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A Framework for Enhanced Virtual Private Network (VPN+) Services
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Abstract

This document describes the framework for Enhanced Virtual Private Network (VPN+) services. The purpose of enhanced VPNs is to support the needs of new applications, particularly applications that are associated with 5G services, by utilizing an approach that is based on existing VPN and Traffic Engineering (TE) technologies and adds characteristics that specific services require over and above traditional VPNs.

Typically, VPN+ will be used to underpin network slicing, but could also be of use in its own right providing enhanced connectivity services between customer sites.

It is envisaged that enhanced VPNs will be delivered using a combination of existing, modified, and new networking technologies. This document provides an overview of relevant technologies and identifies some areas for potential new work.

Compared to traditional VPNs, it is not envisaged that large numbers of VPN+ services will be deployed in a network. In other word, it is not intended that all existing VPNs supported by a network will use VPN+ techniques.

Status of This Memo

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1. Introduction

Virtual private networks (VPNs) have served the industry well as a means of providing different groups of users with logically isolated connectivity over a common network. The common or base network that is used to provide the VPNs is often referred to as the underlay, and the VPN is often called an overlay.

Customers of a network operator may request a connectivity services with advanced characteristics such as low latency guarantees, bounded jitter, or stricter isolation from other services or customers so that changes in some other service (such as changes in network load, or events such as congestion or outages) have no or acceptable effect on the throughput or latency of the services provided to the customer. These services are referred to as "enhanced VPNs" (known as VPN+) in that they are similar to VPN services providing the customer with the required connectivity, but in addition they have enhanced characteristics.

The concept of network slicing has gained traction driven largely by needs surfacing from 5G [NGMN-NS-Concept] [TS23501] [TS28530]

[BBF-SD406]. According to [TS28530], a 5G end-to-end network slice consists of three major types network segments: Radio Access Network (RAN), Transport Network (TN), and Mobile Core Network (CN). The transport network provides the connectivity between different entities in RAN and CN segments of a 5G end-to-end network slice, with specific performance commitment.

An IETF network slice [I-D.ietf-teas-ietf-network-slice-definition] is a virtual (logical) network with its own network topology and a set of shared or dedicated network resources, which are used to provide the network slice consumer with the required connectivity, appropriate isolation, and a specific Service Level Objective (SLO). In this document (which is solely about IETF technologies) we refer to an "IETF network slice" simply as a "network slice": a network slice is considered one possible use case of an enhanced VPN.

A network slice could span multiple technologies (such as IP or Optical) and multiple administrative domains. Depending on the consumer's requirement, a network slice could be isolated from other network slices in terms of data plane, control plane, and management plane resources.

Network slicing builds on the concepts of resource management, network virtualization, and abstraction to provide performance assurance, flexibility, programmability, and modularity. It may use techniques such as Software Defined Networking (SDN) [RFC7149], network abstraction [RFC7926] and Network Function Virtualization (NFV) [RFC8172] [RFC8568] to create multiple logical (virtual) networks, each tailored for use by a set of services or by a particular tenant or a group of tenants that share the same or similar requirements. These logical networks are created on top of a common underlay network. How the network slices are engineered can be deployment-specific.

VPN+ can be used to instantiate a network slice, but the technique can also be of use in general cases to provide enhanced connectivity services between customer sites.

The requirements of enhanced VPN services cannot be met by simple overlay networks, as these services require tighter coordination and integration between the underlay and the overlay network. VPN+ is built from a VPN overlay and an underlying Virtual Transport Network (VTN) which has a customized network topology and a set of dedicated or shared resources in the underlay network. The enhanced VPN may also include a set of invoked service functions located within the underlay network. Thus, an enhanced VPN can achieve greater isolation with strict performance guarantees. These new properties,

which have general applicability, are also of interest as part of a network slicing solution.

It is not envisaged that VPN+ services will replace traditional VPN services. Traditional VPN services will continue to be delivered using pre-existing mechanisms and can co-exist with VPN+ services.

This document describes a framework for using existing, modified, and potential new technologies as components to provide a VPN+ service. Specifically, we are concerned with:

- The functional requirements and service characteristics of an enhanced VPN.
- The design of the enhanced data plane.
- The necessary protocols in both the underlay and the overlay of the enhanced VPN.
- The mechanisms to achieve integration between overlay and underlay.
- The necessary Operation, Administration, and Management (OAM) methods to instrument an enhanced VPN to make sure that the required Service Level Agreement (SLA) between the customer and the network operator is met, and to take any corrective action (such as switching traffic to an alternate path) to avoid SLA violation.

The required layered network structure to achieve this is shown in Section 4.1.

Note that, in this document, the relationship of the four terms "VPN", "VPN+", "VTN", and "Network Slice" are as follows:

- A VPN refers to the overlay network that provides the connectivity between different VPN sites, and that maintains traffic separation between different VPN customers.
- An enhanced VPN (VPN+) is an evolution of the VPN service that makes additional service-specific commitments. An enhanced VPN is made by integrating an overlay VPN with a set of network resources allocated in the underlay network.
- A VTN is a virtual underlay network that connects customer edge points. The VTN has the capability to deliver the performance characteristics required by an enhanced VPN customer and to provide isolation between separate VPN+ instances.

o A network slice could be provided by building an enhanced VPN.

2. Terminology

The following terms are used in this document. Some of them are newly defined, some others reference existing definitions.

ACTN: Abstraction and Control of Traffic Engineered Networks [RFC8453]

DetNet: Deterministic Networking. See [DETNET] and [RFC8655]

FlexE: Flexible Ethernet [FLEXE]

TSN: Time Sensitive Networking [TSN]

VN: Virtual Network [I-D.ietf-teas-actn-vn-yang]

VPN: Virtual Private Network. IPVPN is defined in [RFC2764], L2VPN is defined in [RFC4664], and L3VPN is defined in [RFC4364].

VPN+: Enhanced VPN.

VTN: Virtual Transport Network.

VTP: Virtual Transport Path. A VTP is a path through the VTN which connects two customer edge points.

3. Overview of the Requirements

This section provides an overview of the requirements of an enhanced VPN service.

3.1. Performance Guarantees

Performance guarantees are made by network operators to their customers in relation to the services provided to the customers. They are usually expressed in SLAs as a set of SLOs.

There are several kinds of performance guarantee, including guaranteed maximum packet loss, guaranteed maximum delay, and guaranteed delay variation. Note that these guarantees apply to conformance traffic, out-of-profile traffic will be handled according to a separate agreement with the customer.

