Network Security:
Real-Time Communication Security
IPsec (AH, ESP), IKE

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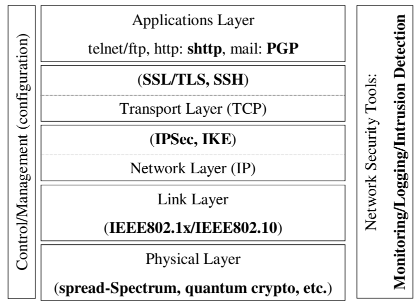
COM3522

Securing Networks

- Where to put the security in a protocol stack?
- Practical considerations:
  - End to end security
  - No modification to OS/network stack



SSL vs. IPsec

- SSL:
  - Avoids modifying TCP and requires minimum changes to the application
  - Authenticates users
- IPsec
  - Transparent to the application and requires modification of the network stack
  - Authenticates network nodes and establishes a secure channel between nodes
  - Application still needs to authenticate the users

Some Issues with Real-time Communication

- Session key establishment
- Perfect Forward Secrecy
  - Diffie-Hellman based PFS
  - Escrow-foilage:
    - If keys are escrowed Diffie-Hellman protects against passive attacks
    - Signature keys are usually not escrowed
- Preventing Denial of Service
  - SYN attack on TCP: use stateless cookies = hash(IP addr, secret)
  - Puzzles: e.g., what 27-bit number has an MD = x?
  - These techniques do not protect against DDOS launched through viruses
- Hiding endpoint identity:
  - DH + authentication allows anonymous connection or detects man-in-the-middle
- Live partner reassurance:
  - modify DH to include a nonce in the computation of the session key

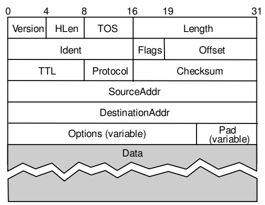
IPsec Protocol Suite (IETF Standard)

- Provides inter-operable cryptographically based security services:
  - **Services: confidentiality, authentication, integrity, and key management**
  - **Protocols:**
    - **Authentication Header (AH): RFC2402**
    - **Encapsulated Security Payload (ESP): 2406**
    - **Internet Key Exchange (IKE)**
  - **Environments: IPv4 and IPv6**
  - **Modes:**
    - **transport (between two hosts)**
    - **tunnel (between hosts/firewalls)**

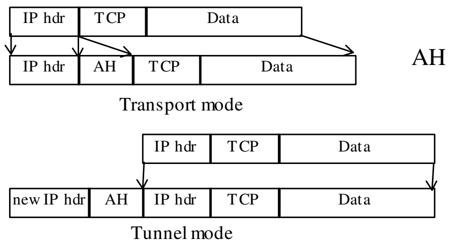
IPsec

- Assumption:
  - End nodes already established a shared session key (manually or through IKE)
- Security Association:
  - Each secure connection is called a *security association* (SA)
  - For each SA: key, end-node, sequence number, services, algorithms
  - SA is unidirectional and identified by (destination-address, SPI = Security Parameter Index)
- Protocols:
  - Authentication Header: integrity protection
  - Encapsulated Security Payload: encryption and/or integrity
- Modes:

IP Packets



AH Formatting



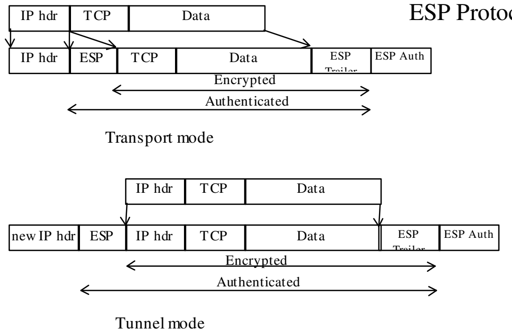
AH Protocol Number = 51

Next Header	Length (8)	Reserved (16)
Security Parameters Index (32)		
Sequence Number Field (32)		
Authentication Data (N*32)		

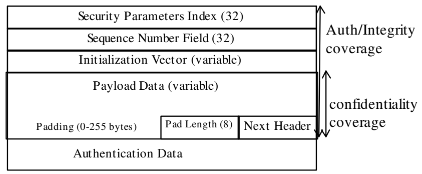
SN: for replay detection

ESP Formatting

ESP Protocol Number = 50



ESP Header



Issues

- NAT boxes:
  - IPsec mode doesn't work
- Firewalls
  - IPsec encrypts information used by firewalls to filter traffic (e.g., port number)
- AH mutable/immutable/predictable fields:
  - Some fields get modified by the intermediate routers and can't be protected by the AH
  - Mutable: type of service, flags, fragment offset, TTL, header checksum
  - Why is PAYLOAD-LENGTH considered immutable (even if packets can be fragmented)? Why not fragment offset. Inconsistency!
  - Mutable but predictable fields are included in the AH computation using their expected value at the destination (e.g., destination address when using source routing)

