Cryptography Applications

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Acknowledgment

- Most of the contents are from
  - Merike Kaeo of Double Shot Security
  - Contact: merike@doubleshotsecurity.com

Virtual Private Networks

- Creates a secure tunnel over a public network
- Any VPN is not automagically secure. You need to add security functionality to create secure VPNs. That means using firewalls for access control and probably IPsec or SSL/TLS for confidentiality and data origin authentication.

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 VPN Implementations

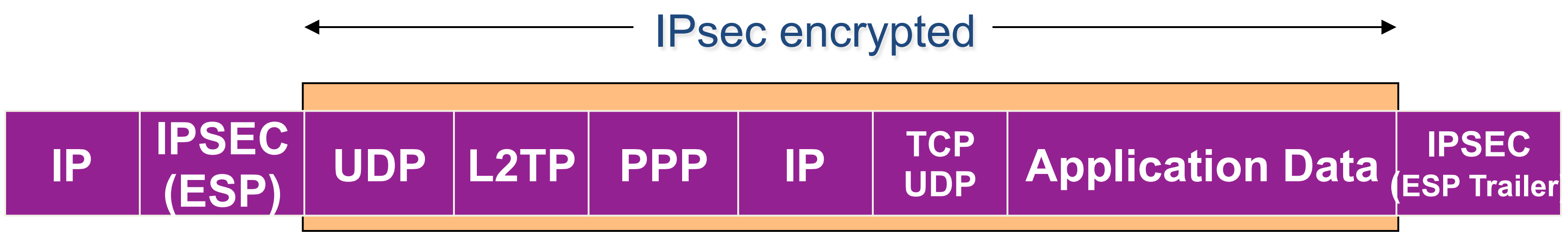
- MPLS VPN
  - Used for large and small enterprises
  - Pseudowire, VPLS, VPRN
- GRE Tunnel
  - Packet encapsulation protocol developed by Cisco
  - Not encrypted
  - Implemented with IPsec
- L2TP IPsec
  - Uses L2TP protocol
  - Usually implemented along with IPsec
  - IPsec provides the secure channel,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

Layer 2 Tunneling Protocol

- Designed in IETF PPP Extensions working group
  - Combination of Cisco L2F & PPTP features
  - L2TP RFC 2661, Aug 1999
  - Uses UDP port 1701 for control and data packets
  - Uses PPP for packet encapsulation – carries most protocols (also non-IP protocols)
- Security Functionality
  - Control session authentication, keepalives
  - EAP for a broader authentication mechanisms
  - IPsec ESP for confidentiality and integrity
  - IKE for key management

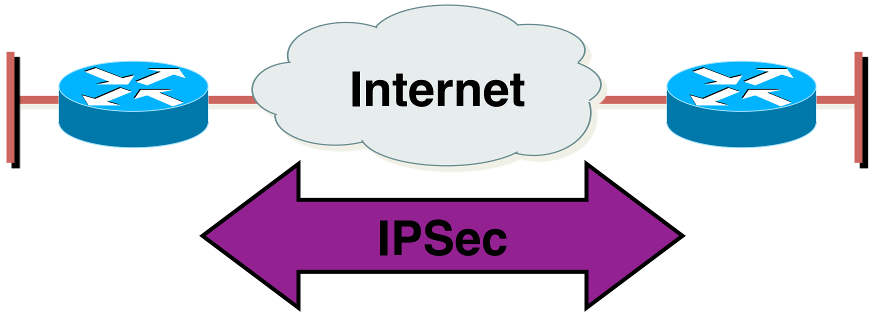
L2TP and IPsec

Multiple Encapsulations
.....careful of packet size!!



Ping with large MTU size....help discover fragmentation issues!!

What is IPSec?

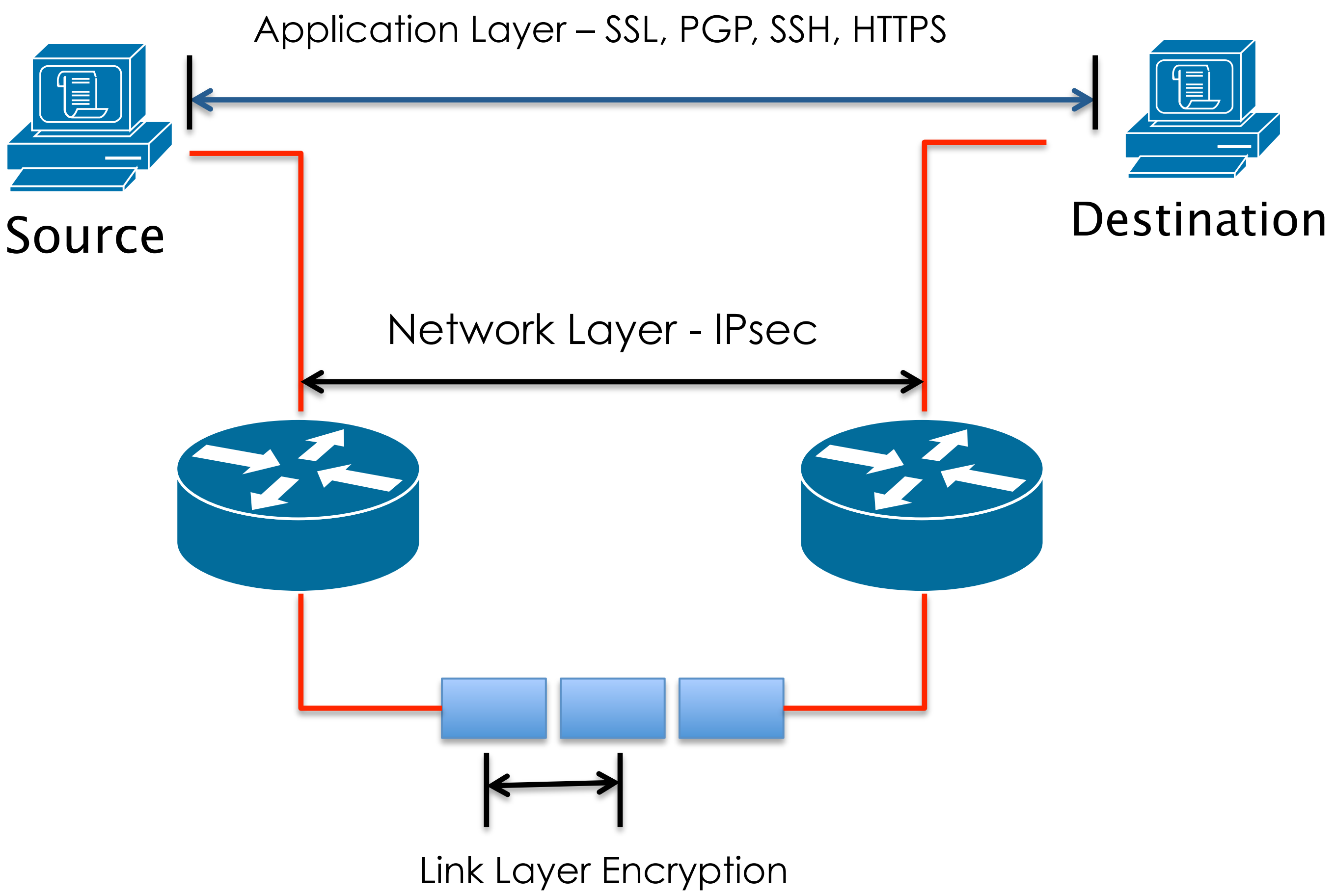


- IETF standard that enables encrypted communication between peers:
  - Consists of open standards for securing private communications
  - Network layer encryption ensuring data confidentiality, integrity, and authentication
  - Scales from small to very large networks

What Does IPsec Provide ?

