External Network-Network Interface (E-NNI) OSPF-based Routing - 1.0 (Intra-Carrier) Implementation Agreement

OIF-ENNI-OSPF-01.0

January 17, 2007

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1 Introduction

As Automatically Switched Optical Networks (ASONs) are deployed into new and existing networks, it cannot be assumed that such networks will be homogeneous (e.g., with respect to transport technologies, vendors, approach to management/control). This is true even within a single carrier's network. In order to support deployment of an optical control plane into a heterogeneous environment, it is essential to introduce and support the concept of control domains, and in particular, the specification of the signaling and routing information exchanged between such domains.

A control domain is an architectural construct from ITU-T Recommendation [G.8080] that provides for encapsulation and information hiding, and the characteristics of the control domain are the same as those of its constituent set of distributed architectural components. The E-NNI reference point is defined to exist between control domains. The nature of the information exchanged between control domains across the E-NNI reference point captures the common semantics of the information exchanged amongst its constituent components, while allowing for different representations inside each control domain. Control domains are generally derived from architectural component types that serve a particular purpose; e.g., signaling control domains, routing control domains, etc. Typically, signaling and routing control domains are expected to be congruent within ASON networks. The E-NNI reference point becomes an E-NNI signaling and routing interface when instantiated by signaling and routing protocols.

Figure 1 illustrates a simple example of a control plane subdivided into routing control domains, interconnected by routing E-NNI interfaces. This example shows different domains potentially utilizing different I-NNI routing protocols, but communicating across the E-NNI interfaces by using a common set of signaling and routing protocols.

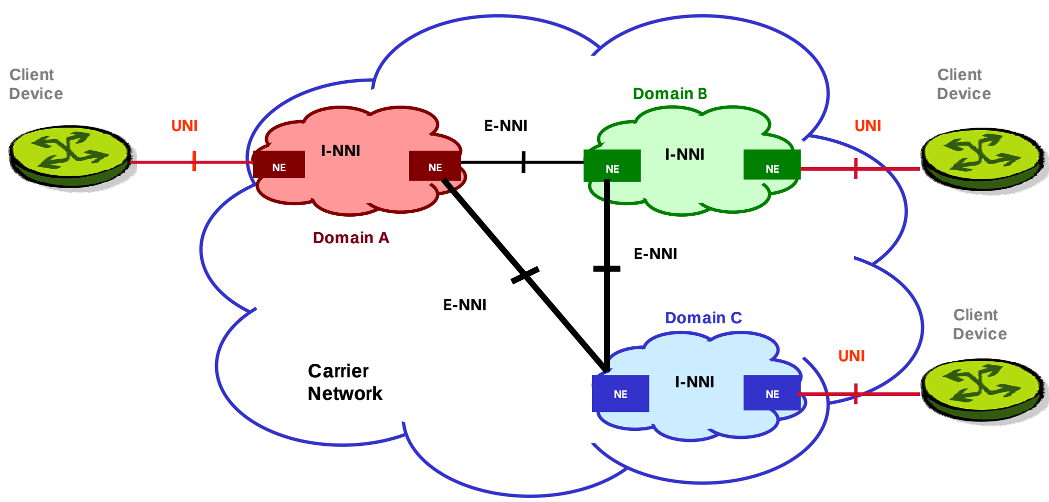

Figure 1. Example Control Plane Configuration with Different Routing Control Domains

1.1 Problem Statement

The advent of the automatic switched transport network has necessitated the development of interoperable procedures for requesting and establishing dynamic connection services across heterogeneous, multi-domain networks. The development of such procedures requires the definition of:

- Control domains and associated reference points (E-NNI, I-NNI, UNI)
- Services offered by the transport network across control domains
- Routing protocols used to disseminate advertisements across E-NNI interfaces

This document addresses OSPF routing information exchange to support ASON routing architecture and requirements for the OIF E-NNI routing interface. Some of the requirements involved are support of interoperability and scalability in a multi-domain environment, support of diverse control plane characteristics within individual domains, and support of ASON-specific characteristics such as per-layer link capacity.

1.2 Scope

The scope of this agreement is to define the E-NNI Routing Interface based on the [G.8080] routing architecture, with details as defined in [G.7715] and [G.7715.1], as applied to OSPF. The current version of this agreement also documents OIF prototype extensions to OSPF that were implemented and tested in multi-vendor interoperability demonstrations from 2003 to 2005, facilitating inter-domain UNI and E-NNI testing and deployment of future services.

The base protocol as defined by this document is OSPF with extensions for Traffic Engineering [RFC3630] and GMPLS [RFC4202, RFC4203]. This document specifies the requirements on and use of OSPF-TE as an E-NNI routing protocol among m domains. It may be used at a single hierarchical level above a set of routing control domains, or with multiple such levels stacking up to form the routing hierarchy. Per the ITU-T G.8080 routing architecture with details as defined in [G.7715] and [G.7715.1], the routing infrastructure in ASON supports hierarchy using a link-state based protocol at each routing level. The OSPF-TE operation at each routing level is independent, i.e., it does not interfere with the operation of routing protocol at other routing levels. However, some of the routing information at a given hierarchical level can be fed up to the next hierarchical level to be advertised in the parent routing area, and at the same time, the routing information at a higher hierarchy can be fed down to lower level of hierarchy, or alternatively, routing information can be accessed by other means outside of routing protocol mechanisms. Collectively this provides a powerful mechanism for scaling of the routing protocol to large networks.

For demonstration purposes, prototype extensions have been defined in the forms of (sub-) TLVs to accommodate the requirements as defined in [G.8080], [G.7715], and [G.7715.1]. These extensions are documented in Appendix I to the main document. NOTE: These extensions use codepoints in the range reserved by IANA for private and experimental use, and are not agreed standard codepoints at this time. Future developments may result in change to the codepoints and/or formats of these extensions.

The OIF interoperability events included OSPF extensions (documented herein) to meet the following aspects of ASON routing:
- Link identification
- Client reachability advertisement
- Layer-specific link capacity advertisement

The OIF interoperability events did not test OSPF extensions for the following aspects of ASON routing:
- Local connection type and adaptation advertisement
- Multi-level hierarchy

In addition, specific OSPF methods were used in these demonstrations to enable routing controllers to establish OSPF optical network adjacencies even when the routing controllers were not topologically adjacent within the SCN.

The following areas are NOT encompassed within this document:
- Requirements for inter-carrier interfaces are not addressed in this document. The extensions in this document were defined within the framework of intra-carrier link state routing protocol requirements for ASON.
- Protocol extensions required to support multi-level hierarchy are not addressed in this document. This document only provides discussion of the target architecture for multi-level hierarchy.

1.3 Relationship to Other Standards Bodies

This document, to the maximum extent possible, utilizes standards and specifications already available from other organizations. Specifically, the SDH/SONET service definitions are based on ITU-T specification [G.707]. The routing protocol requirements are based upon [G.7715] and [G.7715.1], and their normative references to IETF RFCs 2328 [OSPF] and 3630 [RFC3630]. This version of the specification also documents prototype extensions, codepoints and formats of these extensions that were tested for interoperability among prototype implementations. As the intent of OIF is to develop E-NNI protocols in close alignment with ITU-T Recommendations, and foundation IETF RFCs, future versions of this specification are intended to align with the IETF and ITU-T standard specifications. It is therefore not guaranteed that the future versions of E-NNI routing will be fully backward compatible with these prototype extensions. In an analogous manner, should new routing capabilities be considered in future OIF work efforts, it is expected that the OIF would liaise this information to both ITU-T and IETF before being included into future versions of this specification.

1.4 Merits to OIF

The E-NNI OSPF Routing 1.0 specification is a key step towards the implementation of an open inter-domain interface that allows offering dynamic setup and release of various services. This activity supports the overall mission of the OIF.

1.5 Working Groups

Architecture & Signaling Working Group
Carrier Working Group
Interoperability Working Group
OAM&P Working Group

1.6 Document Organization

This document is organized as follows:

- Section 1: Introduction and Scope of the Document
- Section 2: Terminology and Abbreviations
- Section 3: Basic Routing Components
- Sections 4-8: ASON-based Routing Requirements and Extensions
- Section 9: OSPF-based Routing with One Hierarchical Level
- Section 10: Architecture for OSPF-based Routing with Multiple Hierarchical Levels
- Appendices

1.7 Keywords

The key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT", "SHOULD", "SHOULD NOT", "RECOMMENDED", "MAY", and "OPTIONAL" in this document are to be interpreted as described in [RFC2119].

2 Terminology and Abbreviations

2.1 Definitions

The following terms are used in this specification.

Control Domain	This terminology is adopted from ITU-T [G.8080]. A type of transport domain where the criterion for membership is the scope of a control plane component that is responsible for the transport resources within the transport domain.
Inter-domain Link	A link with endpoints in two different Routing Areas at a particular level of the routing hierarchy.
Intra-domain Link	A link with both endpoints within the same Routing Area at a particular level of the routing hierarchy.
Layer	This terminology is adopted from ITU-T [G.805]. A layer (network) is a "topological component" that represents the complete set of access groups of the same type which may be associated for the purpose of transferring information

Level — This terminology is adopted from ITU-T [G.8080]. A routing hierarchy describes the relationships between an RA and a containing RA or contained RAs. RAs at the same depth within the routing hierarchy are considered to be at the same routing level.

Node ID — This terminology is adopted from ITU-T [G.7715.1]. The Node ID identifies a node in the transport topology graph. A node may represent both an abstraction of a Routing Area or a subnetwork. Note: this definition differs from that given in the OIF UNI 1.0 specification.

Protocol Controller — This terminology is adopted from ITU-T [G.8080]. The Protocol Controller provides the function of mapping the parameters of the abstract interfaces of the control components into messages that are carried by a protocol to support interconnection via an interface.

RC ID — The RC ID is a unique value that identifies an RC instance. This identifier may be used by the database synchronization function for record ids.

RC PC ID — The RC PC ID is a unique value that identifies an RC Protocol Controller. As per [G.8080], the Protocol Controller takes the primitive interface supplied by one or more architectural components, and multiplexes this interface into a single instance of a protocol

RC PC SCN Address — The SCN Address where the RC attaches, via its Protocol Controller (PC), to the IP SCN. An RC may have multiple associated PCs that support the procedures and formats of specific protocols and attaches to the SCN. The address referred to in this document is for the RC's OSPF PC.