IPsec: Internet Key Exchange

- Goal:
  - Mutual authentication and establishment of a shared secret session key using:
    - Pre-shared secret key or public signature-only key, or public encryption key
  - Negotiation of features and cryptographic algorithms
- Specification documents:
  - ISAKMP (Internet Security Association and Key Management Protocol): RFC 2408
  - IKE: RFC 2409
  - DOI (Domain Of Interpretation): RFC 2407

Photuris

- Photuris goal: signed Diffie-Hellman exchange
  1. A -> B: C_A
  2. B -> A: C_A, C_B, crypto offered
  3. A -> B: C_A, C_B, g^a mod p, crypto selected
  4. B -> A: C_A, C_B, , g^b mod p
  5. A -> B: C_A, C_B, g^{ab} mod p{A, signature on previous message}
  6. B -> A: C_A, C_B, , g^{ab} mod p{B, signature on previous message}

  – Role of C_A, C_B, and messages
  – Additional features: SPI selection
  – Why not sign messages 3 & 4…?

Simple Key-Management for Internet Protocol (SKIP)

- Uses long Diffie-Hellman keys
- Parties assumed to know each other public keys (i.e., g^a mod p) or exchange certificates
- Session key $X = g^{ab}$ mod p is established in 0 messages
- Each packet is encrypted using data key S and each packet contains: X{S}
  – Same S can be used for several packets
- Later on PFS was added by periodically forgetting the keys and doing a new DH

ISAKMP (RFC2408)

- Proposed by NSA as a framework and accepted by IETF
  – Runs over UDP and allows to exchange fields to create a protocol
- IKE (RFC2409) based on OAKLEY & SKEME using ISAKMP syntax

- IKE phases:
  1. Mutual authentication and session key establishment (also called ISAKMP or IKE SA)
  2. AH/ESP SAs establishment

– Each source/destination/port has its own SA/keys otherwise ESP traffic not using integrity could be decrypted…

Phase 1 IKE

- Two modes:
  – Aggressive mode: mutual authentication and session key establishment in three messages
    - A -> B: g^a mod p, A, crypto proposal
    - B -> A: g^b mod p, crypto choice, proof I'm B
    - A -> B: proof I'm A
  – Main: additional features such as hiding end-points identities and negotiating crypto DH algorithm
    - A -> B: crypto suite I support
    - B -> A: crypto suite I choose
    - A -> B: g^a mod p
    - B -> A: g^b mod p
    - A -> B: g^{ab} mod p {A, proof I'm A}
    - B -> A: g^{ab} mod p {B, proof I'm B}

Phase 1 IKE

- Key types:
  - Pre-shared secret key
  - Public encryption key: fields are separately encrypted using the public key
  - Optimized public encryption key: used to encrypt a random symmetric key, and then data is encrypted using the symmetric key
  - Public signature key: used only for signature purpose

⇒ 8 variants of IKE phase 1: 2 modes x 4 key types

- Proof of Identity:
  - Required in messages 2-3 aggressive mode and 5-6 main mode
  - Proves the sender knows the key associated with the identity
  - Depends on the key type
  - Hash of identity key, DH values, nonces, crypto choices, cookies
  - Alternative: MAC of previous messages

Phase 1 IKE

- Negotiating cryptographic parameters
  - *A* specifies suites of acceptable algorithms:
    - {(3DES, MD5, RSA public key encryption, DH), (AES, SHA, pre-shared key, elliptic curve), …}
  - The standard specifies a MUST be implemented set of algorithms:
    - Encryption=DES, hash=MD5/SHA, authentication=pre-shared key/DH
  - The lifetime of the SA can also be negotiated
- Session keys:
  - Key seed: SKEYID
    - Signature public keys: SKEYID = prf(nonces, g^{xy}mod p)
    - Encryption public keys: prf(hash(nonces), cookies)
    - Pre-shared secret key: prf(pre-shared secret key, nonces)
  - Secret to generate other keys: SKEYID_d = prf(SKEYID, (gxy, cookies, 0)
  - Integrity key: SKEYID_a = prf(SKEYID, (SKEYID_d, (g^{xy}, cookies, 1))
  - Encryption key: SKEYID_e = prf(SKEYID, (SKEYID_a, (g^{xy}, cookies, 2))
- Message IDs:
  - Random 32-bits serves the purpose of a SN but in an inefficient manner because they have to be remembered

IKE Phase 1: Public Signature Keys, Main Mode

- Description:
  - Both parties have public keys for signatures
  - Hidden endpoint identity (except for …?)
- Protocol:
  - *A* -> *B*: *CP*
  - *B* -> *A*: *CPA*
  - *A* -> *B*: g^a mod p, nonce$_A$
  - *B* -> *A*: g^b mod p, nonce$_B$

  $K = f(g^{ab}$ mod p, nonce$_A$, nonce$_B)$
  - *A* -> *B*: *K*{*A*, proof I'm *A*, [certificate]}
  - *B* -> *A*: K{*B*, proof I'm *B*, [certificate]}
- Questions:
  - What is the purpose of the nonces?
  - Can we make to protocol shorter (5 messages)? At what expense?

