

IDEALIST Control and Service Management Solutions for Dynamic and Adaptive Flexi-grid DWDM Networks

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Abstract: Wavelength Switched Optical Networks (WSON) were designed with the premise that all channels in a network have the same spectrum needs, based on the ITU-T DWDM grid. However, this rigid grid-based approach is not adapted to the spectrum requirements of the signals that are best candidates for long-reach transmission and high-speed data rates of 400Gbps and beyond. An innovative approach is to evolve the fixed DWDM grid to a flexible grid, in which the optical spectrum is partitioned into fixed-sized spectrum slices. This allows facilitating the required amount of optical bandwidth and spectrum for an elastic optical connection to be dynamically and adaptively allocated by assigning the necessary number of slices of spectrum. The ICT IDEALIST project will provide the architectural design, protocol specification, implementation, evaluation and standardization of a control plane and a network and service management system. This architecture and tools are necessary to introduce dynamicity, elasticity and adaptation in flexi-grid DWDM networks. This paper provides an overview of the objectives, framework, functional requirements and use cases of the elastic control plane and the adaptive network and service management system targeted in the ICT IDEALIST project.

Keywords: GMPLS/PCE control plane, adaptive network manager, elastic networks

1. Introduction

IP backbone networks rely on dynamic transport networks to enable IP traffic offloading. Traffic Offloading allows reducing costs, simplifying operations, and increasing the network scalability, since IP packets are directly sent from the ingress to the egress router using a transport connection at layer 2 (e.g. in OTN or MPLS-TP networks) or/and layer 1, such as a lightpath within the so called Wavelength Switched Optical Networks (WSONs). WSONs were designed with the premise that all channels in a network have the same spectrum needs (e.g. a 50 GHz channel spacing is the most common approach for 100Gb/s transmission, requiring 37,5 GHz with DP-QPSK). In this sense, the ITU-T normalized the

allowed frequencies (where each frequency represents one optical channel) by specifying the DWDM grid with fixed optical channels spacing. However, this rigid grid-based approach is not adapted to the spectrum requirements of the signals that are best candidates for long-reach transmission and high-speed data rates of 400Gbps and beyond (e.g. 400 Gbps using DP-QPSK does not fit in the 50 GHz DWDM grid).

One conservative approach is to increase the channel spacing (e.g. 150 GHz for 400 Gb/s using DP-QPSK), or to demultiplex 400Gb/s into four 100Gb/s channels in order to fit in the 50GHz DWDM grid (inverse multiplexing). However, it is particularly inefficient in terms of spectrum efficiency [1]. An innovative approach is to evolve the fixed DWDM grid to a flexible grid, in which the optical spectrum is characterized by a frequency grid having nominal central frequencies with a granularity (e.g. 6.25 GHz) [3]. The required amount of optical bandwidth/spectrum (the so called “frequency slot”) for an optical channel is determined by the signal modulation format and its data rate, and it can be dynamically and adaptively allocated to an (elastic) optical connection by selecting a nominal central frequency and a slot width. The key element of the flexi-grid DWDM networks are the (bandwidth/spectrum)-variable transponders (BVT), which generate optical signals supporting multiple modulation formats and bit-rates that can be dynamically modified according to the needs (i.e., rate and distance-adaptive transmission). The same bit-rate can be achieved with different spectral efficiency modulation formats, requiring different spectrum needs (e.g. 400 Gb/s requires 37GHz with DP-32QAM and 150GHz with DP-QPSK. However, high spectral efficiency modulation schemes (e.g. DP-32QAM) will only allow short-reach transmission distance. Thus, there is a clear trade-off between distance/bit-rate and spectrum needs.

The ICT IDEALIST project targets architectural design, protocol specification, evaluation and standardization of a control plane and a network and service management system (Figure 1), in order to introduce dynamicity, elasticity and adaptation in flexi-grid DWDM networks [1]. On the one hand, IDEALIST deals with the design and specification of a GMPLS control plane with path computation being provided by the PCE (Path Computation Element). The objective is to provide an interoperable and scalable multi-vendor flexi-grid optical network, applicable to multi-domain and multi-layer scenarios. The control plane being developed must be capable of providing of dynamic and elastic optical connection service provisioning, recovery and concurrent optimization and network resource defragmentation (reoptimization).

