**Network Service Interface Architecture**

Status of This Document

This document provides information to the Grid community on the service interface between a requesting software agent and the provider software agent that offers and delivers a network service. It is intended to describe the processes and environment in which software agents interact to deliver the service(s). Representing applications or other networks, these agents may request certain services of other network agents. Distribution is unlimited.

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Abstract

The Network Service Interface is defined to be the set of protocols and parameters that are used between a software agent requesting a network service and the software agent providing that network service. The Network Service Interface Architecture describes a service plane network topology model, and associated processes and concepts that occur among the Network Service Agents in order to satisfy service requests. This document and its partner document the NSI Protocol recommendation (GWD-R) form the NSI definition.

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# Context and Overview

Over the last decade, global networks have begun delivering high performance transport services directly to applications that require performance levels or capabilities unavailable in conventional best-effort IP networks. The ability to create connections between a fixed set of ports worldwide, with specific, predictable, and often demanding performance characteristics, enables emerging global collaborations to establish well-defined and highly customized network environments to support the end users and their applications. This is particularly true within the Research and Higher Education space and the growing Grid community.

Connections across these transport networks have been historically reserved and provisioned in a variety of ways. The most common approach is manual provisioning by someone - typically a network engineer - who is directed by traffic capacity planners. More recently, some networking communities have developed tools and protocols to automate the process of network resource allocation and to allow the user or application to participate directly in the path planning process. These new approaches to automating transport connection provisioning are the basis for the standardization effort being described in this recommendation.

Connection-oriented transport capabilities are being deployed by Research & Education (R&E) providers as well as by commercial providers, and could eventually be implemented in home/ retail networks as deployment progresses.

These automated provisioning systems, while created by different groups, have all developed software based control and/or management agents to regulate access to these resources, to schedule and reserve resources, to trigger or control timely provisioning of the network resources, and to monitor and release resources. These controllers are deployed in two different contexts. One context is application (or Grid) centric, where a network provides a resource to an application. The other context is network centric, where network resources are collaboratively shared among networks to expand or improve network performance or reach. In the former context, a user or application agent is requesting the service of a network provider. In the latter context, one network is interacting with other network(s) to manage these resources and deliver a comprehensive and well integrated service portfolio to the user community. This informational document defines an architecture for the NSI protocol which works in either of these contexts.

The NSI defines several key architectural elements: the Network Service Interface (NSI), the Network Service Agent (NSA), the NSI Protocol, the supporting topology model, and a set of basic services. These concepts are assigned to a nominal Service Plane. The Network Service Interface (NSI) architecture describes an environment within which network capabilities and components are abstracted and manipulated as “network resources.” Within the NSI architecture, network resources can be selected, allocated, interrogated, and manipulated by software agents on behalf of networked applications. Network resources and capabilities are presented to the consumer through a set of “network services.” The Network Service Interface presents a simple “one-stop shopping” model for interacting with these services.

Version 1.0 of these NSI supports only one Network Service – the Connection Service.

Network Services are delivered by the capabilities of participating operators. They will make use of a range of network related functional capabilities such as topology sharing, path finding, resource reservation, hardware provisioning, and other ancillary services and functions.

This NSI Architecture document describes the broad concepts, models, and key objects necessary to realize the delivery of these services. The NSI Protocol recommendation (GWD-R-XXX) forms the partner document to this architecture document and describes the specific and detailed messages, associated parameters, transactions, and state transitions that occur to request and deliver network services.

## The Network Service Interface

The Network Service Interface (NSI) provides secure and reliable sessions for service related communication between NSAs. An instance of the NSI exists at the boundary between two communicating software agents: the Requester NSA and the Provider NSA. These agents interact to realize the delivery of a Network Service intrinsic to the network infrastructure. In this model, the Requester NSA requests some service, and the Provider NSA attempts to deliver it (see Figure 1).

Figure 1: NSI interface

## The Network Service Agent

The NSA is central to the NSI architecture since all NSI processes are invested in the Network Service Agent (NSA). The role of the NSI is to provide a platform for delivering Network Services by exchanging information between NSAs. Each NSA can also interact with its Transport Plane to deliver the local part of the Network Service and with other infrastructures such as those for security and monitoring.

The NSA assumes two possible roles - Requester and Provider. As a Requester, the NSA requests network resources and as a Provider it delivers these network resources to create a service. The Network Service Agent may at times act as a requester over one NSI interface while acting as a provider at a different NSI interface.

The NSA incorporates a number of functional components – some of which may be defined NSI Network Services others may be NSA internal functions Figure 2. An example of the former might be a Connection Service or a Topology Service. An example of the latter may be a path-finding function.

The NSA may incorporate a Network Resource Manager (NRM). The NRM manages the part the Network Service implemented locally.

Figure 2: 3 roles of Network Service Agent

The NSI architecture allows many Network Service Agents (NSAs) interconnected with NSI interfaces; details relating to such a federation of networks are described in section 1.6.

## NSI Services

The NSI protocol deals with an abstracted model of transport services. This abstraction reduces or hides many of the real-world complexities of delivering a particular transport service. For instance, the NSI Connection Service takes a rather complex data transport circuit and presents it as if it were a simple pipe of a certain size between two locations. The user only needs to specify the ends, and the diameter of the pipe. The user places data in one end of the pipe and it emerges some time later from the other end in the same manner. This abstract concept is a simplified and convenient means of presenting the key functional aspects of the service object while hiding most or all of technical details that are in general not relevant to the application.

