Cryptography Applications:

VPN and IPsec

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APNIC

Overview

- Introduction to VPN
- IPsec Fundamentals
- Tunnel and Transport Mode IPsec
- Architecture and Components of IPsec
- Internet Key Exchange
- Configuring IPsec for IPv4 and IPv6

Virtual Private Network

- Creates a secure tunnel over a public network
  - Client to firewall
  - Router to router
  - Firewall to firewall
- Uses the Internet as the public backbone to access a secure private network
  - Remote employees can access their office network
- Two types:
  - Remote access
  - Site-to-site VPN

VPN Implementation

- Hardware
  - Usually a VPN-type router
  - Pros: highest network throughput, plug and play, dual purpose
  - Cons: cost and lack of flexibility
- Software
  - Ideal for two end-points in different organisations
  - Pros: flexible, and low relative cost
  - Cons: lack of efficiency, more labor training required, lower productivity; higher labor costs
- Firewall
  - Pros: cost effective, tri-purpose, hardens the operating system
  - Cons: still relatively costly

VPN Protocols

- PPTP (Point-to-Point tunneling Protocol)
  - Developed by Microsoft to secure dial-up connections
  - Operates in the data-link layer
- L2F (Layer 2 Forwarding Protocol)
  - Developed by Cisco
  - Similar as PPTP
- L2TP (Layer 2 Tunneling Protocol)
  - IETF standard
  - Combines the functionality of PPTP and L2F
- IPsec (Internet Protocol Security)
  - Open standard for VPN implementation
  - Operates on the network layer

Other Modern VPNs

- MPLS VPN
  - Used for large and small enterprises
  - Pseudowire, VPLS, VPRN
- GRE Tunnel
  - Packet encapsulation protocol developed by Cisco
  - Not encrypted
  - Implemented with IPsec
- L2TP IPsec
  - Uses L2TP protocol
  - Usually implemented along with IPsec
  - IPsec provides the secure channel, while L2TP provides the tunnel

Advantages of VPN

- Cheaper connection
  - Use the Internet connection instead of a private lease line
- Scalability
  - Flexibility of growth
  - Efficiency with broadband technology
- Availability
  - Available everywhere there is an Internet connection

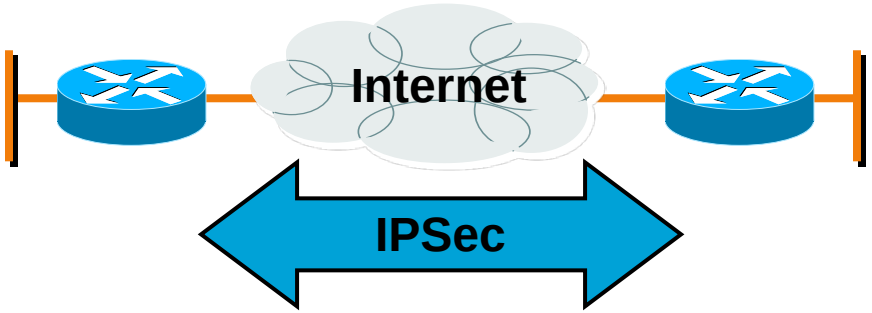
Disadvantages of VPN

- VPNs require an in-depth understanding of public network security issues and proper deployment precautions
- Availability and performance depends on factors largely outside of their control
- VPNs need to accommodate protocols other than IP and existing internal network technology

IPsec

- Provides Layer 3 security (RFC 2401)
  - Transparent to applications (no need for integrated IPsec support)
- A set of protocols and algorithms used to secure IP data at the network layer
- Combines different components:
  - Security associations (SA)
  - Authentication headers (AH)
  - Encapsulating security payload (ESP)
  - Internet Key Exchange (IKE)
- A security context for the VPN tunnel is established via the **ISAKMP**

What is IPSec?



- IETF standard that enables encrypted communication between peers:
  - Consists of open standards for securing private communications
  - Network layer encryption ensuring data confidentiality, integrity, and authentication
  - Scales from small to very large networks

IPsec Standards

- RFC 4301 “The IP Security Architecture”
  - Defines the original IPsec architecture and elements common to both AH and ESP
- RFC 4302
  - Defines authentication headers (AH)
- RFC 4303
  - Defines the Encapsulating Security Payload (ESP)
- RFC 2408
  - ISAKMP
- RFC 5996
  - IKE v2 (Sept 2010)
- RFC 4835
  - Cryptographic algorithm implementation for ESP and AH

Benefits of IPsec

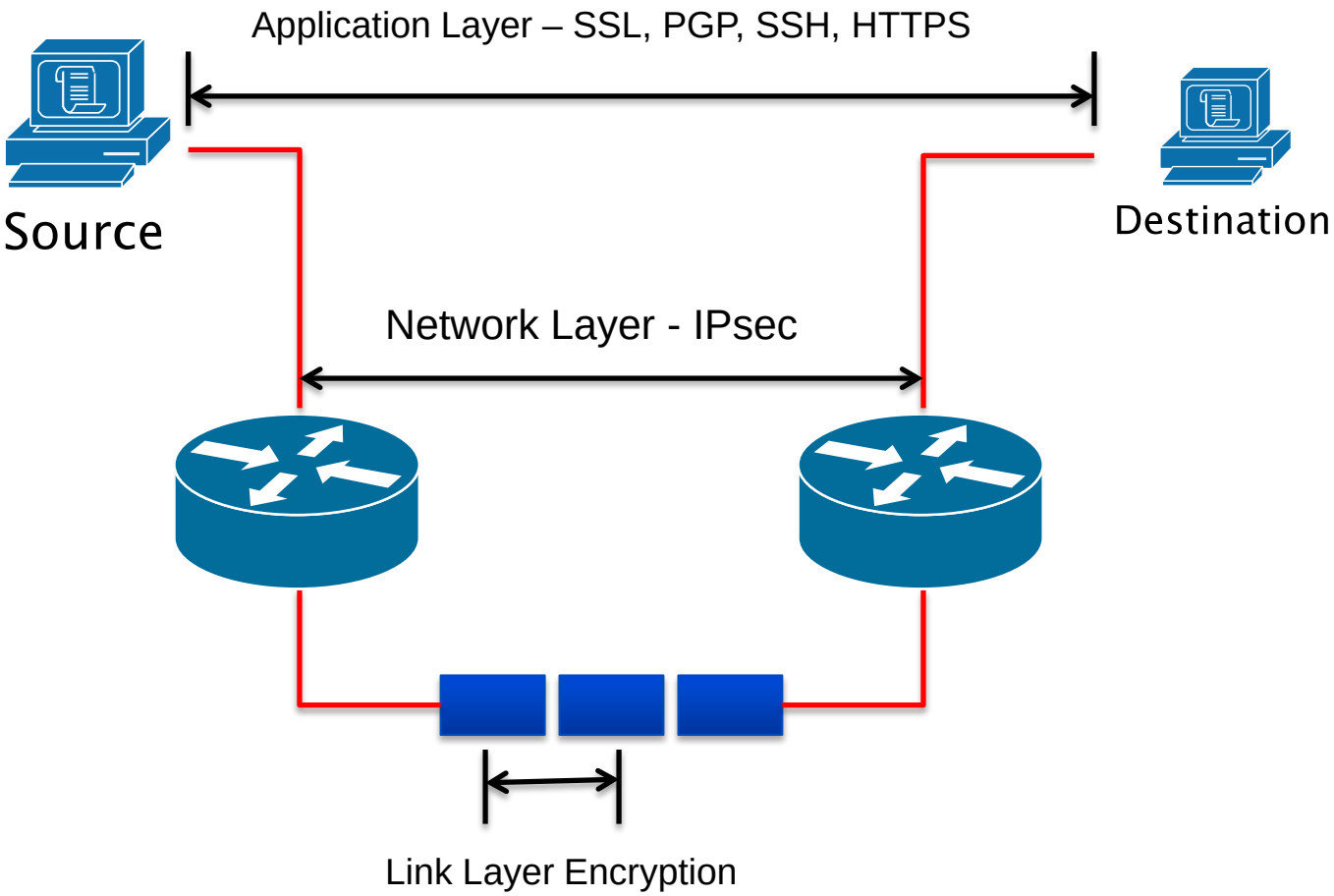
- Confidentiality
  - By encrypting data
- Integrity
  - Routers at each end of a tunnel calculates the checksum or hash value of the data
- Authentication
  - Signatures and certificates
  - All these while still maintaining the ability to route through existing IP networks

"IPsec is designed to provide interoperable, high quality, cryptographically-based security for IPv4 and IPv6" - (RFC 2401)

Benefits of IPsec

- Data integrity and source authentication
  - Data “signed” by sender and “signature” is verified by the recipient
  - Modification of data can be detected by signature “verification”
  - Because “signature” is based on a shared secret, it gives source authentication
- Anti-replay protection
  - Optional; the sender must provide it but the recipient may ignore
- Key management
  - IKE – session negotiation and establishment
  - Sessions are rekeyed or deleted automatically
  - Secret keys are securely established and authenticated
  - Remote peer is authenticated through varying options

