Multicast Routing and Wavelength Assignment in WDM Mesh Networks with Sparse Splitting

Fen Zhou, and Miklós Molnár
IRISA / INSA Rennes
Campus de Beaulieu
Rennes, France, 35042
Email: {fen.zhou, molnar}@irisa.fr

Bernard Cousin
IRISA / University of Rennes 1
Campus de Beaulieu
Rennes, France, 35042
Email: bernard.cousin@irisa.fr

Abstract—In this paper routing and wavelength assignment for supporting multicast traffic is investigated in WDM mesh networks under sparse splitting constrain. This problem is generally solved in two phases respectively with the purpose of minimizing the number of wavelengths required. Alternative routing is first proposed to route each session by pre-computing a set of candidate light-forests. Then wavelength assignment is formulated as a coloring problems by constructing a conflict graph. Potential heuristic algorithms are proposed.

Index Terms—WDM Networks, Multicast, Routing and Wavelength Assignment (RWA), Sparse Splitting,

I. INTRODUCTION

Optical wavelength division multiplexing (WDM) networking has been identified as an effective technique for future wide area network environments, due to its potential ability to meet rising demands of high bandwidth and low latency communication [1]. For bandwidth-driven and time sensitive applications such as video-conference, shared workspace, distributed interactive simulation and software upgrading in WDM networks, multicasting is advised. The purpose of multicast routing is to provide efficient communication services for applications that necessitate the simultaneous transmission of information from one source to multiple destinations. To support multicast in WDM networks, the network nodes should be equipped with light splitters, which is capable of splitting the incoming light signal into all the outgoing ports. However, in sparse splitting WDM networks, only a fraction of nodes are capable of splitting (named multicast capable nodes, i.e. MC [2]) while the rest only have TaC (Tap and Continue) [3] capacity (called MI nodes [2]), which is able to tap into the light signal for local consumption and forward it to only one output port. Besides, the wavelength converters are not available because of its expensive fabrication.

II. MULTICAST ROUTING AND WAVELENGTH ASSIGNMENT IN WDM MESH NETWORKS

Multicast routing and wavelength assignment in WDM networks is a challenging work. This problem can be generally formulated as follows: given the number of wavelengths $|W|$ supported per fiber link, try to maximize the number of multicast demands established. In other words, it is to minimize the number of wavelengths required per fiber so that a set of concurrent multicast demands $Traffic = \{ms_i(s_i, D_i)|i \in [1, I]\}$ could be accommodated. Generally this problem is either decomposed into two subproblems and each one is resolved separately by heuristic algorithms, or it is formulated as an Integer Linear Programming (ILP) and solved entirely. ILP works well when the topology is small and the group size is not big. Nervelessness, heuristic algorithm is more time efficient while giving an efficient approximated results. Considering the time efficiency, we prefer to separate the multicast routing and wavelength assignment problem into two phases. The first phase is multicast routing, which tries to find the light-forest for routing the multicast demand. After this phase, the wavelength assignment operation for the computed light-trees is performed. This subproblem aims to minimize the number of wavelengths required by the multicast sessions while complying the WDM layer impairments.

A. Multicast Routing with Sparse Splitting

In full splitting WDM networks, where all nodes are capable of light splitting, one light-tree (LT) is sufficient to span all the multicast members and thus it is able establish the multicast session. As proved in [5], it is a Steiner problem and NP-hard to find the light-tree with the optimal fiber link cost. In spare splitting WDM networks [2], only a fraction of nodes are MC nodes while the rest are MI nodes. In this case, the out degree of a node in the light-tree is restricted according to its splitting capacity. Thus, one light-tree [4] may not be able to cover all the members, and several ones with the same source is required, i.e. light-forest [6]). And the latest research shows that a set of light-hierarchies can be a good candidate for sparse splitting multicast routing [7].