In practice, the abstraction of a service presents a basic set of service primitives and a bounded set of parameters on those primitives that fully define what will be delivered as result of the service. To make this point, the NSI Connection Service provides primitives such as ReserveRequest and CancelRequest that perform very clear operations on a Connection, and these primitives are carefully bounded by the parameters associated with each – such as capacity, or end points, or start time. The detail of coordinating schedules and the exchange of circuit provisioning information across possibly many networks is hidden.

In the NSI Architecture, these Services exist in the form of service specific agents known to, or incorporated within, the NSA. The NSI Protocol provides an extensible framework for the definition and incorporation of network services. The NSI has defined only one initial service: the Connection Service to meet the emerging need for automated creation and management of network connections.

## NSI service extensibility

The NSI Interface must provide a common framework in which Network Services can be delivered. To achieve this aim, the NSI Architecture is extensible; it inherently supports the ability to add new Network Services as they emerge. Examples of anticipated services include a Topology Service to distribute topology information and a Connection Monitoring service. The Network Service Agents must support these services and functions in order to provide the integrated service envisioned.

Version 1.0 of the NSI supports only a Connection Service, this service allows connection-oriented circuits to be requested and managed.

## The NSI Service Plane

For the purposes of defining layering, this architecture assigns the NSI to a Service Plane. Here we define the service plane as incorporating participating NSAs and the associated NSI sessions between these NSAs. This is depicted in Figure 3.

In general, the NSI Service Plane relies on the capabilities of the control plane and management plane (not shown) to effect changes in the Transport Plane, where the control and management planes follow conventional definitions. The transport resources and the physical instance of the Connection reside on the Transport Plane.

The NSI Service Plane operates on an abstracted representation of the transport plane resources. In this abstracted view, transport resources within a particular network are treated as a single opaque object under the control of a Provider NSA. Representation of transport resources is described further in the section 3.

Considering the example of the NSI Connection Service, the service managed on the NSI Service Plane is the ability to create a Connection, with a set of simple, well defined manipulation rules that operate within a network and are defined by the NSI. These abstractions are exchanged and processed in the NSI Service Plane. The NSI Service Plane contains information about owners, permissions, performance parameters, schedule, and Path information.

Figure : Transport Plane and Service Plane

Connection should be thought of as an NSI Service Plane construct that binds high level service planning results (such as path selection, authorization, reservation, and scheduling) to the low level configuration and management information necessary to provision the transport physical instances that make up path in the transport plane.

## Hierarchical communications model and federation

The NSI protocol is intended to allow services to be delivered across multiple participating networks. To facilitate this, the forwarding of service messages is designed to be flexible. This section describes the options supported for NSI message forwarding.

No assumptions are made about the reachability of participating NSAs, an NSA may be directly reachable or reachable only via a gateway NSA. For instance, an arbitrary set of Networks may band together under NSI rules and peer exclusively with a single parent “Federation NSA”. The parent federation NSA may have no transport resources of its own – just those resources under management of the children NSAs. Service requests will flow along the trusted sessions hierarchically among NSAs, even if the transport connection itself takes a different route through the transport infrastructure.

In the case of a gateway NSA, the NSA becomes a communications parent for its child NSAs. An example of this is shown in Figure 4. where NSA A communicates with NSA D via NSA B.

The message forwarding model described here is intended to be flexible and is designed to support both the tree and chain model of path-finding described later in the Connection Service.

Figure : Hierarchical communications

As described in the introduction, two operational scenarios have been identified as driving the standardization of the NSI. In the application-to-operator scenario, the Requester NSA is associated with an application (such as grid middleware) and the Provider NSA is associated with a Network. In the inter-operator model, each NSA is associated with a Network and multiple Networks interact with one another to create inter-operator Network Services. The NSI is designed to support both scenarios. This is achieved by generalizing the associations of the Requester NSAs, it may be associated with either an application or a network provider.

# The NSI Protocol

## Protocol Sessions and trust relations

Network Services are delivered with the use of the NSI Protocol. This protocol defines the constructs, state machines, messages, and parameters associated with the NSI services model. An NSA, by definition, is an agent that implements the NSI Protocol. The details of this protocol are out of scope of this document. The NSI Protocol recommendation (GWD-R-XXX) provides a detailed definition of the NSI protocol.

The NSI Protocol requires a “trust relationship” between NSAs. These trust relationships mean that each NSA believes the other to be whom they claim to be (authentication) and that both NSAs are willing to accept service requests from the other and act to satisfy them (authorization). Further, there must be a comfort level that the messages have not been tampered with, and optionally that they have not been exposed to unauthorized/untrusted third parties.

These trust relationships can exist in one of two modes: First, for high volume and/or persistent peering relationships, an authenticated, authorized, secure (encrypted) and reliable session can be established between the NSAs. Traffic passed across such a session is known to be trusted and can proceed directly to the service handler. The second mode is to employ a more message based trust framework such as Web Services. This message based form is more appropriate for occasional messaging as might occur between an application agent and various provider NSAs.

