In-operation Network Planning

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Abstract—Current transport networks are statically configured and managed, because they experience a rather limited traffic dynamicity. As a result, long planning cycles are used to upgrade the network and prepare it for the next planning period. To guarantee that the network can support the forecast traffic and deal with failure scenarios, spare capacity is usually installed, thus increasing network expenditures. Moreover, results from network capacity planning are manually deployed in the network, which limits network agility. In this article we propose a control and management architecture to allow the network to be dynamically operated. Taking advantage of those dynamicity capabilities, the network can be reconfigured and re-optimised in response to traffic changes in an automatic fashion, so resource over-provisioning can be minimized and network costs reduced.

Keywords: In-Operation Network Planning, Network Reconfiguration, Network Re-optimisation, Network Control and Management.

1 INTRODUCTION

Network capacity planning requires the placement of network resources to satisfy expected traffic demands and network failure scenarios. Today, the network capacity planning process is typically an offline activity, and is based on very long planning cycles (yearly, quarterly). Generally, this is due to the static and inflexible nature of current networks. This can be said for both the transport -optical and Ethernet- layer, as well as for the IP/MPLS layer, which should be inherently more dynamic compared to the underlying transport infrastructure. The latter might use automated Traffic Engineering (TE) techniques to place IP/MPLS traffic where the network resources are.

Increasing transport capacity (bandwidth) to meet predicted IP/MPLS traffic changes and failures does provide limited network flexibility, but due to the fixed and rigid nature of provisioning in the transport layer, network planning and TE still require significant human intervention, which entails high Operational Expenditures (OPEX). In addition, to ensure that the network can support the forecast traffic and all the failure modes that need to be protected against, operators add spare capacity (over-provision) in different parts of the network to address likely future scenarios. This entails inefficient use of network resources and significantly increases network Capital Expenditures (CAPEX).

Notwithstanding, optical transport platforms are designed to facilitate the setting up and tearing down of optical connections (lightpaths) within minutes or even seconds [1]. Combining remotely configurable optical cross-connects (OXCs) with a control plane provides the capability of automated lightpath set-up for regular provisioning, and real-time reaction to failures, being thus able to reduce OPEX. However, to exploit existing capacity, increase dynamicity, and provide automation in future networks, current management architectures, based upon Network Management Systems (NMS) need to be radically transformed.

In a scenario where lightpath provisioning can be automated, network resources can be made available by reconfiguring and/or re-optimising the network on-demand and in real-time. We call that as in-operation network planning. We propose to take advantage of novel network reconfiguration capabilities and new network management architectures to perform in-operation planning, aiming at reducing network CAPEX by minimising the over-provisioning required in today's static network environments.

In this article, we highlight current standardisation work and propose a control and management architecture based on the Application-Based Network Operations (ABNO) model [2], which is capable of performing in-operation planning. We illustrate this novel network planning technique by studying two use cases: 1) virtual topology reconfiguration as a consequence of network failures or catastrophic event (disaster), and 2) re-optimisation to improve network resource efficiency and utilisation.
2 ARCHITECTURES TO SUPPORT IN-OPERATION NETWORK PLANNING

2.1 Static network operation

Operation of the currently deployed carriers’ transport networks is very complex; multiple manual configuration actions are needed for provisioning purposes (e.g., hundreds of thousands of node configurations per year in a mid-size network). In fact, transport networks are currently configured with big static fat pipes based on capacity over-provisioning, since they are needed for guaranteeing traffic demand and Quality of Service (QoS). Furthermore, network solutions from different vendors typically include a centralised service provisioning platform, using vendor-specific NMS implementations along with an operator-tailored umbrella provisioning system, which may include a technology specific Operations Support System (OSS). Such complicated architectures (Fig. 1a) generate complex and long workflows for network provisioning: up to two weeks for customer service provisioning and more than six weeks for core routers connectivity services over the optical core.

Fig. 1b illustrates the fact that such static networks are designed to cope with the requirements of several failure scenarios, and predicted short-term increases in bandwidth usage, thus requiring capacity over-provisioning and significantly increasing CAPEX. It shows a simple network consisting in three routers connected to a central one through a set of lightpaths established on an optical network. Two different scenarios are considered, although the same amount of IP traffic is conveyed in each of them. In the scenario A, router R3 needs three lightpaths to be established to transport its IP traffic towards R4, whereas R1 and R2 need only one lightpath. In contrast in the scenario B, R1 and R2 need two lightpaths whilst R3 needs only one lightpath. In static networks, where lightpaths in the optical network are staticallly established, each pair of routers has to be equipped with the number of interfaces for the worst case, resulting in 14 interfaces in total. However, if the optical network can be dynamically reconfigured setting up and tearing down lightpaths on demand, each router can be dimensioned separately for the worst case, regardless of the peering routers. As a result, only 10 interfaces are needed, thus saving 28.5% of interfaces.

