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CSCI 454/554 Computer and Network Security

Topic 8.2 Internet Key Management

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Outline

- Key Management
  - Security Principles
- Internet Key Management
  - Manual Exchange
  - SKIP
  - Oakley
  - ISAKMP
  - IKE

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Key Management

- Why do we need Internet key management
  - AH and ESP require encryption and authentication keys
- Process to negotiate and establish IPsec SAs between two entities

Security Principles

- Basic security principle for session keys
  - Compromise of a session key
    - Doesn't permit reuse of the compromised session key.
    - Doesn't compromise future session keys and long-term keys.

Security Principles (Cont'd)

- Perfect forward secrecy (PFS)
  - Compromise of current keys (session key or long-term key) doesn't compromise past session keys.
  - Concern for encryption keys but not for authentication keys.
  - Not really "perfect" in the same sense as perfect secrecy for one-time pad.

Escrow Foilage Protection

- Key escrow: communicating parties have to store their long-term keys with a third-party (authorities, etc.)
- Escrow-foilage: key stored at the third party is used maliciously
- Escrow Foilage Protection: the conversation between Alice and Bob can still be made secret against a passive eavesdropper with prior knowledge of Alice and Bob's long-term keys.
- Anything with PFS will also have escrow-foilage against a passive attacker.

Internet Key Management

- Manual key management
  - Mandatory
  - Useful when IPsec developers are debugging
  - Keys exchanged offline (phone, email, etc.)
  - Set up SPI and negotiate parameters

Internet Key Management (Cont'd)

- Automatic key management
  - Two major competing proposals
  - Simple Key Management for Internet Protocols (SKIP)
  - ISAKMP/OAKLEY
    - Photuris
      - Ephemeral D-H + authentication + Cookie
      - The first to use cookie to thwart DOS attacks
    - SKEME (extension to Photuris)
    - Oakley (RFC 2412)
    - ISAKMP (RFC 2408)
    - ISAKMP/OAKLEY → IKE (RFC 2409)

A Note about IKE

- IKE v2 was introduced in RFC 4306 (December 2005)
- IKE v2 does not interoperate with IKE v1
  - Both version can unambiguously run over the same UDP port
- IKE v2 combines the contents of previously separate documents
  - ISAKMP
  - IKE v1
  - DOI
  - NAT
  - …

Automatic Key Management

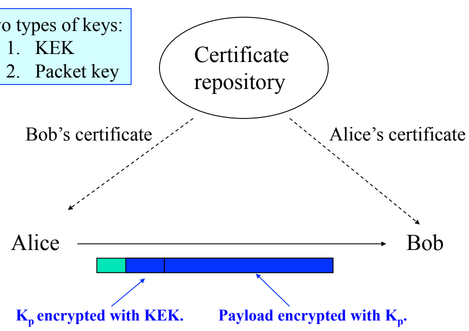
- Key establishment and management combined
  - SKIP
- Key establishment protocol
  - Oakley
    - focus on key exchange
- Key management
  - Internet Security Association & Key Management Protocol (ISAKMP)
    - Focus on SA and key management
    - Clearly separated from key exchange.

SKIP

- Simple Key-Management for Internet Prococols
- Idea
  - IP is connectionless in nature
  - Using security association forces a pseudo session layer underneath IP
  - Proposal: use sessionless key establishment and management
    - Pre-distributed and authenticated D-H public key
    - Packet-specific encryption keys are included in the IP packets

SKIP (Cont'd)

Two types of keys:
1. KEK
2. Packet key



SKIP (Cont'd)

- KEK should be changed periodically
  - Minimize the exposure of KEK
  - Prevent the reuse of compromised packet keys
- SKIP's approach
  - KEK = $h(K_{AB}, n)$, where h is a one-way hash function, K_{AB} is the the long term key between A and B, and n is a counter.

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SKIP (Cont'd)

- Limitations
  - No Perfect Forward Secrecy
    - Can be modified to provide PFS, but it will lose the sessionless property.
  - No concept of SA; difficult to work with the current IPsec architecture
- Not the standard, but remains as an alternative.

