Reliable Control and Management Plane Design in Multi-Domain Optical Networks

Péter Szegedi¹, János Szigeti², Tibor Cinkler²
¹Magyar Telekom – PKI Telecommunications Development Institute
9 Magyar tudósok krt., Budapest H-1117, Hungary
E-mail: szegedi.peter3@t-com.hu Tel.: +36 1 481 7560
²Budapest University of Technology and Economics – Dept. of Telecommunications and Media Informatics
2 Magyar tudósok krt., Budapest, H-1117, Hungary
E-mail: (cinkler, szigeti)@tmit.bme.hu Tel.: +36 1 463 1861

ABSTRACT
In this paper a multi-domain optical service environment is envisioned to demonstrate the role of the distributed control plane and management processes based on different standardization approaches. Emerging reliability requirements are discussed and the performance of optical networks is investigated by simulations on several control and/or management failure cases. The simulation results are extended towards multi-domain environments using practical considerations to provide simple analytical models on connection provisioning delay.

Keywords: ASON, GMPLS, Control and Management Plane Design

1. INTRODUCTION AND MOTIVATIONS
Nowadays, multi-vendor and multi-technology networks are deployed in the carriers’ networks hence network operators require integrated, or at least well co-operated, control and management platforms on the network layers to deliver QoS-aware customer services with lower operational cost. Since the typical country wide and cross-country service environments have become more like multi-domain nature, the control platforms must be unified enough to provide efficient inter-working between the different operational and administrative domains. The concept of the distributed control plane has been arisen in several industrial fora (e.g., Optical Internetworking Forum (OIF), Metro Ethernet Forum (MEF), etc.) and standardization bodies (e.g., Internet Engineering Task Force (IETF), International Telecommunication Union (ITU), etc.).

The IETF is extending the IP-based protocols originally designed for multi-protocol label switched networks (MPLS), to support a wide range of transport technologies. The ITU-T Study Group 15 has focused to the network architectures to standardize the Automatically Switched Optical Networks (ASON) [1] with separated data, control and management planes. Industrial fora, like the OIF [3], aim to make these theoretical architectures and protocols suitable for real implementations defining the user-network and network-network interfaces.

2. APPROACHES ON CONTROL PLANE DESIGN AND MANAGEMENT PROCESSES
The architectural contexts of the dynamically controlled optical networks are well studied so far, starting from the IP-based integrated control of the peer-to-peer model [4] to the limited vertical interoperability provided by the overlay model [1] via several augmented control approaches [1]. The first world-wide protocol interoperability tests [3] were also successfully performed by OIF among different vendors’ equipments.

2.1. Routing and signaling in a distributed control plane
From the optical networks’ architectural perspective, the physical data plane and the logical control plane topologies need not to be congruent, thus the applied routing protocols are responsible for advertising both topologies. One approach to design a scalable routing protocol is to minimize global information by keeping information and decision making local wherever possible. The optical networks have different requirements on the advertised routing information than the packet-based networks have. The traditional IP network routing protocols are being extended to allow distribution of link resource information (e.g., bandwidth) on per-connection basis, which is needed in circuit-based optical networks. Such IETF routing extensions hence potentially result in large information overhead. Network operators need to tune protocol parameters to trade off message overhead against stale resource information [1]. According to the IETF’s first proposal, inside the optical domain a centralized routing (e.g., OSPF-TE or IS-IS) can be used, while between the domains a hop-by-hop routing, like BGP protocol, is suitable. The lack of BGP protocol is that the routers never exchange network state information such as path bandwidth utilization or path delays, which are essential for Traffic Engineering purposes. BGP routers allocate only one route (the best one), furthermore, BGP advertises only highly aggregated information. The latest PCE-based approach [4] proposed by the IETF tries to tackle with these shortcomings of the BGP protocol. The idea behind the distributed control plane with possibly some centralized Path Computation Elements (PCEs) is that a group of OXCs forms a network segment, and the PCE
calculates the best route among these OXCs inside the segment and distribute TE information on the selected route towards the adjacent PCEs. The PCE can select the best segments along the connection paths based on the TE information. According to this approach the end-to-end TE capabilities can be achieved and the accuracy of the solution depends on the optimal size and number of the network segments in the whole domain. Beside the routing protocols, the signaling protocols also need several extensions for optical networks [1]. It can be said that a robust signaling protocol requires end-to-end message acknowledgements for correct failure detections, while hop-by-hop message acknowledgements are essential for fast message recovery.

