Practical Aspects of Modern Cryptography

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Lecture 9: Kerberos and IPSEC

Kerberos & IPSEC

- We’ve already seen SSL/TLS and how it’s used to secure two-party communications over the web
- Today we look at two additional protocol suites in widespread use today to secure client-server and peer-to-peer transactions
  - Kerberos
  - IPSEC

Kerberos

- Designed for single “administration domain” of machines & users: users, client machines, server machines, and the Key Distribution Center (KDC)
- No public key crypto
- Provides authentication & encryption services
- “Kerberized” servers provide authorization on top of the authenticated identities

Kerberos History

- Designed as part of MIT’s Project Athena in the 1980’s
  - Kerberos v4 published in 1987
- Migration to the IETF
  - RFC 1510 (Kerberos v5, 1993)
- Used in a number of products
  - Example: part of Windows 2000
  - Passport is essentially Kerberos done w/ client-side cookies over HTTP

The Kerberos Model

- Clients
- Servers
- The Key Distribution Center (KDC)
- Centralized trust model
  - KDC is trusted by all clients & servers
  - KDC shares a secret, symmetric key with each client and server
- A “realm” is single trust domain consisting of one or more clients, servers, KDCs

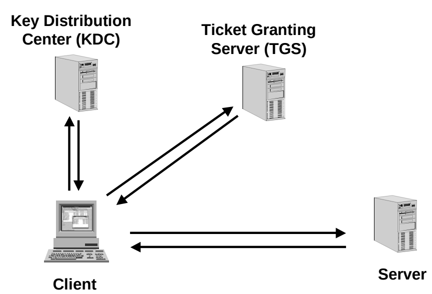
Joining a Kerberos Realm

- One-time setup
  - Each client, server that wishes to participate in the realm exchanges a secret key with the KDC
  - If the KDC is compromised, the entire system is cracked
- Because the KDC knows everyone's individual secret key, the KDC can issue credentials to each realm identity

Kerberos Credentials

- Two types of credentials in Kerberos
  - Tickets
  - Authenticators
- Tickets are credentials issued to a client for communication with a specific server
- Authenticators are additional credentials that prove a client knows a key at a point in time
  - Basic idea: encrypt a nonce

Picture of a Kerberos Realm



The Basic Kerberos Protocol

Assume client C wishes to authenticate to and communicate with server S

Phase 1: C gets a Ticket-Granting Ticket (TGT)

Phase 2: C gets a Ticket for S

Phase 3: C communicates with S

Protocol Definitions

Following Schneier (Section 24.5):

- C = client, S = server
- TGS = ticket-granting service
- K_x = x's secret key
- $K_{x,y}$ = session key for x and y
- $\{m\}K_x$ = m encrypted in x's secret key
- $T_{x,y}$ = x's ticket to use y
- $A_{x,y}$ = authenticator from x to y
- N_x = a nonce generated by x

The Basic Kerberos Protocol (1)

Phase 1: C gets a Ticket-Granting Ticket

1. C sends a request to the KDC for a "ticket-granting ticket" (TGT)
   - A TGT is a ticket used to talk to the special ticket-granting service
   - A TGT is relatively long-lived (~8-24 hours typically)

$$C \Rightarrow KDC: C, TGS, N_C$$

Sent in the clear!

The Basic Kerberos Protocol (2)

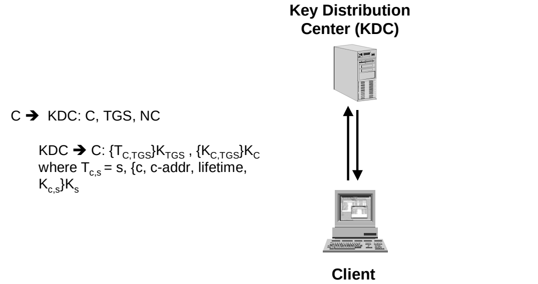
Phase 1: C gets a Ticket-Granting Ticket

2. KDC responds with two items
   - The ticket-granting ticket
     - A ticket for C to talk to TGS
   - A copy of the session key to use to talk to TGS, encrypted in C's shared key