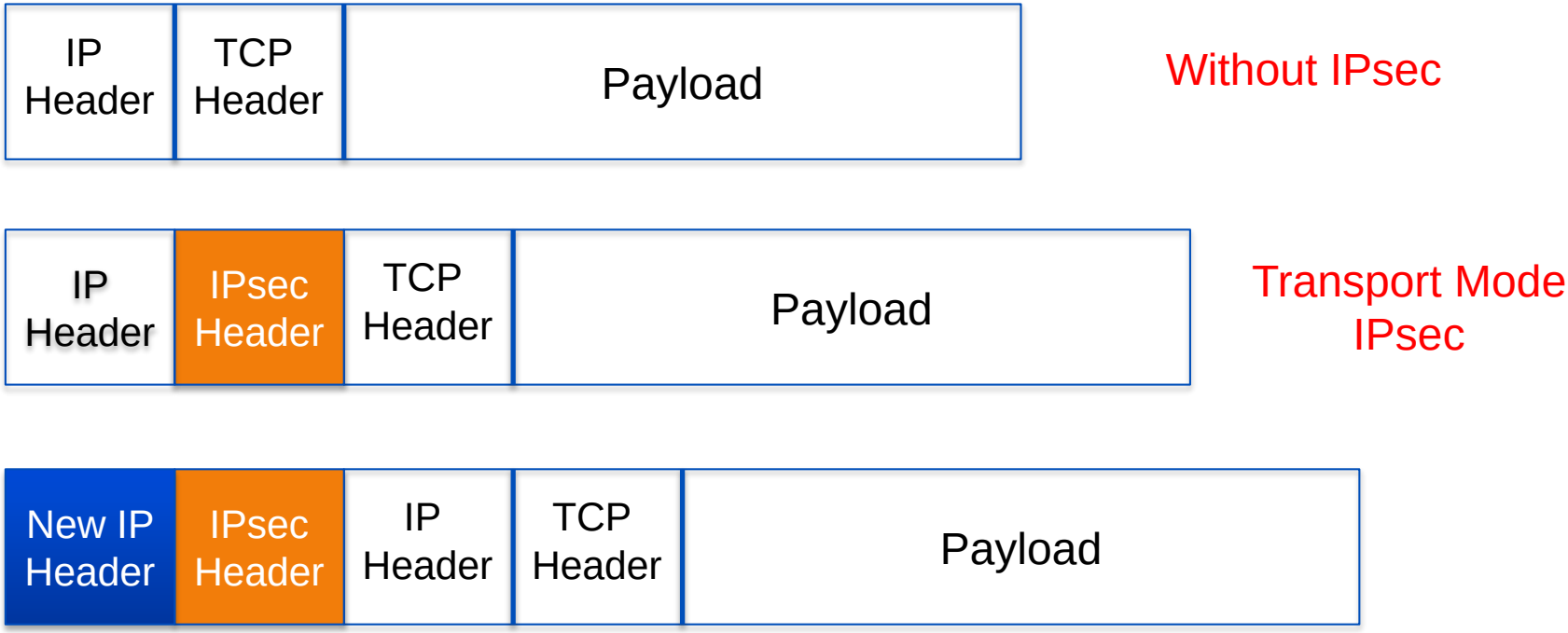
Different Layers of Encryption



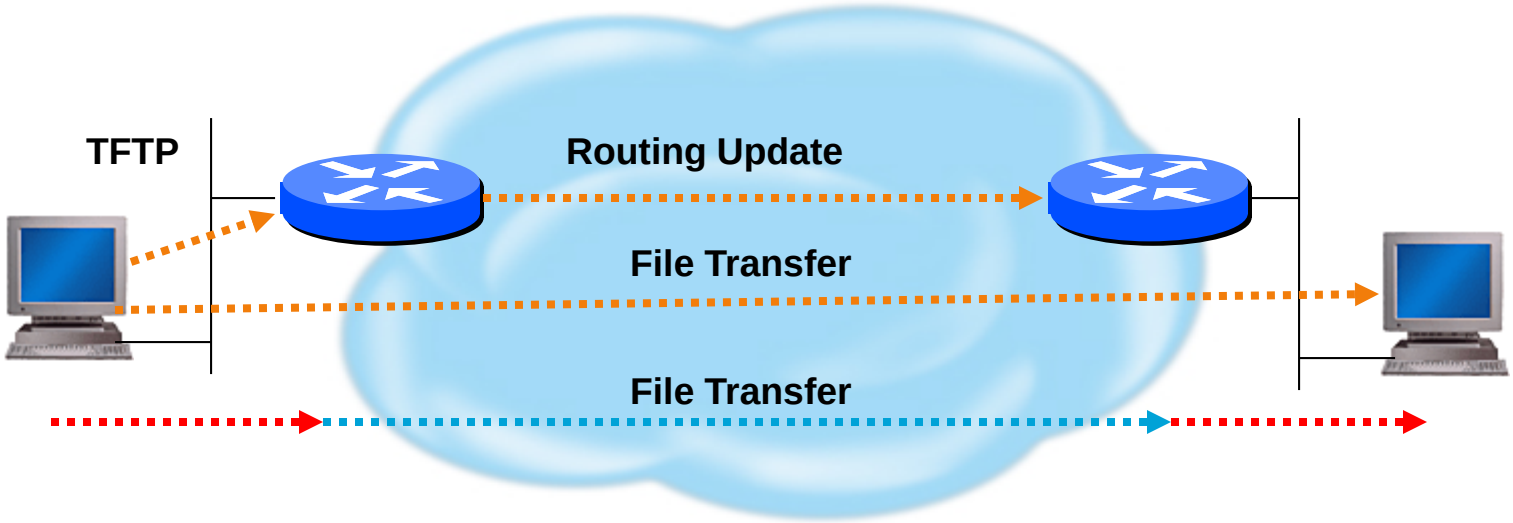
IPsec Modes

- Tunnel Mode
  - Entire IP packet is encrypted and becomes the data component of a new (and larger) IP packet.
  - Frequently used in an IPsec site-to-site VPN
- Transport Mode
  - IPsec header is inserted into the IP packet
  - No new packet is created
  - Works well in networks where increasing a packet's size could cause an issue
  - Frequently used for remote-access VPNs

Tunnel vs. Transport Mode IPsec



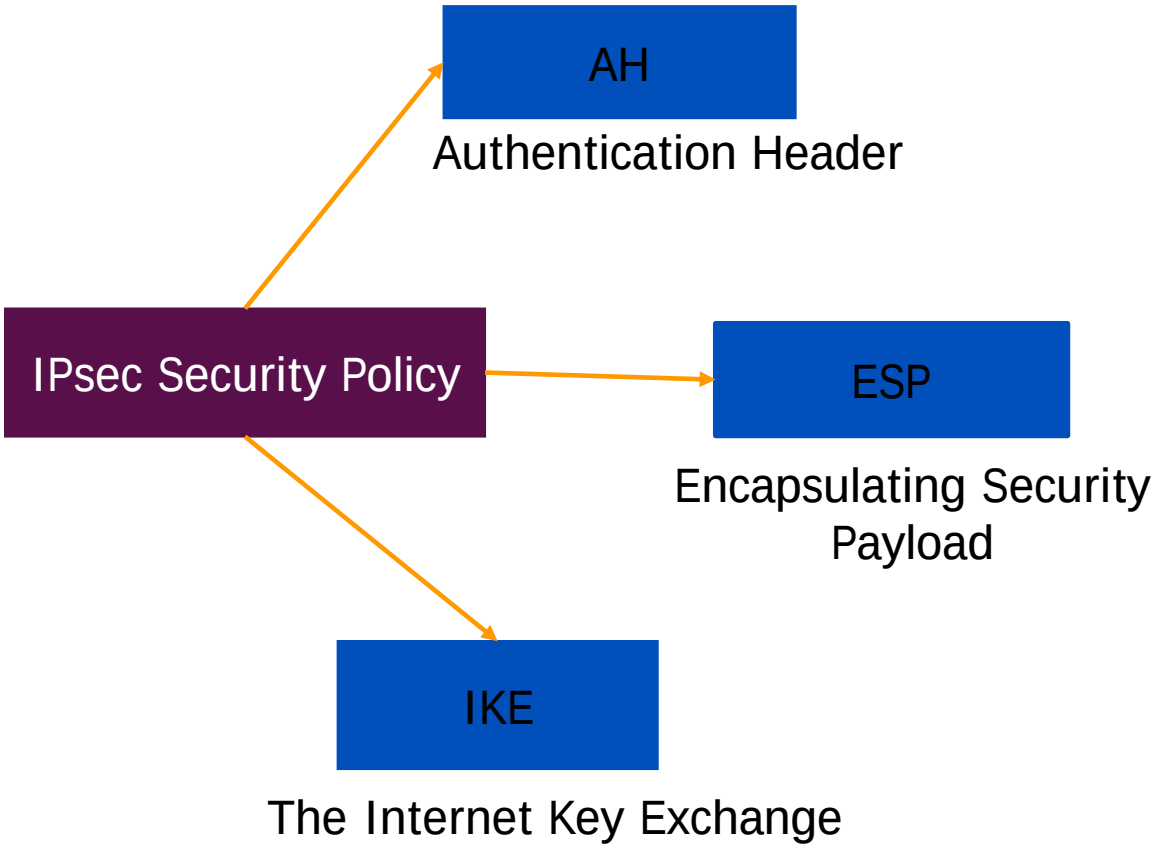
Transport vs Tunnel Mode



Transport Mode: End systems are the initiator and recipient of protected traffic

Tunnel Mode: Gateways act on behalf of hosts to protect traffic

IPsec Architecture



Security Associations (SA)

