What Is a VPN? - Part I

March 1998

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The term "VPN," or ***Virtual Private Network***, has become almost as recklessly used in the networking industry as has "QoS" (Quality of Service) to describe a broad set of problems and "solutions," when the objectives themselves have not been properly articulated. This confusion has resulted in a situation where the popular trade press, industry pundits, and vendors and consumers of networking technologies alike generally use the term VPN as an offhand reference for a set of different technologies. This article provides a commonsense definition of a VPN, and an overview of different approaches to building one.

"The wonderful thing about virtual private networks is that its myriad definitions give every company a fair chance to claim that its existing product is actually a VPN. But no matter what definition you choose, the networking buzz-phrase doesn't make sense. The idea is to create a private network via tunneling and/or encryption over the public Internet. Sure, it's a lot cheaper than using your own frame relay connections, but it works about as well as sticking cotton in your ears in Times Square and pretending nobody else is around." [1]

A Common-Sense Definition

As Wired Magazine notes in the quotation, the myriad definitions of a VPN are less than helpful in this environment. Accordingly, it makes sense to begin this examination of VPNs to see if it is possible to provide a common-sense definition of a VPN. Perhaps the simplest method of attempting to arrive at a definition for VPNs is to look at each word in the acronym individually, and then tie each of them together in a simple, commonsense, and meaningful fashion.

Let's start by examining the word "network." This term is perhaps the least difficult one for us to define and understand, because the commonly accepted definition is fairly uncontroversial and generally accepted throughout the industry. A network consists of any number of devices that can communicate through some arbitrary method. Devices of this nature include computers, printers, routers, and so forth, and they may reside in geographically diverse locations. They may communicate in numerous ways because the electronic signalling specifications, and data-link, transport, and application-layer protocols are countless. For the purposes of simplicity, let's say that a "network" is a collection of devices that can communicate in some fashion, and can successfully transmit and receive data among themselves.

The term "private" is fairly straightforward, and is intricately related to the concept of "virtualization" insofar as VPNs are concerned, as we'll discuss in a moment. In the simplest of definitions, "private" means communications between two (or more) devices is, in some fashion, secret—that the devices that are not participating in the "private" nature of communications are not privy to the communicated content, and that they are indeed completely unaware of the private relationship altogether. Accordingly, data privacy and security (data integrity) are also important aspects of a VPN that need to be considered when implementing any particular VPN.

Another means of expressing this definition of "private" is through its antonym, "public." A "public" facility is one that is openly accessible, and is managed within the terms and constraints of a common public resource, often via a public administrative entity. By contrast, a private facility is one where access is restricted to a defined set of entities, and third parties cannot gain access. Typically, the private resource is managed by the entities who have exclusive right of access. Examples of this type of private network can be found in any organizational network that is not connected to the Internet, or to any other external organizational network, for that matter. These networks are private because there is no external connectivity, and thus no external network communications.

Another important aspect of privacy in a VPN is through its technical definition. For example, privacy in an addressing and routing system means that the addressing used within a VPN community of interest is separate and discrete from that of the underlying shared network, and from that of other VPN communities. The same holds true for the routing system used within the VPN and that of the underlying shared network. The routing and addressing scheme within a VPN should, in general, be self-contained, but this scenario degenerates into a philosophical discussion of the context of the term "VPN." Also, it is worthwhile to examine the differences between the "peer" and "overlay" models of constructing VPNs—both of which are discussed in more detail later under the heading "Network-Layer VPNs."

"Virtual" is a concept that is slightly more complicated. The New Hacker's Dictionary (formerly known as the Jargon File) [2] defines virtual as:

> virtual /adj./ [via the technical term "virtual memory," prob. from the term "virtual image" in optics] 1. Common alternative to{logical}; often used to refer to the artificial objects (like addressable virtual memory larger than physical memory) simulated by a computer system as a convenient way to manage access to shared resources. 2. Simulated; performing the functions of something that isn't really there. An imaginative child's doll may be a virtual playmate. Oppose {real}.

Insofar as VPNs are concerned, the second definition is perhaps the most appropriate comparison for virtual networks. The "virtualization" aspect is one that is similar to what we briefly described previously as private, but the scenario is slightly modified—the private communication is now conducted across a network infrastructure that is shared by more than a single organization. Thus, the private resource is actually constructed by using the foundation of a logical partitioning of some underlying common, shared resource rather than by using a foundation of discrete and dedicated physical circuits and communications services. Accordingly, the private network has no corresponding private physical communications system. Instead, the private network is a virtual creation that has no physical counterpart.

