Solution Overview—Getting Started with IPv6

Executive Summary

The purpose of this white paper is to provide Cisco's customers with a snapshot in time of Cisco's Global Government Solutions Group (GGSG) migration to IPv6 and how it fits within Cisco's internal processes to migrate to IPv6 as a company. GGSG's specific efforts are focused on providing Cisco's pilot capability of deploying IPv6 to the edge for selected GGSG facilities. GGSG's relationships with government customers put it in a unique position as a trusted advisor as these customers start or are in the process of migrating to IPv6. GGSG's internal network functionality helps minimize the impact of the migration on the broader Cisco community while still allowing development of lessons learned for ultimate knowledge transfer to others, based on real-world experience and best practices for an actual IPv6 network migration.

The primary audience of this white paper is our federal sales force as they engage government customers globally who are investigating and planning their own IPv6 adoption strategies and migrations.

The migration to IPv6 will naturally occur in multiple phases over multiple years. This will be the first in a series of white papers that will document GGSG's IPv6 migration effort as it reaches its planned milestones and phases. In addition, there will be other IPv6 migration white papers that discuss Cisco's broader IPv6 migration as we adopt it across Cisco's large global network.

Moving from Four to Six

The Internet has exceeded expectations and defied predictions many times in its short history. Network growth and the increasing capabilities and connectivity of devices are straining the addressing and routing capabilities of the current IPv4 network. This reality is especially true in some European and Asian countries that are experiencing significant network growth but without the depth of IPv4 addresses available in North America. As IPv4 address exhaustion approaches, organizations are more actively considering the need to deploy and integrate IPv6 into the network, often with many questions. Where to start with IPv6? What are the costs and return on investment? What are the best practices?

Even though IPv6 was initially defined more than 10 years ago, deployment is still a small fraction of global networks. At Cisco, IPv6 has been in parts of the network for almost 10 years, initially for product testing. Moving to IPv6 will not immediately resolve the address shortage, because the dual-stack IPv4/IPv6 approach to migration still requires IPv4 addresses. However, it is an overdue first step. A few countries and large organizations have begun the migration to IPv6 because of imminent exhaustion of their IPv4 address allocation. GGSG at Cisco has been a trusted advisor on some of these projects, and is acting in a similar capacity for an internal project to deploy IPv6 throughout one of the company's larger development facilities.

Deployment of IPv6 is an overall effort across Cisco that incorporates many groups and objectives. This paper is the first in a series that will share the experiences, lessons learned, and best practices of the Cisco teams as they expand IPv6 deployment from the Cisco Engineering Labs to the internal production network and the external web presence. This initial paper focuses on a project to deploy IPv6 throughout the GGSG facilities.

History, Version 6

IPv6 is not new to Cisco. Development of IPv6 functions began soon after publication of the initial standards document in 1998. As functions progressed, a small group took ownership of an IPv6 tunneling solution that allowed the labs to communicate across the corporate network for interoperability testing. Limited support for end-user

systems was added in 2003, enabling developers to connect directly to the test labs as well as the external IPv6 Internet.

