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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

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

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.

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.

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.

Internet Key Management

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- 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)

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- 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

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- 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

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- 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

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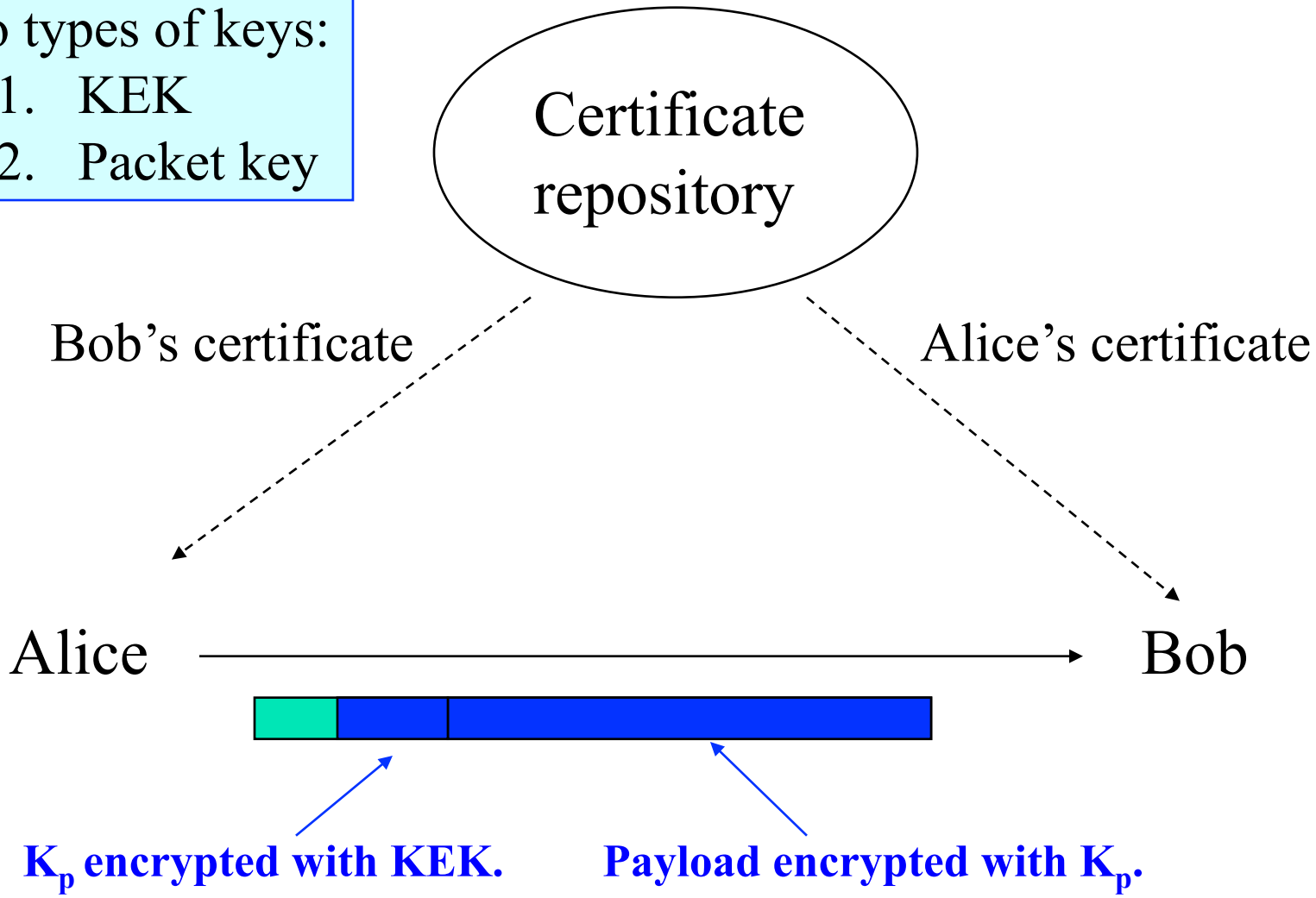
- Simple Key-Management for Internet Prococols
- Idea
  - IP is connectionless in nature
  - Using security association forces a pseudo session layer underneath IP
  - Proposal: use sessionless key establishment and management
    - Pre-distributed and authenticated D-H public key
    - Packet-specific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

SKIP (Cont'd)

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



SKIP (Cont'd)

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- 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.

SKIP (Cont'd)

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- 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.

Oakley

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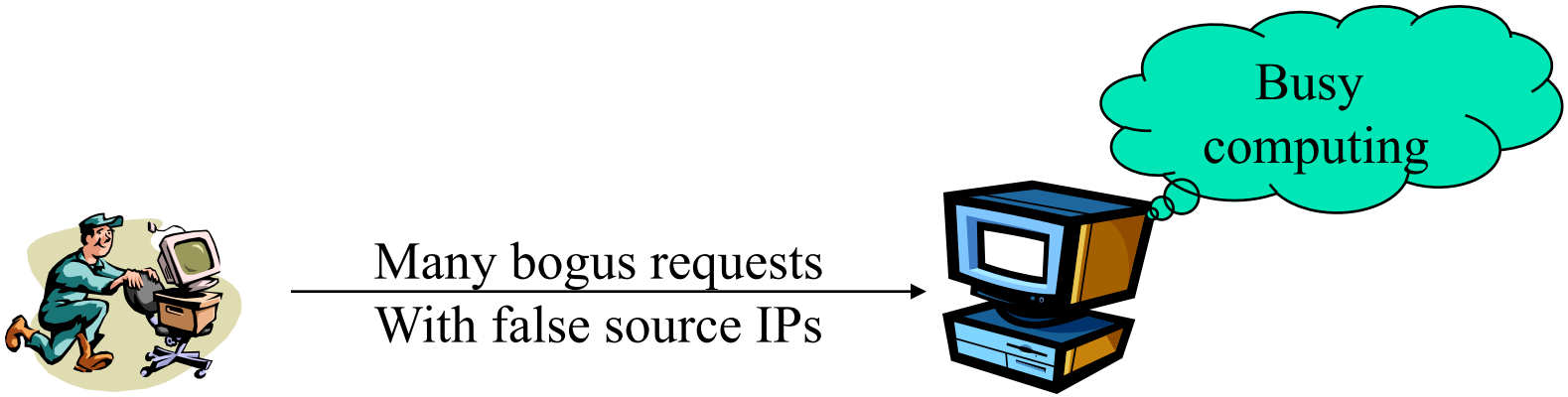
- Oakley is a refinement of the basic Diffie-Hellman key exchange protocol.
- Why need refinement?
  - Resource clogging attack
  - Replay attack
  - Man-in-the-middle attack
  - Choice of D-H groups

