TECHNOLOGY WHITE PAPER

Role of Network Management in Network Restoration and Resilience

The introduction of a distributed control plane in the transmission nodes, improvements in the path control mechanisms in packet switched networks, and ever increasing pressure on operating expenses are affecting the role network management plays in network restoration and resilience. Intelligent traffic restoration mechanisms can reduce the (unused) bandwidth reserved for protection and provide an acceptable recovery time in the event of transmission path problems. As this new technology needs to be implemented in existing networks, an evolutionary approach is required. Consequently it is essential for the path control functions between existing centralized network management systems to be able to coexist with the distributed control plane driven path controls.

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ROLE OF NETWORK MANAGEMENT IN NETWORK RESTORATION AND RESILIENCE

New network management system features will have an important role in managing the successful evolution of optics and data networks to implement distributed control plane architectures.

Introduction

The past few years have seen tremendous changes for all players in the telecommunication arena. Ever-increasing demand from "users" for more and more innovation in the access, edge, metro and core networks includes:

- More bandwidth and added value, consisting of service diversity and control requirements.
- A revolution in terabit routing, switching and transport infrastructures, such as Optical Transport Networks (OTN).
- Innovative optical network elements, protocols, and management and control systems used in innovative network configurations.

Today, data services are the dominant users of bandwidth in many service providers' networks. Also, because of the dominance of enterprise applications, Internet Protocol (IP) traffic management and control capabilities are beginning to complement traditional connection-oriented traffic management systems. In many instances, service providers are also attempting to differentiate their service offerings by considering advanced network architectures based on new intelligent transmission technology. These architectures focus on reducing operating expenditures and improving network management flexibility by taking advantage of intelligent control functions in the nodes.

New control capabilities are being introduced into nodes in both optical Time Division Multiplex (TDM)[1] transmission networks and cell/packet switched networks. It is difficult to predict the pace of this transition, which will take place at different times for the TDM and data layers. Consequently, the network management design must evolve, complementing the new control plane functions. At the same time, it must take into account the network operator's migration scenario when the transition takes place in an operational environment.

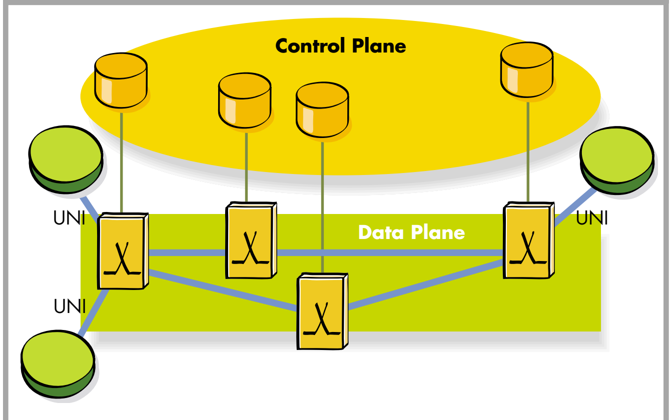
[1] Here, TDM is used as shorthand for Synchronous Digital Hierarchy (SDH), Synchronous Optical NETwork (SONET) and Dense Wavelength Division Multiplex (DWDM) optical transmission technologies.

Control Plane Models

Definition of Control Plane

The control plane is implemented by deploying intelligence in the nodes, enabling them to gather information about the network environment. *Figure 1* shows the control plane as a logical layer, parallel to the 'data plane'. The real-time collection of network configuration data enables network nodes to collaborate, offering the possibility to perform coordinated reconfiguration actions without the intervention of an external manager.