## NSI messages

The NSI protocol is made up of NSI message which are a datagram style. Each message envelope contains sufficient information to route the message to the proper network service agent, followed by sufficient service specific information to associate the request to an appropriate service instance and to identify the service primitive. The message canbe broken into smaller sizes by the underlying layers for transport of the message. These NSI messages are handled completely by the provider and should return at a minimum either a confirmation or rejection of the request in its entirety.

An NSI Message must allow identification of the Network Service type. (eg Connection Service, Topology Service, etc). An NSI Message must allow identification of the Connection service version (v1.0, v2.0 etc). NSI Messages mustinclude a mechanism to ensure that ordering is maintained in a NSI Message Thread.  Note that the NSI message ordering just does not prevent asynchronous operation of the service protocol, it just ensures that the message sequence is preserved across the secure session.

An NSI Message mustinclude a mechanism to associate it with an NSI Message Thread to allow differentiation of message streams associated with simultaneous and asynchronous service functions occurring between pairs of NSAs

Authentication of the source of all messages may be done on a message by message basis or with an authenticated session.

## Service Instances and primitives

The base NSI protocol handler recognizes NSI messages between NSAs. The protocol examines each message received for its Service Identifier and forwards that message to the appropriate service specific agent.

Each NSI service defines a “service instance” and a set of “service primitives” that operate within the context of a service instance. This service instance is an independent, uniquely identifiable deliverable unit of the service. The NSI Connection Service refers to a particular connection as a “service instance”. A topology distribution service may define an instance to be a particular topology graph, or a topology transaction such as a full dump or incremental update. In general, a service specific state machine allocated and associated with each service instance, and the service primitives drive the transitions of that state machine. A service primitive may require a sequence of messages or even its own state machine to affect an exchange of messages

The service defines the full set of capabilities that are offered to requesters. The service instance defines one specific instance of the service. Put another way, the service instance is the object or capability that is delivered to the user in fulfillment of a service request. As an example, a service instance for a connection service is a particular connection. A service instance for a topology request might be a snapshot of the local topology database. The nature of a service and a service instance is specific to the function the service is intended to perform.

Service Instances are processed asynchronously with respect to other service instances. For example, one connection may transition from reserving, to scheduled, to in-service, to release at a vastly different speed than another connection established by the same service agent.

The network service instanced must be locally unique.  Should have a field large enough to hold policy based ids such as GLIF.

## Service definitions

The concept of Service Definitions is introduced to allow operators to readily define their own sub-set of service types. The Service Definition formally describes each aspect of a service. Each aspect is denoted by a Parameter and each Parameter is assigned a specific and bounded set, or range, of values. For instance, an “Ethernet Transport Service” might define a Parameter called “Capacity” that defines a range of allowable service capacities between 1 Mbps and 10 Gbps. This is a very important formalization of the Service offering and so is included here as part of the NSI Architecture. The Service Definition has its roots and most immediate application in definition of the NSI Connection Service offering(s), and for NSI v1.0 that is the sole purpose for which the Service Definition is adopted. (Note that the notion of formal service specifications is still a widely researched topic with new application to emerging network services from Connections to Topology to Monitoring. Further exploration and refinement of this helpful concept within the NSI Architecture will be a continuing effort in NSI futures.)

## Temporal aspects of services

Services, in which resources are dynamically requested, reserved and provisioned, require temporal aspects to be understood and controlled. Each NSA must maintain its own real-time clock, and it is necessary for these clocks to be synchronized. NSAs may implement NTP or radio time and frequency services to achieve this synchronization.

When resources are sought by a requester NSA from a provider NSA, a service instance is created and an identifier is assigned to that service instance. Then, according to the parameters of the request (i.e. its service definition), the provider NSA identifies and reserves a set of available resources which satisfy the request and associates them to the instance. The resources are provisioned and released at some point on the temporal axis. The time information and signaling are used to specify the time boundary of the requested connection in-service period. It is the responsibility of the Provider NSA to attempt to deliver the connection as close to the start and end times as it is able. It should be noted that this may have some uncertainty as typically the duration of the provisioning phase cannot be precisely predicted.

Advance reservation requests will specify the required resources and the provisioning start and end time. The request is processed by a scheduler, and the scheduler finds a set of resources available for the requested duration and allocates them to the request to create a reservation. If the scheduler cannot find an available set of resources which satisfies the request, the request is denied. This scheduling process is part of path finding in the connection service. A reservation database (i.e. calendar) should be maintained by the scheduler or resource managers, and referred and updated by the scheduler.

# Representing network resources

## Resource Abstraction

The network itself is abstracted into a simplified topology model based on STPs and Networks. This model only exposes salient network characteristics at each level of scale. Networks are simple abstracted representations of large interoperating transport infrastructures. A knowledge of the details of each of the network devices in every network is not usually necessary at the service plane.

The process of creating an abstraction of resources is performed locally to each network. The NRM offers the NSA part of or all the network resources it controls based on local policy. The number of resources offered may be affected by either a human-intervened process carried out by the NRM administrator and the NSA operator or an automated discovery process conditioned by topology access policies.

