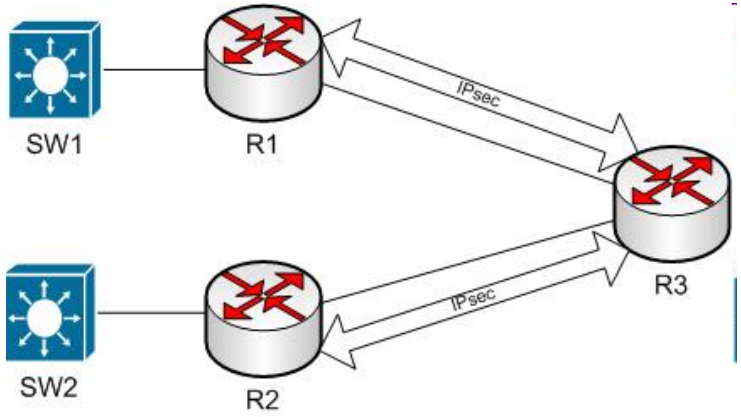
IP Security



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Audio/Video recordings of this lecture are available at:

http://www.cse.wustl.edu/~jain/cse571-11/

Overview

1. IPSec
2. Authentication Header (AH)
3. Encapsulating Security Payload (ESP)
4. Internet Key Exchange (IKE)

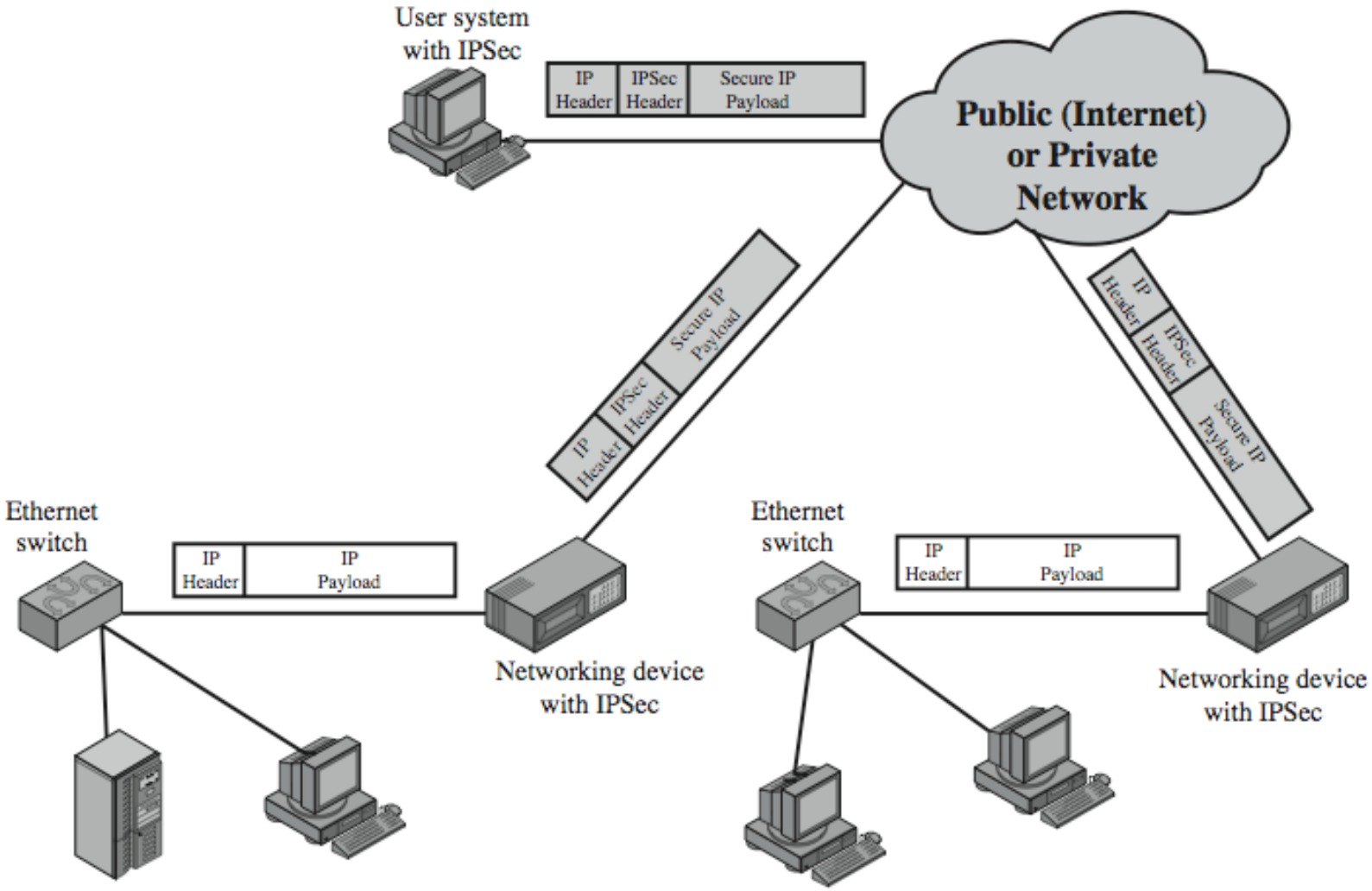
These slides are based partly on Lawrie Brown's slides supplied with William Stallings's book "Cryptography and Network Security: Principles and Practice," 5th Ed, 2011.

IP Security

- IPSec provides
  - Access control: User authentication
  - Data integrity
  - Data origin authentication
  - Rejection of replayed packets
  - Confidentiality (encryption)
  - Limited traffic flow confidentiality
- Benefits:
  - Security at Layer 3 ⇒ Applies to all transports/applications
  - Can be implemented in Firewall/router
    ⇒ Security to all traffic crossing the perimeter
  - Transparent to applications and can be transparent to end users
  - Can provide security for individual users
- Applications: VPNs, Branch Offices, Remote Users, Extranets