Fig. 1 Relationship between the control plane and data plane



UNI: User-Network Interface

A set of protocols between the control plane parts exchange network information and coordinate any reconfiguration. Recently there has been a flurry of activity in several standards groups aimed at marrying Multi Protocol Label Switching (MPLS) and SDH/SONET/DWDM networking technologies to define a protocol set that is also suitable for a control plane in the TDM world. In this case, MPLS is referred to as Generalized MPLS (GMPLS). GMPLS extends the notion of label swapping with MPLS to timeslots and wavelengths. The emergence of the Private Network to Network Interface (PNNI) routing protocol supports a similar trend in Asynchronous Transfer Mode (ATM) networks.

The International Telecommunications Union – Telecommunications (ITU-T) Automatic Switched Optical Network (ASON) architecture gives an extended view, with the network being composed of layered domains that interact with other domains in a standard way. The "user" is an endpoint device that can request connection services dynamically over a UNI.

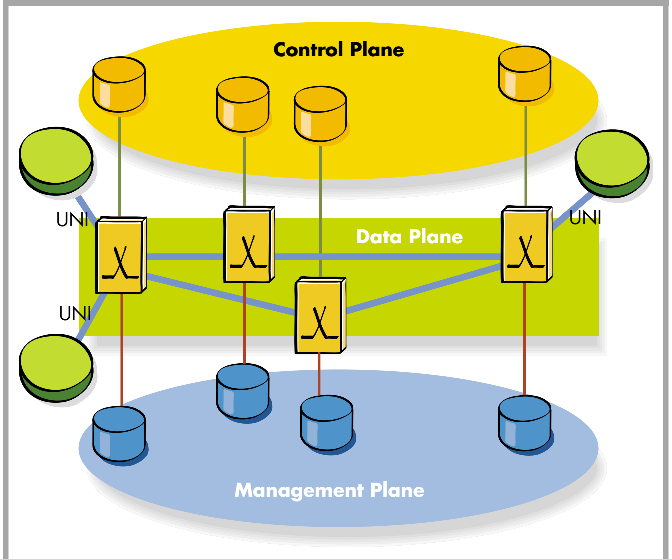
Role of Network Management

One inherent feature of a control plane is the ability to reroute traffic in the event of a fault, a feature known as restoration. This mechanism requires all the network resources to be permanently monitored, including those that are not used, to ensure that they are available should rerouting be required.

The functionality assigned to the control plane may vary, but the correct strategy is to use it to enhance the nodes with multi-vendor and real-time capabilities. Trying to exchange all the management information using the control plane will result in it being overloaded, eventually leading to a critical performance problem. Thus the control plane will complement rather than replace the Network Management (NM) system, as shown in *Figure 2*. NM will have to ensure consistency between the network resources and the carrier's internal database. Other features related to fault reporting/handling, accounting, performance monitoring and security would remain under NM control, which will now also include management of the control plane.

Control plane actions and network management operations are designed to be complementary. The role of NM is to prepare the configuration data to enable the control plane, acting as a real-time tool, to set up and tear down services and preserve them in the event of network faults. Traffic engineering tools are one such application; they provide the right configuration parameters for optimal distributed routing decisions. Once correctly configured, the control plane will be able to operate even if the NM is unavailable. On the other hand, NM must be able to override the control plane if necessary. For example, the status of resources could be changed and hidden from the control plane. The visibility of the network state is an essential NM feature, enabling the operator to repair a faulty component (with the traffic already automatically rerouted) and to control the network so that it operates in a stable and predictable manner.

Fig. 2 Adding the management plane



Evolution of Network Management Applications

The evolution of NM applications must take into account the benefits of the control plane functions implementing data path service routing, mechanisms to recognize services affected by failed resources, and reconfiguration of the data path across the controlled network. Two evolutionary aspects are considered below:

- Evolution of the Alcatel 1354 Network Manager (NM) in optical networks with the introduction of a distributed control plane in the OTN.
- Alcatel 5620 NM improved path control mechanisms in cell/packet switched networks.

Key Elements of Intelligent Optical Networks

There are two scenarios for implementing an optical network with intelligent nodes: a "greenfield" implementation or evolution from an existing network in which the nodes have no control plane capabilities. The second scenario is analyzed here because it does not preclude the first one; it might even facilitate it.