## Describing network topologies

In order to develop and define network services – services that interact with and manipulate network resources - the NSI Architecture must posit a basic network model.– i.e. a minimal set of objects and rules that describe a simplified generic network. With regard to the NSI, we are most concerned with the inter-domain network topology. (see Figure 5)

Figure 5: Inter-Domain Topology

The NSI works with an abstracted topology. That is, it only knows of logical attributes of the network rather than just the nominal physical arrangement of the hardware. These attributes include representations of administrative boundaries and/or logical relationships such as federations of networks. The primary purpose of the NSI topology model is to describe how Networks are interconnected.

The NSI Architecture assigns the management of low level Transport Plane components to an NSA function called the Network Resource Manager (NRM). The NSA is responsible for the high level interactions between Networks via the NSI Protocol. The NRM is shown as the green part of the NSA in Figure 6.

It is important to note here that the arrangement of NSI interfaces between NSAs is *not* necessarily congruent with the connectivity between Networks.

Figure 6: NSA connectivity and Network connectivity are independent

There are two levels of topology recognized by the NSI Architecture: the inter-domain topology which is concerned with describing the global topology of Networks, and the intra-domain topology concerned with the transport resources within the Network. The formal representation of Network-internal topology is out of scope for the NSI. However, the inter-Network topology plays an important role defining how the NSI service plane interacts to establish global service reach. Therefore, we discuss topology here in order to define key concepts that the NSI relies upon to function.

NSI supports the administrative grouping of Transport Plane resources into a single topology object called a Network. At the transport plane, Networks interconnect with other Networks via edge constructs called Ports, as in the NML Node. However, at the NSI inter-Network level, these are logical constructs and may not have a direct physical analog in the transport plane. NSI Ports differentiate inter-domain transport links originating or terminating in a particular Network. It is the responsibility of the NSAs to define a valid mapping function to relate the inter-Network relationships to the actual transport devices.

By aggregating detailed transport topology into a single Network, or by grouping several Networks together to form a federated Network object, the global network topology may be reduced substantially. How such a federation is implemented and the resulting simplified inter- Network topology map is out of scope for at least this version of NSI. Successful implementation for a particular deployment will allow Pathfinders to inexpensively compute coarse grained path(s) between any pair of networks. Each NSA along the candidate path is then consulted to reserve and confirm the resources. (For most of the NSI discussion (certainly for V1.0 inter-domain discussion) we assume each Network has a transfer function that is a simple non-blocking any-port-to-any-port crossbar switching function. Any other path constraints are managed by the Resource Manager.)

An important aspect of this topology discussion is to note that there are two levels of pathfinding recognized by the NSI Architecture: the inter-domain pathfinding which is concerned with choosing a coarse Path across the global topology of Networks, and the intra-domain pathfinding concerned with the transport resources within the Network, Pathfinding algorithms and processes are generally speaking out-of-scope for NSI, However, since processes such as Connection Request processing necessarily involves and depends upon network selection, path finding is often referred to in order to obtain a path or information about a path. The upper level NSI coarse grained path selection does not skip the low level path planning and reservation phases, but it effectively prunes the search space early in the process to produce a “good bet” path that has a high likelihood of success.

From a global perspective, hiding detailed transport topology within an opaque Network object substantially reduces the size and complexity of the topology information base. This has positive implications for coherence and convergence, for dynamic topology distribution, path finding efficiency, and for scalability in the global environment. It has the less desirable effect of reducing optimality – it becomes increasingly difficult to choose a resource efficient path. The trade off is an issue of pragmatism, and will be steered by best practices as the experience base improves.

## Service Termination Points

The NSI Architecture adopts a generalized notion of a Service Termination Point (STP). An STP names a topological location that acts as a concatenation point connecting two Connections. This is the junction between the ingress of a Connection in one Network and the egress of a Connection in the next Network.

A prerequisite for an STP is the existence of a physical connection between Networks. This preexisting capability (typically made up of a physical port on each network) can be advertised by each network to the NSA. Note that the choice about which resources to advertize is subject to local policy. Once advertised, these capabilities may be used by the pathfinding function of the NSA.

An STP capability can be a list of possible STP instances, or a more flexible representation like wildcard and constraints. For example, if there are 10 links (1, 2, 3, …, 10) and any two of these links can be aggregated, there are 90 possible STP instances (1-2, 1-3, …, 9-10). A wildcard like representation may be better than listing all of such STPs individually.

An STP can function as both an ingress point on one side and an egress point on the other. Two such connections that share a single STP in this way are said to be concatenated. These two concatenated connections then appear to the user payload as a single end-to-end transport plane data-path. In this way an STP becomes intermediate transit-point of a path or connection, i.e a routing point through which the connection must pass.

STPs may be uni or bi-directional and are typically associated with Ports in the topology. In the uni-directional case, the STP functions either as an ingress point or an egress point, this is defined by the flow polarity of the associated Port, and which side of the junction is the user side, and which side is the network side.

Two adjacent networks agree on the STP capability between the two networks in advance. The STP capability is the information which describes all possible STPs which can be instantiated between them. Constraints are also included in the information.

Once the STP capabilities are advertised, the STP needs to be dynamically generated for an inter-network connection over the STP to be instantiated.