![Fig. 1 Current static architecture (a) and an example of dynamic planning and reconfiguration (b).](image-url)
2.2 Migration towards in-operation network planning

The classical network planning life-cycle typically consists of several steps that are performed sequentially. The initial step receives inputs from the service layer and from the state of the resources in the already deployed network and configures the network to be capable of dealing with the forecast traffic, for a period of time. That period is not fixed and actual time length usually depends on many factors, which are operator and traffic type specific. Once the planning phase produces recommendations, the next step is to design, verify and implement changes in the network. While in operation, the network capacity is continuously monitored and that data is used as input for the next planning cycle. In case of unexpected increases in demand or network changes, nonetheless, the planning process may be restarted.

As technologies are developed to allow the network to become more agile, it may be possible to provide response to traffic changes by reconfiguring the network near real-time. In fact, some operators have deployed Generalized Multi-Protocol Label Switching (GMPLS) control planes, mainly for service set-up automation and recovery purposes. However, those control only parts of the network and do not support holistic network reconfiguration. This functionality will require an in-operation planning tool that interacts directly with the data and control planes and operator policies via OSS platforms, including the NMS.

Assuming the benefits of operating the network in a dynamic way are proven, the classical network life-cycle has to be augmented to include a new step focused on reconfiguring and re-optimising the network, as represented in Fig. 2a. We call that step in-operation planning and, in contrast to the traditional network planning, the results and recommendations can be immediately implemented on the network.

![Networks life cycle diagram](image)

**Fig. 2** Networks life cycle (a), and future dynamic architecture based on ABNO; an in-operation planning tool computes network reconfiguration (b).

To support dynamicity, however, the current network architecture depicted in Fig. 1a will need evolve to include a functional block between the service layer and the network elements to support multi-service provisioning in multi-vendor and multi-technology scenarios; two standard interfaces are required. Firstly, the north bound interface that,
among other tasks, gives an abstracted view of the network, enabling a common entry point to provision multiple services and to provision the planned configuration for the network. Moreover, this interface allows coordinating network and service layer according to service requirements. Secondly, the south bound interface covering provisioning, monitoring, and information retrieval.

Finally, operators should require some human-machine iteration, and new configurations have to be reviewed and acknowledged before being implemented in the network.

2.3 ABNO architecture and required functionalities for in-operation planning

Standardisation bodies, especially the IETF, have been working to address all the above requirements, and as a result, the ABNO architecture [2] is now being proposed as solution. The ABNO architecture consists of a number of standard components and interfaces which, when combined together, provide a method for controlling and operating the network. A simplified view of the ABNO architecture is represented in Fig. 2b. It includes:

- The ABNO controller as the entrance point to the network for NMS/OSS and the service layer for provisioning and advanced network coordination. It acts as a system orchestrator invoking its inner components accordingly to a specific workflow.
- The Path Computation Element (PCE) [3] defined as an entity to serve paths computation requests. The PCE Communication Protocol (PCEP) is used to carry paths computation requests and PCE responses. Requests can be processed independently of each other or in groups, utilising a view of the network topology stored in the TE Database (TED) (stateless PCE) or considering as well information regarding Label Switched Paths (LSPs) that have been set-up in the network, stored on the LSP Database (LSP-DB) (stateful PCE). Finally, a PCE is said to be Active if it can modify in-place LSPs [4] based on network trends.
- The Virtual Network Topology Manager (VNTM) [5] coordinates Virtual Network Topology (VNT) configuration by setting up or tearing down lower-layer LSPs, and advertising the changes to higher-layer network entities.
- The Provisioning Manager is responsible for the establishment of LSPs. This can be done by interfacing the control plane or by directly programming the data path on individual network nodes using Network Configuration Protocol (NetConf) or acting as an OpenFlow controller [6].
- The Operations, Administration, and Maintenance (OAM) handler is responsible for detecting faults and taking actions to react to problems in the network. It interacts with the nodes to initiate OAM actions such as monitoring and testing new links and services.