     KDC ➔ C: $\{T_{C,TGS}\}K_{TGS}$, $\{K_{C,TGS}\}K_C$

     where $T_{c,s}$ = s, {c, c-addr, lifetime, $K_{c,s}\}K_s$
   - Only the TGS can decrypt the ticket
   - C can unlock the second part to retrieve $K_{C,TGS}$

Picture of a Kerberos Realm



The Basic Kerberos Protocol (3)

Phase 2: C gets a Ticket for S

3. C requests a ticket to communicate with S from the ticket-granting service (TGS)
   - C sends TGT to S along with an authenticator requesting a ticket from C to S

   C ➔ TGS: $\{A_{C,S}\}K_{C,TGS}$, $\{T_{C,TGS}\}K_{TGS}$

   where $A_{c,s}$ = {c, timestamp, opt. subkey}$K_{c,s}$
   - First part proves to TGS that C knows the session key
   - Second part is the TGT C got from the KDC

The Basic Kerberos Protocol (4)

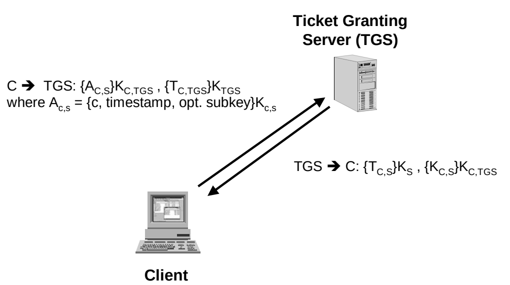
Phase 2: C gets a Ticket for S

4. TGS returns a ticket for C to talk to S

   (Just like step 2 above...)

   TGS ➔ C: $\{T_{C,S}\}K_S$, $\{K_{C,S}\}K_{C,TGS}$
   - Only S can decrypt the ticket
   - C can unlock the second part to retrieve $K_{C,S}$

Picture of a Kerberos Realm



The Basic Kerberos Protocol (5)

Phase 3: C communicates with S

5. C sends the ticket to S along with an authenticator to establish a shared secret

   C ➔ S: $\{A_{C,S}\}K_{C,S}$, $\{T_{C,S}\}K_S$

   where $A_{c,s}$ = {c, timestamp, opt. subkey}$K_{c,s}$
   - S decrypts the ticket $T_{C,S}$ to get the shared secret $K_{C,S}$ needed to communicate securely with C

The Basic Kerberos Protocol (6)

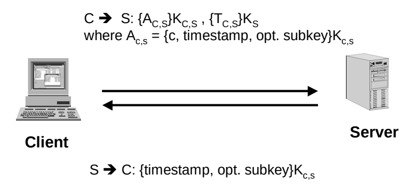
Phase 3: C communicates with S

6. S decrypts the ticket to obtain the $K_{C,S}$ and replies to C with proof of possession of the shared secret (optional step)

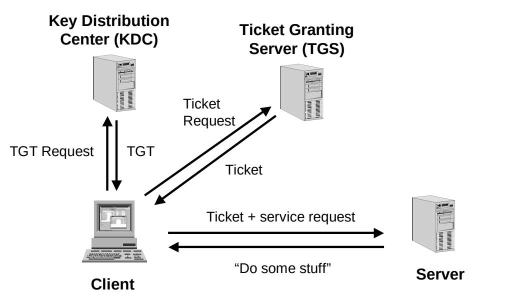
   S ➔ C: {timestamp, opt. subkey}$K_{c,s}$

   Notice that S had to decrypt the authenticator, extract the timestamp & opt. subkey, and re-encrypt those two components with $K_{c,s}$

Picture of a Kerberos Realm



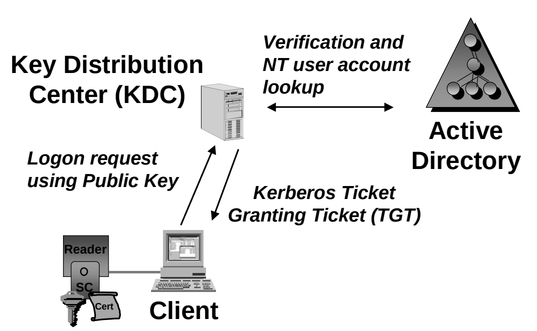
Picture of a Kerberos Realm



Thoughts on Kerberos...