The virtual communications between two (or more) devices is because the devices that are not participating in the virtual communications are not privy to the content of the data, and they are also altogether unaware of the private relationships between the virtual peers. The shared network infrastructure could, for example, be the global Internet and the number of organizations or other users not participating in the virtual network may literally number into the thousands or even millions.

A VPN can also said to be a *discrete network* [3]:

> (discrete \dis*crete"\, a. [L. discretus, p.p. of discernere. See Discreet.] 1. Separate; distinct; disjunct).

The discrete nature of VPNs allows both privacy and virtualization. Although VPNs are not completely separate, intrinsically, the distinction is that they operate in a discrete fashion across a shared infrastructure, providing exclusive communications environments that do not share any points of interconnection.

The combination of these terms produces VPN—a private network, where the privacy is introduced by some method of virtualization. A VPN could be built between two end systems or between two organizations, between several end systems within a single organization or between multiple organizations across the global Internet, between individual applications, or any combination.

It should be noted that there is really no such thing as a nonvirtual network, if the underlying common public transmission systems and other similar public infrastructure components are considered to be the base level of carriage of the network. What separates a VPN from a truly private network is whether the data transits a shared versus a nonshared infrastructure. For instance, an organization could lease private line circuits from various telecommunications providers and build a private network on the base of these private circuit leases, but the circuit-switched network owned and operated by the telecommunications companies are actually circuits connected to their Digital Access and Crossconnect Systems (DACSs) network and subsequently their fiber-optics infrastructure. This infrastructure is shared by any number of organizations through the use of multiplexing technologies. Unless an organization is actually deploying private fiber and layered transmission systems, any network is layered with "virtualized" connectivity services in this fashion.

A VPN doesn't necessarily mean communications isolation, but rather the controlled segmentation of communications for communities of interest across a shared infrastructure.

The common and somewhat formal characterization of the VPN, and perhaps the most straightforward and strict definition, follows:

> A VPN is a communications environment in which access is controlled to permit peer connections only within a defined community of interest, and is constructed though some form of partitioning of a common underlying communications medium, where this underlying communications medium provides services to the network on a nonexclusive basis.

A simpler, more approximate, and much less formal description follows:

> A VPN is private network constructed within a public network infrastructure, such as the global Internet.

It should also be noted that although VPNs may be constructed to address any number of specific business needs or technical requirements, a comprehensive VPN solution provides support for dial-in access, support for multiple remote sites connected by leased lines (or other dedicated means), the ability of the VPN service provider (SP) to "host" various services for the VPN customers (for example, Web hosting), and the ability to support not just intra-, but also inter-VPN connectivity, including connectivity to the global Internet.

VPN Motivations

There are several motivations for building VPNs, but a common thread is that they all share the requirement to "virtualize" some portion of an organization's communications—in other words, make some portion (or perhaps all) the communications essentially "invisible" to external observers, while taking advantage of the efficiencies of a common communications infrastructure.

The base motivation for VPNs lies in the economics of communications. Communications systems today typically exhibit the characteristic of a high fixed-cost component, and smaller variable-cost components that vary with the transport capacity, or bandwidth, of the system. Within this economic environment, it is generally financially attractive to bundle numerous discrete communications services onto a common, high-capacity communications platform, allowing the high fixed-cost components associated with the platform to be amortized over a larger number of clients. Accordingly, a collection of virtual networks implemented on a single common physical communications plant is cheaper to operate than the equivalent collection of smaller, physically discrete communications plants, each servicing a single network client. Therefore, if aggregation of communications requirements leads to a more cost-effective communications infrastructure, why not pool all these services into a single public communications system? Why is there still the requirement to undertake some form of partitioning within this common system that results in these "virtual private" networks?

In response to this question, the second motivation for VPNs is that of communications privacy, where the characteristics and integrity of communications services within one closed environment is isolated from all other environments that share the common underlying plant. The level of privacy depends greatly on the risk assessment performed by the subscriber organization—if the requirement for privacy is low, then the simple abstraction of discretion and network obscurity may serve the purpose. However, if the requirement for privacy is high, then there is a corresponding requirement for strong security of access and potentially strong security applied to data passed over the common network.