Once allocated, an STP may have properties such as a framing, bandwidth and a VLAN id. Some of these properties may reflect the requirements specified in the service definition. Labeling (cf. fiber id, wavelength, VLAN id) and aggregation (cf. an STP may be provisioned by aggregating multiple switch ports) can be modeled as a property of STP.

To instantiate an inter-network connection, the requester NSA requests STPs with the same representation to the adjacent networks. Each network then keeps a calendar of reservations.

Figure : STPs

Assume there are two networks, X and Y, and possible STP instances between X and Y are: v1, v2, v3 and I1, I5, I9. This information is advertised by X and Y in advance. To request an inter-network connection, the requester NSA requests:

• To network X: connection between somewhere to to\_Y:v1

• To network Y: connection between to\_X:v1 to somewhere.

Each network looks up its own calendar and check availability of v1. The availability may be different by the networks.

When the above intra-network connections are instantiated, they are inherently connected.

An STP is a symbolic reference, i.e. it is comprised of a parsable alphanumeric string containing two components: 1) a Network identifier string in the higher order portion, and 2) a local STP identifier in the lower order portion. An STP must always resolve to a specific topological Port object as defined in the NSI topology. It is an implementation decision as to how to map that NSI Port identification to the corresponding resource in the physical transport plane.

It is important to note that the NSI inter-network topology model is composed of Networks interconnected by STPs. It should be noted that this topology is neither a standard nor does it imply that an NSI implementation must adopt specifically any particular schema for its database in the code.

# The NSI Services

The NSI Protocol is designed to mediate trust sessions and deliver messages between many NSA based services. NSI v1.0 stipulates a single NSI Service: The NSI Connection Service, this is described below.

## NSI Connection Service

### Connection service concepts

The NSI Connection Service is the Network Service that manages Connections.

There is a growing requirement to integrate customized networks resources into existing grid resources pools and applications. The ability to manage network connections effectively and easily by the grid community is perhaps the most pressing driver for the OGF NSI specification effort. This particular requirement has had a significant influence on design decisions and prioritization of capabilities incorporated into the NSI Architecture.

The NSI Connection Service reserves, schedules, and instantiates Connection instances. Only single channel, unidirectional, point-to-point connections are supported in v1.0. Where bi-directional connectivity is required, two separate service requests may be submitted by the requester.

The NSI Connection Service is designed to create Connections that support a high capacity, highly asymmetric data flow such as occur in large file transfers or real-time streaming of digital media content.

Figure : Anatomy of a Connection

As illustrated in Figure 8, the Connection consists of three basic components: an ingress point where user data enters the connection, a transport section that carries the data across the network, and an egress point where user data exits the connection. The network components that present the user data to the ingress point or carry the user data away from the egress point are the access sections. The network infrastructure that carries user data from the ingress point through the network to the egress point is the transport section. The end of the transport section or the junction between the transport section and the access section is called the Service Termination Point (STP).

The user data (the “payload data”) is carried across each section of the network inside a “framing protocol”. The framing protocol, provides the necessary timing, control, and data integrity functions required to move the payload from node to node through the network. It is important to distinguish between a) the access framing protocols, b) the transport framing protocols, and c) the user payload data carried inside each of these protocols.

* *It is the user payload data stream that must be preserved from ingress to egress in a Connection.*

The transport framing can be any framing protocol as long as the end-to-end preservation requirement is honored. In fact, the only constraints on the transport framing is that the transport section be able to adapt the ingress payload data to each of the successive transport protocols that may be used along the path and ultimately be able to adapt the user payload to the egress framing at the egress point. While specification of the connection end points, access framing, and other parameters associated with a connection are defined by the connection requester (or implicitly by the service definition), the choice of the transport protocol and associated transport path parameters are explicitly delegated to the network service provider in order to allow the provider the greatest latitude in finding a valid, available, and optimal path for the connection request. This is another example of how abstraction separates the user perception of a “connection” from that of the provider. While this abstraction simplifies the service concept, the NSI Architecture allows the omniscient requester to participate in these connection planning decisions.

* *The transport section may influence the service levels as experienced by the payload data.*
* *Typically the Service Definition will allow the Requestor to specify the payload transit service levels rather than the Network-internal transport section protocols.*
* *It is the job of the local Network to decide how to fulfill these service levels by selecting the appropriate transport section protocol.*

### Service Definitions for Connection Services

The Service Definition is a set of attributes that formally and explicitly define the complete scope of a service offering. In particular, the NSI Connection Service uses the Service Definition as a baseline set of parameters to bound the scope of the service that will be offered to requesters.

The Service Definition specifies the complete set of service parameters that define a service instance. The Service Definition also describes the *range* of allowed values for each service parameter, and a default value can be specified. The parameters in the Service Definition form a kind of template that the service request must fill in. I.e. A service request must fill in the template with an explicit value - or a default value taken from the service definition - for each parameter of the service it is requesting. A service instance is then the service capability that results when all parameters of a service have been fully determined.

If a service request describes a service instance that lies within the bounds of the set of defined service parameters, then it forms a valid request. Further, by merit of the comprehensive service parameters in the Service Definition, and the instance specific parameters present in the request, the bounds of the network commitment are formalized and explicit to both the requester and the provider. This explicitly defined service commitment allows the user to verify the delivered service and determine if it is meeting the commitment. It also acts as objective criteria for determining the status of a connection: “up and available” meaning it is operating within the committed service levels, and “down” meaning the connection is not operating within the committed service level.