Guaranteed maximum packet loss is usually addressed by setting packet priorities, queue size, and discard policy. However this becomes more difficult when the requirement is combined with latency

requirements. The limiting case is zero congestion loss, and that is the goal of DetNet [DETNET] and TSN [TSN]. In modern optical networks, loss due to transmission errors already approaches zero, but there is the possibilities of failure of the interface or the fiber itself. This type of fault can only be addressed by some form of signal duplication and transmission over diverse paths.

Guaranteed maximum latency is required by a number of applications particularly real-time control applications and some types of virtual reality applications. DetNet [DETNET] is relevant, however additional methods of enhancing the underlay to better support the delay guarantees may be needed, and these methods will need to be integrated with the overall service provisioning mechanisms.

Guaranteed maximum delay variation is a performance guarantee that may also be needed. [RFC8578] calls up a number of cases where that need this guarantee, for example in electrical utilities. Time transfer is an example service that needs a performance guarantee, although it is in the nature of time that the service might be delivered by the underlay as a shared service and not provided through different enhanced VPNs. Alternatively, a dedicated enhanced VPN might be used to provide this as a shared service.

This suggests that a spectrum of service guarantees need to be considered when deploying an enhanced VPN. As a guide to understanding the design requirements we can consider four types of service:

- Best effort
- Assured bandwidth
- Guaranteed latency
- Enhanced delivery

The best effort service is the basic service as provided by current VPNs.

An assured bandwidth service is one in which the bandwidth over some period of time is assured. This can be achieved either simply based on a best effort service with over-capacity provisioning, or it can be based on MPLS traffic engineered label switching paths (TE-LSPs) with bandwidth reservations. Depending on the technique used, however, the bandwidth is not necessarily assured at any instant. Providing assured bandwidth to VPNs, for example by using per-VPN TE-LSPs, is not widely deployed at least partially due to scalability

concerns. VPN+ aims to provide a more scalable approach for such services.

A guaranteed latency service has an upper bound to edge-to-edge latency. Assuring the upper bound is sometimes more important than minimizing latency. There are several new technologies that provide some assistance with this performance guarantee. Firstly, the IEEE TSN project introduces the concept of scheduling of delay- and loss-sensitive packets. The DetNet work is also of relevance in assuring an upper bound of end-to-end packet latency. FlexE is also useful to help provide these guarantees. The use of such underlying technologies to deliver VPN+ services needs to be considered.

An enhanced delivery service is one in which the underlay network (at Layer 3) attempts to deliver the packet through multiple paths in the hope of eliminating packet loss due to equipment or media failures. Such a mechanism may need to be used for VPN+ service.

3.2. Isolation between Enhanced VPN Services

One element of the SLA demanded for an enhanced VPN may be a guarantee that the service offered to the customer will not be affected by any other traffic flows in the network. This is termed "isolation" and a customer may express the requirement for isolation as an SLO.

One way for a network operator to meet the requirement for isolation is simply by setting and conforming to other SLOs. For example, traffic congestion (interference from other services) might impact on the latency experienced by a VPN+ customer. Thus, in this example, conformance to a latency SLO would be the primary requirement for delivery of the VPN+ service, and isolation from other services might be only a means to that end.

Another way for a service provider to meet this SLA is to control the degree to which traffic from one service is isolated from other services in the network. There are different grades of how isolation may be enabled by a network operator and this may result in different levels of service perceived by the customer. These range from simple separation of service traffic on delivery (ensuring that traffic is not delivered to the wrong customer, which is a basic requirement of all existing VPN services), all the way to complete separation within the underlay so that the traffic from different services use distinct network resources.

There is a fine distinction between how isolation is requested by a customer and how it is delivered by the service provider. In general, the customer is interested in service performance and not

how it is delivered. Thus, for example, the customer wants specific quality guarantees and is not concerned about how the service provider delivers them. However, it should be noted that some aspects of isolation may be directly measurable by a customer if they have information about the traffic patterns on a number services supported by the same service provider. Furthermore, a customer may be nervous about disruption caused by other services, contamination by other traffic, or delivery of their traffic to the wrong destinations. In this way, the customer may want to specify (and pay for!) the level of isolation provided by the service provider.

Delivery of isolation is achieved in the realization of a VPN+ through existing technologies that may be supplemented by future mechanisms. The service provider chooses which processes to use to deliver this service requirement just as they choose how to meet all other SLOs. Isolation may be achieved in the underlying network by various forms of resource partitioning ranging from dedicated allocation of resources for a specific enhanced VPN, to sharing of resources with some form of safeguards. For example, interference avoidance may be achieved by network capacity planning, allocating dedicated network resources, traffic policing or shaping, prioritizing in using shared network resources, etc.

The terms hard and soft isolation are used to indicate different levels of isolation. A VPN has soft isolation if the traffic of one VPN cannot be received by the customers of another VPN. Both IP and MPLS VPNs are examples of VPNs with soft isolation: the network delivers the traffic only to the required VPN endpoints. However, with soft isolation, as the network resources are shared, traffic from VPNs and regular non-VPN traffic may congest the network resulting in packet loss and delay for other VPNs. The ability for a VPN service or a group of VPN services to be sheltered from this effect is called hard isolation. Hard isolation may be needed so that applications with exacting requirements can function correctly, despite other demands (perhaps a burst of traffic in another VPN) competing for the underlying resources. An operator may offer its customers a choice of different degrees of isolation ranging from soft isolation to hard isolation. In practice isolation may be offered as a spectrum between soft and hard, and in some cases soft and hard isolation may be used in a hierarchical manner with one enhanced VPN being built on another.

An example of the requirement for hard isolation is a network supporting both emergency services and public broadband multi-media services. During a major incident, the VPNs supporting these services would both be expected to experience high data volumes, and it is important that both make progress in the transmission of their data. In these circumstances the VPN services would require an

appropriate degree of isolation to be able to continue to operate acceptably. On the other hand, VPNs servicing ordinary bulk data may expect to contest for network resources and queue packets so that traffic is delivered within SLAs, but with some potential delays and interference. While the VPN for the emergency service could be provided by specifying hard SLOs (for bandwidth, latency, etc.) the customer may feel more comfortable with an SLO that specifies hard isolation, and the service provider may decided that the best way to ensure that the SLA is met is to utilize hard isolation.

To provide the required level of isolation, resources may need to be reserved in the data plane of the underlay network and dedicated to traffic from a specific VPN or a specific group of VPNs to form different enhanced VPNs in the network. This may introduce scalability concerns, thus some trade-off needs to be considered to provide the required isolation between some enhanced VPNs while still allowing reasonable sharing.