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)

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- 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)

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- 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

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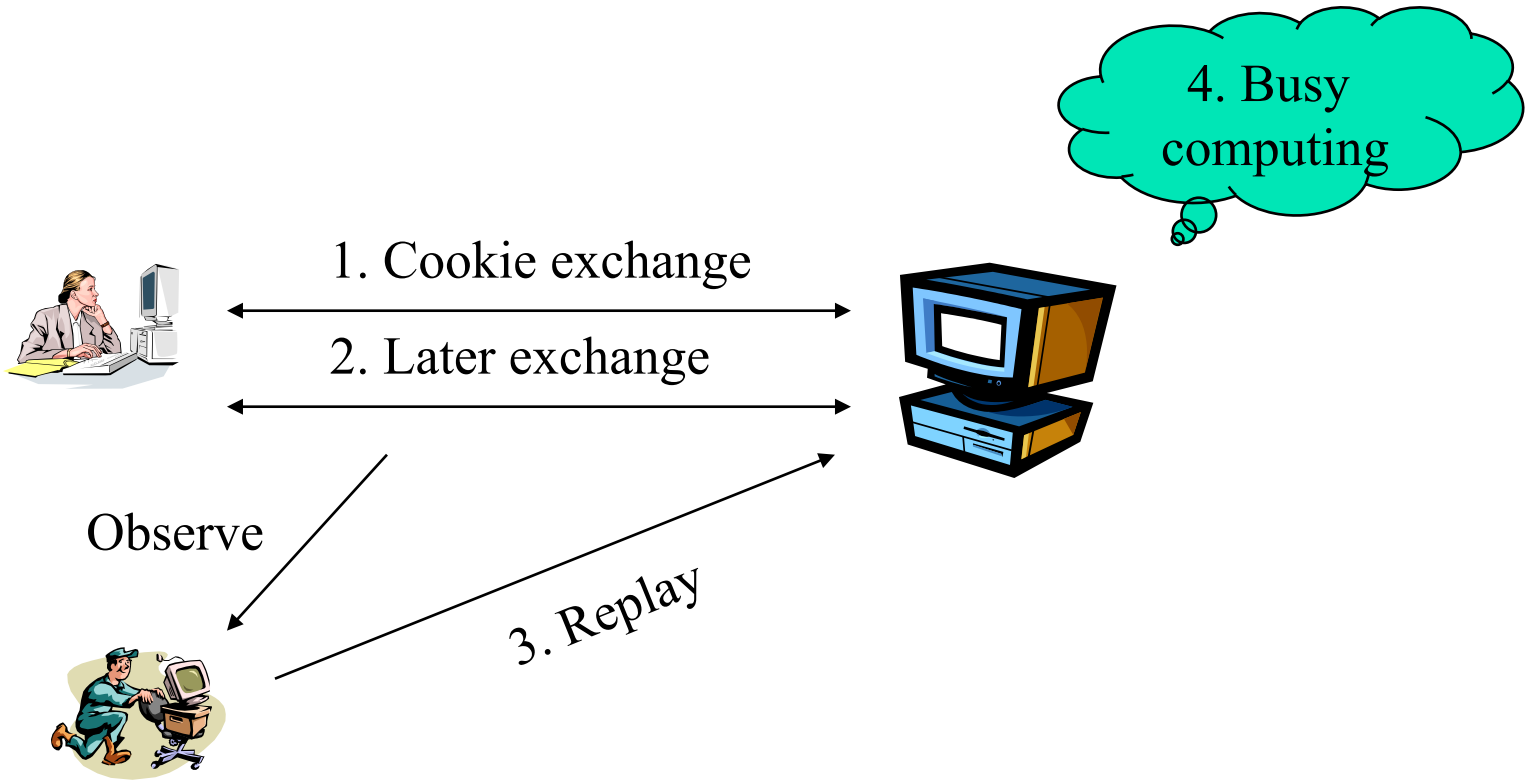
- The cookie must depend on the specific parties.
  - Prevent an attacker from reusing cookies.
- Impossible to forge
  - Use secret values
- Efficient
- Cookies are also used for key naming
  - Each key is uniquely identified by the initiator's cookie and the responder's cookie.

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

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- 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

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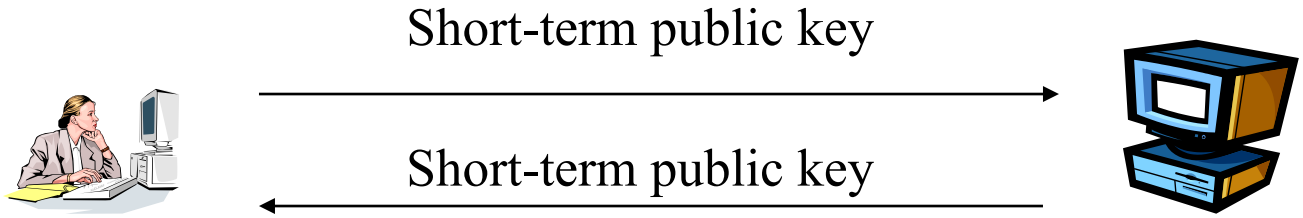

- Session key is computed on the basis of short-term DH public-private keys.
- Exchange of these short-term public keys requires authentication and integrity.
  - Digital signatures.
  - Keyed message digests.
- The only protocol known to support Perfect Forward Secrecy.

Ephemeral Diffie-Hellman

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

ISAKMP

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- 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

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- 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