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Oakley

- Oakley is a refinement of the basic Diffie-Hellman key exchange protocol.
- Why need refinement?
  - Resource clogging attack
  - Replay attack
  - Man-in-the-middle attack
  - Choice of D-H groups

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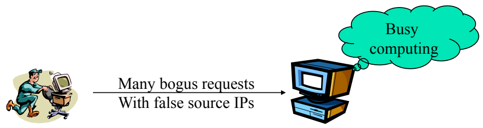
Resource Clogging Attack



- Stopping requests is difficult
  - We need to provide services.
- Ignoring requests is dangerous
  - Denial of service attacks

Resource Clogging Attack (Cont'd)

- Counter measure
  - If we cannot stop bogus requests, at least we should know from where the requests are sent.
  - Cookies are used to thwart resource clogging attack
    - Thwart, not prevent

Resource Clogging Attack (Cont'd)

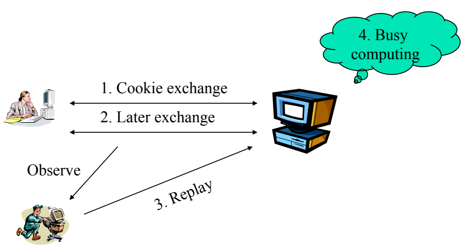
- Cookie
  - Each side sends a pseudo-random number, the cookie, in the initial message, which the other side acknowledges.
  - The acknowledgement must be repeated in the following messages.
  - Do not begin D-H calculation until getting acknowledgement for the other side.

Requirements for cookie generation

- The cookie must depend on the specific parties.
  - Prevent an attacker from reusing cookies.
- Impossible to forge
  - Use secret values
- Efficient
- Cookies are also used for key naming
  - Each key is uniquely identified by the initiator's cookie and the responder's cookie.

Replay Attack

- Counter measure
  - Use nonce



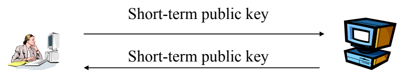
Man-In-The-Middle Attack

- Counter measure
  - Authentication
  - Depend on other mechanisms.
    - Pre-shared key.
    - Public key certificates.

Oakley Groups

- How to choose the DH groups?
  - 0 no group (placeholder or non-DH)
  - 1 MODP, 768-bit modulus
  - 2 MODP, 1024-bit modulus
  - 3 MODP, 1536-bit modulus
  - 4 EC2N over GF(2^{155})
  - 5 EC2N over GF(2^{185})

Ephemeral Diffie-Hellman



- Session key is computed on the basis of short-term DH public-private keys.
- Exchange of these short-term public keys requires authentication and integrity.
  - Digital signatures.
  - Keyed message digests.
- The only protocol known to support Perfect Forward Secrecy.

Ephemeral Diffie-Hellman

- Question: What happens if the long term key is compromised?

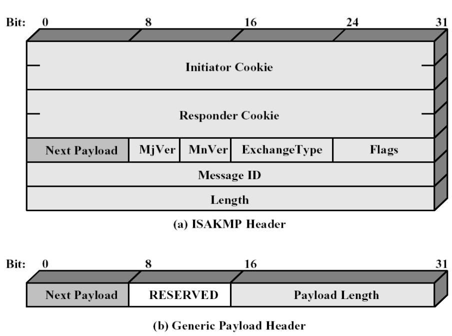
ISAKMP

- Oakley
  - Key exchange protocol
  - Developed to use with ISAKMP
- ISAKMP
  - Security association and key management protocol
  - Defines procedures and packet formats to establish, negotiate, modify, and delete security associations.
  - Defines payloads for security association, key exchange, etc.

ISAKMP Message

- Fixed format header
  - 64 bit initiator and responder cookies
  - Exchange type (8 bits)
  - Next payload type (8 bits)
  - Flags: encryption, commit, authentication, etc.
  - 32 bit message ID
    - Resolve multiple phase 2 SAs being negotiated simultaneously
  - Variable number of payloads
    - Each has a generic header with
      - Payload boundaries
      - Next payload type (possible none)

ISAKMP Formats



ISAKMP Phases

- Phase 1
  - Establish ISAKMP SA to protect further ISAKMP exchanges
  - Or use pre-established ISAKMP SA
  - ISAKMP SA identified by initiator cookie and responder cookie
- Phase 2
  - Negotiate security services in SA for target security protocol or application.

ISAKMP

- Disadvantage
  - Additional overhead due to 2 phases
- Advantages
  - Same ISAKMP SA can be used to negotiate phase 2 for multiple protocols
  - ISAKMP SA can be used to facilitate maintenance of SAs.
  - ISAKMP SA can simplify phase 2.

ISAKMP Domain Of Interpretation (DOI)

- DOI defines
  - Payload format
  - Exchange types
  - Naming conventions for security policies, cryptographic algorithms
- DOI for IPsec has been defined.

