# Availability and Operability in Optical Transport Network Architectures

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***Abstract*—A typical optical transport network interconnects multitudes of offices. With the advent of the Internet of Things (IoT) networking approach, it has become necessary for such transport structures to be flexible enough to accommodate heterogeneous communication services that generate escalating traffic loads every time. It is also key not only to accommodating continuously escalating traffic levels, but also to maintain a consistent Quality of Service, operability as well availability. This can only be achieved through the provisioning of effective and dynamic network control. In this paper, we explore the various operational issues such as incompatibilities in terms of physical layer transmission requirements and other control and management challenges emerging in present and future/ (envisaged) optical transport networks.**

***Keywords—Multi-domain networks, Optical and physical layer control; power stability; availability, operability, Introduction***

The emergence of high bandwidth applications and services coupled with a surge in global traffic has necessitated the design and deployment of optical transport networks that are highly flexible enough in order to accommodate the ever-surging heterogeneous traffic load. Primarily, it is imperative that not only should such an optical transport network continuously accommodate the escalating traffic levels, but also to maintain a consistent end-to-end quality of service, operability as well availability. This can only be achieved through the provisioning of flexible controllability in cooperation with service layer networks. Key to cost effective realization of such an optical transport network would be the incorporation of control techniques in such architectures that will enhance overall dynamic operation as a result of the heterogeneity of the traffic that the optical transport serves [1].

A typical optical transport network interlinks multitudes of periphery as well as access networks in order to ensure seamless interconnectivity among end users. The high quality, availability as well as operability of such an infrastructure is achieved by way of appropriately dimensioning and allocation of the potential and available resources, implementation of hitless protection switching, real-time failure detections as well as general redundancy design of key functional blocks. Hierarchical controllability with all active service layer network will lead to efficient as well as rapid execution of rapid network resources re-dimensioning procedures without noticeable interruption to services. Examples of resources re-dimensioning include bandwidth increment requests, topology modifications, as well as routine system renovations. The paper overviews and explores the design and operational issues in current, future directions in design and operation, the impact of software designed embedded optical network controls, and also propose an architecture for future optical transport networks and operational issues that emerge in present optical transport networks. We also provide a description of envisaged future such networks. As such the paper is laid out as follows:

In the next section, we discuss the smart networking issues in the context of future optical transport networks. This will be followed by a discussion on architectural as well as operational problems in current optical transport networks. The same section will also overview advances in optical transport network configuration as well as network-control approaches. Section 4 describes a possible architecture of future optical transport networks.

## I. SMART OPTICAL NETWORKING ISSUES AND TRENDS

The general concept of Smart Optical Networking (SON) assumes a single, integrated control framework that will enable executing as well as instantiating any control architectures within the base optical transport network. The concept will thus provision integrated connectivity. The Smart Networks approach in a way is likely to ease the rollout of new services and application domains in upper layers of a high-performance optical transport infrastructural network [2]. This is illustrated in Figure 1.

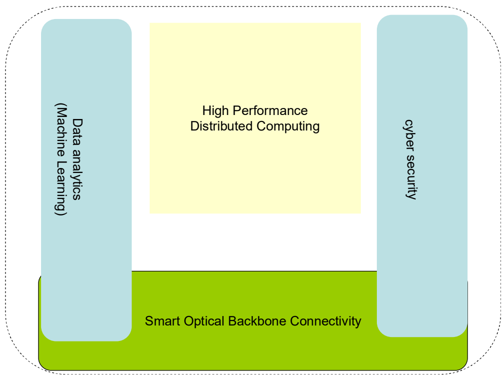


Fig. 1. Smart Optical Transport concept

The main challenges towards the realization of a Smart Optical Network control layer includes the tasks of control and management of all available network resources (systems and elements). Such a task is accomplished by implementing a distributed control and management overlay network. Consequently, this will facilitate network availability, operability, flexibility in adding or dropping of services or applications and privacy preservations for individual services [3].