An optical underlay can offer a high degree of isolation, at the cost of allocating resources on a long term and end-to-end basis. On the other hand, where adequate isolation can be achieved at the packet layer, this permits the resources to be shared amongst a group of services and only dedicated to a service on a temporary basis.

There are also several new technologies that provide some assistance with these data plane issues. Firstly, there is the IEEE's TSN project which introduces the concept of packet scheduling of delay and loss sensitive packets. Then there is FlexE which provides the ability to multiplex multiple channels over one or more Ethernet links in a way that provides hard isolation. Finally, there are advanced queuing approaches which allow the construction of virtual sub-interfaces, each of which is provided with dedicated resource in a shared physical interface. These approaches are described in more detail later in this document.

The next section explores a pragmatic approach to isolation in packet networks.

3.2.1. A Pragmatic Approach to Isolation

A key question is whether it is possible to achieve hard isolation in packet networks that were designed to provide statistical multiplexing through sharing of data plane resources, a significant economic advantage when compared to a dedicated, or a Time Division Multiplexing (TDM) network. Clearly, there is no need to provide more isolation than is required by the applications, and an approximation to full hard isolation is sufficient in most cases.

For example, pseudowires [RFC3985] emulate services that would have had hard isolation in their native form.

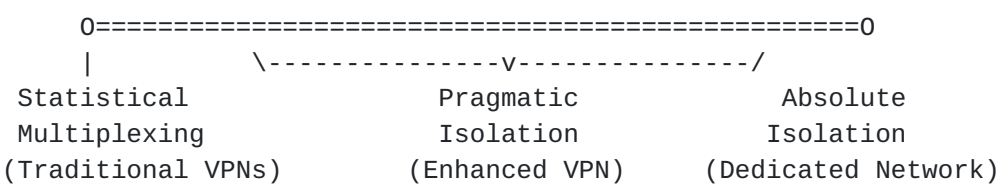


Figure 1: The Spectrum of Isolation

Figure 1 shows a spectrum of isolation that may be delivered by a network. At one end of the spectrum, we see statistical multiplexing technologies that support traditional VPNs. This is a service type that has served the industry well and will continue to do so. At the opposite end of the spectrum, we have the absolute isolation provided by dedicated transport networks. The goal of enhanced VPNs is "pragmatic isolation". This is isolation that is better than what is obtainable from pure statistical multiplexing, more cost effective and flexible than a dedicated network, but is a practical solution that is good enough for the majority of applications. Mechanisms for both soft isolation and hard isolation would be needed to meet different levels of service requirement.

3.3. Integration

The way to achieve the characteristics demanded by an enhanced VPN (such as guaranteed or predictable performance) is by integrating the overlay VPN with a particular set of resources in the underlay network which are allocated to meet the service requirement. This needs be done in a flexible and scalable way so that it can be widely deployed in operators' networks to support a reasonable number of enhanced VPN customers.

Taking mobile networks and in particular 5G into consideration, the integration of the network with service functions is likely a requirement. The IETF's work on service function chaining (SFC) [SFC] provides a foundation for this. Service functions can be considered as part of enhanced VPN services. The detailed mechanisms about the integration between service functions and enhanced VPNs are out of the scope of this document.

3.3.1. Abstraction

Integration of the overlay VPN and the underlay network resources does not need to be a tight mapping. As described in [RFC7926], abstraction is the process of applying policy to a set of information

about a traffic engineered (TE) network to produce selective information that represents the potential ability to connect across the network. The process of abstraction presents the connectivity graph in a way that is independent of the underlying network technologies, capabilities, and topology so that the graph can be used to plan and deliver network services in a uniform way.

Virtual networks can be built on top of an abstracted topology that represents the connectivity capabilities of the underlay network as described in the framework for Abstraction and Control of TE Networks (ACTN) [RFC8453] as discussed further in Section 5.5. [I-D.king-teas-applicability-actn-slicing] describes the applicability of ACTN to network slicing and is, therefore, relevant to the consideration of using ACTN to enable enhanced VPNs.

3.4. Dynamic Changes

Enhanced VPNs need to be created, modified, and removed from the network according to service demand. An enhanced VPN that requires hard isolation (Section 3.2) must not be disrupted by the instantiation or modification of another enhanced VPN. Determining whether modification of an enhanced VPN can be disruptive to that VPN, and whether the traffic in flight will be disrupted can be a difficult problem.

The data plane aspects of this problem are discussed further in Section 5.1,Section 5.2, and Section 5.3.

The control plane aspects of this problem are discussed further in Section 5.4.

The management plane aspects of this problem are discussed further in Section 5.5.

Dynamic changes both to the VPN and to the underlay transport network need to be managed to avoid disruption to services that are sensitive to changes in network performance.

In addition to non-disruptively managing the network during changes such as the inclusion of a new VPN endpoint or a change to a link, VPN traffic might need to be moved because of changes to traffic patterns and volumes.

3.5. Customized Control

In some cases it is desirable that an enhanced VPN has a customized control plane, so that the customer of the enhanced VPN can have some control over how the resources allocated to this enhanced VPN are

used. For example, the customer may be able to specify the service paths in their own enhanced VPN. Depending on the requirements, an enhanced VPN may have its own dedicated controller, which may be provided with an interface to the control system run by the network operator. Note that such control is within the scope of the tenant's enhanced VPN: any additional changes beyond this would require some intervention by the network operator.

A description of the control plane aspects of this problem are discussed further in Section 5.4. A description of the management plane aspects of this feature can be found in Section 5.5.

3.6. Applicability

The concept of an enhanced VPN can be applied to any pre-existing VPN overlay services including:

- Layer-2 point-to-point services such as pseudowires [RFC3985]
- Layer-2 VPNs [RFC4664]
- Ethernet VPNs [RFC7209]
- Layer-3 VPNs [RFC4364], [RFC2764]

Where such VPN service types need enhanced isolation and delivery characteristics, the technologies described in Section 5 can be used to provide an underlay with the required enhanced performance.

3.7. Inter-Domain and Inter-Layer Network

In some scenarios, an enhanced VPN service may span multiple network domains. A domain is considered to be any collection of network elements within a common realm of address space or path computation responsibility [RFC5151] for example, an Autonomous System. In some domains the network operator may manage a multi- layered network, for example, a packet network over an optical network. When enhanced VPNs are provisioned in such network scenarios, the technologies used in different network planes (data plane, control plane, and management plane) need to provide mechanisms to support multi-domain and multi-layer coordination and integration, so as to provide the required service characteristics for different enhanced VPNs, and improve network efficiency and operational simplicity.

