Experimental Evaluation of a Dynamic PCE-Based Regenerator-Efficient IA-RWA Algorithm in Translucent WSON

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Abstract *We devise a novel dynamic PCE-based impairment-aware RWA algorithm in translucent GMPLS WSON that minimizes regenerator usage. Experimental evaluation carried out on the Open GMPLS/PCE control plane of CTTC ADRENALINE test-bed shows that significant improvements (>340%) are attained in terms of the offered traffic load.*

Introduction

Translucent networks allow deploying regional-scale, e.g. European, optical networks meeting end-to-end quality of transmission (QoT) of optical signals. 3R regenerators are placed at some intermediate nodes and used when a signal needs to be electrically regenerated before arriving to the receptor. Being regenerators expensive resources[1] their use must be optimized.

When optical signals are propagated from transmitter to receiver its QoT is degraded as a result of physical layer impairments which might cause high bit error rate (BER) at the receiver. QoT can be evaluated at the destination node of a lightpath by computing the optical signal-to-noise ratio (OSNR)[1].

Translucent wavelength-switched optical networks (WSON) can be controlled by using the GMPLS protocol suite so to set-up and tear down optical connections dynamically[2]. In that context, impairment-aware routing and wavelength assignment (IA-RWA) algorithms have been proposed in the literature to compute end-to-end translucent optical connections consisting in a succession of transparent lightpaths that meet some OSNR requirement[1,3]. Each lightpath is computed by solving the IA-RWA problem subject to the wavelength continuity constraint (WCC).

A centralized Path Computation Element (PCE) can be used to solve the IA-RWA problem on demand. PCE is called to find routes and wavelength assignments meeting the required OSNR threshold for incoming connection requests. To this end, the Traffic Engineering Database (TED) containing the status of the resources in the network can be used.

In this paper we focus on dynamic translucent WSON and devise and experimentally evaluate a novel dynamic PCE-based IA-RWA algorithm which minimizes regenerators usage.

Translucent IA-RWA proposed algorithm

Before describing the IA-RWA problem, we need to introduce some notation. We are given a TED describing the network topology and the state of the resources (wavelength channels at every link and regenerators availability at every node). We represent that network topology by the graph $G(N, E, W)$, where N is the set of optical nodes, E is the set of optical links, and W is the set of wavelengths. Let $N_R \subseteq N$ be the subset of nodes with regeneration capability, and conversely $N_T \subseteq N$ the subset of nodes without regeneration capability. Thus $N = N_R \cup N_T$. Additionally, we are given a pair of source and destination nodes $\{s,t\}$ for the connection being requested.

The IA-RWA problem consists in finding a feasible route and wavelength assignment for the requested connection, so to minimize the number of regenerators needed to guarantee the QoT for that connection. As a secondary objective, the length of the route, in terms of number of hops, should be minimized.

To fulfill the regenerators minimization objective, we build an auxiliary directed graph (digraph) $\mathcal{D}_{st}(\mathcal{N}_{st}, \mathcal{A})$, where $\mathcal{N}_{st} = N_R \cup \{s,t\}$ and $\mathcal{A}$ is the set of directed arcs. Each arc $a=(u,v) \in \mathcal{A}$ connects two nodes $u,v \in \mathcal{N}_{st}$, where $u \in N_R \cup \{s\}$ and $v \in N_R \cup \{t\}$. An arc $a=(u,v)$ exists only if a feasible lightpath can be found between u and v in G, where the route has an acceptable OSNR level and the WCC is satisfied.

For illustrative purposes, Fig. 1 shows an example of auxiliary digraph construction. There, digraph $\mathcal{D}_{st}$ is built upon the reception of a connection request between nodes s and t. To this end, the set N_R with those nodes with regeneration capabilities currently available (colored circles) and nodes s and t belong to $\mathcal{N}_{st}$. Directed arcs are created connecting s and nodes in N_R to t and other nodes in N_R, provided that a feasible lightpath exists in G. In such scenario, routes {s,2,t} and {s,5,t} minimize the number of regenerators used. Note that other routes, such as {s,2,6,t}, being feasible, need more regenerators than the previous ones. To compute those routes, we label each node and link in *N* with the inverse of its linear OSNR level. Then, the RWA problem can be solved by using the Dijkstra's algorithm to find the best route between two nodes in terms of OSNR in graph *G*, and the first-fit heuristic for assigning a wavelength.

Finally, to solve the IA-RWA problem we use the proposed Translucent IA-RWA (TrIA-RWA) algorithm described in Table 1. We first compute a set of k-shortest paths between *s* and *t* in the auxiliary graph $\mathcal{D}_{st}$, so that the number of hops ($|\mathcal{A}(k)|$) equals that of the computed shortest path. This ensures that the number of regenerators is minimized (first objective). Next, each k-route is transformed to a translucent optical connection in graph *G,* expanding each transparent optical segment (lightpath) and using regenerators to stitch the segments. The translucent connection minimizing the total number of hops, $|E(x)|$, (second objective) is eventually returned.