- There's no public key crypto anywhere in the base Kerberos spec, but you can modify the base protocols to use PK...
  - Example: the initial "login" to the KDC could be done with public key for added security (e.g. PKINIT protocol)
  - More on this from final project presentations...

PKINIT in Windows 2000



Thoughts on Kerberos...(2)

- Only the KDC needs to know the user's password (used to generate the shared secret)
  - You can have multiple KDCs for redundancy, but they all need to have a copy of the username/password database
- Only the TGS needs to know the secret keys for the servers
  - You can split KDC from TGS, but it is common for those two services to reside on the same physical machine

Thoughts on Kerberos...(3)

- Cross-realm trust is possible
  - Just need to share a secret key between the KDCs for the two realms...
  - Once accomplished, a user in realm A can get a ticket for a service in realm B

Thoughts on Kerberos...(4)

- "Time" is very important in Kerberos
  - All participants in the realm need accurate clocks
  - Timestamps are used in authenticators to detect replay; if a host can be fooled about the current time, old authenticators could be replayed
  - Tickets tend to have lifetimes on the order of hours, and replays are possible during the lifetime of the ticket

Thoughts on Kerberos...(5)

- Password-guessing attacks are possible
  - Capture enough encrypted tickets and you can brute-force decrypt them to discover shared keys
  - (Another reason to use public key...)

Thoughts on Kerberos...(6)

- It's possible to screw up the implementation
  - In fact, Kerberos v4 has had a colossal security breach due to bad implementations

RNGs in Kerberos v4

- Session keys were generated from a PRNG seeded with the XOR of the following:
  - Time-of-day in seconds since 1/1/1970
  - Process ID of the Kerberos server process
  - Cumulative count of session keys generated
  - Fractional part of time-of-day seconds
  - Hostid of the machine running the server

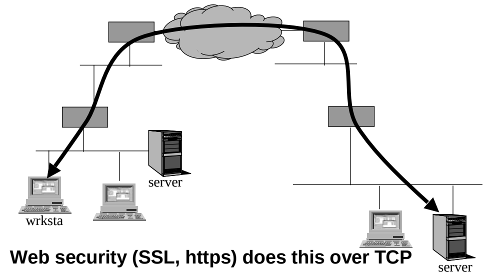
RNGs in Kerberos v4 (continued)

- The seed is a 32-bit value, so while the session key is used for DES (64 bits long, normally 56 bits of entropy), it has only 32 bits of entropy
- What's worse, the five values have predictable portions
  - Time is completely predictable
  - ProcessID is mostly predictable
  - Even hostID has 12 predictable bits (of 32 total)

RNGs in Kerberos v4 (continued)

- Of the 32 seed bits, only 20 bits really change with any frequency, so Kerberos v4 keys (in the MIT implementation) only have 20 bits of randomness
  - They could be brute-force discovered in seconds
- The hole was in the MIT Kerberos sources for *seven years!*

Ideal Protection: End-to-End



- **Web security (SSL, https) does this over TCP**
- **IPSEC does this for any IP packet, at network layer**
- **Apps aware of/control SSL, don't have to be for IPSec**

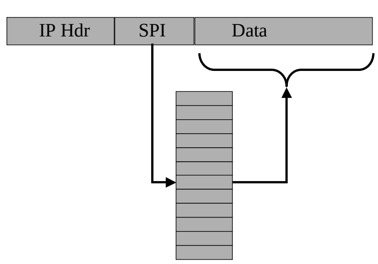
IPSEC

- IPSEC = IP (Internet Protocol) Security
  - Suite of protocols that provide encryption, integrity and authentication services for IP packets
  - Mandatory-to-implement for IPv6, optional (but available) for IPv4
- Consists of two main components:
  - IPSEC proper (encryption & auth of IP packets)
  - IPSEC key management

IPSEC Architecture

- Key management establishes a Security Association (SA) for a session
  - SA used to provide authentication/confidentiality services for that session
  - SA is referenced via a security parameter index (SPI) in each IP datagram header