- Confidentiality….many algorithms to choose from
- Data integrity and source authentication
  - Data “signed” by sender and “signature” verified by the recipient
  - Modification of data can be detected by signature “verification”
  - Because “signature” 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



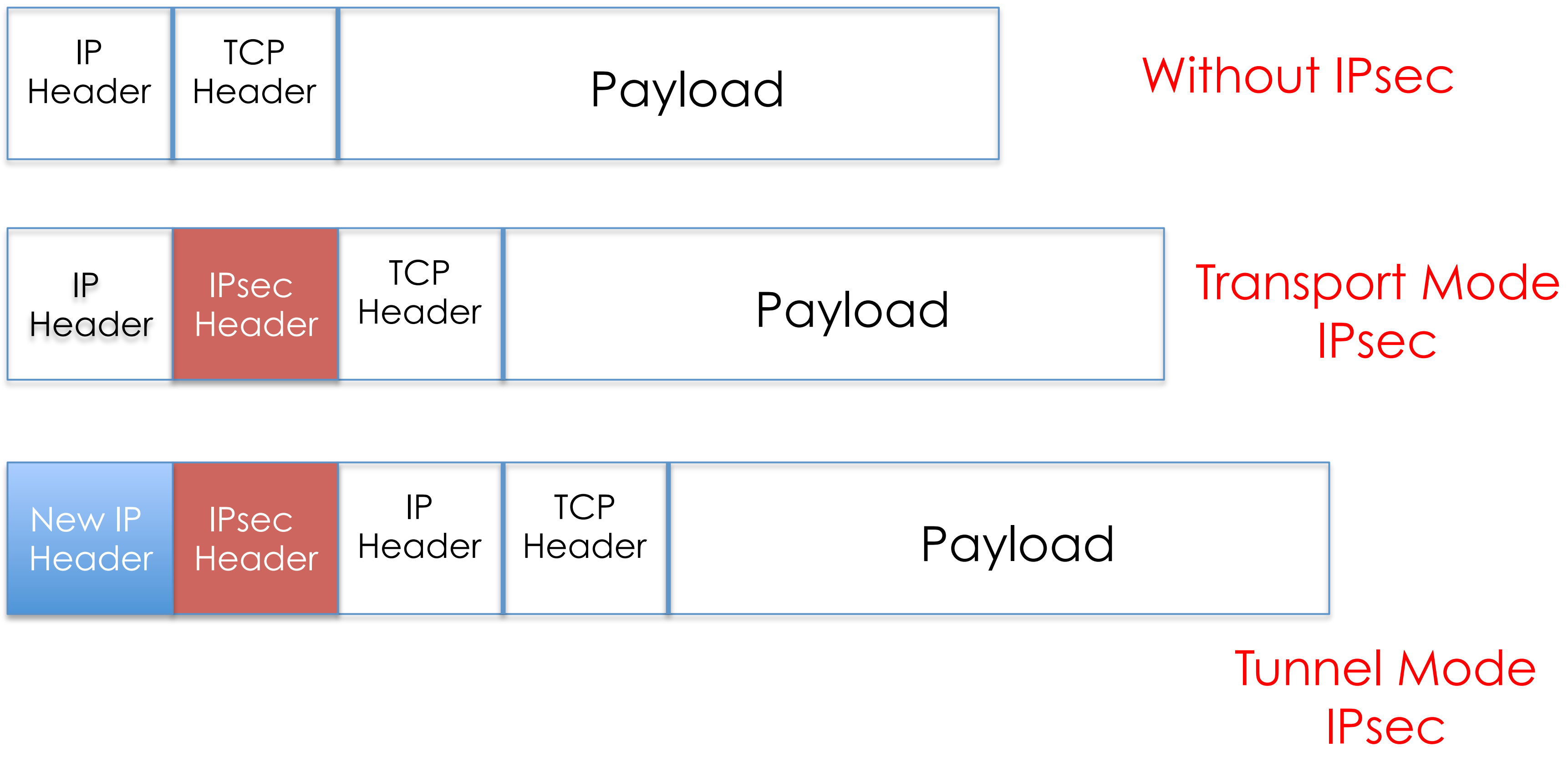
Relevant Standard(s)

- IETF specific
  - rfc2409: IKEv1
  - rfc4301: IPsec Architecture (updated)
  - rfc4303: IPsec ESP (updated)
  - rfc4306: IKEv2
  - rfc4718: IKEv2 Clarifications
  - rfc4945: IPsec PKI Profile
- IPv6 and IPsec
  - rfc4294: IPv6 Node Requirements
  - Rfc4552: Authentication/Confidentiality for OSPFv3
  - rfc4877: Mobile IPv6 Using IPsec (updated)
  - rfc4891: Using IPsec to secure IPv6-in-IPv4 Tunnels