A major concern regarding the above algorithm is scalability. Note that an auxiliary digraph $\mathcal{D}_{st}$ needs to be built to solve the IA-RWA problem for each single connection request. To solve that issue, a set of auxiliary digraphs $\mathcal{D}_S(N, \mathcal{A})$ are computed off-line and stored to be used upon the reception of connection requests. Note that $|N|$ digraphs are built, one $\mathcal{D}_S$ for each node *s* in *N*. In addition, although each digraph $\mathcal{D}_S$ contains all the nodes, being *s* the source one, the rules to construct each of the directed arcs are the same as above; only *s* and nodes in N_R can be source of arcs. At this stage, N_R contains the set of nodes where regeneration capabilities have been installed.

When a connection request (*s*,*t*) arrives, the algorithm gets the pre-computed digraph $\mathcal{D}_S$ and updates regeneration availability removing those arcs (u,v) in $\mathcal{A}$ where $u \neq s$ and *u* has not regenerators currently available. Next, algorithm in Table 1 is executed taking into account that solving the RWA problem for transparent segments may result into unfeasible routes (due to accumulated impairments) as a consequence of the current state of the resources.

The next section reports the conducted experimental performance evaluation of the proposed TrIA-RWA algorithm.

Table 1. Proposed TrIA-RWA algorithm

$SP \leftarrow$ Shortest Path (in terms of hops) in $\mathcal{D}_{st}$
if *SP* not found **then**
return BLOCK_REQUEST
$K \leftarrow$ {k-shortest paths (hops) in $\mathcal{D}_{st}$: $\lvert\mathcal{A}(k)\rvert=\lvert\mathcal{A}(SP)\rvert$}
$Q \leftarrow \emptyset$
for each $k \in K$ **do**
$q \leftarrow \emptyset$; $Q \leftarrow Q \cup \{q\}$
for each $a=(u,v) \in \mathcal{A}(k)$ **do**
$q = q \cup$ {expand *a* into a lightpath in *G*}
if $v \neq t$ **then** use one regenerator in *v*
return $x \in Q$: $\forall q \in Q$ $\lvert E(x)\rvert \leq \lvert E(q)\rvert$

Experimental results

Experimental evaluation of the TrIA-RWA algorithm described in the previous section was carried out in the Open GMPLS/PCE control plane of ADRENALINE test-bed[4]. Emulated optical nodes are controlled by a GMPLS control plane implemented on Linux-based routers with Intel Xeon 3 GHz processors. The connection requests are dynamically served by a dedicated centralized stateless PCE.

The TrIA-RWA algorithm was implemented in C++ and deployed as a callable algorithm in the PCE. Aiming at comparing the performance of the proposed TrIA-RWA algorithm, the IRWA algorithm proposed in [3] was also deployed in the PCE as a benchmark.

To experimentally evaluate the performance of both algorithms the European Optical Network

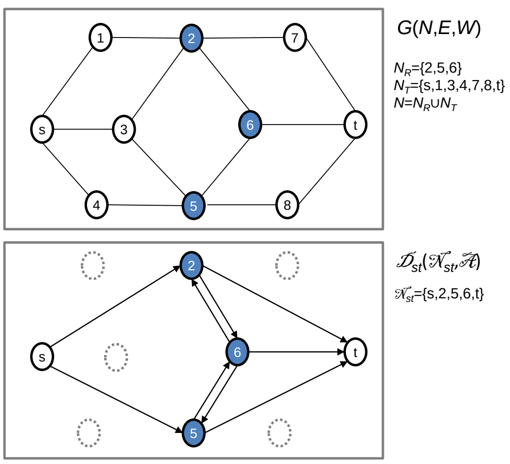

Fig. 1 Original (top) and auxiliary (bottom) graphs.

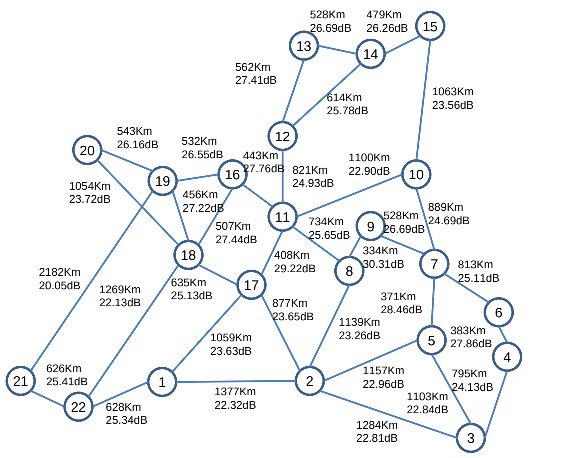

Fig. 2 22-node and 34-link EON. Length and OSNR values of the links are given.

