Applying Prediction Concepts to Routing on Semi-Transparent Optical Transport Networks

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ABSTRACT

This contribution deals with the RWA (routing and wavelength assignment) in semi-transparent optical networks. In semi-transparent networks, a parameter called Maximum Transmission Distance (MTD) is used to indicate the distance reachable in wavelength continuity. When for a given lightpath, the signal cannot be detected at the destination node a regenerator has to be installed in an intermediate node. The regenerator breaks up the optical continuity and the optical network becomes a semi-transparent optical network. The new RWA mechanism proposed in this paper will take into account the physical impairment such as the Maximum Transmission Distance (MTD). Moreover this new RWA algorithm will be based on the Prediction-Based Routing (PBR) mechanism and will take into account the routing inaccuracy problem. The goal of the proposed algorithm will be both, to reduce the number of blocked connections due to the routing inaccuracy problem and to select routes that fulfil the MTD physical impairment.

1. INTRODUCTION

An Optical Transport Network (OTN) is a communication network in which data is transmitted over fiber optic lines as pulses of light. Optical networks achieve high capacity by means of a multiplexing technique called Wavelength-Division Multiplexing (WDM). Unlike traditional IP networks where the routing process only involves a physical path selection, in WDM networks the routing process not only involves a path selection process but also a wavelength assignment process.

On the other hand, transparent optical networks do not convert the signal to the electrical domain in the intermediate nodes but rather keep the signal in the optical domain from source to destination. Full transparency is not however always achievable in long distance networks, due to the degradation an optical signal accumulates in propagation. In semi-transparent optical networks regenerators are employed when the quality of the signal falls below the level required for an acceptably correct detection.

In general, the physical model for computing the global impairment of an optical connection (a lightpath) has to take many parameters and system characteristics into account. The Bit Error Rate (BER), which represents the quality of the signal perceived by the user, can be evaluated as a function of the so-called Q Personick's factor [1]. Such type of model can be used to evaluate the BER in a satisfactory way for operational or design purposes. When this method cannot be applied for lack of information or because a simpler approach is preferred, the concept of Maximum Transmission Distance (MTD) can be used instead. The concept is simple: MTD is the maximum distance a signal can be routed on without any regeneration. When for a given lightpath, the signal cannot be detected at the destination node a regenerator has to be installed in an intermediate node. The regenerator breaks up the optical continuity and the optical network becomes a semi-transparent optical network. We assume that in a semi-transparent network routes are divided into transparent sub-routes between signal regenerators.

This paper deals with the Routing and Wavelength Assignment (RWA) problem in semi-transparent networks with inaccurate network state information. When selecting a lightpath (route and wavelength), a RWA algorithm for a semi-transparent network has to take into account the physical constraints, such as the MTD, as well as the wavelength availability. But, for different reasons the information about wavelength availability is not accurate and usual RWA algorithms utilize inaccurate network state information, negatively impacting on the network performance. This is known as the routing inaccuracy problem. We propose a new RWA mechanism for semi-transparent networks, which consists on a new routing algorithm, the Minimum Coincidence and Distance (MINCOD) routing algorithm, and a new RWA algorithm, the Prediction Routing according to the MTD (PR-MTD). The MINCOD routing algorithm tackles the problem of selecting the suitable end-to-end K-paths where the traffic must be forwarded. On the other hand the PR-MTD RWA algorithm is based on both the MTD concept and the PBR (Prediction-Based Routing) [7] mechanism. The PR-MTD

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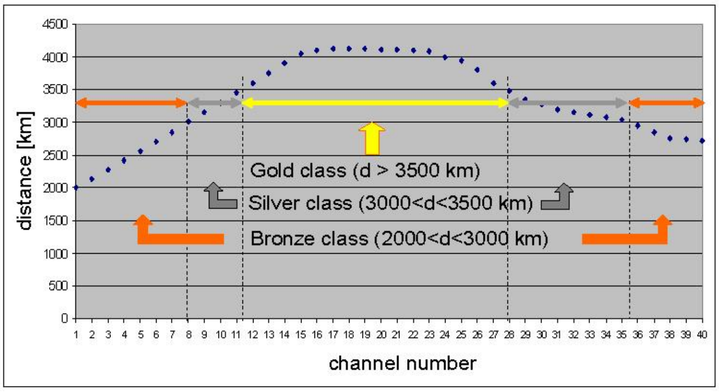