The service definition provides a publicly available description of the service, and should be made available in a native language document that the users can reference in developing or configuring their applications. The users should consult this service definition in order to understand what service levels are available to them within a given service offering.

It is important to stress one more aspect of a service definition; if a parameter is not identified within the service definition document, then the user can make no inference about its presence or value in the service. For instance, if a service definition has no jitter specifications, the user can make no predictions or assumptions about the jitter. And the network has made no commitments regarding jitter. A request on Monday might have excellent jitter characteristics, and the exact same request submitted Tuesday might have horrid jitter characteristics. As long as the request constraints on both requests were met, these are – from a formal service perspective – properly performing and identical service instances.

The converse is also true. The network should be very careful about how it defines service parameters. For instance, an Ethernet service may define connection capacities in “bits per second” (bps). On its face, one might construe that a 1 Gbps connection would accept bits at 1 billion bits each second measured over any one second period. However, if this 1 Gbps connection is provisioned over a 10 Gbps network link, this interpretation would allow a 100 millisecond burst at 10 Gbps followed by a 900 millisecond quiescent period. Such a burst of 125 megaBytes can easily induce buffer overruns and packet discards on interfaces along the connection path. And yet the user would have been perfectly within their performance profile. The implication here is that simple fixed capacity connections in asynchronous packet transport networks requires sophisticated and detailed planning in order to guarantee service capabilities.

The Connection Service Definition and the Connection Service Request are tightly integrated.

### The Connection Service States

The states of a connection relate to the life cycle of the connection. In the NSI, a connection goes through five phases: Reserving, Scheduled, Provisioning, In-Service, Releasing.

First, a request is submitted to a provider thus beginning the life cycle of the connection within that provider Agent’s network. This first phase is called the “Reserving” phase. It includes path selection and resource reservation. In the NSI, path selection includes future scheduling as well as the performance and authorization checking. Once the scheduling phase is complete, the Requester NSA is notified and connection goes into a “Scheduled” state.

For automatically provisioned connections, when the service start time arrives, the connection goes into a “Provisioning” phase. For signaled connections, the “Provisioning” phase is initiated by a signal from the Requester NSA. Provisioning is the process where the connection is physically instantiated by configuring each device along the path to reflect the path plan developed and reserved in the Reservation phase.

Once provisioning is complete, the connection then moves into an “In-Service” state and the user are notified that the connection is ready for use. The In-Service phase is where user data is allowed to transit the connection.

When the connection is no longer needed (or the scheduled time expires) the connection is “Releasing”. The Releasing phase is where each network along the path is informed of the Release event and resources associated with the connection are released back to the available pool. Upon entering the releasing phase, the connection will no longer pass traffic. When the Release has completed, the connection object is deleted from the Service Plane.

Figure : Connection Lifecycle

### Connection reservation messages

Advance vs. immediate reservation

The connection request can have either a start-time and end-time, or a start-time and duration.

If the connection request includes a valid start-time and an end-time then the request is considered to be an advance reservation request. If the connection request has the start-time set to ‘asap’ and has a duration field rather than an end time field, the request is considered to be an immediate reservation request.

Automatic vs. explicit provisioning mode

Provisioning of a connection is achieved using a 1 phase commit mode. The transition from Scheduled state to Provisioning state can be either explicit (i.e. signaled by the requester NSA) or automatic (i.e initiated by the provider NSA). Each connection request will include a *flag* to indicate which of these two provisioning modes is to be used. It is not possible to mix these modes in a single connection.

When operating in explicit mode, it is the responsibility of the requestor NSA to signal the reservation to begin provisioning and to begin de-provisioning of the connection. These signals are known as the ProvisionRequest and CancelRequest.

Responses to connection requests

The provider NSA will send a response back to the Requester NSA once it has completed processing a connection request. This response will send back a pass/fail response and will confirm the state of the provider NSA.

When provisioning and de-provisioning have been completed it is necessary for the provider NSA to send a notification back to the requester NSA.

As shown in Figure 4, a requester NSA first sends a ReserveRequest message to a provider NSA. The provider NSA schedules resources, and notifies the requester whether it can deliver the request. If explicit provisioning is used, the requester must send a ProvisonRequest message to the provider NSA, and the NSA then provisions a service instance. If the automatic provisioning is used, the resources are provisioned at the start time. The requester may send a CancelRequest message. A CancelRequest message received before the provisioning has begun removes the reservation from the reservation database. A CancelRequest message received after the provisioning is completed releases the provisioned resources.



Figure : Service instance lifecycle.

The phases of the connection are as follows:

P1 Reserving phase.

P2 Scheduled phase.

P3 Provisioning phase.

P4 In-service phase.

P5 Releasing Phase.

### Connection reservation and timing parameters

For advance reservation with *automatic* provisioning, the start-time refers to the time at which the connection moves from provisioning state to in-service state. It is the responsibility of the provider NSA to make sure that this in-service start time is met. This may require beginning the provisioning process in advance of the start-time and will require some knowledge of the expected provisioning time.