History

This article cannot do justice to the concept of VPNs without some historical perspective, so we need to look at why VPNs are an evolving paradigm, and why they will continue to be an issue of confusion, contention, and disagreement. This examination is important because opinions on VPN solutions are quite varied, as well as how they should be approached.

Historically, one of the precursors to the VPN was the Public Data Network (PDN), and the current familiar instance of the PDN is the global Internet. The Internet creates a ubiquitous connectivity paradigm, where the network permits any connected network entity to exchange data with any other connected entity. The parallels with the global Public Switched Telephone Network (PSTN) are, of course, all too obvious—where a similar paradigm of ubiquitous public access is the predominate characteristic of the network.

The Public Data Network has no inherent policy of traffic segregation, and any modification to this network policy of permitting ubiquitous connectivity is the responsibility of the connecting entity to define and enforce. The network environment is constructed using a single addressing scheme and a common routing hierarchy, which allows the switching elements of the network to determine the location of all connected entities. All these connected entities also share access to a common infrastructure of circuits and switching.

However, the model of ubiquity in the "Internet PDN" does not match all potential requirements, especially the need for data privacy. For organizations that wish to use this public network for private purposes within a closed set of participants (for example, connecting a set of geographically separated offices), the Internet is not always a palatable possibility. Numerous factors are behind this mismatch, including issues of Quality of Service (QoS), availability and reliability, use of public addressing schemes, use of public protocols, site security, and data privacy and integrity (the possibility of traffic interception). Additionally, a corporate network application may desire more stringent levels of performance management than are available within the public Internet, or indeed may wish to define a management regime that differs from that of the underlying Internet PDN.

Service-Level Agreements

It is worthwhile at this point to briefly examine the importance of Service-Level Agreements (SLAs) in regards to the deployment of VPNs. SLAs are negotiated contracts between VPN providers and their subscribers; they contain the service criteria to which the subscriber expects specific services to be delivered. The SLA is arguably the only binding tool at the subscriber's disposal with which to ensure that the VPN provider delivers the service(s) to the level and quality as agreed, and it is in the best interest of the subscribers to monitor the criteria outlined in the SLA for compliance. However, SLAs present some challenging technical issues for both the provider and the subscriber.

For the subscriber, the challenge is to devise and operate service measurement tools that can provide a reasonable indication as to what extent the SLA is being honored by the provider. Also, it should be noted that a subscriber may use an SLA to bind one or more providers to a contractual service level, but if the subscriber's VPN spans multiple providers' domains, the SLA must also encompass the issue of provider interconnection and the end-to-end service performance.

For the provider, the challenge lies in honoring multiple SLAs from a number of service providers. In the case of an Internet PDN provider, the common mode of best-effort service levels is not conducive to meeting SLAs, given the unpredictable nature of the host's resource allocation mechanisms. In such environments, the provider either has to ensure that the network is generously engineered in terms of the ratio of subscriber access capacity to internal switching capacity, or the provider can deploy service differentiation structures to ensure that minimum resource levels are allocated to each SLA subscriber. It must be noted that the former course of action does tend to reduce the benefit of aggregation of traffic, which in turn has an ultimate cost implication, while the latter course of action has implications in terms of operational management complexity and scalability of the network.

Alternatives to the VPN

The alternative to using the Internet as a VPN today is to lease circuits, or similar dedicated communications services, from the public network operators (the local telephone company in most cases), and create a completely private network. It is a layering convention that allows us to label this as "completely private," because these dedicated communications services are (at the lower layers of the protocol stack) again instances of virtual private communications systems constructed atop a common transmission bearer system. Of course, this scenario is not without precedent, and it must be noted that most of the early efforts in data networking, and many of the current data networking architectures, do not assume a deployment model of ubiquitous public access.

It is interesting to note that this situation is odd, when you consider that the inherent value of an architecture where ubiquitous public access over a chaotic collection of closed private networks had been conclusively demonstrated in the telephony marketplace since the start of the 20th century. Although the data communications industry appears to be moving at a considerable technological pace, the level of experiential learning, and consequent level of true progress as distinct from simple motion, still leaves much to be desired!