IPSEC Architecture



Security information maintained by host

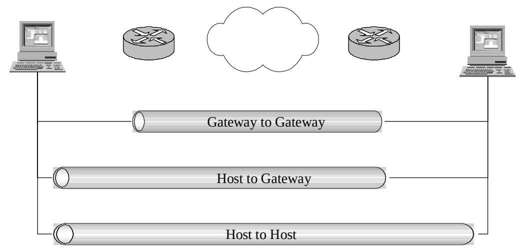
IPSEC Operation

- Provides two modes of protection
  - Tunnel Mode
  - Transport Mode
- Protection protocols
  - Authentication and Integrity (AH)
  - Confidentiality (ESP)
  - Replay Protection

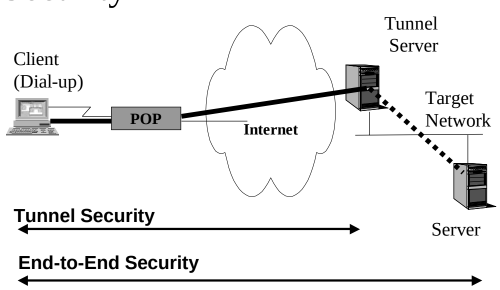
Tunnel Mode

- Encapsulates the entire IP packet within IPSC protection
- Tunnels can be created between several different node types
  - Gateway to gateway
  - Host to gateway
  - Host to host

Three Types of Tunnels



Tunnel Security vs End-to-End Security



Transport Mode

- Encapsulates only the transport layer information within IPSEC protection
- Can only be created between host nodes

Authentication and Integrity

- Verification of the origin of data
- Assurance that data sent is the data received
- Assurance that the network headers have not changed since the data was sent

Confidentiality

- Encrypts data to protect against eavesdropping
- Can hide data source when encryption is used over a tunnel

Replay Prevention

- Causes retransmitted packets to be dropped.

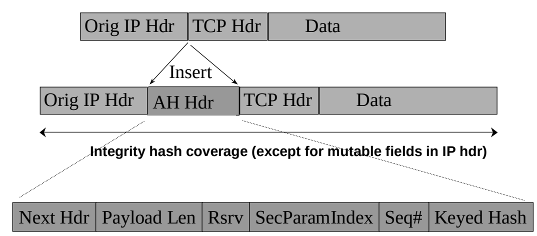
IPSEC Protection Protocols

- Authentication Header (AH)
  - Authenticates payload data
  - Authenticates network header
  - Gives anti-replay protection
- Encapsulated Security Payload (ESP)
  - Encrypts payload data
  - Authenticates payload data
  - Gives anti-replay protection

Authentication Header (AH)

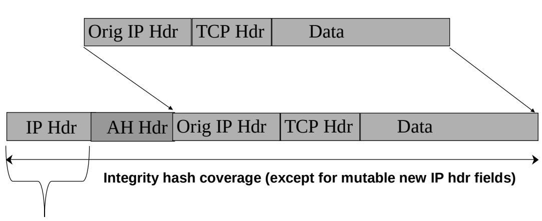
- Authentication is applied to the entire packet, with the mutable fields in the IP header zeroed out
- If both ESP and AH are applied to a packet, AH follows ESP

IPSEC Authentication Header (AH) in Transport Mode



AH is IP protocol 51 24 bytes total

IPSEC AH in Tunnel Mode

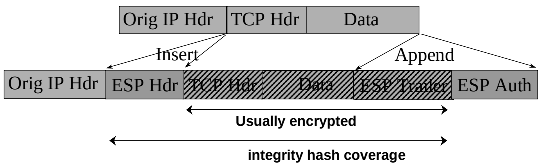


New IP header with source & destination IP address

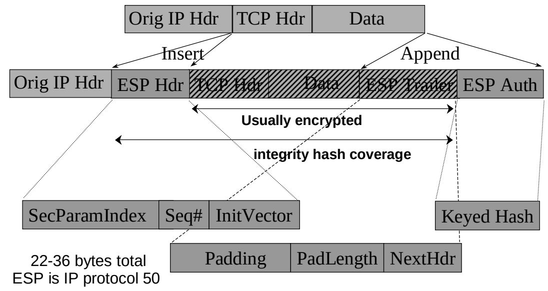
Encapsulated Security Payload (ESP)