Routing Area (RA) — This terminology is adopted from [G.8080]: A routing area is defined by a set of subnetworks, the SNPP links that interconnect them, and the SNPPs representing the ends of the SNPP links exiting that routing area. A routing area may contain smaller routing areas interconnected by SNPP links. The limit of subdivision results in a routing area that contains a subnetwork.

Routing Controller (RC) — This terminology is adopted from [G.7715]. The Routing Controller functional component provides the routing service interface and is responsible for coordination and dissemination of routing information.

Routing Control Domain — This terminology is adopted from [G.8080]. A transport domain is a set of transport resources that are grouped as a result

	of some criteria that is established by operator policies. An RCD is a type of transport domain where the criterion for membership is assignment to an RC federation for the purposes of transport resource advertisement.
Signaling Control Network (SCN)	The packet network that carries Control Plane messages between Protocol Controllers
TE Link	This definition is per [RFC 4203], which defines a TE link as a "logical" link that has TE properties. The TE link is logical in a sense that it represents a way to group/map the information about certain physical resources (and their properties) into the information that is used by Constrained SPF for the purpose of path computation.

2.2 Abbreviations

The following abbreviations are used in this specification.

ASON	Automatically Switched Optical Networks
CC	Connection Controller
CD	Control Domain
GMPLS	Generalized Multi-Protocol Label Switching
GRE	Generic Routing Encapsulation
E-NNI	External Network-Network Interface
ERO	Explicit Route Object
ID	Identifier
IETF	Internet Engineering Task Force
I-NNI	Internal Network- Network Interface
ITU-T	International Telecommunications Union - Telecommunications
LSA	Link State Advertisement
NNI	Network-Network interface
OSPF	Open Shortest Path First
PC	Protocol Controller
PCE	Path Computation Element
RA	Routing Area
RC	Routing Controller
RCD	Routing Control Domain
SCN	Signaling Communications Network
SN	Subnetwork
SNPP	Subnetwork Point Pool
SPF	Shortest Path First
SRLG	Shared Risk Link Group
TE	Traffic Engineering
TLV	Type/Length/Value
TNA	Transport Network Assigned Address

TTL	Time To Live
UNI	User-network interface
UNI-C	Client side of a UNI
UNI-N	Network side of a UNI
VLAN	Virtual Local Area Network

3 Basic Components for OSPF-based E-NNI Routing

This routing specification is based on [RFC3630] but with a hierarchical operational model per [G.7715] for ASON networks as defined per G.8080. This specification utilizes the base OSPF protocol as defined in [RFC 2328], in [RFC3630] and in [RFC 4203], although some additional requirements for optical transport networks are defined in the following Sections.

It should be noted that this specification does not include the use of OSPF for the maintenance of SCN topology, and as a result does not include the use of OSPF types 1-4 LSAs, path computation for IP routing or area border routers.

3.1 Basic Assumptions

This specification conforms to the routing architecture as specified for ASON in [G.7715], It assumes that the network can be organized into a hierarchy of Routing Areas, as defined in [G.7715].

This specification implements the routing elements defined in ITU-T Recommendation [G.7715.1] for Link State Routing Protocols, using OSPF as the basis. It makes use of work done in IETF on TE extensions to [RFC3630] and GMPLS extensions to OSPF [RFC4203] but identifies additional requirements and potential extensions as needed for ASON.

The hierarchical organization of Routing Areas used in this specification (as per [G.8080]) is orthogonal to the OSPF multi-area operation defined for IP networks in [RFC 2328]. Applicability of future GMPLS multi-area operations is for further study.

The purpose of this routing specification is to re-use OSPF-TE in networks with architecture as defined by G.8080, but is not aimed at providing IP layer datagram routing. In addition it assumes that an IP based control communications network or SCN, compliant with [G.7712], is in place to support communications between the various control entities.

3.2 Transport and Traffic Considerations for Routing Messages

It should be noted that sending of extraneous or invalid routing information, e.g., zero-length advertisements, should be prevented in order to reduce the overall traffic and processing load due to the routing protocol. Extraneous or invalid routing information SHOULD NOT be recorded in the routing database, and SHOULD NOT cause failure of the routing controller.

Unlike traditional IP networks where OSPF routers that are usually physically interconnected to create adjacencies, the RCs that would like to form adjacencies in this specification are most likely not topologically adjacent within the control plane, and not always one IP-hop away in the SCN topology.

A number of methods are available to create one-hop adjacencies between OSPF instances in nodes that are not topologically adjacent, including a variety of tunneling methods (esp. GRE, IP-in-IP and IPSec), use of VLANs at layer 2, and use of OSPF virtual links. A number of associated impacts or limitations have been identified: VLANs can only be applied within SCNs consisting of a single ethernet broadcast domain; virtual links are an optional capability and currently are restricted to being part of an OSPF backbone area, which is a different topology than assumed for the E-NNI.

The point-to-multipoint method defined below was used in all OIF E-NNI interoperability testing. Tunneling as described below is an alternative method; selection of a particular tunneling type is for further study.

3.2.1 Point-to-Multipoint Method

The following configuration of OSPF point-to-multipoint mode was used for all OIF E-NNI interoperability testing. As in OSPF point-to-multipoint, all adjacencies between RCs are configured, and the OSPF Hello is not used for discovery purposes. OSPF adjacencies are allowed to be created between RCs more than one hop apart by allowing the IP TTL to be greater than 1 (as is done for OSPF virtual links).

It should be noted that the OSPF instance used for the E-NNI is providing Optical Network routing and not IP layer routing for the SCN. As a result, the same OSPF adjacency type used for the E-NNI is independent of the actual interfaces used to connect to the SCN.

For point-to-multipoint adjacencies to operate across a multi-hop IP SCN, the IP TTL field for Optical E-NNI Routing OSPF PDUs MUST be set to a value greater than 1 and SHOULD be set to a value of 255. Further, the Network mask included in OSPF Hello PDUs MUST be set to 0x00000000 to allow adjacencies with nodes that are not immediate neighbors. Note: this configuration deviates from the typical configuration of OSPF for IP routing.

3.2.2 Tunneling Method

Tunneling is a commonly used technique between non-adjacent nodes, however tunneling introduces direct SCN links between non-adjacent RCs that could potentially be used for any application traffic, if the creation of the tunnel generates an entry in the node's IP forwarding table. In this case, in order to avoid unintended traffic routing and potential traffic looping, additional management is required to ensure that the tunnels are used only for E-NNI messages. Tunneling requires establishing appropriate tunnels between RCs, and then turning these tunnels into interfaces for Optical E-NNI related OSPF-TE instances only.

3.3 Considerations for Hierarchy and Topology Abstraction

Hierarchical routing can be used to enable the network to scale, and to provide isolation between different network domains. Topology abstraction can be used to reduce the amount of information carried by the inter-domain routing protocol. When hierarchy is created and topology abstraction is used, the externally advertised topology can be a transformed view of the actual internal topology of a contained Routing Area. This transformed view is intended specifically to provide information for computation of paths crossing the Routing Area, represented by advertisements of links and associated costs. This can impact routing performance, depending on the conditions within the Routing Area and the use of tools that provide additional routing information, e.g., a Path Computation Element as discussed below. If the available bandwidth in a domain is large compared to the average service request, node level abstraction will also have little negative impact on computed path quality.

Advertisement of an abstracted topology of a multi-node domain MUST support a valid representation of connectivity within that domain in order to support correct path computation, i.e., if multiple border nodes are advertised for a domain, some topological component MUST also be advertised to indicate when there is connectivity between these border nodes. This will avoid failure of path computation across the domain. In general, path computation should not have to infer from the control identifiers in use (such as the RC identifier) the data plane topology.

Work is ongoing in standards to define a capability to query an outside entity to determine the cost of a path or the optimal path through a particular domain, and this would potentially allow path computation across the domain with more precise information than is advertised externally using the E-NNI routing protocol. This functional entity is known as a Path Computation Element. A PCE can be supported in a number of ways, including via the management plane.

3.4 Security Considerations for Routing Messages

Security considerations for link state routing protocols are covered in Section 9 of the Addendum to the Security Extension for UNI and NNI [SecAdd], which updates the Security Extension [SecExt]. Section 9.1 of the Addendum [SecAdd] recommends how implementations not using the Security Extension MAY provide authentication of OSPF messages. Section 9.2 of the Addendum describes how implementations using the Security Extension to protect signaling protocols MUST extend these mechanisms to OSPF routing.

4 Support of G.7715.1 Link Attributes – Link Identification

4.1 Link Identification with full separation of Node ID and RC/SC IDs

ASON has defined a number of different functional entities, each with their own identifier spaces. The identifier spaces used by ASON Routing are described in the Section 7.1 of [G.7715.1]:

There are three categories of identifiers used for ASON routing: transport plane names, control plane identifiers for components, and SCN addresses.

- Transport plane names describe [G.805] resources and are defined in G.8080/Y.1304.
  - SNPP names give a routing context to SNPs and are used by the control plane to identify transport plane resources. However, they do not identify control plane components but represent a (G.805) recursive subnetwork context for SNPs. Multiple SNPP name spaces may exist for the same resources.
  - UNI Transport Resource names are used to identify transport resources at a UNI reference point if they exist. They represent clients in (G.8080/Y.1304) access group containers and may be disseminated by RCs.
- Control plane identifiers for G.8080/Y.1304 components may be instantiated differently from each other for a given ASON network. For example, one can have centralized routing with distributed signalling. Separate identifiers are thus used for:
  - Routing Controllers (RCs)
  - Connection Controllers (CCs)
- Additionally, components have Protocol Controllers (PCs) that are used for protocol specific communication. These also have identifiers that are separate from the (abstract) components like RCs.
- SCN addresses enable control plane components to communicate with each other via the SCN as described in [G.7712].

Using these definitions, Table 1 reviews the different identifiers used in [RFC3630], and suggests a logical mapping to ASON identifiers. Note: IETF has also defined a lexicography comparing GMPLS and ASON terminology [RFC4397], for general mapping of terminology.