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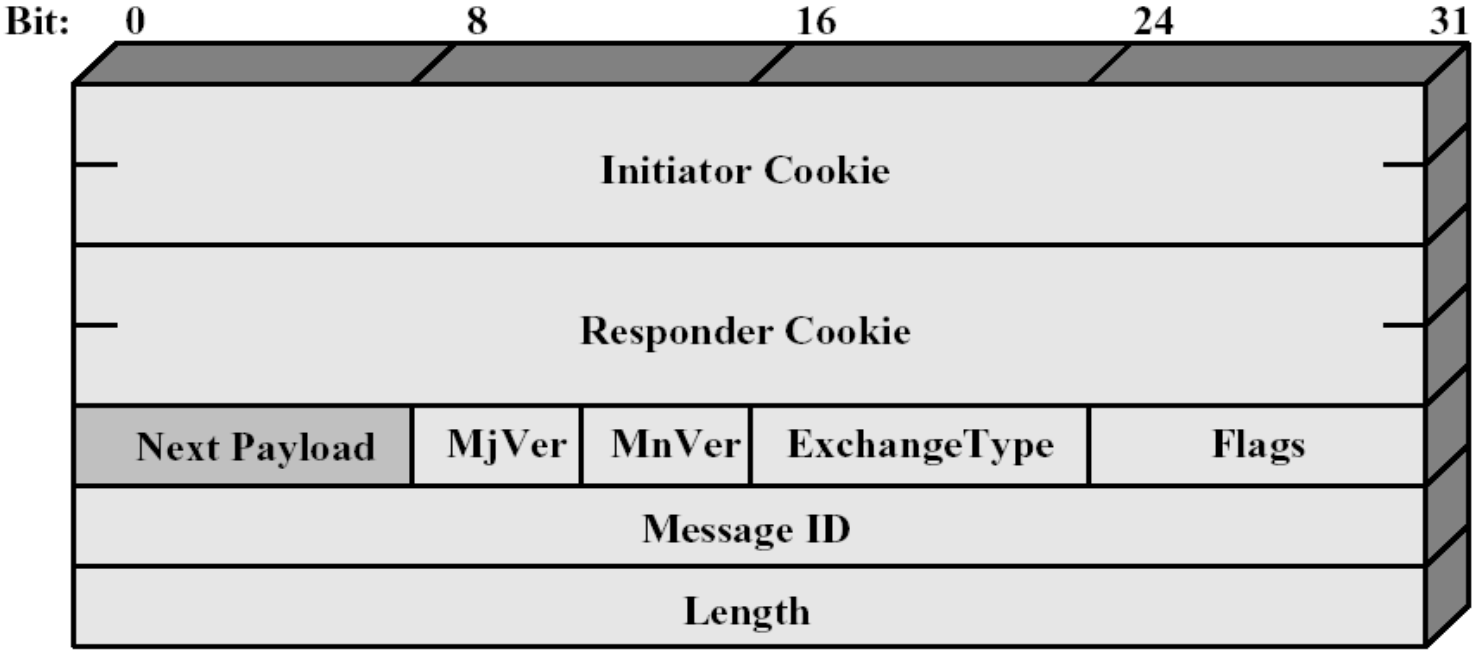

(a) ISAKMP Header

(b) Generic Payload Header

ISAKMP Phases

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- 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

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- 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)

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

ISAKMP Exchange Types

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- 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

ISAKMP Exchange Types

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- 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

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- 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)

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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)

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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)

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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)

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Informational Exchange

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

Red message: Payload encrypted after ISAKMP header

IKE Overview

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- 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)

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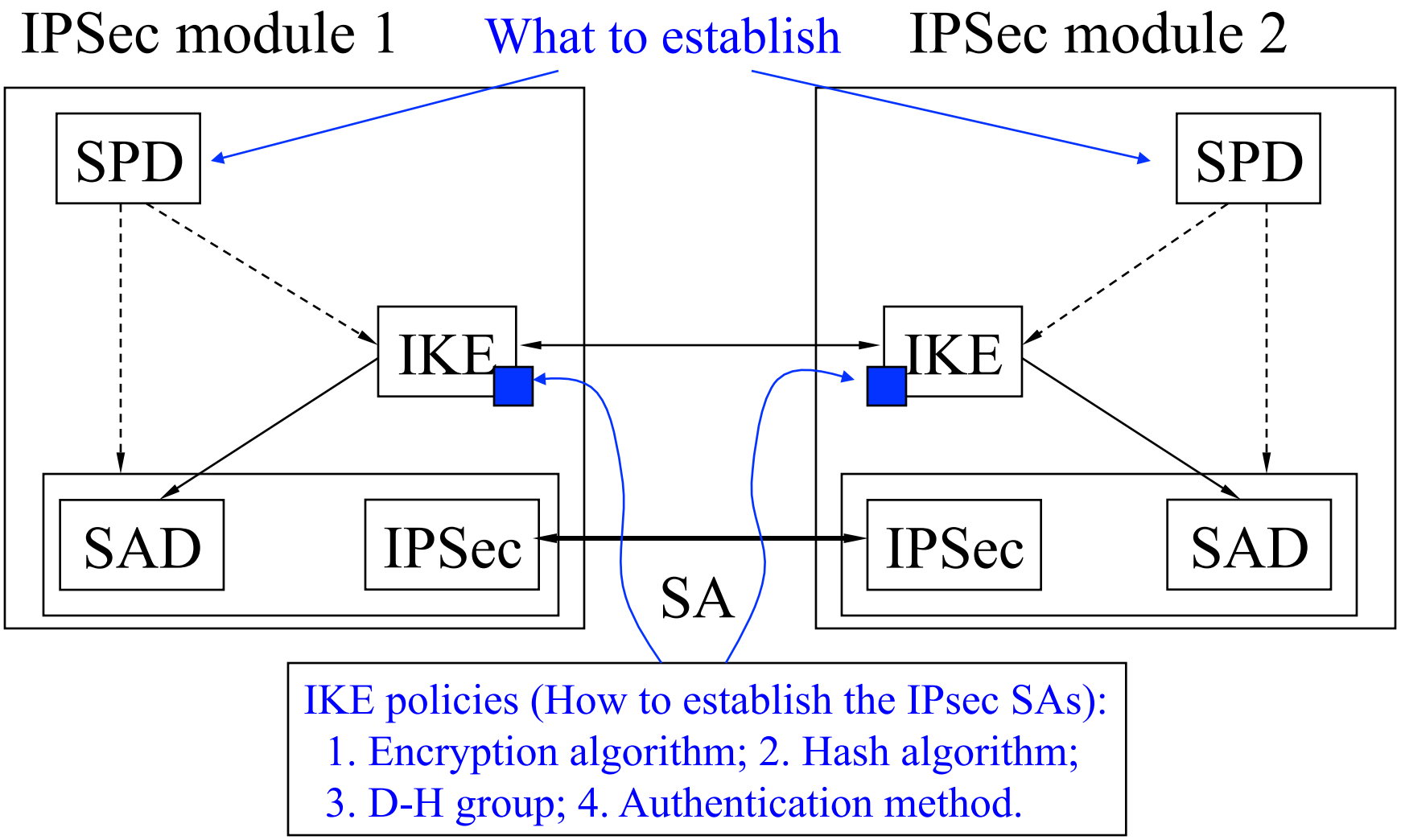
- Several Modes
  - Phase 1:
    - Main mode: identity protection
    - Aggressive mode
  - Phase 2:
    - Quick mode
  - Other modes
    - New group mode
      - Establish a new group to use in future negotiations
      - Not in phase 1 or 2;
      - Must only be used after phase 1
    - Informational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

IPsec Architecture Revisited



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)

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- 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)

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- 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)

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- 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