- Must encrypt and/or authenticate in each packet
- Encryption occurs before authentication
- Authentication is applied to data in the IPSEC header as well as the data contained as payload

IPSEC ESP in Transport Mode

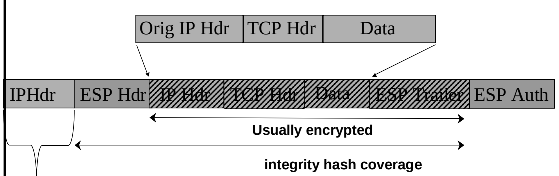


IPSEC ESP in Transport Mode



22-36 bytes total
ESP is IP protocol 50

IPSEC ESP Tunnel Mode



New IP header with source & destination IP address

IPSEC Key Management

- IPSEC Key Management is all about establishing and maintaining Security Associations (SAs) between pairs of communicating hosts

Security Associations (SA)

- New concept for IP communication
  - SA not a “connection”, but very similar
  - Establishes trust between computers
- If securing with IPSEC, need SA
  - ISAKMP protocol negotiates security parameters according to policy
  - Manages cryptographic keys and lifetime
  - Enforces trust by mutual authentication

Internet Key Exchange (IKE)

- Phase I
  - Establish a secure channel(ISAKMP SA)
  - Authenticate computer identity
- Phase II
  - Establishes a secure channel between computers intended for the transmission of data (IPSEC SA)

ISAKMP/OAKLEY

- Merge of two key management protocols
  - ISAKMP: Internet Security Association and Key Management Protocol
    - NSA-designed protocol to exchange security parameters (but not establish keys)
  - OAKLEY
    - Diffie-Hellman based key management protocol

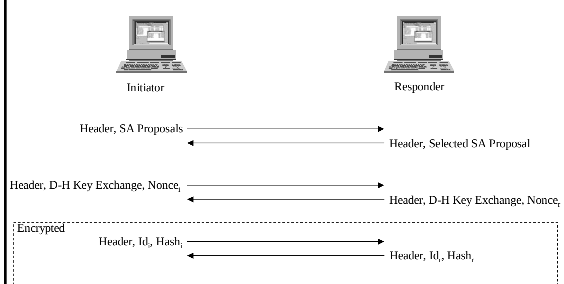
ISAKMP/OAKLEY (2)

- What's used today is a combination
  - ISAKMP provides the protocol framework
  - OAKLEY provides the security mechanisms

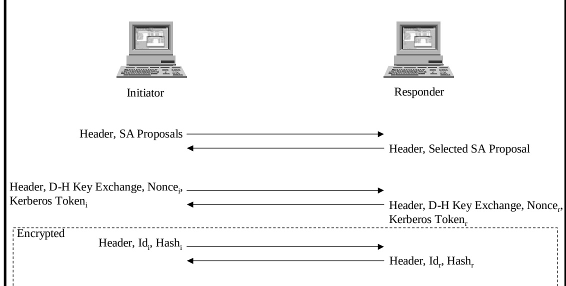
Main Mode

- Main mode negotiates an ISAKMP SA which will be used to create IPSEC SA
- Three steps
  - SA negotiation
  - Diffie-Hellman and nonce exchange
  - Authentication

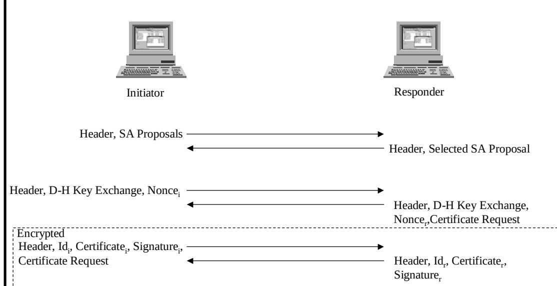
Main Mode (Pre-shared Key)



Main Mode (Kerberos)