All optical transport networks comparably have higher capacity, energy efficiency as well as transmission reach. The same infrastructure provides optical connectivity to GSM mobile networks which by themselves offer the basis for Internet of things (IoT) and other smart networking applications. In essence, IoT rely on optical transport network infrastructures in order to increase their own bandwidth capabilities, lower latencies, enhance environmental hardening, programmability as well as energy efficient operations. In general, optical links are immune from EMF interference. This makes them not susceptible to eavesdropping and thus are quite an ideal platform for critical services such as private enterprise and vehicular networks. They will also address challenges with regards to scaling electronic speeds as new optical networking systems, elements and components are deployed in the optical network infrastructure [4].
Optical transport networks are steadily extending further towards customer premises because of the ever-increasing demand for bandwidth and latency requirements in the access network segments E.g fiber-to-the-x (FTTx) technologies are gradually replacing copper cables and other legacy periphery access technologies, where fiber cabling can easily be installed and mobility not being a hindering factor.

## II. ARCHITECTURE AND OPERATIONAL ISSUES IN CURRENT OPTICAL TRANSPORT INFRASTRUCTURES

Optical transport networking in general addresses the transport, control, management planes, as well as design aspects in optical transport networks, where end to end path networks, encompassing various technologies are mapped. Multiple paths each of which is an end to end virtual or physical circuit, facilitating communication between two communication capable terminals are established across such a network. The paths and networks are regarded a key integral part of the transport plane. Example technologies such as multi-protocol label switching (MPLS) as well as generalized MPLS (GMPLS) are both related to the transport as well as control planes, whereas path computation element (PCE) is related to network design and also to the control and management planes. We also have SDON and virtualization that provisions robust network control and management planes.

Illustrated in Figure 2 is an example of an optical transport network that provides a path network to various service networks. The infrastructure is pillared on transmission path, physical as well as cabling layers. In order for a Service Provider to provide services, a service system in the infrastructure that comprises cross-connect switches, routers and so on is necessary to provide a dedicated service network. The Service Provider thus maps a service utilizing the available service systems that are connected via path-sets. There is a gradual increase in the number as well as diversity of service networks due to the proliferation of applications and services and hence optical transport networks have to contend with provisioning the ever-increasing bandwidth demands. The emergency of IoT-enabled devices and systems is necessitating the provisioning of IoT device control service networks to cater for automation in industrial areas and thus a further demand for more bandwidth capacities [5]. The vast numbers and diversity of service networks escalates traffic growth, and therefore the need for optical transport networks to always keep pace with the new bandwidth demands as well as provide sufficient numbers of path-sets in a cost-effective manner. This calls for new approaches to systems configuring, as well as control. Furthermore, network or service disruptions as well as quality of service degradation must be carefully managed as they tend to be more diversified as well as complex. The ever-surging heterogeneous traffic data levels and patterns by service networks directly affect the rate and scale of overall available bandwidth increase/decrease as well as path-sets reconfiguring in conjunction with service networks.

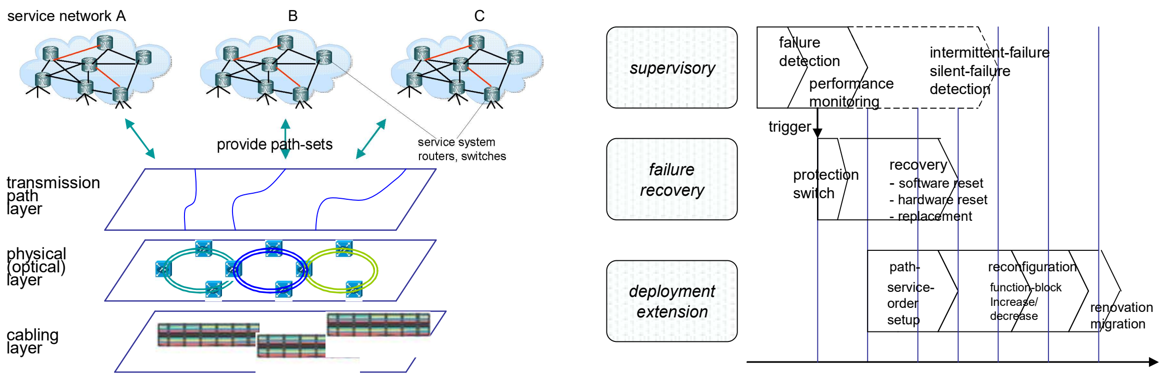


Fig. 2. Optical transport network infrastructure

As illustrated in Figure 2, the current transport network problems can be viewed as a fundamental operational cycle, which encompasses deployment/ extension, failure recovery as well as supervisory functions. These are briefly described in the next subsections