Centralized control in OTNs

In this scenario, protection mechanisms like linear Multiplexer Section Protection (MSP), Sub-Network

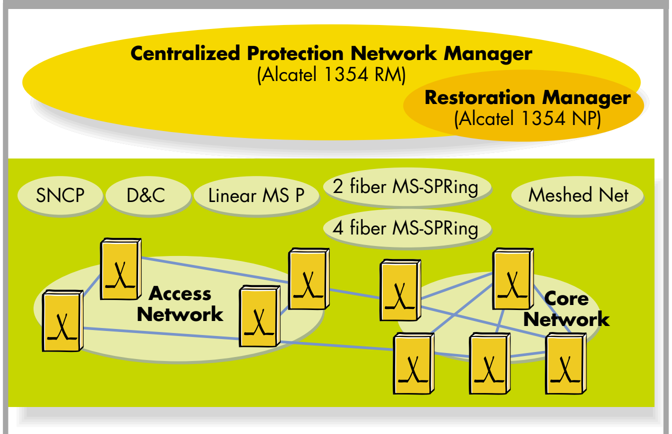
Connection Protection (SNCP), Drop & Continue (D&C), and Multiplexer Section Shared Protection Ring (MS-SPRing) (two or four fibers) are used to increase fault resilience in both the metro and core transport networks. Protection mechanisms sometimes require an *ad hoc* communication protocol between the various network elements involved. Protection is normally set up and supervised by a central network manager which implements management functions like path provisioning, network configuration, fault reporting/handling, accounting, performance monitoring and security.

The Alcatel 1354 Regional Manager (RM) provides this type of Network Management System (NMS) for both SDH and (D)WDM networks. In the core of the network it is common to have meshed subnetworks where a central NMS provides fault resilience through "restoration" actions, to improve bandwidth optimization compared with the previously listed protection architectures. This NMS collects real-time alarm information from the Network Elements (NE) and reconfigures the meshed subnetwork based on a globally optimized view.

The Alcatel 1354 Network Protector (NP) is one of the most efficient restoration managers, capable of rearranging an optical core subnetwork within a few seconds, even in the event of multiple faults.

To provide a single point of management for the whole network and to share large NEs between protection- and restoration-based mechanisms, the 1354 RM acts as a manager of managers, providing an integrated view, including the subnetworks controlled by the 1354 NP. End-to-end path provisioning is computed by the 1354 RM, which requests a nominal route across the restoration-based subnetworks to the 1354 NP. In the same way, typical management functions (path setup, fault management, etc) are handled for the whole network, as shown in *Figure 3*.

Fig. 3 Centralized network management

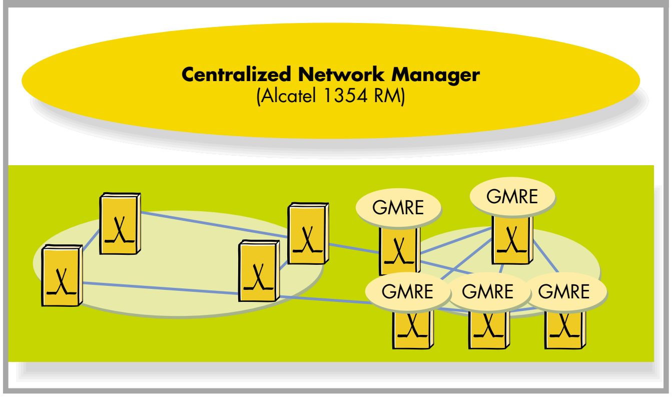


Distributed control in OTNs

By adding more intelligence to the NEs in restoration-based subnetworks, the previous scenario can be implemented using distributed restoration control within the subnetworks. This additional intelligence is realized by adding the ability to take local routing decisions based on topology and resource information which is exchanged with other NEs that are members of the subnetwork.