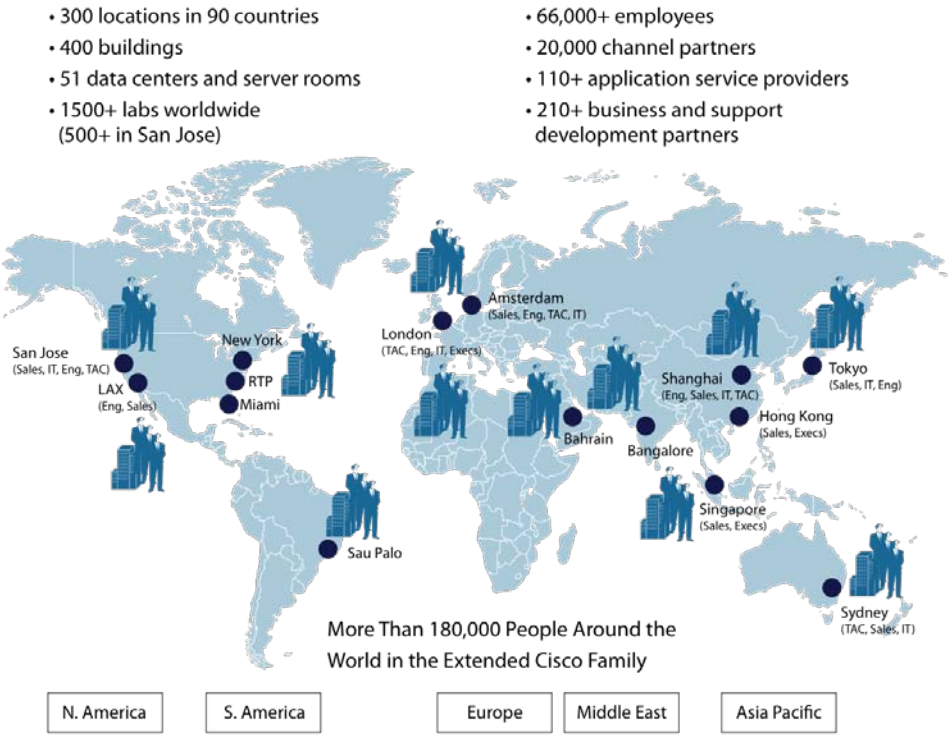
Business Reasons

One of the first matters to sort out is why IPv6 integration is important to the organization. The answer to this question will help set the priority, scope, and timing of the project. There are numerous business reasons for deploying IPv6: corporate growth, compliance with national policies, enabling new functions, communicating with other IPv6 users and organizations, and extending connectivity to sensors or other small devices are the most commonly referenced. IPv6 deployment at Cisco currently has two primary business justifications: growth of the corporation and delivery of industry-leading functions as a vendor of network products.

More than just Addresses

Corporate growth is an important influencer for the Cisco IT department to move ahead with IPv6. The company has more than 66,000 employees, spread across 400 buildings in 90 countries, supported by more than 50 data centers (see Figure 1). Various business functions, including engineering, quality assurance, and customer advocacy, rely on more than 1500 labs. A large network of partners in development, manufacturing, sales, and service more than triples the size of the network. Even with Network Address Translation (NAT), address depletion in IPv4 is imminent, and the IT department wants to move to IPv6 before it becomes critical and potentially affects the company's business operations.

Figure 1. Information about Cisco



Moving to IPv6 is about more than just address space. IPv6 makes address assignment more effective and improves routing performance with a simplified header. The new protocol also complicates matters with a vastly expanded routing table and new security concerns.

Like many organizations, Cisco IT is under constant pressure to evolve. Upgrades to servers and PCs introduce operating system versions that have been IPv6-enabled. A strategy needs to be put in place to deal with the

presence of IPv6 on the network (planned and unplanned) to address potential effects on existing services. It is also critical to address the security implications of having another network transport available.

Cisco IT also has to be able to respond to other business objectives when looking at IPv6 integration. Projects such as server virtualization, cloud computing, data center consolidation and modernization, and network infrastructure upgrades compete for IT resources and affect profitability with regard to how Cisco delivers services to our customers.

More than just Products

For Cisco, delivering IPv6 products ready for customer deployment is at least as important as the internal deployment. The engineering and manufacturing organizations need to increase the corporate infrastructure for development and testing of IPv6 products to ensure that products and solutions are ready for broader deployment. In addition, smart and connected communities and green initiatives are focus areas for next-generation products and services. As these architectures and solutions evolve, many of them require some level of IPv6 deployment.

