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IP Security
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In 1994, the *Internet Architecture Board* (IAB) issued a report entitled "Security in the Internet Architecture" (RFC 1636). The report stated the general consensus that the Internet needs more and better security, and it identified key areas for security mechanisms. Among these were the need to secure the network infrastructure from unauthorized monitoring and control of network traffic and the need to secure end-user-to-end-user traffic using authentication and encryption mechanisms.

These concerns are fully justified. As confirmation, the 1998 annual report from the *Computer Emergency Response Team* (CERT) lists over 1,300 reported security incidents affecting nearly 20,000 sites. The most serious types of attacks included IP spoofing, in which intruders create packets with false IP addresses and exploit applications that use authentication based on IP address; and various forms of eavesdropping and packet sniffing, in which attackers read transmitted information, including logon information and database contents.

In response to these issues, the IAB included authentication and encryption as necessary security features in the next-generation IP, which has been issued as IPv6. Fortunately, these security capabilities were designed to be usable both with the current IP (IPv4) and IPv6, meaning that vendors can begin offering these features now, and many vendors do now have some *IP Security Protocol* (IPSec) capability in their products.

Applications of IPSec

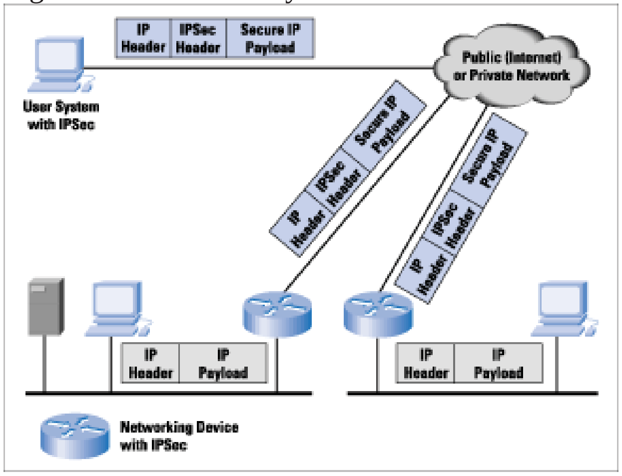
The Internet community has developed application-specific security mechanisms in numerous application areas, including electronic mail (*Privacy Enhanced Mail, Pretty Good Privacy* [PGP]), network management (*Simple Network Management Protocol Version 3*[SNMPv3]), Web access (Secure HTTP, *Secure Sockets Layer* [SSL]), and others. However, users have some security concerns that cut across protocol layers. For example, an enterprise can run a secure, private TCP/IP network by disallowing links to untrusted sites, encrypting packets that leave the premises, and authenticating packets that enter the premises. By implementing security at the IP level, an organization can ensure secure networking not only for applications that have security mech-anisms but also for the many security-ignorant applications.

IPSec provides the capability to secure communications across a LAN, across private and public WANs, and across the Internet. Examples of its use include:

- Secure branch office connectivity over the Internet: A company can build a secure virtual private network over the Internet or over a public WAN. This enables a business to rely heavily on the Internet and reduce its need for private networks, saving costs and network management overhead.
- Secure remote access over the Internet: An end user whose system is equipped with IP security protocols can make a local call to an *Internet Service Provider* (ISP) and gain secure access to a company network. This reduces the cost of toll charges for traveling employees and telecommuters.
- Establishment of extranet and intranet connectivity with partners: IPSec can be used to secure communication with other organizations, ensuring authentication and confidentiality and providing a key exchange mechanism.
- Enhancement of electronic commerce security: Most efforts to date to secure electronic commerce on the Internet have relied upon securing Web traffic with SSL since that is commonly found in Web browsers and is easy to set up and run. There are new proposals that may utilize IPSec for electronic commerce.

The principal feature of IPSec that enables it to support these varied applications is that it can encrypt or authenticate all traffic at the IP level. Thus, all distributed applications, including remote logon, client/server, e-mail, file transfer, Web access, and so on, can be secured. Figure 1 shows a typical scenario of IPSec usage. An organization maintains LANs at dispersed locations. Traffic on each LAN does not need any special protection, but the devices on the LAN can be protected from the untrusted network with firewalls. Since we live in a distributed and mobile world, the people who need to access the services on each of the LANs may be at sites across the Internet. These people can use IPSec protocols to protect their access. These protocols can operate in networking devices, such as a router or firewall that connects each LAN to the outside world, or they may operate directly on the workstation or server. In the diagram, the user workstation can establish an IPSec tunnel with the network devices to protect all the subsequent sessions. After this tunnel is established, the workstation can have many different sessions with the devices behind these IPSec gateways. The packets going across the Internet will be protected by IPSec but will be delivered onto each LAN as a normal IP packet.