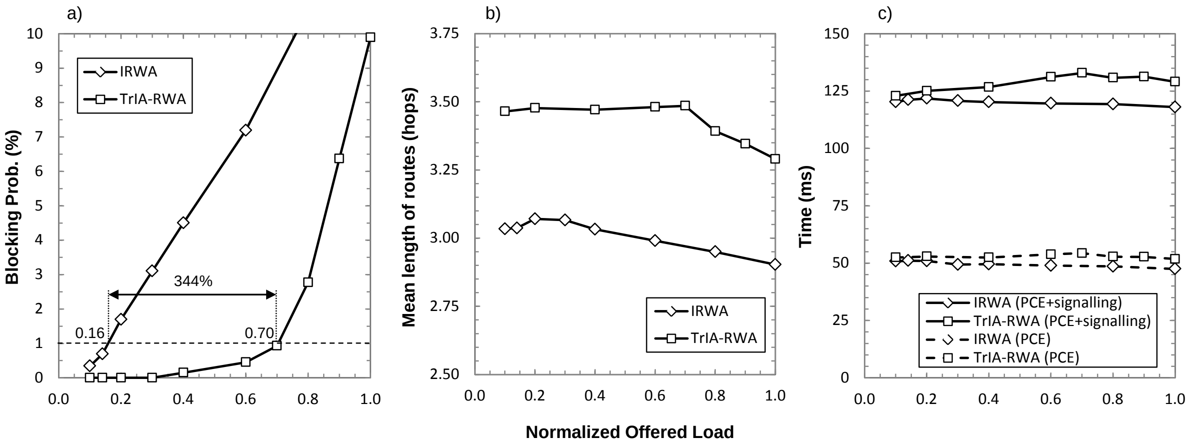

Fig. 3 Performance evaluation against normalized load. a) Blocking probability. b) Route length. c) Route computation and set-up times.

(EON) topology was deployed (Fig. 2), where each optical link supports 32 wavelength channels and each node was equipped with 3 regenerators. Fig. 2 details the OSNR levels for each optical link which is computed according to the fiber distance and the placed optical amplifier segments. In addition, nodes contribute with a fixed OSNR level set to 41dB.

Uniformly distributed connection requests arrive to the network following a Poisson process whereas connection holding time follows a negative exponential distribution. Different offered traffic loads to the network were used by fixing the mean inter-arrival time of the requests to 4s, so to ensure OSPF-TE convergence, and changing the mean holding time. We assume an OSNR threshold equal to 19 dB.

Fig. 3 evaluates the performance of the proposed algorithm, where each data point was obtained after requesting 10,000 connections.

Fig. 3a plots the blocking probability as a function of the offered traffic load, where traffic load has been normalized to the load where the TrIA-RWA algorithm unleashes a blocking probability equal to 10% (250 Erlangs). We can observe that TrIA-RWA clearly outperforms IRWA in the whole range of traffic loads. In fact, comparing the offered traffic load at 1% of blocking probability a gain of 344% is attained. This is due to the fact that TrIA-RWA uses regenerators more efficiently which in turn leads to increase the accepted traffic when compared to IRWA.

Fig. 3b shows the average length (in hops) of the routes for the established connections. We observe that using the IRWA shorter routes are achieved compared to the TrIA-RWA. The rationale behind that is that, when IRWA is used, connections with long routes (which needs regenerators) are frequently blocked resulting in higher blocking probability. In the case of TrIA-RWA, the length of the routes is constant until the load increases and blocking probability appears (load>0.7), where the mean length decreases as a consequence of that connections with longest routes are blocked due to the lack of free regenerators.

Finally, Fig. 3c examines the path computation and set-up times. As shown, TrIA-RWA takes slightly longer computation times, in the order of 6.5%, than that of IRWA. Regarding set-up times, which includes path computation and signaling, TrIA-RWA needs 7% more time than IRWA. The difference is as a result of the longer routes to be established when using the former.

Conclusions

A novel impairment aware RWA in translucent WSON, named TrIA-RWA, has been presented. The algorithm uses auxiliary digraphs to minimize regeneration usage and path length in terms of number of hops.

Results showed that using the TrIA-RWA algorithm more traffic load can be offered to the network. In fact, compared with other existing algorithm, a gain of more than 340% in terms of offered load can be obtained. In addition, it was shown that path computation and set-up times are in line with that of existing algorithms.

Acknowledgements

The research leading to these results has received funding from the European Community's Seventh Framework Programme FP7/2007-2013 under grant agreement no. 247674 STRONGEST project and by the Spanish Science Ministry through the ELASTIC (TEC2011-27310) and DORADO (TEC2009-07995) projects.

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