- A collection of parameters required to establish a secure session
- Uniquely identified by three parameters consisting of
  - Security Parameter Index (SPI)
  - IP destination address
  - Security protocol (AH or ESP) identifier
- An SA is either uni- or bidirectional
  - IKE SAs are bidirectional
  - IPsec SAs are unidirectional
    - Two SAs required for a bidirectional communication
- A single SA can be used for AH or ESP, but not both
  - must create two (or more) SAs for each direction if using both AH and ESP

Security Parameter Index (SPI)

- A unique 32-bit identification number that is part of the Security Association (SA)
- It enables the receiving system to select the SA under which a received packet will be processed.
- Has only local significance, defined by the creator of the SA.
- Carried in the ESP or AH header
- When an ESP/AH packet is received, the SPI is used to look up all of the crypto parameters

How to Set Up SA

- Manually
  - Sometimes referred to as “manual keying”
  - You configure on each node:
    - Participating nodes (I.e. traffic selectors)
    - AH and/or ESP [tunnel or transport]
    - Cryptographic algorithm and key
- Automatically
  - Using IKE (Internet Key Exchange)

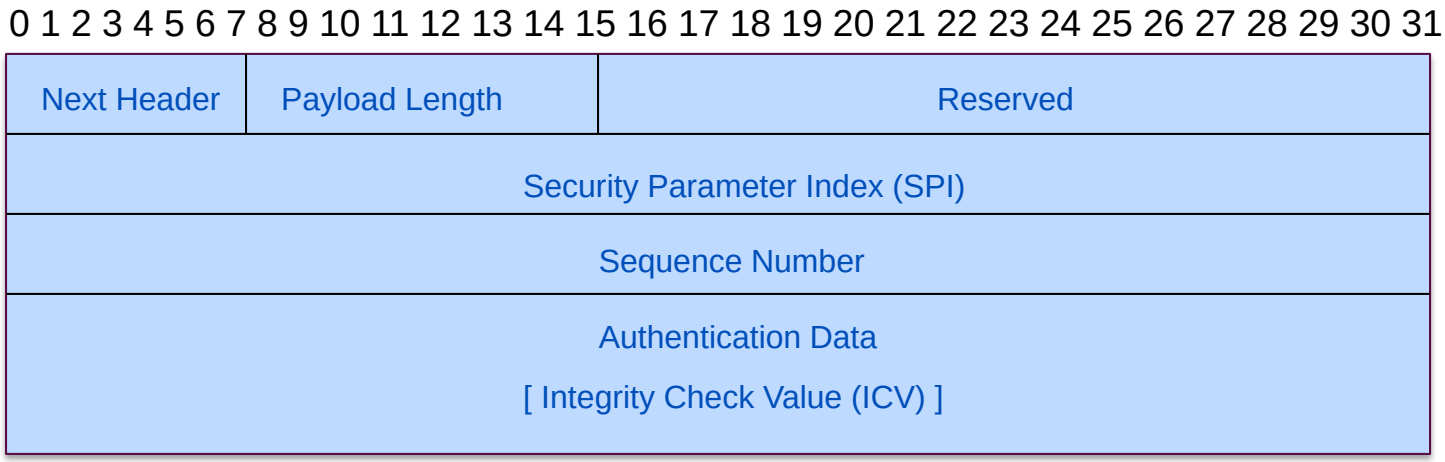
ISAKMP

- Internet Security Association and Key Management Protocol
- Used for establishing Security Associations (SA) and cryptographic keys
- Only provides the framework for authentication and key exchange, but key exchange is independent
- Key exchange protocols
  - Internet Key Exchange (IKE)
  - Kerberized Internet Negotiation of Keys (KINK)

Authentication Header (AH)

- Provides source authentication and data integrity
  - Protection against source spoofing and replay attacks
- Authentication is applied to the entire packet, with the mutable fields in the IP header zeroed out
- If both AH and ESP are applied to a packet, AH follows ESP
- Operates on top of IP using protocol 51
- In IPv4, AH protects the payload and all header fields except mutable fields and IP options (such as IPsec option)

AH Header Format



Next Header (8 bits): indicates which upper layer protocol is protected (UDP, TCP, ESP)

Payload Length (8 bits): size of AH in 32-bit longwords, minus 2

Reserved (16 bits): for future use; must be set to all zeroes for now

SPI (32 bits): arbitrary 32-bit number that specifies to the receiving device which security association is being used (security protocols, algorithms, keys, times, addresses, etc)

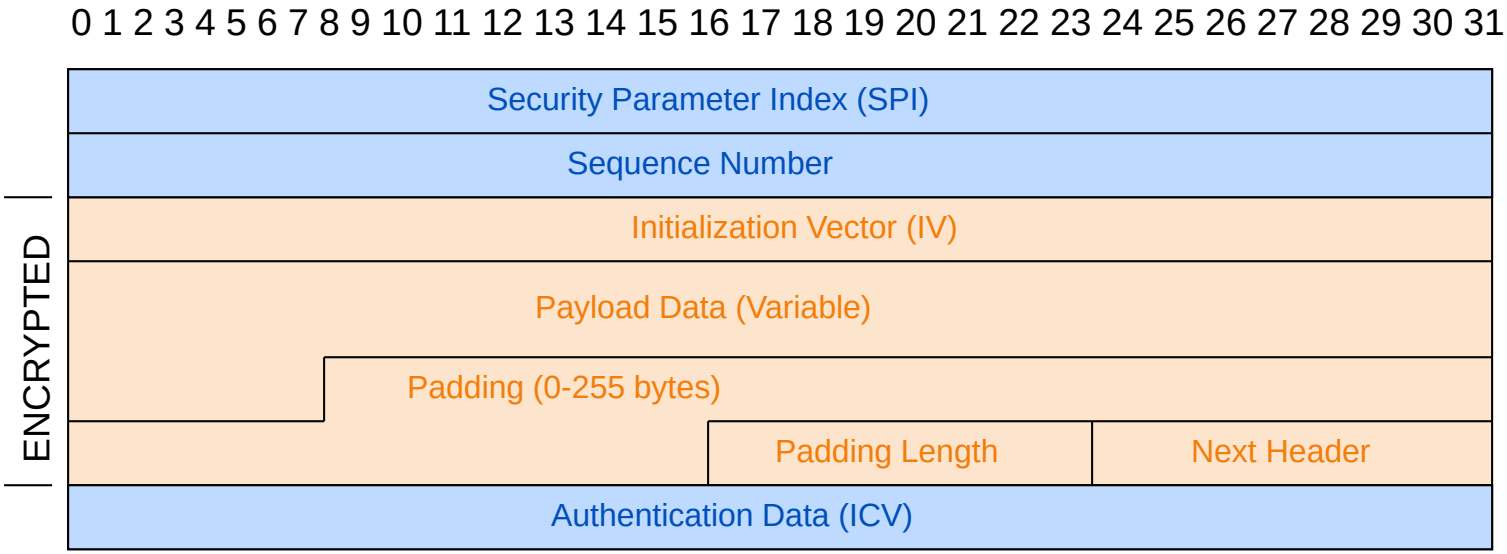
Sequence Number (32 bits): start at 1 and must never repeat. It is always set but receiver may choose to ignore this field

Authentication Data: ICV is a digital signature over the packet and it varies in length depending on the algorithm used (SHA-1, MD5)

Encapsulating Security Payload (ESP)

- Uses IP protocol 50
- Provides all that is offered by AH, plus data confidentiality
  - uses symmetric key encryption
- Must encrypt and/or authenticate in each packet
  - Encryption occurs before authentication
- Authentication is applied to data in the IPsec header as well as the data contained as payload

ESP Header Format



SPI: arbitrary 32-bit number that specifies SA to the receiving device

Seq #: start at 1 and must never repeat; receiver may choose to ignore

IV: used to initialize CBC mode of an encryption algorithm

Payload Data: encrypted IP header, TCP or UDP header and data

Padding: used for encryption algorithms which operate in CBC mode

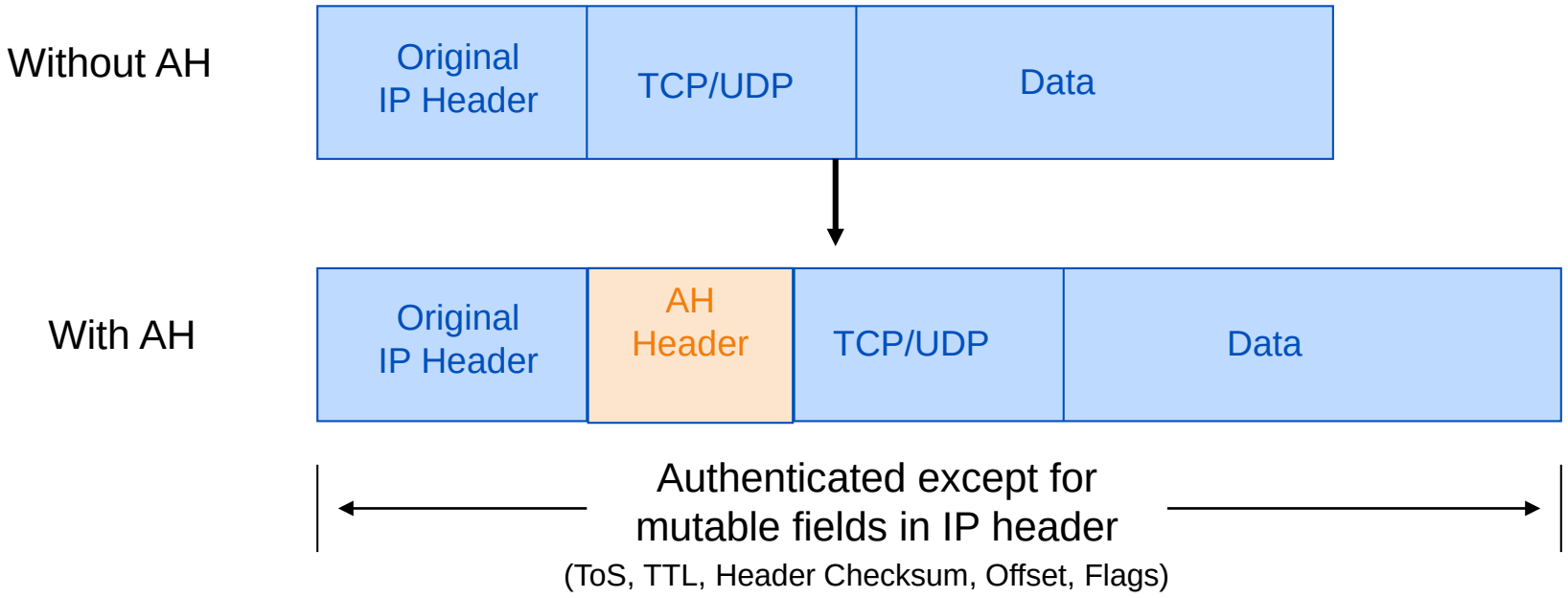
Padding Length: number of bytes added to the data stream (may be 0)