Table 1: Identifier Table

Instance in OSPF-TE [RFC3630]	**Description**	**OSPF-TE Address Space**	**G.8080 Architectural Name**
Source and Destination IP Addresses.	This is the address used by the RC PCs to communicate with each other. It is also known as the RC PC IP address. Located in the IP packet header of the packet containing OSPF PDUs.	IPv4 Address space.	RC PC SCN Address.
Router Address	Traffic Engineering TopLevel TLV from [RFC3630]. This is contained in an Opaque type 10 LSA.	IPv4 Address. ([RFC3630] states that this is a "reachable" IPv4 address.)	Linked to Transport Plane Node ID as well as RC and SC PC SCN address
Router ID in OSPF PDU Header	Used to identify the neighbor that generated the PDU containing LSAs.	Router ID.	Control Plane Name: RC PC ID
Advertising Router ID.	Field contained in an LSA Header. For a given PDU, this is likely to be different from the Router ID in the OSPF Header. For a TE Link TopLevel TLV, this field identifies the router at the near end of a link.	Router ID. (see Note)	Linked to both RC ID and Transport Plane Node ID
Link ID.	SubTLV contained in a TE Link TopLevel TLV. For a given PDU, this is likely to be different from the Router ID in the OSPF Header. For a TE Link TopLevel TLV, this identifies the router at the far end of a link.	Router ID. (see Note)	Linked to both RC ID and Transport Plane Node ID

Note: RFC 2328 [OSPF] defines the SPF algorithm used to traverse the topology shared by OSPF nodes in an area. This algorithm specifically uses Router ID as the Vertex ID when identifying a point-to-point link between two routers in the topology, as shown in Section 16.1 of [OSPF]. This is further underscored in Section 16.1 Step 2 and Step 2b where Router-LSAs for vertex V (the near end of a link) and vertex W (the far end of a link) are retrieved using the Vertex ID. Since the Router IDs for the near end of a TE link and the far end of a TE link in [RFC3630] are located in the Advertising Router ID and the Link ID fields for the Link TLV (see [RFC 3630] Sect 2.4.2 and 2.5.2), these fields are used in [RFC3630] to identify the link ends that exist in the TE topology.

By using different categories of identifiers for Transport plane entities, Control plane entities and SCN addresses, it is possible in ASON to support a number of different function distributions including:

- 1:N relationship between an RC and Subnetworks
- N:1 relationship between RCs and a Subnetwork

This allows a separation between the transport plane entity being controlled, the control plane entity supporting it, and the SCN address where the control plane entity can be reached.

Support for these distributions is considered useful for domain-to-domain networking and allows flexibility for support of E-NNI routing by domains with different characteristics. It helps support domains with differing characteristics and abstraction of domain topology and resource information as called for in OIF carrier requirements [CarReq].

4.2 Local/Remote Node ID for Prototype Testing

To support 1:N or N:1 relationships as described above for unnumbered links, the capability is needed to uniquely identify unnumbered links when advertising. The method used in prototype testing was to advertise the Transport Plane Node ID for local and remote link ends, separately from the RC associated with the link. SubTLV formats and codepoints to advertise the Node IDs associated with link ends were introduced for OIF prototype testing and are given in Appendix I.

Note: Since the Node ID extensions provide the Transport Plane Name for a Local Vertex and Remote Vertex on a link in the Transport Topology, the Advertising Router ID and Link ID fields are no longer used to identify the nodes at the ends of a link, reducing the role of the Advertising Router ID field to a part of the Database key used to name LSAs.

Futhermore, since the Node ID comes from the Transport Plane namespace, it is used as the identifier in an Explicit Route Object, removing the dependence on the Router Address TLV.

4.3 Standard Protocol Extensions

For further study pending completion of associated standards in IETF and ITU-T. Initial work evaluating ASON requirements against existing routing protocol can be found in [Eval], and potential solutions being discussed in IETF can be found in [Soln].

5 Support of G.7715.1 Node Attributes –Reachability Advertisement

5.1 Client reachability advertisement

In IP routing, it is expected that the way to calculate a route to an endpoint is for the endpoint to be announced in the routing protocol. However, end equipment in IPv4 networks is typically attached using Ethernet subnetworks advertised via NetworkLSAs or ExternalLSAs. This makes separate end equipment advertisement unnecessary. Unfortunately, the optical network environment discussed in this document is outside the IPv4 network and does not have an analogous method for a router to advertise the UNI endpoints associated with a vertex in the area’s topology. Consequently, a capability to advertise client reachability is needed, as is identified in [G.7715.1].

5.2 TNA Address and Node ID Advertisement for Prototype Testing

It should be noted that this is only one of many possible solutions that may be implemented by a carrier. Other solutions are beyond the scope of this Implementation Agreement and were not used in OIF prototype testing. Additional solutions for client reachability advertisement may be defined in future versions of this document.
Note: the OIF "TNA address" is an instantiation of the G.8080 "UNI Transport Resource Identifier" and both are used in this document to refer to the same thing.

A new Top-level TLV was used in prototype testing for advertising attached UNI endpoints. An LSA containing this new top-level TLV is only announced by the Routing Controller (RC) responsible for the Node in a topology to which the UNI Transport Resource Identifier, or TNA, is attached.

The new TLV contains a list of the UNI Transport Resource Identifiers attached to a Node. The list MAY include more than one Node ID and more than one TNA Address in order to advertise reachability for multiple nodes.

The Node ID identifies the node that the immediately related TNA Addresses are attached to. Consequently, a Node ID MUST be given for each TNA Address advertised.

It is also possible for more than one LSA to be issued by a Routing Controller (RC) with Node IDs for the same node.

When an abstract topology is created in an upper area from a topology in a lower area that includes a Node with attached UNI Transport Resource Identifiers, the abstract topology associates the UNI Transport Resource Identifier with at least one Node in the abstract topology as allowed by Policy.

Formats for a TNA Reachability TLV and Node ID and TNA Address sub-TLVs as used in OIF prototyping are given in Appendix I.

5.3 Standard Protocol Extensions

For further study pending completion of associated standards in IETF and ITU-T. Initial work evaluating ASON requirements against existing routing protocol can be found in [Eval], and potential solutions being discussed in IETF can be found in [Soln].

6 Support of G.7715.1 Link Attributes – Layer-specific Link Capacity

6.1 Advertisement of Layer-specific link capacity

GMPLS Routing extensions to OSPF define an Interface Switching Capability Descriptor (ISCD) that delivers information about the (maximum/minimum) bandwidth per priority an LSP can make use of. In the ASON context, other representations are possible, e.g., in terms of a set of tuples <signal_type; number of unallocated timeslots>. The latter also may require definition of additional signal types (from those defined in

[RFC 3496]) to represent contiguous concatenation, i.e. STS-(3xN)c SPE / VC-4-Nc, N = 4, 16, 64, 256.

As [G.7715.1] specifies link capacity as a link characteristic specific to a particular layer network, a representation in the form of tuples of <signal_type; number of unallocated timeslots> is most closely consistent with ASON requirements and provides accurate and separable information on a fine grained, per layer network basis.

6.2 Switching Capability Descriptor enhancement for Prototype Testing

To provide this functionality, a new format for Switching Capability Descriptor was used in prototype testing that incorporates information about available connections at specific signal types. This allows more accurate accounting of resource availability, in particular taking into account impact of time slot allocation on the availability of connections using contiguous concatenation.

The format for the Switching Capability Descriptor used in OIF prototyping is given in Appendix I.

6.3 Standard Protocol Extensions

For further study pending completion of associated standards in IETF and ITU-T. Initial work evaluating ASON requirements against existing routing protocol can be found in [Eval], and potential solutions being discussed in IETF can be found in [Soln].

7 Support of G.7715.1 Link Attributes – Local Type/Adaptations Supported

7.1 Local Connection Type and Adaptations advertisement

[G.7715.1] identifies the need to advertise Local Adaptation support associated with a link in the link state routing protocol. This requirement applies to the E-NNI routing interface.

No OIF interop testing has been done for protocol extensions advertising local type/adaptations supported.

7.2 Standard Protocol Extensions

For further study pending completion of associated standards in IETF and ITU-T. Initial work evaluating ASON requirements against existing routing protocol can be found in [Eval], and potential solutions being discussed in IETF can be found in [Soln].

8 Support of Routing Hierarchy

8.1 Support of multi-level hierarchy

[G.7715] and [G.7715.1] specify that routing protocol for ASON supports multiple levels of hierarchy, although they do not define specific mechanisms to support multiple hierarchical levels of RAs. In particular, if RCs bound to adjacent levels of the RA hierarchy were allowed to redistribute routing information in both directions between adjacent levels of the hierarchy without any additional mechanisms, they would not be able to determine looping of routing information.

It is necessary to have a means by which routing protocol LSAs indicate that particular routing information has been learned from a higher level RC when propagated to a lower level RC. Any downward RC from this level, which receives an LSA with this information would omit the information in this LSA and thus not re-introduce this information back into a higher level RC.

No OIF interop testing has been done of protocol extensions for multi-level hierarchy.

8.2 Standard Protocol Extensions

For further study pending completion of associated standards in IETF and ITU-T. Initial work evaluating ASON requirements against existing routing protocol can be found in [Eval], and potential solutions being discussed in IETF can be found in [Soln].

9 E-NNI OSPF-based Routing with a Single Hierarchical Level

A prerequisite for hierarchical OSPF routing is that each control domain has at least one Routing Controller as defined in [G.7715]. This RC advertises topology associated with a Routing Area (with a specific RA ID), and has an RC ID and an SCN address for its OSPF Protocol Controller, to which all protocol messages will be addressed.

Via discovery or configuration, each RC finds out about its peer RCs within their common parent RA. Their RC IDs and corresponding SCN addresses are discovered or configured. Automated discovery of peer RCs is for further study.

If peer RCs are determined via configuration, a decision is made to establish a control adjacency with a particular neighbor RC for the purposes of routing information exchange.

9.1 Configuration

In order to bring up the hierarchy, there is a set of configuration parameters as described in the following sections.

The example of Figure 2 shows an optical network with three routing control domains. A single level of hierarchy of OSPF is configured as described in the following sections.