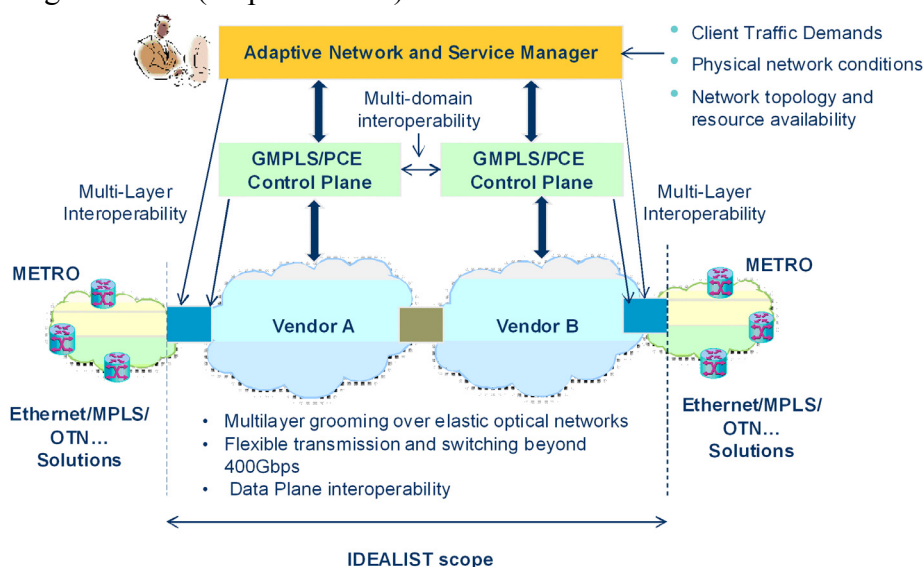


Figure 1: IDEALIST network control and service management architecture

In addition, the IDEALIST team also considers design and development of the control plane to be complementary to the adaptive network and service management system of elastic optical connectivity services. The latter is achieved by monitoring the current network resource status and traffic forecasts, adaptively planning and selecting which parameters of existing elastic connections need to be modified (e.g., modulation and data rate), added or removed, in the event of network defragmentation, or entire or subset optimization of existing elastic connections. The following sections present the proposed elastic GMPLS and PCE control plane and adaptive network and service manager planned in the ICT IDEALIST project.

2. Elastic GMPLS and PCE control plane

The research and development work will be split into several parallel activities. The first activity aims at defining a common control plane solution that is suitable for standardization within the IETF CCAMP and PCE working groups, clearly oriented towards a reduced set of stable functions, suitable for the ITU-T network model and capabilities [2]. By definition, this task encompasses the basic functions that can be provided assuming a common abstraction of the underlying optical hardware. The other activities take a step forward by working on the advanced capabilities that the two specific elastic nodes developed in IDEALIST provides, exploiting, for example new functions characteristic of novel software-based sliceable BVT (Bit rate Variable Transponder). Whereas the main goal of the first activity is to standardize a set of functions in order to ensure the inter-operability of different implemented solutions, the latter ones explore innovative control functions based on the advanced capabilities of the IDEALIST nodes.

2.1 Common GMPLS and PCE control plane for IETF standardization

This section details the process that is being followed by the IDEALIST project in what concerns IETF standardization of the common GMPLS/PCE control plane. The first sub-objective is to define a framework with a common terminology and a set of requirements, and the second, subsequent one, is to extend control plane protocols to address such requirements.

2.1.1 Framework for applying GMPLS and PCE to flexi-grid networks

The work began using a basic framework, including terminology and assumptions for a common understanding, based on reference networks and network element models, to allow the definition of an interoperable GMPLS and PCE control plane solution, capable of efficient allocation of optical spectral bandwidth for high bit-rate systems.