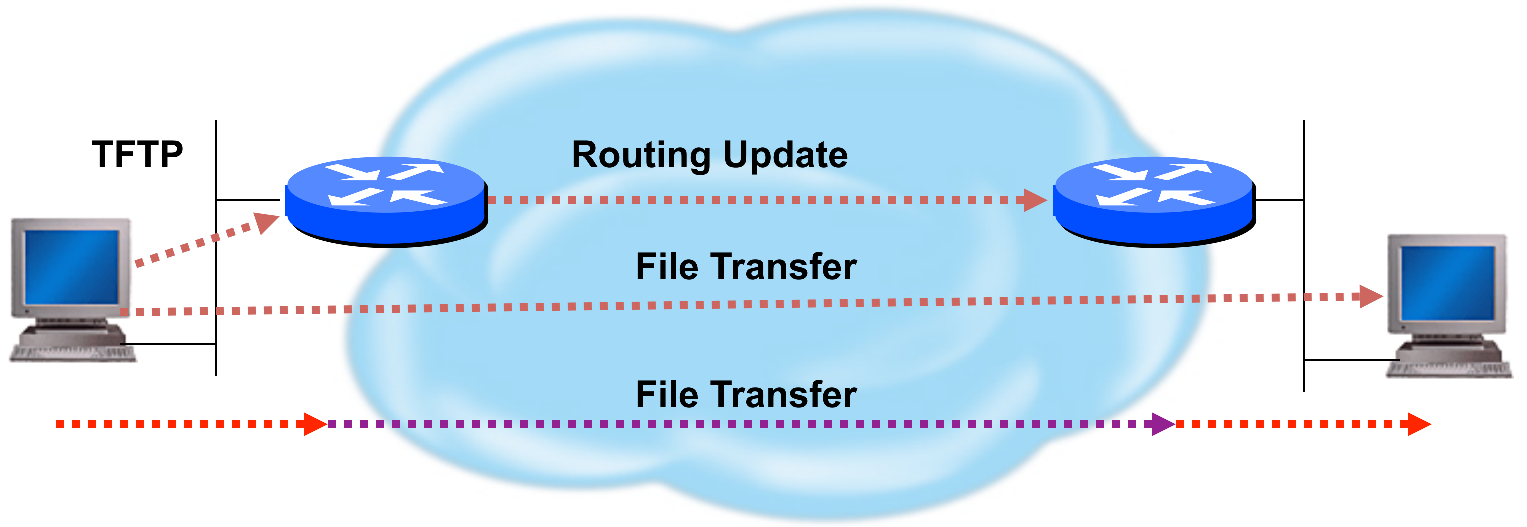
IPsec Modes

- 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



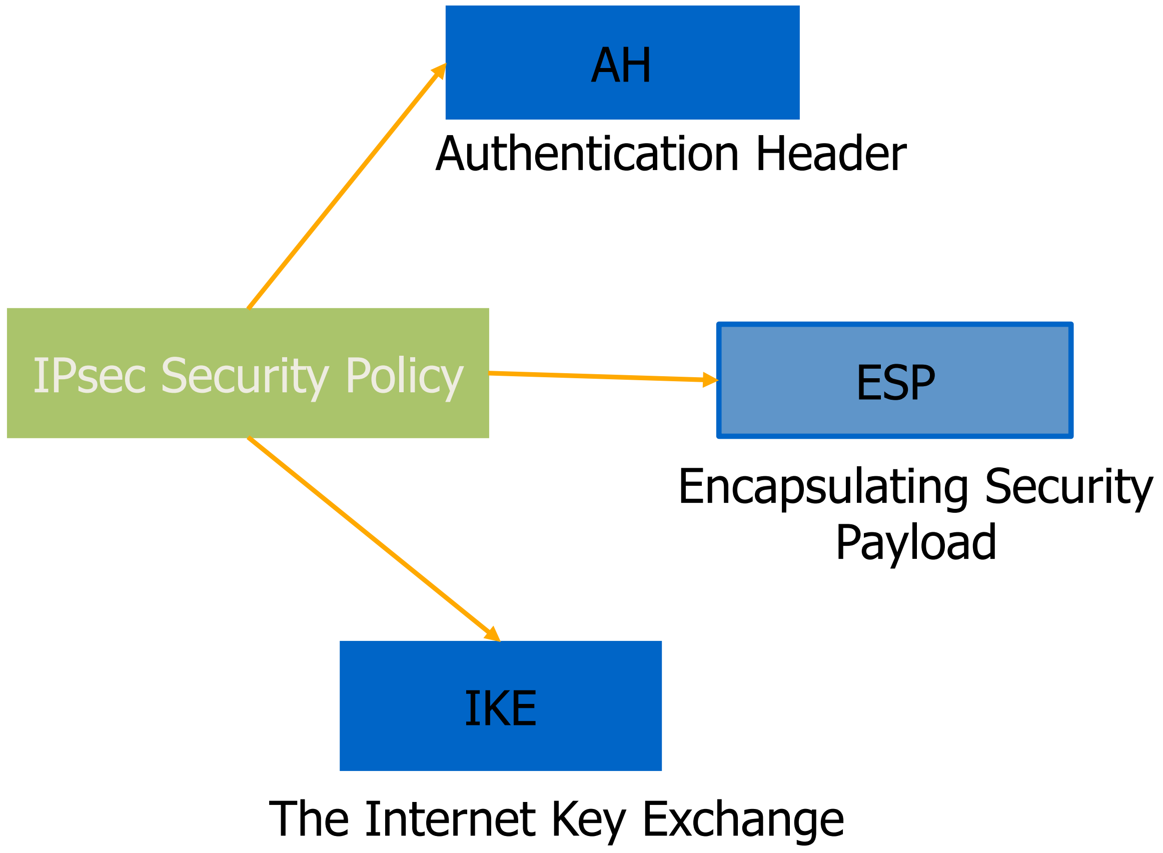
Transport Mode: End systems are the initiator and recipient of protected traffic

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

IPsec Components

- AH (Authentication Header)
  - Authentication is applied to the entire packet, with the mutable fields in the IP header zeroed out
  - If both ESP and AH are applied to a packet, AH follows ESP
  - Standard requires HMAC-MD5-96 and HMAC-SHA1-96….older implementations also support keyed MD5
- ESP (Encapsulating Security Payload)
  - 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
  - Standard requires DES 56-bit CBC and Triple DES. Can also use RC5, IDEA, Blowfish, CAST, RC4, NULL
- IKE (Internet Key Exchange)
  - Automated SA (Security Association) creation and key management

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 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

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)

Encapsulating Security Payload (ESP)

- Uses IP protocol 50
- Provides all that is offered by AH, plus data confidentiality
  - It 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