### A. Deployment and Extension Cycles

The deployment and extension cycle is concerned with and addresses migration to new technologies, resources increment/decrement, network service topology modification or reconfiguring, lightpath service order setup as well as system renovation. The key deployment and extension cycle procedures are summarized in Figure 3.

Individual service-network ooperators determine and map their own desired service network configurations depending on the projected numbers of subscribers/users, QoS, network availability, and service costs. In order to ensure a long-term reliable service as well as OPEX/CAPEX minimization, the sservice operators are expected to liaise as well as cooperate with the optical transport network ooperators with regards to deploying their own service networks. As an example, proper coordination must be maintained between the service network operators and the optical transport network when the earlier requests a modification of current resources. A request in modification of resources can be caused by a sudden increase/or decrease in data traffic volumes between cooperating service systems, which will in turn require the optical transport network operator to accordingly modify the corresponding lightpath (lightpath-service order). Upgrading of a service network that will require a point-of-interface (POI) as well as topology changes will result in the ooptical transport network executing a reallocation of lightpath-sets. All network systems and equipment have their own life spans at the expiry of which necessitates renovations as well as migrations to newer technologies. In the process, these procedures will inevitably include mandatory system-software updates.

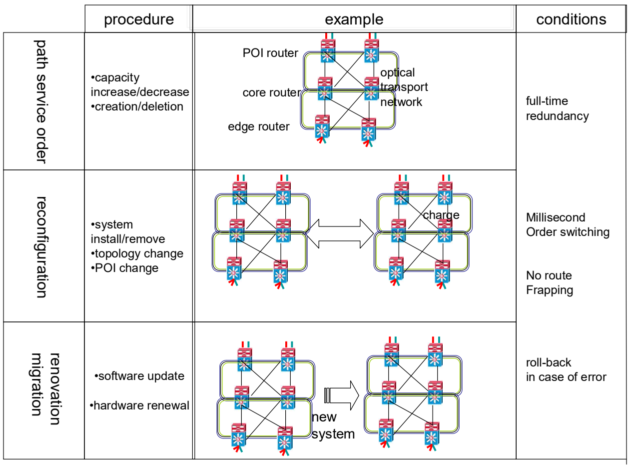


Fig. 3. Deployment-and-extension cycle procedures

The work in [6], [7] provide some analysis on the number of deployment and extension procedures for a practical optical transport network whose aggregate traffic volume surge significantly on an annual basis. The network is assumed to comprise 4 hierarchical sub-network levels namely; area, prefecture aggregation networks, as well as transport and core networks. This is illustrated in Figure 4 in which the area aggregation sub-network comprise eight user-access buildings, a prefecture-aggregation network with ten area buildings each representing an area-(aggregation network), an optical transport network with eight prefecture buildings, and lastly six POI buildings. The analysis makes a few assumptions as follows in determining the frequency of deployment and extension cycle procedures:

- That the twenty operational service networks provide a single dedicated POI layer 3 switch ( L3 switch) in each prefecture section, and each area section 3 edge routers.
- That the traffic is confined within six POI sections.
- Only core network has a mesh topology, otherwise the rest of the network sections utilises star topologies.

<lightpath path-service order>

With regards, to the desired lightpath path-service order demands, the network increases them in orders of 10 or 100 Gbit/s units.

The total number of sections is thus $8 \times 10 \times 8 \times 6 = 3840$ and the number of routers is $6 \times 20 + 48 \times 20 + 480 \times 3 = 2520$ deployed in each area section.

