Application of Cryptography: IPsec & IKE

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Textbook: "Network Security",

Kauffman – Perlman - Speciner

Reading: Chapters 17-18

Outline

- Introduction to secure networking
- IPsec:
  - Authentication Header and Encapsulated Secure Payload
- Internet Key Exchange (IKE)

Approach to Secure Networking

- Key Distribution Centers: Trusted Third Parties

  or

- Public Key Systems + Public Key Infrastructure

Key Distribution Center

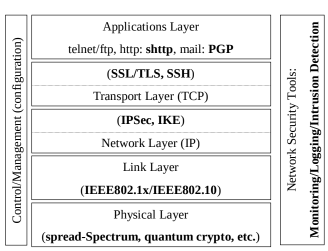
- Solve the scalability problem of a set of *n* nodes using secret key
  - $n*(n-1)/2$ keys
- New nodes are configured with a key to the KDC
  - e.g., K_A for node *A*
- If node *A* wants to communicate with node *B*
  - *A* sends a request to the KDC
  - The KDC securely sends to *A*: $E_{KA}(R_{AB})$ and $E_{KB}(R_{AB}, A, B)$
- Advantage:
  - Single location for updates, single key to be remembered
- Drawbacks:
  - If the KDC is compromised!
  - Single point of failure/performance bottleneck => multiple KDC?
- Example of systems: Kerberos

Public Keys and Certification Authorities

- How do you know the public key of a node?
- Typical solution:
  - Use a trusted node as a certification authority (CA)
  - The CA generates certificates: Signed(A, public-key, validity information)
  - Every body needs to know the CA public key
  - Certificates can be stored in a directory service or exchanged during the authentication process
- Advantages:
  - The CA doesn't have to be online => more physical protection
  - Not a performance bottleneck, not a single point of failure
  - Certificates are not security sensitive: only threat is DoS
  - A compromised CA cannot decrypt conversation but can lead to impersonation
  - A certification hierarchy can be used: e.g., X.509

Securing Network Stacks

- 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 stack" and requires minimum changes to the application
  - Mostly used to authenticate servers
- 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 fully 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
- Optimization using parallel computation, session resumption, deniability

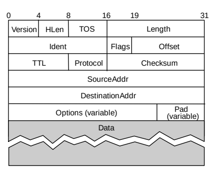
IPsec Protocol Suite (IETF Standard)

- 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)

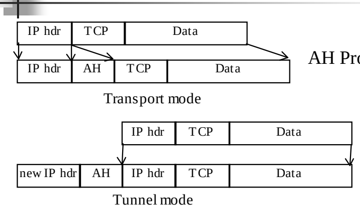
IPsec

- Assumption:
  - End nodes already established a shared session key (manually or 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

IP Packets



AH Formatting



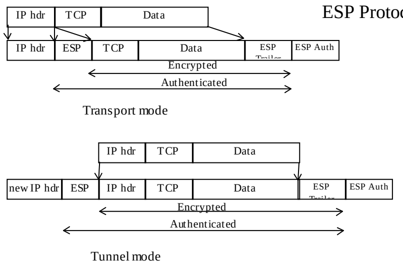
AH Protocol Number = 51

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

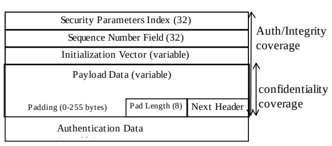
SN: for replay detection

ESP Formatting

ESP Protocol Number = 50



ESP Header



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 of previous message}
  6. B -> A: C_A, C_B , g^{ab} mod p{B, signature of 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 term 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 SA 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…
- – IKE uses default port 500

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, (g^{xy}, 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

  $K = f(g^{ab} \bmod p, \text{nonce}_A, \text{nonce}_B)$
  - *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, {nonce$_A$}$_B$, {A}$_B$
  - B -> A: CPA, g^b mod p, {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: {nonce$_A$}$_B$, K_A{g^a mod p}, K_A{A}, [K_A{A's cert}]

  K_B = hash(nonce$_B$, cookie$_B$)
  - B -> A: {nonce$_B$}$_A$, K_B{g^b mod p}, K_B{B}

  K = f(g^{ab} mod p, nonce$_A$, nonce$_B$, cookie$_A$, 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, {nonce$_A$}$_B$, K_A{g^a mod p}, K_A{A}, [K_A{A's cert}]

  K_B = hash(nonce$_B$, cookie$_B$)
  - B -> A: CPA, {nonce$_B$}$_A$, K_B{g^b mod p}, K_B{B}, proof I'm B

  K = f(g^{ab} mod p, nonce$_A$, nonce$_B$, cookie$_A$, 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, $[g^a \bmod p]_{optional}$
  - *B -> A: X, Y, CPA, traffic*, SPI_B, nonce_B, $[g^b \bmod p]_{optional}$
  - *A -> B: X, Y, ack*
- All messages are encrypted using SKEYID_e, and integrity protected using SKEYID_a (except *X, Y*)
- Parameters:
  - *X*: pair of 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