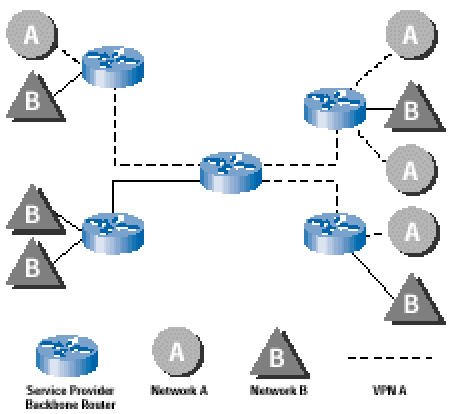
Instead of a public infrastructure deployment, the deployment model used has been that of a closed (or private) network environment where the infrastructure, addressing scheme, management, and services were dedicated to a closed set of subscribers. This model matched that of a closed corporate environment, where the network was dedicated to serve a single corporate entity as the sole client. This precursor to the VPN, which could be called the private data network, was physically constructed using dedicated local office wiring and dedicated leased circuits (or private virtual circuits from an underlying switching fabric such as X.25) to connect geographically diverse sites.

However, this alternative does have an associated cost, in that the client now has to manage the network and all its associated elements, invest capital in network switching infrastructure, hire trained staff, and assume complete responsibility for the provisioning and ongoing maintenance of the network service. Such a dedicated use of transport services, equipment, and staff is often difficult to justify for many small-to-medium sized organizations, and whereas the functionality of a private network system is required, the expressed desire is to reduce the cost of the service through the use of shared transport services, equipment, and management. Numerous scenarios can address this need, ranging from outsourcing the management of the switching elements of the network (managed network services), to outsourcing the capital equipment components (leased network services), to outsourcing the management, equipment, and transport elements to a service provider altogether.

An Example VPN

In the simple example illustrated in Figure 1, Network "A" sites have established a VPN (depicted by the dashed lines) across the service provider's backbone network, where Network "B" is completely unaware of its existence. Both Networks "A" and "B" can harmoniously coexist on the same backbone infrastructure.

Figure 1:A Virtual Private Network of "A" Sites



This type of VPN is, in fact, the most common type of VPN—one that has geographically diverse subnetworks that belong to a common administrative domain, interconnected by a shared infrastructure outside their administrative control (such as the global Internet or a single service provider backbone). The principal motivation in establishing a VPN of this type is that perhaps most of the communications between devices within the VPN community may be sensitive (again, a decision on the level of privacy required rests solely on a risk analysis performed by the administrators of the VPN), yet the total value of the communications system does not justify the investment in a fully private communications system that uses discrete transmission elements.

On a related note, the level of privacy that a VPN may enjoy depends greatly on the technology used to construct the VPN. For example, if the communications between each VPN subnetwork (or between each VPN host) is securely encrypted as it transits the common communications infrastructure, then it can be said that the privacy aspect of the VPN is relatively high.

In fact, the granularity of a VPN implementation can be broken down further to a single end-to-end, one-to-one connectivity scenario. Examples of these types of one-to-one VPNs are single dialup users who establish a VPN connection to a secure application, such as an online banking service, or a single user establishing a secure, encrypted session between a desktop and server application, such as a purchasing transaction conducted on the World Wide Web. This type of one-to-one VPN is becoming more and more prevalent as secure electronic commerce applications become more mature and are further deployed in the Internet. (See article starting on page 20.) It is interesting to note that the concept of virtualization in networking has also been considered in regard to deploying both research and production services on a common infrastructure. The challenge in the research and education community is one in which there is a need to satisfy both network research and production requirements. VPNs have also been considered as a method to segregate traffic in a network such that research and production traffic behave as "ships in the night," oblivious to one another's existence, to the point that major events (for example, major failures, instability) within one community of interest are completely transparent to the other. This concept is further documented in MORPHnet [4] .

It should also be noted that VPNs may be constructed to span more than one host communications network, so that the "state" of the VPN may be supported on one or more VPN provider networks. This scenario is perhaps at its most robust when all the providers explicitly support the resultant distributed VPN environment, but other solutions that do not necessarily involve knowledge of the overlay VPN are occasionally deployed with mixed results.

Types of VPNs

The confusion factor comes into play in the most basic discussions regarding VPNs, principally because there are actually several different types of VPNs, and depending on the functional requirements, several different methods of constructing each type of VPN are available. The process of selection should include consideration of what problem is being solved, risk analysis of the security provided by a particular implementation, issues of scale in growing the size of the VPN, and the complexity involved in implementation of the VPN, as well as ongoing maintenance and troubleshooting.

