# L10: Networks and Cryptography

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# Acknowledgement

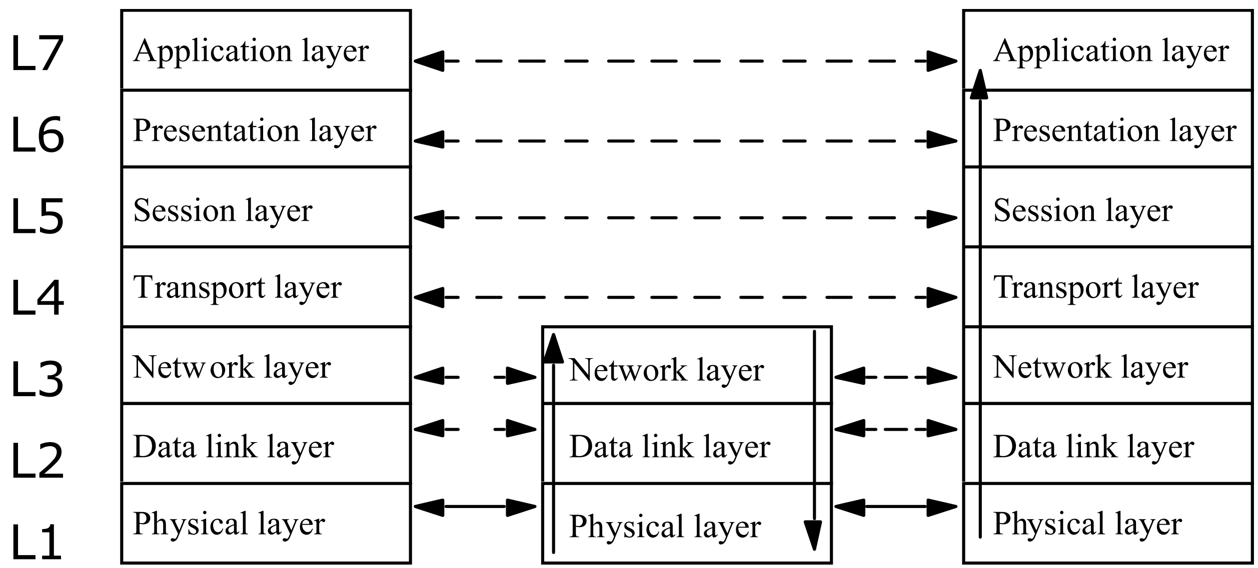
- Many slides are from or are revised from the slides of the author of the textbook
  - Matt Bishop, Introduction to Computer Security, Addison-Wesley Professional, October, 2004, ISBN-13: 978-0-321-24774-5. Introduction to Computer Security @ VSU's Safari Book Online subscription
  - http://nob.cs.ucdavis.edu/book/book-intro/slides/

# Outline

- ISO/OSI 7-layer model
- Link and End-to-End protocols
- Concept of traffic analysis
- Two example protocols
  - PEM
  - IPSec