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

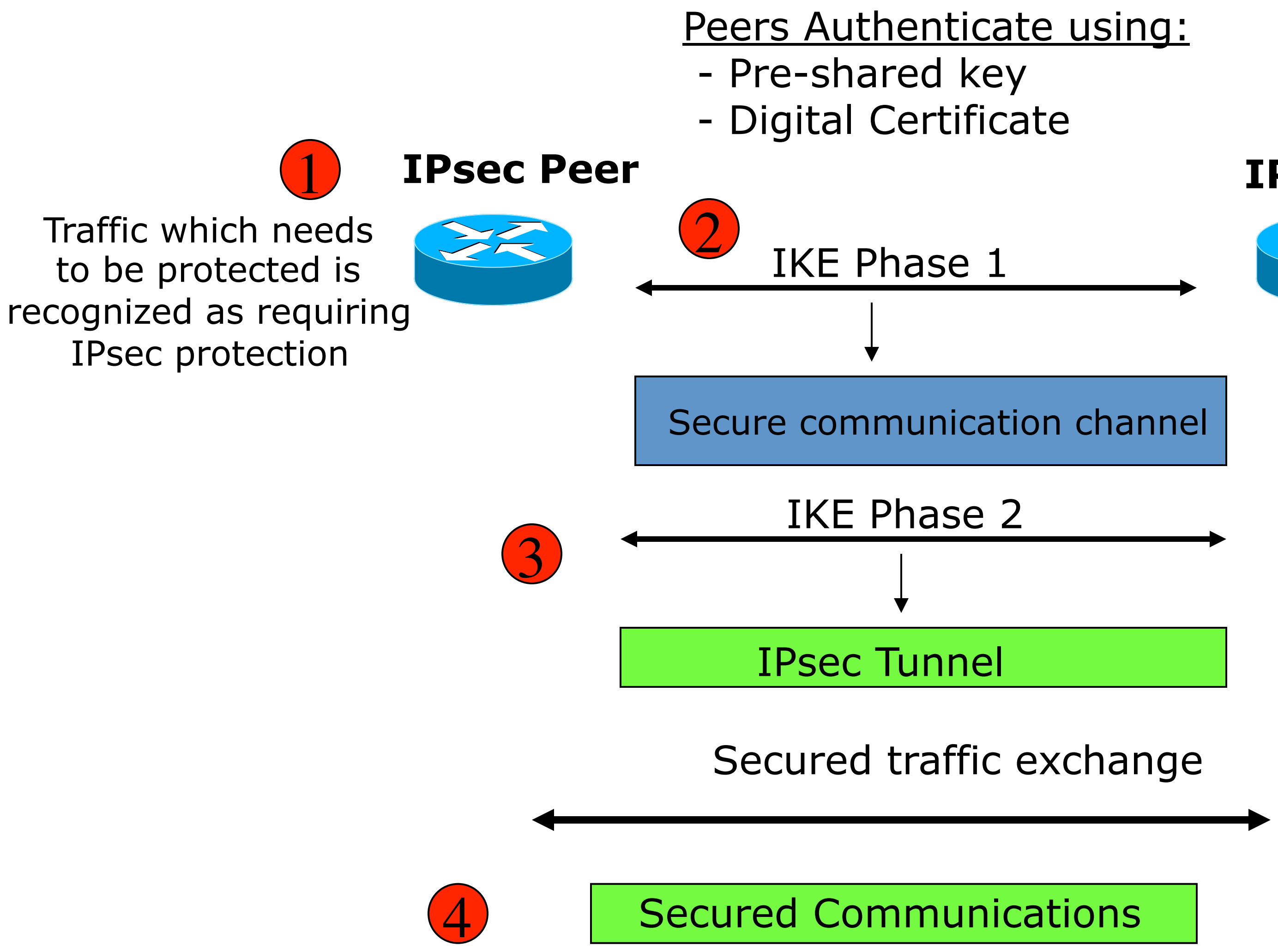
IKE Modes

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 Diffie-Hellman (DH) key exchange Establish ISAKMP session
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