Next Header: the type of protocol from the original header which appears in the encrypted part of the packet

Authentication Header: ICV is a digital signature over the packet and it varies in length depending on the algorithm used (SHA-1, MD5)

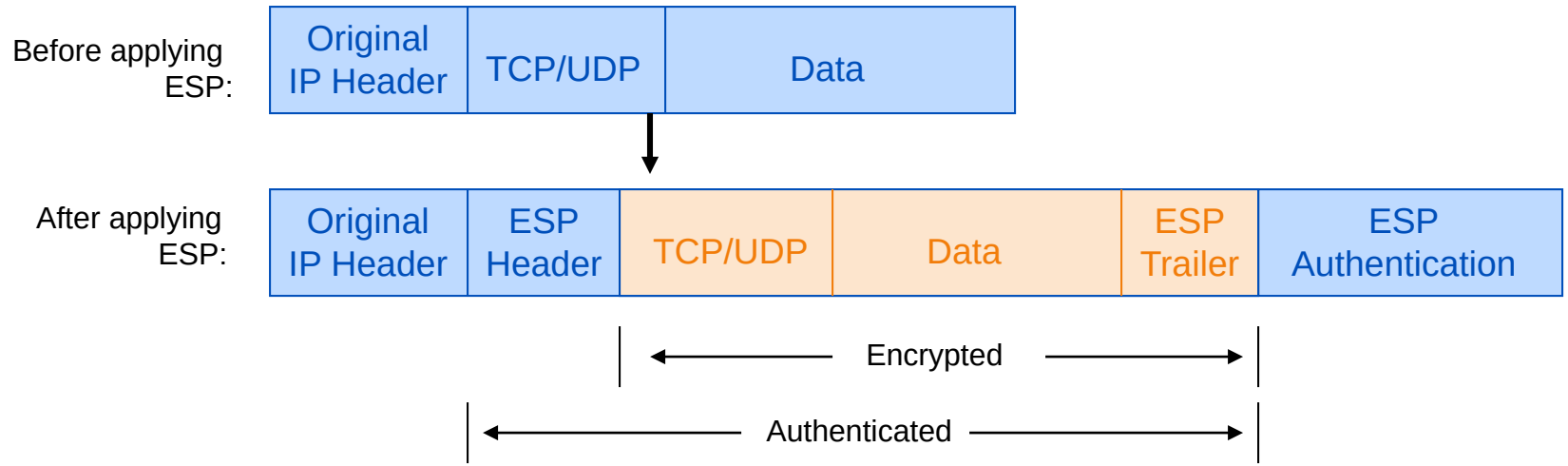
Packet Format Alteration for AH Transport Mode

Authentication Header



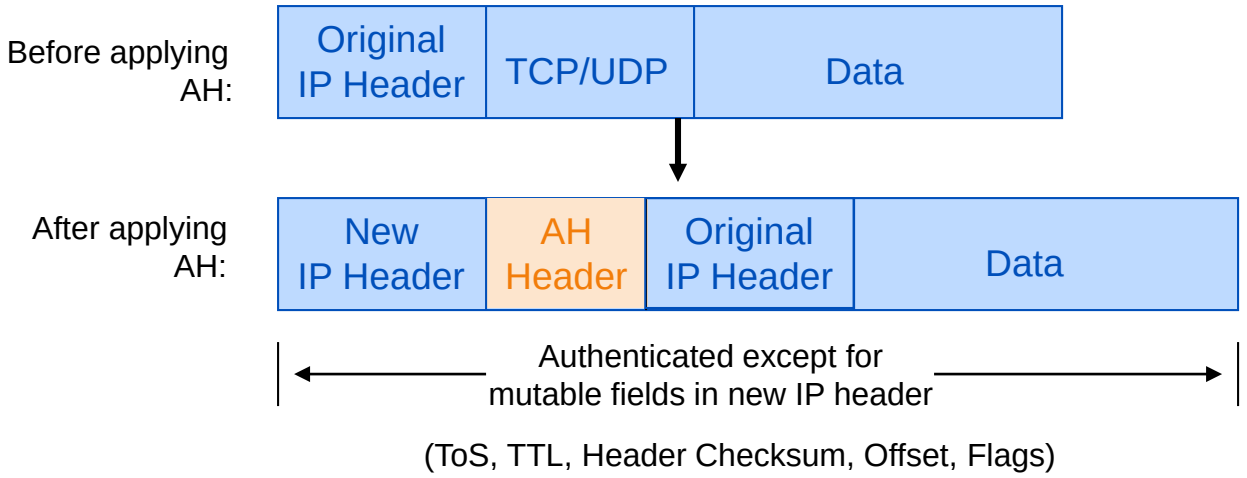
Packet Format Alteration for ESP Transport Mode

Encapsulating Security Payload



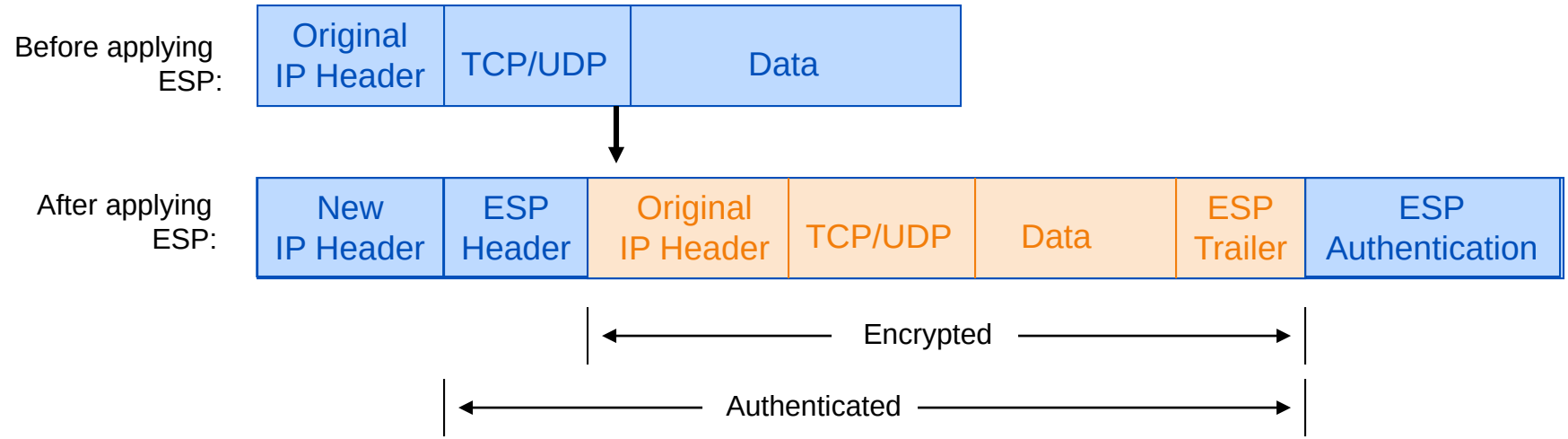
Packet Format Alteration for AH Tunnel Mode

Authentication Header



Packet Format Alteration for ESP Tunnel Mode

Encapsulating Security Payload



Internet Key Exchange (IKE)

- “An IPsec component used for performing mutual authentication and establishing and maintaining Security Associations.” (RFC 5996)
- Typically used for establishing IPsec sessions
- A key exchange mechanism
- Five variations of an IKE negotiation:
  - Two modes (aggressive and main modes)
  - Three authentication methods (pre-shared, public key encryption, and public key signature)
- Uses UDP port 500

