LIGHTPATH SURVIVABILITY WITH QOT GUARANTEES

Key Issues in Wavelength-Routed Photonic Networks

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Abstract: The Routing and Wavelength Assignment (RWA) problem has been extensively studied over the last decade, but only in recent years algorithms were specifically developed (or adapted) to consider transmission layer physical impairments in photonic (all-optical) networks, while providing lightpath survivability. This work discuss the last contributions in the field, and presents a new impairment-aware RWA algorithm for survivable photonic networks. As a work in progress, the new algorithm is presented with open design decisions.

1 INTRODUCTION

Nowadays, the Internet backbone traffic is mainly carried by Wavelength Routed Networks (WRN) based on WDM lines due to the high capacity, low Bit Error Rate (BER) and low per-bit monetary transmission cost of these systems. In order to setup a lightpath (LP), i.e., an optical circuit between two nodes, a route must be calculated and available wavelengths must be allocated in all links that compose the path. This problem is NP-complete, and is known as Route and Wavelength Assignment (RWA). It has been extensively studied in the last decade considering different aspects, mainly minimization of resource allocation, online operation and LP survivability. For online operation, usually the RWA problem is divided in two sub-problems that are solved separately: first, a shortest path algorithm is used to compute the route, then an heuristic is used for wavelength allocation.

With the advance of DWDM systems (carrying hundreds of channels per fiber, each one operating at rates up to 40 Gb/s), the electronic processing at the nodes has became a bottleneck. To overcome this problem, all-optical (or photonic) crossconnects (PXCs) that do not realize optical-electrical-optical (OEO) conversion were introduced, and meshed WRNs based on PXCs without wavelength conversion capabilities (all-optical wavelength conversion is still an immature technology) are slowly being deployed. As a side effect of OEO absence, signals are not regenerated at each hop anymore, and accumulate transmission impairments that affect the QoT and consequently the BER at the end node. Impairments-aware RWA (IA-RWA) algorithms have being envisaged, using different network impairment models, resulting in different performance (Azodolmolky, et al., 2008). However, specifically regarding network survivability, the IA-RWA problem is even more complex, and a reduced number of works is available (Zhai, et al., 2007).

In the first part of this work, the most recent IA-RWA solutions for Survivable Photonic WRNs are reviewed. Aspects such as key issues, design decisions and performance evaluation metrics are discussed. The second part presents the IA-RWA for survivable networks being developed by the authors. Comparisons between the algorithm under study and the previously presented works are also depicted. At the end, conclusions are shown.

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2 SURVIVABLE IA-RWA

Generally speaking, the main goal of all survivable IA-RWA algorithms is to provide LP resilience. Despite that fact, they can be designed in very different ways, depending on the constraints considered for the WRN itself but also for the LPs. Survivable IA-algorithms can be classified in function of the network impairment model used, the type of the combined IA-RWA process, the type of resilience and the quality levels offered (evaluated using ad-hoc performance metrics). In the following subsections the most recent IA-RWA solutions (Zhai, et al., 2007; Askarian, et al., 2008; Kim, et al., 2008; Markidis & Tzanakaki, 2008; Jirattigalachote, et al., 2009) are reviewed under the perspective of each of these characteristics.

2.1 Network Impairment Models

Transmission in optical fibers is affected by a number of physical impairments. The most relevant are intersymbol interference (ISI), amplified spontaneous emission (ASE), polarization mode dispersion (PMD) and node and interchannel crosstalking (Zhai, et al., 2007). The predominant impairment depends on many factors, like the quality of fibers and node components, the LP optical signal power and bandwidth, and the wavelength spacing between channels.

All of the cited works consider ISI, ASE and both crosstalking forms as noise-like terms, and the sum of their variances is accounted for the Q factor calculation, which is a signal-to-noise ratio. The LP BER is estimated in function of the Q factor with a simple equation.

PMD was ignored in all works, because it is relevant only at data rates of 40 Gb/s and beyond.