In Alcatel NEs, the Generalized MPLS Routing Engine (GMRE), a software package deployed in each node, optionally implements this distributed control plane in existing nodes (see *Figure 4*). The add-on capability of the control plane is complemented by the essential ability to migrate step-by-step (or to assign part of) the node resources to a set controlled by the distributed control plane instead of to the central network manager, as far as circuit provisioning control is concerned.

Fig. 4 Adding distributed control plane functionality to OTN NEs



As information sharing and connection setup orders are performed through standard signaling protocols (GMPLS), this solution is open to a multi-vendor environment.

An additional advantage of this distributed approach is that restoration decisions are taken by each node, in near real-time, even if the NMS is not present or not connected to the NE. The disadvantage is that each node takes its restoration decisions autonomously, without any coordination. Consequently, such decisions may not be globally optimized or may be slow to converge in large, highly loaded subnetworks. To help overcome this last drawback, better standard algorithms are required which take into account contributions from the central network management to pre-calculate recovery routes and strategies.

In any case, the central network manager retains its various roles, including fault reporting/management, performance monitoring, and security. An additional feature of the 1354 RM enables the operator to ask the NM to activate the setup of circuits in order to send commands to the appropriate GMRE, which will initiate signaling throughout the distributed controlled subnetwork.

Evolution from existing OTNs

New intelligent networks hold out the promise of reducing capital expenditure and operating expenses (through multi-vendor compatibility, advanced scalability, faster provisioning, network auto-discovery, efficient bandwidth usage for restoration etc) and providing new services (like bandwidth on demand).

Moving from the traditional to the new types of network, Alcatel is proposing an evolutionary approach whereby established networks are "boosted" by central applications to provide similar functionality to that of the new distributed control plane technologies.

As an example, in the case of bandwidth on demand, a central GMPLS proxy "enriches" the established non-GMPLS networks to provide, in real-time, circuits in response to requests coming from a user through the UNI (so-called switched connections). In this way, this function is available not only across the new GMPLS-capable network, but also through the traditional network.

In this case, the GMPLS proxy – Alcatel 1355 Bandwidth on Demand (BonD) – reroutes the UNI requests through the NMS that interfaces the non-GMPLS NEs(see *Figure 5)*. The central network manager acts as a common repository in which the UNI request is verified for compliance with existing Service Level Agreements (SLA).

A similar approach is used for restoration where traditional subnetworks supported by a central restoration manager coexist and interwork with networks based on GMPLS restoration .

On top of the complete network, the Alcatel 1354 RM provides a uniform view and uniform procedures to minimize the impact on the operational process. This approach also facilitates evolution where the distributed control plane is not being introduced in a greenfield environment.

