


WILLIAM
& MARY

CSCI 454/554 Computer and Network Security

Topic 8.2 Internet Key Management




Outline

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

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Key Management

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- 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

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Security Principles

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- 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.

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Security Principles (Cont'd)

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- 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.

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Escrow Foilage Protection

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- **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.

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Internet Key Management WILLIAM & MARY

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

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Internet Key Management (Cont'd) WILLIAM & MARY

- 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)

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A Note about IKE WILLIAM & MARY

- 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
 - ...

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Automatic Key Management WILLIAM & MARY

- 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.

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SKIP WILLIAM & MARY

- Simple Key-Management for Internet Proccols
- 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

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SKIP (Cont'd) WILLIAM & MARY

Two types of keys:

- KEK
- Packet key

The diagram illustrates the SKIP process. A central 'Certificate repository' provides 'Bob's certificate' to Alice and 'Alice's certificate' to Bob. Alice then sends a packet to Bob. The packet contains a 'K_p encrypted with KEK' (represented by a green box) and a 'Payload encrypted with K_p' (represented by a blue box).

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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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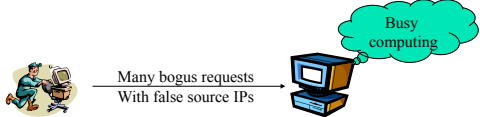
Oakley

- 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

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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

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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.

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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.

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Replay Attack

- Counter measure
 - Use nonce

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Man-In-The-Middle Attack

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

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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 $GF(2^{185})$

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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.

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Diffie-Hellman for PFS using Signature Keys

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Ephemeral Diffie-Hellman WILLIAM & MARY

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

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ISAKMP WILLIAM & MARY

- 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.

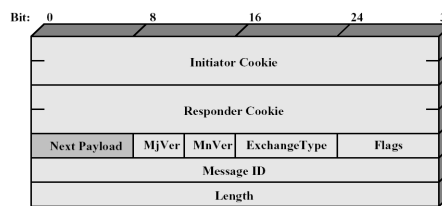
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ISAKMP Message WILLIAM & MARY

- 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)

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ISAKMP Formats WILLIAM & MARY



(a) ISAKMP Header



(b) Generic Payload Header

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ISAKMP Phases WILLIAM & MARY

- 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.

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ISAKMP WILLIAM & MARY

- 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.

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ISAKMP Domain Of Interpretation (DOI) WILLIAM & MARY

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

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ISAKMP Exchange Types WILLIAM & MARY

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

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ISAKMP Exchange Types WILLIAM & MARY

- 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.

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ISAKMP Payload Types WILLIAM & MARY

- 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

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ISAKMP Payload Types WILLIAM & MARY

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

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ISAKMP Payload Types WILLIAM & MARY

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.

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ISAKMP Exchanges WILLIAM & MARY

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

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ISAKMP Exchanges (Cont'd) WILLIAM & MARY

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

Red messages: Payload encrypted after ISAKMP header

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ISAKMP Exchanges (Cont'd) WILLIAM & MARY

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

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ISAKMP Exchanges (Cont'd) WILLIAM & MARY

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 initiator; Key generated; Basic SA agreed upon;
3. I→R: AUTH	• Initiator id verified by responder; SA established

Red messages: Payload encrypted after ISAKMP header

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ISAKMP Exchanges (Cont'd) WILLIAM & MARY

Informational Exchange

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

Red message: Payload encrypted after ISAKMP header

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IKE Overview WILLIAM & MARY

- 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

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IKE Overview (Cont'd) WILLIAM & MARY

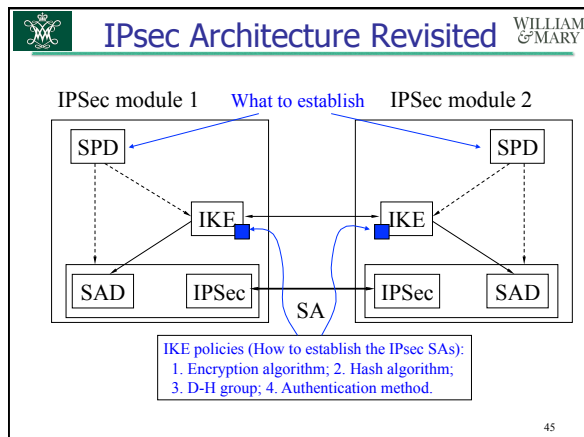
- A separate RFC has been published for IKE
 - RFC 2409
- Request-response protocol
 - Initiator
 - Responder
- Two phases
 - Phase 1: Establish an IKE (ISAKMP) SA
 - Essentially the ISAKMP phase 1
 - Bi-directional
 - Phase 2: Use the IKE SA to establish IPsec SAs
 - Key exchange phase
 - Directional