IKE Modes

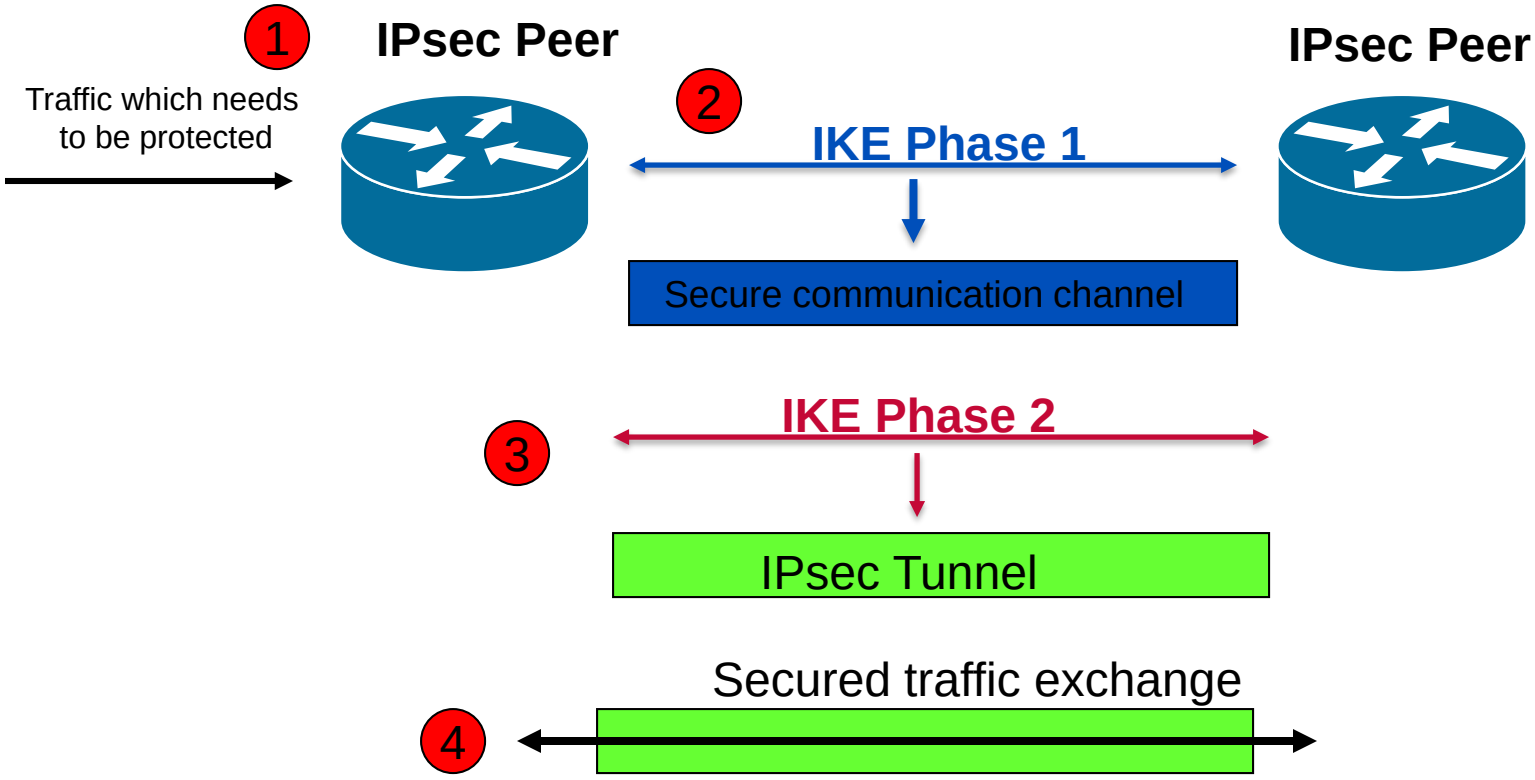
Mode	Description
Main mode	Three exchanges of information between IPsec peers. Initiator sends one or more proposals to the other peer (responder) Responder selects a proposal
Aggressive Mode	Achieves same result as main mode using only 3 packets First packet sent by initiator containing all info to establish SA Second packet by responder with all security parameters selected Third packet finalizes authentication of the ISAKMP session
Quick Mode	Negotiates the parameters for the IPsec session. Entire negotiation occurs within the protection of ISAKMP session

Internet Key Exchange (IKE)

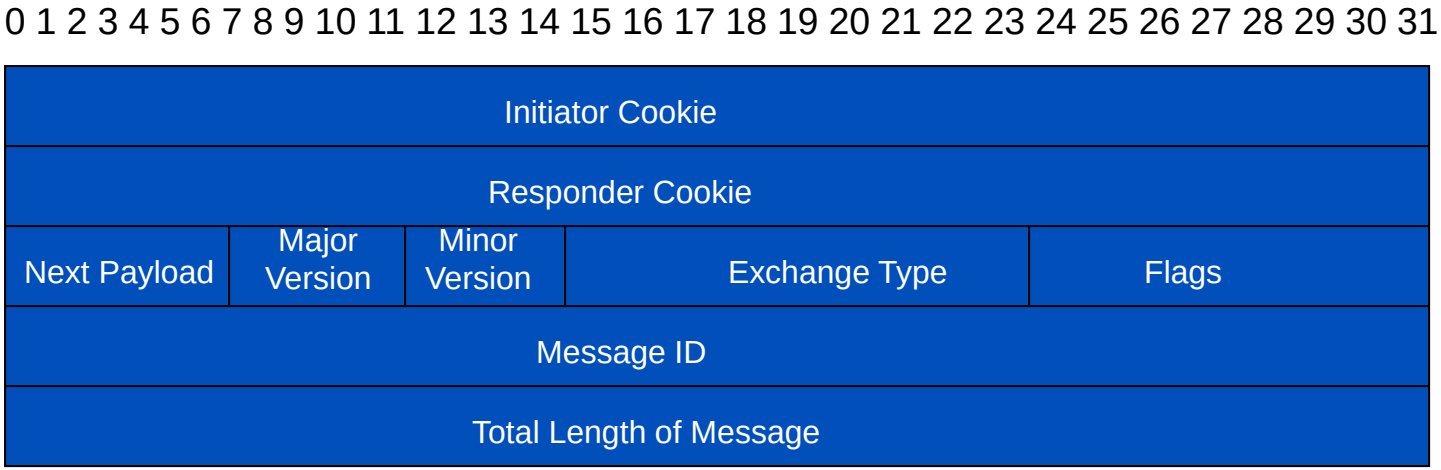
- Phase I
  - Establish a secure channel (ISAKMP SA)
  - Using either main mode or aggressive mode
  - Authenticate computer identity using certificates or pre-shared secret

- Phase II
  - Establishes a secure channel between computers intended for the transmission of data (IPsec SA)
  - Using quick mode

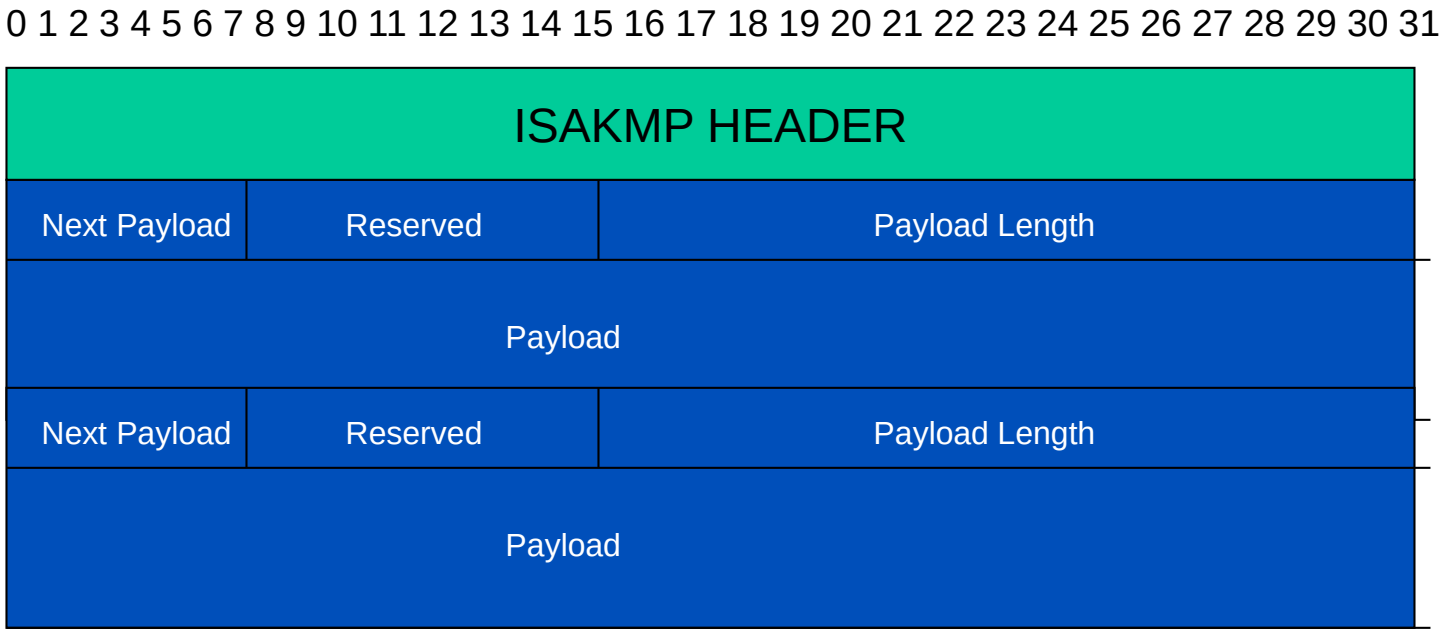
Overview of IKE



ISAKMP Header Format



ISAKMP Message Format



Next Payload: 1byte; identifier for next payload in message. If it is the last payload It will be set to 0