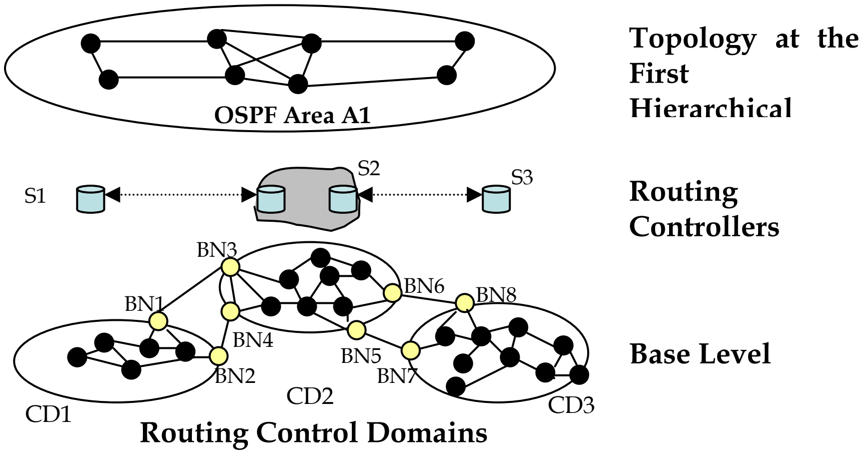

Figure 2. Example of Single Level OSPF-TE Operation.

9.1.1 Routing Controllers

Each routing control domain includes at least one routing controller. A routing controller is identified by its RC ID.

In the example of Figure 2, S2 is a federation of multiple RCs that advertises routing information for CD2 within Area A1.

9.1.2 Routing Controllers in Adjacent Routing Control Domains (per RC)

For each routing controller advertising for a given routing control domain, there exists at least one peer RC advertising for each adjacent control domain, and for each RC, the following information MUST be available:

1) The Routing Controller ID of the neighboring Routing Controller.
2) The SCN address of the neighboring Routing Controller.

Example - Information about adjacent control domains that is provisioned in S2 as follows:

Table-2 Adjacent Routing Controllers of S2 in Figure 2

Neighboring RCs	RC ID	SCN Address
S1	S1's Router ID	S1's SCN address
S3	S3's Router ID	S3's SCN address

9.1.3 Inter-domain Links (per RC)

Information on inter-domain links can be configured on a RC. An inter-domain link reflects an inter-connection with an adjacent domain along with the traffic parameters in the outgoing direction, i.e., from the local node to the remote (adjacent) node.

Example - There are a total of 4 inter-domain links in the perspective of CD2 that are provisioned on S2 as follows:

Table-3 Inter-domain Links Configured on RC S2 in Figure 2

Inter-domain links	Local border node	Remote border node
BN3-BN1	BN3	BN1
BN4-BN2	BN4	BN2
BN5-BN7	BN5	BN7
BN6-BN8	BN6	BN8

9.1.4 Intra-Domain Links (per RC)

One or more intra-domain links can be configured on an RC if it advertises an intra-domain topology, or may be derived by the RC from internal domain routing information. An intra-domain link reflects some characteristics of traversing the domain, as reflected by advertised link traffic parameters on one direction, i.e. from the ingress node to the egress node.

In the example of Figure 2, 12 intra-domain links are advertised by S2 to reflect characteristics of traversing CD2 from one border node to another as follows:

Table-4 Intra-domain links Configured on RC S2 in Figure 2

Intra-domain links	Local border node	Remote border node
BN3-BN4	BN3	BN4
BN4-BN3	BN4	BN3
BN3-BN5	BN3	BN5
BN5-BN3	BN5	BN3
BN3-BN6	BN3	BN6
BN6-BN3	BN6	BN3
BN4-BN5	BN4	BN5
BN5-BN4	BN5	BN4
BN4-BN6	BN4	BN6
BN6-BN4	BN6	BN4
BN5-BN6	BN5	BN6
BN6-BN5	BN6	BN5

Note the intra-domain links are abstract in nature, reflecting the aggregation of the topology in the RC. Also the number of intra-domain links that need to be provisioned is a local matter.

9.1.5 The reachable TNA addresses (per RC)

The TNA addresses that are attached to NEs in a given RA are advertised by the RC in the RA at the next hierarchical level. These can be summarized before the advertising for scaling purposes.

Example - TNA addresses that are reachable within the CD2 and need to be advertised by S2 are provisioned on S2 or derived from internal routing information.

9.2 Operation

The purpose of the configuration as described in the section above is to start the first hierarchical level of an OSPF-TE based routing control domain. Each RC that has been configured starts to run as an OSPF-TE node at the first hierarchical level by exchanging OSPF-TE messages with the neighboring RCs. No routing adjacencies are created directly between neighboring border nodes unless they are also serving as RCs for their respective domains.

The RCs in the first hierarchical level will form routing adjacencies in the control plane, and at the same time, each RC will advertise the links that correspond to the inter-domain and intra-domain links for its associated domain. Also, each RC will advertise the reachable TNA addresses for that domain.

In the example as illustrated in Figure 2, RCs S1, S2 and S3 will form regular OSPF routing adjacencies in the control plane [Note: the detailed implementation of S2 as a federation of routing controllers is beyond the scope of this document]. At the same time, S2 will advertise the abstract links that correspond to Table-3 as part of the topology of the first hierarchical level area (OSPF area A1 in the Figure). The links that correspond to Table-3 specify the link attributes from CD2 to CD1 and from CD2 to CD3, and the corresponding link attributes from CD1 to CD2 and from CD3 to CD2 will be advertised by S1 and S3, respectively. The links that correspond to Table-4 expose routing information associated with CD2, and are useful during the routing path selections for connections that traverse CD2, i.e., which entry border node to use for ingress, and which exit border node to use for egress. In addition, S2 will advertise CD2's reachable TNA addresses throughout OSPF area A1.

Operation of the routing protocol (e.g., Database Synchronization and Link State Advertisement Flooding) otherwise follows procedures defined in RFC 2328 [OSPF] and in Section 3. Timers for generating link advertisements must be configurable by the operator to avoid mismatch at sending and receiving nodes.

10 Architecture for Operation with Multiple Hierarchical Levels

The routing hierarchy as proposed by this document is achieved by stacking separate routing areas vertically. The requirements defined in this section are intended to be consistent with requirements for hierarchical routing defined in [G.7715.1], Section 8. In a given routing area, there is a single routing protocol that runs independently, and there is at least one RC, selected either via provisioning or election, which represents that RA at the next higher level in the routing hierarchy. There usually exist some communication mechanisms between the RC at hierarchical level N and routing entities within the control domain it represents in order to exchange routing information in both directions, i.e., routing information feed-up and feed-down, however this is internal to the domain.

10.1 Configuration

Some configuration is required to build up the routing hierarchy. An operator decides the hierarchical structure of the routing areas, that is, the containment hierarchy of routing areas, which is usually a reflection of the hierarchical organization of the operator's network.

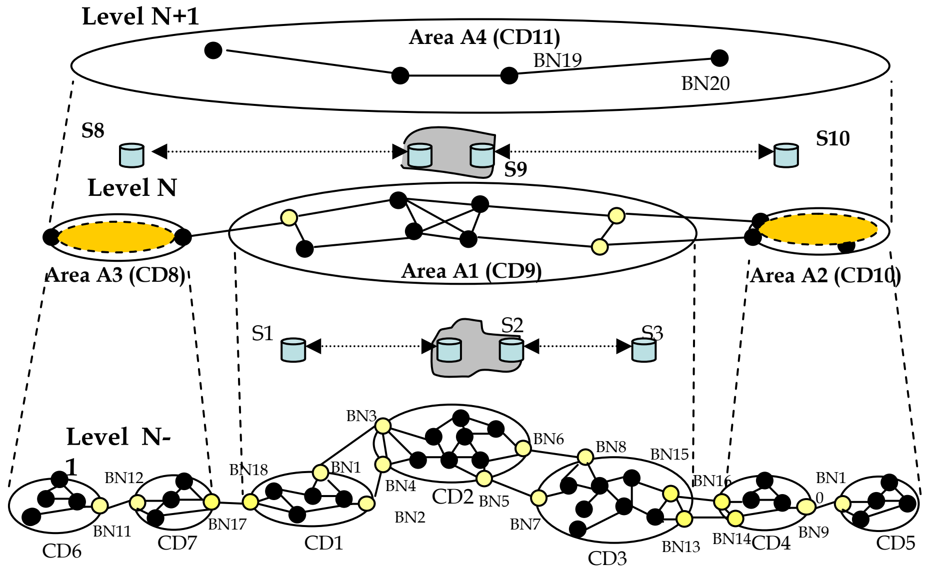

Figure 3. An Example of a Multi-level Hierarchy.

For example in Figure 3, the network is arranged into 2 levels of routing hierarchy. In level N of the hierarchy there are three distinct routing areas: A1, A2, and A3. No routing messages are exchanged by routing controllers within these areas and routing controllers within these areas only can find routes across their respective areas. All three of these routing areas are hierarchically contained in a fourth routing area which operates up a level in the hierarchy. In area A4 the RCs are advertising routing information for routing control domains encompassing the areas A1, A2 and A3 (respectively S8, S9, and S10).

10.1.1 Routing Controllers and Routing Areas

For a Routing Area RA^n that is at hierarchical level *N*, there is at least one Routing Controller RC^{n+1} at hierarchical level *N+1,* up to the highest level of the hierarchy.

With the hierarchical routing model as proposed by this document, the operation at each level of hierarchy that is associated with the single Routing Area is independent. However, the routing information obtained as a result of executing link state routing at a given hierarchy level can feed up (except at the highest hierarchical level) and feed down (except at the lowest hierarchical level), or alternatively be configured on the Routing Controller for that level.

The reason for information feed-up is so that the routing information that is associated with one Routing Area can be advertised to others and can be used for routing decisions for the setup of connections that cross optical control domains. The feed-up of routing information is performed level-by-level on a given node. It is desirable that the feed-up is accomplished together with aggregation and summarization for scaling purposes. The routing information fed up from level *N* is advertised by the Routing Controller RC^{n+1} at the Level *N*+1 with the advertiser identified as RC^{n+1}. Therefore there is no need for the Routing Controllers at higher levels of the hierarchy to learn about the identifiers (Routing Controller ID, Routing Area ID, etc.) at lower levels. Another reason for the information feed-up is to reduce the configuration burden, i.e., some components especially in the data plane can be automatically aggregated by RCs at lower level.

The reason for information feed-down is so that the routing information associated with other Routing Areas is available in the "local" Routing Area and the routing for connections across or to the remote Routing Areas can be calculated by nodes in the "local" Routing Area in a distributed fashion. The information provided from the LSAs are that originated by RCs in Routing Areas at higher-levels are actually extensions in both control plane and data plane to Routing Areas beyond the local one, with aggregation and summarization, and the information can be directly used in the call/connection routing procedure.