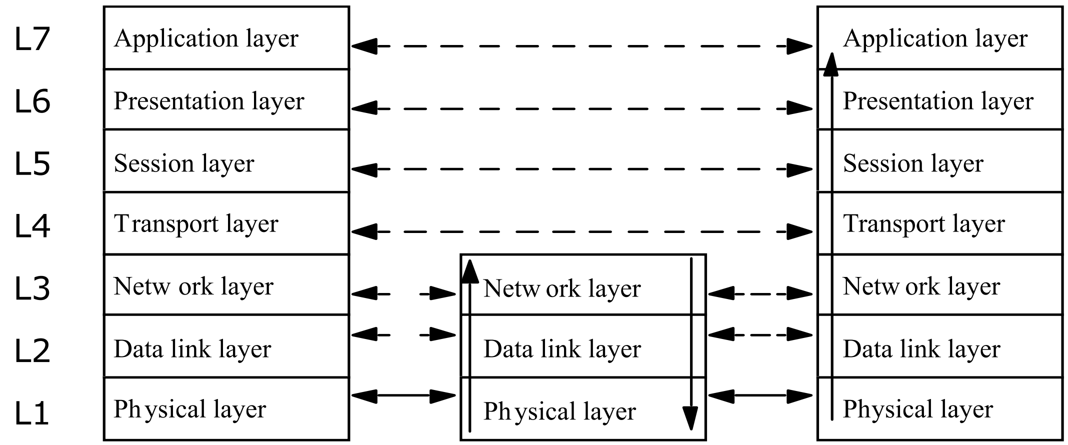
# ISO/OSI Model

- *Conceptual* model for for digital communications and computer networks



# ISO/OSI Model: Concepts

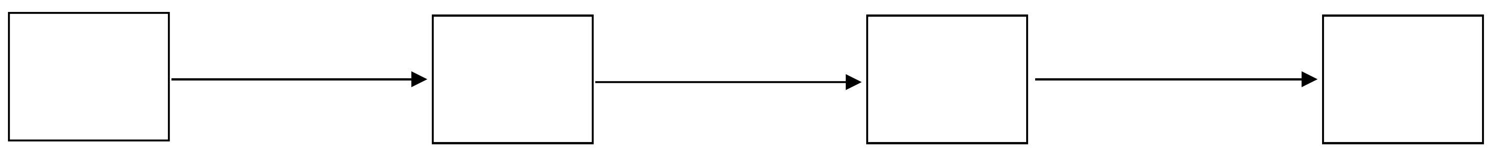
- Each host has a principal at each layer
- Principals at the same layer of different hosts are peers
- Peers communicate with peers at same layer
- Layer 1, 2, and 3 principals interact with peers at neighboring hosts (directly connected hosts)
- Layer 4, 5, 6, and 7 principals interact only with similar principals at the other end of the communication
- Use host to refer to the appropriate principal in the discussion that follows



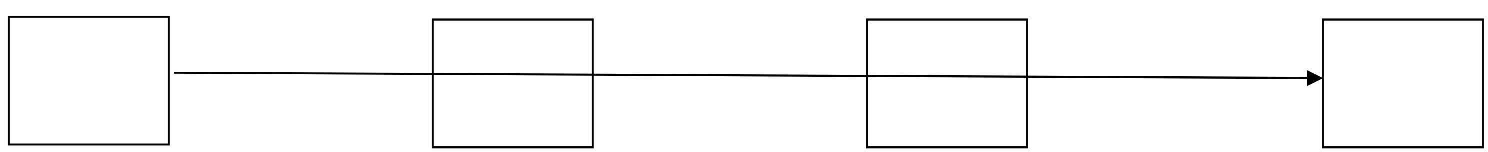
# Link and End-to-End Protocols

- Hosts: $C_0$ … $C_n$ and $C_i$ and $C_{i+1}$ are directly connected
- Link Protocol: $C_j$ and $C_{j+1}$ as comm. end points
- End-to-End Protocol: $C_0$ and $C_n$ as comm. end points

Link Protocol



End-to-End (or E2E) Protocol



# Encryption

- Link encryption
  - Each host enciphers message so host at “next hop” can read it
  - Message can be read at intermediate hosts
- End-to-end encryption
  - Host enciphers message so host at other end of communication can read it
  - Message cannot be read at intermediate hosts

# Examples

- Secure Shell (SSH) protocol
  - Messages between client and server enciphered
  - Encipherment and decipherment occur only at these hosts
  - End-to-end protocol
- PPP Encryption Control Protocol
  - Host gets message, deciphers it
    - Figures out where to forward it
    - Enciphers it in appropriate key and forwards it
  - Link protocol

# Cryptographic Considerations

- Link encryption
  - Each host shares key with neighbor
  - Can be set on per-host or per-host-pair basis
    - Hosts windsor, stripe, and seaview each have own keys
    - One key for (windsor, stripe); one for (stripe, seaview); one for (windsor, seaview)
- End-to-end
  - Each host shares key with destination
  - Can be set on per-host or per-host-pair basis
  - Message cannot be read at intermediate nodes

# Traffic Analysis

- Deduce information from metadata (e.g., sender and recipient)
- Link encryption
  - Can protect headers of packets
  - Possible to hide source and destination
    - Note: may be able to deduce this from traffic flows
- End-to-end encryption
  - Cannot hide packet headers
    - Intermediate nodes need to route packet
  - Attacker can read source, destination

# Traffic Analysis: Example

- All traffic are enciphered using end-to-end encryption in a company that has leaked proprietary data.
- Investigator Alice monitors senders and recipients of network traffic.
  - Connection from host *larry* always occur between midnight and four in the morning
  - In correlation with the time the leak occurred, Alice suggests that host *larry* is likely involved in the leak.
- Alice has not read any enciphered data in the network, only the metadata (in the clear)