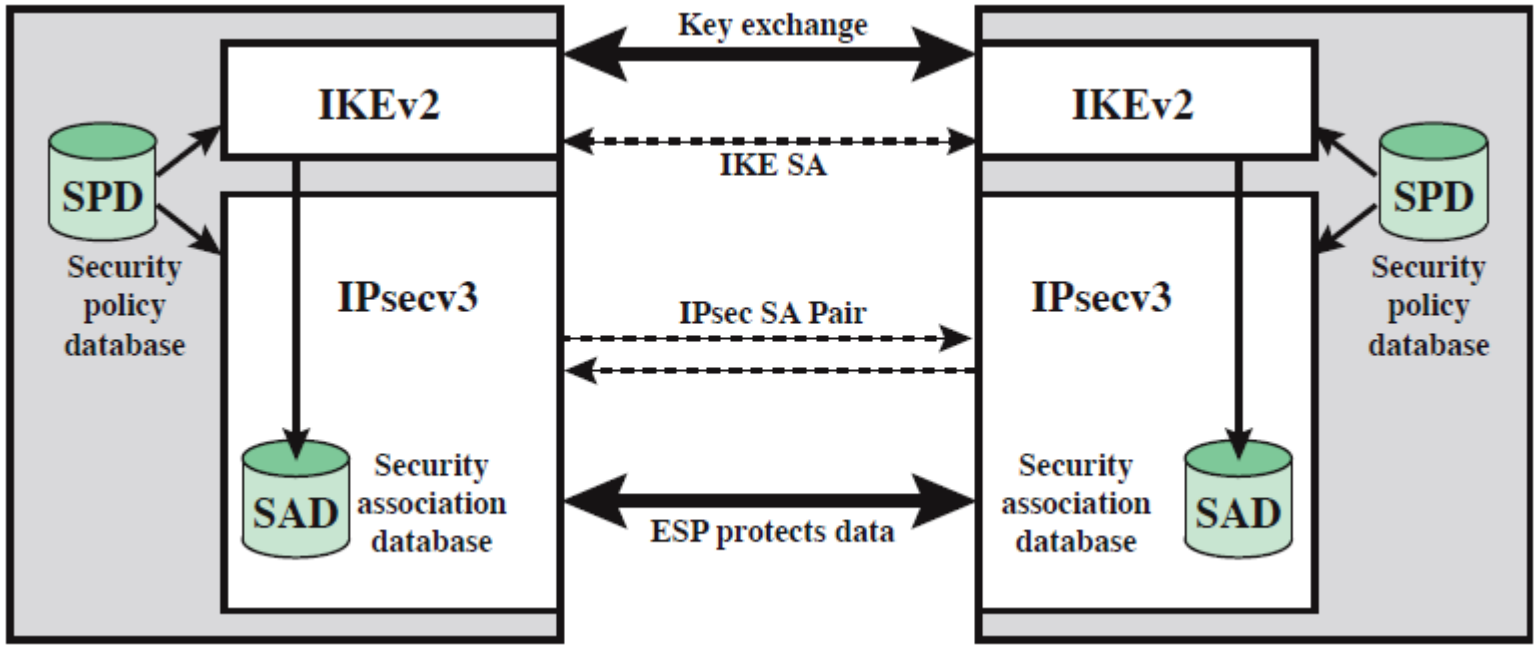
Ref: http://en.wikipedia.org/wiki/IPsec

IP Security Applications



IP Security Architecture

- Internet Key Exchange (IKE)
- IPSec
- Security Association Database
- Security Policy database



Security Association Database

- Each host has a database of Security Associations (SAs)
- SA = One-way security relationship between sender & receiver
  Two-way may use different security ⇒Two SA's required
- Defined by 3 parameters:
  - Security Parameters Index (SPI)
  - IP Destination Address
  - Security Protocol Identifier: AH or ESP
- For each SA, the database contains:
  - SPI
  - Sequence number counter and counter overflow flag
  - Anti-replay window
  - AH Information and ESP information
  - Lifetime of the SA
  - Mode: Transport or tunnel or wildcard
  - Path MTU

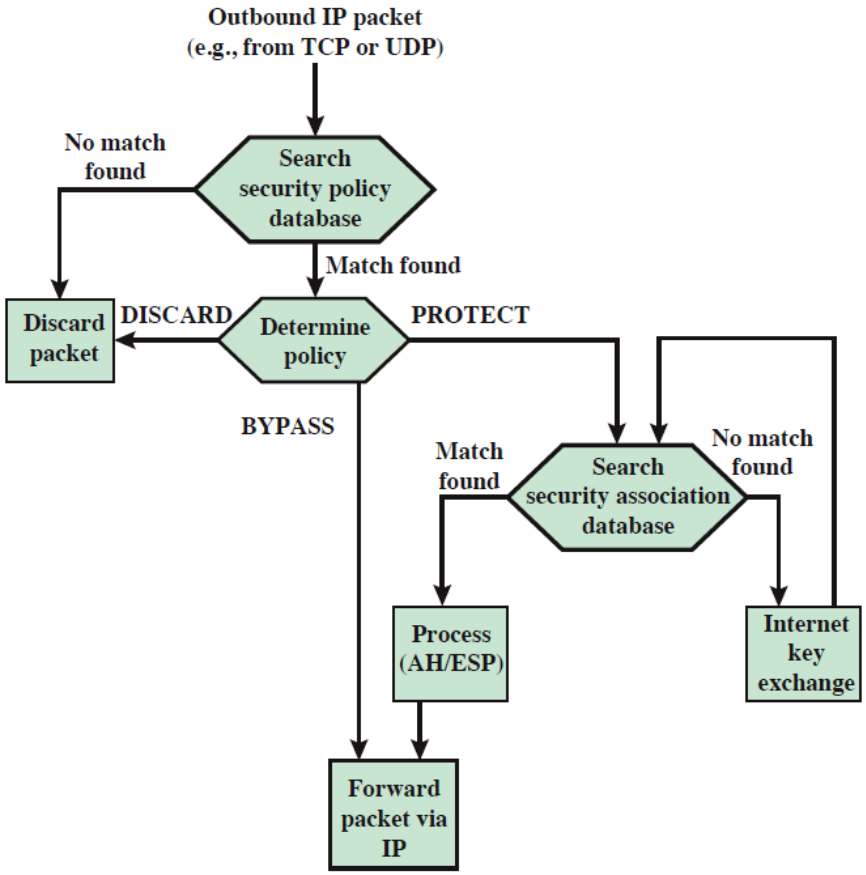
Ref: http://en.wikipedia.org/wiki/Security_association