4. Architecture of Enhanced VPNs

A number of enhanced VPN services will typically be provided by a common network infrastructure. Each enhanced VPN consists of both the overlay and a VTN with a specific set of network resources and service functions allocated in the underlay to satisfy the needs of the VPN customer. The integration between overlay and various underlay resources ensures the required isolation between different enhanced VPNs, and achieves the guaranteed performance for different services.

An enhanced VPN needs to be designed with consideration given to:

- An enhanced data plane.
- A control plane to create enhanced VPNs, making use of the data plane isolation and performance guarantee techniques.
- A management plane for enhanced VPN service life-cycle management.

These topics are expanded below:

- Enhanced data plane
  - Provides the required resource isolation capability, e.g. bandwidth guarantee.
  - Provides the required packet latency and jitter characteristics.
  - Provides the required packet loss characteristics.
  - Provides the mechanism to associate a packet with the set of resources allocated to the enhanced VPN to which the packet belongs.
- Control plane
  - Collects information about the underlying network topology and available resources, and exports this to nodes in the network and/or a centralized controller as required.
  - Creates the required VTNs with the resources and properties needed by the enhanced VPN services that are they support.
  - Determines the risk of SLA violation and takes appropriate avoiding action.

    * Determines the right balance of per-packet and per-node state according to the needs of the enhanced VPN services to scale to the required size.

- Management plane

    * Provides an interface between the enhanced VPN provider (e.g., operator's network management system) and the enhanced VPN clients (e.g. a customer or service with enhanced VPN requirement) such that some of the operation requests can be met without interfering with the enhanced VPN of other clients.

    * Provides an interface between the enhanced VPN provider and the enhanced VPN clients to expose the network capability information toward the enhanced VPN client.

    * Provides the service life-cycle management and operation of enhanced VPNs (e.g., creation, modification, assurance/ monitoring, and decommissioning).

- Operations, Administration, and Maintenance (OAM)

    * Provides the OAM tools to verify the connectivity and performance of the enhanced VPN.

    * Provide the OAM tools to verify whether the underlay network resources are correctly allocated and operated properly.

- Telemetry

    * Provides the mechanisms to collect network information about the operation of the data plane, control plane, and management plane. More specifically:

        + Provides the mechanisms to collect network data from the underlay network for overall performance evaluation and for planning enhanced VPN services.

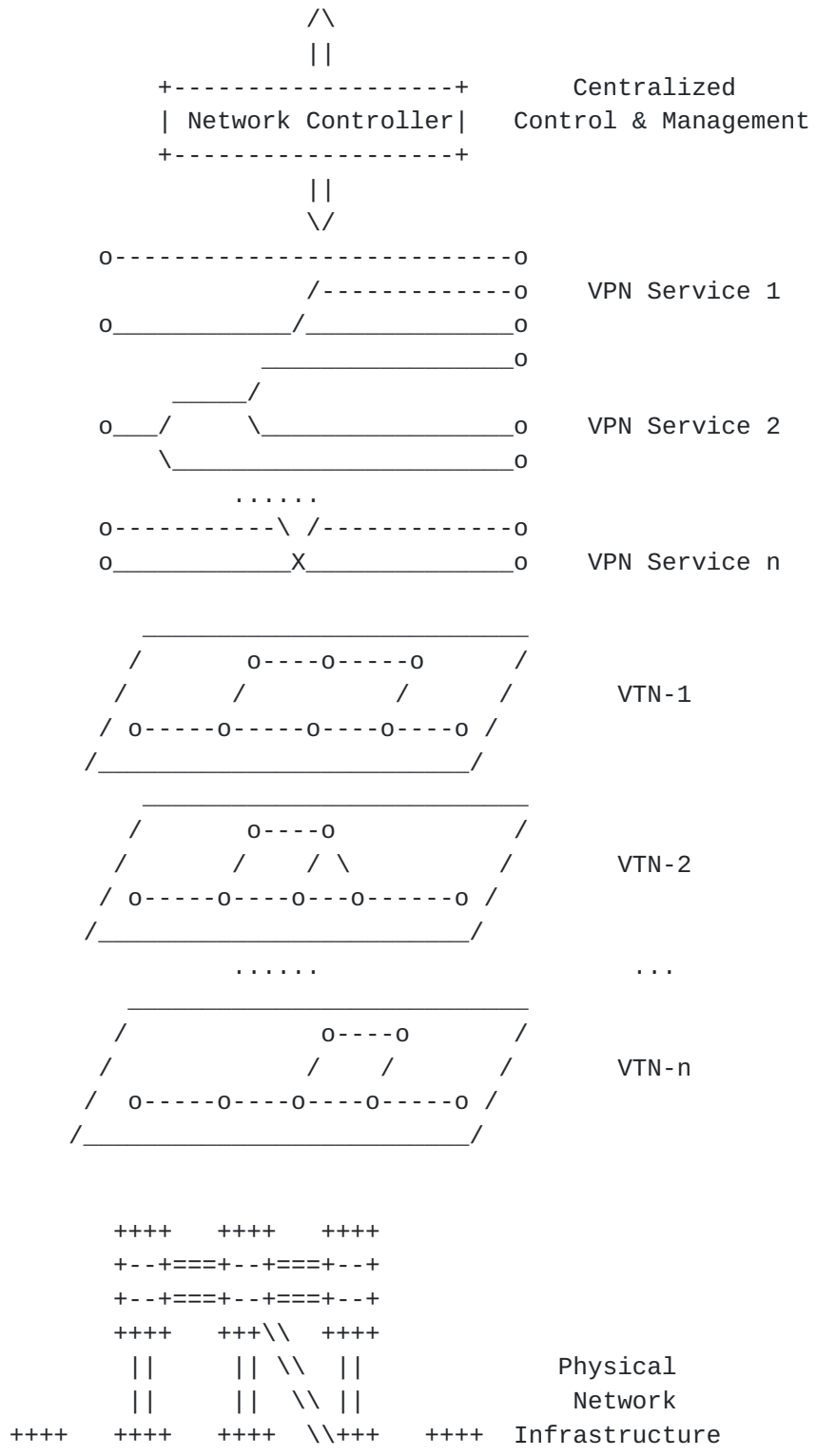
        + Provides the mechanisms to collect network data for each enhanced VPN and for monitoring and analytics of the characteristics and SLA fulfillment of enhanced VPN service.

4.1. Layered Architecture

The layered architecture of an enhanced VPN is shown in Figure 2.

Underpinning everything is the physical network infrastructure layer which provide the underlying resources used to provision the

separated virtual transport networks (VTNs). This includes the partitioning of link and/or node resources. Each subset of link or node resource can be considered as a virtual link or virtual node used to build the VTNs.