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IKE Overview (Cont'd) WILLIAM & MARY

- 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

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IKE Phase 1 WILLIAM & MARY

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

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IKE Phase 1 (Cont'd) WILLIAM & MARY

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

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IKE Phase 1 (Cont'd) WILLIAM & MARY

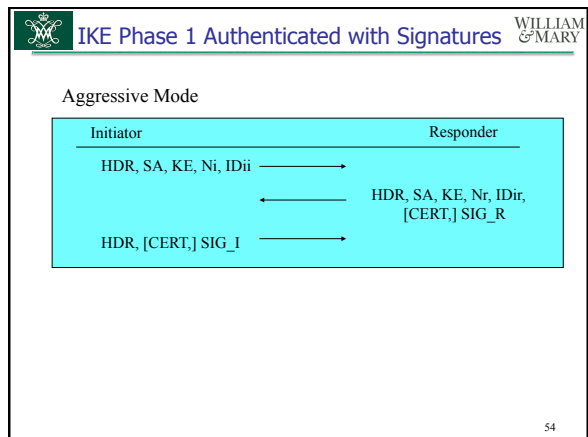
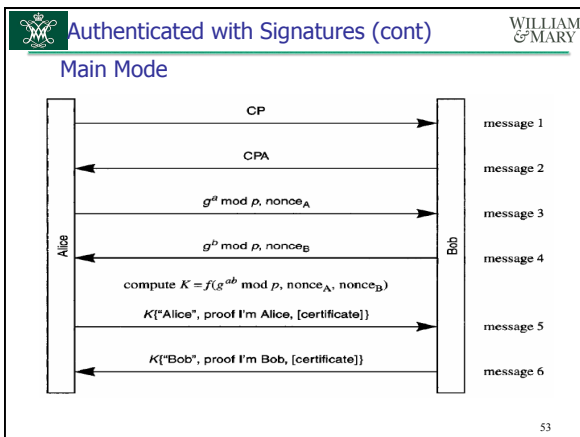
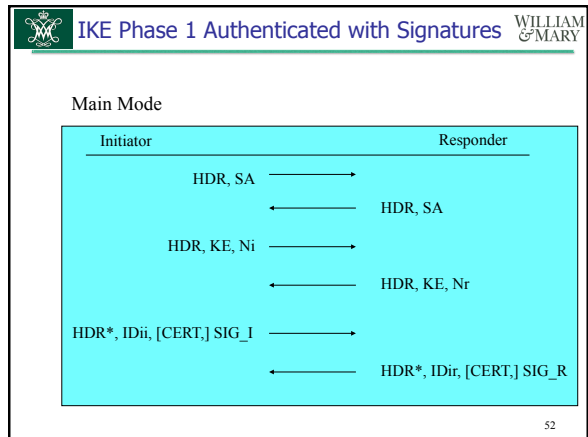
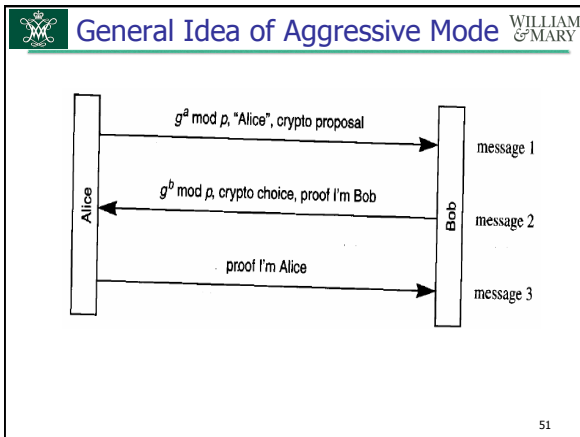
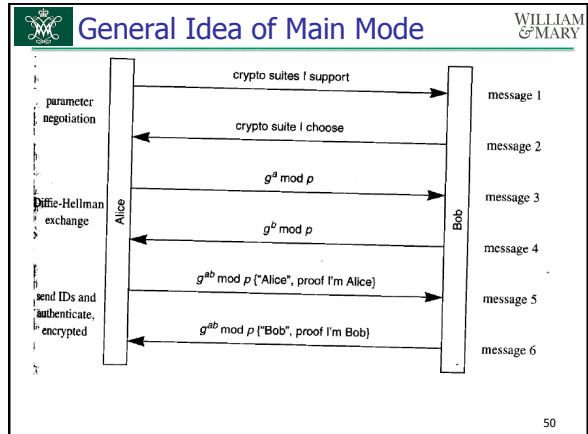
- Three groups of keys
 - Derived key for non-ISAKMP negotiations
 - $SKEYID_d = \text{prf}(SKEYID, g^{xy} | CKY-I | CKY-R | 0)$
 - Authentication key
 - $SKEYID_a = \text{prf}(SKEYID, SKEYID_d | g^{xy} | CKY-I | CKY-R | 1)$
 - Encryption key
 - $SKEYID_e = \text{prf}(SKEYID, SKEYID_a | g^{xy} | CKY-I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