Note the feed-down of routing information is optional; see the following sections for details.

10.1.2 Routing Controllers in Adjacent RCDs (per RC)

The provisioning of information concerning RCs in adjacent domains is exactly the same as described in the Section 9.1.2.

Example – In Figure 3, suppose S9 is a federation of RCs representing Area A1, and S10 and S8 are RCs for areas A3 and A2, respectively. The Router ID and SCN address of S8 and S10 are configured on S9, and the Router IDs and SCN addresses of S9 are configured on S8 and S10, respectively, as well.

10.1.3 Inter-Domain links (per RC)

The configuration for inter-domain links may be different from that described in Section 9.1.3 due to additional aggregation of the border nodes and inter-domain links at higher levels of the routing hierarchy.

Example - When interconnecting the control domains CD9 and CD10 where there exist two physical links BN13-BN14 and BN15-BN16, the border nodes and links are aggregated at the higher level so that the following configuration is applied to S9 and S10:

Table-5 Inter-Domain Links Configured on S9 in Figure-3

Inter-domain links	**Local border node**	**Remote border node**
BN19-BN20	BN19	BN20

Table-6 Inter-Domain Links Configured on S10 in Figure-3

Inter-domain links	Local border node	Remote border node
BN20-BN19	BN20	BN19

10.2 Operation

10.2.1 Adjacency in the Control Plane

Given a routing area RA^N at hierarchical level *N*, there is a correspondent routing controller RC^{N+1} in RA^{N+1} at hierarchical level *N+1.* In the Figure 3, the domains CD9, CD10 and CD8 are represented by RCs S8, S9 and S10, respectively in area A4 (corresponding to CD11), and form routing adjacencies for exchange of OSPF routing information for area A4.

10.2.2 Topology Aggregation and Feed-Up for Advertising

Topology of the control domain from Level 1 up can be aggregated by RCs and advertised at the next level of hierarchy automatically, or through configuration. Note: alternatives to topology aggregation may be defined in future versions of this document.

10.2.2.1 Inter-Domain Links

As described in Section 9.1.2, information on the inter-domain links can be configured on the routing controllers at the level of the routing hierarchy containing both link endpoints.

10.2.2.2 Intra-Domain Links

Intra-domain links can be configured as described in Section 9.1.4 in a hierarchical routing network with multi-level hierarchies, but they can also be discovered and originated automatically. When there are at least 2 border nodes advertised externally for a routing area, the intra-domain topology can be aggregated by computing virtual intra-domain links. The intra-domain links, once aggregated, can be advertised by the RCs that belong to the control domain in the next higher level of hierarchy.

10.2.3 TNA Address Summarization and Feed-Up for Advertising

In a routing area that is at the hierarchical level N (N >=1), each node in that area can advertise one or more TNA addresses throughout that area. The RC in that area can perform summarization on all these reachable TNA addresses, before advertising TNA reachability at the next higher level of hierarchy.

10.2.4 Routing Information Feed Down from Level N to N-1

Routing information that is recorded at the nodes at hierarchical level N (N >= 2) can be fed down to the nodes at level N-1 with a standardized mechanism such as is described below. Note: alternatives to feed down that reduce the information storage requirements for lower level RCs may be defined in future versions of this document.

The feed-down of the routing information can be performed by the RC at Level N by passing the routing information down to an associated RC or RCs at Level N-1, which then in turn advertise the routing information throughout the routing area where the RC belongs.

The routing information that can be fed down includes the following:

1) LSA that contains inter-domain links.
2) LSA that contains intra-domain links.
3) LSA that contains reachable TNA addresses.

The LSAs at Level N that have been fed down may be advertised by the RC at Level N-1 as is. The same information can also be further fed down to Level N-2, etc., in the same manner.

The purpose of the routing information feed-down is to distribute the traffic engineering information across the control domains to all nodes at the lower hierarchy levels, possibly also to all nodes at Level 0, so that the path selection for end-to-end connections can be accomplished in distributed manner.

11 References

ITU-T

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[G.805] ITU-T Recommendation G.805 (2000), "Generic Functional Architecture of Transport Networks"
[G.8080] ITU-T Recommendation G.8080/Y.1304 (2003), "Architecture of the Automatic Switched Optical Network (ASON)"

OIF

[CarReq] oif2002.229.05, Inter-domain Control Plane Prioritized Requirements
[SecAdd] Optical Internetworking Forum Implementation Agreement, "Addendum to the Security Extension for UNI and NNI," OIF-SEP-02.1, March 2006.
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IETF

[RFC2119] IETF RFC 2119, "Key Words for Use in RFCs to Indicate Requirement Levels", March 1997.
[RFC3630] IETF RFC 3630, "Traffic Engineering Extensions to OSPF Version 2", September. 2003
[RFC3946] IETF RFC 3946, "Generalized Multiprotocol Label Switching Extensions for SONET/SDH Control", October 2004.
[RFC4202] IETF RFC 4202, "Routing Extensions in Support of Generalized Multi-Protocol Label Switching", October 2005.
[RFC4203] IETF RFC 4203, "OSPF Extensions in Support of Generalized MPLS", October 2005.
[RFC4397] IETF RFC 4397, "A Lexicography for the Interpretation of GMPLS Terminology within the Context of ITU-T ASON Architecture", February 2006.
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[OSPF] IETF RFC 2328, "OSPF version 2", April 1998.
[Soln] Papadimitriou, "OSPFv2 Routing Protocol Extensions for ASON Routing", draft-ietf-ccamp-gmpls-ason-routing-ospf-01.txt, Work in Progress, August 2006.

12 Appendix I: Formats of Protocol Elements As Used for Prototype Testing

12.1 New and Extended Sub-TLVs for E-NNI OSPF-based Routing

The prototype extensions defined in this appendix allow for full separation of different control identifiers as required for ASON. However, this does not imply that different values are always used for each identifier. An implementation MAY use duplicate values (in mandatory fields) when full separation is not required; it MUST however accept TLVs from peer implementations that do support full separation.

12.1.1 Local Node ID Sub-TLV

The Local Node ID sub-TLV (Type 32773) is included in an inter-domain or intra-domain TE link LSA to indicate the local end point of a link. This is used to support separation of the control and data planes, as well as topology abstraction. The format of this sub-TLV is defined as:

```
 0                   1                   2                   3
 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|           Type (32773)        |           Length              |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                     Local Node ID                             |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

12.1.2 Remote Node ID Sub-TLV

The Remote Node ID sub-TLV (Type 32774) is included in an inter-domain or intra-domain TE link LSA to indicate the remote end point of a link. This is used to support separation of the control and data planes, as well as topology abstraction. The format of this sub-TLV is defined as:

```
 0                   1                   2                   3
 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|           Type (32774)        |           Length              |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                   Remote Node ID                              |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

12.1.3 Sonet/SDH Interface Switching Capability Descriptor sub-TLV

This sub-TLV (Type 32775 and Length (4 + n x 4) octets) is dedicated to Sonet/SDH bandwidth accounting, and has the following format:

```
 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|        Type (32775)           |        Length = 4 + n*4       |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
| Switching Cap |   Encoding    |            Reserved           |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|  Signal Type  |        Number of Unallocated Timeslots        |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|  Signal Type  |        Number of Unallocated Timeslots        |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                                                               |
//                            . . .                            //
|                                                               |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|  Signal Type  |        Number of Unallocated Timeslots        |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

Note: n defines the number of signal types supported on this link, and thus defined as greater or equal to 1.

Inherited from [RFC 4203], the Switching Capability field and the Encoding field MUST take the following values for Sonet/SDH interfaces:
Switching Capability (8 bits): value 100 (TDM).
Encoding (8 bits): value 5 for Sonet/SDH.
Reserved (16 bits): set to zero when sent and ignored when received.
Signal Type (8 bits): inherited from [RFC 3946], the Signal Type field(s) MUST take one of the following values:

Value	Type	Comment
1	VT1.5 SPE / VC-11	Unused
2	VT2 SPE / VC-12	Unused
3	VT3 SPE	Unused
4	VT6 SPE / VC-2	Unused
5	STS-1 SPE / VC-3	
6	STS-3c SPE / VC-4	
21	STS-12c SPE/VC-4-4c	New value
22	STS-48c SPE/VC-4-16c	New value
23	STS-192c SPE/VC-4-64c	New value

Number of Unallocated Timeslots (24 bits):

Specifies the number of identical unallocated timeslots per Signal Type and per Link. As such, the initial value(s) of this TLV indicates the total capacity in terms of number of timeslots per link. The signal type included in the BW announcement is specific to the layer link being reported and is not derived from some other signal type (e.g. STS-48c is not announced as 16 x STS-3c)

For instance on an OC-192/STM-64 interface either the number of STS-3c SPE/VC-4 unallocated timeslots is initially equal to 64, or the number of STS-48c SPE/VC-4-16c unallocated timeslots is equal to 4 or even a combination of both type of signals depending on the interface capabilities. Once one of these components gets allocated for a given connection, the number of unallocated timeslots is decreased by the number of timeslots this connection implies

The number of available timeslots per link is calculated independently for each signal type as resource utilization on the link changes. For example, an OC-192/STM-64 interface with one STS-1 timeslot in use would be advertised with the following unallocated timeslots (assuming that the link is able to support a full range of STS-192c and lower rate signals):

sts192c	0
sts48c	3
sts12c	15
sts3c	63
sts1	191

(0*sts192c <= 191, 3*sts48c <= 191, 15*sts12c <= 191, 63* sts3c <= 191, 191*sts1 <=191)

Fragmentation of bandwidth caused by utilized timeslots can impact the usability of timeslots at higher rate signals, and are accounted for in the number of unallocated timeslots advertised.

12.1.4 TNA Address Sub-TLV

The TNA Address sub-TLV specifies one TNA address. Three possible formats are defined for the TNA address: IPv4, IPv6, or NSAP. The TNA Address TLV may include at least one Node_Id sub-TLV in addition to the TNA Address sub-TLV. It MAY include more than one Node_Id sub-TLV and more than one TNA Address sub-TLV.

The format of the TNA Address sub-TLV (Type 32776 and Length Variable) for IPv4 is defined as follows:

```
 0                   1                   2                   3
 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|              type (32776)     |          Length (variable)    |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|  Addr length  |                Reserved                       |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                            One TNA                            |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

Other defined type values are:

1) IPv6 TNA – 32778
2) NSAP TNA – 32779

The addr_length specifies the length of the TNA address specified in number of bits.