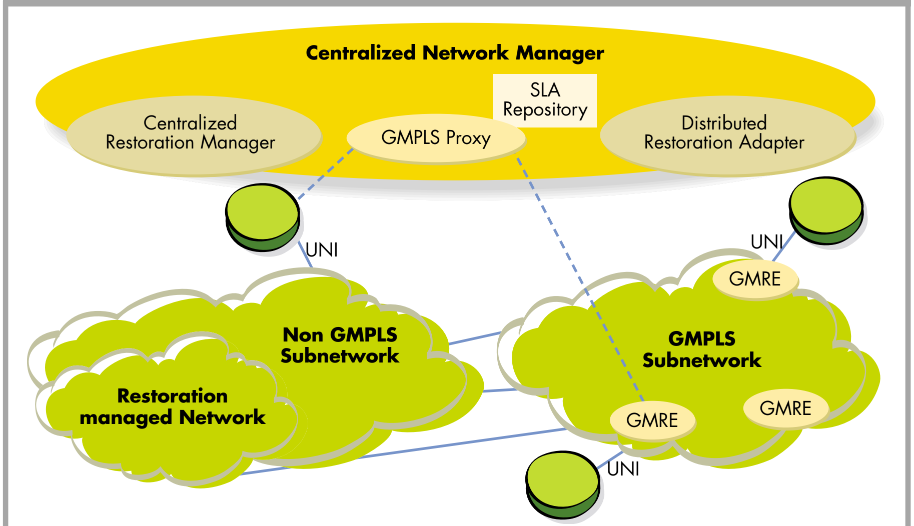
Key elements in 5620 managed networks

The Alcatel 5620 NMS has established its reputation as a data network management system because of its end-to-end provisioning capabilities, which are delivered ubiquitously across the broad range of equipment types and associated path types that it manages (circuit-switched data, circuit-switched voice, ATM, frame relay, MPLS, Ethernet, etc).

In much the same way as in OTNs, the traditional NM paradigm is based on control from a central management plane. The emergence of the PNNI routing protocol within the ATM Forum has provided an opportunity to realize the improvements offered by a distributed control plane. Similar techniques are employed in MPLS networks to add traffic engineering and Quality of Service (QoS) capabilities to IP networks.

PNNI or MPLS will typically be introduced in established networks, rather than in new or "greenfield" environments. ATM networks tend to be a mixture of ATM and non-ATM equipment and will often evolve into a central PNNI network core with segments of non-PNNI capable equipment connected at the network edge. Similar islands of MPLS capable and non-MPLS capable NEs will also be typical of IP networks. A sophisticated NMS must provide the necessary measures to ensure a seamless approach to managing such networks.

Fig. 5 Interworking between GMPLS and non-GMPLS subnetworks



PNNI/MPLS overview

The enabling of PNNI in ATM networks and MPLS in IP networks removes the tasks of route selection and connection administration from the NM and distributes them to the source endpoint of each path or Soft Permanent Virtual Circuit (SPVC) or Label Switched Path (LSP). The PNNI/MPLS-enabled multiservice switch (or "node") that hosts the source endpoint for the path, stores a prioritized list of routing tables that define possible routes from itself to each of the other "nodes" that it can see in the network. These routing tables are generated via a peer-to-peer exchange of topology information with its neighboring nodes. The improvement in connection establishment rates is substantial since each node in the network can act unilaterally and asynchronously to connect or restore the SPVCs under its control. An additional performance benefit is derived from the fact that route selection does not need to be computed at connection time. This performance improvement creates opportunities for network resilience and recovery strategies that rely on the rerouting performance of the network rather than on simple physical line and/or card redundancy.

Evolution from the existing ATM to PNNI and IP to MPLS networks

While a compelling argument can be made for service providers to migrate existing ATM networks to PNNI networks and IP to MPLS networks, such a migration is a logistical challenge. (How do we get there from here?) The act of PNNI enabling an ATM network involves considerable effort in the areas of network configuration and establishment of the required network infrastructure. The key components of a PNNI network are:

- Addressing scheme to uniquely identify the various network elements.
- Web or mesh of links supporting inter-nodal routing and signaling messages within the PNNI network.

The Alcatel 5620 supports the configuration of the necessary point-to-point Virtual Path Connection Links (VPCL), each of which has an associated PNNI link (supporting the exchange of PNNI routing information, also called a Routing Control Channel or RCC) and a signaling link (used for sending connection requests). In addition to these basic network building blocks, the PNNI standard provides the ability to scale networks to large numbers of nodes by grouping them into a hierarchy, with each level represented by a single node in the group – the Logical Group Node (LGN). This is achieved by applying a three-tiered hierarchy to the PNNI addressing scheme in which each node has a unique address at each level in the hierarchy, and a single node represents the LGN as peer group leader.

As might be expected, a substantial amount of manual configuration is required to establish these hierarchical networks. However, some information is common to the nodes in a given subtree within the hierarchy (i.e. summary address information). The 5620 facilitates these configuration exercises by automatically propagating any change to a single node that triggers the need for the same change to be made to other nodes.