Reserved: 1byte; set to 0

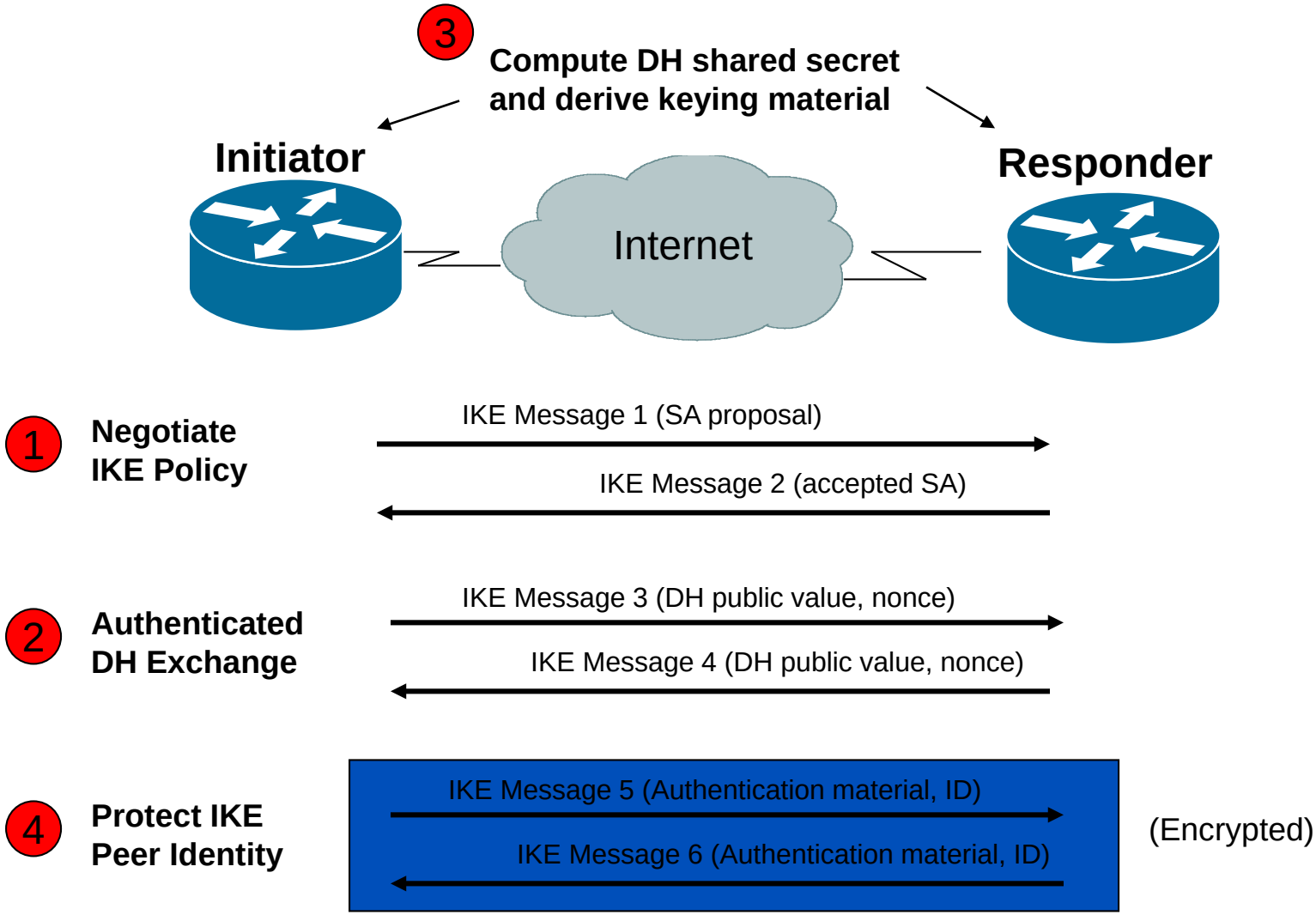
Payload Length: 2 bytes; length of payload (in bytes) including the header

Payload: The actual payload data

IKE Phase 1 (Main Mode)

- Main mode negotiates an ISAKMP SA which will be used to create IPsec SAs
- Three steps
  - SA negotiation (encryption algorithm, hash algorithm, authentication method, which DF group to use)
  - Do a Diffie-Hellman exchange
  - Provide authentication information
  - Authenticate the peer

IKE Phase 1 (Main Mode)



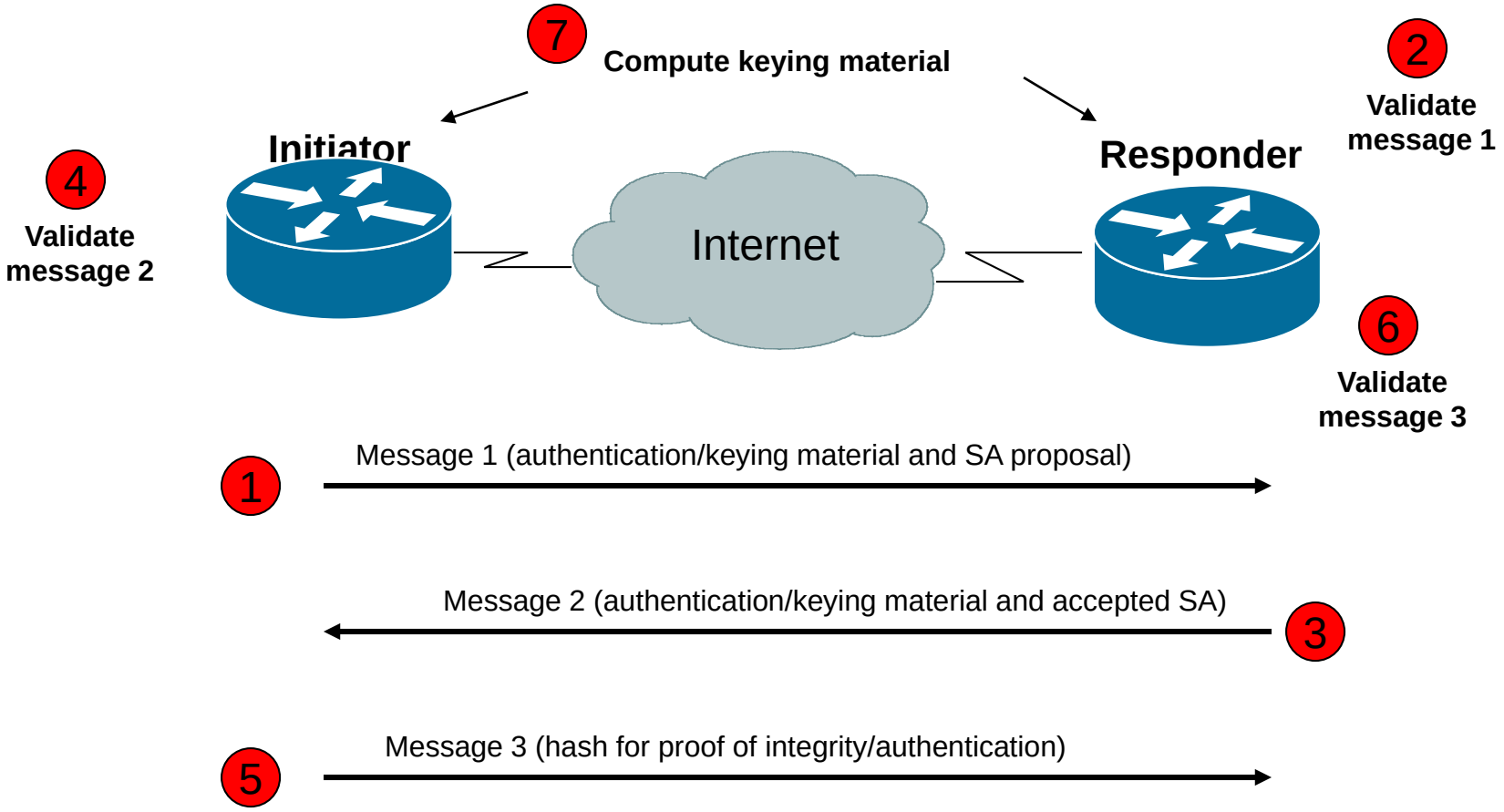
IKE Phase 1 (Aggressive Mode)

- Uses 3 (vs 6) messages to establish IKE SA
- No denial of service protection
- Does not have identity protection
- Optional exchange and not widely implemented

IKE Phase 2 (Quick Mode)

- All traffic is encrypted using the ISAKMP Security Association
- Each quick mode negotiation results in two IPsec Security Associations (one inbound, one outbound)
- Creates/refreshes keys

IKE Phase 2 (Quick Mode)



IKE v2: Replacement for Current IKE Specification

- Feature Preservation
  - Most features and characteristics of baseline IKE v1 protocol are being preserved in v2
- Compilation of Features and Extensions
  - Quite a few features that were added on top of the baseline IKE protocol functionality in v1 are being reconciled into the mainline v2 framework
- Some New Features