The initial control plane definition and input for future standardization in the IETF is based on the data plane reference model defined by the ITU-T Standardization Sector Study Group 15, which started work on flexi-grid by defining the concept of "frequency slot", a new set of nominal central frequencies and smaller channel spacing in the new G694.1 recommendation [3]. From a networking perspective, a flexible grid network is assumed to be a layered network [2] in which the flexi-grid layer (also referred to as the media layer) is the server layer and the OCh Layer (also referred to as the signal layer) is the client layer. In the media layer, switching is based on a frequency slot, and the size of a media channel is given by the properties of the associated frequency slot. Within this layered network, the media channel itself can be dimensioned to contain one or more Optical Channels. Thus, the data plane connection to be managed is switched based on allocated, variable-sized frequency ranges within the optical spectrum.

2.1.2 Functional requirements for a reference GMPLS/PCE control plane architecture

The functional requirements of a GMPLS and PCE control plane for elastic optical networks are being discussed within the relevant IETF working groups. Such requirements cover different aspects, including all control plane functional components: link management, routing, topology management, signalling, and path computation.

For link management, a control plane must provide ways for which neighbouring nodes are able to correlate their Traffic Engineering (TE) link identifiers, and announce what properties such links support, like grid spacing, spectral frequencies, etc.

The routing aspect mainly implies that the topology dissemination protocol (e.g. OSPF-TE or IS-IS) should be able to disseminate the details of the underlying network elements. In particular, the routing protocol should facilitate topology management and allow the synchronization of a Traffic Engineering Database (TED) including node and link attributes and status to be used in path computation. Furthermore, a path computation entity (PCE or source node) must be aware of node capabilities, including bandwidth variable transceiver tunability capability, status of the nominal central frequencies, and frequency slots that are in use. Additional aspects that may constitute a constraint are the internal node architecture (since optical nodes can typically be asymmetric or present an internal connectivity that does not allow an “any-to-any” connection, unlike packet switched nodes) or the constraints due to the optical technology (such as continuous/contiguous spectrum allocation, physical impairments, etc.).

Signaling requirements are, for the moment, restricted to being able to allocate and dynamically change frequency slots in the media (spectrum) layer. How optical channels are mapped to media layer network channels requires further study. The formal definition of a flexi-grid network, composed of two layers, raising additional questions of whether the control plane should consider this as a multi-layer or multi-region network or it is only for the purposes of a containment relationship between optical channels and the media channels. Finally, once the requirements are identified, protocol extensions will be discussed. Some basic blocks are already considered sufficiently stable, such as the definition and encoding of the “label”, within the context of flexi-grid represents a frequency slot, and the resource is being switched [4].

2.2 Specific GMPLS and PCE control plane solutions for advanced functionalities

2.2.1 Node capabilities and specific control functions (multi-layer border node)

The intention of the multi-layer border node within the IDEALIST project is twofold. Firstly, network configuration and reconfiguration with grooming and switching capabilities, capable of accepting new traffic connections based on varying traffic parameters (day/night variations) Secondly, restoration mechanisms capable of resolving unexpected events or failures within the network. Several architectural options will be studied during the project among which the OTN/Ethernet interfacing may adapt the number of active lanes or the bit rate per lane to provide a varying traffic flow to the BVT. To answer the extra capacity demand (or longer reach requests), the BVT will support flexible transmission parameters such as modulation format, symbol rate or optimized power allocation for all connection. In the latter case, for instance, it would be possible to adjust the power per connection in a meshed network so as to optimize a cost function (e.g., minimize the BER of all connections). Hitless reconfiguration is also desirable but challenging. Once the requirements will be defined and agreed, various solutions will be proposed in accordance with the control plane management.

Another element of the multi-layer border node is a flexible optical cross-connect whose functionalities are based on the novel concept of Architecture on Demand (AoD)

[12]. Such architecture provides an unprecedented degree of flexibility, supporting multiple services and arbitrary switching granularity. Further capabilities will be studied including hitless reconfiguration, spectrum defragmentation and node resiliency.

Based on the aforementioned node capabilities, the following advanced control functions will be studied, together with the required protocol extensions:

- Provisioning of optical connections adjusting the advanced modulation parameters for Optical OFDM (e.g., number of subcarriers, bit/power loading profile) for an optimal resource usage [11].
- Modification of the bit-rate, modulation format parameters or frequency slot of existing elastic optical connections without changing the route.
- Rerouting/restoration of existing optical connections, modifying the bit-rate, modulation format and frequency slot.
- Defragmentation/reoptimization based on Global Concurrent Optimization (GCO).
- Support for dynamic provisioning, modification and rerouting of elastic optical connections leveraging sliceable-BVTs.