To simplify the description of the different types of VPNs, they are broken down in this article into categories that reside in the different layers of the TCP/IP protocol suite; Link Layer, Network Layer, Transport Layer, and Application Layer.

Network-Layer VPNs

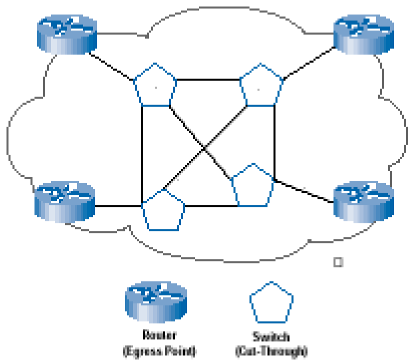
The network layer in the TCP/IP protocol suite consists of the IP routing system - how reachability information is conveyed from one point in the network to another. There are a few methods to construct VPNs within the network layer - each is examined in the following paragraphs. A brief overview of non-IP VPNs is provided in Part II of this article.

A brief overview of the differences in the "peer" and "overlay" VPN models is appropriate at this point. Simply put, the "peer" VPN model is one in which the network-layer forwarding path computation is done on a hop-by-hop basis, where each node in the intermediate data transit path is a peer with a next-hop node. Traditional routed networks are examples of peer models, where each router in the network path is a peer with its next-hop adjacencies. Alternatively, the "overlay" VPN model is one in which the network-layer forwarding path is not done on a hop-by-hop basis, but rather, the intermediate link-layer network is used as a "cut-through" to another edge node on the other side of a large cloud. Examples of "overlay" VPN models include ATM, Frame Relay, and tunnelling implementations.

Having drawn these simple distinctions between the peer and overlay models, it should be noted that the overlay model introduces some serious scaling concerns in cases where large numbers of egress peers are required because the number of adjacencies increases in direct proportion to the number of peers—the amount of computational and performance overhead required to maintain routing state, adjacency information, and other detailed packet forwarding and routing information for each peer becomes a liability in very large networks. If all the egress nodes in a cut-through network become peers in an effort to make all egress nodes one "Layer 3" hop away from one another, the scalability of the VPN overlay model is limited quite remarkably.

For example, as the simple diagram (Figure 2) illustrates, the routers that surround the interior switched infrastructure represent egress peers, because the switches in the core interior could be configured such that all egress nodes are one Layer 3 hop away from one another, creating what is commonly known as a "cut-through." This scenario forms the foundation of an overlay VPN model.

Figure 2: A Cut-Through VPN

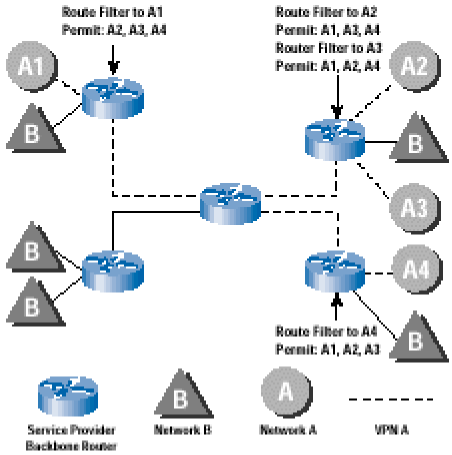


Alternatively, if the switches in the interior are replaced with routers, then the routers positioned at the edge of the cloud become peers with their next-hop router nodes, not other egress nodes. This scenario forms the foundation of the peer VPN model.

Controlled Route Leaking

"Controlled route leaking" (or ***route filtering***) is a method that could also be called "privacy through obscurity" because it consists of nothing more than controlling route propagation to the point that only certain networks receive routes for other networks that are within their own community of interest. This model can be considered a "peer" model, because a router within a VPN site establishes a routing relationship with a router within the VPN provider's network, instead of an edge-to-edge routing peering relationship with routers in other sites of that VPN. Although the common underlying Internet generally carries the routes for all networks connected to it, this architecture assumes that only a subset of such networks form a VPN. The routes associated with this set of networks are filtered such that they are not announced to any other set of connected networks, and all other non-VPN routes are not announced to the networks of the VPN. For example, in Figure 1, if the SP routers "leaked" routing information received from one site in Network "A" to only other sites in Network "A," then sites not in Network "A" (for instance, sites in Network "B") would have no explicit knowledge of any other networks which where attached to the service provider's infrastructure (as shown in Figure 3). Given this lack of explicit knowledge of reachability to any location other than other members of the same VPN, privacy of services is implemented by the inability of any of the VPN hosts to respond to packets which contain source addresses from outside the VPN community of interest.