Address prefixes can be used to aggregate TNA addresses. The addr_length is used to represent TNA address prefixes. For example, the address prefix 192.10.3.0/24 can be advertised with a TNA of 193.10.3 with an addr_length = 24.

12.1.5 Node_ID Sub-TLV

The Node ID sub-TLV (Type 32777) is included in the TNA Address TLV and contains the node hosting this TNA address(es). The format of this optional sub-TLV is defined as:

```
 0                   1                   2                   3
 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|           Type (32777)        |            Length             |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                            Node ID                            |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

12.2 Opaque TE LSAs for E-NNI OSPF-based Routing

12.2.1 Overview

[RFC 4203] defines two types of top-level TLVs, i.e., the node level TLV and the link level TLV. This specification adds an address TLV as the third type of top-level TLV. The purpose of the address TLV, or TNA address TLV is to advertise the TNA in a given Routing Area.

Type	Top Level TLV	Semantics	Reference	Scope
1	Router Address TLV	No standard semantics defined for prototype testing	OSPF-TE [RFC3630]	Originated from any RC participating in the RA. Mandatory for consistency with [RFC 3630]
2	(TE) Link TLV	Point-to-point link	OSPF-TE [RFC3630]	Originated from any RC advertising one (or more) TE Link . Mandatory for NNI routing.
3	Reachable TNA Address TLV	Reachable TNA's	Section 5	Originated from any RC advertising TNA Reachability . Carrier dependent (see note below).

Table A1-1: Opaque TE LSAs

Advertisement of the Router Address TLV and (TE) Link TLV is *mandatory* for NNI routing. Advertisement of TNA Address TLVs is dependent on the carrier network. However, if received these MUST be stored and flooded to neighboring RCs.

Note: as per [RFC 3630], the Router Address TLV appears in exactly one Traffic Engineering LSA originated by a RC. Only one Link TLV SHALL be carried in each Traffic Engineering LSA originated by a RC. In addition, only one Reachable TNA Address TLV SHALL be carried in each Traffic Engineering LSA originated by a RC.

12.2.2 Routing Controller Opaque LSA

A Routing Controller (RC) represents a routing control domain. [G.7715.1] describes the set of information that has to be included in the mandatory Routing Controller Opaque LSA where the top-level TLV is the Router Address TLV format defined in [RFC 4203].

No.	TLV	Semantics	Reference	Optional/Mandatory
1	Router IP Address top TLV	Top level TLV	[RFC3630]	Mandatory

Table A1-2: Routing Controller Information

12.2.3 TE link Opaque LSA

The TE link opaque LSA is used to represent an inter-domain link or an intra-domain link. The Routing Controller field in the OSPF packet header carries the advertising RC ID for both cases, whereas the Link ID sub-TLV carries the peer RC ID for inter-/intra-domain links or the peer RC ID for inter-domain links and the unknown value for intra-domain links. The latter occurs when an abstracting RC ID originates TE link opaque LSAs representing intra-domain links.

A TE link LSA contains the following information:

No.	TLV	Semantics	Reference	Mandatory/Optional
1	Link top TLV	Top level TLV	[RFC3630]	M (mandatory)
2	Link type sub-TLV	Point-to-point link	[RFC3630]	M
3	Link ID sub-TLV	Peer's Router ID (RC-ID) **Note**: For inter-domain links this value MUST be set to the peering RC-ID. For intra-domain links in domains with a single routing controller this value is considered as "unknown" (and MUST be set to 0.0.0.0). For intra-domain links in domains with multiple routing controllers this value is set to a peering Routing Controller ID (RC-ID).	[RFC3630]	M
4	Link metric sub-TLV	Link cost	[RFC3630]	M (by default equal to 1)
5	Link resource class sub-TLV	Color	[RFC3630]	M (by default bit mask equal to 0…0)
6	Local Identifier in the Link local/remote identifier sub-TLV	Local interface ID	[RFC 4203]	M
7	Remote Identifier in the Link local/remote identifier sub-TLV	Remote interface ID	[RFC 4203]	M (if unknown SHOULD be set to 0.0.0.0)
8	Link protection type sub-TLV	Link protection type	[RFC 4203]	O (by default unprotected links)
9	SRLG sub-TLV	Shared risk link group	[RFC 4203]	O (by default Link ID is the SRLG)
10	Local node ID sub-TLV	Local endpoint (E.g., border node ID)	See Section 11.1.1	M
11	Remote node ID sub-TLV	Remote endpoint (E.g., remote border node ID)	See Section 11.1.2	M
12	SONET/SDH Interface Switching Capability	Describe the TE link bandwidth information in the form that suitable in	See Section 11.1.3	M

	Descriptor TLV	optical networks. NOTE – the exact format of bandwidth encoding is described in Section 5.2.2.3		

Table-A1-3 Inter-domain and Intra-domain Link information

Note 1: per [RFC3630], Link Type and Link_ID sub-TLV's MUST appear exactly once. Remote Node ID, Link metric and Interface ID sub-TLVs defined above MAY occur at most once.
Note 2: setting of the Link ID to 0.0.0.0 as described in the table above deviates from the use of the Link ID as defined in [RFC3630].

The Local Identifier (#6 in the table above) and the Remote Identifier (#7 in the table above) are both part of the Link Local/Remote Identifiers sub-TLV (Type 11) defined in [RFC4203]. The format of this sub-TLV is defined as:

```
 0                   1                   2                   3
 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                   Link Local Identifier                       |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                   Link Remote Identifier                      |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

Note 1: under certain conditions the Link Remote Identifier MAY be coded "0" where the Identifier value is not known. When this is true, the link advertisement is not included in path calculation.
Note 2: under certain conditions the Link ID and Remote Node ID can contain redundant information. In this case the Remote Node ID is used.

12.2.4 New ReachableTNA Opaque LSA

No.	TLV	Semantics	Reference	Optional/Mandatory
1	Reachable TNA top TLV	Top level TLV	See below	Mandatory
2	Node_ID sub-TLV	Specifies Node associated with TNA	See Section 11.1.5	Optional
3	TNA Address sub-TLV	Specifies TNA address(es)	See Section 11.1.4	Mandatory

Table A1-4: TNA LSA Information

Within a single area, in a multi-domain environment, reachability information for connection endpoints can be exchanged. A new top level TNA Address TLV is used for this purpose. This TLV is originated as a Traffic Engineering LSA of Type 1 and follows the flooding rules of an Opaque LSA of Type 10. . The TNA Address TLV is advertised by a control domain routing controller towards RCs belonging to different control domains.