Security Policy Database

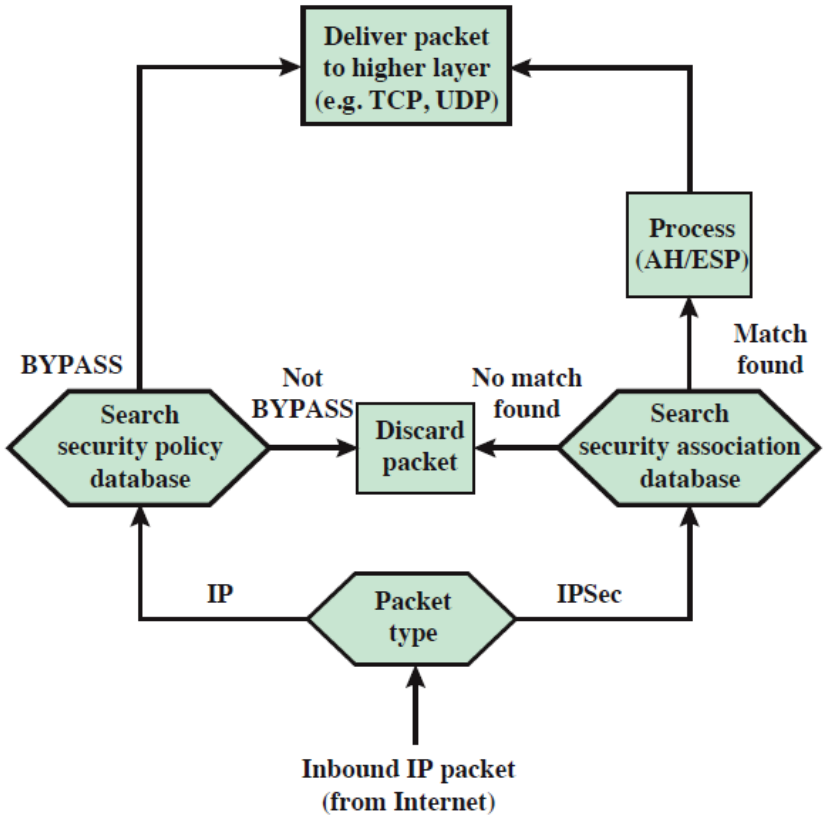
- Relates IP traffic to specific SAs
  - Match subset of IP traffic to relevant SA
  - Use selectors to filter outgoing traffic to map
  - Based on: local & remote IP addresses, next layer protocol, name, local & remote ports

Protocol	Local IP	Port	Remote IP	Port	Action	Comment
UDP	1.2.3.101	500	*	500	BYPASS	IKE
ICMP	1.2.3.101	*	*	*	BYPASS	Error messages
*	1.2.3.101	*	1.2.3.0/24	*	PROTECT: ESP intransport-mode	Encrypt intranet traffic
TCP	1.2.3.101	*	1.2.4.10	80	PROTECT: ESP intransport-mode	Encrypt to server
TCP	1.2.3.101	*	1.2.4.10	443	BYPASS	TLS: avoid double encryption
*	1.2.3.101	*	1.2.4.0/24	*	DISCARD	Others in DMZ
*	1.2.3.101	*	*	*	BYPASS	Internet

Processing Models

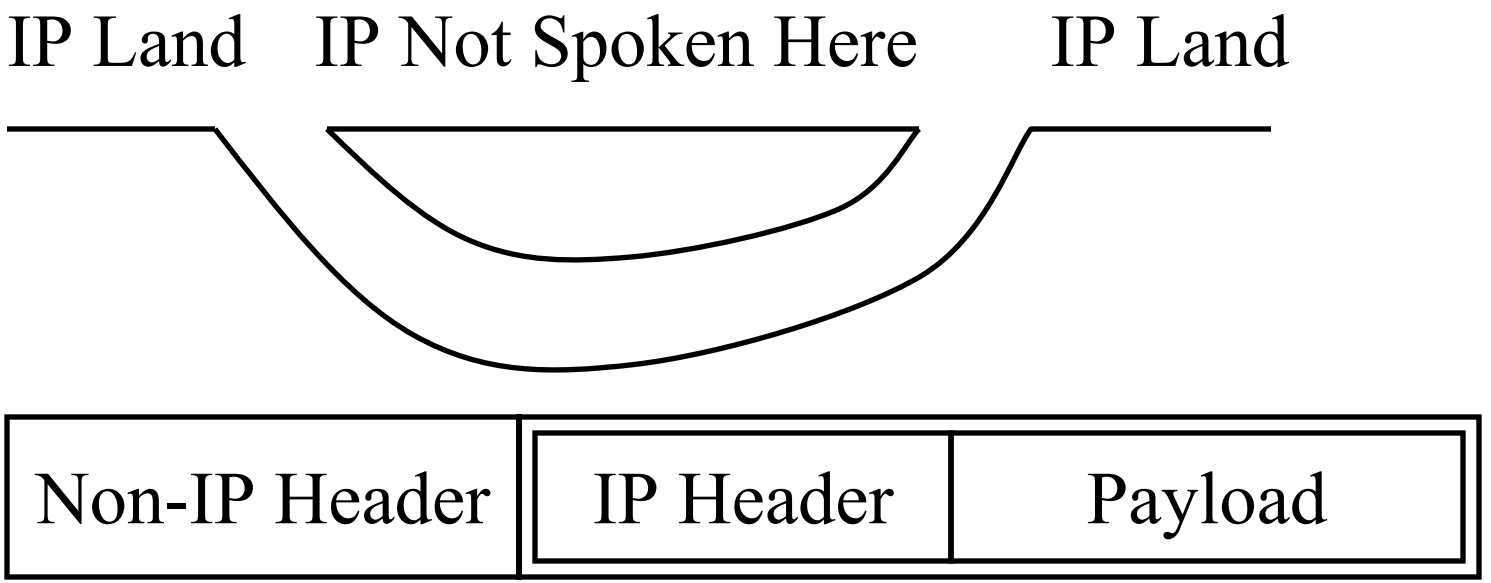


a. Outbound Packets



b. Inbound Packets

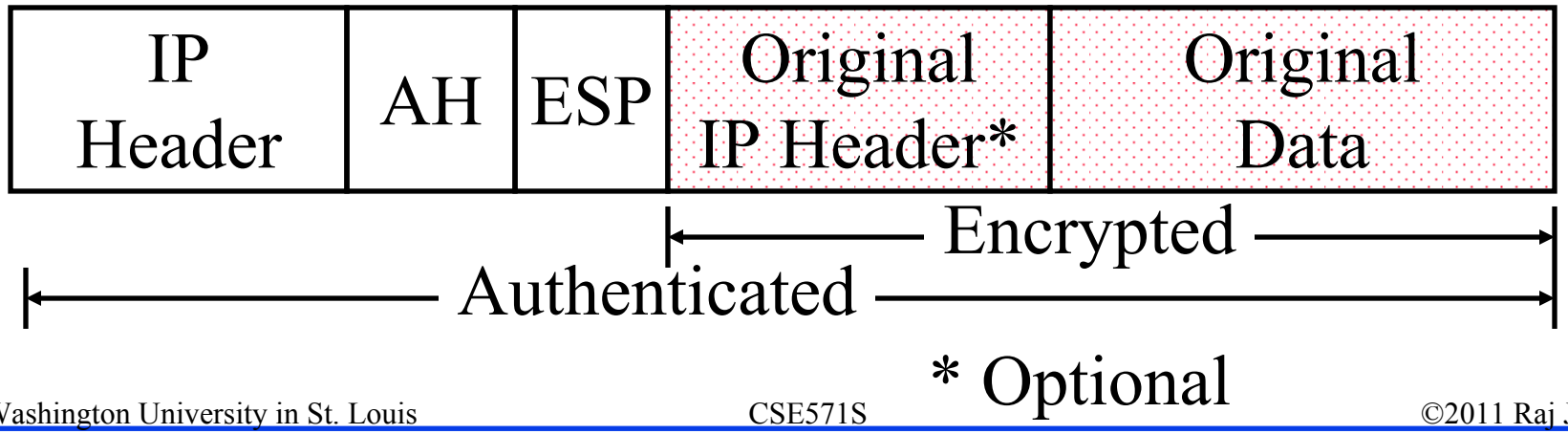
Tunnel



- Tunnel = Encaptulation
- Used whenever some feature is not supported in some part of the network, e.g., multicasting, mobile IP