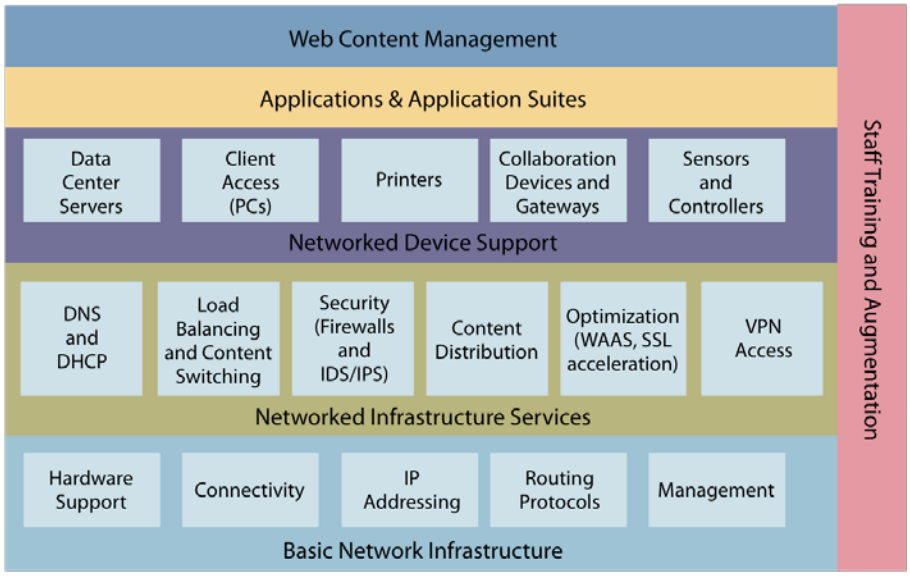
Because Cisco is the worldwide leader in networking, customers around the globe look to Cisco to provide guidance on IPv6 migration. Cisco employees also aim to be on the leading edge of the technologies and features that are running in the network. By internally deploying features and solutions, Cisco is able to identify gaps earlier and provide feedback on our experiences. Using the resulting best practices and lessons learned, Cisco helps customers integrate new technologies more easily.

Governments are facing IPv6 deployment pressure and are developing policies and guidelines for IPv6 support in their internal and national networks. IPv6 migration at government agencies and national carriers is the primary objective, but there is a ripple effect on equipment and services companies. As a result, GGSG at Cisco is at the forefront of many IPv6 projects.

Challenges of Technology, Resources, and Organization

IPv6 deployment is an enterprise-wide problem, covering not just networks and servers, but also desktops, applications, security, and other endpoints (see Figure 2). The basic network infrastructure is the first priority, including IP addressing and routing protocols. Network services are next. Most of these functions are available in IPv6 implementations today. The challenge is mostly one of configuration and testing. However, some network services, especially security, rely heavily on IPv4 packet header information, and require modifications to provide the same level of service in IPv6.

Figure 2. Enterprise IPv6 Adoption



Desktops, laptops, and servers can use a dual-stack approach, supporting simultaneous connectivity with both IP versions. Traditional devices, such as printers, may be accessible only through IPv4, whereas newer devices, such as small sensors and controllers, may use only IPv6. The dual-stack approach integrates both types of devices into the network.

Most of the technology challenges are a matter of resources. It takes time to learn the configuration and operation details for the additional protocol. Staff requires additional training. The team needs to upgrade or replace some network devices because of product gaps and other protocol support concerns. Commercial IPv6 offerings may not be available everywhere, requiring temporary tunneling. Remote office deployment can be very time-consuming. And, like any project, detailed budgets and headcount numbers are required for approval.

Building the Team

Because the network reaches into every aspect of business, organizational concerns become the biggest challenge in IPv6 deployment. This type of project is not solely within the domain of IT, and IT cannot unilaterally implement a solution. The interconnected and always-on nature of the business means that a bottom-up approach is insufficient. Many different groups have to work together for an IPv6 project to be successful, and executive support and leadership is critical for success. As a result, the team needs to be cross-functional and the pilot implementation cannot rely on the resources of a single department.

GGSG, which is acting as the catalyst, began with resources from its internal services organization and added representation from Cisco global IT, local network and desktop support teams, and information security. This core team remained relatively small but communicated broadly, bringing in additional resources when necessary. Engaging corporate IT initially, sharing the corporate vision, and being willing to accept risk and be an early IPv6 adopter are fundamental to any pilot IPv6 implementation with resource support from the corporate team.

Goals, Requirements, and Scope

One of the first steps of any project is to define the goals, requirements, and scope. The project team started with a brainstorming session on where and how IPv6 integration might happen, creating a wide range of options, including voice services, wireless devices, building automation, and data centers. Upon further analysis, the team decided that, although any of these options would show great progress, they were secondary implementations that required IPv6 on the network infrastructure.