# Example Protocols

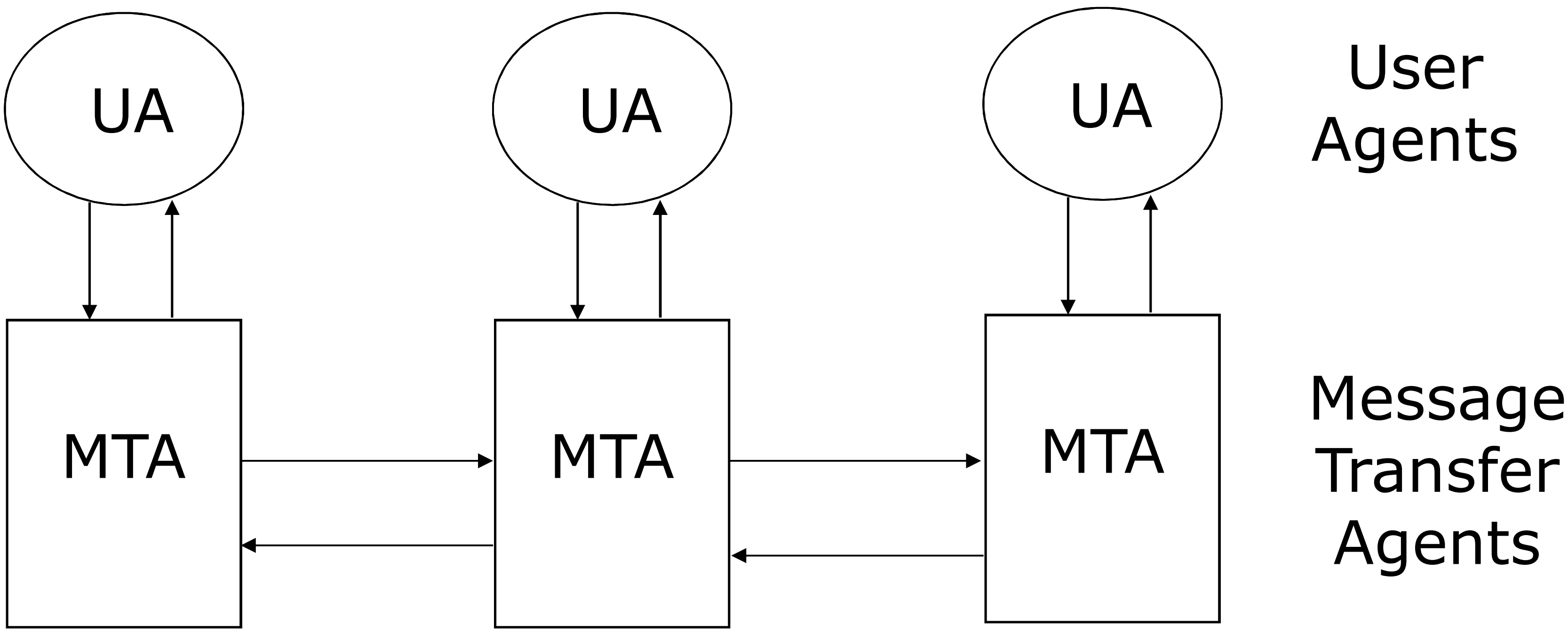
- Privacy-Enhanced Electronic Mail (PEM)
  - Applications layer protocol
- IP Security (IPSec)
  - Network layer protocol

# Privacy-Enhanced Electronic Mail (PEM)

- Overview of E-mail service
- Threats to E-mail service
- Design goals of PEM
- Design for confidentiality
- Design for integrity and authentication
- Design for non-repudiation
- Practical considerations

# Message Handling System

- Authentication is minimal and easily evaded



# Threats to E-mail Services

- Violation of confidentiality
- Violation of Authentication
- Violation of message integrity
- Violation of non-repudiation

# Goals of PEM

- To enhance E-mail service with
  - Confidentiality
    - Only sender and recipient(s) can read message
  - Origin authentication
    - Identify the sender precisely
  - Data integrity
    - Any changes in message are easy to detect
  - Non-repudiation of origin
    - Whenever possible …

# Design Principles

- Do not change related existing protocols
  - Cannot alter SMTP
- Do not change existing software
  - Need compatibility with existing software
- Make use of PEM optional
  - Available if desired, but email still works without them
  - Some recipients may use it, others not
- Enable communication without prearrangement
  - Out-of-bands authentication and key exchange are problematic

# Basic Design: Keys

- Two keys
  - *Interchange keys* tied to sender and recipients and are static (for some set of messages)
    - Must be available *before* messages sent
    - If symmetric ciphers are used, the keys must be exchanged out-of-bands
    - If public keys are used, the sender needs to obtain the certificate of the recipient
  - *Data exchange keys* generated for each message
    - Like a session key, session being the message