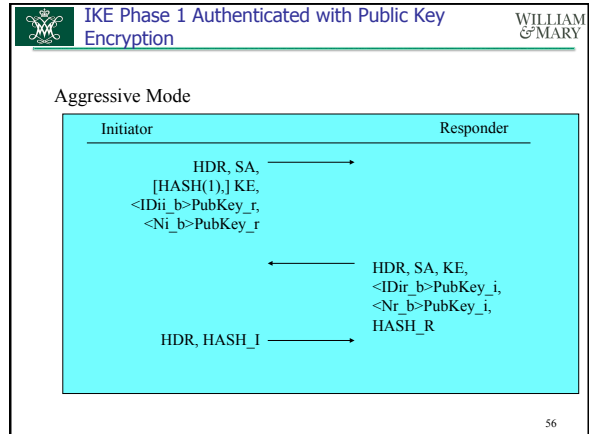
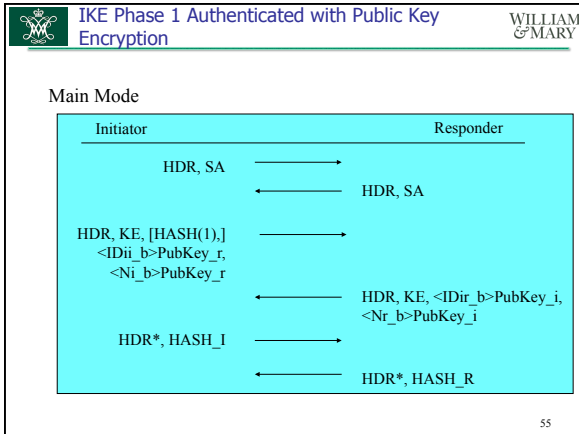
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IKE Phase 1 (Cont'd)