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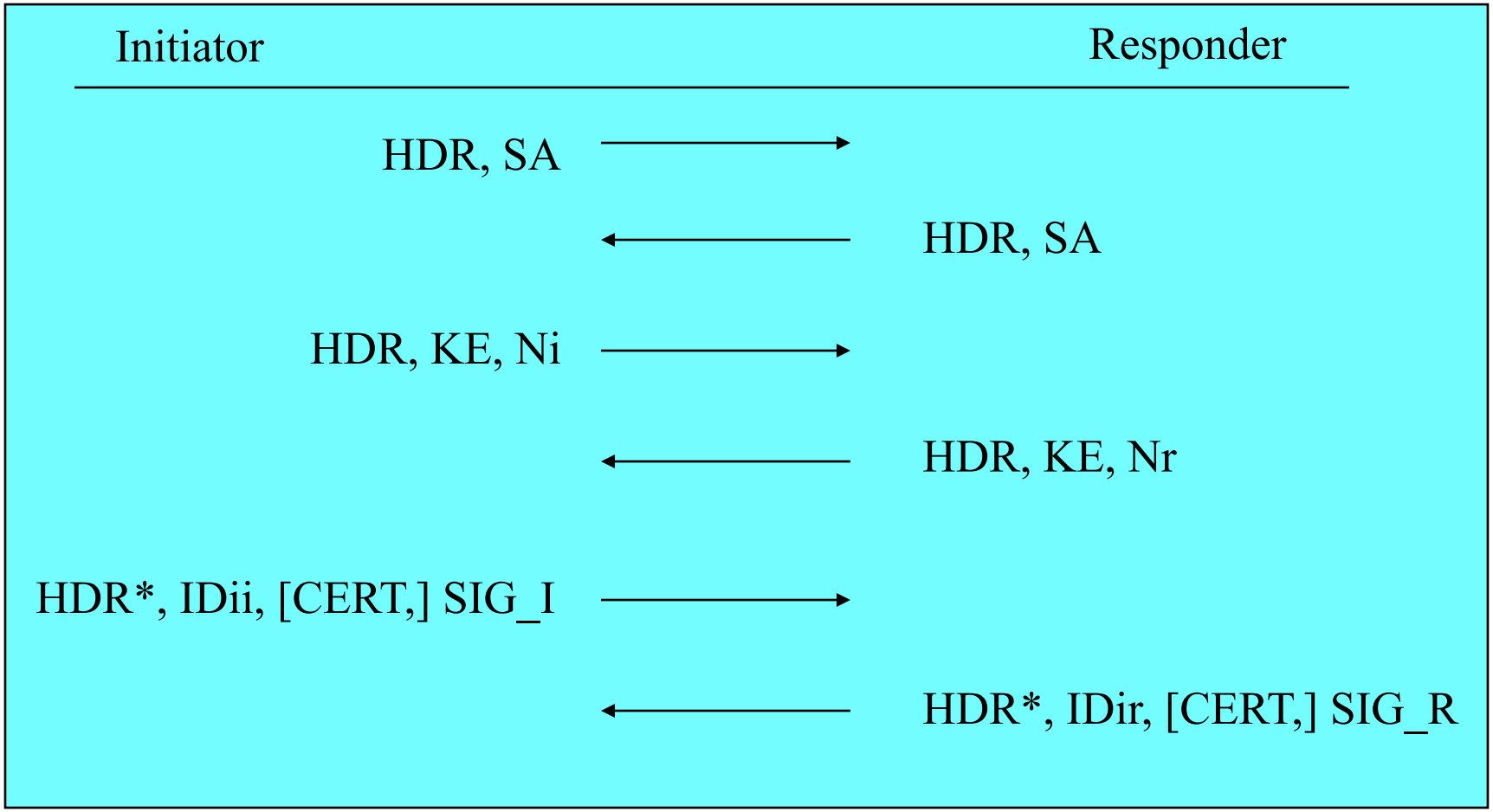
Main Mode



IKE Phase 1 Authenticated with Signatures

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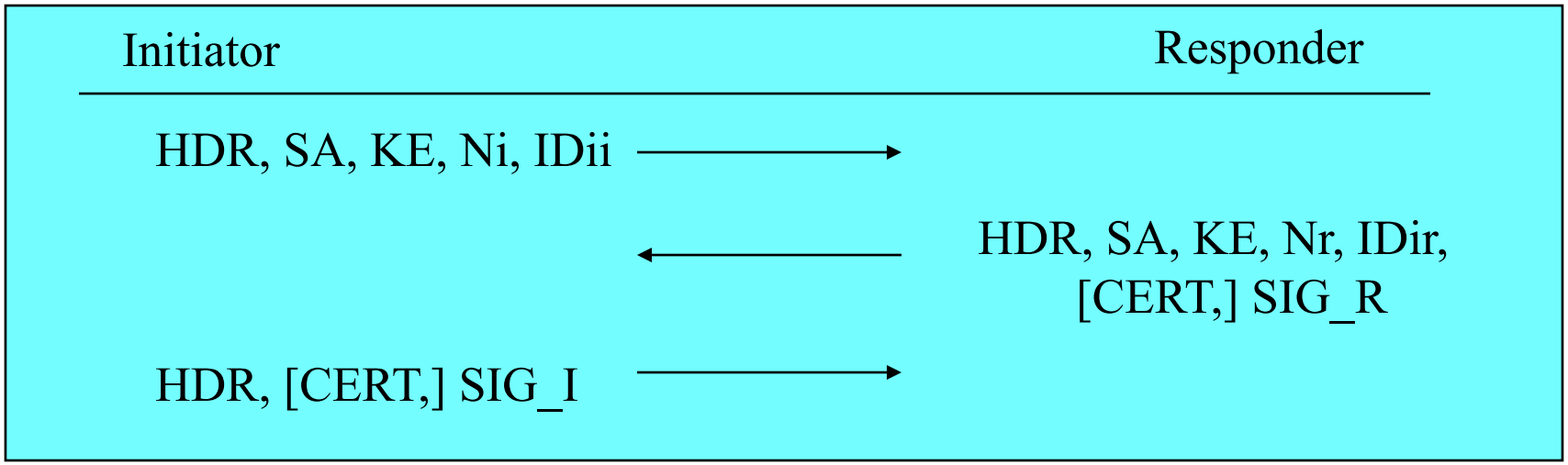
Aggressive Mode