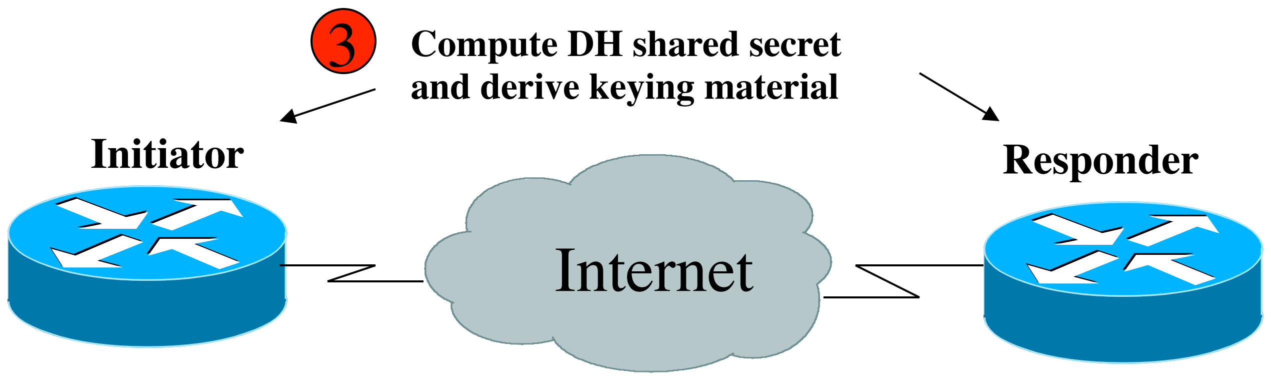
IPsec with IKE

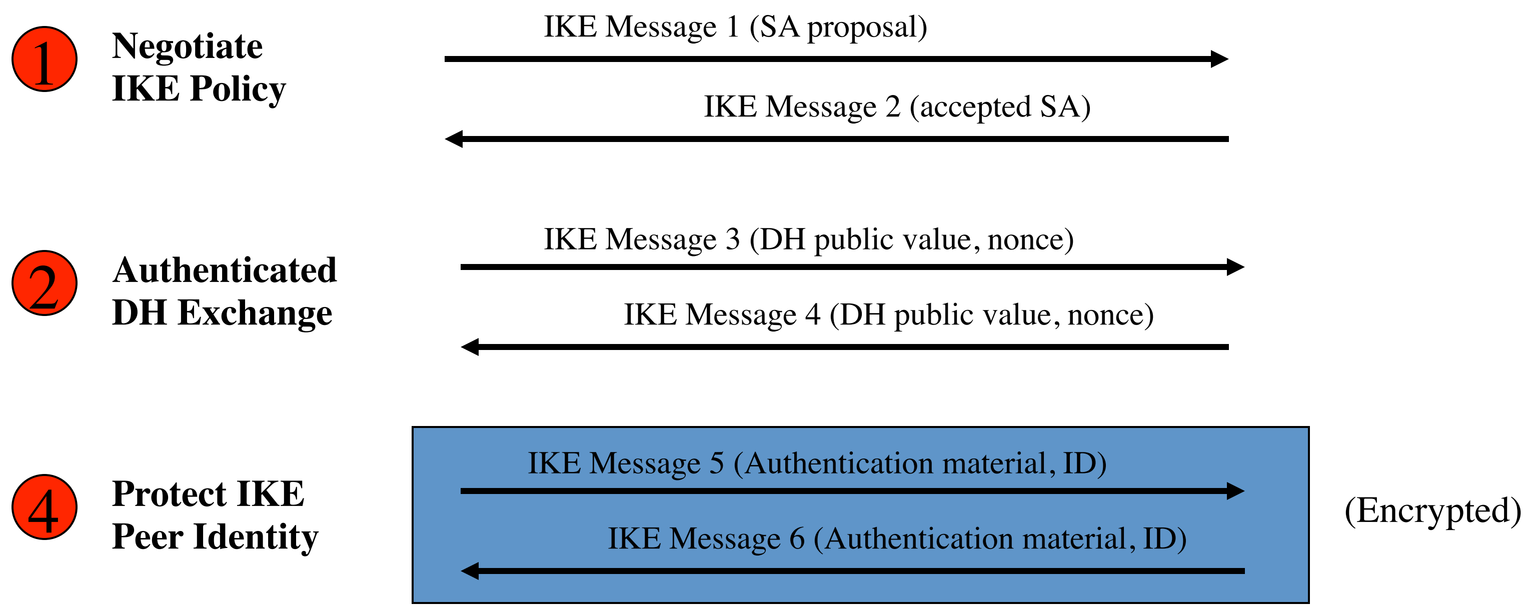


IPsec IKE Phase 1 Uses DH Exchange

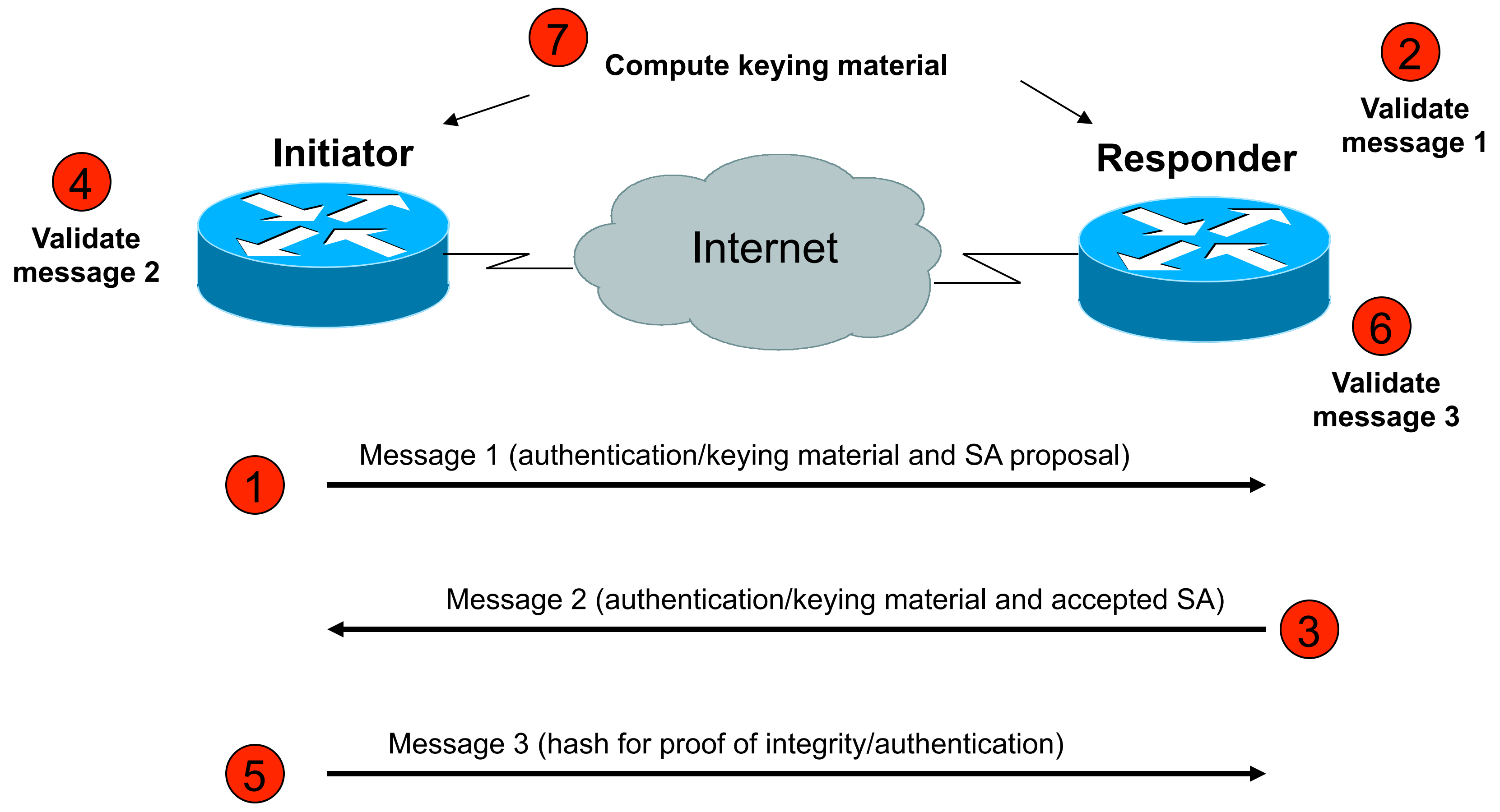
- First public key algorithm (1976)
- Diffie Hellman is a key establishment algorithm
  - Two parties in a DF exchange can generate a shared secret
  - There can even be N-party DF changes where N peers can all establish the same secret key
- Diffie Hellman can be done over an insecure channel
- IKE authenticates a Diffie-Hellman exchange
  - Pre-shared secret
  - Nonce (RSA signature)
  - Digital signature

IKE Phase 1 Main Mode




1
Negotiate
IKE Policy
IKE Message 1 (SA proposal)
IKE Message 2 (accepted SA)
2
Authenticated
DH Exchange
IKE Message 3 (DH public value, nonce)
IKE Message 4 (DH public value, nonce)
4
Protect IKE
Peer Identity
IKE Message 5 (Authentication material, ID)
IKE Message 6 (Authentication material, ID)
(Encrypted)

IKE Phase 2 Quick Mode


7
Compute keying material
2
Validate message 1
Initiator
Responder
4
Validate message 2
Internet
6
Validate message 3
1
Message 1 (authentication/keying material and SA proposal)
Message 2 (authentication/keying material and accepted SA)
3
5
Message 3 (hash for proof of integrity/authentication)