The format of the TNA Address TLV (Type 32768 and Length Variable) is defined as follows:

```
 0                   1                   2                   3
 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|             Type              |         Length (variable)     |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                        Node_Id sub-TLV                        |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                      TNA Address sub-TLV                      |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                                                               |
//                            . . .                            //
|                                                               |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                      TNA Address sub-TLV                      |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                                                               |
//                            . . .                            //
|                                                               |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                        Node_Id sub-TLV                        |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                      TNA Address sub-TLV                      |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
//                            . . .                            //
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                      TNA Address sub-TLV                      |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

The Node_ID SubTLV identifies the node that the immediately following TNA Address TLV(s) are attached to. Consequently, a Node_ID TLV MUST always appear before the TNA Address TLV(s). Subsequent Node_ID SubTLVs signify the end of the TNA Address list for a node and identifies the node for the TNA Address TLV(s) that immediately follow it.

It is possible for one Top Level TLV to contain multiple Node_ID SubTLVs for the same node. It is also possible for more than one LSA to be issued by a Routing Controller (RC) with Node_ID SubTLVs for the same node.

13 Appendix-II Single Level Example

This appendix gives an E-NNI routing/signaling example for a single level of hierarchy.

The example uses a single RC node for each domain that advertises the domain topology. In practice, multiple RCs can be associated with a single domain.

And the following are examined:

1) Control plane topology

2) Data plane topology
3) Connection path computation and ERO construction
4) Call progression at the domain boundary

13.1 The Control Domains

In a routing hierarchy, an RA is partitioned to create a lower level of RAs and interconnecting SNPP links. The internal structure of the RA is known "inside" the RA, but not from "outside". (I.e., inside RA 1, the topology is known to include three child RAs interconnected by two SNPP links; from outside this is opaque).

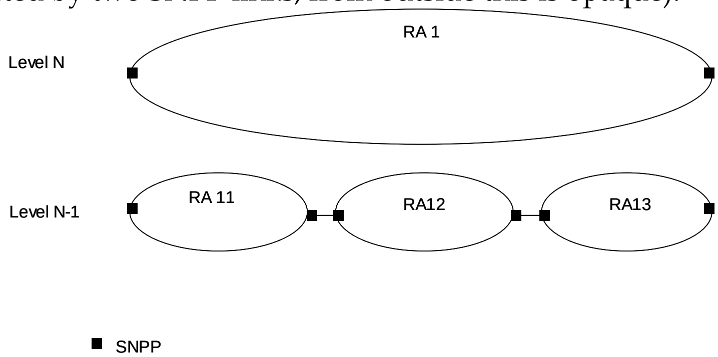

Figure A2-1: ASON Routing Hierarchy

Consider now two RCDs at a given hierarchical routing level with an SNPP link between them.

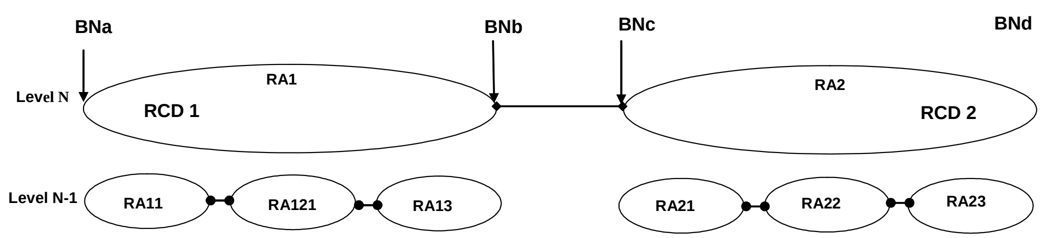

Figure A2-2: Routing Control Domains

There are several potential approaches to advertising costs of traversing an RCD. Two approaches are discussed below.

Abstract node: The representation of an RCD is as a single node with no internal structure. The topology seen in the E-NNI routing protocol at Level N includes two nodes (AN1 and AN2) and one (inter-RCD) link as below.

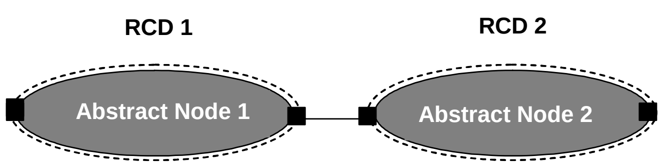

Figure A2-3: Abstract Node Representation

Abstract link: The representation of an RCD is in terms of its border nodes and intervening (intra-RCD) “abstract” SNPP links. The resulting topology seen in the E-NNI routing protocol at Level N includes 4 nodes (BNa, BNb, BNc and BNd), and three SNPP links.

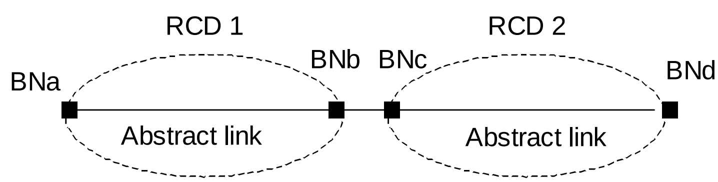

Figure A2-4: Abstract Link Representation

There are 4 routing control domains in the example for single level hierarchy as shown in Figure A2-5, i.e., CD1, CD2, CD3 and CD4.

In this example, the abstract link model is used for CD 1 and 2 and the abstract node model is used for CD 3 and 4.

13.2 The Control Plane

There are 4 OSPF nodes as shown in Figure A2-5, i.e., RC1, RC2, RC3 and RC4 that form the control adjacencies as shown in the red color. The 4 OSPF nodes represent the 4 control domains, respectively. Again, the example uses one RC per domain, but in practice, multiple RCs may be used for a particular domain.

13.3 Data Plane

The data plane and its topology are shown as in Figure A2-5. Note there are border nodes, inter-domain links and intra-domain links. Both border node ID (B1, B2, etc.) and link interface ID (13, 31, etc.) are marked in Figure-A2-5.

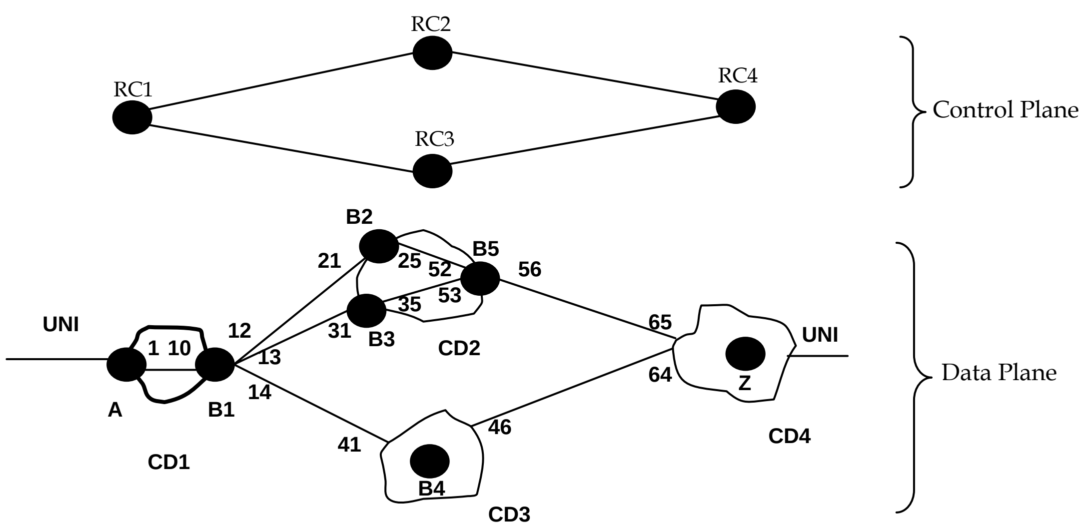

Figure A2-5: Example Topology

13.4 Advertising Links from RC1

The links that are advertised by RC1 are the following:

a) `B1->B2 (an inter-domain link)`

- Advertising Router is RC1
- Local Node ID sub-TLV contains B1
- Remote Node ID sub-TLV contains B2
- Local interface ID sub-TLV contains 12
- Remote interface ID sub-TLV contains 21
- Link ID sub-TLV contains RC2

b) `B1->B3 (an inter-domain link)`

- Advertising Router is RC1
- Local Node ID sub-TLV contains B1
- Remote Node ID sub-TLV contains B3
- Local interface ID sub-TLV contains 13
- Remote interface ID sub-TLV contains 31
- Link ID sub-TLV contains RC2

c) `B1->B4 (an inter-domain link)`

- Advertising Router is RC1
- Local Node ID sub-TLV contains B1
- Remote Node ID sub-TLV contains `B4`
- Local interface ID sub-TLV contains 14
- Remote interface ID sub-TLV contains 41
- Link ID sub-TLV contains RC3

d) A->B1 (an intra-domain link)

- Advertising Router is RC1
- Local Node ID sub-TLV contains A
- Remote Node ID sub-TLV contains B1
- Local interface ID sub-TLV contains 1
- Remote interface ID sub-TLV contains 10
- Link ID sub-TLV set to 0.0.0.0

e) B1->A (an intra-domain link)

- Advertising Router is RC1
- Local Node ID sub-TLV contains B1
- Remote Node ID sub-TLV contains A
- Local interface ID sub-TLV contains 10
- Remote interface ID sub-TLV contains 1
- Link ID sub-TLV set to 0.0.0.0

13.5 Advertising Links from RC2

The links that are advertised by RC2 are the following:

a) `B2->B1 (an inter-domain link)`

- Advertising Router is RC2
- Local Node ID sub-TLV contains B2
- Remote Node ID sub-TLV contains B1
- Local interface ID sub-TLV contains 21
- Remote interface ID sub-TLV contains 12
- Link ID sub-TLV contains RC1

b) `B3->B1 (an inter-domain link)`

- Advertising Router is RC2
- Local Node ID sub-TLV contains B3
- Remote Node ID sub-TLV contains B1
- Local interface ID sub-TLV contains 31
- Remote interface ID sub-TLV contains 13
- Link ID sub-TLV contains RC1

c) `B5->Z (an inter-domain link)`

- Advertising Router is RC2
- Local Node ID sub-TLV contains B5
- Remote Node ID sub-TLV contains `Z`
- Local interface ID sub-TLV contains 56
- Remote interface ID sub-TLV contains 65
- Link ID sub-TLV contains RC4

d) B2->B5 (an intra-domain link)

- Advertising Router is RC2
- Local Node ID sub-TLV contains B2
- Remote Node ID sub-TLV contains B5
- Local interface ID sub-TLV contains 25
- Remote interface ID sub-TLV contains 52
- Link ID sub-TLV set to 0.0.0.0

e) B5->B2 (an intra-domain link)

- Advertising Router is RC2
- Local Node ID sub-TLV contains B5
- Remote Node ID sub-TLV contains B2
- Local interface ID sub-TLV contains 52
- Remote interface ID sub-TLV contains 25
- Link ID sub-TLV set to 0.0.0.0

f) B3->B5 (an intra-domain link)

- Advertising Router is RC2
- Local Node ID sub-TLV contains B3
- Remote Node ID sub-TLV contains B5
- Local interface ID sub-TLV contains 35
- Remote interface ID sub-TLV contains 53
- Link ID sub-TLV set to 0.0.0.0

g) B5->B3 (an intra-domain link)

- Advertising Router is RC2
- Local Node ID sub-TLV contains B5
- Remote Node ID sub-TLV contains B3
- Local interface ID sub-TLV contains 53
- Remote interface ID sub-TLV contains 35
- Link ID sub-TLV set to 0.0.0.0

13.6 Advertisements from RC3

The links that are advertised by RC3 are the following:

a) B4->B1 (an inter-domain link)

- Advertising Router is RC3
- Local Node ID sub-TLV contains B4
- Remote Node ID sub-TLV contains B1
- Local interface ID sub-TLV contains 41
- Remote interface ID sub-TLV contains 14
- Link ID sub-TLV contains RC1

b) B4->Z (an inter-domain link)

- Advertising Router is RC3
- Local Node ID sub-TLV contains B4
- Remote Node ID sub-TLV contains Z
- Local interface ID sub-TLV contains 46
- Remote interface ID sub-TLV contains 64
- Link ID sub-TLV contains RC4

13.7 Advertisements from RC4

The links that are advertised by RC4 are the following:

a) Z->B5 (an inter-domain link)

- Advertising Router is RC4
- Local Node ID sub-TLV contains Z