Figure 3: Controlled Route Leaking



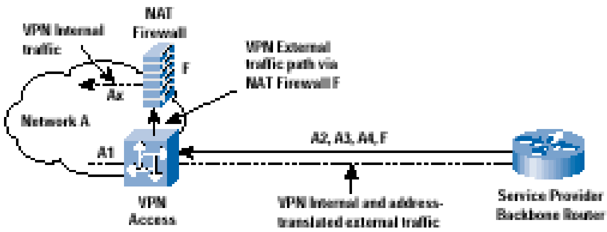
This use of partial routing information is prone to many forms of misconfiguration. One potential problem with route leaking is that it is extremely difficult, if not impossible, to prohibit the subscriber networks from pointing default to the upstream next-hop router for traffic destined for networks outside their community of interest. From within the VPN subscriber's context, this action may be reasonable, in that "default" for the VPN is reachability to all other members of the same VPN, and pointing a default route to the local egress path is, within a local context, a reasonable move. Thus, it is no surprise that this is a common occurrence in VPNs in which the customer configures and manages the customer premise equipment (CPE) routers. If the SP manages the configuration of the CPE routers, then this is rarely a problem. Otherwise, the SP might be wise to place traffic filters on first-hop routers to prohibit all traffic destined for networks outside the VPN community of interest.

It should also be noted that this environment implicitly assumes a common routing core. A common routing core, in turn, implies that each VPN must use addresses that do not clash with those of any other VPN on the same common infrastructure, and cannot announce arbitrary private addresses into the VPN. Another, perhaps less obvious, side effect of this form of VPN structure is that it is not possible for two VPNs to have a single point of interconnection, nor is it possible for a VPN to operate a single point of interconnection to the public Internet in such an environment. (This single point would be a so-called "gateway," where all external traffic is passed through a control point that can enforce some form of access policy and record a log of external transactions.) The common routing core uses a single routing paradigm, based solely on destination address.

It should also be noted that this requirement highlights one of the dichotomies of VPN architectures. VPNs must assume that they operate in a mutually hostile environment, where any vulnerability that exposes the private environment to access by external third parties may be exploited in a hostile fashion. However, VPNs rarely are truly isolated communications environments, and typically all VPNs do have some form of external interface that allows controlled reachability to other VPNs and to the broader public data network. The trade-off between secure privacy and the need for external access is a constant feature of VPNs.

Implementation of inter-VPN connectivity requires the network to route externally originated packets to the VPN interconnection point, and if they are admitted into the VPN at the interconnection point, the same packet may be passed back across the network to the ultimate VPN destination address. Without the use of ***Network Address Translation*** (NAT) technologies at the interconnection point of ingress into the VPN, this kind of communications structure is insupportable within this architecture (Figure 4).

Figure 4: Segregating VPN traffic via address translation



In general, the technique of supporting private communities of interest simply by route filtering can at best be described as a primitive method of VPN construction, which is prone to administrative errors, and admits an undue level of insecurity and network inflexibility. Even with comprehensive traffic and route filtering, the resulting environment is not totally robust. The operational overhead required to support complementary sets of traditional routing and traffic filters is a relevant consideration, and this approach does not appear to possess the scaling properties desirable to allow the number of VPNs to grow beyond the bounds of a few hundred, using today's routing technologies.

Having said that, however, a much more scalable approach is to use Border Gateway Protocol (BGP) communities [5] as a method to control route propagation. The use of BGP communities scales much better than alternative methods with respect to controlling route propagation and is less prone to human misconfiguration. Briefly, the use of the BGP communities attribute allows a VPN provider to "mark" BGP Network-Layer Reachability Information (NLRI) with a community attribute, such that configuration control allows route information to propagate in accordance with a community profile.

Because traffic from different communities of interest must traverse a common shared infrastructure, there is no significant data privacy in the portion of the network where traffic from multiple communities of interest share the infrastructure. Therefore, it can be said that although connected subnetworks?or rather, subscribers to the VPN service— may not be able to detect the fact that there are other subscribers to the service, multiple interwoven streams of subscriber data traffic pass unprotected in the core of the service provider's network.