Similarly, in MPLS networks the IP links between routers must be configured to carry MPLS signaling messages. A good NMS solution, such as the 5620, would enable an operator to easily configure and view the MPLS-enabled parts of the IP topology, specify how much of the link bandwidth should be reserved for MPLS forwarding and IP forwarding, and which MPLS signaling protocols are enabled on the link.

Once the requisite PNNI/MPLS network infrastructure (i.e. signaling and routing links) has been established, a set of management functions is still needed to manage the ATM virtual channels or MPLS LSPs, even if the actual connection setup is performed in the network.

In the ATM case, there is usually a substantial logistical hurdle in completing the network migration: how to convert the existing network management system controlled PVCs to PNNI controlled SPVCs. Clearly, this conversion must be performed with minimal service disruption to the provider's customers. A tool in the 5620 performs this PVC to SPVC conversion, connecting paths and verifying the establishment of the new connection. Should one of the converted paths fail to connect for any reason, the 5620 automatically restores the original PVC.

When the PNNI network is fully operational, the challenge for the NMS is to provide operators with similar levels of control and network visibility as were previously offered by the central management of the PVC network. The 5620 provides the operator with a number of tools to influence and correct (as needed) the routes taken by paths through the PNNI network. The Operator Directed Routing (ODR) tool allows an operator to specify a list of the NEs through which a given path must pass. Similar LSP management functions are provided in the MPLS case. The routes that an LSP may take through the network can be determined using the NMS point and click capabilities on a view of the MPLS topology. In addition, MPLS realizes the concept of strict and loose routing; the NMS application allows the operator to specify whether an LSP *must use* or *may use* a particular router as it transits the network.

In addition to managing LSP routing, the 5620 can provide numerous LSP configuration parameters to ease the administration of MPLS networks (e.g. easy setting of traffic management parameters and classification parameters).

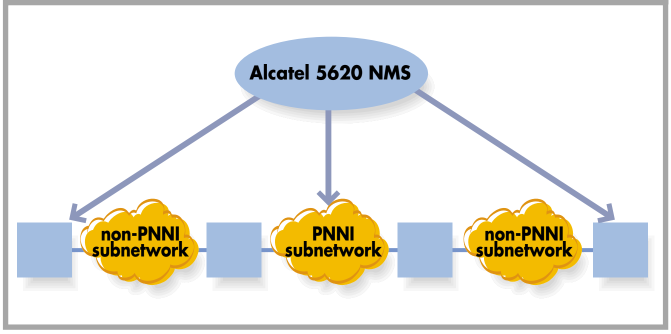
In the ATM case, the Alcatel 5620 provides a sophisticated console for administering network path optimization. Path optimization of SPVC segments is achieved using the ATM Forum standard "bridge and roll" technique, known as "domain-based routing". This technique allows the PNNI network to connect the intermediate segment of the proposed new route for an SPVC before releasing the established path. This dramatically reduces data loss, allowing optimization to be achieved in less than 50 ms – effectively a "hitless" connection move.

Hybrid ATM and PNNI controlled ATM networks

In the ATM case, there are other scenarios in which advanced management tools can make a difference to operational excellence, even for networks with distributed connection control planes. One such example is referred to as hybrid PVC and SPVC networks. This situation arises because firstly few "greenfield" data networks are deployed using a homogeneous technological approach, and secondly, distributed routing protocols such as PNNI pertain to a particular technology (i.e. ATM). While such a technology may exist in one segment of a network, the service provider's end-to-end data path will probably traverse or terminate on other legacy technologies.

In order to support this, the NM must know about the entry and exit points of the PNNI network. *Figure* 6 shows how this is done with the 5620; the NMS provisions two separate PVC segments in addition to an SPVC segment, resulting in a seamless end-to-end managed path commonly referred to as a hybrid SPVC (a concatenation of PVC and SPVC segments).