# Basic Design: Confidentiality

- Confidentiality
  - $m$ message
  - $k_s$ data exchange key
  - $k_B$ Bob's interchange key

$$\text{Alice} \xrightarrow{\{\, m \,\}_{k_s} \,||\, \{\, k_s \,\}_{k_B}} \text{Bob}$$

# Basic Design: Integrity

- Integrity and authentication:
  - $m$ message
  - $h(m)$ hash of message $m$ —Message Integrity Check (MIC)
  - $k_A$ Alice's interchange key
- Non-repudiation: if $k_A$ is Alice's interchange key, this establishes that Alice's interchange key was used to sign the message

$$\text{Alice} \xrightarrow{m\ \{\ h(m)\ \}_{k_A}} \text{Bob}$$

# Basic Design: Putting Together

- Confidentiality, integrity, authentication:
  - Notations as in previous slides

$$\text{Alice} \xrightarrow{\{\, m \,\}_{k_s} \,||\, \{\, h(m) \,\}_{k_A} \,||\, \{\, k_s \,\}_{k_B}} \text{Bob}$$

# Design Goal: Non-Repudiation

- Non-Repudiation
  - Notations as in previous slides
  - If a public key cipher is bing used and $k_A$ is Alice's private key, get non-repudiation

$$\text{Alice} \xrightarrow{\{\, m \,\}_{k_s} \,||\, \{\, h(m) \,\}_{k_A} \,||\, \{\, k_s \,\}_{k_B}} \text{Bob}$$

# Practical Considerations

- Limits of SMTP
  - Only ASCII characters, limited length lines
- Use encoding procedure
  1. Map local character representation into canonical format
     - Format meets SMTP requirements
  2. Compute and encipher MIC over the canonical format; encipher message if needed
  3. Map each 6 bits of result into a character; insert newline after every 64th character
  4. Add delimiters around this ASCII message

# Problem

- Recipient without PEM-compliant software cannot read it
  - If only integrity and authentication used, should be able to read it
- Mode MIC-CLEAR allows this
  - Skip step 3 in encoding procedure
  - Problem: some MTAs add blank lines, delete trailing white space, or change end of line character
  - Result: PEM-compliant software reports integrity failure

# PEM vs. PGP

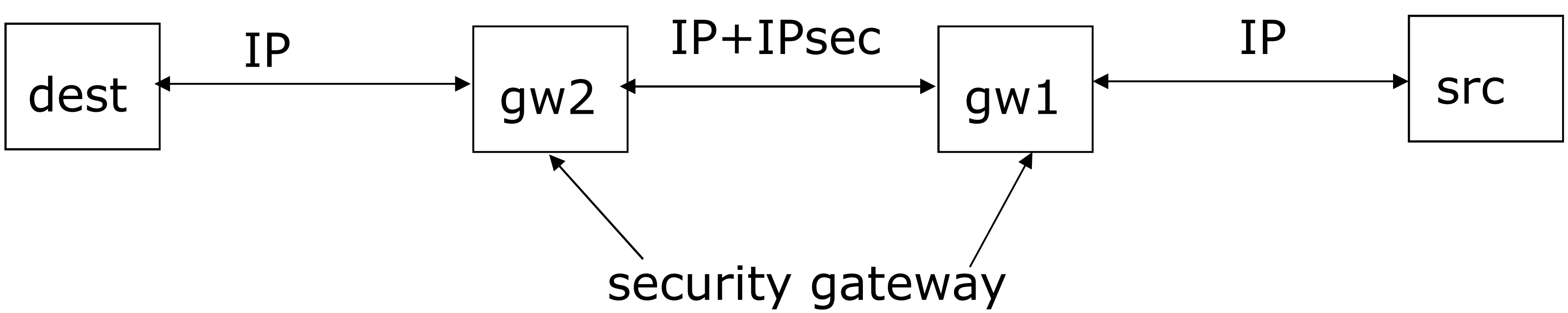
- Use different ciphers
  - PGP uses IDEA cipher
  - PEM uses DES in CBC mode
- Use different certificate models
  - PGP uses general “web of trust”
  - PEM uses hierarchical certification structure
- Handle end of line differently
  - PGP remaps end of line if message tagged “text”, but leaves them alone if message tagged “binary”
  - PEM always remaps end of line

# IPsec

- Design goals
- Transport mode and tunnel mode
- IPsec architectures
- IPsec protocols