2.2.2 Node capabilities and specific control functions (elastic optical node)

The optical node architecture under definition within the IDEALIST project relies on bandwidth variable wavelength selective switch (BV-WSS) technology. A multi-degree core node architecture (e.g., NxN) includes a significant number of BV-WSS, which are combined to enable any input frequency slot to be routed towards any possible output port. To enable the effective configuration of such core node architecture, the control plane functionalities just have to support the basic flex-grid specifications (i.e., with minimum granularity of 12.5 GHz), without accounting for specific constraints in terms of directionality or spectrum assignment for pass-through traffic.

However, according to the considered transmission technology, specific control plane functionalities and provisioning strategies may be required to account for possible edge node constraints. The following main functionalities are discussed, together with their implications in the control plane:

- *Wavelength tunability (single carrier technology)*. Current laser sources enable the full tunability in the whole C band, with limited additional costs with respect to fixed laser sources. At both the transmitter (TX) and receiver (RX) side, tunable lasers are employed. At RX, where coherent detection is applied, a tunable laser is indeed employed as local oscillator. Full wavelength tunability is thus considered within the TX and RX modules. Moreover, in add/drop modules, fixed arrayed waveguide gratings are substituted by different solutions, and no specific constraints or functionalities have to be considered in the control plane for wavelength tunability and spectrum assignment.
- *Modulation formats and adaptation*. Two main modulation formats can be considered: PM-QPSK and PM-16QAM. The former guarantees larger optical reaches but requires additional spectrum occupation. Adaptation between such formats is supported (e.g., to optimize spectrum utilization in case of rerouting due to failure/recovery). The provisioning technique has to account for the required optical reach and it has to support the dynamic configuration of the modulation format, including adaptation capabilities.
- *Defragmentation*. Hitless defragmentation at the optical layer has been demonstrated in [5]. Such technique, called push-pull, relies on dynamic lightpath frequency retuning upon proper reconfiguration of allocated spectrum resources. To support such technique, the central frequency at the control plane has to be decoupled with the frequency of the TX laser. In addition, warning and fatal alarms, typically introduced to

monitor the central frequency stability, have to be disabled during push-pull operations. See [5] for further details.

In addition to the aforementioned technologies and functionalities, the IDEALIST project will specifically address also the implementation and the support of *super-channels*. A super-channel represents an ultra-high aggregate capacity channel containing multiple carriers. According to the considered transmission technique, sub-carriers may be required to be rerouted (e.g., with OFDM transmission). Alternatively, if frequency-packing technique with faster-than-Nyquist transmission is employed, the constraint on sub-carrier co-routing could be relaxed, given the independence of each sub-carrier transmission at the physical layer. This drives the implementation of a *sliceable* transponder, where cost-effective transponder implementations can be achieved while guaranteeing certain flexibility in the provisioning strategy (e.g., the activation, according to traffic needs, of just a subset of sub-carriers, each with some specific transmission parameters). In sliceable transponders, cost and power savings can be achieved by exploiting photonic integration and component sharing among different sub-carriers.

3. Adaptive Network and Service Manager

3.1 Definition

Adaptive Network Manager (ANM) monitors network resources, and decides the optimal network configuration based on the status, bandwidth availability and user service. It is important that an ANM provides a set of standard interfaces, which facilitates communication with other network elements and key network components. These components include the Operation Support Systems (OSS), Network Management Systems (NMS) and the PCE, to provide additional capabilities, including automated network configuration and resource optimization. The main task of ANM is to coordinate, or orchestrate, network procedures based on received requests. ANM starts processes after receiving triggers from the operator via NMS, failures, measurements or periodical requests. After a trigger is received, ANM processes it and starts a workflow or queues it for later analysis. Once a workflow is run, ANM can return the answer to the operator so network configuration can be accepted, rejected or modified. There are other workflows that do not require human involvement. Finally, ANM can be focused exclusively on elastic optical networks or it can also take into account the impact of client layers like IP/MPLS. Table 1 shows a classification for the different scenarios where ANM operates.