For advance reservation with *explicit* provisioning, the start-time refers to the time at which the provider is able to accept a provision signal. It is now the requestor’s responsibility to advance the explicit signal to ensure good in-service time. The reservation end-time refers to the time at which the reservation is removed. (If the user has not yet sent a CancelRequest signal the connection is de-provisioned first)

“Infinite” can be used as an end time. In this case, resources are reserved forever (i.e. until a release request is received or may be overwritten by policy limits). Note that the resource reserved forever cannot be used for other requests of later time.

It takes some time to process a request. Possible maximum time required to process a request and make resources ready for provisioning is called “guard time”. Each provider NSA must define its guard time and provide it to requester NSAs. A requester NSA should not request a reservation which start time is smaller (earlier) than (current time + guard time). Time required for message delivery should also be taken into account.

A flag is included to indicate whether a start-time later than specified guard is allowed. When allowed, these start times are treated as ‘now’ and warning may be sent back to the Requester NSA. Otherwise, if a provider NSA receives a reservation request which start time is before (current time + guard time), it simply denies the request (the start time is a constraint in the path finding process). Note also, that if explicit provisioning is used, the processing of a ProvisionRequest message will take some time to complete.

This system is designed to be compatible with systems based on 2PC. In a 2PC system, an additional phase exists between P2 and P3. This phase is the ‘commit’ phase. The commit phase allows the originating requestor NSA to collect reservation confirmations from child NSAs. The originating requester then sends out a commit request once all confirmations have been received. The purpose is to prevent provisioning beginning on any networks before all participating networks have confirmed their reservation. This prevents partially provisioned connections being created.

This operation can be replicated in the 1PC system defined here with the use of explicit provisioning mode. In this case the original requester may wait for all child NSAs to confirm their reservation before issuing a ProvisionRequest message. This in effect combines the commit and provision requests of the 2PC method into a single message.

### The Path Object

The “Path Object” (or Path) describes a route through the topology. When present in a Connection Request, the Path specifies an ordered set of Service Termination Points (STPs) that the connection must transit, and in the order the connection must transit them. Within a Connection Request, the Path Object, at a minimum, must specify the ingress and egress STPs for the Connection. Additional intermediate transit points may be included in the Path, and when present, they are considered a required constraint on the Connection’s route and must be honored.

A Path Object associated with a confirmed Connection contains, or references, a significant amount of information regarding the user, the source or destination of flows, the global topology, and internal detail of specific networks, etc. This Path information may pose a security or privacy issue to the user or the involved networks, or may just be considered proprietary information. Within the NSI, access to such information is considered a policy decision of each agent involved. Therefore, Path information is available to external agents via an authorized Query() primitive to the Connection Service.

The provider NSA is responsible for maintaining, among other things, a Path describing the fully specified path for any Connection reserved across its network. In order to protect the PO, the provider NSA must store the Path locally and return a redacted Path containing a list of STPs, and/or Named Path, specified in order, according to its internal authorization policies.

Since Connection Requests submitted to other NSAs may return a Path identifier rather than a Path Object itself, there must be means for distinguishing the two and a clear understanding of how a path object fits into the path algebra. Since the Connection Request segmentation processing is tree-like, it follows that the reserved Path Objects will also be tree-like. So a Path Object must be able to contain not just directly referenced STP Names, but must be able to contained Named POs as well. A Path Object then consists of a list of objects that either directly or indirectly resolve to topological points. For named POs, the NSA that owns the Named PO must also maintain authorization association(s) for the PO.

### Tree and Chain Connection modes for inter-domain pathfinding

The NSA builds connections across networks. Connections extending across multiple networks can be constructed by concatenating connections built across the individual networks. The one prerequisite for building concatenated connections is choosing appropriate STPs such that the egress STP of one connection corresponds directly with the ingress STP of the successive connection. These STPs are the inter-domain transit points between the two inter-connected networks. Note that here the term inter-network is synonymous with inter-domain.

The choice of which sequence of networks to use is a path finding function and dependent upon topology and information being available to the local pathfinder to choose a candidate inter-domain path. While the end-to-end concatenated path is not confirmed until all individual constituent connections have been reserved and confirmed, once a set of inter-domain transit points is chosen, the connection requests corresponding to each segment can be issued simultaneously and directly to the NSAs responsible for each of the corresponding networks. This is called a “Tree” model reservation process. The process can be recursively implemented in for creating multi-level trees in the Service Plane. That is, several NSAs without direct control over the NRM/networks can be deployed in a hierarchical architecture with one or more levels

Alternatively, if the local NSA does not have sufficient topology information or authorization credentials to identify and interact directly with all the downstream networks, the local NSA can simply choose a neighbor network as the next hop, and using the interconnect STP as the ingress point, forward a request to that next hop NSA for handling. This conventional hop-by-hop approach is called the “Chain” model approach.

The reservation process, in general, involves a constraint-based search of the topology for a set of contiguous resources meeting the constraints specified in the user Connection Request. As resources conforming to these constraints are identified, they are reserved in an atomic compare-reserve process. While these are, strictly speaking, part of Path finding and outside the scope of NSI, it was considered important that the Interface be able to support both styles of reservation – the former being more traditionally found in existing protocols and intra-domain topologies, and the latter providing more control to the requester regarding path selection.