ISAKMP Exchange Types

- 0 none
- 1 base
- 2 identity protection
- 3 authentication only
- 4 aggressive
- 5 informational
- 6-31 reserved
- 32-239 DOI specific use
- 240-255private use

ISAKMP Exchange Types

- Base exchange
  - reveals identities
- Identity protection exchange
  - Protects identities at cost of extra messages.
- Authentication only exchange
  - No key exchange
- Aggressive exchange
  - Reduce number of message, but reveals identity
- Informational exchange
  - One-way transmission of information.

ISAKMP Payload Types

- 0 none
- 1 SA security association
- 2 P proposal
- 3 T transform
- 4 KE key exchange
- 5 ID identification
- 6 CERT certificate
- 7 CR certificate request

ISAKMP Payload Types

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- 8 H — hash
- 9 SIG — signature
- 10 NONCE — nonce
- 11 N — notification
- 12 D — delete
- 13 VID — vender ID
- 14-127 — reserved
- 128-255 — private use

ISAKMP Payload Types

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Type	Parameters	Description
Security Association (SA)	Domain of Interpretation, Situation	Used to negotiate security attributes and indicate the DOI and Situation under which negotiation is taking place.
Proposal (P)	Proposal #, Protocol-ID, SPI Size, # of Transforms, SPI	Used during SA negotiation; indicates protocol to be used and number of transforms.
Transform (T)	Transform #, Transform-ID, SA Attributes	Used during SA negotiation; indicates transform and related SA attributes.
Key Exchange (KE)	Key Exchange Data	Supports a variety of key exchange techniques.
Identification (ID)	ID Type, ID Data	Used to exchange identification information.
Certificate (CERT)	Cert Encoding, Certificate Data	Used to transport certificates and other certificate-related information.
Certificate Request (CR)	# Cert Types, Certificate Types, # Cert Auths, Certificate Authorities	Used to request certificates; indicates the types of certificates requested and the acceptable certificate authorities.
Hash (HASH)	Hash Data	Contains data generated by a hash function.
Signature (SIG)	Signature Data	Contains data generated by a digital signature function.
Nonce (NONCE)	Nonce Data	Contains a nonce.
Notification (N)	DOI, Protocol-ID, SPI Size, Notify Message Type, SPI, Notification Data	Used to transmit notification data, such as an error condition.
Delete (D)	DOI, Protocol-ID, SPI Size, # of SPIs, SPI (one or more)	Indicates an SA that is no longer valid.

ISAKMP Exchanges

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Basic Exchange

1. I→R: SA; NONCE	Begin ISAKMP-SA negotiation
2. R→I: SA; NONCE	Basic SA agreed upon
3. I→R: KE; ID_I; AUTH	Key generated; Initiator id verified by responder
4. R→I: KE; ID_R; AUTH	Responder id verified by initiator; key generated; SA established

ISAKMP Exchanges (Cont'd)

Identity Protection Exchange

1.	I→R: SA	Begin ISAKMP-SA negotiation
2.	R→I: SA	Basic SA agreed upon
3.	I→R: KE; NONCE	Key generated;
4.	R→I: KE; NONCE	key generated;
5.	I→R: ID_I; AUTH	Initiator id verified by responder
6.	R→I: ID_R; AUTH	Responder id verified by initiator; SA established

Blue messages: Payload encrypted after ISAKMP header

ISAKMP Exchanges (Cont'd)

Authentication Only Exchange

1.	I→R: SA; NONCE	Begin ISAKMP-SA negotiation
2.	R→I: SA; NONCE; ID_R; AUTH	Basic SA agreed upon; Responder id verified by initiator
3.	I→R: ID_I; AUTH	Initiator id verified by responder; SA established

ISAKMP Exchanges (Cont'd)

Aggressive Exchange

1.	I→R: SA; KE; NONCE; ID_I	Begin ISAKMP-SA negotiation and key exchange
2.	R→I: SA; KE; NONCE; ID_R; AUTH	Responder identity verified by responder; Key generated; Basic SA agreed upon;
3.	I→R: AUTH	Initiator id verified by responder; SA established

Red messages: Payload encrypted after ISAKMP header

ISAKMP Exchanges (Cont'd)

Informational Exchange

1.	I→R: N/D	Error or status notification, or deletion.

Red message: Payload encrypted after ISAKMP header

IKE Overview

- IKE = ISAKMP + part of OAKLEY + part of SKEME
  - ISAKMP determines
    - How two peers communicate
    - How these messages are constructed
    - How to secure the communication between the two peers
    - No actual key exchange
  - Oakley
    - Key exchange protocol
  - Combining these two requires a Domain of Interpretation (DOI)
    - RFC 2407

IKE Overview (Cont'd)