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

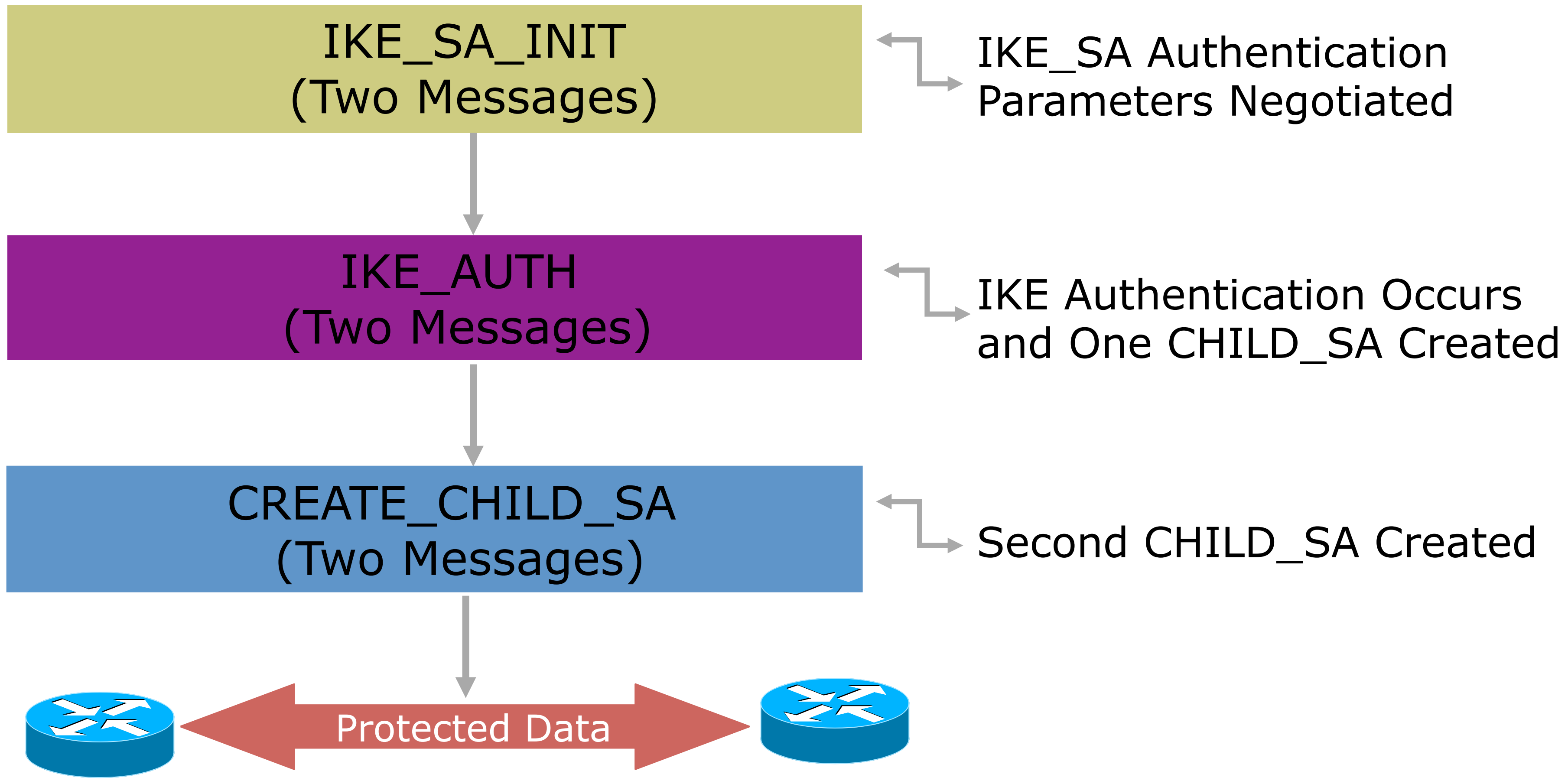
IKE v2: What Is Not Changing

- 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

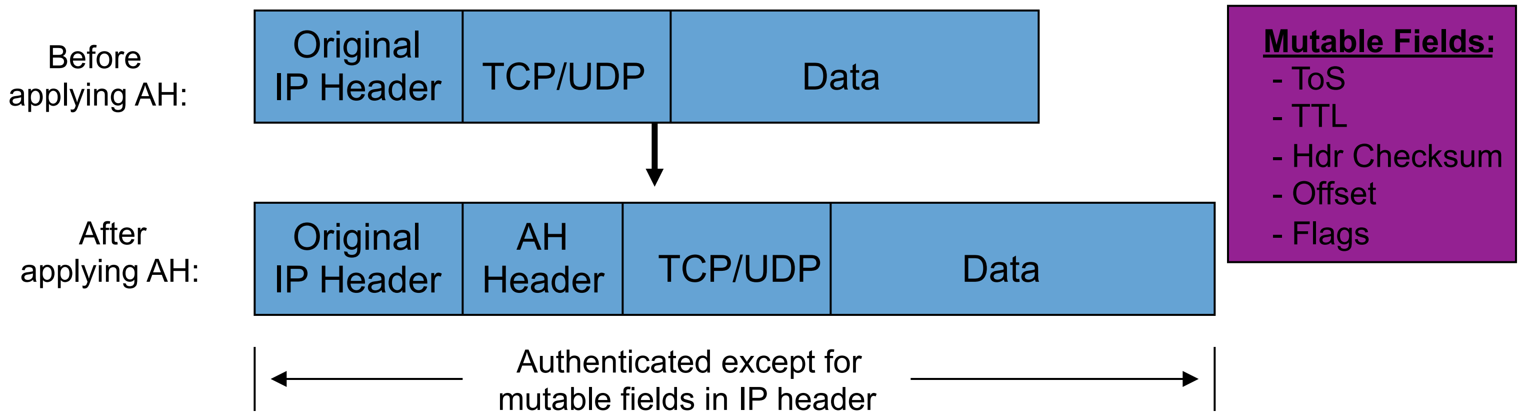
- Significant Changes Being to the Baseline Functionality of IKE
  - EAP adopted as the method to provide legacy authentication integration with IKE
  - Public signature keys and pre-shared keys, the only methods of IKE authentication
  - Use of ‘stateless cookie’ to avoid certain types of DOS attacks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

How Does IKE v2 Work?