Fig. 6 Interworking between PNNI and non-PNNI enabled subnetworks



To provision such a path, a network operator need only select the two endpoints for the path and specify the desired path attributes (bandwidth, service category, etc). The 5620 automatically identifies all the path points required along the PVC segments, the entry and exit points of the PNNI network for the SPVC segment, and sends all the connection requests needed to complete the path. While the NMS is not involved in selecting and connecting the route for the SPVC segments, it does select the source and destination endpoints for the SPVC and sends a connection request to the selected SPVC source node. Upon receipt of this request, the SPVC source node signals a setup request, specifying a selected route from itself to the specified destination node.

Additional monitoring and diagnostic capabilities for PNNI/MPLS networks

In addition to end-to-end provisioning capabilities, network operators need to maintain the end-to-end visibility of network paths. The strength of this capability directly influences the service provider's ability to provide a quality service. To support this endeavor, the Alcatel 5620 provides a diagnostic interface for the use of ATM Forum standard *connection trace* and also for MPLS *ping* and *trace route* operations. In the ATM case, this tool allows users to query the network and display a drawing showing the network elements traversed by a given SPVC. The ATM Forum *path trace* routine is used when attempting to identify why a particular call setup failed. The resulting drawing clearly shows the routes that were used in an attempt to set up the call, and the reasons why the call failed to establish along the specified routes. These utilities are integrated with the Alcatel 5620 *route trace* utility, which is used for similar diagnostic efforts on the PVC segments of a hybrid SPVC to maintain end-to-end visibility of the complete network path.

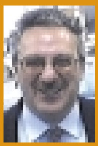
In the MPLS case, diagnostic tools are provided to enable operators to launch traditional IP ping and trace route commands, direct which LSP the test packet should use, and specify how many packets of which size to send. The results can be displayed graphically for easy viewing by the operator, showing information such as the route traveled by the packet and the delay experienced.

The need for network visibility extends beyond the visualization of single end-to-end paths to the gathering of statistical data that can accurately describe the performance and the behavior of the PNNI/MPLS signaling network. The reliability and performance of the network carrying the signaling and routing messages is the foundation of the QoS delivered by the network as a whole.

Conclusion

The move towards introducing network control intelligence in the nodes requires an evolutionary network management approach to support network operations, taking maximum advantage of the functional distribution between the control plane and the network management applications.

Different technologies offer different solutions for similar problems, taking into account technology-specific issues. Furthermore, the introduction of these innovations should take into account interworking with existing parts of the overall network. Alcatel offers a comprehensive set of network management systems that provide a consistent vision of the solutions needed to realize this evolutionary approach across different network technologies.



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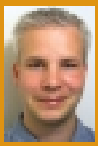

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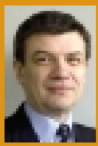

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Abbreviations

ASON Automatic Switched Optical Network
ATM Asynchronous Transfer Mode
BonD Bandwidth on Demand
D&C Drop & Continue
(D)WDM (Dense) Wavelength Division Multiplexing
GMPLS Generalized Multi-Protocol Label Switching
GMRE GMPLS Routing Engine
IP Internet Protocol
ITU-T International Telecommunications Union-Telecommunication
LGN Logical group Node
LSP Labelled Switched Path
MPLS Multi-Protocol Label Switching
MSP Multiplex Section Protection
MS-SPRing Multiplex Section Shared Protection Ring
NE Network Element
NM(S) Network Management (System)
NP Network Provider
ODR Operator Directed Routing
OTN Optical Transport Network
PNNI Private Network to Network Interface
PVC Permanent Virtual Circuit
QoS Quality of Service
RCC Routing Control Channel
RM Regional Manager
SDH Synchronous Digital Hierarchy
SLA Service Level Agreement
SNCP Sub-Network Connection Protection
SONET Synchronous Optical Network
SPVC Soft Permanent Virtual Circuit
TDM Time Division Multiplexing
UNI User-Network Interface
VPCL Virtual Path Connection Link

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