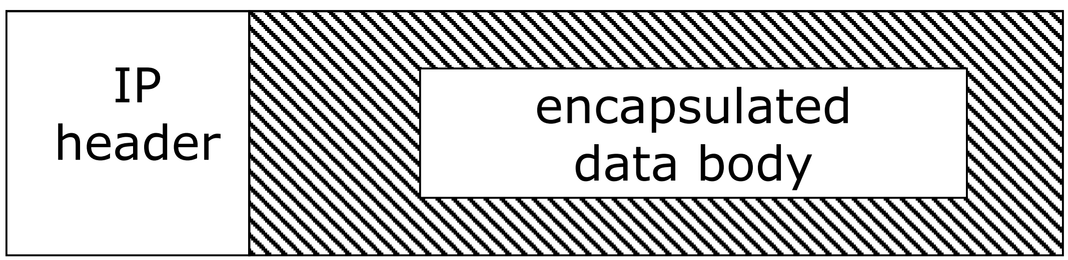
# Design Goals

- Network layer security
  - Provides confidentiality, integrity, authentication of endpoints, replay detection
- Protects all messages sent along a path



# IPsec Transport Mode

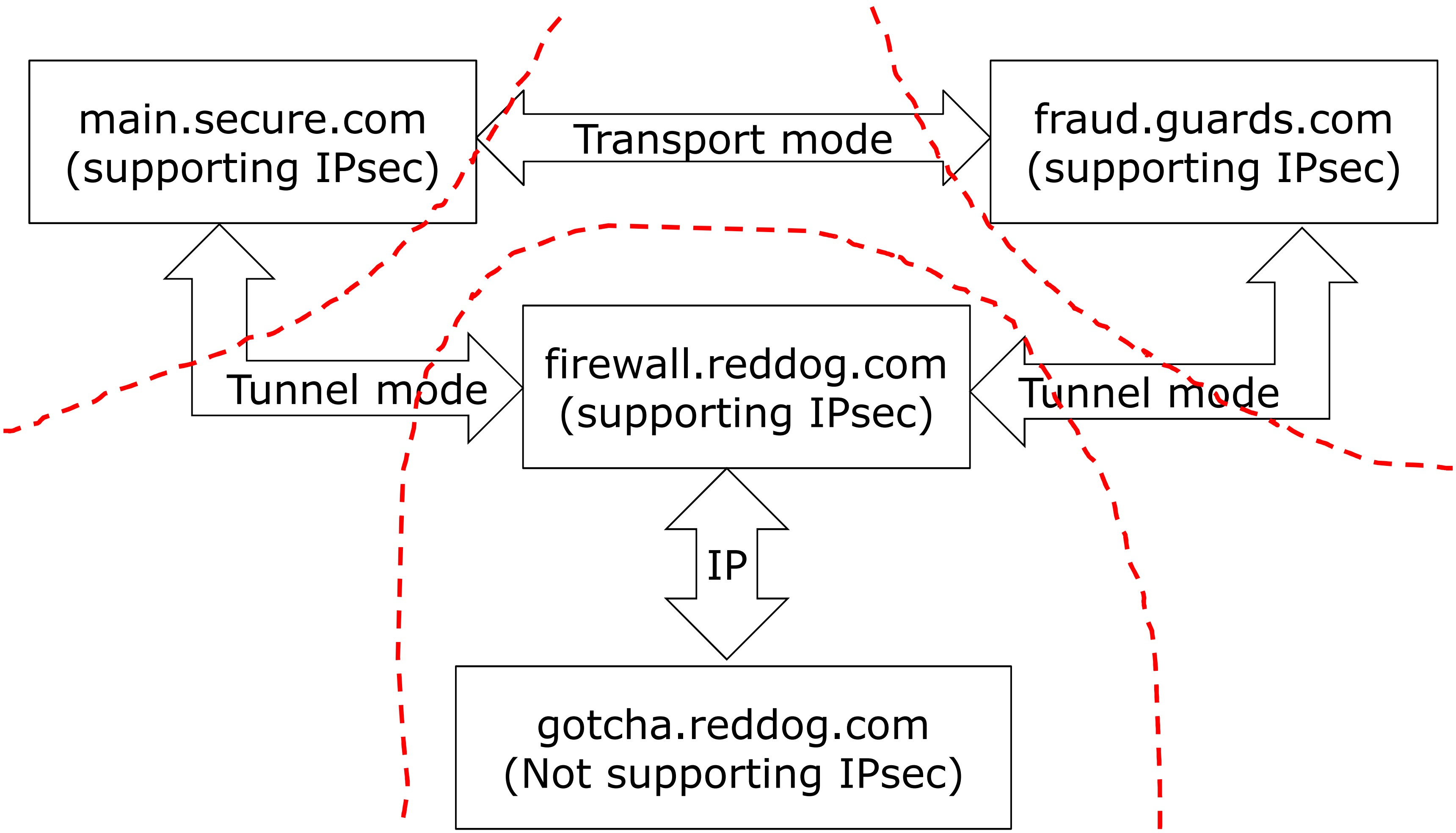
- Encapsulate IP packet data area (containing upper layer packet, e.g., TCP segments) to form IPsec-wrapped data packet
- Use IP to send IPsec-wrapped data packet
- Note: IP header not protected
- Used when both endpoints support IPsec