Figure 1.Example of maximum distance reached by the wavelengths of a system of 40 channels.

algorithm, with limited computational complexity, selects lightpaths on one hand accomplishing the MTD constraint in each one of the sub-routes of the selected route, and on the other hand basing the decision on the history of previous blocked connections on that lightpath. Moreover, the PR-MTD algorithm reduces the signalling overhead because the update messages with network state information are not needed.

2. ROUTING AND WAVELENGTH ASSIGNMENT IN SEMI-TRANSPARENT OPTICAL NETWORKS

Unlike traditional IP networks where the routing process only involves a physical path selection, in WDM networks the routing process not only involves a physical path selection process, but also a wavelength assignment process, named the routing and wavelength assignment (RWA) problem. Many efficient Routing and Wavelength Assignment (RWA) algorithms have been specifically developed to minimize the blocking probability in fully transparent networks.

However, in a semi-transparent network, routes are divided into transparent sub-routes between signal regenerators and new RWA algorithms have to be developed which select lightpaths accomplishing the physical constraints in each one of the different sub-routes. Considering the MTD physical constraint, these RWA algorithms has to take into account that wavelengths are classified into different classes (with different MTD value). As each wavelength taking part a system shows a different behaviour in terms of 'quality' of the signal, the adopted model introduces the concept of 'wavelength class'. 'Quality' means here the Bit Error Rate shown by the wavelength at the end of its path. The reach of a wavelength (i. e. the maximum distance for which BER stay under a given reference value) change with the position of the wavelength in the spectrum. In Figure 1 the reach of the wavelength belonging to a comb of 40 wavelengths is shown

The definition of wavelength classes, as well as a proposal of a RWA algorithm and regenerator placement algorithm has been investigated in the Nobel project [2] for static traffic. On the other hand, in an analysis phase, the network is evaluated with regard to aspects like the capacity of carrying a given traffic load or the capacity to survive against single or multiple failures. In general connections set-up and tear-down are generated statistically and then the traffic is dynamic. The RWA problem with dynamic traffic in semi-transparent networks implies to select on demand a route and to assign an available wavelength accomplishing a physical constraint (such as the MTD constraint) in all the sub-routes of the route.

3. HANDLING THE ROUTING INACCURACY PROBLEM IN OPTICAL NETWORKS

Source-based routing is one of the recommendations stated in the ASON specifications [3]. According to the source-based routing, routes are dynamically computed in the source nodes based on the routing information contained in their network state databases. Most of the RWA algorithms assume that the network state databases contain accurate information. Unfortunately, when this information is not accurate enough, the routing decisions taken at the source nodes could be incorrectly performed hence producing a significant connection blocking increment. In highly dynamic networks, inaccuracy arises mainly due to the restriction to aggregate routing information in the update messages, the frequency of updating the network state databases and the latency associated with the flooding process. Some of the most recent studies dealing with the routing inaccuracy problem in optical networks can be found in [4]-[6]. However, these RWA algorithms have not specially designed for semi-transparent optical networks.

3.1 The Prediction-Based Routing Mechanism

The main concept of the Prediction Based Routing (PBR) mechanism is based on extending the branch prediction concepts used in the computer architecture area [7]. Bringing this concept to a network scenario, the PBR mechanism selects the lightpath (route and wavelength) between a source-destination node pair from the behavior of previous connection request. Thus, the PBR mechanism does not need update messages with global network state to compute the lightpath.

