

Modulation Format-aware Re-Optimization in Flexgrid Optical Networks: Concept and Experimental Assessment

Ll. Gifre⁽¹⁾, R. Martínez⁽²⁾, R. Casellas⁽²⁾, R. Vilalta⁽²⁾, R. Muñoz⁽²⁾, and L. Velasco⁽¹⁾

⁽¹⁾ Universitat Politècnica de Catalunya (UPC), Barcelona, Spain. lgifre@ac.upc.edu

⁽²⁾ Centre Tecnològic de Telecomunicacions de Catalunya (CTTC), Barcelona, Spain.

Abstract A modulation format-aware algorithm to re-optimize resource utilization after a link repair is proposed. The proposed workflow implemented on an ABNO architecture and protocol extensions for SBVT and modulation format selection are experimentally assessed in a distributed test-bed.

Introduction

Sliceable Bandwidth-variable Transponders (SBVTs) enhance the configurability and flexibility of Flexgrid optical networks [1]. A single SBVT can be used to transmit and receive several optical signals each modulated with a specific format. A SBVT can be seen as a set of sub-transponders that can be specifically configured to end a specific *lightpath*, by defining, among other parameters, the modulation format and the central frequency to be used. Modulation formats are characterized by its spectrum efficiency and reachability. Therefore, when a new lightpath needs to be set up, not only the route and spectrum allocation (RSA) [2] needs to be computed, but also a modulation format must be chosen for the requested bitrate and the distance between source and destination nodes, thus defining the RSMA problem. This motivates that GMPLS control plane protocols need to be extended to convey information related to SBVTs and to specify the use of modulation formats when Label Switched Paths (LSP) are signalled [3].

When a failure occurs, a restoration algorithm running in the Path Computation Element (PCE) can compute a global solution for all the affected LSPs [2]. However, as result of the combined effect of longer routes and lack of resources, the bitrate of the restored LSPs could become squeezed. Consequently, when the failure is repaired, an in-operation planning algorithm [4] can be run to compute shortest routes that allow, not only save resources as proposed in [5], but also increase the bitrate of those LSPs which bitrate was squeezed.

Modulation Format-aware AFRO (MF-AFRO)

In this paper, we extend our previous work in [5] and propose the MF-AFRO problem that selects the appropriate modulation format, among those available in the installed SBVTs, for the LSPs being re-optimized.

An example of MF-AFRO is illustrated in Fig. 1 for the depicted 14-node Spanish topology. Table 1 shows the spectral efficiency and reachability of the considered modulation formats. Three LSPs are established in Fig. 1b;

the route over the network is shown and the main characteristics are given in Table 2. In the event of a failure in link 4-8, LSPs are restored; Table 2 shows the resulting restored LSPs characteristics, where main changes are highlighted in red colour.

Three different cases can be identified as a result of a longer restoration route and/or the lack of resources: *i)* the lower spectral efficiency of the new modulation format entailed using more slices to serve all the requested bitrate (*lsp1*); *ii)* although the number of slices was kept invariant the restored bitrate was squeezed (*lsp2*); and *iii)* the number of slices was reduced and the bitrate squeezed (*lsp3*).

It is clear that when link 4-8 is repaired, re-optimization in the network can be performed to, not only improve resource utilization by using shorter routes, but also changes in the used modulation format can be performed for every LSP to serve the bitrate originally requested.

The MF-AFRO problem can be formally stated as follows:

Given:

- a network topology $G(N, E)$ with the set of optical nodes N and the set of optical links E .
- the availability of every frequency slice in the optical spectrum of every link in E ;
- the characteristics and availability of sub-transponders in the installed SBVTs;
- an set M of modulation formats supported by the SBVTs. M is ordered by its spectral efficiency;
- a set D of demands candidate for re-optimization, each with the requested bitrate.

Output: the sub-transponders and the RSMA for each demand in D .

Objective: minimize the optical resources so as to serve the bitrate originally requested by the demands in D .

To solve the MF-AFRO, we propose the heuristic algorithm presented in Table 3. The algorithm first de-allocates the demands in D (line 2) and runs *maxIter* iterations allocating the demands in D in a random order to generate a solution S (lines 5-10). S is stored if it improves the best solution found so far (*bestS*) (lines 11-

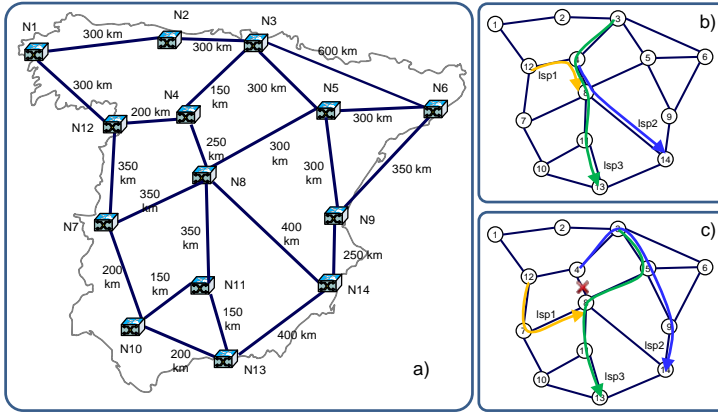


Fig. 1. Network topology considered (a). Example network before failure (b) and after restoration (c).