IKE Phase 1 Authenticated with Public Key Encryption

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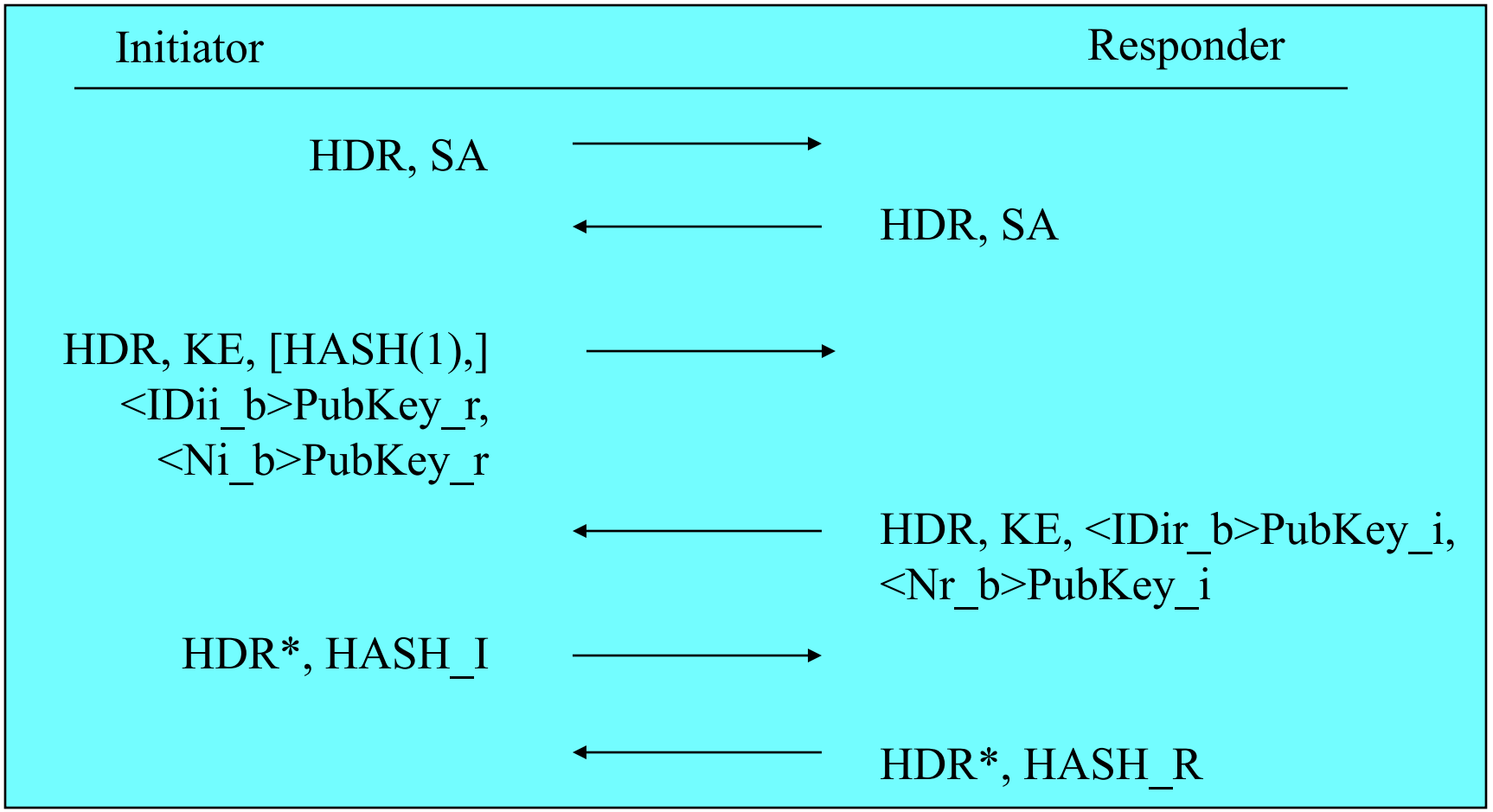
Main Mode



IKE Phase 1 Authenticated with Public Key Encryption

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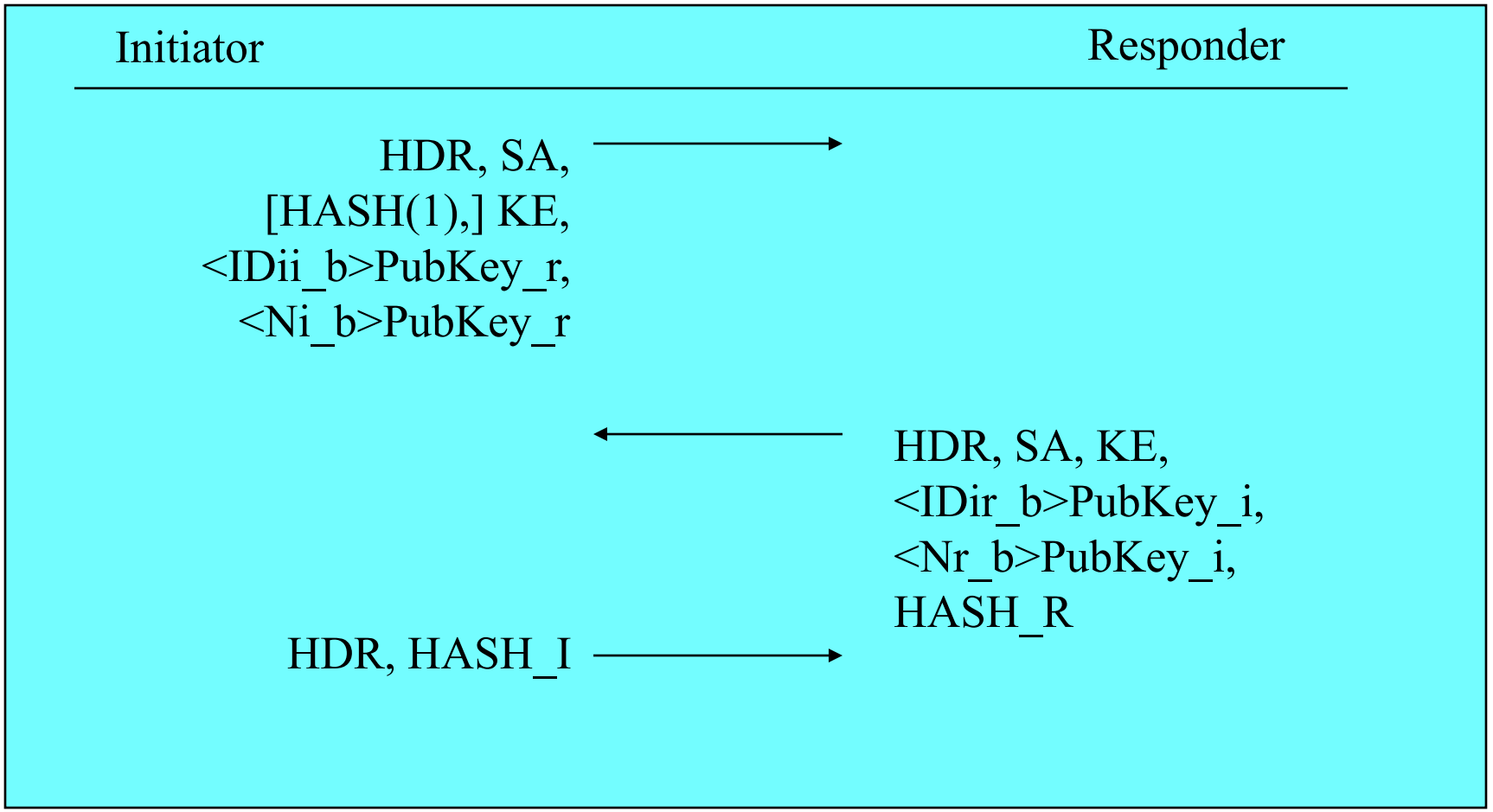
Aggressive Mode