2.2. Possible migration from traditional management to distributed control

The well known control architectures and the ongoing protocol extensions by standardization bodies can be validated by real implementation tests done by the industrial fora. In these early tests the control plane functionality was implemented outside of the network elements by a proxy agent. Two adjacent control plane agents in reality do not necessarily need direct physical connectivity - the only requirement is the reachability between adjacent control nodes. This reachability may be provided by any TCP/IP based packet network, like IPSec tunnels via public Internet [3]. These implementations are fit for protocol interoperability tests but do not deal with the enhanced reliability, security and authentication issues.

3. OPERATION OF CONTROL AND MANAGEMENT PROCESSES IN FAILURE CASES

The traditional Network Management System (NMS) has a centralized management application placed usually in the NOC (Network Operation Centre) and several distributed NMSs collecting the information from the network remotely. The concept of forming a distributed control plane (in parallel with the NMS) is based on the idea that some of the centralized management functions can be distributed among the network nodes to operate more efficiently.

According to the basic ITU-T approach, there are two separated planes (management and control) beside the data plane. On the contrary, the traditional IETF approach treats the distributed control functions as the logical part of the management system [1]. The traditional management functions are; fault, configuration, accounting, performance and security management (FCAPS). In case of a separate control plane implementation, the fault and performance management function are passed to the control plane, while the on-demand routing, signaling and auto-discovery functions may appear as new network capabilities [2]. Adding distributed intelligence to the network means that the network operations may be simpler. The role of the NOC becomes more like managing of the automated network functions instead of real controlling of the network processes.

3.1. Inter-domain control plane failures

The logical control channels between control plane elements are used to exchange messages. Against IP-based control network link failures the standard IP layer re-routing processes (e.g., OSPF) can be used. This is reliable as long as the control plane is still connected, but its disadvantage is the long time needed for the convergence. The control node is responsible for managing the data plane node status as the NMS probe does it in the traditional network management systems. If there is no control on the data plane node, the exact status of the node is not known. In case of separate control and data plane failure detection the data plane node can be checked but still not controlled. If the control is completely lost on some network segments a synchronisation process is needed after recovery [2]. Since the distributed routing and signaling processes are implemented as separate software components, they may fail independently. It probably means that the network will be working based on partially out-of-date (stale) routing information.

3.2. Multi-domain extension of control and management processes

Most of the ongoing work at the IETF is still focused on single domain issues [4]. Even through the multi-domain case has begun to be analysed, the discussions are in an early stage, but it can be seen that the PCE based approach can be easily extended to support multi-domain network environments. The multi-domain environment raises several questions regarding e.g. the admission control, accounting, performance and security management, etc. through administrative domains, which are more related to the traditional FCAPS management functions. So, during the delay model extension an additional management plane communication and processing delay should be involved in the connection set-up/tear-down process chain at the domain borders. The critical question is about the visibility of the other service providers’ domains. In this case, the information flooding is more limited than in the PCE-based intra-domain communication case between two PCE segments. The basics of the inter-domain communications are defined in technical contracts, and the upgrade from the traditional network management to the automatic control of network resources is very complicated from administrative perspective. The technical content of these contracts could be very different depending on the contractors, hence simplified analytical models are proposed in this paper with highly flexible parameters to illustrate the optical connection provisioning delay over different administrative domains.
4. ILLUSTRATIVE SIMULATION RESULTS AND ANALYTICAL MODELS

In this section our intra-domain simulation results and multi-domain delay model extensions are discussed. To simulate and analyse the effect of intra-domain control plane failures the network simulator uses the LEMON project’s graph template library.

4.1. Simulation results on different control plane failures

First of all, the intra-domain connection provisioning delays in different CP failure cases are illustrated in two well-distinct architectural scenarios. In Scenario 1, the CP topology is exactly the same as the DP topology (Fig. 1a). Basically, out-of-fiber signaling links (I-NNIs) are assumed with OSPF-like routing protocol on the CP. In Scenario 2 a dual-star control topology is assumed (Fig. 1b) where the control interfaces (CCI) are run parallel to the data plane links forming groups of shared risk (SRGs). This way the numerical comparison of the scenarios becomes feasible. All OXCs have redundant proxy control functions. The two proxies are connected by out-of-fiber I-NNI (conducted also parallel to the DP links) for synchronisation purposes.