However, in order to achieve the global objective, the alternative routing should be employed instead of the traditional fixed routing. This is to say, for each multicast session $ms_i(s_i, D_i)$, a set of candidate light-forests (LF) $\{LF_{i1}, LF_{i2}, ..., LF_{iJ}\}$ are pre-computed. And one of them is employed when routing a multicast sessions. Hence, the key operation of this subproblems is how to choose a set of light-forest for the same multicast session. Potential methods for computing candidate J light-forests are listed below.

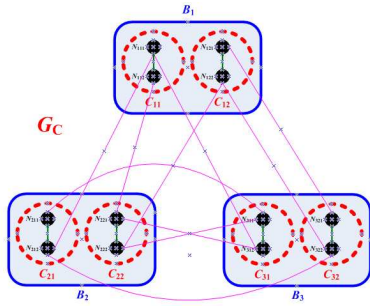- Choosing J light-forests as link disjoint as possible.

Fig. 1. An example auxiliary graph G_c

- Choosing the J light-forests which require as few wavelength as possible.
- Choosing the J light-forests which consumes as little cost as possible.

B. Wavelength Assignment for Multicast Communications

After the routing stage is finished, the wavelengths should be assigned for each light-forest. Due to the absence of wavelength converters, wavelength continuity constraint and distinct wavelength constraint should be respected. Hence, a pair of light-trees can be assigned the same wavelength if and only if they are link disjoint. Obviously, the light-trees in the same light-forest should use distinct wavelengths, because they always share some common links. Based on this constraint, an auxiliary conflict graph G_C can be constructed to help to resolve the wavelength assignment problem. The auxiliary graph is built following the rules below.

- Each multicast session $ms_i(s_i, D_i)$ is represented by a block B_i.
- In B_i, each light-forest constructed for $ms_i(s_i, D_i)$ is denoted by a circle C_{ij}
- Each light-tree in a light-forest C_{ij} is replaced by a node N_{ijk}.
- In each circle $C_{i,j}$, draw a line between each pair of nodes.
- For each pair of light-trees in different blocks, says N_{1jk} and N_{2jk} which are in B_1 and B_1 respectively, draw a line between them if they share a common link.

With the help of the built auxiliary graph, the RWA problem is translated into a coloring problem, which tries to minimize the number of colors in G_c so that one and only one circle C_{ij} is selected for each block B_i and adjacent nodes have distinct colors. An example auxiliary graph is is shown in Fig 1. Three multicast sessions are considered. For each session, two candidate light-forests are provided. And each light-forest contains two light-trees. i.e. $I = 3, J = 2, K = 2$.

We can see that when full splitting is adopted in WDM networks, $J = 1$ and $K = 1$, i.e., only one light-forest is pre-computed for a multicast session, and there is only one light-tree in each light-forest. In this case, the wavelength assignment problem is equivalent the traditional coloring problem, which is proven NP-complete. However, under sparse slitting constraint, this problem becomes even harder. Therefore,

heuristic algorithm should be developed. One possible method is described as following.

- Calculate the out degree (the number of connection lines to the other circles) for all the the circle C_{ij} in the graph G_c.
- In each block B_i, select the C_{ij} with the smallest out degree, and remove the rest together with the connection lines from G_c.
- In the modified graph, say G'_c, it is a traditional coloring problem.
- In each circle $C_{i,j}$, draw a line between each pair of nodes.
- Next, use the well-known stand coloring heuristics to solve the problem. For instance, degree Largest-First, degree Smallest-First, Color-Degree [8], and Tabu search algorithms [9] .

III. CONCLUSION

The routing and wavelength assignment for a set of multicast demands is studied in this paper. The objective of this problem is to minimize the session blocking probability or minimize the number of wavelengths needed per fiber link. We divide this problem into two subproblems and solve them respectively. To route the multicast sessions, alternative routing method is employed, which pre-computes a set of light-forests for each session. And the wavelength assignment for the light-forests is translated into to a coloring problem by constructing an auxiliary conflict graph. By combing the two steps, the multicast routing and wavelength assignment problem can be solved. However, simulation should be done to assess the verify the proposed methods.

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