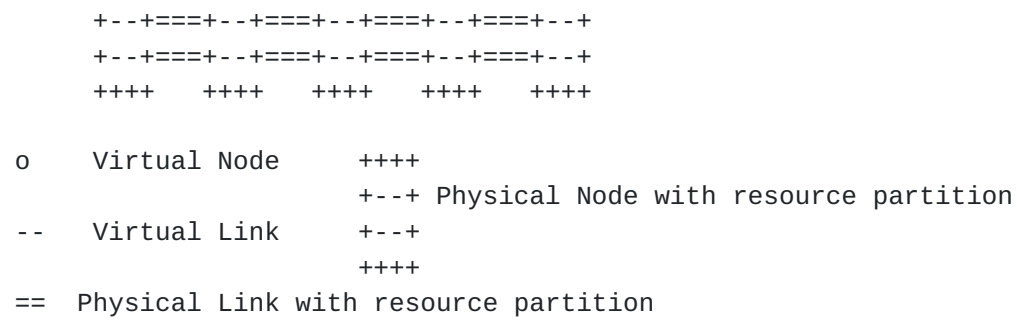


Figure 2: The Layered Architecture of VPN+

Various components and techniques discussed in Section 5 can be used to enable resource partitioning, such as FlexE, TSN, DetNet, dedicated queues, etc. These partitions may be physical or virtual so long as the SLA required by the higher layers is met.

Based on the network resources provided by the physical network infrastructure, multiple VTNs can be provisioned, each with customized topology and other attributes to meet the requirement of different enhanced VPNs or different groups of enhanced VPNs. To get the required characteristic, each VTN needs to be mapped to a set of network nodes and links in the network infrastructure. And on each node or link, the VTN is associated with a set of resources which are allocated for the processing of traffic in the VTN. VTN provides the integration between the virtual network topology and the required underlying network resources. The VTN is an essential scaling technique, as it has the potential of eliminating per-path state from the network. In addition, when a group of enhanced VPNs is supported by a single VTN, there is need only to maintain network state for the single VTN (see Section 4.4 for more information).

The centralized network controller is used to create the VTN, and to instruct the network nodes to allocate the required resources to each VTN and to provision the enhanced VPN services on the VTNs. A distributed control plane may also be used for the distribution of the VTN topology and attribute information between nodes within the VTNs.

The process used to create VTNs and to allocate network resources for use by VTNs needs to take a holistic view of the needs of all of its tenants (i.e., of all customers and their associated enhanced VPNs), and to partition the resources accordingly. However, within a VTN these resources can, if required, be managed via a dynamic control plane. This provides the required scalability and isolation.

4.2. Multi-Point to Multi-Point (MP2MP) Connectivity

At the VPN service level, the required connectivity for an MP2MP service is usually full or partial mesh. To support such VPN services, the corresponding VTN connectivity also needs to have an abstracted MP2MP connectivity.

Other service requirements may be expressed at different granularities, some of which can be applicable to the whole service, while some others may only be applicable to some pairs of end points. For example, when a particular level of performance guarantee is required, the point-to-point path through the underlay of the enhanced VPN may need to be specifically engineered to meet the required performance guarantee.

4.3. Application Specific Data Types

Although a lot of the traffic that will be carried over the enhanced VPN will likely be IPv4 or IPv6, the design must be capable of carrying other traffic types, in particular Ethernet traffic. This is easily accomplished through the various pseudowire (PW) techniques [RFC3985]. Where the underlay is MPLS, Ethernet can be carried over the enhanced VPN encapsulated according to the method specified in [RFC4448]. Where the underlay is IP, Layer Two Tunneling Protocol - Version 3 (L2TPv3) [RFC3931] can be used with Ethernet traffic carried according to [RFC4719]. Encapsulations have been defined for most of the common Layer-2 types for both PW over MPLS and for L2TPv3.

4.4. Scaling Considerations

VPNs are instantiated as overlays on top of an operator's network and offered as services to the operator's customers. An important feature of overlays is that they can deliver services without placing per-service state in the core of the underlay network.

Enhanced VPNs may need to install some additional state within the network to achieve the features that they require. Solutions must consider minimizing and controlling the scale of such state, and deployment architectures should constrain the number of enhanced VPNs that would exist where such services would place additional state in the network. It is expected that the number of enhanced VPNs will be small at the beginning, and even in future the number of enhanced VPNs will be much fewer than traditional VPNs because pre-existing VPN techniques are good enough to meet the needs of most existing VPN-type services.

In general, it is not required that the state in the network be maintained in a 1:1 relationship with the VPN+ services. It will usually be possible to aggregate a set or group of VPN+ services so that they share the same VTN and the same set of network resources (much in the same way that current VPNs are aggregated over transport tunnels) so that collections of enhanced VPNs that require the same behavior from the network in terms of resource reservation, latency bounds, resiliency, etc. can be grouped together. This is an important feature to assist with the scaling characteristics of VPN+ deployments.

[I-D.dong-teas-enhanced-vpn-vtn-scalability] provides more details of scalability considerations for enhanced VPNs, and Section 6 includes a greater discussion of scalability considerations.

5. Candidate Technologies

A VPN is a network created by applying a demultiplexing technique to the underlying network (the underlay) to distinguish the traffic of one VPN from that of another. A VPN path that travels by other than the shortest path through the underlay normally requires state in the underlay to specify that path. State is normally applied to the underlay through the use of the RSVP-TE signaling protocol, or directly through the use of an SDN controller, although other techniques may emerge as this problem is studied. This state gets harder to manage as the number of VPN paths increases. Furthermore, as we increase the coupling between the underlay and the overlay to support the enhanced VPN service, this state will increase further.

In an enhanced VPN, different subsets of the underlay resources can be dedicated to different enhanced VPNs or different groups of enhanced VPNs. Thus, an enhanced VPN solution needs tighter coupling with the underlay than is the case with existing VPN techniques. We cannot, for example, share the network resource between enhanced VPNs which require hard isolation.

5.1. Layer-Two Data Plane

Several candidate Layer 2 packet- or frame-based data plane solutions which can be used provide the required isolation and guarantees are described in the following sections.

5.1.1. Flexible Ethernet

FlexE [FLEXE] provides the ability to multiplex channels over an Ethernet link to create point-to-point fixed- bandwidth connections in a way that provides hard isolation. FlexE also supports bonding links to create larger links out of multiple low capacity links.

However, FlexE is only a link level technology. When packets are received by the downstream node, they need to be processed in a way that preserves that isolation in the downstream node. This in turn requires a queuing and forwarding implementation that preserves the end-to-end isolation.