Implementation across the network infrastructure and a defined set of desktops provided the foundation for services and applications to use when they are ready. As a result, the IPv6 team identified three important goals for the project:

- Provide a publicly accessible IPv6 Internet presence
- Facilitate IPv6-enabled user access in the network
- Build toward end-to-end IPv6 in the network using dual stacks

Supporting both IPv4 and IPv6 devices with a common infrastructure is the goal, providing a consistent user experience without users needing to be aware of which protocol they are using. Over the longer term, IPv4 will fade away, but this process could take 10 or more years. In the meantime, the team identified the fundamental project requirements:

- Integration must not affect any existing services and applications.
- There must be no reduction in the corporate security posture.
- Reuse existing infrastructure, capabilities, content, and application environments whenever possible.
- There will be some willingness to sacrifice IPv6 (but not IPv4) user experience, manageability, and service levels for near-term goals.
- Deployment covers a broad range of applications and devices and must be prioritized across all IT functions.

The next step was to establish the scope of the project, with GGSG acting as the catalyst to pilot IPv6 integration on the Cisco network. GGSG provides consulting and engineering services to Cisco customers in the public sector market segment. Its experience interacting with the U.S. Federal Government and other national groups on IPv6 is a definite advantage. This group is also contained within a single Cisco building, limiting the organizational effect on Cisco as a whole. When the project is complete, the team will have a template for deploying IPv6 to the more than 400 Cisco buildings around the world.

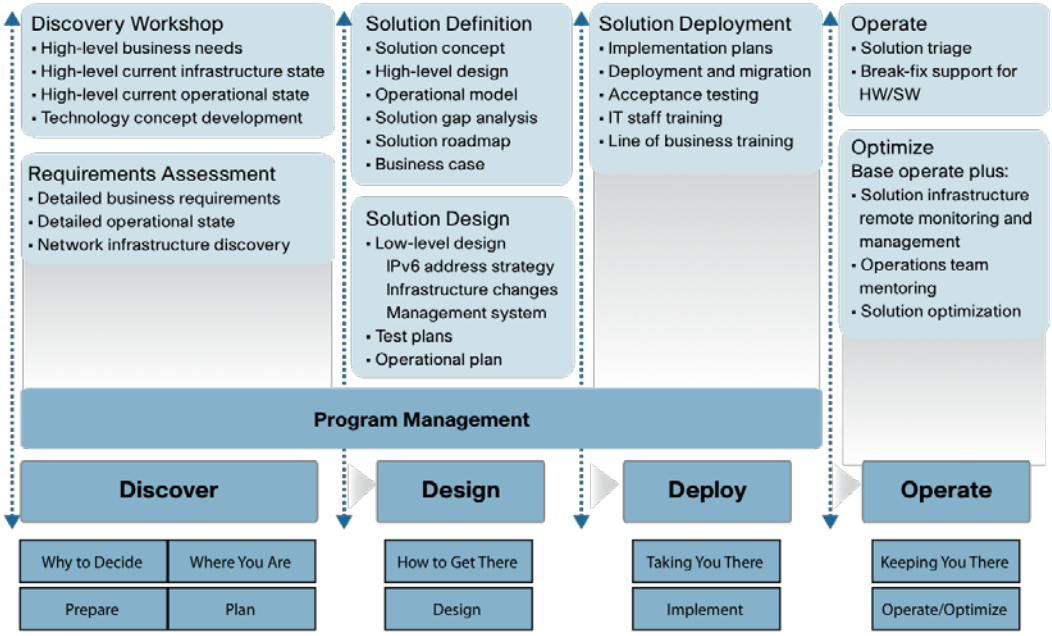
Planning and Design

With the goals, requirements, and scope defined, the team moved on to planning and design, consulting people from all parts of the IT organization. With the resulting high-level design, the team evaluated each component for IPv6 functions, separating them into three groups:

- Products that have IPv6 capability installed but may require configuration changes
- Products without IPv6 installed but with upgrades readily available
- Products with no IPv6 support available within a reasonable timeframe

Checking the devices requiring upgrades or replacements against the IT department’s life-cycle planning schedule highlighted that most could be upgraded or replaced within the existing budget. The remaining units were added to the project budget for approval.

