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A load balancing technique for efficient survivable multicasting in mesh optical networks ☆

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ABSTRACT

The current paper deals with the problem of survivable multicasting in mesh optical networks. A load balancing technique is presented that can be combined with any appropriate survivable multicast algorithm. Simulations on several test networks have shown that the proposed technique outperforms the conventional methods as it efficiently intersperses the network load, as well as keeps low the percentage of highly congested arcs at each network state, thus decreasing the blocking ratio for the newly arriving multicast requests.

1. Introduction

Core optical networks utilizing intelligent switching elements and an appropriate control plane are currently being employed to accommodate a large number of bandwidth-intensive network applications [1]. These networks are currently employing wavelength division multiplexing (WDM) technology, but networks with flex-grid technology are also attracting increased attention, mainly by the research community. One category of network applications that have lately become very popular is *multicasting* applications, such as high-definition television, video conferencing, interactive distance learning, live auctions, distributed games, and video-on-demand. These applications are based on the calculation of light-trees, simultaneously distributing information to multiple destinations [2].

The vast amount of information that a fiber carries, as well as the amount of information loss in case of a failure on a light-tree that can affect the traffic to multiple destinations, have led to the development of a number of efficient survivable multicasting techniques (e.g., [3–7]). For the case of survivable routing of *dynamically*[1] arriving multicast requests, the main objective is to minimize the number of non-established (blocked) connection requests (due to lack of resources) [1]. In other words, to minimize the *Blocking Ratio (BR)*, i.e., the ratio of the blocked requests over the total number of them. To the best of our knowledge, none of the existing techniques for survivable multicasting of dynamically arriving requests take into account the current network state when provisioning a new multicast request. This can lead to inefficient load distribution into the network, i.e., some network links may have (almost) all their resources utilized, whereas other

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[1] requests that arrive in the network according to a certain distribution and stay in the network, holding resources, for a finite amount of time, while the upcoming requests arrive.

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links will have (almost) all their resources free. This, at several network states, may lead to a disconnected network, thus leading to a high *BR*.

The main contribution of this work is a *general load balancing technique (LBT)*, that can be combined with any appropriate survivable multicasting approach, to achieve a balanced distribution of the network load, thus leading to a decreased *BR* compared to the case where the survivable technique is applied without the combination with the proposed LBT. Simulations on the well known USNET network, as well as on several randomly created graphs, with various amounts of load, have shown that the proposed technique, combined with an illustrative survivable multicasting technique (called *OPP-SDP*), achieves an important reduction of the *BR* compared to the case of the standalone OPP-SDP, as well as to the case the latter is combined with an existing load balancing approach. It is important to note here that the proposed load balancing technique (LBT) is generic, i.e., it can be combined with any routing algorithm (unicast or multicast, for unprotected or protected routing). The main reason the case of survivable multicasting was selected in this work is the fact that this case is very demanding in terms of network resources and it is a very good use case to demonstrate the advantages and applicability of the proposed approach.

Another contribution of the current paper is the quantification of the load dispersion of the network's links at several network instants. A random variable *L* is defined and its variance at several network states gives the load dispersion at these states; low (high) variance means that small (large) percentage of network links are too low or too highly loaded. Therefore, a good load balancing technique achieves to keep the variance of *L* as low as possible at any network state. This is utilized for the evaluation of the proposed technique. The reader should note that even though the proposed technique is presented here for the case of WDM optical networks it can also be applied to networks utilizing other types of technologies as well. For example, flex grid networks have recently emerged as a promising replacement for the conventional fixed-grid WDM networks, where the optical spectrum can be used much more flexibly compared to the fixed grid approach (WDM networks). Multicasting techniques have also been proposed for these networks as outlined in [8–13]. The proposed load balancing technique (LBT) is generic, i.e., it can be combined with any multicast routing algorithm for any network utilizing different technologies (e.g., considering “slices” instead of wavelengths). Therefore, for the case of elastic networks, LBT can be applied with only slight modifications (left as a continuation of the work presented in this paper).

The rest of the paper is organized as follows. Section 2 gives the notation and definitions used throughout the paper. Since no work can be found in the literature that utilizes load balancing for survivable multicasting, some of the most important load balancing methods designed for unicasting are presented in Section 3. The quantification of load dispersion is given in Section 4, while Section 5 presents the proposed load balancing technique. This is combined with the survivable multicasting algorithm given in Section 6 and the resulting algorithm is evaluated in Section 7. The conclusions and ongoing work are discussed in Section 8.

2. Preliminaries

A mesh WDM optical network with bidirectional links [comprising two fibers with opposite orientation (*arcs*)] is assumed, with full wavelength conversion capabilities at the network nodes. The assumption for full wavelength conversion capabilities at the network's nodes mainly stems from that fact that current deployments of optical cross-connects utilize opaque network nodes where wavelength conversion is a by-product of the optical node architecture. It is also assumed that no information regarding the upcoming requests, is available. Throughout the paper the following are used:

- $G(V,A)$ is the network graph consisting of $n=|V|$ nodes and $m=|A|$ arcs.
- (x, y) is the arc from node x to node y.
- a_x is the number of arcs ending at node x ($\sum_x a_x = m$).
- b_x is the number of arcs originating from node x ($\sum_x b_x = m$).
- $C(x,y)$ is the cost of arc (x, y). Initially, all arcs have the same cost.
- W is the number of wavelengths of every arc.
- $w_o(x,y)$ is the number of wavelengths that are occupied (used) on arc (x, y).
- *Incoming Ability of Flow of node x (IAoF(x))* is the total number of free wavelengths of the arcs that end at node x.
- *Outgoing Ability of Flow of node x (OAoF(x))* is the total number of free wavelengths of the arcs originating at x.
- *Ability of Flow of node x (AoF(x))* is defined as the minimum between $IAoF(x)$ and $OAoF(x)$.
- *Ability of Flow of arc (x, y) (AoF(x,y))* is defined as the number of free (unused) wavelengths of arc (x, y).
- *Blocking Ratio (BR_X)* is the ratio of blocked requests over the total number of requests, if routing technique X is utilized.
- The multicast session is denoted by $S=\{s,d_1,d_2,\ldots,d_k\}=\{s,D\}$, where s is the source node and $D=\{d_1,d_2,\ldots,d_k\}$ is the destination set consisting of k destinations (i.e., $|D|=k$).

An illustrative example of the aforementioned definitions is presented in Fig. 1. Here, it is assumed that W=64, and the free wavelengths are given next to each link. According to the prior definitions, for nodes x and y, and for arc (x, y), $IAoF(x)=55$, $OAoF(x)=40$, $AoF(x)=40$, $IAoF(y)=17$, $OAoF(y)=90$, $AoF(y)=17$, and $AoF(x,y)=15$.

3. Existing approaches

To the best of our knowledge, no work can be found in the literature that utilizes load balancing techniques to decrease the blocking ratio of dynamically arriving survivable multicasting requests. Therefore, the existing approaches described in this section are some of the most important ones designed for unicast requests. One of the