The prediction mechanism is based on two-bit counters. In the source nodes, there is one of such two-bit counters for every lightpath to every destination. The two-bit counter value corresponding to a lightpath is compared to a certain threshold value. According to this, 0 and 1 stand for the lightpath availability and 2 and 3 stand for the lightpath unavailability. When a new connection request is set up the two-bit counter of the selected lightpath is updated, decreasing the counter. On the other hand, if the connection request is blocked, the counter is increased. A new algorithm, named Route and Wavelength Prediction (RWP) algorithm inferred from the PBR mechanism was presented in [7]. The RWP performs as follows. It is assumed that K shortest routes have been previously computed for every source-destination node pair. The RWP algorithm selects among these K routes the shortest lightpath with two-bit counter lower than 2 and output link availability. If after checking the two-bit counters of the K paths, the algorithm predicts that all the wavelengths on both paths will not be available, the source node tries to forward the connection request through the first available wavelength on the output link towards one of the K paths. The two-bit counter of the selected lightpath is updated by either increasing or decreasing it.

3.2 The Minimum-Coincidence and Distance Routing Algorithm

Traditional methods to select paths along the network are based on the Shortest Path First (SPF) algorithm, which selects the K-shortest routes between the source and destination node pair minimizing the number of hops. Therefore, a wavelength assignment algorithm in use should take into account when assigning a wavelength that some links might suffer from a high level of utilization. Taking into consideration this drawback, we propose a new routing algorithm called Minimum Coincidence and Distance (MINCOD) routing algorithm. In order to enhance the route selection the MINCOD algorithm takes into account the concept of minimum coincidence between paths to balance the traffic load, hence reducing the network congestion. The MINCOD algorithm computes K-paths considering the paths that have minimum distance and less shared links. The MINCOD algorithm looks for the K-paths in three steps as follows. Firstly, it chooses the shortest path (in distance) from the list of feasible paths between the source-destination node pair, already pre-computed. Secondly, it associates a metric to the shortest routes left in the list. This metric is named Minimum Shared Link (MSL) and is computed according to the following expression

$$MSL = DP * (1 + SL) \tag{1}$$

where DP is the end-to end distance of the particular path and SL is the number of links shared between the particular path and the path previously selected in the first step. The MINCOD algorithm selects the path with minimum MSL as the second path. For computing the third path, the SL parameter will be the number of shared links between a particular path and the first already calculated path and the second already calculated path. Finally, we repeat this process in order to provide an ordered list of K-paths.

4. THE PR-MTD IN SEMI-TRANSPARENT NETWORKS

In this section the new RWA algorithm for semitransparent networks, the PR-MTD (Prediction Routing according the Maximum Transmission Distance) is described. We assume that the network is yet designed; the number of fibers and wavelengths is fixed and the regenerators are distributed in some nodes of the network.

The new RWA algorithm takes into account the physical impairment such as the MTD. We will assume that the wavelengths are divided in 3 different classes, according to this physical impairment. The goal of the proposed algorithm will be both, to reduce the number of blocked connections due to the routing inaccuracy problem and to select routes that fulfill the physical impairments.

The PR-MTD algorithm runs as follows. In every source node there are K previously computed routes by means of the MINCOD algorithm, for every possible destination. The information about these K routes is in a Routing Table. In each entry of the Routing Table there is the following information: the transparent sub-routes that compose the route and the distance in kilometers of each one of these sub-routes. On the other hand, to implement the PBR mechanism it is necessary a two-bit counter for every lightpath. Assuming there are W wavelengths, there will be W two-bit counters for every route, placed as W fields in each entry of the Routing Table. The PR-MTD algorithm will select (among the K x W possible lightpaths) the shortest lightpath with two-bit counter lower than 2, with output link availability and with the distance of every subroute of the route shorter than the MTD of the wavelength. If two or more wavelengths of the shortest route accomplish the three conditions, the algorithm will select the least loaded wavelength. The information about which is the least loaded wavelength is only from the point of view of the source node, local information.