Figure 3. IPv6 Solution Services Framework



The next step in the plan was extending the existing IT department cookbooks to cover IPv6, aiming to keep every deployment as standardized as possible (see Figure 3). The team planned to build or modify its network management and deployment tools to handle IPv6 addresses. A spreadsheet-based tool generates the appropriate addresses, subnets, and VLANs for each router, using a consistent numbering scheme. The tool then generates the Cisco IOS® Software router configuration changes, stripping out any traditional IPv6 commands and tunnels. With this level of basic automation, the team can generate router configurations for the 60+ routers involved in this phase in less than 1 hour, and deploy the changes in less than 2 hours. Standardized numbering and consistent network topology between different sites is vital for automating this complex task.

An important part of the implementation and Cisco best practice for large or complex deployments is a controlled lab environment. Building the lab allowed the team to test and evaluate the effect of dual-stack operations on the network. The team could look for adverse side effects IPv6 might have on the existing IPv4 network and applications. Using the lab, the team discovered that some aspects of the network management and security systems were not going to support IPv6 within the original timeline, adding more time, people, and money to the project budget.

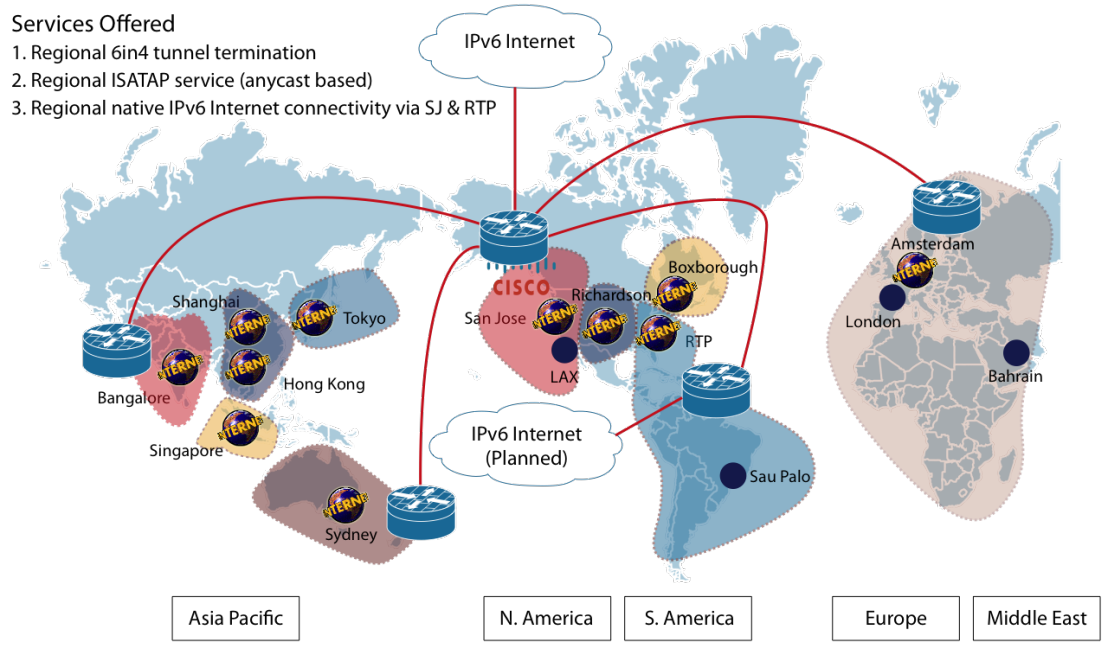
Phased Implementation

After analyzing the business goals and priorities and looking at other internal initiatives, the Cisco IPv6 team decided on a phased implementation. The team separated the IPv6 integration problem into component areas that were easier to implement individually and independent of each other, allowing them to do some work in parallel when resources were available:

- Phase 0: Experimental (Intra-Site Automatic Tunnel Addressing Protocol [ISATAP])
- Phase I: Core and Tunneling
- Phase IA: Labs and Key Sales Locations
- Phase II: Desktop and Data Center pilots
- Phase III: Full Implementation

The early phases of the protocol migration used tunnels that carry IPv6 traffic in IPv4 packets, a technique called **6in4**. In phase 0, the team deployed a single tunnel headend to provide IPv6 connectivity from the company headquarters in San Jose, California. Desktops use ISATAP to generate an IPv6 address from their IPv4 address. This implementation allowed for interested internal users across the global Cisco network to gain access to the IPv6 Internet without having to enable IPv6 on the internal network. Phase 0 operated informally without any extra budget or dedicated resources, offering no guarantees on the availability or quality of service. However, it provided some experience and exposure to IPv6 operations for interested parties without affecting business operations. This is an effective starting point, but suffers from high latency for intra-region traffic because of the single tunnel.