Tunneling

Sending specific portions of network traffic across a tunnel is another method of constructing VPNs. Some tunneling methods are more effective than others. The most common tunneling mechanisms are Generic Routing Encapsulation (GRE) [6] tunneling between a source and destination router, router-to-router or host-to-host tunneling protocols such as Layer 2 Tunneling Protocol (L2TP) [7] and Point-to- Point Tunneling Protocol (PPTP) [8] , and Distance Vector Multicast Routing Protocol (DVMRP) [9] tunnels.

Tunneling can be considered an overlay model, but the seriousness of the scaling impact depends on whether the tunnels are point-to-point or point-to-multipoint. Point-to-point tunnels have fewer scaling problems than do point-to-multipoint tunnels, except in situations where a single node begins to build multiple point-to-point tunnels with multiple endpoints. Although a linear scaling problem is introduced at this point, the manageability of point-to-point tunnels lies solely in the administrative overhead and the number of the tunnels themselves. On the other hand, point-to-multipoint tunnels use "cut-through" mechanisms to make greater numbers of endpoints one hop away from one another and subsequently introduce a much more serious scaling problem.

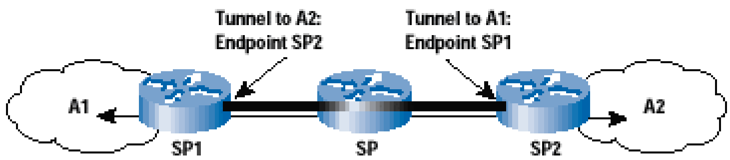
Although the Multicast Backbone (Mbone) itself could literally be considered a global VPN, and although DVMRP tunnels are still widely used by organizations to connect to the Mbone, it really is not germane to the central topic of VPNs, because the focus of this article is on unicast traffic.

Traditional Modes of Tunneling

GRE tunnels, as mentioned previously, are generally configured between a source (ingress) router and a destination (egress) router, such that packets designated to be forwarded across the tunnel (already formatted with an encapsulation of the data with the "normal" protocol-defined packet header) are further encapsulated with a new header (the GRE header), and placed into the tunnel with a destination address of the tunnel endpoint (the new next-hop). When the packet reaches the tunnel endpoint, the

GRE header is stripped away, and the packet continues to be forwarded to the destination, as designated in the original IP packet header (Figure 5).

Figure 5: Tunneling across a Service Provider



GRE tunnels are generally point-to-point—that is, there is a single source address for the tunnel and usually only a single destination tunnel endpoint. However, some vendor implementations allow the configuration of point-to-multipoint tunnels—that is, a single source address and multiple destinations. Although this implementation is generally used in conjunction with Next Hop Resolution Protocol (NHRP) [10] , the effectiveness and utility of NHRP is questionable and should be tested prior to deployment. It is also noteworthy that NHRP is known to produce steady-state forwarding loops when used to establish shortcuts between routers. In the scenario discussed previously, NHRP is used for establishing shortcuts between routers. Tunnels, however, do have numerous compelling attractions when used to construct VPNs. The architectural concept is to create VPNs as a collection of tunnels across a common host network. Each point of attachment to the common network is configured as a physical link that uses addressing and routing from the common host network, and one or more associated tunnels. Each tunnel endpoint logically links this point of attachment to other remote points from the same VPN. The technique of tunneling uses a tunnel egress address defined within the address space of the common host network, whereas the packets carried within the tunnel use the address space of the VPN, which in turn constrains the tunnel endpoints to be collocated to those points in the network where the VPN and the host network interconnect.

Pros and Cons

The advantage of this approach is that the routing for the VPN is isolated from the routing of the common host network. The VPNs can reuse the same private address space within multiple VPNs without any cross impact, providing considerable independence of the VPN from the host network. This requirement is key for many VPNs in that private VPNs typically may not use globally unique or coordinated address space, and there is often the consequential requirement to support multiple VPNs which independently use the same address block. Such a configuration is not supportable within a controlled route leakage VPN architecture. The tunnel can also encapsulate numerous different protocol families, so that it is possible for a tunnelbased VPN to mimic much of the functionality of dedicated private networks. Again, the need to support multiple protocols in a format which preserves the functionality of the protocol is a critical requirement for many VPN support architectures. This requirement is one in which an IP common network with controlled route leakage cannot provide such services, whereas a tunneling architecture can segment the VPN-private protocol from the common host network. The other significant advantage of the tunneled VPN is the segregation of the common host routing environment with that of the VPN. To the VPN, the common host network assumes the properties of numerous point-to-point circuits, and the VPN can use a routing protocol across the virtual network which matches the administrative requirements of the VPN. Equally, the common host network can use a routing design which matches the administrative requirements of the host network (or collection of host networks), and is not constrained by the routing protocols used by the VPN client networks.