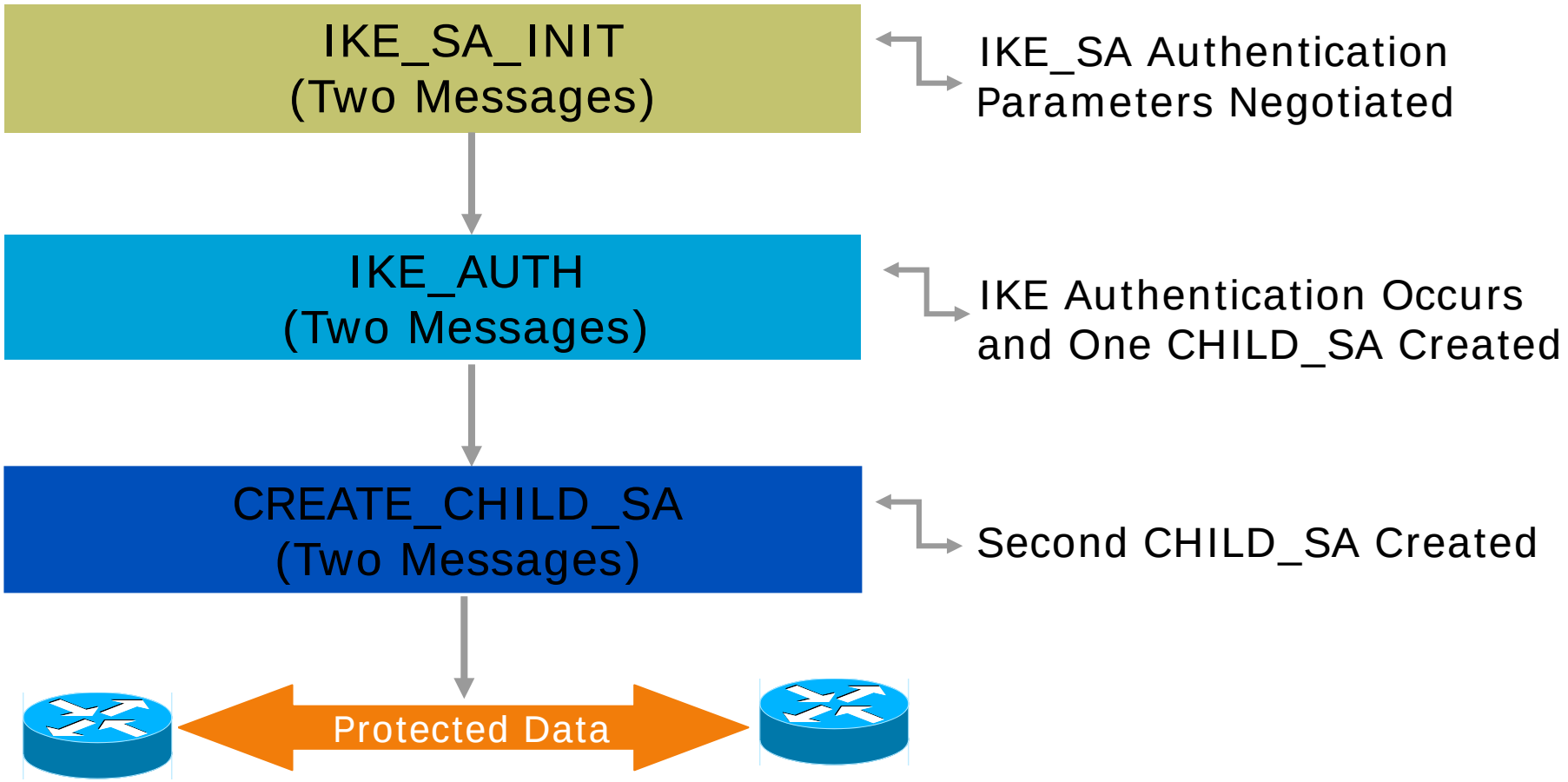
IKE v2: What Is Not Changing

- Features in v1 that have been debated but are ultimately being preserved in v2
  - Most payloads reused
  - Use of nonces to ensure uniqueness of keys
- v1 extensions and enhancements being merged into mainline v2 specification
  - Use of a ‘configuration payload’ similar to MODECFG for address assignment
  - ‘X-auth’ type functionality retained through EAP
  - Use of NAT Discovery and NAT Traversal techniques

IKE v2: What Is Changing

- Significant Changes Being to the Baseline Functionality of IKE
  - EAP adopted as the method to provide legacy authentication integration with IKE
  - Public signature keys and pre-shared keys, the only methods of IKE authentication
  - Use of ‘stateless cookie’ to avoid certain types of DOS attacks on IKE
  - Continuous phase of negotiation

How Does IKE v2 Work?



Considerations For Using IPsec

- Security Services
  - Data origin authentication
  - Data integrity
  - Replay protection
  - Confidentiality
- Size of network
- How trusted are end hosts – can apriori communication policies be created?
- Vendor support
- What other mechanisms can accomplish similar attack risk mitigation

Non-Vendor Specific Deployment Issues

- Historical Perception
  - Configuration nightmare
  - Not interoperable
- Performance Perception
  - Need empirical data
  - Where is the real performance hit?
- Standards Need Cohesion

Vendor Specific Deployment Issues

- Lack of interoperable defaults
  - A default does NOT mandate a specific security policy
  - Defaults can be modified by end users
- Configuration complexity
  - Too many knobs
  - Vendor-specific terminology
- Good News: IPv6 support in most current implementations

IPsec Concerns

- Are enough people aware that IKEv2 is not backwards compatible with IKEv1?
  - IKEv1 is used in most IPsec implementations
  - Will IKEv2 implementations first try IKEv2 and then revert to IKEv1?
- Is IPsec implemented for IPv6?
  - Some implementations ship IPv6 capable devices without IPsec capability and host requirements is changed from MUST to SHOULD implement
- OSPFv3
  - All vendors ‘IF’ they implement IPsec used AH
  - Latest standard to describe how to use IPsec says MUST use ESP w/Null encryption and MAY use AH

IPsec Concerns (cont)

- What is transport mode interoperability status?
  - Will end user authentication be interoperable?
- PKI Issues
  - Which certificates do you trust?
  - How does IKEv1 and/or IKEv2 handle proposals with certificates?
  - Should common trusted roots be shipped by default?
  - Who is following and implementing pki4ipsec-ikecert-profile (rfc4945)
- Have mobility scenarios been tested?
  - Mobility standards rely heavily on IKEv2
- ESP – how determine if ESP-Null vs Encrypted

IPsec Best Practices

- Use IPsec to provide integrity in addition to encryption
  - Use ESP option
- Use strong encryption algorithms
  - AES instead of DES
- Use a good hashing algorithm
  - SHA instead of MD5
- Reduce the lifetime of the Security Association (SA) by enabling Perfect Forward Secrecy (PFS)
  - Increases processor burden so do this only if data is highly sensitive

Configuring IPsec

- Step 1: Configure the IKE Phase 1 Policy (ISAKMP Policy)

  crypto isakmp policy [priority]

- Step 2: Set the ISAKMP Identity

  `crypto isakmp identity {ipaddress|hostname}`

- Step 3: Configure the IPsec transfer set

  `crypto ipsec transform-set transform-set-name <transform1> <transform2> mode [tunnel|transport]`

  `crypto ipsec security-association lifetime seconds seconds`

Configuring IPsec

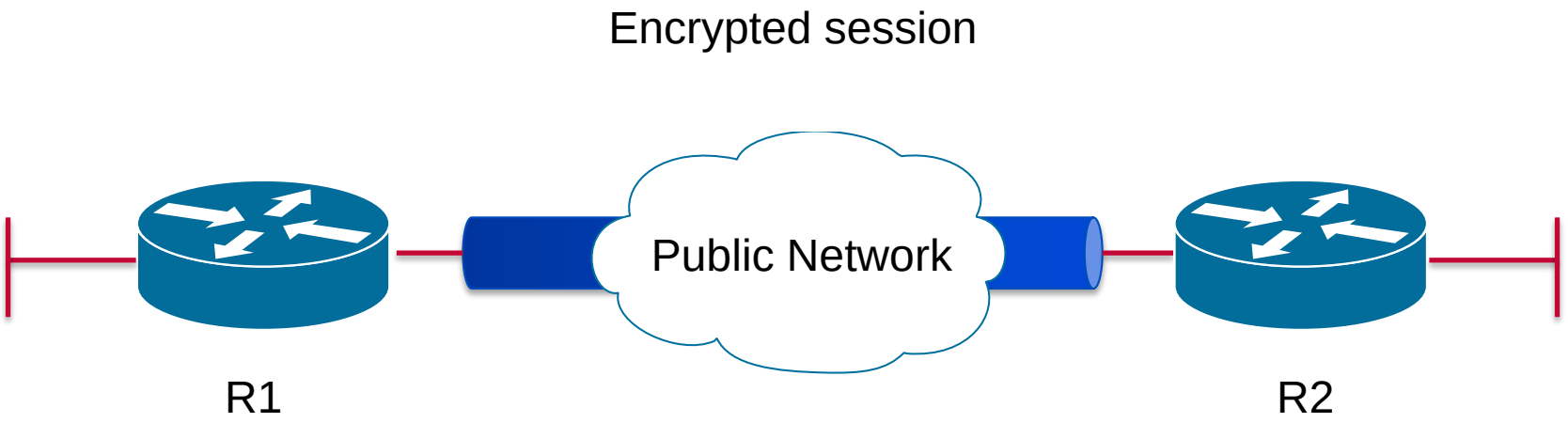
- Step 5: Creating map with name

```
crypto map crypto-map-name seq-num ipsec-isakmp
match address access-list-id
set peer [ipaddress|hostname]
set transform-set transform-set-name
set security-association lifetime seconds seconds
set pfs [group1|group2]
```