Figure 4. Cisco IT: Regional IPv6 Tunnel Head Ends—Phase I



Phase I of the project is a formal implementation enabling native IPv6 transport in the network core, and extending connectivity with tunnels between the five major regions (see Figure 4). The Cisco core network and global WAN begin the migration from tunneling to a dual-stack approach, running both protocol versions. This step reduces latency between the regions and adds redundancy with multiple tunnel endpoints. Phase IA is a small pilot project in selected remote Cisco offices to measure the effect of an IPv6 deployment in terms of network stability, support, and security. These small projects allow the team to identify the benefits, risks, and gaps of a larger implementation.

Phase II pushes the integration process into the desktop and access parts of the network. This phase focuses on a single building and organization to evaluate processes and procedures and capture lessons learned, providing further refinements before the broad deployment in phase III. One of the advantages of these project components is that phases I and II can run in parallel. Until the corporate backbone becomes IPv6-enabled, the phase II activities can use the existing tunnels.

The team is realizing the full extent of IPv6 deployment on the IT organization. The network and data center services are obviously at the core of the project, with significant effect on almost all operational areas. Application hosting and databases are also affected, especially the infrastructure and management functions that support the servers. Most important, and a gating concern to the deployment, is the effect on security. Security monitoring is heavily dependent on packet header information, and requires significant technology updates to provide the same level of security for IPv6 devices.

Phase III will see the full deployment of IPv6, building on the lessons from the earlier steps and integrating into all aspects of the network. The next sections of this paper focus on the challenges and lessons learned in preparing for the phase II pilot implementation.

Security from Lab to Production

The first few years of IPv6 support on the Cisco network provided internal connections between labs and some developers, with no external connections. As a result, a small team managed the tunneling services on a best-effort basis, with little security management or monitoring. Increased availability of external IPv6 sites and changing demands on the internal network from developers to more general user access, including default enablement of the IPv6 stack on Windows and Apple Mac platforms, has changed the risk profile, because hundreds, perhaps thousands, of users and devices have access to the IPv6 Internet.

External IPv6 threats have also begun to appear, both intentional and accidental, as more networks provide IPv6 support. The current range of IPv6 security threats derives largely from new automatic addressing techniques and header features of the protocol, and affects user privacy, network availability, protocol transparency, and infrastructure.

User Privacy and Security

The increase in IPv6 addressing space makes host configuration easier and eliminates the need for NAT. The lower 64 bits can accommodate the unique MAC address of a device and use it as an extended unique identifier, allowing devices to configure themselves without requiring a Dynamic Host Configuration Protocol (DHCP) server. However, this Stateless Address Autoconfiguration creates some security benefits and risks. One of the main benefits (for inbound security) is the slight increase in user attribution. Without address translation, it is much easier to locate and identify the source of packet flows. This situation translates to a threat for outbound security, because it reduces the strength of a perimeter security model. With no translation to hide behind, corporate computing addresses are clearly visible to the outside world. In addition, devices can trigger updates directly to the Dynamic Domain Name System, instead of limiting updates to a trusted server. Developing appropriate policy in this area involves trade-offs between ease of operations, user privacy, and information security.

Transparency and Tunneling

Tunneling is a significant component of IPv6 migration, and one that causes some security challenges. When using 6in4 tunnels, the IPv6 traffic is encapsulated in a single flow between networks. Like other IP tunnels, this encapsulation makes it difficult to differentiate between traffic flows or take actions based on the real source and destination address. Security processing for IPv6 moves from the network perimeter to the IPv6 gateway, bypassing the firewalls and access control lists (ACLs). Tunnels also make deep packet inspection more challenging, and there are already documented cases of attacks using 6in4 tunnels in an attempt to get through a firewall.

Infrastructure

Packet header and address nomenclature changes create most of the risks with IPv6 because of limited deployment experience. These risks will diminish over time as vendors put the appropriate functions into security and infrastructure products. However, in the meantime it is important to understand the nature of various risks to network infrastructure, from ACLs to routing headers.