Observations

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- 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

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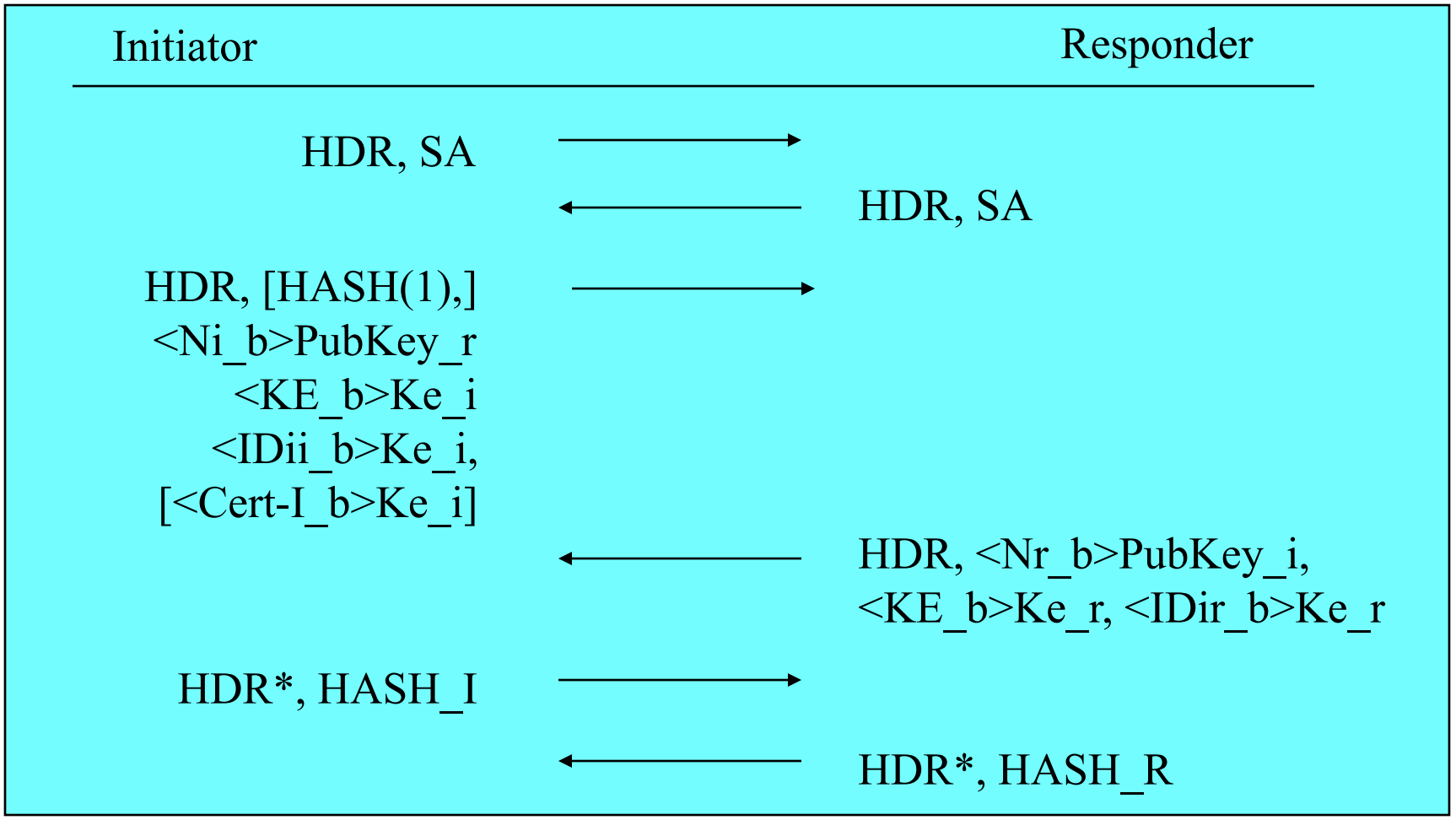
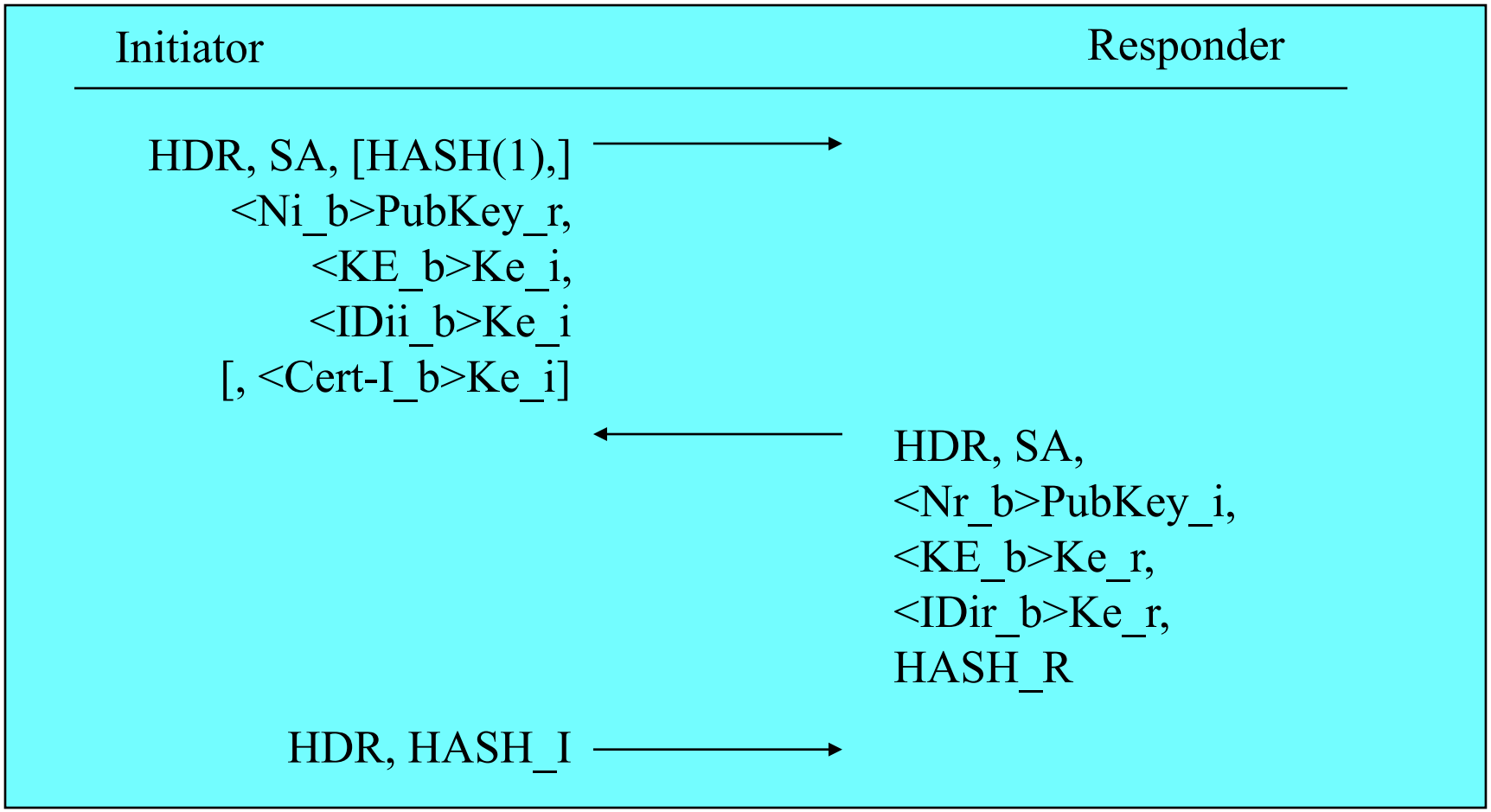
Main Mode