# IPsec Tunnel Mode

- IP header not protected in IP transport mode
- Protect IP header using IP tunnel mode, i.e., encapsulate entire IP packet in an IPsec envelope and forward it using IP
- Used when either or both endpoints do not support IPsec but two intermediate nodes do

# IPsec: Example Scenario



# IPsec Protocols

- Authentication Header (AH) protocol
  - Message integrity
  - Origin authentication
  - Anti-replay
- Encapsulating Security Payload (ESP) protocol
  - Confidentiality
  - Others provided by AH
- Internet Key Exchange (IKE) protocol
  - Key management

# IPsec Architecture: SPD

- Security Policy Database (SPD)
  - Determine how to handle messages (discard them, add security services, forward message unchanged)
  - SPD associated with network interface
  - SPD determines appropriate entry from packet attributes
    - Including source, destination, transport protocol

# SPD: Example

- Goals
  - Discard SMTP packets from host 192.168.2.9
  - Forward packets from 192.168.19.7 without change
- SPD entries

```
src 192.168.2.9, dest 10.1.2.3 to 10.1.2.103, port 25, discard
src 192.168.19.7, dest 10.1.2.3 to 10.1.2.103, port 25, bypass
dest 10.1.2.3 to 10.1.2.103, port 25, apply IPsec
```

- Note: entries scanned in order
  - If no match for packet, it is discarded

# IPsec Architecture: SA

- Security Association (SA)
  - Association between peers for security services
    - Identified uniquely by destination address, security protocol (AH or ESP), unique 32-bit number (security parameter index, or SPI)
  - Unidirectional
    - Can apply different services in either direction
  - SA uses either ESP or AH, but not both. If both required, use 2 SAs

# SA Database (SAD)

- Entry describes SA; some fields for all packets:
  - AH algorithm identifier, keys
    - When SA uses AH
  - ESP encipherment algorithm identifier, keys
    - When SA uses confidentiality from ESP
  - ESP authentication algorithm identifier, keys
    - When SA uses authentication, integrity from ESP
  - SA lifetime (time for deletion or max byte count)
  - IPsec mode (tunnel, transport, either)

# SAD Fields

- Antireplay (inbound only)
  - When SA uses antireplay feature
- Sequence number counter (outbound only)
  - Generates AH or ESP sequence number
- Sequence counter overflow field
  - Stops traffic over this SA if sequence counter overflows
- Aging variables
  - Used to detect time-outs

# IPsec Architecture

- Packet arrives
- Look in SPD
  - Find appropriate entry
  - Get dest address, security protocol, SPI
- Find associated SA in SAD
  - Use dest address, security protocol, SPI
  - Apply security services in SA (if any)