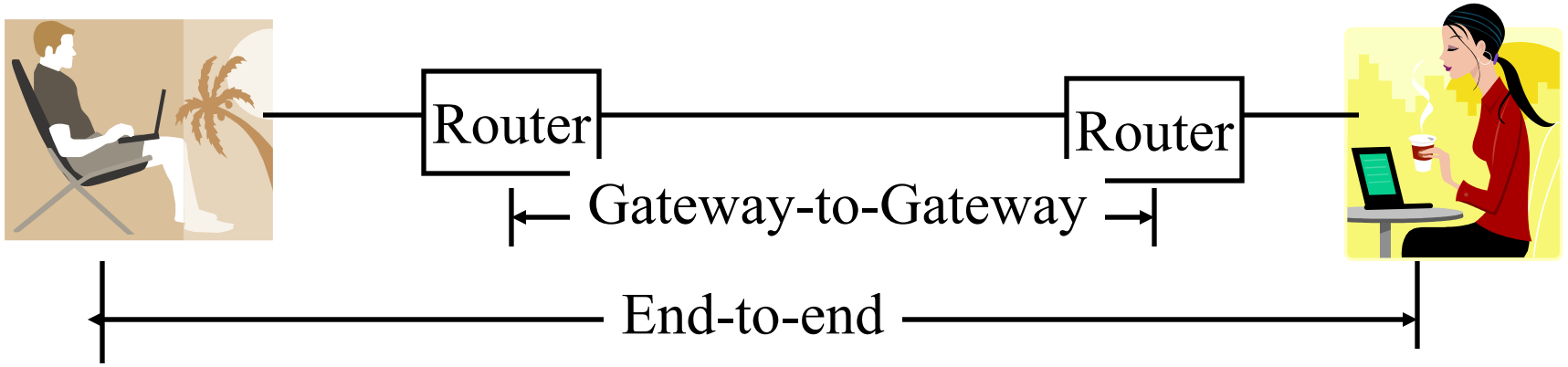
IPSec

- Secure IP: A series of proposals from IETF
- Separate Authentication and privacy
- Authentication Header (AH) ensures data *integrity* and *data origin authentication*
- Encapsulating Security Protocol (ESP) ensures *confidentiality, data origin authentication, connectionless integrity, and anti-replay service*

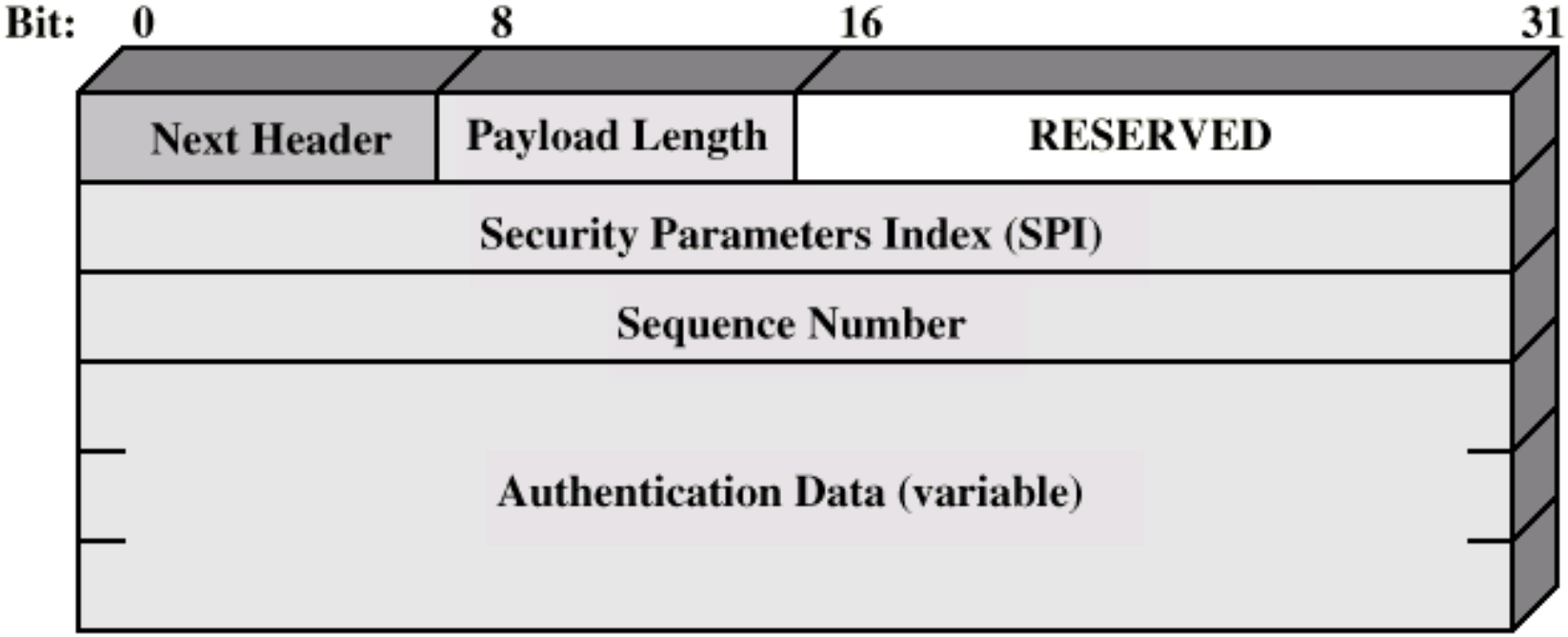


Tunnel vs. Transport Mode

- Gateway-to-gateway vs. end-to-end

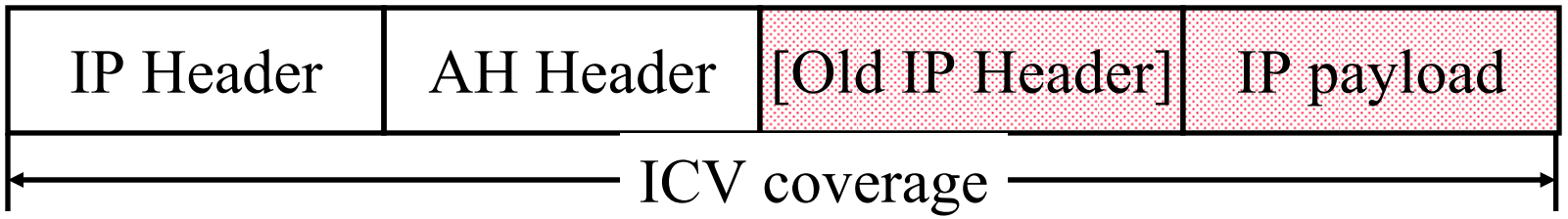


Authentication Header



- Next Header = TCP=6, UDP=17, IP=4, AH=51
  ⇒ Designed by IPv6 fans
- Payload Length = Length of ***AH*** in 32-bit words − 2 (for IPv4)
  =Length of AH in 64-bit words -1 (for IPv6)
- SPI = Identifies Security association (0=Local use, 1-255 reserved)
- Authentication data = Integrity Check Value