IKE Phase 1: Public Signature Keys, Aggressive Mode

- Protocol:
  - *A* -> *B*: *CP*, g^a mod p, nonce$_A$, *A*
  - *B* -> *A*: *CPA*, g^b mod p, nonce$_B$, *B*, proof I'm *B*, [certificate]
  - *A* -> *B*: proof I'm *A*, [certificate]

IKE Phase 1: Public Encryption Keys, Main Mode, Original

- Protocol:
  - A -> B: CP
  - B -> A: CPA
  - A -> B: g^a mod p, $\{\text{nonce}_A\}_B$, $\{A\}_B$
  - B -> A: g^b mod p, $\{\text{nonce}_B\}_A$, $\{B\}_A$

  $K = f(g^{ab} \bmod p, \text{nonce}_A, \text{nonce}_B)$
  - A -> B: K\{proof I'm A\}
  - B -> A: K\{proof I'm B\}

IKE Phase 1: Public Encryption Keys, Aggressive Mode, Original

- Protocol:
  - A -> B: CP, g^a mod p, $\{\text{nonce}_A\}_B$, $\{A\}_B$
  - B -> A: CPA, g^b mod p, $\{\text{nonce}_B\}_A$, $\{B\}_A$, proof I'm B
  - A -> B: proof I'm A

IKE Phase 1: Public Encryption Keys, Main Mode, Revised

- Protocol:
  - A -> B: CP
  - B -> A: CPA

  K_A = hash(nonce_A, cookie_A)
  - A -> B: $\{\text{nonce}_A\}_B$, $K_A\{g^a \bmod p\}$, $K_A\{A\}$, [K_A\{A's cert\}]

  K_B = hash(nonce_B, cookie_B)
  - B -> A: $\{\text{nonce}_B\}_A$, $K_B\{g^b \bmod p\}$, $K_B\{B\}$, [K_B\{B's cert\}]

  $K = f(g^{ab} \bmod p, \text{nonce}_A, \text{nonce}_B, \text{cookie}_A, \text{cookie}_B)$
  - A -> B: K\{proof I'm A\}
  - B -> A: K\{proof I'm B\}

IKE Phase 1: Public Encryption Keys, Aggressive Mode, Revised

- Protocol:

  K_A = hash(nonce_A, cookie_A)
  - A -> B: CP, $\{\text{nonce}_A\}_B$, $K_A\{g^a \bmod p\}$, $K_A\{A\}$, [K_A\{A's cert\}]

  K_B = hash(nonce_B, cookie_B)
  - B -> A: CPA, $\{\text{nonce}_B\}_A$, $K_B\{g^b \bmod p\}$, $K_B\{B\}$, proof I'm B

  $K = f(g^{ab} \bmod p, \text{nonce}_A, \text{nonce}_B, \text{cookie}_A, \text{cookie}_B)$
  - A -> B: K\{proof I'm A\}

IKE Phase 1: Shared Secret Keys, Main Mode

- Assumption A and B share a secret J
- Protocol:
  - A -> B: CP
  - B -> A: CPA
  - A -> B: g^a mod p, nonce$_A$
  - B -> A: g^b mod p, nonce$_B$

  $K = f(J, g^{ab} \bmod p, \text{nonce}_A, \text{nonce}_B, \text{cookie}_A, \text{cookie}_B)$
  - A -> B: K{proof I'm A}
  - B -> A: K{proof I'm B}

IKE Phase 1: Shared Secret Keys, Aggressive Mode

- Protocol:
  - A -> B: CP, g^a mod p, nonce$_A$, A
  - B -> A: CPA, g^b mod p, nonce$_B$, B, proof I'm B
  - A -> B: proof I'm A

IKE: Phase 2

- Also known as "Quick Mode": 3- messages protocol
  - *A -> B: X, Y, CP, traffic,* SPI_A, $nonce_A$, $[g^a \bmod p]_{\text{optional}}$
  - *B -> A: X, Y, CPA, traffic,* SPI_B, $nonce_B$, $[g^b \bmod p]_{\text{optional}}$
  - *A -> B: X, Y, ack*
- All messages are encrypted using SKEYID_e, and integrity protected using SKEYID_a (except *X, Y*)
- Parameters:
  - *X*: cookies generated during phase 1
  - *Y*: 32-bit number unique to this phase 2 session chosen by the initiator
  - CP: Crypto Proposal, CPA: Crypto Proposal Accepted
  - DH is optional and could be used to provide PFS
  - Nonces and cookies get shuffled into SKEYID to produce the SA encryption and integrity keys