5. PERFORMANCE EVALUATION

A set of simulations have been carried out on the topology of the PanEuropean network shown in Figure 2. The simulation environment consists of the following features:

There are 2 fibres per link and 40 wavelengths per fibre. Wavelengths are divided into three classes, gold, silver and bronze, with MTD of 4000, 3500 and 3000 km respectively. Nodes Madrid, Barcelona, Paris, Dublin, Milan, Frankfurt, Amsterdam, Prague, Stockholm and Athens act as source and destination; and nodes, Frankfurt, Amsterdam, Vienna, Milan, Prague and Warsaw have regenerators. The traffic is modelled according to a Poisson distribution for the connection arrival time and an exponential distribution for the holding time. The average holding time is 10 units of time. Every simulation is computed using 90.000 call connections.

Three algorithms are compared considering 1 or 2 pre-computed routes. The Shortest Path-Least Loaded (SP-LL) algorithm utilizes 1 pre-computed route (the shortest in distance), and it assigns the least loaded wavelength accomplishing the MTD impairment. The MINCOD-LL algorithm utilizes 2 pre-computed routes according to the MINCOD routing algorithm. This algorithm selects the shortest lightpath with availability in all the links of the route and fulfilling the MTD constraint in all the sub-routes of the route. If more of one wavelength fulfils these constraints in the shortest route, it selects the least loaded. And finally, the PR-MTD also utilizes 2 pre-computed routes according to the MINCOD routing algorithm. In order to introduce the inaccuracy of the network state information, this information is updated every 1, 5 or 10 units of time for the SP-LL and the MINCOD-LL algorithms. Figure 3 shows the percentage of blocked connections (versus the traffic load in Erlangs) produced by the SP-LL, the MINCOD-LL and the PR-MTD. We observe that, both algorithms, SP-LL and MINCOD-LL, degrades the performance when the update period is larger. The lower percentage of blocked connections corresponds to the 2_MINCOD-LL with updating every unit of time, which implies a high signaling overhead. Besides, the PR-MTD algorithm with similar performance does not need update messages and then the signaling overhead is completely eliminated.

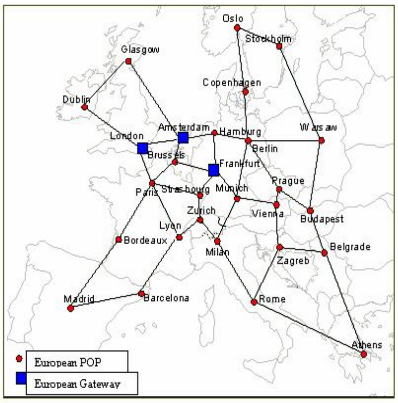

Figure 2. PanEuropean Network.

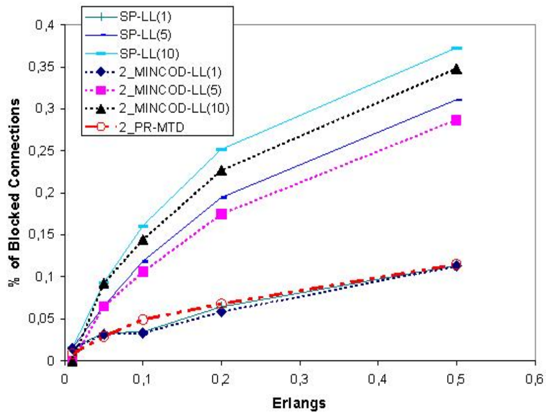

Figure 3. % of blocked connections versus traffic load.

6. CONCLUSIONS

We have presented a RWA mechanism for semi-transparent optical networks which takes into account the Maximum Transmission Distance (MTD) physical constraint, and also the inherent inaccuracy of network information with dynamic traffic. This mechanism is composed by a new routing algorithm, the Minimum Coincidence and Distance (MINCOD) algorithm, and a new RWA algorithm, the Prediction Routing according to the MTD (PR-MTD). The MINCOD routing algorithm demonstrates the advantages of using a routing algorithm which balances the traffic load not only considering the shortest path but also taking into account the minimum shared links between the pre-computed end-to-end routes. The PR-MTD RWA algorithm assigns wavelengths according to the MTD physical impairment, but also taking into account the inaccuracy of the network state information. The proposed PR-MTD algorithm achieves a trade-off between the performance in terms of blocking probability and of the signalling overhead.

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