AH ICV Computation



The AH ICV is computed over:

- IP header fields that are either *immutable* in transit or that are *predictable* in value upon arrival at the endpoint for the AH SA, e.g., source address (immutable), destination address with source routing (mutable but predictable)
- The AH header (Next Header, Payload Len, Reserved, SPI, Sequence Number, and the Authentication Data (which is set to zero for this computation), and explicit padding bytes (if any))
- The upper level protocol data, which is assumed to be immutable in transit

AH Version 3

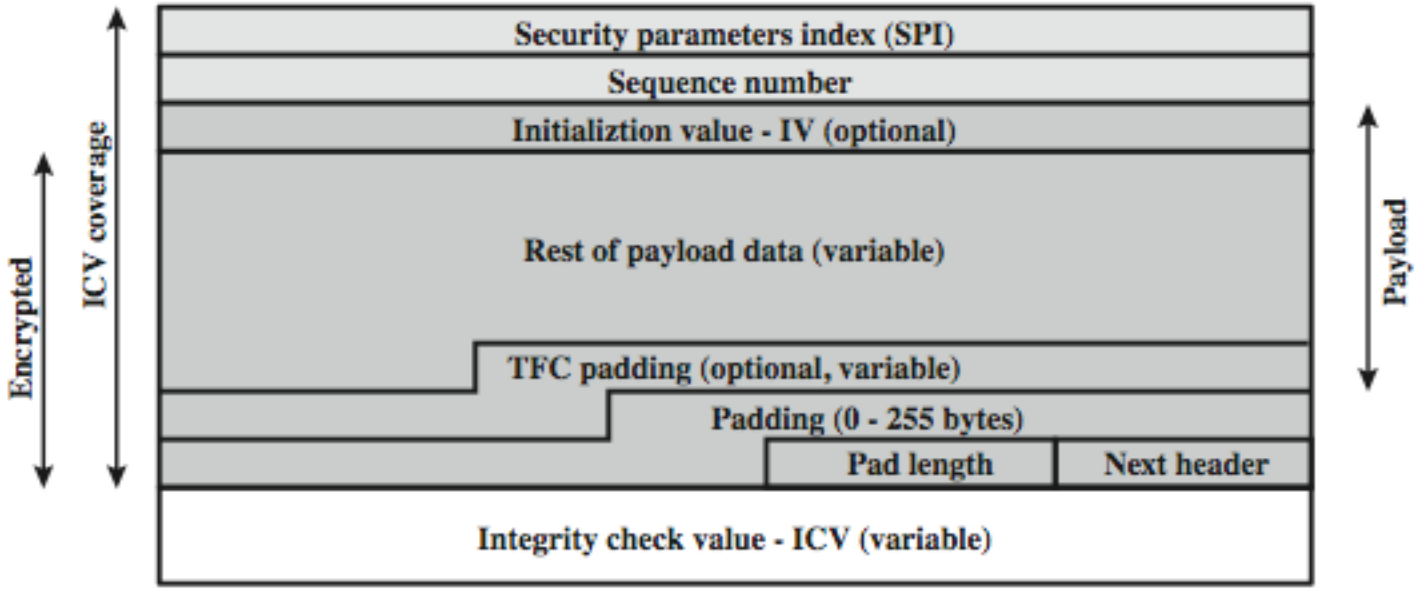
- RFC4302, December 2005 (V2 in RFC2402, November 1998, V1 in RFC1826, August 1995)
- Uniform algorithm for Security Parameter Index (SPI) for unicast and multicast
- Unicast: SPI alone, or SPI+protocol may be used to select SA
- Multicast: SPI+DA or SPI+DA+SA
- Extended 64-bit sequence numbers for high-speed communications
- Separate RFC for mandatory algorithms

Encapsulating Security Payload (ESP)

Provides:

- Message content confidentiality,
- Data origin authentication,
- Connectionless integrity,
- Anti-replay service,
- Limited traffic flow confidentiality
- Services depend on options selected when establish Security Association (SA), net location
- Can use a variety of encryption & authentication algorithms

ESP Packet



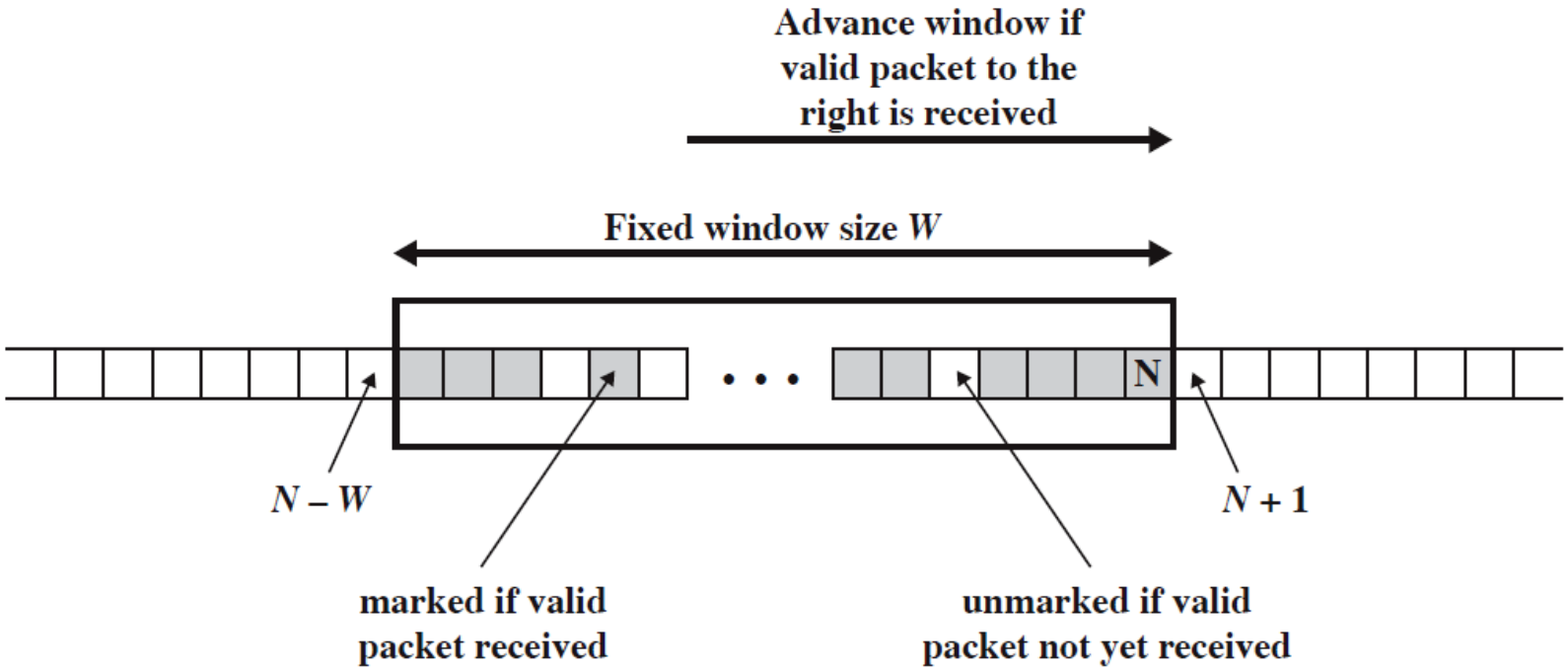
- Payload data: IP, TCP, UDP packet
- Pad Length in bytes
- Next Header: Type of payload (TCP, UDP, …)
- Authentication Data: Integrity Check Value over ESP packet