- Step 6: Apply the IPsec Policy to an Interface

```
crypto map crypto-map-name local-address interface-id
```

IPsec Layout



Router Configuration

```
crypto isakmp policy 1
  authentication pre-share
  encryption aes
  hash sha
  group 5
crypto isakmp key Training123 address 172.16.11.66
!
crypto ipsec transform-set ESP-AES-SHA esp-aes esp-sha-hmac
!
crypto map LAB-VPN 10 ipsec-isakmp
  match address 101
  set transform-set ESP-AES-SHA
  set peer 172.16.11.66
```

Phase 1 SA

Encryption and authentication

Phase 2 SA

Router Configuration

```
int fa 0/1
crypto map LAB-VPN
Exit
!
access-list 101 permit ip 172.16.16.0
0.0.0.255 172.16.20.0 0.0.0.255
```

Apply to an outbound interface

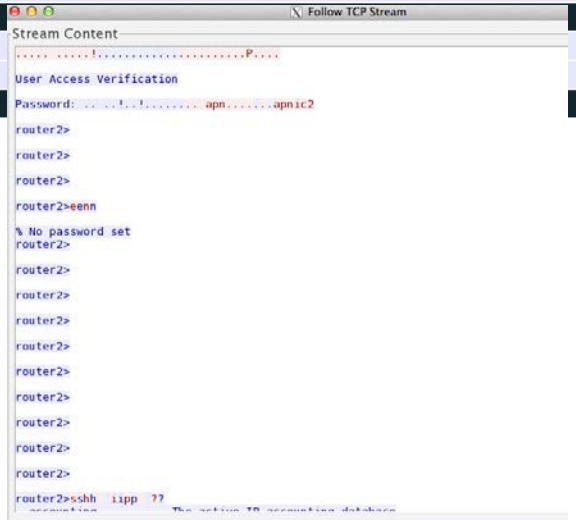
Define interesting VPN traffic

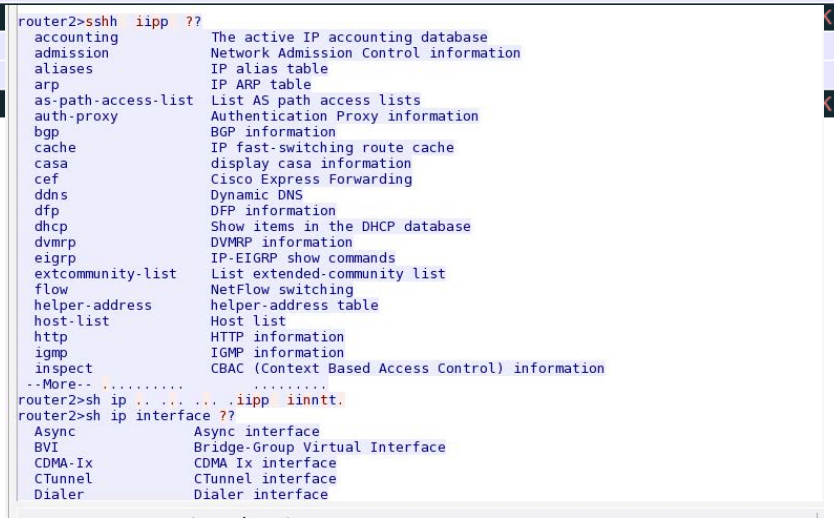
IPsec Debug Commands

- **sh crypto ipsec sa**
- **sh crypto isakmp peers**
- **sh crypto isakmp sa**
- **sh crypto map**

Capture: Telnet

8	3.113043	Cisco_de:76:91	Spanning-tree-(for-bridges)	STP	60 Conf. Root = 32768/1/00:13:80:de:76:80 Cost = 0 Port =
9	3.125855	192.168.1.1	172.16.2.1	TELNET	60 Telnet Data ...
10	3.127649	172.16.2.1	192.168.1.1	TELNET	60 Telnet Data ...
11	3.127651	172.16.2.1	192.168.1.1	TCP	60 [TCP Keep-Alive] telnet > 56784 [PSH, ACK] Seq=1 Ack=2 Wi
12	3.279317	2001:df0:aa::5	ff02::1:ff00:1	ICMPv6	86 Neighbor Solicitation for 2001:df0:aa::1 from 00:0d:28:49
13	3.328358	192.168.1.1	172.16.2.1	TCP	60 56784 > telnet [ACK] Seq=2 Ack=2 Win=3987 Len=0
14	3.470005	192.168.1.1	172.16.2.1	TELNET	60 Telnet Data ...
15	3.471802	172.16.2.1	192.168.1.1	TELNET	60 Telnet Data ...
16	3.471804	172.16.2.1	192.168.1.1	TCP	60 [TCP Keep-Alive] telnet > 56784 [PSH, ACK] Seq=2 Ack=3 Wi
17	3.672949	192.168.1.1	172.16.2.1	TCP	60 56784 > telnet [ACK] Seq=3 Ack=3 Win=3986 Len=0
18	3.854380	192.168.1.1	172.16.2.1	TELNET	60 Telnet Data ...
19	3.856188	172.16.2.1	192.168.1.1	TELNET	60 Telnet Data ...
20	3.856190	172.16.2.1	192.168.1.1	TELNET	60 [TCP Retransmission] Telnet Data ...
21	3.978556	192.168.1.1	172.16.2.1	TELNET	60 Telnet Data ...
22	3.980454	172.16.2.1	192.168.1.1	TELNET	60 Telnet Data ...
23	3.980456	172.16.2.1	192.168.1.1	TCP	60 [TCP Keep-Alive] telnet > 56784 [PSH, ACK] Seq=6 Ack=5 Wi
24	4.099046	192.168.1.1	172.16.2.1	TELNET	60 Telnet Data ...
25	4.100949	172.16.2.1	192.168.1.1	TELNET	60 Telnet Data ...
26	4.100950				K] Seq=7 Ack=6 Wi
27	4.243593				
28	4.245501				
29	4.245503				K] Seq=8 Ack=7 Wi





Capture: Telnet + IPsec

178 67.482685	2001:db8:aa::8	ff02::1:ff00:2	ICMPv6	86 Neighbor Solicitation for 2001:
179 67.594031	192.168.1.1	192.168.1.2	ESP	134 ESP (SPI=0x7ea7f8ed)
180 67.601908	192.168.1.2	192.168.1.1	ESP	118 ESP (SPI=0x742f79b4)
181 67.601910	192.168.1.2	192.168.1.1	ESP	118 ESP (SPI=0x742f79b4)
182 67.605809	192.168.1.1	192.168.1.2	ESP	118 ESP (SPI=0x7ea7f8ed)
183 67.626089	192.168.1.2	192.168.1.1	ESP	134 ESP (SPI=0x742f79b4)
184 67.626091	192.168.1.2	192.168.1.1	ESP	134 ESP (SPI=0x742f79b4)
185 67.627695	192.168.1.2	192.168.1.1	ESP	166 ESP (SPI=0x742f79b4)
186 67.627697	192.168.1.2	192.168.1.1	ESP	166 ESP (SPI=0x742f79b4)
187 67.631728	192.168.1.1	192.168.1.2	ESP	118 ESP (SPI=0x7ea7f8ed)
188 67.632884	192.168.1.1	192.168.1.2	ESP	118 ESP (SPI=0x7ea7f8ed)
189 67.751716	192.168.1.1	192.168.1.2	ESP	150 ESP (SPI=0x7ea7f8ed)
190 67.765217	192.168.1.2	192.168.1.1	ESP	118 ESP (SPI=0x742f79b4)
191 67.765219	192.168.1.2	192.168.1.1	ESP	118 ESP (SPI=0x742f79b4)
192 67.766634	192.168.1.2	192.168.1.1	ESP	118 ESP (SPI=0x742f79b4)
193 67.766636	192.168.1.2	192.168.1.1	ESP	118 ESP (SPI=0x742f79b4)
194 67.768056	192.168.1.2	192.168.1.1	ESP	118 ESP (SPI=0x742f79b4)
195 67.768058	192.168.1.2	192.168.1.1	ESP	118 ESP (SPI=0x742f79b4)
196 67.769385	192.168.1.2	192.168.1.1	ESP	118 ESP (SPI=0x742f79b4)
197 67.769387	192.168.1.2	192.168.1.1	ESP	118 ESP (SPI=0x742f79b4)
198 67.770803	192.168.1.2	192.168.1.1	ESP	118 ESP (SPI=0x742f79b4)
199 67.770804	192.168.1.2	192.168.1.1	ESP	118 ESP (SPI=0x742f79b4)
200 67.770963	192.168.1.1	192.168.1.2	ESP	134 ESP (SPI=0x7ea7f8ed)

Pretty Good IPsec Policy

- IKE Phase 1 (aka ISAKMP SA or IKE SA or Main Mode)
  - 3DES (AES-192 if both ends support it)
  - Lifetime (8 hours = 480 min = 28800 sec)
  - SHA-2 (256 bit keys)
  - DH Group 14 (aka MODP# 14)
- IKE Phase 2 (aka IPsec SA or Quick Mode)
  - 3DES (AES-192 if both ends support it)
  - Lifetime (1 hour = 60 min = 3600 sec)
  - SHA-2 (256 bit keys)
  - PFS 2
  - DH Group 14 (aka MODP# 14)


Questions

THANK YOU

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