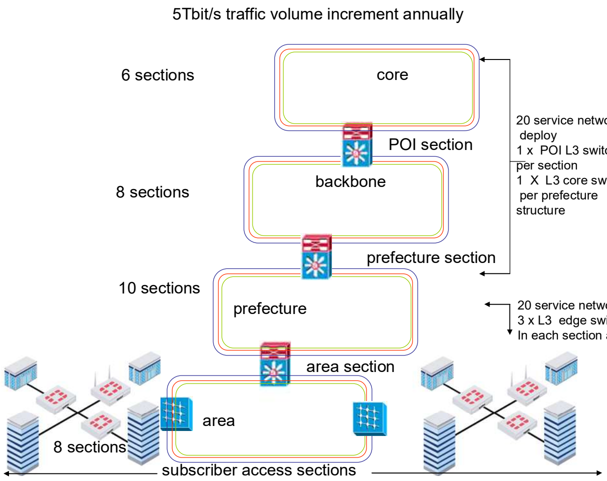


Fig. 4. Deployment-and- extension frequency estimation

The data provided in table 1 can be used to calculate the capacity increase per year for the various subnetworks. For the core subnet, the capacity increase frequency is:

$$\frac{1 \times 15 \times 139}{100} \times 2 \approx 42 \text{ events per year.}$$

Table 1. Llightpath increase frequency

| subnetwork | no. of subnetworks | path topology | no of s-d pairs/sub network | Capacity increase/year for s-d pair | path increase unit | **increase even/year** |
|---|---|---|---|---|---|---|
| area | **480** | **star** | **7** | **1.3G** | **10G** | 875 |
| prefecture | **48** | **star** | **9** | **10.4G** | **10G** | 900 |
| backbone | **6** | **star** | **7** | **104G** | **100G** | 88 |
| **core** | 1 | mesh | 15 | 139G | 100G | 42 |

The capacity increase events for the area, prefecture, backbone are likewise calculated. In total, the entire optical transport network registers nearly 2000 path increase events per year. This will obviously increase much further with larger volumes of traffic growth.

<reconfiguration>.

The traffic volumes of each service network increasing every year hence necessitating the installation of additional routers, as well as establishing cut-through paths between routers. This is normally performed routinely about three times hence a reconfiguration frequency for the optical transport network of about sixty events annually [8], [9]. Furthermore, OPEX can be reduced by reconfiguring each service network dynamically, but this will be at the expense of further increased reconfiguration frequency.

<renovation> Key software upgrades in routers are supplied years to realize new functions as well as fix bugs of previous versions [10]. Router hardware ages every 15 years i.e. EOS/EOL time [10], [11]. General software update interval of routers is approximately 5 years, thus the renovation frequency for the optical transport network is;

$$\frac{[3840\times 1+2520\times 3]}{15}\approx 760 \text{ events per year.}$$

During renovations, it is important to avoid service interruption as well as network GoS/QoS degradations hence additional measures such as maintaining redundancy during the entire process. However, ideally each service network may prefer to execute the renovation procedures only when it is conducive to do so as to avoid revenue loss as well as minimize renovation time. Once an SDON control architecture is in place, it should be possible to execute maintenance related functions without interrupting the services [12].

### B. Failure Recovery Cycles

The failure-recovery cycle is involved in the protection switching as well as recovery operation of failed functions. Examples of the latter include hardware replacement and software resetting.

As per ITU-T recommendations, all networks are expected to provide an end-to-end 99.99% service availability [13]. The availability constraint also covers the access sections of the network. This can only be achieved by provisioning redundancy for each network function as well as execute hitless protection switching to protect against failures. All failed systems, components as well as functions must be speedily attended to in order to avoid further degradations that otherwise may lead to proliferation of failures.