ESP Version 3

- RFC4303, December 2005 (V2 in RFC2406, November 1998, V1 in RFC1827, August 1995)
- Uniform algorithm for SPI for unicast and multicast
- Extended 64-bit sequence numbers
- Separate RFC for mandatory algorithms
- Combined Mode algorithms: Combined Confidentiality+Integrity algorithms in addition to separate confidentiality and integrity algorithms
- Can add extra bytes before padding for traffic flow confidentiality
- Can generate and discard dummy padding packets (Next header=59)
- Issue: No version number in the header. But older versions will reject new algorithms and options

Anti-Replay Service

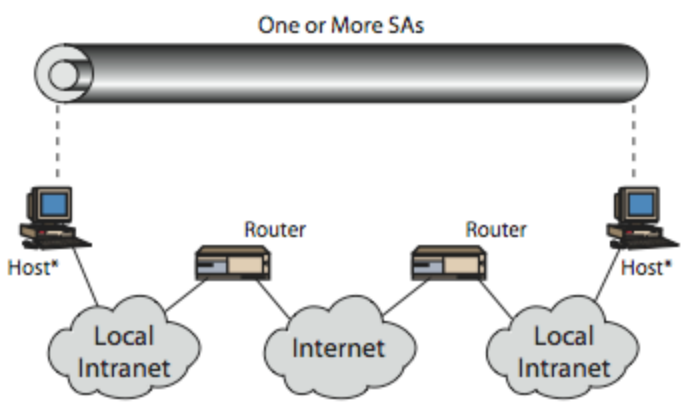
- Sender initializes sequence number to 0 when a new SA is established. Increment for each packet
- Receiver then accepts packets with sequence # within window of $(N-W+1)$



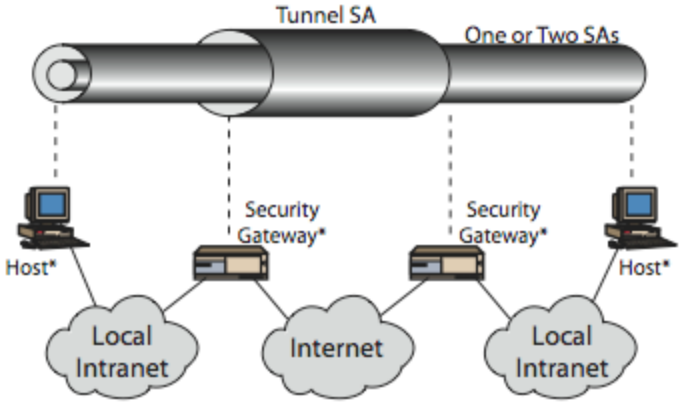
Combining Security Associations

- SAs can implement either AH or ESP
- To implement both need to combine SAs to form a security association bundle
- Transport adjacency: Outer AH over Inner ESP
- Iterated tunneling: Multiple with different end points
  - 1. All security between end-systems: AH Transport, ESP Transport, ESP inside AH transport, any one of the first 3 inside AH or ESP Tunnel
  - 2. Between gateways (routers or firewalls): Single SA. No nesting.
  - 3. Case 1 inside Case 2
  - 4. Tunnel between a remote host and firewall. One or two SAs may be used as in Case 1.

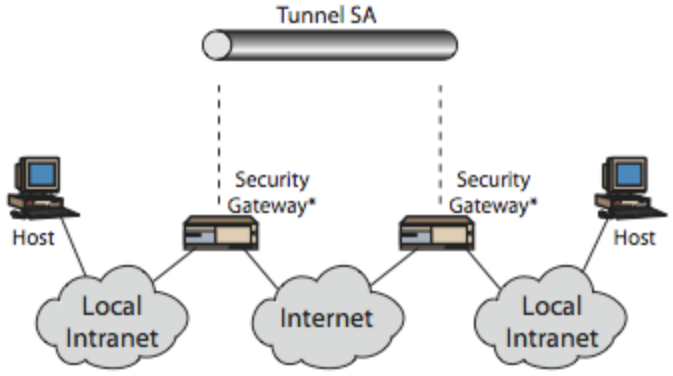
Combining Security Associations



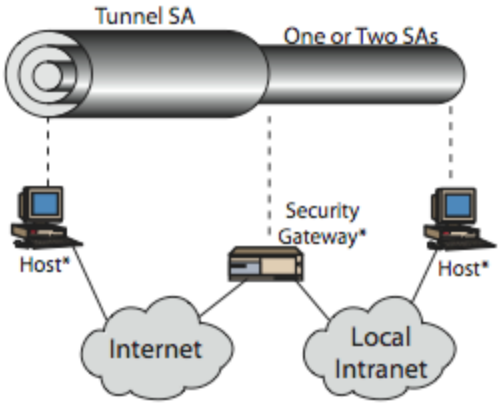
(a) Case 1



(c) Case 3



(b) Case 2



(d) Case 4

IPSec Key Management (IKE)

- Handles key generation & distribution
- Typically need 2 pairs of keys
  - 2 per direction for integrity and confidentiality
- Manual key management
  - Sys admin manually configures every system
- Automated key management
  - Automated system for on demand creation of keys for SA's in large systems
  - Oakley key exchange and ISAKMP key management
  - IKEv2 no longer uses Oakley & ISAKMP terms, but basic functionality is same