Triggers	Processing triggers	Human involvement	Network scope
Human	Start process	Automatic configuration	Single layer
Failure	Queue for correlation	User assisted configuration	Multi-layer
Measurement			
Periodic			

Table 1: Classification for the different ANM scenarios

3.2 Use Cases

3.2.1 Automatic IP Link provisioning

The following use case describes how the ANM framework can be applied to the provisioning of an IP link between two routers. In this example, the photonic meshed network is composed of (elastic) ROADMs providing connectivity to several IP routers.

IP link provisioning is a basic operation done by network operators. This operation is used to provide customer services, including Internet connectivity, VPN or IPTV. When operators deploy additional capacity, new IP link equipment may be installed in the network. This process typically requires manual intervention and is scheduled and deployed periodically. Once equipment is installed in the network and operator receives a request to create a new IP link between two locations, there is a dialog between the IP and transport department to complete the configuration of both layers. This configuration process may take days to complete, even when network elements are already set-up in the network. ANM is intended to automate the configuration process, and in specific cases dynamically, by utilizing control plane technologies, and using an interface to configure IP routers (like OpenFlow or NetConf) to configure individual network elements. Also, the optical layer can be directly configured from the router using either User Network Interface (UNI) or PCE Protocol (PCEP) to trigger control plane mechanisms [6].

3.2.2 Dynamic Bandwidth Allocation based on traffic changes

Current network provisioning of packets over circuits is done in a static manner. Network operators are willing to provide services to end-users (Internet access, VPN, etc.). In aggregation networks, traffic from multiple sources is multiplexed so large traffic streams are sent to backbone networks. There are monitoring probes in the network, which provide periodical information to network operators, but modifications of circuits is not done. Typically new connections are created yearly or at specific time intervals (six months) in the network.

ANM can deal with this dynamic information and decide on the bandwidth adaptation of the connections thanks to the elasticity of BVT. ANM requires retrieve information from routers (such as SNMP) or monitoring probes depending on the traffic patterns in the network. Based on this information, ANM would decide modifications in the parameters of the connections and apply changes to the configuration of the router or BVT. This use case is shown in Figure 2.

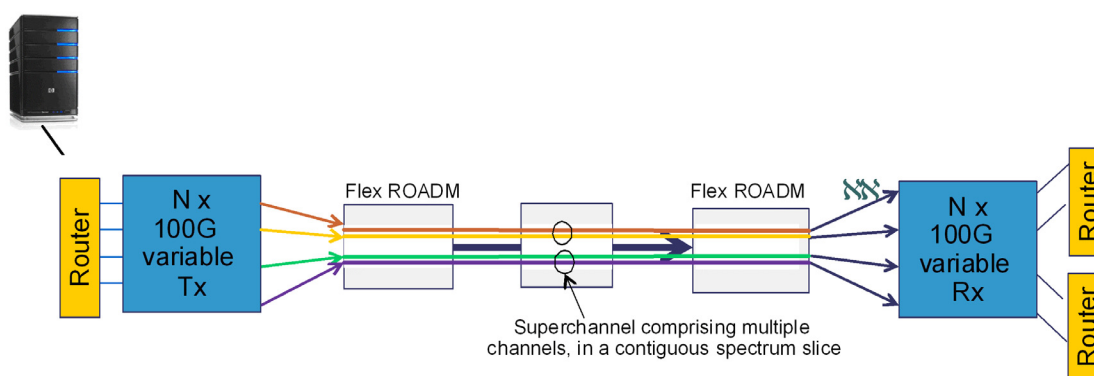


Figure 2: Example scenario for dynamic bandwidth allocation use case

Previous example focused on the parameter modification of an already established link. Another scenario is the case of the creation of a by-pass link when all the existing bandwidth on an intermediate link between two routers has already been entirely used up (or crosses a pre-defined threshold). Based on monitoring information, ANM would start an Automated IP Link Provisioning workflow as defined in previous section. If there are Sliceable BVTs (SBVT) in the network, ANM can split the interface's bandwidth in two (or more) fragments, reducing the bandwidth of the original connection (the one to the next IP hop) and using the new available bandwidth for a new direct connection to the destination router.

