Technological Forecasting & Social Change xxx (xxxx) xxx–xxx

Contents lists available at ScienceDirect

Technological Forecasting & Social Change

journal homepage: www.elsevier.com/locate/techfore

The capacity expansion approach in optical transport networks with fixed and flexible grids

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ARTICLE INFO

Keywords:
Technology upgrade, WDM networks
Capacity planning
Demand forecasting

ABSTRACT

This paper addresses the issue of the backbone infrastructure capacity planning of WDM optical network related to upgrading of the existed fixed grid with the flexible grid technology. In order to determine the appropriate time for making the technology migration we propose a novel approach that is based on the penalty function as well as on the Blocking Bandwidth Ratio (BBR) metric. The penalty function depends on the forecasted traffic demands and relates to the congestion level of the considered link. According to these indicators the upgrade plan is determined. Through the case study the proposed approach is demonstrated.

1. Introduction

The expansion of network capacity became the standard part of the network operators' strategic decisions, considering the constant rise of the Internet traffic volumes caused by the rapid development of the digital market. The correlation between the growth of highly consuming Internet services and the growth of internet traffic volumes could be confirmed by many global reports, such as (Akamai Technologies, 2016; Cisco Systems, 2014). This fact creates the need for developing of the efficient tool for network upgrade decision timing, which leads to the significant cost savings for network operators.

Existing backbone/long-haul WDM networks which connect different regions and/or metro areas operate mostly using the fixed spectrum grid at the 50 GHz granularity (ITU-T G.692) (International Telecommunications Union (ITU), 1998), regardless of real throughput carried by each channel. This might lead to inefficient spectrum utilisation that reflects to the revenues for network operators. By slicing the spectrum into finer configurable slots of 12.5 GHz granularity, the flexible-grid technologies can efficiently overcome these limitations for the purpose of the on-demand provisioning. Considering the investments needed for the new technology implementation, it is not cost effective to make technology upgrade of the whole network. Rather, the partial network capacity expansion realized through the upgrade of certain number of bottleneck nodes by forming the “flexible islands” (Yu et al., 2015) makes a more acceptable scenario from the network operator's perspective. In this way, the already-implemented fixed-grid WDM equipment could be preserved. This implies the coexistence of fixed and flexible grid technologies, making it challenging from the network planner's perspective, in both, the space and time domain. The interoperability of fixed-grid and flexible-grid technologies is an actual issue that is analysed in the recent works (Yu et al., 2015; Ruiz et al., 2014).

The next-generation broadband networks will enable access to the applications (the Internet of things, big data, mobile technologies, cloud computing and data storage). In order to achieve these targets it is necessary to provide broadband Internet access at a speed of at least 100 Mbps to 96% of households by 2020 and a speed of not less than 30 Mbps to the remaining percentage of households (Skouby et al., 2014; Zhao et al., 2013a). Our investigation is according to this perspective. Considering this future level of demands at the broadband services market, the capacity upgrading of the network resources becomes the crucial task of the network planning process.

The reliable demand forecast is very important input for capacity upgrading of the optical network resources. For this purpose, we applied the diffusion theory to forecast traffic demand (Mahajan et al., 2000). The basic Bass diffusion model was chosen to forecast the future traffic growth of total fixed broadband access services/technologies at the telecommunication market (Bass, 1969). Considering the coexistence of above-mentioned optical technologies and the need for effective return on investments, it could be worth to investigate how long the already installed fixed-grid network equipment could be used on the certain network link.

This paper proposes a novel approach for determination the input parameters for the capacity expansion plan of the backbone WDM link. Due to a high speed of traffic changes we introduced the penalty function as well as the Bandwidth Blocking Ratio (BBR). The main innovative aspect of our research is related to combine these two metrics in order to decrease uncertainty of the forecasted demands. The

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http://dx.doi.org/10.1016/j.techfore.2017.10.009
Received 29 May 2017; Received in revised form 26 September 2017; Accepted 6 October 2017

proposed approach gives the appropriate time for making decision about the capacity expansion of a certain fixed-grid WDM link during the considered period, regarding the scenario of the enlargement of "flexible island(s)". The proposed approach is demonstrated in the case of a given optical network. The forecasted fixed broadband traffic is obtained by diffusion theory.

The remainder of this paper is organized as follows. Section 2 surveys the related works. Section 3 gives the statement of the WDM link capacity expansion problem. The proposed approach is presented in Section 4. The case study provides the experimental results in Section 5, followed by the conclusions at the end of the paper.

2. Related works

Different approaches were proposed for the network capacity expansion/upgrade problem. Some of them related to fixed-grid WDM technology (Pickavet and Demeester, 1999) considered the long-term WDM network planning problem. These authors proposed three different models in order to compare the cost implications of these approaches on network expansion decisions, depending on different dynamic characteristics of network planning. Also, in (Melián et al., 2004) authors developed the optimal upgrading plan by mixed integer programming (MIP) model with the aim to find the best solutions to place the additional optical fibers, optical cross-connects (OXCs) and other WDM components within the given network at minimal costs. However, this model did not treat the traffic demands as uncertain. Considering the previous approaches related to the flexible-grid technologies, in (Papanikolaou et al., 2015) authors proposed integer linear programming (ILP) model that considered the capital expenditure of modular IP/MPLS routers at the optical network edges in the multilayer flex-grid network planning model. Shakya et al. (2015) proposed an ILP model to formulate the time-varying traffic assignment problem in flex-grid networks. The authors also proposed three novel spectrum assignment schemes heuristics based on the interference graph (IG) technique.