Ref: http://en.wikipedia.org/wiki/Internet_Key_Exchange

Oakley

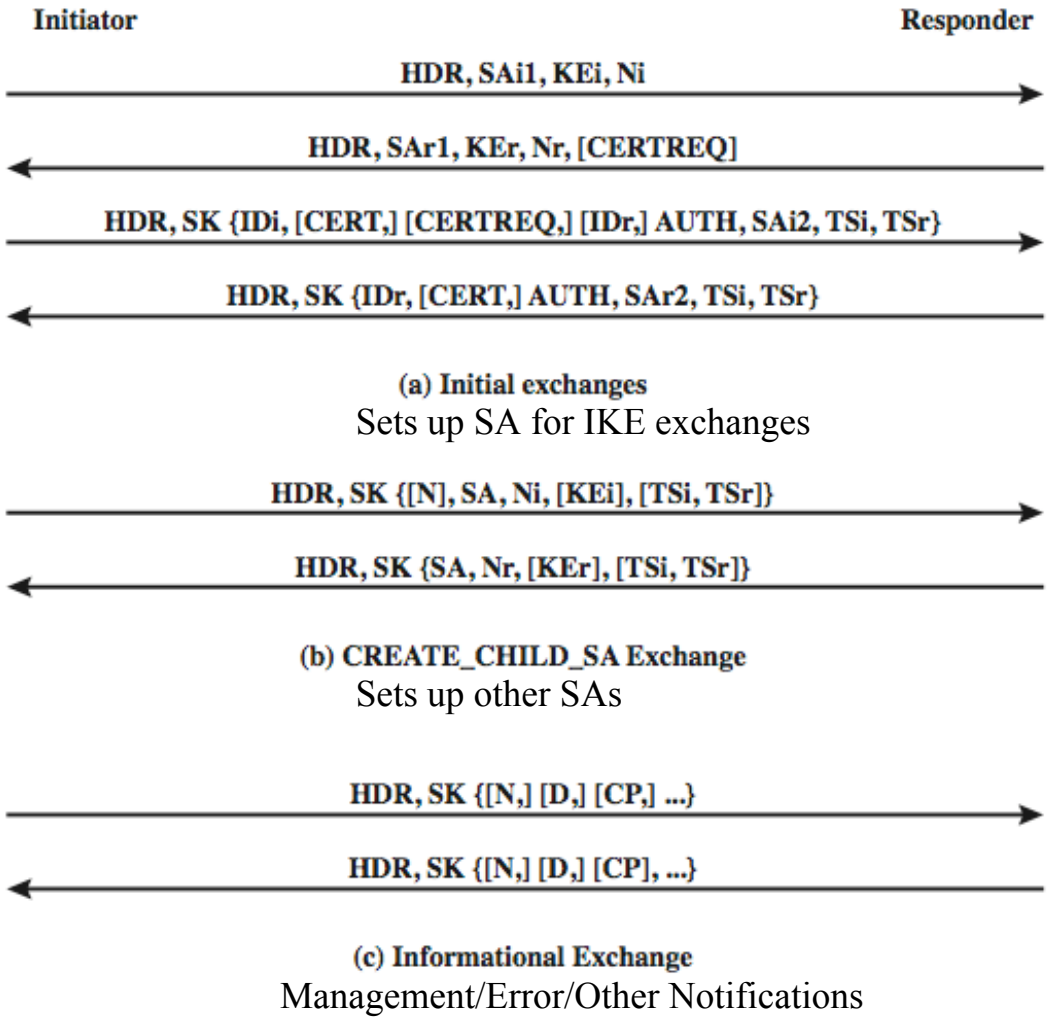
- A key determination protocol based on D-H key exchange
- Adds features to address weaknesses of D-H.
  D-H has no info on identities of parties, is subject to man-in-middle attack, is computationally expensive
- Oakley adds
  - Cookies to thwart DoS attacks
  - Several groups of pre-specified global parameters
  - Nonces to protect against replay
  - DH public key exchange with authentication using Digital signature, Public Key Encryption, or Symmetric Key Encryption
- Can use arithmetic in prime fields or elliptic curve fields

ISAKMP

- Internet Security Association and Key Management Protocol
- Provides framework for key management
- Defines procedures and packet formats to establish, negotiate, modify, and delete SAs
- Independent of key exchange protocol, encryption algorithm, and authentication method

Ref: http://en.wikipedia.org/wiki/Internet_Security_Association_and_Key_Management_Protocol