3.2.3 Periodic defragmentation to improve bandwidth allocation

The reoptimization (defragmentation) process is roughly defined as the process by which an ANM affects the state of currently active connections in the network by changing some of their attributes. Such attributes typically correspond to the actual reserved resources and changing them may involve, for example, shifting the nominal central frequency of the frequency slot allocated to a connection and/or adjusting its allocated frequency slot width (i.e., due to a change of modulation formats or bitrate) or even the physical routes that were assigned to the connections during path computation. In general, the main purpose of the reoptimization process is to improve the utilization of the network resources, since the main observable result is a sub-optimal throughput. This process can be triggered either manually by a network operator or based on automated maintenance process.

Figure 3 shows an example of this use case. Let us assume that for a given path of three routers there is a set of demands 1, 2, 3 as shown in the figure. If demand 1 is tear down and a new demand 4 of 25 GHz is requested, it is possible that the path selected uses free spectrum from deletion of demand 1. If a new demand 5 of 50GHz is requested, there would not be free spectrum for this request. A de-fragmentation request is sent which ANM, which runs a GCO algorithm using PCE or an external dedicated planning tool. The algorithms needed to efficiently compute an updated layout that satisfies the traffic matrix and demands have notable requirements such as minimizing network disruption, and are commonly based on constrained minimum interference routing and bin-packing heuristics.

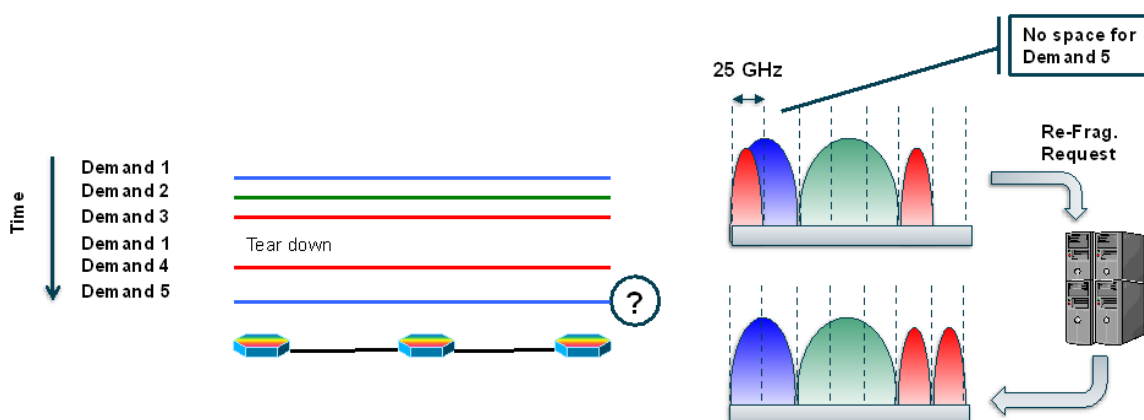


Figure 3: Periodic defragmentation to improve bandwidth allocation

3.2.4 Network reoptimization after network failure recovery

In optical transport networks, operators are commonly required to deploy some form of resilience when transporting client data. Such resilience can be implemented by means of either dynamic restoration of failed connections (i.e., a new path is computed and established after a failure is localized) or dedicated/shared protection by establishing at the same time, e.g., for a given traffic demand, the corresponding working and backup paths.

In both cases, if network connections are flagged with elasticity (i.e., their properties and attributes can be dynamically adjusted) of the physical path, bitrate or modulation format, such elasticity can be exploited to improve the network survivability by dynamically adapting those attributes to the network state. As there are dynamic control plane mechanisms, which run after each failure, they can lead to an inefficient network configuration. Hence, after multiple failures, ANM can check using an algorithm in a PCE or an external tool if current network configuration is optimal or not. Based on this information, ANM can alert operator, who decide if this new configuration should be loaded in the network.