Aggressive Mode



Further Details

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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

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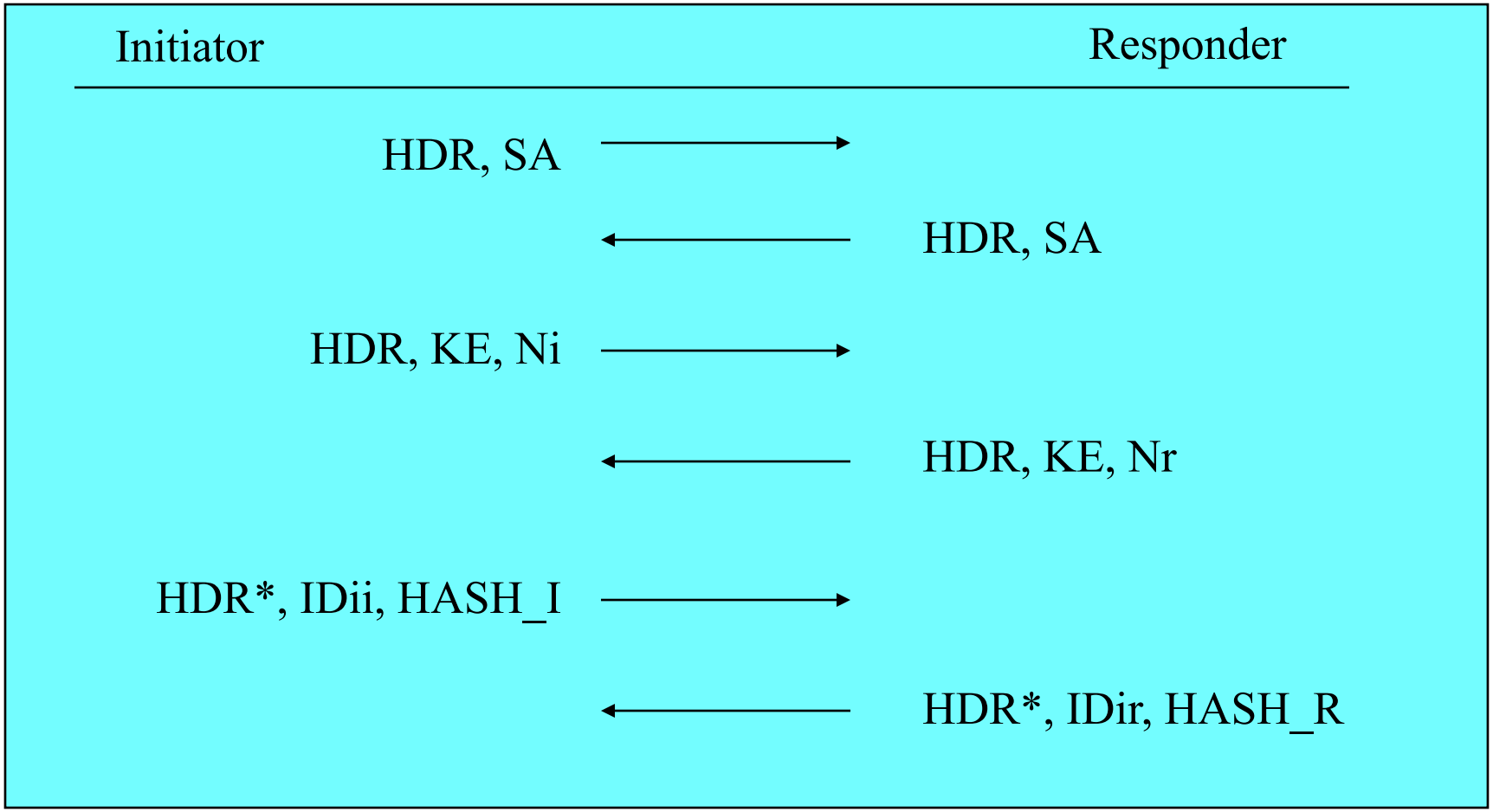
Main Mode