Directly connected to the ABNO architecture, the in-operation planning tool can be deployed as a dedicated back-end PCE for performance improvements and optimisations. The back-end PCE is accessible via the PCEP interface, so the ABNO components can forward requests to the planning tool.

Furthermore, in-operation network planning can only be achievable if planning tools are synchronised with the state of network resources, so new configurations can be computed with updated information, and those configurations can be easily deployed in the network. In the proposed architecture, the back-end PCE gathers network topology and current state of network resources, via the ABNO components, using protocols designed to convey link-state and traffic engineering information, such as BGP-LS [7].

There are several architectures utilising IETF components, which are suitable for providing in-operation network planning. These are described Table 1 with the corresponding strengths and weaknesses.

| Architecture | Strengths | Weaknesses |
|--------------|-----------|------------|
| Stateless PCE | • Path computation can be off-loaded onto a dedicated entity capable of complex computations with bespoke algorithms and functions.  
• Has a standard and mature interface and protocol.  
• Supports simple optimisation, such as bulk path computation [8]. | • Is unaware of existing LSPs and has no view of the current network resource utilisation and key choke points.  
• Cannot configure by itself any LSP in the network.  
• Delays need to be introduced to sequence LSP set-up [9]. |
| Stateful PCE | • Maintains a database of LSPs that are active in the network, i.e., so that new requests can be more efficiently placed optimising network resources.  
• Supports optimization involving already established LSPs. | • More complex than a stateless PCE, requires additional database and synchronization.  
• No existing LSPs can be modified, e.g. for network re-configuration purposes. |
LSPs is based on the PCEP protocol and interface, using messages [12]. The new allocated resources are \texttt{PCUpdate} with each head-end node. The provisioning interface, by which the provisioning manager is able to suggest re-routing of new LSPs minimising disruption.

In case that an operator needs to approve the new (virtual) layout, the PCE forwards it to the ABNO controller (6). Obtained (4), the set of light paths is replied in a Path Computation Reply \texttt{(PCRe}) to the NMS/OSS (1), who then forwards it to the PCE via the VNTM (2). For performance reasons, a back-end PCE which contains an active solver is responsible for computing new virtual topology layout taking into account the current state of the network. Therefore, the PCE sends a request towards the in-operation planning tool running in that back-end PCE to compute the new virtual topology (4). The tool considers all the links and nodes are up and which connections are optically feasible, considering optical impairments. When a result is obtained (4), the set of lightpaths is replied in a Path Computation Reply \texttt{(PCRe}) message (5) towards the originating NMS/OSS (1), who then forwards it to the ABNO controller (6). The computed layout is then presented to the operator for final approval (7). When the operator acknowledges the new optimised layout (8), it is passed to the VNTM (9) which computes the sequence of operations to carry out in terms of re-routing existing new LSPs minimising disruption.

The sorted sequence of actions on existing LSPs is passed to the provisioning manager (10), who then forwards it to the PCE via the VNTM (2). For performance reasons, a back-end PCE which contains an active solver is responsible for computing new virtual topology layout taking into account the current state of the network. Therefore, the PCE sends a request towards the in-operation planning tool running in that back-end PCE to compute the new virtual topology (4). The tool considers all the links and nodes are up and which connections are optically feasible, considering optical impairments. When a result is obtained (4), the set of lightpaths is replied in a Path Computation Reply \texttt{(PCRe}) message (5) towards the originating NMS/OSS (1), who then forwards it to the ABNO controller (6). The computed layout is then presented to the operator for final approval (7). When the operator acknowledges the new optimised layout (8), it is passed to the VNTM (9) which computes the sequence of operations to carry out in terms of re-routing existing new LSPs minimising disruption.

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reported back to the provisioning manager and ultimately the VNTM, using PCReport messages. Note that after a successful re-optimisation the LSP-DB is updated accordingly. In our example in Fig. 3c, a new lightpath is created between R1 and R2 and as a result the IP/MPLS LSP R2-R3 can be rerouted and its initial capacity restored.

