Quantifying the Benefit of BER-based Differentiated Path Provisioning in WDM Optical Networks

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ABSTRACT
In this paper we propose the use of Bit Error Rate (BER) as a differentiation of service parameter for connection provisioning in optical Wavelength Division Multiplexing (WDM) networks. This is achieved through the use of Impairment Constraint Based Routing (ICBR), whereby various BER thresholds are set for accepting/blocking requests at the connection provisioning phase, depending on QoS requirements. The performance of the proposed scheme is evaluated through simulations, using dynamic traffic demands as an input at 10 Gb/s bit rate. The evaluation results reveal significant improvement in term of connection blocking, as compared to non-differentiated conventional RWA and ICBR algorithms.
Keywords: impairment constraint based routing (ICBR), differentiation of services, signal quality, physical impairments, transparent optical networks

1. INTRODUCTION

Transparent optical WDM networks constitute a promising solution to cater for the rapid growing of bandwidth demand in next generation networks and the future Internet. In such networks, the signal is transported from source to destination nodes in the optical domain through all-optical channels (lightpaths), without intermediate optoelectronic conversion. Many routing and wavelength assignment (RWA) algorithms [1], [2] that have been proposed for lightpath provisioning base their routing decisions on the availability of network resources, and assume that optical fibres and components are ideal. In reality, however, physical impairments inherent in transparent optical networks degrade the quality of the optical signal propagating through fibre segments and optical components [3]. As a countermeasure, Impairment Constraint Based Routing (ICBR) that considers physical impairments during connection provisioning is developed in order to prevent selecting the lightpaths with poor signal quality.

Furthermore, next generation networks and the future Internet are expected to support a variety of services with potentially disparate QoS requirements, such as peer-to-peer (P2P) applications, high definition television (HDTV), Audio Video On Demand (AVOD). Despite the varying requirements of these services in terms of signal quality, bandwidth, delay, etc., state of the art ICBR schemes [4], [5] treat all connection requests in a flat-based manner, i.e. support a single signal quality requirement uniform to all requests, independently from the characteristics of the applications requesting connection provisioning. Furthermore, most of existing ICBR schemes always select the path with lowest BER (impairment-aware best-path IABP routing). This flat-based approach may unnecessary block requests that could sustain a higher BER than the single BER threshold used by a flat-service ICBR scheme. For these lower requirements requests that are accepted, the flat schemes allocate more resources than necessary. To overcome these deficiencies, this paper proposes and evaluates a novel ICBR algorithm supporting differentiation of services at BER level.

2. SERVICE DIFFERENTIATION APPROACH

In this section, we present our novel ICBR algorithm that is capable of supporting service differentiation based on requested BER level.

2.1 Definitions and Assumptions

In this paper, we assume that a bandwidth demand of each connection request is one wavelength unit and that wavelength conversion capability is not available, i.e. wavelength continuity is also a constraint in our routing problem. Furthermore, the proposed algorithm assumes random, dynamic incoming connection requests that are sequentially served without prior knowledge of future incoming requests.

As mentioned earlier, we propose a novel ICBR algorithm supporting differentiation of services, whereby connection requests are divided into two distinct classes with regards to signal quality requirements, i.e. Class-1 requests that require higher signal quality in the term of maximum tolerated BER and Class-2 requests that can tolerate quality degradation higher than Class-1, but yet up to a given threshold. An additional asset of our proposed algorithm is a novel path selection scheme that chooses the path with maximum BER from the set of k feasible paths, unlike path selection in traditional impairment-aware best-path (IABP) routing, where the path with minimum BER is chosen, our path selection scheme provides for more efficient resource utilization.

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In this work, the effect of physical impairments is quantified by using the quality factor Q, following the work presented in [5]. The considered Q-factor includes both linear and nonlinear physical impairments, namely Amplified Spontaneous Emission (ASE) noise, Four-Wave Mixing (FWM), the combined Self-Phase Modulation/Group Velocity Dispersion (SPM/GVD) and optical filtering effects, and Cross-Phase Modulation (XPM). ASE, FWM and XPM are calculated assuming they follow a Gaussian distribution. For the combined SPM/GVD and optical filtering effects, they are quantified through an eye closure penalty metric calculated on the most degraded bit-pattern.

2.2 Proposed Algorithm

In Fig. 1, the flow chart of the proposed algorithm is presented. The algorithm starts with an initialization phase collecting the network topology information, e.g. number of nodes, number of links, link lengths, link capacities, and the physical parameters required for the calculation of the Q-penalty of each link.