2.2 RWA Combined Process

As stated by Azodolmolky, et al. (2008), the routing, wavelength assignment and QoT evaluation processes can be combined in many ways, with different levels of complexity and performance. The best (and most complex) IA-RWA algorithms consider the physical impairments during the RWA phase, and also estimate the BER of the candidate LP.

Three of the reference works divide the IA-RWA problem in two sub-problems. To calculate the work and backup paths, it was used fixed-alternate routing with Yen's algorithm (offline) and Dijkstra algorithm (online). Non IA-routing used link length as link cost metric, and IA-routing used the Q-penalty metric (Markidis & Tzanakaki, 2008), that is also calculated as noise-like terms. The wavelength Assignment was realized using the following algorithms: First Fit (FF), Last Fit (LF), Best Fit (BF), Random Pick (RP) and Most Used (MU). It is important to note that these heuristics present different behavior in ideal networks and physical impaired networks (He, et al., 2009). Zhai, et al. (2007) and Markidis & Tzanakaki (2008) presented single-phase RWA process, where the shortest path for each wavelength plane is calculated.

All proposals evaluate the BER of candidate LPs. If the BER is under a predefined value (usually Q factor equal to 6 or 7), the request is blocked.

2.3 Protection and Restoration

LP resilience can be pre-configured or just pre-planned. In both cases the backup LP is already computed, but only in the former case the resources are already allocated to the backup LP. If the backup LP carries the same traffic as the working LP even before failure, this kind of resilience is called 1+1 dedicated protection. If the backup LP is used for Best Effort traffic or not used at all, it is called 1:1 dedicated protection. Protection is very efficient (service disruption is inferior to 50 ms), but is also the most expensive kind of resilience.

Pre-planned resilience is also called restoration, and can be dedicated or shared. In both cases the wavelength remains unused in the fiber links until the restoration mechanisms are activated. Therefore, the fiber remains “dark”, at least for that particular channel. In the case of shared restoration, a wavelength reserved for shared backup remains free to be used in other shared backup path computations, i.e., it can (and possibly will) be used to protect more than one LP. Restoration is better for the overall network QoT, because the backup LPs remain dark and do not interfere with the QoT of the working LPs. Also, shared restoration improves the network resources utilization. On the other hand, when a LP must be restored through a pre-planned computation, there is no guarantee that a) it will satisfy the required BER and b) it will not compromise the QoT of other established LPs. That situation is even worse in the case of shared restoration. That happens because when a new LP must be setup, the IA-RWA engine does not take into account the physical impairments of dark wavelengths used to restore LPs.

All kind of resilience described in this section are investigated in the referred works, with interesting results.

2.4 Performance Evaluation Metrics

Usually, IA-RWA algorithms are evaluated through simulations using either real-world topologies (like the classic 14 nodes NSF topology) or mesh toroid networks due to the high degree of symmetry and connectivity. Results are in the form of the blocking probability in function of the traffic load. Other interesting metrics found in the cited works are:

- Vulnerability Ratio or QoT-Vulnerability: the probability that, in the case of a link failure, a pre-planned backup LP cannot be restored due to unacceptable QoT;
- Cascading Failure Vulnerability: the probability that a given LP become unusable due to physical impairments induced by the activation of pre-planned backup LPs;
- Failure Ratio: it is defined as the ratio between the number of connections that are not recovered due to unacceptable QoT to the number of working LPs affected by a link failure. It is averaged over all single link failures;
- Running time: The time needed to compute the LP from the instance of request arrival. Interesting values are the average and worst case scenario.

2.5 LP Application

LPs are used by the clients of the optical layer to transport two types of traffic, basically: mission critical and non-critical applications traffic. The former requires strict QoT guarantees and protection mechanisms (downtime can be as low as 5 min per year), usually remains active for very long periods but do not require a short setup time. On the other hand, non-critical applications require a short setup time, but have loose requirements regarding QoT and resilience. An IA-RWA must be designed to satisfy one or another type of LPs, due to the tradeoffs involved. Most of the IA-RWA algorithms presented in the referred works have different versions with protection and restoration.