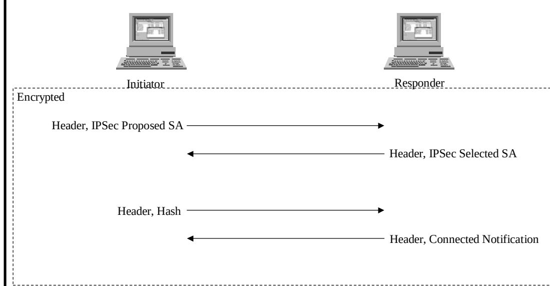
Main Mode (Certificate)



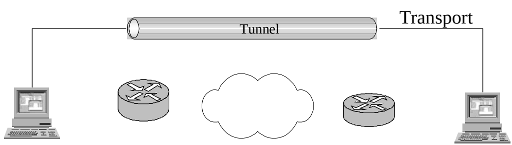
Quick Mode

- All traffic is encrypted using the ISAKMP Security Association
- Each quick mode negotiation results in two IPSec Security Associations (one inbound, one outbound)

Quick Mode Negotiation



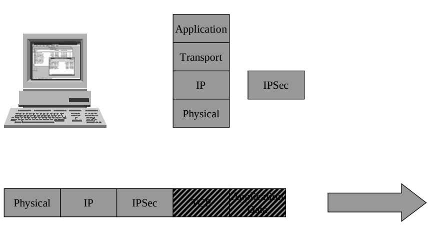
How It All Fits Together



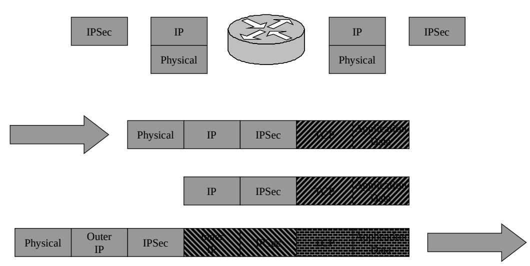
IPSEC Bundling/Wrapping

- Multiple IPSEC transforms may be wrapped successively around a single IP datagram
  - Example: IPSEC transport sent over an IPSEC tunnel

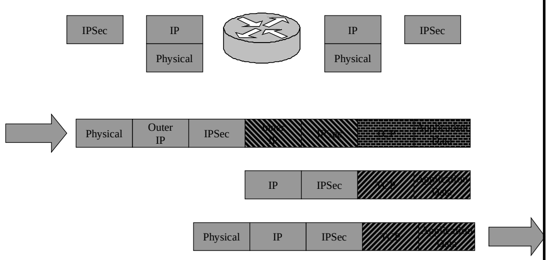
Sending in Transport Mode



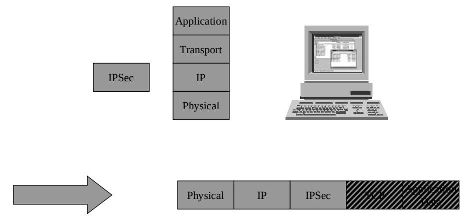
Sending in Tunnel Mode



Receiving in Tunnel Mode



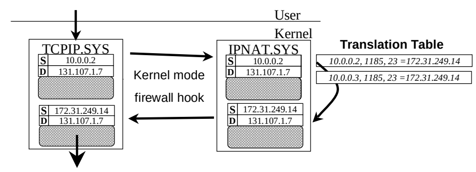
Receiving in Transport Mode



What is Network Address Translation (NAT) ?

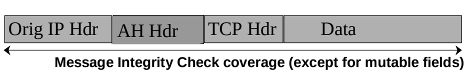
- Network Address Translation (NAT)
  - Dynamically modifies source address
  - Dynamically recomputes interior UDP/TCP checksums
- Port Address Translation (PAT)
  - Dynamically modifies TCP/UDP source address and port
  - Dynamically recomputes interior UDP/TCP checksums

NATs Rewrite Address/Port Pairs



IPSEC AH and NAT

- Change in address or port will cause message integrity check to fail
  - Packet will be rejected by destination IPSEC
  - AH cannot be used with NAT or PAT devices



IPSEC ESP and NAT

- Can change IP header in special cases only
  - Special TCP/UDP ignores pseudo header used in checksum calculation
- Port information encrypted!
- Can't change ESP header because integrity hash coverage