If different FlexE channels are used for different services, then no sharing is possible between the FlexE channels. This means that it may be difficult to dynamically redistribute unused bandwidth to lower priority services in another FlexE channel. If one FlexE channel is used by one customer, the customer can use some methods to manage the relative priority of their own traffic in the FlexE channel.

5.1.2. Dedicated Queues

DiffServ based queuing systems are described in [RFC2475] and [RFC4594]. This approach is not sufficient to provide isolation for enhanced VPNs because DiffServ does not provide enough markers to differentiate between traffic of a large number of enhanced VPNs. Nor does DiffServ offer the range of service classes that each VPN needs to provide to its tenants. This problem is particularly acute with an MPLS underlay, because MPLS only provides eight traffic classes.

In addition, DiffServ, as currently implemented, mainly provides per-hop priority-based scheduling, and it is difficult to use it to achieve quantitative resource reservation.

To address these problems and to reduce the potential interference between enhanced VPNs, it would be necessary to steer traffic to dedicated input and output queues per enhanced VPN: some routers have a large number of queues and sophisticated queuing systems which could support this, while some routers may struggle to provide the granularity and level of isolation required by the applications of enhanced VPN.

5.1.3. Time Sensitive Networking

Time Sensitive Networking (TSN) [TSN] is an IEEE project to provide a method of carrying time sensitive information over Ethernet. It introduces the concept of packet scheduling where a packet stream may be given a time slot guaranteeing that it experiences no queuing delay or increase in latency beyond the very small scheduling delay. The mechanisms defined in TSN can be used to meet the requirements of time sensitive services of an enhanced VPN.

Ethernet can be emulated over a Layer 3 network using an IP or MPLS pseudowire. However, a TSN Ethernet payload would be opaque to the underlay and thus not treated specifically as time sensitive data. The preferred method of carrying TSN over a Layer 3 network is through the use of deterministic networking as explained in Section 5.2.1.

5.2. Layer-Three Data Plane

This section considers the problem of enhanced VPN differentiation and resource representation in the network layer.

5.2.1. Deterministic Networking

Deterministic Networking (DetNet) [RFC8655] is a technique being developed in the IETF to enhance the ability of Layer-3 networks to deliver packets more reliably and with greater control over the delay. The design cannot use re-transmission techniques such as TCP since that can exceed the delay tolerated by the applications. Even the delay improvements that are achieved with Stream Control Transmission Protocol Partial Reliability Extension (SCTP-PR) [RFC3758] may not meet the bounds set by application demands. DetNet pre-emptively sends copies of the packet over various paths to minimize the chance of all copies of a packet being lost. It also seeks to set an upper bound on latency, but the goal is not to minimize latency.

5.2.2. MPLS Traffic Engineering (MPLS-TE)

MPLS-TE [RFC2702][RFC3209] introduces the concept of reserving end-to-end bandwidth for a TE-LSP, which can be used to provide a point-to-point Virtual Transport Path (VTP) across the underlay network to support VPNs. VPN traffic can be carried over dedicated TE-LSPs to provide reserved bandwidth for each specific connection in a VPN, and VPNs with similar behavior requirements may be multiplexed onto the same TE-LSPs. Some network operators have concerns about the scalability and management overhead of MPLS-TE system especially with regard to those systems that use an active control plane, and this has lead them to consider other solutions for their networks.

5.2.3. Segment Routing

Segment Routing (SR) [RFC8402] is a method that prepends instructions to packets at the head-end of a path. These instructions are used to specify the nodes and links to be traversed, and allow the packets to be routed on paths other than the shortest path. By encoding the state in the packet, per-path state is transitioned out of the network.

An SR traffic engineered path operates with a granularity of a link. Hints about priority provided using the Traffic Class (TC) or Differentiated Services Code Point (DSCP) field in the header. However, to achieve the latency and isolation characteristics that are sought by enhanced VPN customers, it will probably be necessary to steer packets through specific virtual links and/or queues on the same link and direct them to use specific resources. With SR, it is possible to introduce such fine-grained packet steering by specifying the queues and resources through an SR instruction list.

Note that the concept of a queue is a useful abstraction for different types of underlay mechanism that may be used to provide enhanced isolation and latency support. How the queue satisfies the requirement is implementation specific and is transparent to the layer-3 data plane and control plane mechanisms used.

With Segment Routing, the SR instruction list could be used to build a P2P path, and a group of SR SIDs could also be used to represent an MP2MP network. Thus, the SR based mechanism could be used to provide both a Virtual Transport Path (VTP) and a Virtual Transport Network (VTN) for enhanced VPN services.

5.3. Non-Packet Data Plane

Non-packet underlay data plane technologies often have TE properties and behaviors, and meet many of the key requirements in particular for bandwidth guarantees, traffic isolation (with physical isolation often being an integral part of the technology), highly predictable latency and jitter characteristics, measurable loss characteristics, and ease of identification of flows. The cost is that the resources are allocated on a long-term and end-to-end basis. Such an arrangement means that the full cost of the resources has be borne by the service that is allocated with the resources.

5.4. Control Plane

An enhanced VPN would likely be based on a hybrid control mechanism that takes advantage of the logically centralized controller for on-demand provisioning and global optimization, whilst still relying on a distributed control plane to provide scalability, high reliability, fast reaction, automatic failure recovery, etc. Extension to and optimization of the centralized and distributed control plane is needed to support the enhanced properties of VPN+.

RSVP-TE [RFC3209] provides the signaling mechanism for establishing a TE-LSP in an MPLS network with end-to-end resource reservation. This can be seen as an approach of providing a Virtual Transport Path (VTP) which could be used to bind the VPN to specific network

resources allocated within the underlay, but there remain scalability concerns as mentioned in Section 5.2.2.

The control plane of SR [RFC8665] [RFC8667] [I-D.ietf-idr-bgp-ls-segment-routing-ext] does not have the capability of signaling resource reservations along the path. On the other hand, the SR approach provides a potential way of binding the underlay network resource and the enhanced VPN service without requiring per-path state to be maintained in the network. A centralized controller can perform resource planning and reservation for enhanced VPNs, while it needs to ensure that resources are correctly allocated in network nodes for the enhanced VPN service. The controller could also compute the SR paths based on the planned or collected network resource and other attributes, and provision the SR paths based on the mechanism in [I-D.ietf-spring-segment-routing-policy] to the ingress nodes of the enhanced VPN services. The distributed control plane may be used to advertise the network attributes associated with enhanced VPNs, and compute the SR paths with specific constraints of enhanced VPN services.