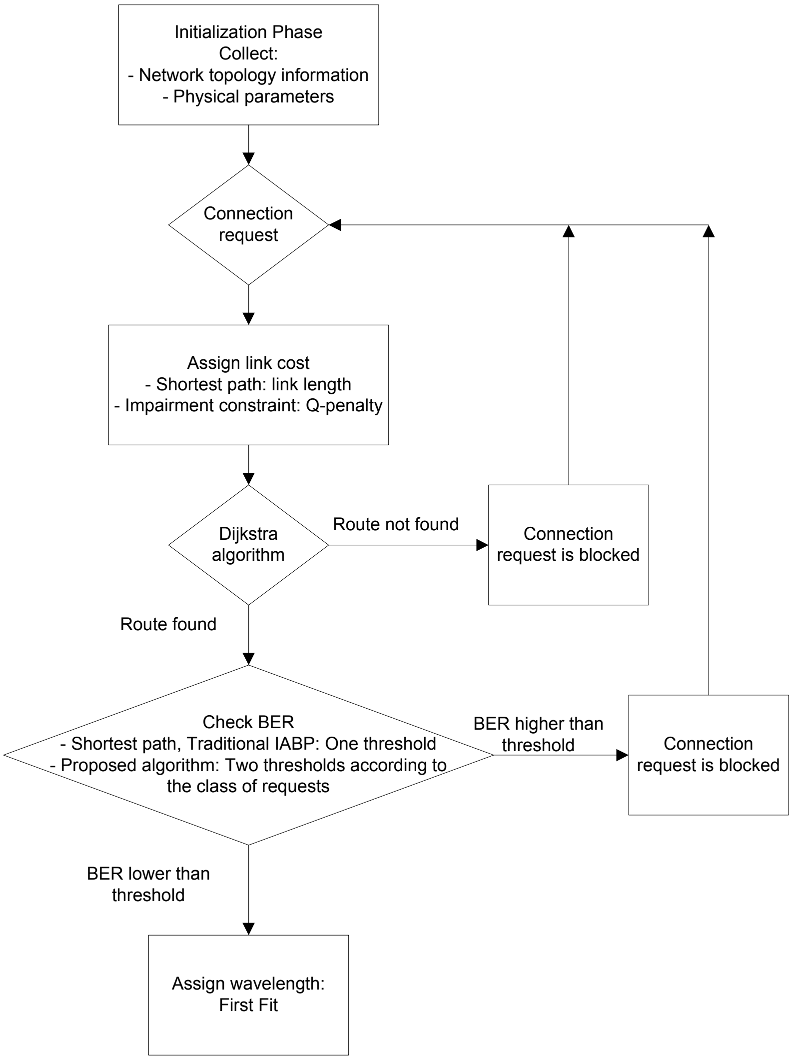


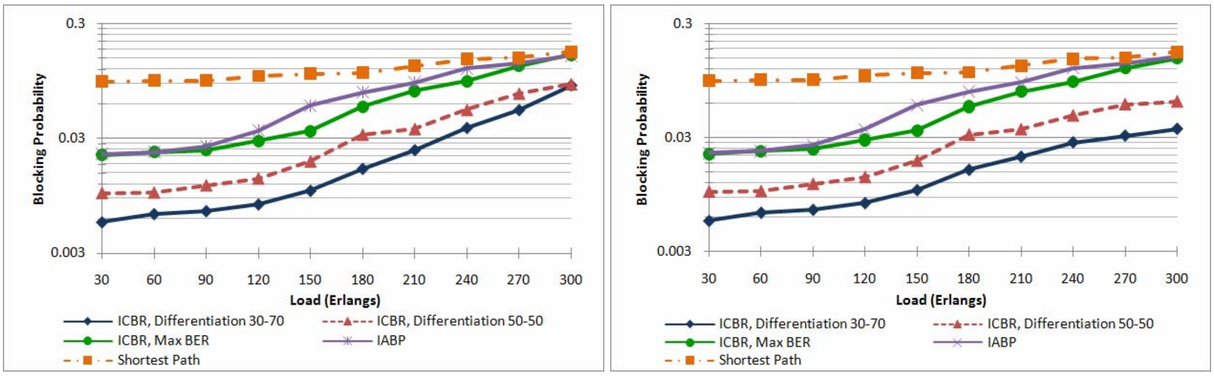
Figure 1. Flowchart of the proposed algorithm.

There are two routing algorithms, shortest path and impairment constraint routing. The cost of each link is assigned according to the chosen routing algorithm. In the case of the shortest path approach, link length is used as link cost, while Q-penalty is considered as link cost for the impairment constraint approach. In addition, the cost of a link is set to infinity if all wavelengths on the particular link are occupied by already provisioned lightpaths. After assigning link costs, the *k* alternative routes for each connection request are computed by using the Dijkstra algorithm. If there is at least one common available wavelength on every link of the found route, this route is stored in the set of candidate routes. Otherwise, if no route is found, the request is blocked. Next, the BER of candidate routes is calculated. In the case of shortest path routing, the shortest route of the set of candidate routes is selected first and the BER of this route is calculated. In the cases of traditional IABP algorithm and our proposed algorithm, the BER of all candidate routes is calculated. If the BER of the selected shortest route doesn't satisfy the signal quality requirement, i.e. single BER threshold independently from the class of requests, then the respective connection request is blocked. In the case of our proposed algorithm, the

BER of each candidate route is compared against the signal quality requirement of the request, i.e. different BER thresholds according to the class of requests, and the route with maximum BER that satisfies the signal quality requirement is selected. In contrast, in the case of the traditional IABP algorithm the route with minimum BER is selected and compared against the single BER threshold. In traditional IABP and our proposed algorithm, if none of candidate routes satisfies the signal quality threshold, the request is blocked. Importantly, our algorithm implements different BER thresholds according to the class of requests, while for shortest path approach and traditional IABP approach there is only one BER threshold independently from the class of requests. Finally, the first wavelength of a list of available wavelengths of the selected route is chosen (First-Fit) to form the lightpath for the request.