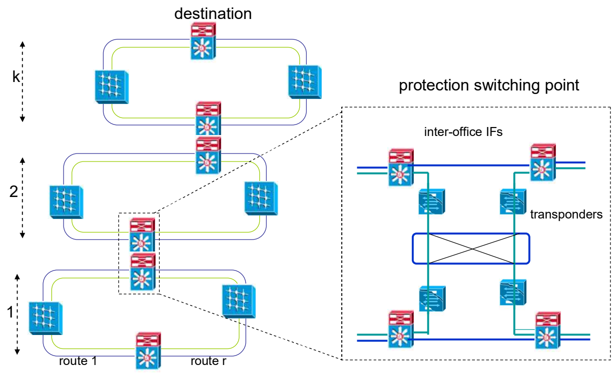


Fig. 5. Problems emerging in failure-recovery cycle

The concept of protection switching segments is illustrated in Figure 5. It is implemented to maintain the connectivity, even in the case of concurrent failures on multiple segments/routes as valuables.

In practice, the failed functions may be scattered in the various buildings, thus it might take a significant amount of time to repair. It may be necessary to have a well-organized and robust systematic maintenance routine plan. Ideally, an SDON can be implemented to optimize and balance between the number of functions in protection switching segments, end-to-end redundancy, and failure-recovery time.

### C. Supervisory Cycle

The supervisory cycle is involved in failure detection in the various sections of the network as well as general performance monitoring at equipment and network levels.

Key supervisory cycle issues and problems are summarized in Figure 6. Cardinal to a high capacity network is ultrafast components such as line interface cards and transponders, all of which will normally incorporate parallel processing as well as high speed clock rates in order to boost overall processing speeds and capabilities. The authors in [14] emphasize the need to balance between a high a clock rate and parallel-processing degree in a given device versus the general aging rate of a device. It is also true that most key components such as CPUs and chipsets in the various network systems become dependent on these commodity devices.

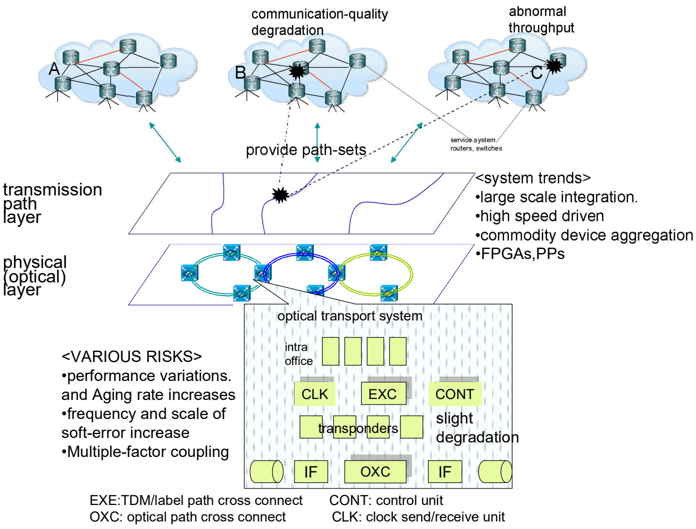


Fig. 6. Issues emerging in supervisory cycles

Therefore system failure or performance degradation is probably increasing gradually along with the increase in performance variation and aging rate of each device, frequency and scale of soft errors, and multiple-factor coupling. Slight degradation may largely impact on quality of services, and silent or intermittent failure may occur more frequently. Therefore if software-defined networking (SDON) is introduced to optical transport networks in the near future, it needs to reveal performance degradations due to diversified and complex factors and signs of large-scale failure earlier.

## III. Availability and Operability

In this section we briefly overview architectural approaches that would ensure of availability as well as operability in future optical-transport-networks.

Generally, it is expected that an optical transport network will facilitate a robust physical-layer performance monitoring mechanism so that system and component failures can be rapidly detected, and actions immediately taken to localize them. The same mechanism must be able to effectively monitor performance correlation for the optical path cut-through region for both analogue and digital signals. Other tasks may also include carrying out in-channel supervision for the electrical processing region, engine-device health-check as well as memory scanning,

The entire optical transport network must ensure hitless protection in all its sections, In so doing it must also ensure flow-through control procedures in liaison with all available service networks, service-network reconfiguring or extension, temporal pool-resource utilization, updating as well as upgrading/renovation of both optical transport as well as service systems. Together with service networks, the optical transport network's control function must be capable of cross-layer supervision and control. The control function should further be able to manage as well as configure all end-to-end lightpath connections and should take responsibilities of cooperative control processes and procedures.