5.5. Management Plane

The management plane provides the interface between the enhanced VPN provider and the clients for life-cycle management of the service (i.e., creation, modification, assurance/monitoring and decommissioning). It relies on a set of service data models for the description of the information and operations needed on the interface.

As an example, in the context of 5G end-to-end network slicing [TS28530], the management of enhanced VPNs is considered as the management of the transport network part of the 5G end-to-end network slice. The 3GPP management system may provide the connectivity and performance related parameters as requirements to the management plane of the transport network. It may also require the transport network to expose the capabilities and status of the network slice. Thus, an interface between the enhanced VPN management plane and the 5G network slice management system, and relevant service data models are needed for the coordination of 5G end-to-end network slice management.

The management plane interface and data models for enhanced VPN can be based on the service models described in Section 5.6.

It is important that the management life-cycle supports in-place modification of enhanced VPNs. That is, it should be possible to add and remove end points, as well as to change the requested

characteristics of the service that is delivered. The management system needs to be able to assess the revised VPN+ requests and determine whether they can be provided by the existing VTN or whether changes must be made, and it will additionally need to determine whether those changes to the VTN are possible. If not, then the customer's modification request may be rejected.

When the modification of an enhanced VPN is possible, the management system should make every effort to make the changes in a non-disruptive way. That is, the modification of the enhanced VPN or the underlying VTN should not perturbate traffic on the enhanced VPN in a way that causes the service level to drop below the agreed levels. Furthermore, in the spirit of isolation, changes to one enhanced VPN should not cause disruption to other enhanced VPNs.

The network operator for the underlay network (i.e., the provider of the enhanced VPN) may delegate some operational aspects of the enhanced VPN to the tenant (the VPN+ customer). In this way, the VPN+ is presented to the customer as a virtual network, and the customer can choose how to use that network. The customer cannot exceed the capabilities of virtual links and nodes, but can decide how to load traffic onto the network, for example, by assigning different metrics to the virtual links so that the customer can control how traffic is routed through the overlay. This approach requires a management system for the overlay network, but does not necessarily require any coordination between the underlay and overlay management systems, except that the overlay management system might notice when the enhanced VPN network is close to capacity or considerably under-used and automatically request changes in the service provided by the underlay.

5.6. Applicability of Service Data Models to Enhanced VPN

This section describes the applicability of the existing and in-progress service data models to enhanced VPN. New service models may also be introduced for some of the required management functions.

The ACTN framework[RFC8453] supports operators in viewing and controlling different domains and presenting virtualized networks to their customers. It highlights how:

- Abstraction of the underlying network resources is provided to higher-layer applications and customers.

- Underlying resources are virtualized and allocated for the customer, application, or service.

- o A virtualized environment is created allowing operators to view and control multi-domain networks as a single virtualized network.

- o Networks can be presented to customers as a virtual network via open and programmable interfaces.

The type of network virtualization enabled by ACTN managed infrastructure provides customers and applications (tenants) with the capability to utilize and independently control allocated virtual network resources as if they were physically their own resources. Service Data models are used to represent, monitor, and manage the virtual networks and services enabled by ACTN. The Customer VPN model (e.g. L3SM [RFC8299], L2SM [RFC8466]) or an ACTN Virtual Network (VN) [I-D.ietf-teas-actn-vn-yang] model is a customer view of the ACTN managed infrastructure, and is presented by the ACTN provider as a set of abstracted services or resources. The L3VPN network model [I-D.ietf-opsawg-l3sm-l3nm] and L2VPN network model [I-D.ietf-opsawg-l2nm] provide a network view of the ACTN managed infrastructure presented by the ACTN provider as a set of virtual networks and the associated resources.

[I-D.king-teas-applicability-actn-slicing] discusses the applicability of the ACTN approach in the context of network slicing. Since there is a strong correlation between network slices and enhanced VPNs, that document can also give guidance on how ACTN can be applied to enhanced VPNs.

5.6.1. An Example of Enhanced VPN Delivery

One typical use case of enhanced VPN is to instantiate a network slice. In order to provide network slices to customers, a technology-agnostic network slice Northbound Interface (NBI) data model may be needed for the customers to communicate the requirements and operations of network slices. These requirements may then be realized using technology-specific Southbound Interface (SBI) to instruct the network to instantiate an enhanced VPN service to meet the requirements of the customer.

As per [RFC8453] and [I-D.ietf-teas-actn-yang], the CNC-MDSC Interface (CMI) of ACTN can be used to convey the virtual network service requirements, which is a generic interface to deliver various TE based VN services. In the context of the network slice NBI, there may be some gaps in the combination of the L3SM/L2SM and VN models. The NBI is required to communicate the connectivity of the network slice, along with the SLO parameters and traffic selection rules, and provides a way to monitor the state of the network slice. This can be described in a more abstract manner, so as to reduce the association with specific technologies used to realize the network

slice, such as the VPN and TE technologies. The network slice NBI model as defined in [I-D.wd-teas-ietf-network-slice-nbi-yang] provides an abstract and generic approach to provide the network slice NBI functions.

The MDSC-PNC Interface (MPI) models in the ACTN architecture can be used for the realization of network slices, for example, in a TE enabled network, and may also be used for cross-layer or cross-domain implementation of network slice.

6. Scalability Considerations

An enhanced VPN provides performance guaranteed services in packet networks, but with the potential cost of introducing additional state into the network. There are at least three ways that this additional state might be present in the network:

- Introduce the complete state into the packet, as is done in SR. This allows the controller to specify the detailed series of forwarding and processing instructions for the packet as it transits the network. The cost of this is an increase in the packet header size. The cost is also that systems will have capabilities enabled in case they are called upon by a service. This is a type of latent state, and increases as we more precisely specify the path and resources that need to be exclusively available to a VPN.

- Introduce the state to the network. This is normally done by creating a path using RSVP-TE, which can be extended to introduce any element that needs to be specified along the path, for example explicitly specifying queuing policy. It is possible to use other methods to introduce path state, such as via an SDN controller, or possibly by modifying a routing protocol. With this approach there is state per path: per path characteristic that needs to be maintained over its life cycle. This is more network state than is needed using SR, but the packets are shorter.

- Provide a hybrid approach. One example is based on using binding SIDs [RFC8402] to create path fragments, and bind them together with SR. Dynamic creation of a VPN service path using SR requires less state maintenance in the network core at the expense of larger packet headers. The packet size can be lower if a form of loose source routing is used (using a few nodal SIDs), and it will be lower if no specific functions or resources on the routers are specified.