3.2.5 Multi-layer restoration

Multi-layer restoration is the process of restoring a fail of any element in the IP/MPLS or optical layer between two client nodes in a coordinated manner. Unlike single layer restoration (i.e., pure optical restoration), the multi-layer restoration process involves the negotiation of the best possible path properties between the optical layer and the IP/MPLS layer, given a failure in the network. There are two scenarios where coordination is beneficial: failure in the optical layer or failure in the IP/MPLS layer.

Existing approaches to optical restoration do not focus on the constraints that must be met for the restoration path. Often these approaches implicitly assume that any viable restoration path is good. This is not a valid assumption in the event the failure takes a long time to repair since the client layer must return to a relatively normal state. Therefore the most optimal approach is to allow the client to define different constraints for the restoration path versus the constraints that have been defined for the working path. With this negotiation between layers, it is possible to dynamically adapt to the requirements of the client layer.

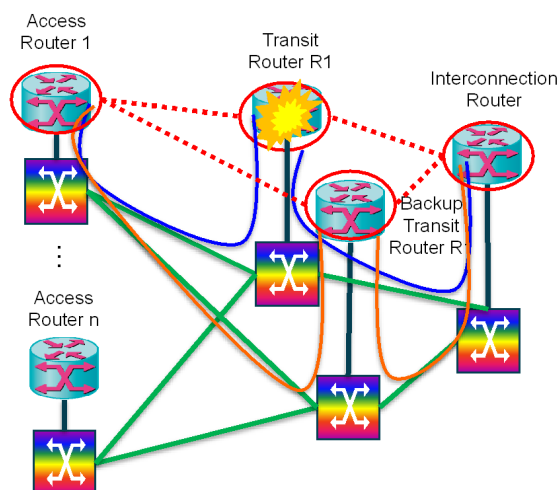


Figure 4: Multi-layer restoration using a remote backup transit router

The second scenario where multi-layer restoration can be interesting is when there is a failure in the IP layer (Figure 4). In case there is a failure on a router, ANM can look for a candidate back-up router at any location of the network, because there is an underlying optical layer. Once a suitable path is found, ANM start the Automated IP Link Provisioning use case.

3.2.6 Disaster recovery in case of mission critical applications

Some applications and services will be considered mission critical, and if this application or service fails for any length of time, then it will have a significant impact on the customer. We might consider that most of business and banking applications have fault and recovery mechanisms to protect transactions, so these types of services can be removed, in order to focus more on mission critical applications [8] for people, infrastructures and industrial processes. Therefore we can consider “critical” all the applications where the reliability and performance of ICT infrastructure are fundamentally affected to changes in availability, time response and bandwidth [7].

ANM can use the elasticity of the optical infrastructure to allocate or reserve optical channels based on the application needs and priority (Service Level Agreement (SLA)). These applications need to be declared and negotiated in advance at the admission control level and translated by the network manager in classes of services like in [7] and cooperate

with strong network monitoring agents that will trigger control plane features to allocate elastic resources at optical data plane. All the concepts discussed also need to be translated into requirements specific for cloud serving infrastructure (IT resources) as well.

3.3 *Next steps and further work*

One of the key issues in ANM is the definition of standard interfaces, so ANM can operate in existing networks. From this perspective, there are three architectures related to concepts presented in the ANM: Active PCE [8], which is capable of set-up and tear down LSPs, SDN controller [9], which is defined mainly for OpenFlow controlled network elements and Application-Based Network Operations (ABNO) controller, recently proposed in IETF [10]. These architectures will be assessed when defining the functional blocks of ANM.

4. Conclusions

This paper has presented a number of requirements related to an elastic control plane currently being developed within the ICT IDEALIST project. This control plane is based on the GMPLS architecture and its set of protocols, along with PCE based path computation approaches, considering both passive and active models. The design of the flexible control plane imply adopting and, where necessary, extending the protocols to cover control plane aspects for elastic network capabilities including link management, routing, topology management, signalling, and path computation. This paper has also presented the definition of Adaptive Network Manager (ANM) and advanced use cases requiring an entity capable of carrying out specific ANM operations and objectives.

Finally, the document outlined an initial starting point for elastic optical network research, but requirements and architecture definition, including those of GMPLS/PCE control plane and ANM, will require further investigation, discussion and documentation.

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