Although it could be said that these advantages indicate that GRE tunneling is the panacea for VPN design, using GRE tunnels as a mechanism for VPNs does have several drawbacks, mostly with regard to administrative overhead, scaling to large numbers of tunnels, and QoS and performance. Since GRE tunnels must be manually configured, there is a direct relationship to the number of tunnels that must be configured and the amount of administrative overhead required to configure and maintain them—each time the tunnel endpoints must change, and they must be manually reconfigured. Also, although the amount of processing required to encapsulate a packet for GRE handling may appear to be small, there is a direct relationship to the number of configured tunnels and the total amount of processing overhead required for GRE encapsulation. Of course, tunnels can be structured to be triggered automatically, but such an approach has numerous drawbacks that dictate careful consideration of related routing and performance issues. The worst end state of such automatic tunnel generation is that of a configuration loop where the tunnel passes traffic over itself. It is important, once again, to reiterate the impact of a large number of routing peering adjacencies that result from a complete mesh of tunnels; this scenario can result in a negative effect on routing efficiency.

An additional concern with GRE tunneling is the ability of traffic classification mechanisms to identify traffic with a fine enough level of granularity, and not become a hindrance to forwarding performance. If the traffic classification process used to identify packets (that are to be forwarded across the tunnel) interferes with the router's ability to maintain acceptable packet-per-second forwarding rates, then this becomes a performance liability.

Privacy of the network remains an area of concern because the tunnel is still vulnerable—privacy is not absolute. Packets that use GRE formatting can be injected into the VPN from third-party sources. To ensure a greater degree of integrity of privacy of the VPN, it is necessary to deploy ingress filters that are aligned to the configured tunnel structure.

It is also necessary to ensure that the CPE routers are managed by the VPN service provider, because the configuration of the tunnel end-points is a critical component of the overall architecture of integrity of privacy. However, most VPN service providers are reluctant to add CPE equipment to their asset inventory and undertake remote management of such CPE equipment, due to the high operational overheads and poor capital efficiencies which are typical of CPE deployment. Arguably, one might suggest that having a dedicated CPE router defeats one of the basic premises of constructing a VPN—the use of shared infrastructure as a way to reduce the overall network cost.

It should be noted that VPNs can be constructed using tunnels without the explicit knowledge of the host network provider, and the VPN can span numerous host networks without any related underlying agreements between the network operators to mutually support the overlay VPN. Such an architecture is little different from provider-operated VPN architecture; the major difference lies in the issue of traffic and performance engineering, and the administrative boundary of the management of the VPN overlay. Independently configured VPN tunnels can result in injection of routes back into the VPN in a remote location, a scenario that can cause traffic to traverse the same link twice, once in an unencapsulated format and again within a tunnel. This situation can then lead to adverse performance impacts.

It is also true that the overlay VPN model has no control over which path is taken in the common host network, nor the stability of that path. This scenario can then lead to adverse performance impacts on the VPN. Aside from the technology aspects of this approach, the major issue is one of whether the VPN management is outsourced to the network provider, or undertaken within administrative functions of the VPN. One of the more serious considerations in building a VPN on tunneling is that there is virtually no way to determine the cost of the route across a tunnel, because the true path is masked by the cut-through nature of the tunnel. This situation could ultimately result in highly suboptimal routing, meaning that a packet could take a path determined by the cut-through mechanism that is excessively suboptimal, while native per-hop routing protocols might find a much more efficient method to forward the packets to their destinations.

Conclusion

So far in our discussion of VPNs, we have introduced a working definition of the term "Virtual Private Network" and discussed the motivations behind the adoption of such networks. We have outlined a framework for describing the various forms of VPNs, and then examined numerous network-layer VPN structures, in particular, that of controlled route leakage and tunneling techniques.

In Part II we will continue this examination of network-layer VPNs, including virtual private dial networks and network-layer encryption. In addition, we will examine link-layer VPNs that use ATM and Frame Relay substrates, and also look at switching and encryption techniques, and issues concerning QoS and non-IP VPNs.

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