Reducing the state in the network is important to enhanced VPN, as it requires the overlay to be more closely integrated with the underlay

than with traditional VPNs. This tighter coupling would normally mean that more state needs to be created and maintained in the network, as the state about fine granularity processing would need to be loaded and maintained in the routers. However, an SR approach allows much of this state to be spread amongst the network ingress nodes, and transiently carried in the packets as SIDs.

Further discussion of the scalability considerations of enhanced VPNs can be found in [I-D.dong-teas-enhanced-vpn-vtn-scalability].

6.1. Maximum Stack Depth of SR

One of the challenges with SR is the stack depth that nodes are able to impose on packets [RFC8491]. This leads to a difficult balance between adding state to the network and minimizing stack depth, or minimizing state and increasing the stack depth.

6.2. RSVP-TE Scalability

The traditional method of creating a resource allocated path through an MPLS network is to use the RSVP-TE protocol. However, there have been concerns that this requires significant continuous state maintenance in the network. Work to improve the scalability of RSVP-TE LSPs in the control plane can be found in [RFC8370].

There is also concern at the scalability of the forwarder footprint of RSVP-TE as the number of paths through a label switching router (LSR) grows. [RFC8577] addresses this by employing SR within a tunnel established by RSVP-TE.

6.3. SDN Scaling

The centralized approach of SDN requires state to be stored in the network, but does not have the overhead of also requiring control plane state to be maintained. Each individual network node may need to maintain a communication channel with the SDN controller, but that compares favorably with the need for a control plane to maintain communication with all neighbors.

However, SDN may transfer some of the scalability concerns from the network to the centralized controller. In particular, there may be a heavy processing burden at the controller, and a heavy load in the network surrounding the controller. A centralized controller also presents a single point of failure within the network.

7. OAM Considerations

The design of OAM for enhanced VPNs needs to consider the following requirements:

- Instrumentation of the underlay so that the network operator can be sure that the resources committed to a tenant are operating correctly and delivering the required performance.

- Instrumentation of the overlay by the tenant. This is likely to be transparent to the network operator and to use existing methods. Particular consideration needs to be given to the need to verify the isolation and the various committed performance characteristics.

- Instrumentation of the overlay by the network provider to proactively demonstrate that the committed performance is being delivered. This needs to be done in a non-intrusive manner, particularly when the tenant is deploying a performance sensitive application.

- Verification of the conformity of the path to the service requirement. This may need to be done as part of a commissioning test.

A study of OAM in SR networks has been documented in [RFC8403].

8. Telemetry Considerations

Network visibility is essential for network operation. Network telemetry has been considered as an ideal means to gain sufficient network visibility with better flexibility, scalability, accuracy, coverage, and performance than conventional OAM technologies.

As defined in [I-D.ietf-opsawg-ntf], the objective of Network Telemetry is to acquire network data remotely for network monitoring and operation. It is a general term for a large set of network visibility techniques and protocols. Network telemetry addresses the current network operation issues and enables smooth evolution toward intent-driven autonomous networks. Telemetry can be applied on the forwarding plane, the control plane, and the management plane in a network.

How the telemetry mechanisms could be used or extended for the enhanced VPN service is out of the scope of this document.

9. Enhanced Resiliency

Each enhanced VPN has a life cycle, and may need modification during deployment as the needs of its tenant change. This is discussed in Section 5.5. Additionally, as the network evolves, there may need to be garbage collection performed to consolidate resources into usable quanta.

Systems in which the path is imposed, such as SR or some form of explicit routing, tend to do well in these applications, because it is possible to perform an atomic transition from one path to another. That is, a single action by the head-end that changes the path without the need for coordinated action by the routers along the path. However, implementations and the monitoring protocols need to make sure that the new path is operational and meets the required SLA before traffic is transitioned to it. It is possible for deadlocks to arise as a result of the network becoming fragmented over time, such that it is impossible to create a new path or to modify an existing path without impacting the SLA of other paths. Resolution of this situation is as much a commercial issue as it is a technical issue and is outside the scope of this document.

There are, however, two manifestations of the latency problem that are for further study in any of these approaches:

- The problem of packets overtaking one another if a path latency reduces during a transition.

- The problem of transient variation in latency in either direction as a path migrates.

There is also the matter of what happens during failure in the underlay infrastructure. Fast reroute is one approach, but that still produces a transient loss with a normal goal of rectifying this within 50ms [RFC5654]. An alternative is some form of N+1 delivery such as has been used for many years to support protection from service disruption. This may be taken to a different level using the techniques of DetNet with multiple in-network replication and the culling of later packets [RFC8655].

In addition to the approach used to protect high priority packets, consideration should be given to the impact of best effort traffic on the high priority packets during a transition. Specifically, if a conventional re-convergence process is used there will inevitably be micro-loops and whilst some form of explicit routing will protect the high priority traffic, lower priority traffic on best effort shortest paths will micro-loop without the use of a loop prevention technology. To provide the highest quality of service to high

priority traffic, either this traffic must be shielded from the micro-loops, or micro-loops must be prevented completely.

10. Operational Considerations

It is likely that enhanced VPN services will be introduced in networks which already have traditional VPN services deployed. Depending on service requirements, the tenants or the operator may choose to use a traditional VPN or an enhanced VPN to fulfill a service requirement. The information and parameters to assist such a decision needs to be reflected on the management interface between the tenant and the operator.

11. Security Considerations

All types of virtual network require special consideration to be given to the isolation of traffic belonging to different tenants. That is, traffic belonging to one VPN must not be delivered to end points outside that VPN. In this regard enhanced VPNs neither introduce, nor experience a greater security risks than other VPNs.

However, in an enhanced Virtual Private Network service the additional service requirements need to be considered. For example, if a service requires a specific upper bound to latency then it can be damaged by simply delaying the packets through the activities of another tenant, i.e., by introducing bursts of traffic for other services. In some respects this makes the enhanced VPN more susceptible to attacks since the SLA may be broken. But another view is that the operator must, in any case, preform monitoring of the enhanced VPN to ensure that the SLA is met, and this means that the operator may be more likely to spot the early onset of a security attack and be able to take pre-emptive protective action.

The measures to address these dynamic security risks must be specified as part to the specific solution are form part of the isolation requirements of a service.

While an enhanced VPN service may be sold as offering encryption and other security features as part of the service, customers would be well advised to take responsibility for their own security requirements themselves possibly by encrypting traffic before handing it off to the service provider.

The privacy of enhanced VPN service customers must be preserved. It should not be possible for one customer to discover the existence of another customer, nor should the sites that are members of an enhanced VPN be externally visible.

12. IANA Considerations

There are no requested IANA actions.

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