Table 3. MF-AFRO Heuristic Algorithm

IN:	OUT:
$G(N, E), D, M, maxIter$	$bestS$
1:	$bestS \leftarrow D$; compute $\Phi(bestS)$
2:	for each d in D do deallocate(G, d)
3:	for $i = 1..maxIter$ do
4:	$S \leftarrow \emptyset$; $G' \leftarrow G$
5:	sort(D , random)
6:	for each d in D do
7:	$\langle R, m, c \rangle \leftarrow findRSMA(G', M, d)$
8:	if $R = \emptyset$ then break
9:	allocate($G', d, \langle R, m, c \rangle$)
10:	$S \leftarrow S \cup \{d\}$
11:	compute $\Phi(S)$
12:	if $\Phi(S) < \Phi(bestS)$ then $bestS \leftarrow S$
13:	return $bestS$

12). The *findRSMA* function returns the best route (R), modulation format (m), and spectrum allocation (c) for the given demand d to serve as much bitrate as possible.

Protocol Extensions and Proposed Workflow

Recently, the IETF has standardized the Applications-based Network Operations (ABNO)-based [8] architecture, which supports in-operation planning. ABNO is based on several components, among which: *i*) the PCE is responsible for solving the RSMA problem for every incoming request; and *ii*) the ABNO controller, implements workflows for each type of request from applications or the Network Management System (NMS). Specifically for in-operation planning problems that might require high computational effort, the PCE can be split into a front-end PCE (fPCE) and an in-operation planning tool, running as a back-end PCE (bPCE), able to solve complex optimization problems, such as the MF-AFRO problem.

Fig. 2 shows the described architecture, where the NMS uses a REST API to send requests to the ABNO controller. ABNO components communicate using PCEP for LSP requests and reports, thus synchronizing their LSP-DBs. BGP-LS is also used to synchronize the Traffic Engineering Database (TED).

In our previous work in [7] we demonstrated the use of BGP-LS to announce link repairs between fPCE and bPCE for the simpler AFRO problem. In this paper, we propose to extend

Table 1. Modulation Formats

Mod. Format	Spectral Efficiency (bit/symbol)	Reach (km)
DP-QPSK	4	3000
DP-QAM8	6	1000
DP-QAM16	8	650

Table 2. LSP configuration

Before Failure				
LSP	BitRate (Gb/s)	Length (km)	Mod. Format	# Slices
lsp1	200	450	DP-QAM16	2
lsp2	400	650	DP-QAM16	4
lsp3	400	900	DP-QAM8	6
After Restoration				
lsp1	200	700	DP-QAM8	4
lsp2	300	1000	DP-QAM8	4
lsp3	200	1100	DP-QPSK	4

BGP-LS to convey information related to SBVTs, needed to solve the MF-AFRO problem. RO objects (e.g., ERO) in PCEP need also to be extended to specify which sub-transponders and modulation formats must be used for a specific LSP (Explicit Transponder Control, ETC sub-object). These extensions are based on those proposed in [3] for OSPF-TE and RSVP-TE, respectively, so we refer the reader to that reference for details.

A workflow needs to be defined to coordinate the components in the ABNO architecture. We assume that the NMS issues a request to run the MF-AFRO workflow after a link has been repaired. In the request, the NMS includes the set of candidate demands with the originally requested bitrate. The request is sent through the REST API toward the ABNO controller interface, which triggers the workflow (Fig. 3).

Upon the reception of the request from the NMS, the controller translates it into a PCEP PCReq message (message 2 in Fig. 3); the message includes a $SVEC$ object to jointly compute the re-optimization of the set of demands and an OF object specifying the optimization algorithm, MF-AFRO in our case. The PCReq message is sent to the fPCE; since the request involves intensive computation, the fPCE delegates its computation to the bPCE by forwarding the PCReq message (3). The bPCE computes the solution and sends it back to the fPCE in a PCRep message (4) that contains either an ERO object with the updated LSP's resource allocation, or a $NO-PATH$ object if the LSP could not be re-optimized. The fPCE is in charge of implementing the solution in the network. In our case, LSPs are first torn-down and then set-up again using the new route, spectrum allocation, and transponders. Thus, a PCInit message is sent to the source PCC of each LSP, which starts signalling the LSP torn-down and sends a PCRpt message toward the fPCE upon its completion. Next, a PCInit is sent for the set-up (messages 5).