- A separate RFC has been published for IKE
  - RFC 2409
- Request-response protocol
  - Initiator
  - Responder
- Two phases
  - Phase 1: Establish an IKE (ISAKMP) SA
    - Essentially the ISAKMP phase 1
    - Bi-directional
  - Phase 2: Use the IKE SA to establish IPsec SAs
    - Key exchange phase
    - Directional

IKE Overview (Cont'd)

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- Several Modes
  - Phase 1:
    - Main mode: identity protection
    - Aggressive mode
  - Phase 2:
    - Quick mode
  - Other modes
    - New group mode
      - Establish a new group to use in future negotiations
      - Not in phase 1 or 2;
      - Must only be used after phase 1
    - Informational exchanges
      - ISAKMP notify payload
      - ISAKMP delete payload

IPsec Architecture Revisited

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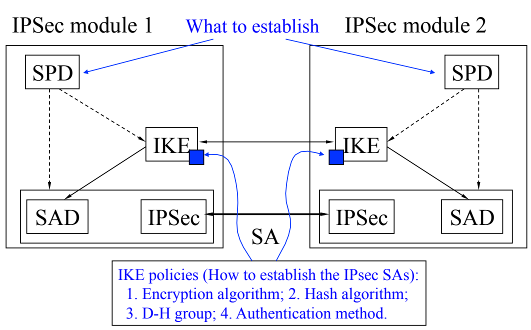

IKE Phase 1

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- Four authentication methods
  - Digital signature
  - Authentication with public key encryption
  - The above method revised
  - Authentication with a pre-shared key

IKE Phase 1 (Cont'd)

- IKE Phase 1 goal:
  - Establish a shared secret SKEYID
  - With signature authentication
    - SKEYID = prf(Ni_b | Nr_b, g^{xy})
  - With public key encryption
    - SKEYID = prf(hash(Ni_b | Nr_b), CKY-I | CKY-R)
  - With pre-shared key
    - SKEYID = prf(pre-shared-key, Ni_b | Nr_b)
  - Notations:
    - prf: keyed pseudo random function prf(key, message)
    - CKY-I/CKY-R: I's (or R's) cookie
    - Ni_b/Nr_b: the body of I's (or R's) nonce

IKE Phase 1 (Cont'd)

- Three groups of keys
  - Derived key for non-ISAKMP negotiations
    - SKEYID_d = prf(SKEYID, g^{xy} | CKY-I | CKY-R | 0)
  - Authentication key
    - SKEYID_a = prf(SKEYID, SKEYID_d | g^{xy} | CKY-I | CKY-R | 1)
  - Encryption key
    - SKEYID_e = prf(SKEYID, SKEYID_a | g^{xy} | CKY-I | CKY-R | 2)

IKE Phase 1 (Cont'd)

- To authenticate the established key
  - Initiator generates
    - HASH_I = prf(SKEYID, g^{xi} | g^{xr} | CKY-I | CKY-R | SAi_b | IDii_b)
  - Responder generates
    - HASH_R = prf(SKEYID, g^{xr} | g^{xi} | CKY-R | CKY-I | SAi_b | IDir_b)
  - Authentication with digital signatures
    - HASH_I and HASH_R are signed and verified
  - Public key encryption or pre-shared key
    - HASH_I and HASH_R directly authenticate the exchange.

IKE Phase 1 Authenticated with Signatures

Main Mode

Initiator		Responder
HDR, SA	→	
	←	HDR, SA
HDR, KE, Ni	→	
	←	HDR, KE, Nr
HDR*, IDii, [CERT,] SIG_I	→	
	←	HDR*, IDir, [CERT,] SIG_R

IKE Phase 1 Authenticated with Signatures

Aggressive Mode

Initiator		Responder
HDR, SA, KE, Ni, IDii	→	
	←	HDR, SA, KE, Nr, IDir, [CERT,] SIG_R
HDR, [CERT,] SIG_I	→	

IKE Phase 1 Authenticated with Public Key Encryption

Main Mode

Initiator		Responder
HDR, SA	→	
	←	HDR, SA
HDR, KE, [HASH(1),] <IDii_b>PubKey_r, <Ni_b>PubKey_r	→	
	←	HDR, KE, <IDir_b>PubKey_i, <Nr_b>PubKey_i
HDR*, HASH_I	→	
	←	HDR*, HASH_R

IKE Phase 1 Authenticated with Public Key Encryption

Aggressive Mode

Initiator		Responder
HDR, SA, [HASH(1),] KE, <IDii_b>PubKey_r, <Ni_b>PubKey_r	→	
	←	HDR, SA, KE, <IDir_b>PubKey_i, <Nr_b>PubKey_i, HASH_R
HDR, HASH_I	→	