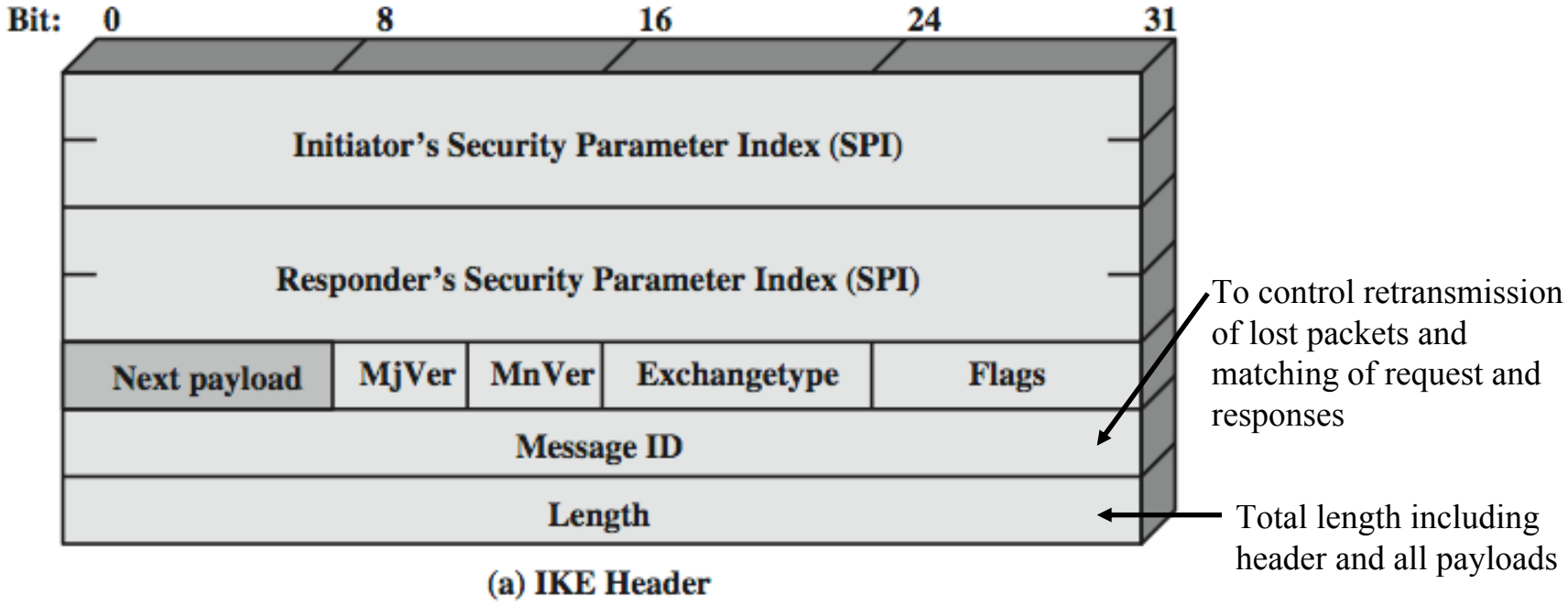
IKEV2 Exchanges



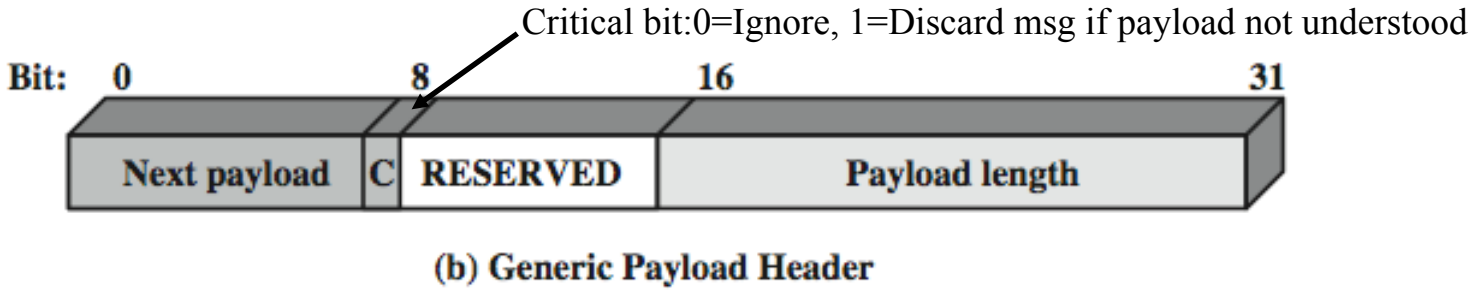
HDR	=	IKE Header
SAx1	=	Offered and Chosen algorithms, DH group
KEx	=	D-H Public key
Nx	=	Nonces
CERTREQ	=	Certificate Request
IDx	=	Identity
CERT	=	Certificate
SK{...}	=	MAC and Encrypt
AUTH	=	Authentication
SAx2	=	Algorithms, parameters for IPsec SA
TSx	=	Traffic Selectors for IPsec SA
N	=	Notify
D	=	Delete
CP	=	Configuration

IKE Header and Payload Formats

- IKE messages= Header + one or more payloads



(a) IKE Header



(b) Generic Payload Header

IKE Payload Types

Type	Parameters
Security Association	Proposals = {Proposal={Protocol={Transform={Attribute}}}}
Key Exchange	DH Group #, Key Exchange Data = Data required to generated a session key
Identification	ID Type, ID Data
Certificate	Cert Encoding, Certificate Data
Certificate Request	Cert Encoding, Certification Authority
Authentication	Auth Method, Authentication Data
Nonce	Nonce Data
Notify	Protocol-ID, SPI Size, Notify Message Type, SPI, Notification Data =Errors or status
Delete	Protocol-ID, SPI Size, # of SPIs, SPI (one or more) = SAs that have been deleted
Vendor ID	Vendor ID
Traffic Selector	Number of TSs, Traffic Selectors
Encrypted	IV, Encrypted IKE payloads, Padding, Pad Length, ICV
Configuration	CFG Type, Configuration Attributes
Extensible Authentication Protocol	EAP Message

Cryptographic Suites: VPN

- RFC 4308: VPN-A: Older, VPN-B: Stronger

	VPN-A	VPN-B
ESP encryption	3DES-CBC	AES-CBC (128-bit key)
ESP integrity	HMAC-SHA1-96	AES-XCBC-MAC-96
IKE encryption	3DES-CBC	AES-CBC (128-bit key)
IKE PRF	HMAC-SHA1	AES-XCBC-PRF-128
IKE Integrity	HMAC-SHA1-96	AES-XCBC-MAC-96
IKE DH group	1024-bit MODP	2048-bit MODP

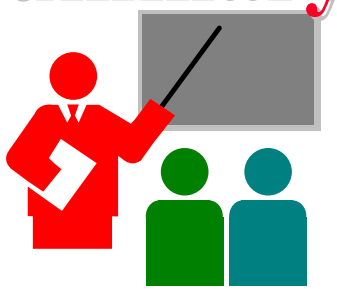
Cryptographic Suites: NSA Suite B

- Specified by NSA for use with sensitive information

	GCM-128	GCM-256	GMAC-128	GMAC-256
ESP encryption/ Integrity	AES-GCM (128-bit key)	AES-GCM (256-bit key)	Null	Null
ESP integrity	Null	Null	AES-GMAC (128-bit key)	AES-GMAC (256-bit key)
IKE encryption	AES-CBC (128-bit key)	AES-CBC (256-bit key)	AES-CBC (128-bit key)	AES-CBC (256-bit key)
IKE PRF	HMAC-SHA-256	HMAC-SHA-384	HMAC-SHA-256	HMAC-SHA-384
IKE Integrity	HMAC-SHA-256-128	HMAC-SHA-384-192	HMAC-SHA-256-128	HMAC-SHA-384-192
IKE DH group	256-bit random ECP	384-bit random ECP	256-bit random ECP	384-bit random ECP
IKE authentication	ECDSA-256	ECDSA-384	ECDSA-256	ECDSA-384

Ref: http://en.wikipedia.org/wiki/NSA_Suite_B_Cryptography

Summary



1. IPSec provides authentication, confidentiality, and key management at Layer 3. Applies to all traffic.
2. Security associations are one-way and can be bundled together.
3. Authentication header for message authentication using HMAC
4. Encapsulating security protocol (ESP) for confidentiality and/or integrity
5. Both can be used end-to-end with original IP header inside (Tunnel) or without original IP header (Transport) mode
6. Oakley is the IKE key determination protocol
7. ISAKMP is the IKE key management protocol

Homework 19

- A. For each of the fields in IPv4 header, indicate whether the field is immutable, mutable but predictable, or mutable (zeroed prior to ICV calculation).
- B. Suppose the current replay window spans from 60 to 124. What will the receiver do with a packet and what will the parameters of the window be if the next incoming packet has a sequence number:
  - a. 50
  - b. 100
  - c. 150