorithm exchanges nodes between the same groups of channels, but in both directions. The number of transfers made at a time is flexible and can be adjusted.

The rest of the paper is organized as follows. The main problem is defined in Section 2. In Section 3, the description of the 1DT and 2DT algorithms is presented. Comparative bounds for the load balance that can be achieved are obtained in Section 4. In Section 5, some simulation results are discussed and a comparison of the algorithms is presented. Section 6 contains a discussion on the time complexity of the various algorithms and Section 7 contains concluding remarks.

2. Problem definition

2.1. The network model

The algorithms to be proposed are applicable to any physical or logical topologies that can be operated as single-hop, broadcast and select WDM networks (see [5] for a discussion of topologies). We make the assumption that all the traffic is single-hop. Two such traditional physical topologies that fall into the single-hop, broadcast and select category are the passive star topology and the passive bus topology, which are shown in Fig. 1 [3,12]. These would be suitable, for example, for application as Local Area Networks (LANs) or Metropolitan Area Networks (MANs). In these topologies a node sends by tuning its transmitter to an appropriate wavelength and receives at a fixed wavelength. In general, the tunable transmitters and fixed receivers can be used for media access purposes. It is assumed that a single node is used to centrally coordinate activities involving the Media Access Control (MAC), the Connection Admission Control (CAC) and the WLA. Further assumptions are

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