Observations

- Authenticated using public key encryption
  - No non-repudiation
    - No evidence that shows the negotiation has taken place.
  - More difficult to break
    - An attacker has to break both DH and public key encryption
  - Identity protection is provided in aggressive mode.
  - Four public key operations
    - Two public key encryptions
    - Two public key decryptions

IKE Phase 1 Authenticated with A Revised Mode of Public Key Encryption

Main Mode

Initiator		Responder
HDR, SA	→	
	←	HDR, SA
HDR, [HASH(1),] <Ni_b>PubKey_r <KE_b>Ke_i <IDii_b>Ke_i, [<Cert-I_b>Ke_i]	→	
	←	HDR, <Nr_b>PubKey_i, <KE_b>Ke_r, <IDir_b>Ke_r
HDR*, HASH_I	→	
	←	HDR*, HASH_R

IKE Phase 1 Authenticated with A Revised Mode of Public Key Encryption

Aggressive Mode

Initiator → Responder

HDR, SA, [HASH(1),] <Ni_b>PubKey_r, <KE_b>Ke_i, <IDii_b>Ke_i [, <Cert-I_b>Ke_i] →

← HDR, SA, <Nr_b>PubKey_i, <KE_b>Ke_r, <IDir_b>Ke_r, HASH_R

HDR, HASH_I →

Further Details

Ne_i=prf(Ni_b, CKY-I)
Ne_r=prf(Nr_b, CKY-R)

- Ke_i and Ke_r are taken from Ne_i and Ne_r, respectively.

IKE Phase 1 Authenticated with Pre-Shared Key

Main Mode

Initiator → Responder

HDR, SA →

← HDR, SA

HDR, KE, Ni →

← HDR, KE, Nr

HDR*, IDii, HASH_I →

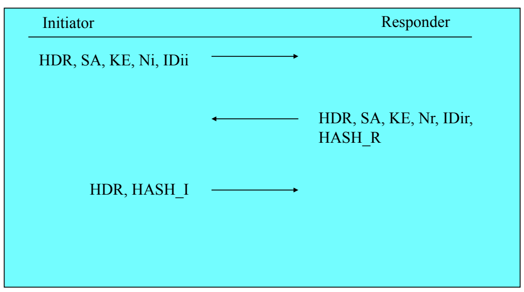
← HDR*, IDir, HASH_R

IKE Phase 1 Authenticated with Pre-Shared Key (Cont'd)

- What provide the authentication?
- Why does it work?

IKE Phase 1 Authenticated with Pre-Shared Key

Aggressive Mode



IKE Phase 2 -- Quick Mode

- Not a complete exchange itself
  - Must be bound to a phase 1 exchange
- Used to derive keying materials for IPsec SAs
- Information exchanged with quick mode must be protected by the ISAKMP SA
- Essentially a SA negotiation and an exchange of nonce
  - Generate fresh key material
  - Prevent replay attack

IKE Phase 2 -- Quick Mode (Cont'd)

- Basic Quick Mode
  - Refresh the keying material derived from phase 1
- Quick Mode with optional KE payload
  - Transport additional exponentiation
  - Provide PFS

IKE Phase 2 -- Quick Mode (Cont'd)

Initiator		Responder
HDR*, HASH(1), SA, Ni, [,KE] [, IDci, IDcr]	→	
	←	HDR*, HASH(2), SA, Nr, [, KE] [, IDci, IDcr]
HDR*, HASH(3)	→	

HASH(1) = prf(SKEYID_a, M-ID | SA | Ni [| KE] [| IDci | IDcr)
HASH(2) = prf(SKEYID_a, M-ID | Ni_b | SA | Nr [| KE] [| IDci | IDcr)
HASH(3) = prf(SKEYID_a, 0 | M-ID | Ni_b | Nr_b)

IKE Phase 2 -- Quick Mode (Cont'd)

If PFS is not needed, and KE payloads are not exchanged, the new keying material is defined as

KEYMAT = prf(SKEYID_d, protocol | SPI | Ni_b | Nr_b)

If PFS is desired and KE payloads were exchanged, the new keying material is defined as

KEYMAT = prf(SKEYID_d, $g(qm)^{xy}$ | protocol | SPI | Ni_b | Nr_b)

where $g(qm)^{xy}$ is the shared secret from the ephemeral Diffie-Hellman exchange of this Quick Mode.

In either case, "protocol" and "SPI" are from the ISAKMP Proposal Payload that contained the negotiated Transform.