Chain style processing reserves resources sequentially beginning at the source STP and working hop by hop successively through each downstream network to the destination. The path computation requires only a simple next hop reachability calculation (though more sophisticated path finders can be implemented), and no resources are reserved until the prefix path has been confirmed. It is highly distributed, scales well and is robust. But it does enforce a provider centric model that hides or delegates much (if not all) network provisioning decisions.

Figure : tree vs chain pathfinding modes.

The Tree model processing computes a course grained inter-domain path first. It uses that network path vector to decompose the connection request into several concatenated connection segments. This decomposition process, while requiring more topology information and a more sophisticated pathfinder, enables the NSA to reserve the segments in parallel via direct interaction with the respective networks. The tree model exposes many new capabilities directly to the user at the cost of significant increase in protocol and operational complexity.

In both the tree style processing and the chain style processing, the end-to-end connection cannot be confirmed until all of the constituent connection segments have been successfully reserved and confirmed. Which model will be more effective is unclear at this time and will likely be directly related to complexity of topology distribution and path analysis, robustness, authorization schemes, request volume, network diameter, utilization density, cost, ease of use, and reach (to name just a few actors.)

Both the Tree and Chain model reduce to a constraint-based search over a topology to build a k-preferred path tree. Both can accept requester guidance in path selection through the inclusion of intermediate transit points in the connection request (discussed further under Path Objects). The method, tree or chain, used to process a request is made exclusively in the requester NSA. The requesting agent implements a Tree model process by submitting individual requests for each connection segment. These individual segment requests are processed asynchronously and in parallel. The requesting agent implements a Chain model by allocating a path through the local network, and then forwarding the request to a neighbor domain to resolve the remaining downstream portion of the connection.

### The Connection Path Algebra

An algebra is a set of rules for symbolically manipulating objects. The NSI Architecture defines a *path algebra* to symbolically describe the operations performed on paths and connections. The path algebra can be used to describe how connection requests can be iteratively decomposed into component segments as the request is processed down the service tree. The path algebra insures that by choosing appropriate termination points for the component segments, that the resulting set of segments will form a single continuous data path. (In this context, it is useful to remind the reader that the NSI definition of a Connection is a single channel, unidirectional, point to point data path. A “path” then is a contiguous sequence of points and/or edges that are visited on a tour of the graph.)

Within this document, the path algebra is referenced due to its utility in discussing and analyzing the manner in which the NSI Connection Service handles connection requests. The NSI path algebra is described in more detail in Appendix A: “A Path Algebra for Describing NSI Path Operations”.

## Future Services

The NSI defines a framework that will allow future Network Services to be added. The framework is defined in such a way that allows each Network Service to be independent.

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# Glossary

Connection

A Connection is a conduit that transparently moves user information across a Network from an ingress point to an egress point. A Connection has a set of properties (for instance, capacity, or authorization, or start time).  These properties, and their allowed range of values, are defined by a service definition. A Connection instance is a particular Connection, identified by a Connection Identifier.

Connection Identifier

A Connection Identifier is a label unique to an NSI interface which can be used to identify a Connection for the purposes of request, instantiation and management.

Connection Service

A Connection Service is a service that allows a Requester NSA to request and manage a Connection from a Provider NSA

Control and Management Planes

The Control Plane and/or Management Plane are not defined in this document, but follow common usage.

Network  
A Network includes all of the transport resources that are managed by a single NSA.

Network Resource Manager (NRM)

The Network Resource Manager owns a particular set of transport resources and has ultimate responsibility for authorizing and managing the use of these resources.

Network Service

A Network Service is an abstract notion that must be implemented by a concrete network service agent (NSA). The Network Service is the service characterized by the set of functionality that is provided in an NSA.

Network Service Agent (NSA)

The Network Service Agent is a concrete piece of software that sends and receives NSI Messages.  The NSA includes a set of capabilities that allow Network Services to be delivered.

Network Service Interface (NSI)

The NSI is the interface between Requester NSAs and Provider NSAs.  The NSI defines a set of interactions or transactions between these NSAs to realize a Network Service.

NSI Message

A NSI Message is a structured unit of data sent between a Requester NSA and a Provider NSA.

Path

A Path is an ordered list of Routing Objects.

Requester/ Provider NSA

An NSA acts in one of two possible roles relative to a particular instance of an NSI.  When an NSA requests a service, it is called a Requester NSA. When an NSA realizes a service, it is called a Provider NSA.

Routing Object

A Routing Object may include the following transport resources.

Service Definition

The Service Definition is the set of attributes associated with connection services (for instance, capacity, or authorization, or start time) and a range of allowed values for these attributes. Each Connection has an associated Service Definition instance.

Service Plane

The Service Plane is a plane in which services are requested and managed; these services include the Network Service. The Service Plane contains set Network Service Agents communicating using Network Service Interfaces.

Topology Rename

The Topology resides in the Service Plane.  The Topology describes both the physical resources and their interconnection as well as the non-physical groupings of various components

Transport Plane

The Transport Plane contains is the set of physical resources that transport user data through the network.  The Transport Plane forms the substrate over which Connections are allocated and provisioned.

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