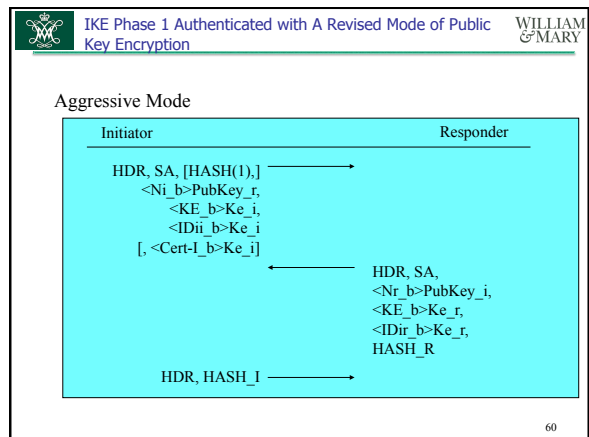
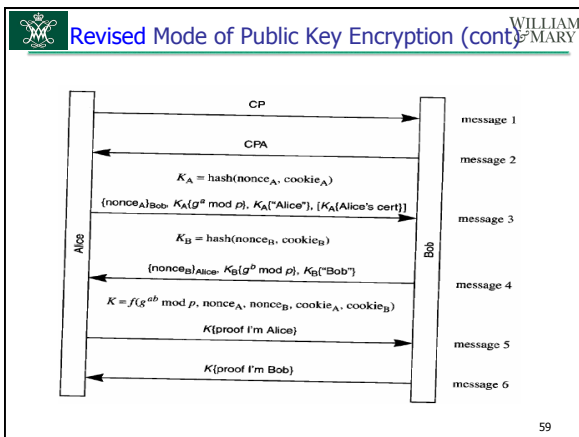
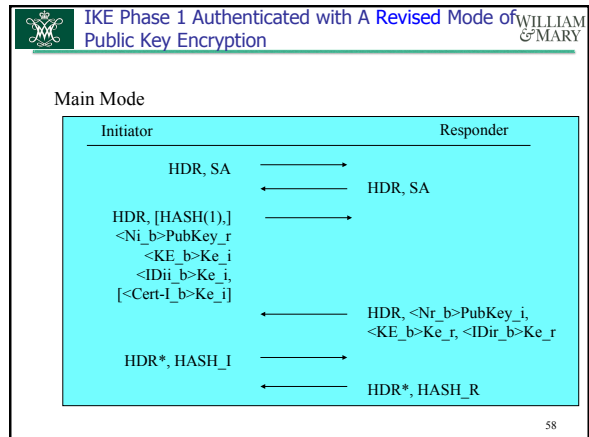
- To authenticate the established key
 - Initiator generates
 - $HASH_I = \text{prf}(\text{SKEYID}, g^{xi} | g^{xr} | \text{CKY-I} | \text{CKY-R} | \text{SAi_b} | \text{IDii_b})$
 - Responder generates
 - $HASH_R = \text{prf}(\text{SKEYID}, g^{xr} | g^{xi} | \text{CKY-R} | \text{CKY-I} | \text{SAi_b} | \text{IDir_b})$
 - 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.

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- Observations**
- WILLIAM & MARY
- 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
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Further Details

$Ne_i = \text{prf}(Ni_b, \text{CKY-I})$
 $Ne_r = \text{prf}(Nr_b, \text{CKY-R})$

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

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IKE Phase 1 Authenticated with Pre-Shared Key

Main Mode

```

sequenceDiagram
    participant Initiator
    participant Responder
    Initiator->>Responder: HDR, SA
    Responder-->>Initiator: HDR, SA
    Initiator->>Responder: HDR, KE, Ni
    Responder-->>Initiator: HDR, KE, Nr
    Initiator->>Responder: HDR*, IDii, HASH_I
    Responder-->>Initiator: HDR*, IDir, HASH_R
    
```

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

```

sequenceDiagram
    participant Alice
    participant Bob
    Note over Alice, Bob: shared secret J
    Alice->>Bob: CP
    Note over Alice, Bob: message 1
    Bob-->>Alice: CPA
    Note over Alice, Bob: message 2
    Alice->>Bob: g^a mod p, nonce_A
    Note over Alice, Bob: message 3
    Bob-->>Alice: g^b mod p, nonce_B
    Note over Alice, Bob: message 4
    Note over Alice, Bob: K = f(J, g^{ab} mod p, nonce_A, nonce_B, cookie_A, cookie_B)
    Alice->>Bob: K("Alice", proof I'm Alice)
    Note over Alice, Bob: message 5
    Bob-->>Alice: K("Bob", proof I'm Bob)
    Note over Alice, Bob: message 6
    
```

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

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

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IKE Phase 1 Authenticated with Pre-Shared Key

Aggressive Mode

```

sequenceDiagram
    participant Initiator
    participant Responder
    Initiator->>Responder: HDR, SA, KE, Ni, IDii
    Responder-->>Initiator: HDR, SA, KE, Nr, IDir, HASH_R
    Initiator->>Responder: HDR, HASH_I
    
```

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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

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IKE Phase 2 -- Quick Mode (Cont'd) WILLIAM & MARY

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

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IKE Phase 2 -- Quick Mode (Cont'd) WILLIAM & MARY

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

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

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IKE Phase 2 -- Quick Mode (Cont'd) WILLIAM & MARY

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

$$\text{KEYMAT} = \text{prf}(\text{SKEYID_d}, \text{protocol} | \text{SPI} | \text{Ni_b} | \text{Nr_b})$$

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

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

where $\text{g}(\text{qm})^{\text{S}}$ 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.

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