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

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

IKE Phase 1 Authenticated with Pre-Shared Key

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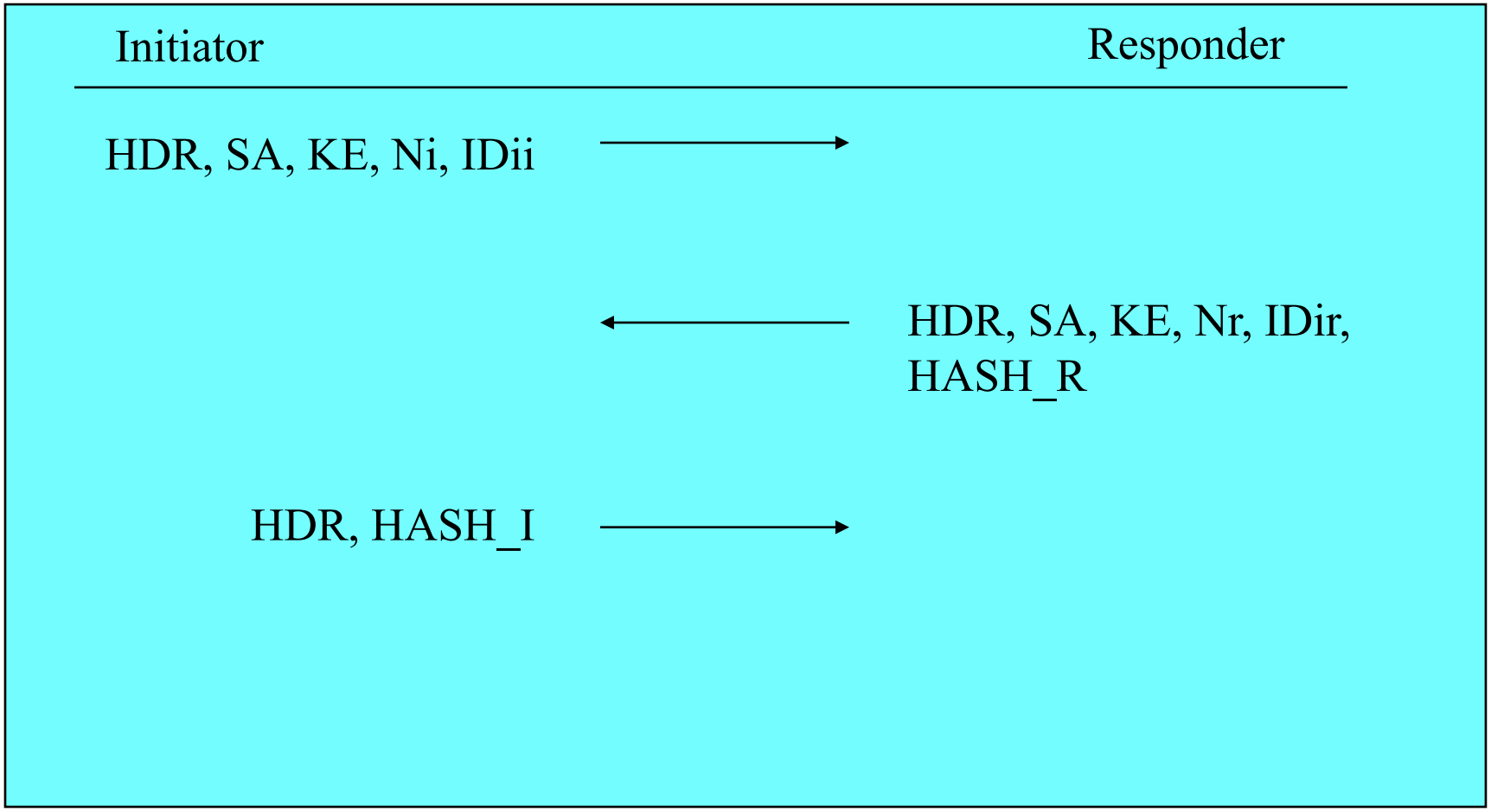
Aggressive Mode



IKE Phase 2 -- Quick Mode

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- 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)

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- 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)

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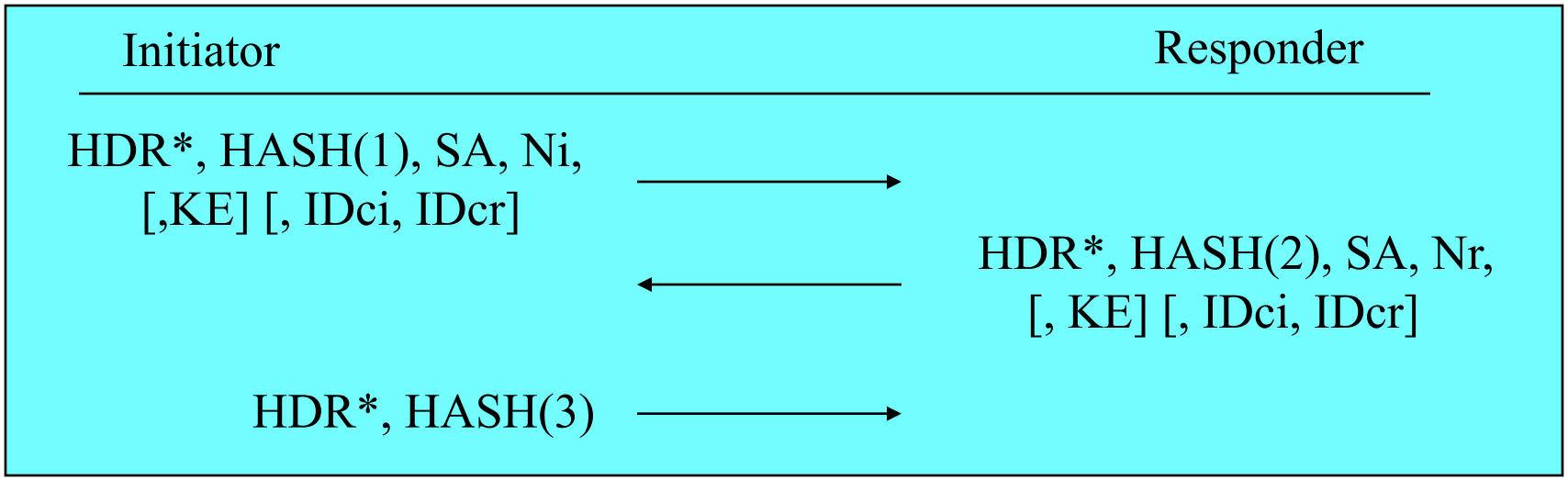

HASH(1) = prf(SKEYID_a, M-ID | SA | Ni [| KE] [| IDci | IDcr)
HASH(2) = prf(SKEYID_a, M-ID | Ni_b | SA | Nr [| KE] [| IDci | IDcr)
HASH(3) = prf(SKEYID_a, 0 | M-ID | Ni_b | Nr_b)

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

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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.