3 PROPOSED ALGORITHM

The objective of the proposed algorithm is to compute LPs with dedicated 1+1 or 1:1 protection, with assured QoT and survivability. The main goal is to satisfy these conditions while minimizing the resource allocation.

Different from the referred works, the network impairment model used in the proposed IA-RWA is not based on the sum of noise-like terms (one for each dominant impairment), but instead is based on the minimum and maximum power constraints. The minimum power constraint, which is best known as sensitivity level, assures that optical signals can be properly detected by all optical devices. Thus, the survivable IA-RWA algorithm not only gives a path and a wavelength for each of the LPs (work and backup), but also the optical power that must be injected at the ingress PXC in order to guarantee the requested BER at the egress PXC. The maximum power constraint imposes a limit to the optical power on fiber links. This way, the fiber nonlinearities (that are completely power-dependent, such as channel crosstalking) can be indirectly managed. The network impairment model and the impairment validation process of the proposed algorithm are based on the ASE noise and on the desired Q factor, and use the analytical model discussed by Pavani, et al. (2008).

The first part of the algorithm solves the RWA problem in a combined way. For each wavelength available to use at the source node (i.e., the wavelengths that the available transponders at ingress PXC can tune), a couple a disjointed shortest paths is calculated using the Suurballe algorithm. Physical impairments are considered during the RWA phase as the link cost metric. The cost of a given fiber link is a function of the residual wavelength and optical power capacity. Thus, the lower is the number of used wavelengths and the total optical power that traverses a link, the lower will be its cost. Another strategy introduced by the proposed algorithm in order to minimize the blocking probability is the Critical Link Avoidance (CLA). The “altruist” idea of avoiding using particular links to save them for future requests was introduced by the Asynchronous Criticality Avoidance (ACA) protocol. Except for sharing this concept, CLA technique is completely different from ACA by any perspective. All links that are labeled as critical are initially pruned from the physical topology. If, after the first attempt, no path is found in any of the wavelength planes, the process is repeated again, but this time considering all critical links. To define a link as critical, upper bounds for the wavelength use and total optical power are being considered.

After the IA-RWA phase, the BER is verified in all work and backup LP candidates. All work-backup LP pairs which the BER is too high or whose links can not accommodate their share of optical power (due to the maximum power constraint) are removed from the list of candidates. It is still to be decided if a work-backup LP pair is to be removed if only the backup LP do not met with the BER requirements. After this step, all candidate LPs are known to satisfy the BER requirements. At this point, the final LP pair selection must take place. To effectively choose the best candidates, a number of simple heuristics are being considered. Simulations must be performed to determine which ones are relevant, and in which order. When more than one candidate matches the criterion, the matched ones are compared on the basis of the next criterion. When only a pair of LP candidates are left (not necessarily with the same wavelength), these are the work and backup LP to be established. The heuristics to be considered (so far) are:

- lowest number of critical links;
- LP pair that uses the same wavelength, if the cost difference between the work and backup LPs (in terms of number of hops and/or transmission power) is bellow a given upper bound;
- lowest transmission power;
- lowest number of hops;
- LP whose wavelength is the FF, MU or other wavelength assignment heuristics.

4 CONCLUSIONS

The RWA problem is a well studied area, but only in the last years works were conducted considering fully transparent (photonic) WRNs, physical impairments and LP survivability. In this work, some of the last contributions in the survivable IA-RWA field were reviewed. It was discussed the network impairment model used, the mechanisms for routing, wavelength assignment and physical impairments validation, and the proposed performance evaluation metrics. It was also presented a new survivable IA-RWA algorithm to compute LPs with dedicated 1+1 or 1:1 protection, with assured QoT and survivability. The proposed algorithm uses a different impairment model based on sensitivity and maximum power constraints, and uses the wavelength load and total optical power as metrics to define the link costs and the criticality levels. The introduced CLA saves critical links in order to minimize the blocking probability.

Simulations are needed to be carried out to verify if the added complexity minimizes the blocking probability of setup requests. The performance evaluation metrics and topologies introduced by the referred works must be considered.

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