When all the PCRpt messages are received, the

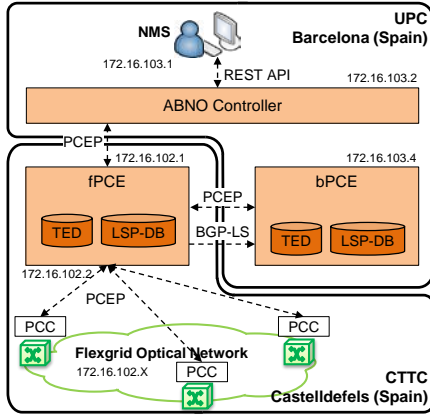


Fig. 2. Control and management architecture

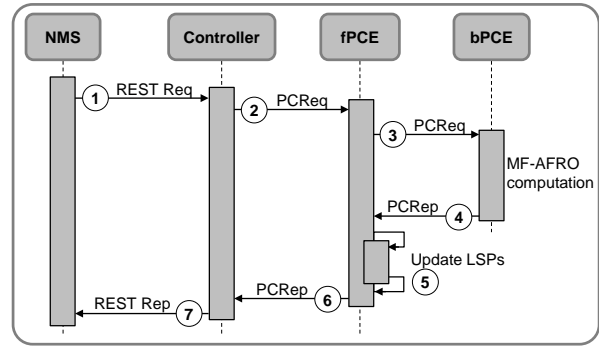


Fig. 3. MF-AFRO workflow

No.	Time	Source	Destination	Protocol	Len	Info
①	281 29.325042	172.16.103.1	172.16.103.2	HTTP/XML	744	POST /abno/MFAFRO HTTP/1.1
②	283 29.326843	172.16.103.2	172.16.102.1	PCEP	220	Path Computation Request (PCReq)
③	285 29.327795	172.16.102.1	172.16.103.4	PCEP	208	Path Computation Request (PCReq)
④	286 29.330020	172.16.103.4	172.16.102.1	PCEP	1164	Path Computation Reply (PCRep)
⑤	287 29.330791	172.16.102.1	172.16.102.2	PCEP	108	Path Computation LSP Initiate (PCInitiate)
	288 29.339431	172.16.102.2	172.16.102.1	PCEP	108	Path Computation LSP State Report (PCRpt)
⑥	305 29.425897	172.16.102.1	172.16.102.2	PCEP	572	Path Computation LSP Initiate (PCInitiate)
	306 29.452719	172.16.102.2	172.16.102.1	PCEP	572	Path Computation LSP State Report (PCRpt)
⑦	309 29.458552	172.16.102.1	172.16.103.2	PCEP	1080	Path Computation Reply (PCRep)
⑧	310 29.459159	172.16.103.2	172.16.103.1	HTTP/XML	1844	HTTP/1.0 200 OK

Fig. 4. REST and PCEP exchange messages for the proposed workflow

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▶RP object
▼EXPLICIT ROUTE object (ERO)
  Object Class: EXPLICIT ROUTE OBJECT (ERO) (7)
  0001 .... = Object Type: 1
  ▶Flags
  Object Length: 300
  ▶SUBOBJECT: Unnumbered Interface ID: 172.16.102.104:18
  ▶SUBOBJECT: Label Control Tx SubTransponders
  ▶SUBOBJECT: Explicit Transponder Control
  ▶SUBOBJECT: Unnumbered Interface ID: 172.16.102.104:8
  ▶SUBOBJECT: Label Control
  ▶SUBOBJECT: Unnumbered Interface ID: 172.16.102.108:14
  ▶SUBOBJECT: Label Control
  ▶SUBOBJECT: Unnumbered Interface ID: 172.16.102.114:28
  ▶SUBOBJECT: Label Control Rx SubTransponders
  ▶SUBOBJECT: Explicit Transponder Control
▶BANDWIDTH object
    
```

Fig. 5. New route for *lsp2* in message (4)

fPCE notifies the controller by sending a PCRep message (6) containing the updated ERO objects, which in turn translates them into a REST Reply message for the NMS (7).

Experimental assessment

Experiments have been carried out in a distributed test-bed connecting premises of UPC and CTTC (Fig. 2). The NMS (IP address ending in .103.1), ABNO controller (.103.2) and bPCE (.103.4) run in UPC's SYNERGY testbed, whereas the fPCE (.102.101) and the GMPLS control plane of the ADRENALINE testbed are in CTTC's premises. All modules were implemented in C++ for Linux. BGP-LS and PCEP protocols with the previously described extensions were used for TED and LSP-DB synchronization and for computation delegation. We reproduced the scenario presented in Fig. 1; Fig. 4 shows the meaningful REST API and PCEP messages exchanged. Fig. 5 shows an

extract of message (4) showing the new computed path and the ETC subobjects in the ERO object for *lsp2*.

Conclusions

MF-AFRO, a modulation format-aware algorithm to re-optimize LSPs after a link repair has been proposed. Extensions to BGP-LS and PCEP protocols to convey SBVTs and modulation format information were experimentally assessed in a distributed test-bed.

Acknowledgements

The research leading to these results has received funding from the European Community's Seventh Framework Programme under grant agreement n° 317999 IDEALIST and from the Spanish MINECO SYNERGY (TEC2014-59995-R) and FARO (TEC2012-38119) projects.

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