When the network supports IPv6, new addresses are required in ACLs, but the potential for user input error is higher because of their length. Automatic mapping of IPv4 to IPv6 addresses may inadvertently bypass existing lists. In addition, the ACLs will also have to process the IPv6 routing header to protect internal devices from inadvertently forwarding unwanted packets. In fact, with both IP protocols in operation on the network, the number of ACLs will double.

Amplification attacks involve structuring packet headers to force a router to spend excessive cycles forwarding packets to multiple destinations or loopback through its own interfaces, or generating multiple responses to an unprocessable packet. Appropriate software and configuration updates will counter this threat in its current form.

Denial-of-service (DoS) attacks have new capabilities to exploit in IPv6. An attacker can overuse the router alert option, consuming processing cycles. Packet fragmentation could overload buffers by sending a large quantity of small fragments without a termination marker. A greater concern is the increasing number of IP-enabled devices, coupled with potential security holes in their software, creating the possibility of larger attacks.

IPv6 neighbor discovery allows a device to find active neighbors and routers on its subnet, and is a critical part of address autoconfiguration. However, this protocol is vulnerable to potential attacks. Unauthorized or maliciously controlled devices can send out their own Router Advertisements to redirect traffic, cut off connectivity, or overload a network. IPv6 security mechanisms such as Secure Neighbor Discovery and Authentication Header provide verification services for router messages.

Project Challenges

This project has faced many challenges, including competing priorities, which fit into three categories: money, people, and functions.

Justifying the cost of an IPv6 migration plan can be challenging without a crisis or compelling business reason. However, waiting until the address space is exhausted can cost many times more in extra resources and operational effects. Developing accurate financial costs and operational benefits is an important part of the early stages of the project, including hardware and software costs and headcount. Demonstrating the existing costs of temporary or basic projects can reduce the incremental cost of personnel. Incorporating device upgrades into existing lifecycle budgets is another effective way of reducing the overall project cost.

One of the biggest challenges is communicating the seriousness of IPv6 migration to decision makers and people within the reporting chain. Having an executive champion is desirable but not sufficient, and it is necessary to communicate the business reasons to everyone in the chain and make sure they have a stake in the outcome. Moving beyond phase II to broad deployment could consume a significant amount of time and resources to migrate more than 400 offices. Address planning, standardized cookbooks, and automated tools are necessary to make this process manageable.

Tools and devices without IPv6 capabilities presented another large challenge. After identifying specific product and security gaps, the project team created a focus group to address the concerns. The concerns included compatibility testing, software version checklists, management tools, and commercial IPv6 service offerings to carry the traffic. One of the bigger challenges has been modifying or upgrading existing in-house management and security applications to support IPv6.

Best Practices and Lessons Learned

As the team continues with the IPv6 deployment, it is learning some valuable lessons about IPv6 deployment and identifying best practices. One important and unanticipated lesson was recognizing legal matters as an integral part of the decision process. As IPv6 functions move out from the lab and into contact with customers and partners, privacy obligations and potential security risks must be evaluated, addressed, and communicated to affected parties.

In the very early stage of IPv6 deployment, when the project amounted to just some tunnels and desktops using ISATAP, the service was a limited offering with best-effort support. Minimal IPv6 knowledge and support resources were acceptable at the beginning, because there was no immediate effect on business if the service was temporarily unavailable. No formal training was required, and this approach enabled the IT team to build IPv6 experience from the early stages, with a combination of lab and production environments. As the deployment expands and begins to

support business-affecting services, the team is identifying important touch points for service-level agreements and socializing with the network and end-user support groups.

Network addressing for this small group of users was not of significant concern. However, developing a high-level IPv6 address distribution plan becomes important quickly. It is not necessary at the beginning, but the sooner you develop a plan, the less work you will have readdressing devices later on. Address management is also important. The Cisco IT team has long had management tools for the IPv4 address space, and the team invested early in similar solutions for IPv6. Automation increases the speed and reduces errors of configuration changes.

Of course, enabling IPv6 requires more than just network connectivity. For example, DHCP services have to handle devices that use stateless autoconfiguration based on their MAC address, and those such as Windows 7 that randomize the unique identifier and change it frequently. Domain Name System (DNS) services are still necessary and the address plan and management tools become useful here. At this point, creation of a small team that covers the necessary network, security, and services will improve the speed and quality of the deployment.