Figure 1: An IP Security Scenario



*Note:Click above for larger view

Benefits of IPSec

The benefits of IPSec include:

- When IPSec is implemented in a firewall or router, it provides strong security that can be applied to all traffic crossing the perimeter. Traffic within a company or workgroup does not incur the overhead of security-related processing.
- IPSec is below the transport layer (TCP, UDP), so is transparent to applications. There is no need to change software on a user or server system when IPSec is implemented in the firewall or router. Even if IPSec is implemented in end systems, upper layer software, including applications, is not affected.
- IPSec can be transparent to end users. There is no need to train users on security mechanisms, issue keying

material on a per-user basis, or revoke keying material when users leave the organization.

- IPSec can provide security for individual users if needed. This feature is useful for offsite workers and also for setting up a secure virtual subnetwork within an organization for sensitive applications.

Is IPSec the Right Choice?

There are already numerous products that implement IPSec, but it is not necessarily the security solution of choice for a network administrator. Christian Huitema, who at the time of the development of the initial IP-Sec documents was the head of the IAB, reports that the debates over how to provide Internet-based security were among the most heated that he ever observed. One issue concerns whether security is being provided at the right protocol layer. To provide security at the IP level, it is necessary for IPSec to be a part of the network code deployed on all participating platforms, including Windows NT, UNIX, and Macintosh systems. Unless a desired feature is available on all the deployed platforms, a given application may not be able to use that feature.

On the other hand, if the application, such as a Web browser/server combination, incorporates the function, the developer can guarantee that the features are available on all platforms for which the application is available. A related point is that many Internet applications are now being released with embedded security features. For example, Netscape and Internet Explorer support SSL, which protects Web traffic. Also, many vendors are planning to support *Secure Electronic Transaction* (SET), which protects credit-card transactions over the Internet. How-ever, for a virtual private network, a network-level facility is needed, and this is what IPSec provides.

The Scope of IPSec

IPSec provides three main facilities: an authentication-only function, referred to as *Authentication Header* (AH), a combined authentication/ encryption function called *Encapsulating Security Payload* (ESP), and a key exchange function. For virtual private networks, both authentication and encryption are generally desired, because it is important both to (1) assure that unauthorized users do not penetrate the virtual private network and (2) assure that eavesdroppers on the Internet cannot read messages sent over the virtual private network. Because both features are generally desirable, most implementations are likely to use ESP rather than AH. The key exchange function allows for manual exchange of keys as well as an automated scheme.

The IPSec specification is quite complex and covers numerous documents. The most important of these, issued in November 1998, are RFCs 2401, 2402, 2406, and 2408.

Security Associations

A key concept that appears in both the authentication and confidentiality mechanisms for IP is the *Security Association* (SA). An association is a one-way relationship between a sender and a receiver that affords security services to the traffic carried on it. If a peer relationship is needed, for two-way secure exchange, then two security associations are required. Security services are afforded to an SA for the use of AH or ESP, but not both. A security association is uniquely identified by three parameters:

- *Security Parameters Index* (SPI): The SPI assigns a bit string to this SA that has local significance only. The SPI is carried in AH and ESP headers to enable the receiving system to select the SA under which a received packet will be processed.
- *IP destination address* : Currently, only unicast addresses are allowed; this is the address of the destination endpoint of the SA, which may be an end-user system or a network system such as a firewall or router.
- *Security protocol identifier* : This indicates whether the association is an AH or ESP security association.

Hence, in any IP packet, the security association is uniquely identified by the destination address in the IPv4 or IPv6 header and the SPI in the enclosed extension header (AH or ESP).

An IPSec implementation includes a security association database that defines the parameters associated with each SA. A security association is defined by the following parameters:

- *Sequence number counter* : A 32-bit value used to generate the sequence number field in AH or ESP headers
- *Sequence counter overflow* : A flag indicating whether overflow of the sequence number counter should generate an auditable event and prevent further transmission of packets on this SA
- *Anti-replay window* : Used to determine whether an inbound AH or ESP packet is a replay, by defining a

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