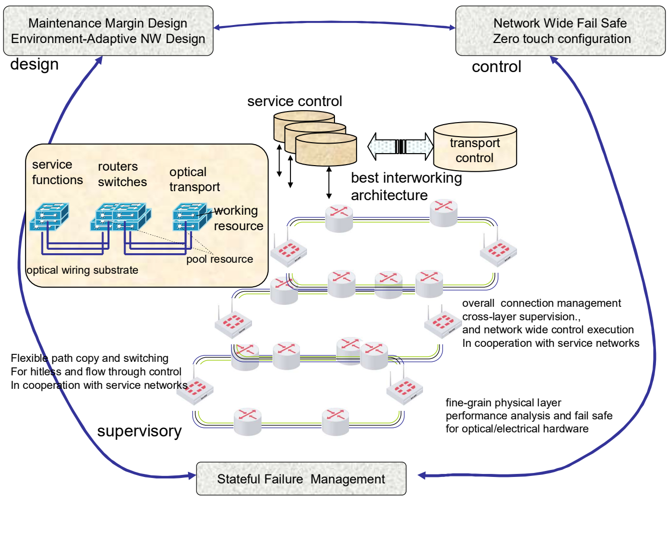


Fig.7. Summary of architectural points for future optical transport network infrastructure]

Finally, it must also aid in the design optimization of each service network's configuration as well as resource assignment of the optical transport network. This is summarized in Figure 7.

Figure 8 summarizes the envisaged key optical transport technologies. Overall, because of the large bandwidth capacities required, multiple ports as well as cost effective OXCs/ROADMs are required [13]. These will perform the grooming of lightpath connections in the optical layers. They should also facilitate optical path layer protection/restoration as well as optical path layer services such as optical circuit switched services. Various studies have also focused on the realization of energy-efficient switching fabrics for constructing OXCs [15].

Focus is also on the mitigation of limitations of optical transmission by way of adopting elastic optical networks (EONs) [18]. EONs can easily handle lightpath connections with high symbol rates and higher-order modulation formats, and hence ensure comparably higher network utilization. Furthermore, EONs do assign the number of frequency slots based on the modulation format of each client signal].

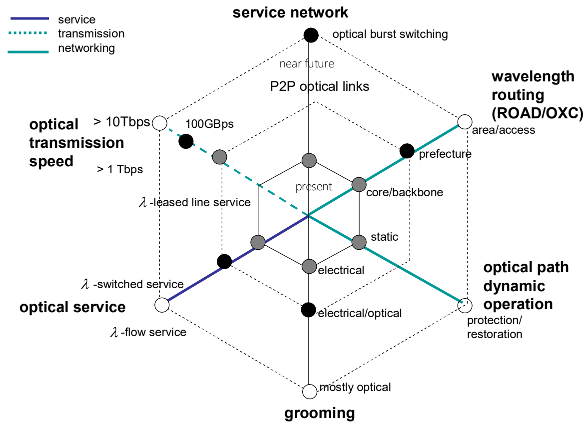


Fig. 8. Eenvisaged optical transport network technologies

However, the irregular passband shape of WSSs in a ROADM/OXC can contribute to serious signal degradation as the signal traverses the network. Typically, the channel narrows, and this tends to accumulate with each node traversed by the optical lightpath. Designers and researchers have suggested an initial broader guard-band between adjacent paths even though this is at the expense of overall capacity utilization. Internode links are facilitated by a fiber and as traffic increases, either multi-core fibers will be incorporated, or alternatively spatial division multiplexing (SDM) will be employed. In this regard, studies in [13], focus on the overall cost of multi-core fibers and related technologies. In particular, the researchers looked at various options including multi-channel optical amplifiers, parallel optical switch elements, connectors as well as opto-electronics integration.