![Figure 1. a) Congruent control plane topology b) Dual-star control plane topology.](image)

In the scenarios source routing is assumed to route data plane traffic demands. Connection setup and release is performed by sending control messages on the CP from the source node’s OCC to each controller of the selected route’s OXCs. The I-NNIs forwarding these messages are assigned by the OSPF CP routing hop-by-hop. In Scenario 1 it is assumed that only NNI link failures may occur, and the CCIs are always up (i.e., software-based integrated control functions are assumed, as in many vendors’ implementation). In Scenario 2 the proxy control agents are physically separated devices (i.e., as is in third party’s standalone control plane implementation) and SRG failures, affecting one or more CCIs may occur. As the OXC ↔ controller mapping is not unambiguous, this scenario is split into two regarding the fact, in which OCC the traffic demand appears. The control messages are then directly sent to the CCI links or, in case the CCI is down, via the I-NNI and the other OCC and CCI.

![Figure 2. a) Number of control messages b) Provisioning delays in different scenarios.](image)

The control messages (Fig 2a) consist of setup/release signaling messages and topology/state information. The state information is essential in case of out-of-fiber control link failures. It supports that the signaling network is automatically restored (as long as it is still connected) but the possible protection path can be longer than the working path (note that the controlled physical connection uses still the same path in the data plane). According to this the service provisioning delay can be longer in case of control plane failures. This delay variation highly depends on the path lengths and on the different control plane topologies of the two scenarios as illustrated in Fig. 2b. In Scenario 2 the delay additionally depends on the physical place of the traffic demand occurrence, as SRG failures affect different CCIs of the two OCCs.

4.2. Delay models for multi-domain network control and management processes

The investigations of the intra-domain provisioning cases can be extended to multi-domain, real size network environments by simple analytical delay models. It is assumed that the intra-domain delay $T_{ID}$ is given (based on the previous simulation results) and in the whole network environment there are $K$ nodes in $D$ domain and each
domain has \( k_d \) nodes. The connection request has uniform distribution regarding the location of the source \( A \) and destination \( B \) nodes, hence the probability of that a node \( A \) is in domain \( k_x \) and the node \( B \) is in domain \( k_y \) is proportional to the number of nodes in the domains:

\[
P(A \in k_x, B \in k_y) = \sum_{k_x} \sum_{k_y} \left( \frac{k_x \cdot k_y}{K^2} \right) \quad \forall k_x, k_y \in \mathbb{Z}^+ > 1
\]

In case of \( x = y \) (i.e. connection remains in the same domain) only intra-domain delay has occurred, in other cases two intra-domain delays and an additional management delay because of the domain border crossings have occurred. The expected length of the provisioned connection is \( n_c \), and it is assumed that the domains are in full-mesh connection, i.e. all the connection demands cross only one or exactly two domains. The expected delay of a multi-domain connection can be calculated as follows:

\[
E[T_{ID}^{mn}] = \begin{cases} 
\sum_{x=1}^{D} \sum_{y=1}^{D} \left( \frac{k_x \cdot k_y}{K^2} \right) \cdot n_c \cdot T_{ID}^l & x = y = d \\
\sum_{x=1}^{D} \sum_{y=1}^{D} \left( \frac{k_x \cdot k_y}{K^2} \cdot \frac{n_c}{k_x + k_y} \left( k_x \cdot T_{ID}^l + k_y \cdot T_{ID}^l + T_{mgu} \right) \right) & x \neq y
\end{cases}
\]

In Fig. 3 the total expected multi-domain connection provisioning delay is illustrated assuming two domains \((D = 2)\) with different number of nodes (the total number of nodes \( K \) is constant = 20) and intra-domain control plane delays \((T_{ID1} = 33\, \text{ms}, T_{ID2} = 48\, \text{ms})\). The provisioned optical connection length \( n_c \) is fixed 4 hops.

The graph shows that as the delay of the management processes assumed is increasing the total expected connection provisioning delay function has a higher humpback. It means that in case of uniform traffic matrix, the expected multi-domain delay highly depends not only on the domain sizes but also on the management plane delay, as well.

5. CONCLUSIONS

In this paper the effect of the control and management plane failures of the dynamic optical networks is discussed. The connection provisioning delays in normal and failure cases highly depend on the architecture and topology of the separated control plane as illustrated by simulations. In typical multi-domain environments the management processes also play key role regarding the on-demand service provisioning delay. The analytical delay model extensions illustrate this consideration, as well.

ACKNOWLEDGEMENT

The authors thank the valuable support for the IST Project MUPBED and additionally many thanks to the LEMON team for their excellent graph template library (http://lemon.cs.elte.hu) used in our simulator.

REFERENCES