3. PERFORMANCE EVALUATION

Our proposed algorithm is evaluated through simulation, using the Pan-European test network topology defined by COST 239 [6] as input. The topology comprises 11 nodes and 26 bidirectional fiber links with 16 wavelengths per fiber. IP traffic measurements of today's Internet [7], [8] show that peer-to-peer and World Wide Web (WWW) traffic dominates bandwidth utilization (97% of the total traffic), whereas streaming media traffic accounts only 3% of total bandwidth utilization. Hence, in this study we differentiate between two distinct classes of connection requests with regards to signal quality requirements quantified via BER. Throughout our simulations, Class-1 and Class-2 requests require BER less than 10^{-15} and 10^{-9} respectively. According to the algorithm proposed herein, a Class-1 connection request is blocked, if there is no lightpath connecting the two endpoints of the request that exhibits BER less than 10^{-15}; whereas a connection request of Class-2 is blocked if there is no lightpath with BER less than 10^{-9}. For benchmarking purposes, we also evaluate two other provisioning algorithms, namely shortest path and IABP. Essentially these two approaches do not employ service differentiation, but instead they handle both Class-1 and Class-2 uniformly and block any request (independent of service class), if there is no lightpath with BER less than 10^{-15} available. Also ICBR with path selection based on maximum BER, but without service differentiation, i.e. single BER threshold, is evaluated. In our experimental model, incoming connection requests follow a Poisson distribution, and source/destination pair per request is randomly chosen among all nodes with equal probability (uniform distribution). Also, the lifetime of established connections is specified at provisioning time using random exponentially distributed time durations. In our experiment we considered two cases in respect to the traffic composition, i.e. input workload of 30%-70% and 50%-50% of Class-1 requests and Class-2 requests. For each input network load value (measured in Erlangs), the blocking probability is recorded after the steady state is detected (transient interval is removed) and we execute enough number of repetitions until the 90% confidence interval of measured mean blocking probability becomes less than 10% relative to the measured mean.



(a) *(b)*

Figure 2. Blocking probability versus load (a) Total blocking probability.
(b) Blocking probability due to impairments.

Our simulation results are presented in Fig. 2. The total blocking probability shown in Fig. 2a accounts for both blocking due to insufficient resources, i.e. either no route or wavelength is available, and due to impairment constraints, i.e. when the candidate routes cannot meet the signal quality requirement. We additionally show the probability of connection blocking due to impairments solely in Fig. 2b. The results show a significant improvement in terms of blocking achieved by our proposed algorithm (ICBR with BER-based differentiation of services), as compared to both shortest path and conventional IABP routing. In addition, the results reveal that ICBR with path selection based on maximum BER yields slight improvement in blocking, as compared to the IABP algorithm. Specifically, when Class-1 and Class-2 requests account for 30% and 70% of the total requests respectively, the benefit achieved by our algorithm is up to 11% and 9%, compared to shortest path and IABP algorithms, respectively. For the case, where Class-1 and Class-2 requests are equally weighted, the benefit reduces to 9% and 7%, compared to shortest path algorithm and IABP algorithm, respectively. The latter is due to our algorithm providing for a lightpath that is just good enough for the signal quality requirement of each service class request, leading to more efficient utilization of resources and thus avoiding unnecessary impairments blocking.

By studying Fig. 2a against Fig. 2b, it can be seen that total blocking for low traffic load is mainly due to impairments, while in high load condition the resource blocking has higher impact on the total blocking probability. For example, it can be seen in Fig. 2a that at load of 300 Erlangs the total blocking probability for 30% – 70% is nearly the same as for 50% – 50%, although the blocking due to impairments at the same traffic load, as shown in Fig. 2b, for the case of 30% – 70% is 3% lower than the impairments blocking of 50% – 50%. This is because in the case of 30% - 70% more lightpaths are established, compared to the case of 50% – 50%. Thus, there may not be enough resources for incoming connection requests and, consequently, the total blocking probability (i.e., the sum of resource blocking and impairments blocking) will be higher.

4. CONCLUSIONS AND FUTURE WORK

In this paper we proposed a novel Impairment Constraint Based Routing algorithm with differentiation of service based on Bit Error Rate (BER) of a lightpath provisioned for each connection request. In contrast to the existing ICBR and IABP algorithms, in our approach BER is considered as a routing constraint that corresponds to the signal quality requirement of connection requests. Simulation results indicate a significant improvement in blocking probabilities of up to 11% and 9%, compared to the shortest path and impairment-aware best-path (IABP) approaches, respectively.

In the future work we will study our ICBR algorithm supporting differentiated signal quality requirement, applied to dedicated and shared path protection schemes. Furthermore, we will extend our work by investigating the effect of the heterogeneity of optical parameters in WDM networks.

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