![Physical Topology](image1)

![Virtual Network Topology](image2)

**a)** No Failures

**b)** Link X2-X3 Fails

**c)** Virtual Network Topology Reconfiguration

![VNT Reconfiguration Process](image3)

**d)** Service Layer

![In-operation Planning](image4)

Fig. 3 An example of reconfiguration. In (a) one lightpath between each router is set-up. In (b) a failure affects an optical link and FRR recovers part of the IP/MPLS traffic. VNT reconfiguration is activated in (c). VNT reconfiguration process (d).
3.2 Disaster Recovery

While most networks are typically designed to survive a single failure without affecting SLAs, they are not designed to survive large scale disasters, such as earthquakes, floods, wars or terrorist acts, simply because of their low failure probability and the high cost of over-provisioning to address such events in today’s network. Since many systems might be affected, large network reconfigurations are necessary during large scale disaster recovery.

The disaster recovery process is similar to that of the virtual topology reconfiguration after a failure. However multiple optical systems, IP links, and possible routers and OXCs (assuming central offices are affected) may be taken offline during the disaster. Several additional planning and operation requirements in response to large scale disasters are highlighted below.

- Consideration of potential IP layer traffic distribution changes, either using MPLS-TE tunnels, or by modification of IP routing metrics, and evaluating benefits based on the candidate topology.
- It may be impossible to reach the desired network end state with one step optimisations. Therefore, it may be necessary two or more step optimisations. For example, to reroute some other optical connections to make room for some of the new connections.
- The system must verify that the intermediate configuration after each such step is robust and can support the current traffic and possibly withstand additional outages.
- Based on pre-emption and traffic priorities, it might be desirable to disconnect some virtual links, so as to reuse the resources for post-disaster priority connections and traffic.

We have described the creation of one disaster recovery plan, but in a real network there may be several possible plans, each with their pros and cons. The tool must present all these plans to the operator so that the operator can select the best plan, and possibly modify it and understand how it will be behave.

To summarise, the above process consists of several steps:

1. Immediate action by the network to recover some of the traffic.
2. Dissemination of the new network state.
3. Root cause analysis to understand what had failed.
4. Operator-assisted planning process to come up with a disaster recovery plan.
5. Execution of the plan - possible in multiple steps.
6. Re-convergence of the network after each step and in its final state.

4 USE CASE II: RE-OPTIMISATION

Algorithms in the control or management planes compute routes and find feasible spectrum allocations for connection requests taking into account the state of network resources at the time each connection is requested. Nonetheless, as a consequence of network dynamics, some resources may not be released so that better routes could be computed and thus, re-optimisation could not be applied to improve network efficiency. For example, imagine an optical connection that due network congestion, is required to circumnavigate optimal nodes and links, so that the end-to-end connection requires intermediate regenerators; at some point additional paths become available and the service could be rerouted to use the shorter route and eliminate regeneration. Additionally, other existing services could be rerouted to remove the bottlenecks and avoid network congestion. Or even allow some connections to increase their capacity when needed.

In this use case we study a specific problem that arises in flexi-grid networks [13] and where re-optimisation could bring clear benefits. In such networks, lightpaths can be allocated using variable-sized frequency slots, whose width (usually a multiple of a basic width such as 12.5 GHz) is a function of the requested bit rate, FEC and modulation format. Such frequency slots must be contiguous in the spectrum and the same along the links in its route. As a consequence of the unavailability of spectrum converters, spectrum fragmentation appears increasing the blocking probability of connection requests, making worse the network grade of service.

An example is shown in Fig.4a where the optical spectrum of a link is represented. Three already established lightpaths share that link; each lightpath uses a different frequency slot width. If a new lightpath needing 37.5 GHz is requested, it would be blocked as a consequence of lack of spectrum contiguity. In such scenario, re-optimisation could be applied to the network before a connection request is blocked, by re-allocating already established lightpaths in the spectrum (Fig.4b) to make enough room for the triggering connection requested (Fig.4c). Authors in [14] describe the SPRESSO algorithm to efficiently compute the set of connections to be reallocated. In [15] the SPRESSO algorithm was integrated into an active stateful PCE and reallocations were performed in a hitless manner by using the Push-Pull technique.
A control and management architecture of transport networks has been proposed to support in-operation planning. The architecture is based on ABNO and allows carriers to operate the network in a dynamic way and to reconfigure and re-optimise the network near real-time in response to changes, like traffic or failures. Networks life cycle is extended achieving better resource utilization, thus reducing network CAPEX. Moreover, process automation reduces manual interventions and, consequently, OPEX.

Two use cases have been used to illustrate how the proposed in-operation planning and control and management
architecture work together. In a multilayer network scenario we analysed VNT reconfiguration after a failure and for disaster recovery. In a flexi-grid network scenario, we studied LSP re-allocation to reduce connection blocking.

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