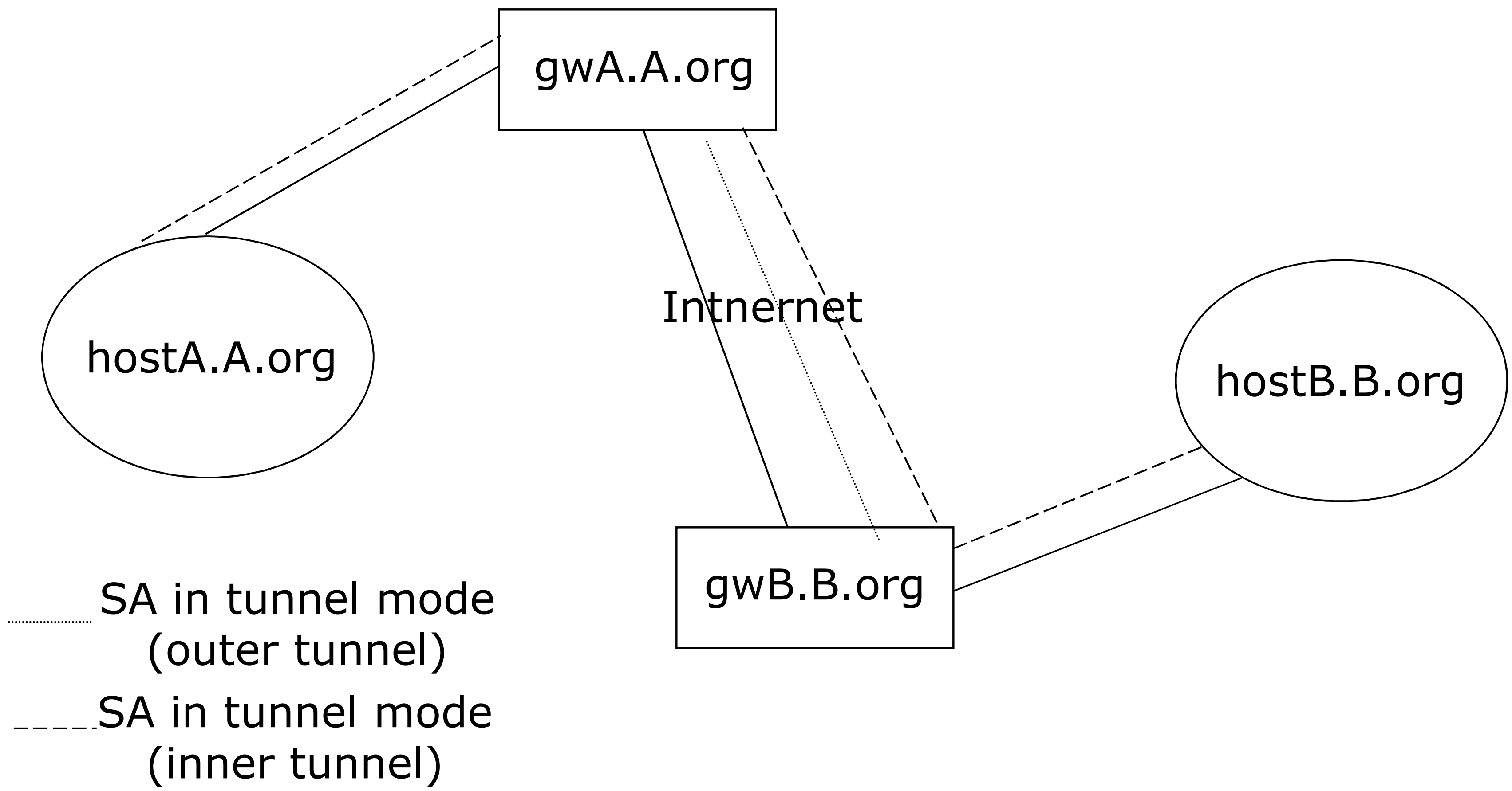
# SA Bundles and Nesting

- Sequence of SAs that IPsec applies to packets
  - This is a *SA bundle*
- Nest tunnel mode SAs
  - This is *iterated tunneling*

# Example: Nested Tunnels

- Group in A.org needs to communicate with group in B.org
- Gateways of A, B use IPsec mechanisms
  - But the information must be secret to everyone except the two groups, even secret from other people in A.org and B.org
- Inner tunnel: a SA between the hosts of the two groups
- Outer tunnel: the SA between the two gateways

# Example: Systems



# Example: Packets

- Packet generated on hostA
- Encapsulated by hostA's IPsec mechanisms
- Again encapsulated by gwA's IPsec mechanisms
  - Above diagram shows headers, but as you go left, everything to the right would be enciphered and authenticated, *etc*.

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| IP header from gwA | AH header from gwA | ESP header from gwA | IP header from hostA | AH header from hostA | ESP header from hostA | IP header from hostA | Transport layer headers, data |

# AH Protocol

- Parameters in AH header
  - Length of header
  - SPI of SA applying protocol
  - Sequence number (anti-replay)
  - Integrity value check
- Two steps
  - Check that replay is not occurring
  - Check authentication data