- Remote Node ID sub-TLV contains B5

- Local interface ID sub-TLV contains 65
- Remote interface ID sub-TLV contains 56
- Link ID sub-TLV contains RC2

`b) Z->B4 (an inter-domain link)`

- Advertising Router is RC4
- Local Node ID sub-TLV contains Z
- Remote Node ID sub-TLV contains `B4`
- Local interface ID sub-TLV contains 64
- Remote interface ID sub-TLV contains 46
- Link ID sub-TLV contains RC3

13.8 Path Computation at the UNI-N and ERO

Suppose one wants to make a connection from A to Z in Figure A2-5: the source node A sees there are 3 possible routes, i.e.,

1) A->B1->B2->B5-> Z
2) A->B1->B3->B5-> Z
3) A->B1->B4-> Z

Supposing the route being chosen is 1) above, then the ERO built by A is:

A:1 -> B1:12 -> B2:25 -> B5:56 -> Z

Supposing the route being chosen is 3) above, then the ERO built by A is:

A:1 -> B1:14 -> B4:46 -> Z

13.9 Path Expansion

If internal topology exists within a CD which is not advertised externally, there needs to be a mapping or expansion of a received ERO to fit the actual internal topology of the CD. For example, if CD3 in the figure above consists of multiple nodes, the ERO entry {B4:46} is expanded internally to match the actual ingress border node and internal path to the destination TNA.

14 Appendix III – Use of SNPP Aliases for Hierarchy

14.1 Introduction

The OIF E-NNI Routing project has had a requirement to support multiple hierarchically organized areas for quite some time. While the OIF E-NNI Routing Interoperability demonstrations held in 2003, 2004, and 2005 did not test this feature, implementations of hierarchical routing were developed and tested. This contribution describes one method developed and tested in all three interoperability events, that requires translation of SNPPs at one hierarchical level into SNPPs at another hierarchical level. It should be noted that the abstraction model used in this example is only one of many possible abstraction models that can be useful in E-NNI routing.

14.2 Area Hierarchy and Abstract Topologies

[G.7715] states, "routing areas may be hierarchically contained, with a separate routing performer associated with each routing area in the hierarchy." Since the routing performer for this area only has visibility to the topology of its area, it has no specific knowledge of the topology of areas that contain it, or any of the areas it contains. However, the routing performer will still show the contained area along with the SNPP links that connect the contained area to other sub-networks and areas.

At the same time, the lower level RA has visibility to the ends of the links that are used to connect the abstract node to other nodes/areas in the upper level area. Visibility to these ends is necessary so that route computations can be performed across the lower level routing area.

Figure A3-1 below (also Figure 7 of [G.7715]) illustrates such a topology. The Areas are represented by the shaded circles, link ends are represented by solid dots, and links are represented by arcs. Note the correspondence between the links shown in the upper area topology and the link ends in the lower level topology.

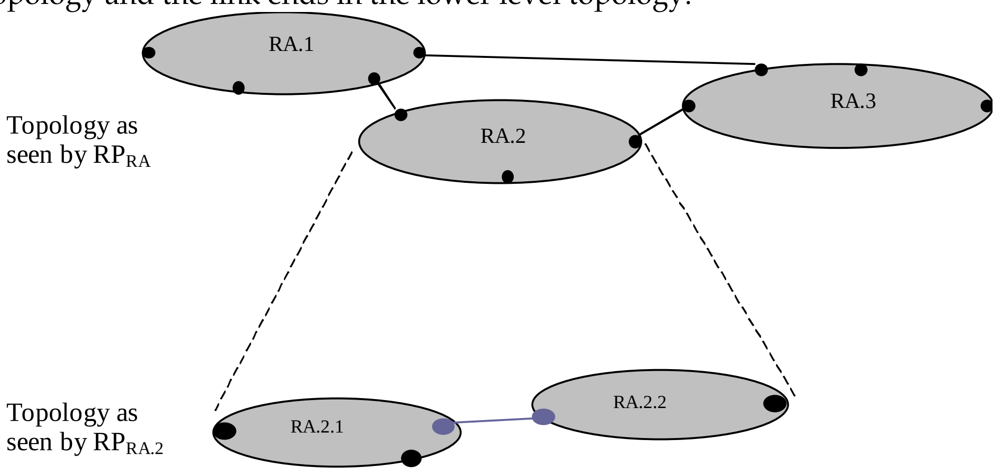

Figure A3-1 Topology Views as Seen by RP Associated with Hierarchical Routing Areas (Figure 7 in [G.7715])

Since the contained routing area is represented as a single node in the containing area, it is actually an abstraction of the contained area's topology. Herein this will be referred to as an "Abstract Node".

14.2.1 SNPP links terminating on Abstract Nodes

The definition of an area in [G.8080] requires that links be wholly contained within an area. Consequently, a link does not exist in any area other than the lowest area that contains both endpoints of a link. The example illustrated in Figure A3-2 shows links that are contained within area RA11, as well a link that is contained within area RA1. As shown, the Routing Controller for RA1 located on SN3 has visibility to the link in RA1, while the Routing Controller in RA11 located on SN3 has visibility limited to the link-end.

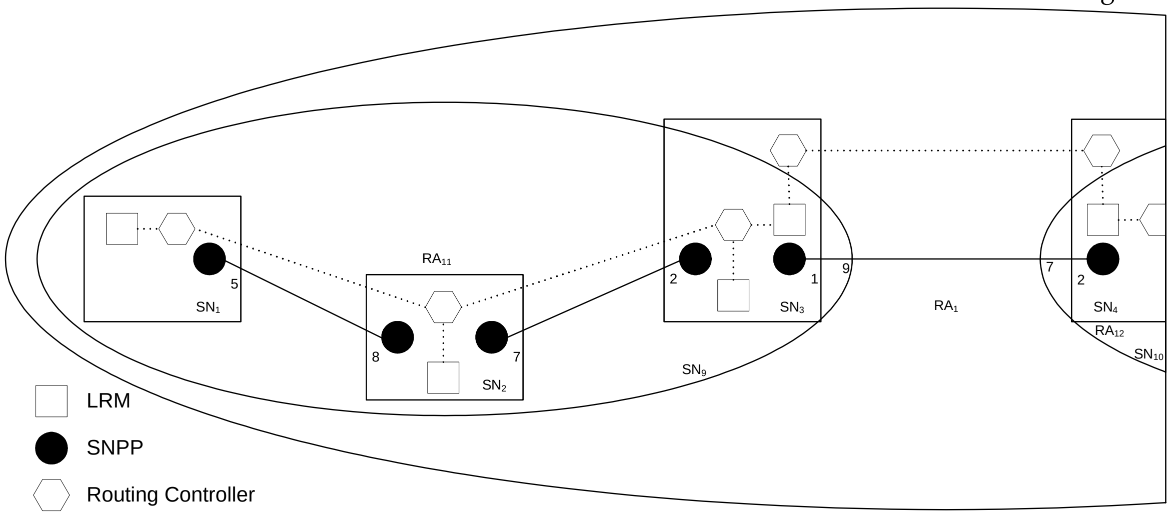

Figure A3-2 Hierarchical Routing Controller Relationships

According to [G.8080] two separate SNPP names exist for the link end in SN_3 that is connected to SN_4:

RA=<RA_1, RA_{11}> SN=SN_3 LC=1 (in the RA_{11} context)

and

RA=< RA_1> SN= SN_9 LC=9 (in the RA_1 context)

How this interacts with the process of Hierarchical Routing is described below.

14.3 Hierarchical Routing Example

As an example of how to apply this representation, Hierarchical Routing can be accomplished by performing path calculations in successively higher areas. As stated in [G.7715]:

"1) The child RC shall first be consulted to develop a path to the destination. If the child RC knows the destination, the path developed by the child RC shall be used. This path shall have the highest preference."

"2) When the child RC does not know the destination, the parent RC shall be requested to develop a path to the destination. If the parent RC is able to develop a path, the first link end of the path returned will identify the SNPP used to exit the child routing area. The child RC will next be consulted for a route to the SNPP. The path that is returned by the child RC is then pre-pended to the path that is returned from the parent RC. This path shall have the lowest preference."

So to compute a path from SN_1 in RA_{11} to SN_4 in RA_{12}, the child RC in RA_{11} will first evaluate the destination to see if it is contained within RA_{11}. Since it is not, the child RC will ask an RC in the parent RA (RA_1) to develop a route to SN_4 in RA_{12}. Again, the RC in parent area RA_1 will evaluate the destination to see if it is contained within RA_1. Since the prefix for SN_4 and/or its TNAs are advertised within RA_1 by the RC for SN_{10}, the RC can compute a path from RA_{11} to RA_{12}. The resulting path through the parent RA (RA_1) specifies the near link end for the link which connects SN_9 to SN_{10}, specifically RA=< RA_1>, SN= SN_9, LC=9. This can then translated into the child RA's SNPP name for the visible link end, specifically RA=<RA_1, RA_{11}>, SN=SN_3, LC=1. The translated name can then be used by the RC in the child area to compute a path across the child RA. These paths are then concatenated, providing the end-to-end path.

This interaction between child and parent RC recurses, allowing any number of hierarchical areas to exist between the lowest level child area and the root of the hierarchy.

14.4 Information Necessary for This Example

In order to perform hierarchical routing as described, a method is necessary to translate the SNPP name used in the parent RA to the SNPP name in the child RA. To accomplish this, a routing announcement is generated by SN_3 in the child RA containing the following information:

Field	# included
Child SNPP name	1
Parent SNPP name	1

This announcement is made into the child RA instead of the parent RA in order to maintain the requirement for hiding the specifics of the child RA.
Communications between the Child RC and Parent RC can be local to a system, or can occur across a Remote Path Computation query interface.

14.5 Scalability

This approach scales linearly with the number of links in the Parent RA that terminate on this RA.

14.6 Versatility

Since [G.8080] defines the use of SNPP aliases for not just hierarchical routing, but also for L1VPN style functionality, the translation information defined above can also be used to facilitate L1VPN services.

15 Appendix IV: List of companies belonging to OIF when document was approved

ADVA Optical Networking
Agere Systems
Agilent Technologies
Alcatel
Altera
AMCC
Ample Communications
Analog Devices
Anritsu
Apogee Photonics, Inc.
AT&T
Atos Origin Integration
Azna
Bay Microsystems
Bookham
Booz-Allen & Hamilton
Broadcom
China Telecom
Ciena Corporation
Cisco Systems
CoreOptics
Cortina Systems
Data Connection
Department of Defense
Deutsche Telekom
Ericsson
Essex Corporation
Finisar Corporation
Flextronics
Force 10 Networks
Foxconn
Freescale Semiconductor
Fujitsu
Furukawa Electric Japan
Hi/fn
Huawei Technologies
IBM Corporation
IDT
Infinera
Intel
IP Infusion
JDSU
KDDI R&D Laboratories
KT Corporation
LSI Logic
Lucent
Mercury Computer Systems, Inc
MergeOptics GmbH
Mintera
MITRE Corporation
Mitsubishi Electric Corporation
Molex
Motorola
NEC
Nortel Networks
NTT Corporation
Opnext
OpVista Inc
Orange World
Paxera Corp
Phyworks Limited
PMC Sierra
Radisys Corp
Redfern Integrated Optics, Inc.
RSoft Design Group, Inc.
Sandia National Laboratories
Santur
Scintera Networks
Siemens
Silicon Logic Engineering
StrataLight Communications
Sun Microsystems, Inc.
SwitchCore AB
Sycamore Networks
Syntune
Tektronix
Telcordia Technologies
Telecom Italia Lab
Tellabs
Texas Instruments
Time Warner Cable
Transwitch Corporation
Tyco Electronics
Verizon
Vitesse Semiconductor
Xilinx
ZTE Corporation