Instead of applying for additional budget to deploy IPv6, the team included the requirements as part of the standard hardware and software lifecycle maintenance process. This scenario takes advantage of the steady turnover of equipment and upgrades to bring in new capabilities and build up a general state of readiness. In some cases, the necessary IPv6 functions were installed but not configured, and in many cases, they were readily available as software-only upgrades. Upgraded desktops and laptops have the opposite problem, with IPv6 enablement creating the potential for rogue users. The team is working with its desktop partners to have IPv6 disabled by default on all new or upgraded systems.

Network monitoring and security tools are the biggest challenge, because they have generally been slower to include IPv6 functions. In the early stages, this situation was not of concern. The team did minimal security and monitoring, because connections were internal and there were few if any external threats. However, security has moved to top of mind as connectivity moves from development lab connections to more general access. The risk profile is much higher with increasing external threats and hundreds if not thousands of people going out to the IPv6 Internet. Staying in close contact with information security is an important practice for the deployment team, to make sure that the maturity of IPv6 functions keeps pace with the increased risk.

Additional Resources

IPv4 Address Space Depletion

Numerous reports provide supporting details and information about IPv4 address depletion that can help justify migration projects, including:

- IPv4 address report: http://www.potaroo.net/tools/ipv4/index.html
- IPv4/IPv6—The Bottom Line: https://www.arin.net/knowledge/v4-v6.html

National Strategies

Many government organizations have published IPv6 deployment policies for their own networks or as guidelines for members. Some of the larger examples follow:

- U.S. Federal Government: http://www.cio.gov/documents/IPv6MemoFINAL.pdf
- Organisation for Economic Co-operation and Development (OECD) Resources on Internet addressing: http://www.oecd.org/sti/ict/ipv6
- European Union: http://ec.europa.eu/information_society/policy/ipv6/index_en.htm
- China Next-Generation Internet (CNGI): http://www.cernet2.edu.cn/en/bg.htm
- Japan: http://www.v6pc.jp/en/

- United Kingdom: http://www.ja.net/development/network-engineering/ipv6/
- India: http://ipv6forum.in/

Os Deployment

Most major computer operating systems already include support for IPv6. Details for three of the largest are available:

- Microsoft: http://technet.microsoft.com/en-us/network/bb530961.aspx
- MacOS: http://docs.info.apple.com/article.html?path=Mac/10.5/en/8708.html
- Linux: http://www.linux.org/docs/ldp/howto/Linux+IPv6-HOWTO/index.html
- Solaris: http://download.oracle.com/docs/cd/E18752_01/html/816-4554/ipv6-ref-83.html

Infrastructure Evolution

- Mobile devices: Smaller devices are slowly adding support for IPv6 as well, with support pending for Apple iPhones and Android-based phones: http://www.networkworld.com/news/2009/061009-verizon-lte-ipv6.html?fsrc=netflash-rss
- Sensors: http://ipv6.com/articles/sensors/IPv6-Sensor-Networks.htm
- Building automation: http://www.automatedbuildings.com/news/jun09/articles/bas/090519010450bas.htm
- Smart grid: http://www.internetnews.com/infra/article.php/3839641/Cisco-IPv6-and-Smart-Grid-Make-Sense-Together.htm
- Smart objects and cloud computing: https://learningnetwork.cisco.com/blogs/on_assignment/2010/09/05/more-on-smartconnected-communities-and-update-itu-t-focus-group-cloud-computing

Cisco Advanced Services

The challenge of migration from an IPv4 network to an IPv6 network is becoming a reality, and careful planning of your IPv6 migration will be critical to your success. To help you meet your goals for network migration, Cisco® Advanced Services offers IPv6 Assessment and Migration Services that can provide you with a comprehensive evaluation and migration plan for your IPv6 network. For more information about Cisco Advanced Services or IPv6 services, contact your local Cisco representative

Cisco Advanced Services:

http://www.cisco.com/en/US/products/svcs/ps2961/serv_category_home.html

Cisco IPv6 White Papers:

http://www.cisco.com/en/US/prod/collateral/iosswrel/ps6537/ps6553/white_paper_c11-563999.html.

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Printed in USA C11-637821-01 03/11