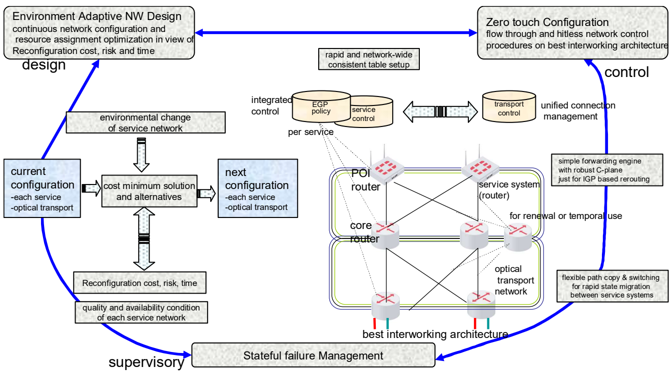


Fig. 9. Envisaged deployment/extension cycle

There is also a need to establish an optimized optical transport network control architecture in cooperation with the service networks that shall perform reconfiguration, renovation and migration at convenient times, with no service disruption risks, flow-through, as well as service-uninterrupted execution procedures. Figure 10 illustrates a possible service and architecture control architecture for flexible reconfiguration, renovation as well as pooling of resources [16].

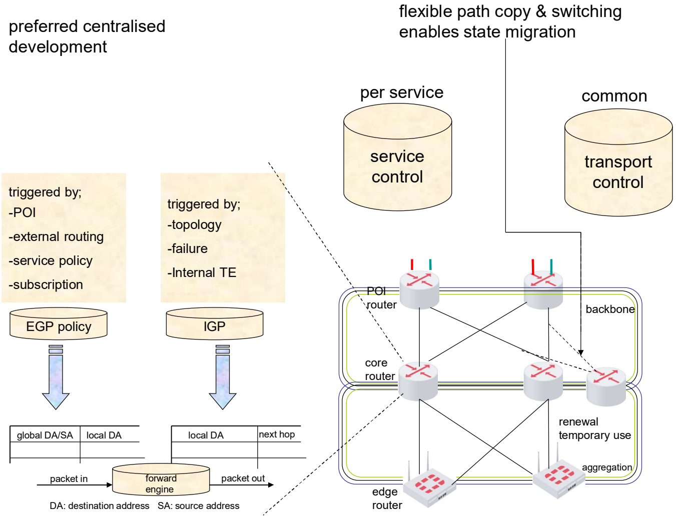


Fig. 10. Control architecture

The following consensus suggestions have been put forward in various literatures:

- That current IP networks Interior gateway protocols (IGPs) perform control functions triggered by internal router topology modification or link failure (hence has local routing and control significance) whereas exterior gateway protocols (EGPs) are generally triggered by point-of-interface (POI) change, received external routing information, service policy, and service-subscription hence has global routing and control significance. However, in future optical transport networks, it would be necessary to rather centrally deploy EGP/policy function for network-wide table consistency.
- That service systems should be rendered as simple forwarding mechanisms and re-routing functions.
- That networks must be enhanced with flexible switching capabilities that will handle state migrations between service systems.

The flow-through capability as well as hitless network-control procedures should be executable on this new architecture, a concept referred to as the "Zero-Touch Configuration". The "Environment-Adaptive Network Design" concept should also be adopted which generally ensures long term as well as stable service delivery and availability.

## IV. Conclusion

The paper has overviewed current and future trends towards designing and operation of optical transport networks.
We commenced the paper by looking at the main challenges towards the realization of a Smart Optical transport network architecture as well as control layer. We then highlighted the challenges with regards to the aspects of control over multiple general-purpose, distributed, network control operating systems; the availability of powerful abstractions to resources and services; new naming schemes for virtualized resources; dynamic and automated discovery; intent-based open APIs and highly configurable policies to control the resource and service access and dynamics; isolation of applications' execution environments and performances. We also looked at architecture and operational issues in present day optical transport networks. We also briefly explored the multi-layer traffic engineering designs and control networks considering resource usages of more than one layer, which leads to use network resources more efficiently than the single-layer traffic engineering adopted independently for each layer.

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