Recent researches consider deployment of the flexible-grid technology covering various aspects. In (Meusburger and Schupke, 2009) the impact of including forecast knowledge to the routing and aggregation decisions has been investigated, in terms of overall capital expenditures. However, this approach did not include the traffic demand forecast. In (Tahon et al., 2013) the problem of partial deployment of flexible-grid technology within the existing fixed-grid network has been considered in term of traffic grow uncertainty impact on the upgrade investment decision. The different technologies migration scenarios have been introduced. However uncertainty is considered only in general. In (Ruiz et al., 2014) the flexible-grid island is introduced as a key element of such a technology migration. This research introduced the migrating flowchart regarding the all-term planning process, also identified certain optimization issues related to the network reconfiguration, as well as key drivers needed to make the successful planning process. Yu et al. (2015) introduced different migration strategies, which have been discussed in the presence of several scenarios regarding the concept of "flexible islands". The coexistence of fixed-grid and flexible-grid technologies within the same optical network has been identified by these authors as research challenge, leaving some issues still opened.

However, abovementioned works have been mostly technology perspective oriented. Some other papers like (Peres et al., 2010; Todd and Doucette, 2017) pay attention to the market drivers and social influences. Generally the diffusion models have been proposed for capturing the lifecycle dynamics of new product/services (Mahajan et al., 2000). The most important model in this stream of research is the basic Bass model (Bass, 1969). In (Turk and Trkman, 2012) it has been shown that the basic Bass model is well suited to estimate broadband diffusion. The main advantages of the basic Bass model are given in (Bass et al., 1994). The later models mainly represented the modifications of the existing one, such as (Krishnan et al., 2000). The paper (Mahajan and Peterson, 1978) gives the necessary assumptions which should be satisfied for the Bass model application. Further, the cumulative number of fixed broadband users function has been used to obtain the forecasted traffic demands according to Stordahl's traffic forecast model for the transport network (Stordahl et al., 2002). Similar approach is applied in (Radojicic et al., 2012) and (Jensen, 2003). In our research, we applied the basic Bass diffusion model as suitable approach to forecast the fixed-broadband market.

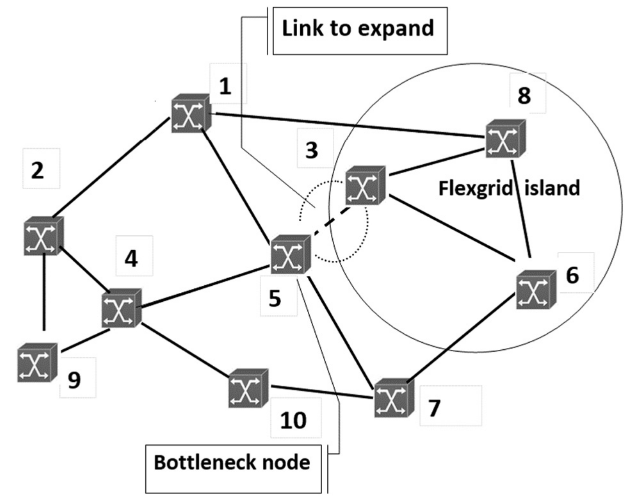

Fig. 1. The topology of gradually upgraded fixed-grid network.

3. The capacity expansion problem

We study the capacity expansion problem of the critical link in the gradually upgraded fixed-grid optical network example, shown by Fig. 1. It connects a number of larger regions/metro areas (represented as nodes) with different broadband service demands. Several nodes, identified as bottlenecks are upgraded with flexible-grid technologies. In this way, the "flexible island" is created due the coexistence of fixed-grid and flexible-grid nodes.

The illustration of such coexistence is shown by Fig. 2, where the fixed-grid node is located between two flexible-grid nodes. In this example, the flexible-grid node generates demand of 200 Gbps toward the other flexible-grid node (through the fixed-grid node) by setting up two lightpaths, each with the capacity of 100 Gbps.

The link is considered as "critical" if it connects fixed-grid node to the flexible-grid node. The 50 GHz granularity certainly imposes the fixed-grid node to become a candidate for the "flexible island" enlargement. Such node becomes the network bottleneck when it begins to suffer due to exhaustion of available wavelengths. Thus, it becomes unable to participate in the process of establishing new lightpaths. If such an issue occurs, it is necessary to upgrade it to the flexible-grid technology by the "flexible island". In this way the traffic losses could be overcome. Besides, it is important to determine an appropriate time when upgrading procedure should be initiated. If the upgrading is realized too early, the available resources utilisation couldn't be at the satisfactory level. In addition, the equipment price could be higher considering the price decline in general. On the contrary, if the upgrading comes too late, the traffic losses will be significant, which might lead to the customers' dissatisfaction and the loss of service provider's revenue.

4. The proposed approach of capacity expansion plan

The main goal of this approach is to determine the best capacity expansion plan considering the future traffic demand. Unlike previous research, the proposed approach introduces two metrics, which are