# Sender

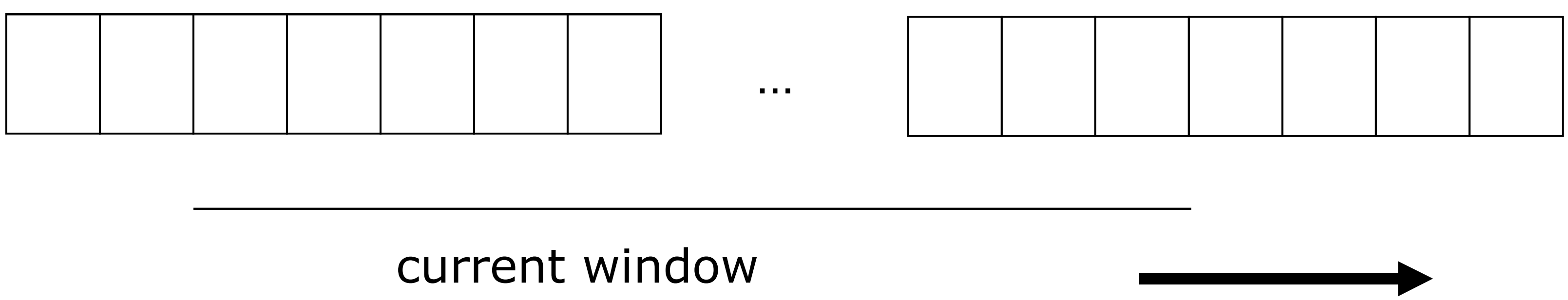
- Check sequence number will not cycle
- Increment sequence number
- Compute IVC of packet
  - Includes IP header, AH header, packet data
    - IP header: include all fields that will not change in transit; assume all others are 0
    - AH header: authentication data field set to 0 for this
    - Packet data includes encapsulated data, higher level protocol data

# Recipient

- Assume AH header found
- Get SPI, destination address
- Find associated SA in SAD
  - If no associated SA, discard packet
- If antireplay not used
  - Verify IVC is correct
    - If not, discard

# Recipient, Using Antireplay

- Check packet beyond low end of sliding window
- Check IVC of packet
- Check packet's slot not occupied
  - If any of these is false, discard packet



# AH Miscellany

- All implementations must support:

  HMAC_MD5

  HMAC_SHA-1
- May support other algorithms

# ESP Protocol

- Parameters in ESP header
  - SPI of SA applying protocol
  - Sequence number (anti-replay)
  - Generic “payload data” field
  - Padding and length of padding
    - Contents depends on ESP services enabled; may be an initialization vector for a chaining cipher, for example
    - Used also to pad packet to length required by cipher
  - Optional authentication data field

# Sender

- Add ESP header
  - Includes whatever padding needed
- Encipher result
  - Do not encipher SPI, sequence numbers
- If authentication desired, compute as for AH protocol *except* over ESP header, payload and *not* encapsulating IP header

# Recipient

- Assume ESP header found
- Get SPI, destination address
- Find associated SA in SAD
  - If no associated SA, discard packet
- If authentication used
  - Do IVC, antireplay verification as for AH
    - Only ESP, payload are considered; *not* IP header
    - Note authentication data inserted after encipherment, so no deciphering need be done

# Recipient

- If confidentiality used
  - Decipher enciphered portion of ESP heaser
  - Process padding
  - Decipher payload
  - If SA is transport mode, IP header and payload treated as original IP packet
  - If SA is tunnel mode, payload is an encapsulated IP packet and so is treated as original IP packet

# ESP Miscellany

- Must use at least one of confidentiality, authentication services
- Synchronization material must be in payload
  - Packets may not arrive in order, so if not, packets following a missing packet may not be decipherable
- Implementations of ESP assume classical cryptosystem
  - Implementations of public key systems usually far slower than implementations of classical systems
  - Not required

# More ESP Miscellany

- All implementations must support (encipherment algorithms):
  - DES in CBC mode
  - NULL algorithm (identity; no encipherment)
- All implementations must support (integrity algorithms):
  - HMAC_MD5
  - HMAC_SHA-1
  - NULL algorithm (no MAC computed)
- Both cannot be NULL at the same time

# Which to Use: PEM, IPsec

- What do the security services apply to?
  - If applicable to one application *and* application layer mechanisms available, use that
    - PEM for electronic mail
  - If more generic services needed, look to lower layers
    - IPsec for network layer, either end-to-end or link mechanisms, for connectionless channels as well as connections
  - If endpoint is host, IPsec sufficient; if endpoint is user, application layer mechanism such as PEM needed

# Key Points

- Key management critical to effective use of cryptosystems
  - Different levels of keys (session *vs*. interchange)
- Keys need infrastructure to identify holders, allow revoking
  - Key escrowing complicates infrastructure
- Digital signatures provide integrity of origin and content

  Much easier with public key cryptosystems than with classical cryptosystems

# Summary

- ISO/OSI 7-layer model
- Link and End-to-End protocols
- Concept of traffic analysis
- PEM
- IPSec