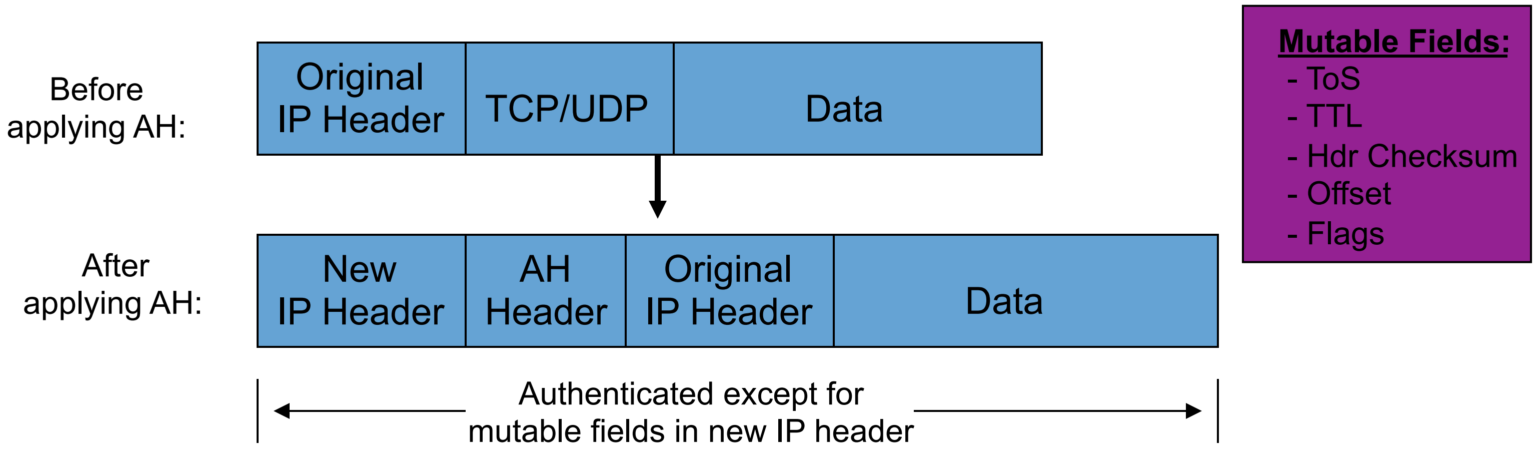


IPv4 IPsec AH

IPv4 AH Transport Mode:

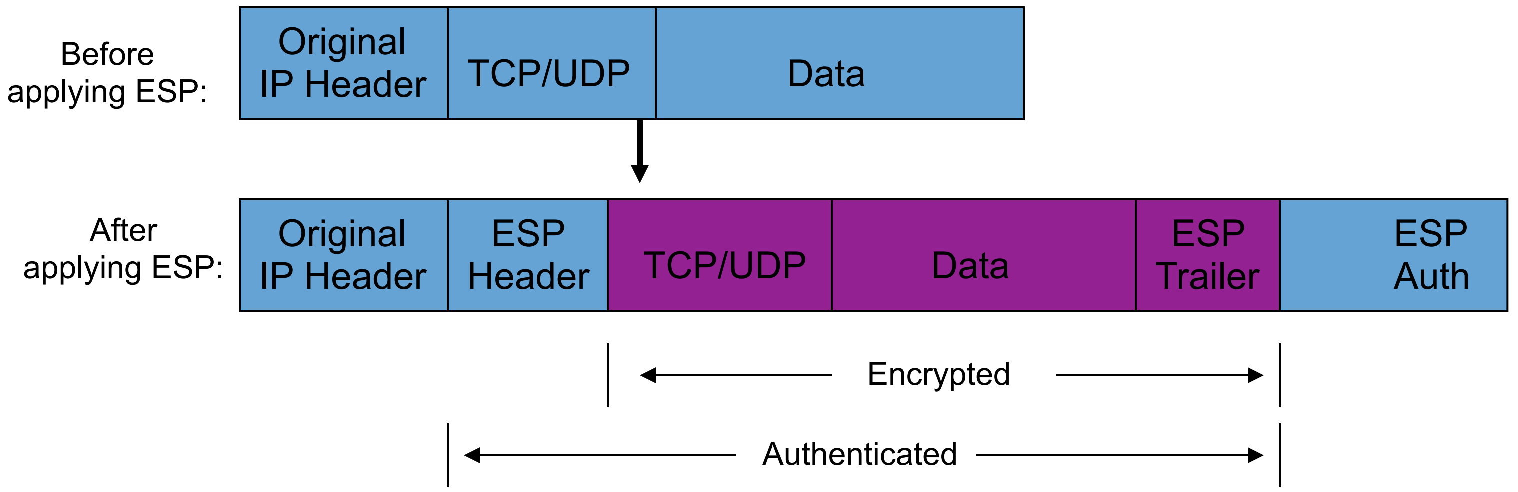


IPv4 AH Tunnel Mode:

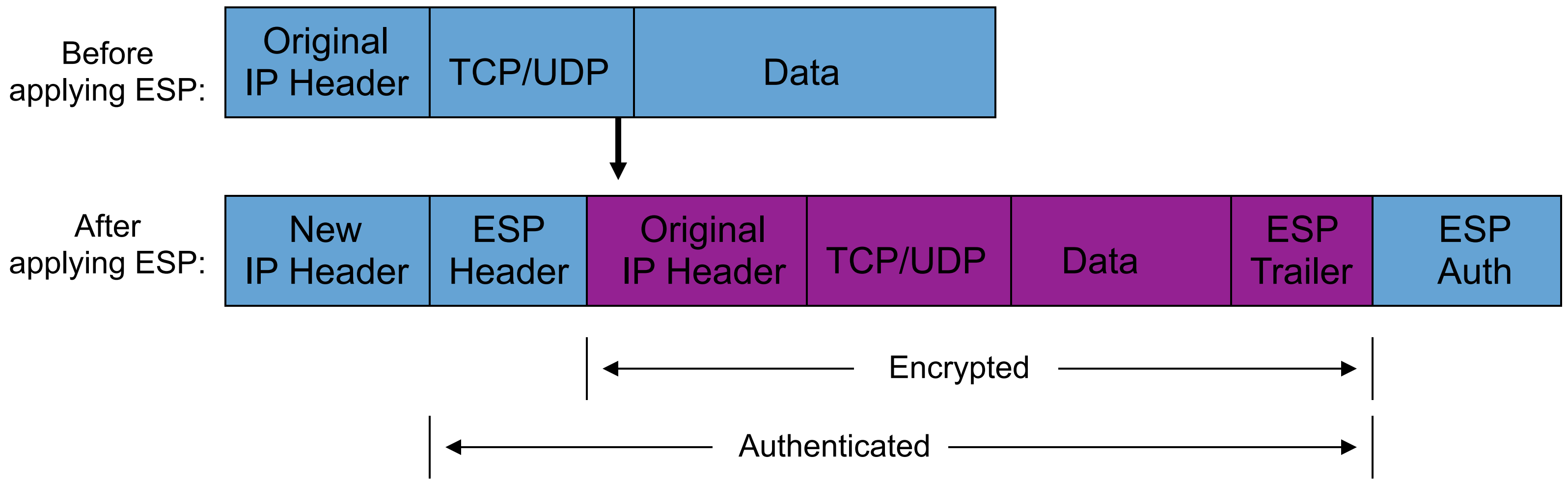


IPv4 IPsec ESP

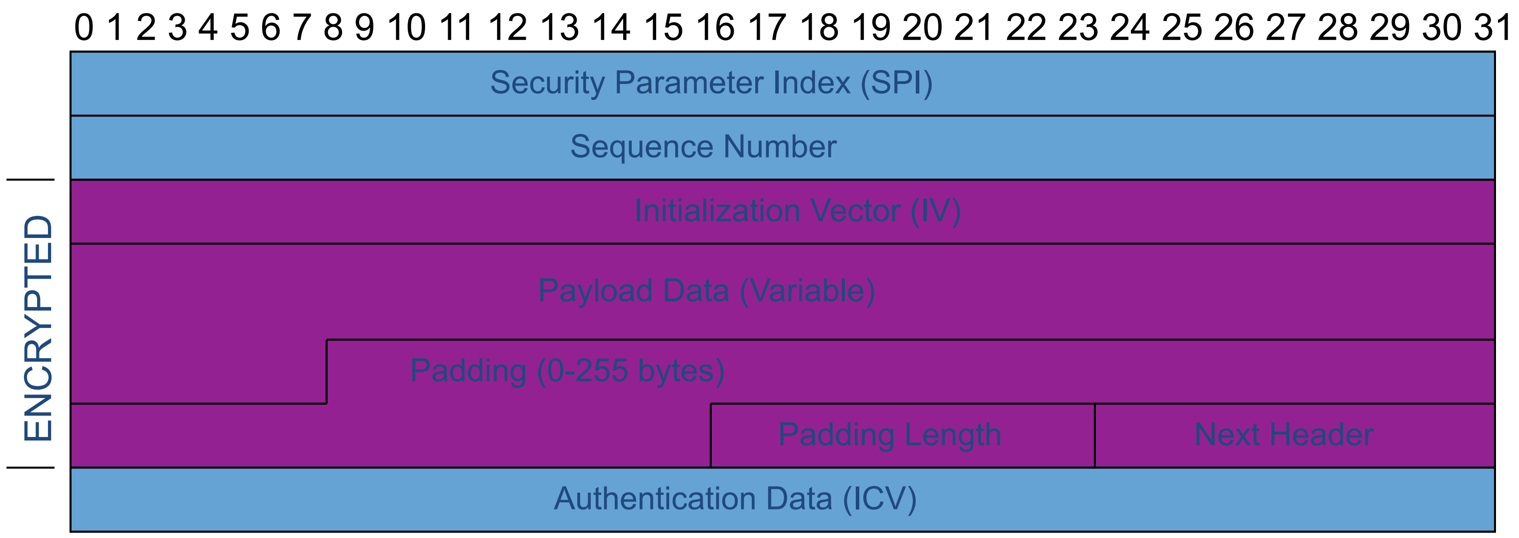
IPv4 ESP Transport Mode:



IPv4 ESP Tunnel Mode:



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

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

Default Issues

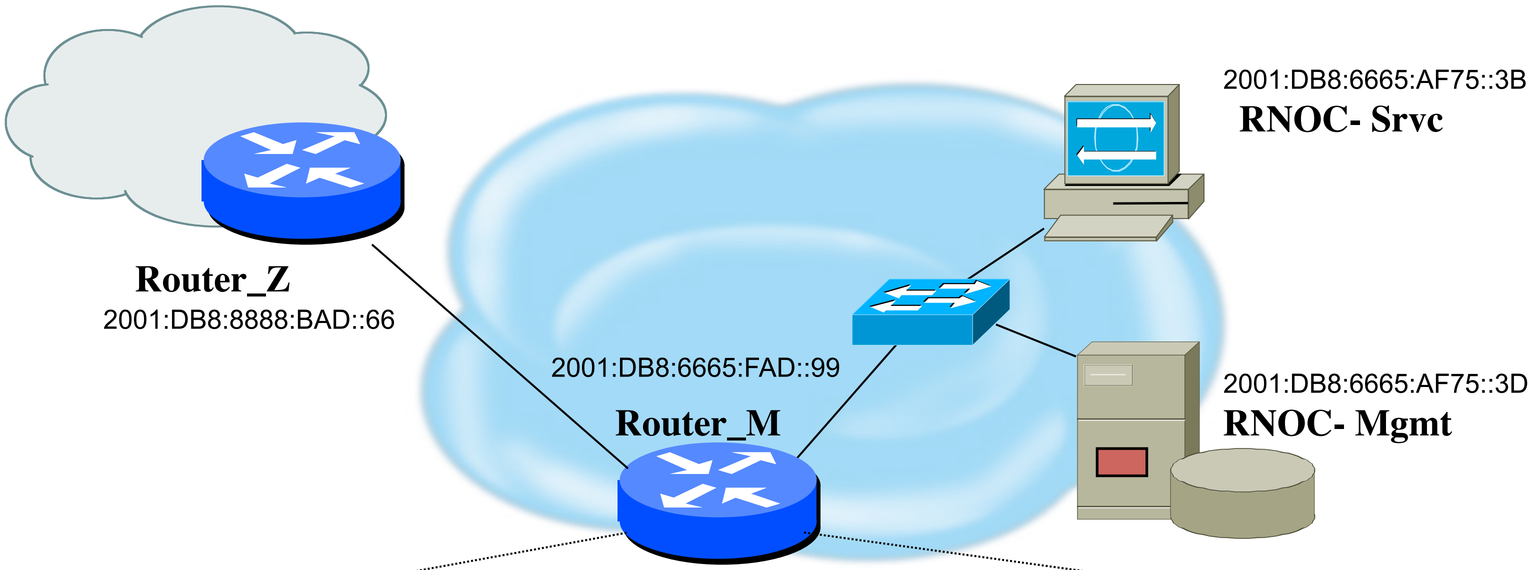
Vendor A	Vendor B	Vendor C
IKE Phase 1	IKE Phase 1	IKE Phase 1
SHA1	MD5	SHA1
RSA-SIG	Pre-Share Key	Pre-Share Key
Group 1	Group 5	Group 2
Lifetime 86400 Sec	Lifetime 86400 Sec	Lifetime 86400 Sec
Main Mode	Main Mode	Aggressive Mode
IKE Phase 2	IKE Phase 2	IKE Phase 2
PFS	PFS	PFS
Group 1	Group 5	Group 2

Terminology Issues

IKE Phase 1	DH Key Length	IKE Phase 2
IKE Phase 1 SA	DH Group	IKE Phase 2 SA
IKE SA	Modp #	IPsec SA
ISAKMP SA	Group #	Quick Mode
Main Mode		

Configuration complexity increased with vendor specific configuration terms

Potentially Easy Configuration



```
Syslog server 2001:DB8:6665:AF75::3D authenticate esp-null sha1 pre-share ‘secret4syslog’

TFTP server 2001:DB8:6665:AF75::3D authenticate esp-null aes128 pre-share ‘secret4tftp’

BGP peer 2001:DB8:8888:BAD::66 authenticate esp-null aes128 pre-share ‘secret4AS#XXX’
```

Interoperable Defaults For SAs

- Security Association groups elements of a conversation together
  - ESP encryption algorithm and key(s)
  - Cryptographic synchronization
  - SA lifetime
  - SA source address
  - Mode (transport or tunnel)

Do we want integrity protection of data ?
Do we want to keep data confidential ?
Which algorithms do we use ?
What are the key lengths ?
When do we want to create new keys ?
Are we providing security end-to-end ?

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)

Sample 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

Sample 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
```

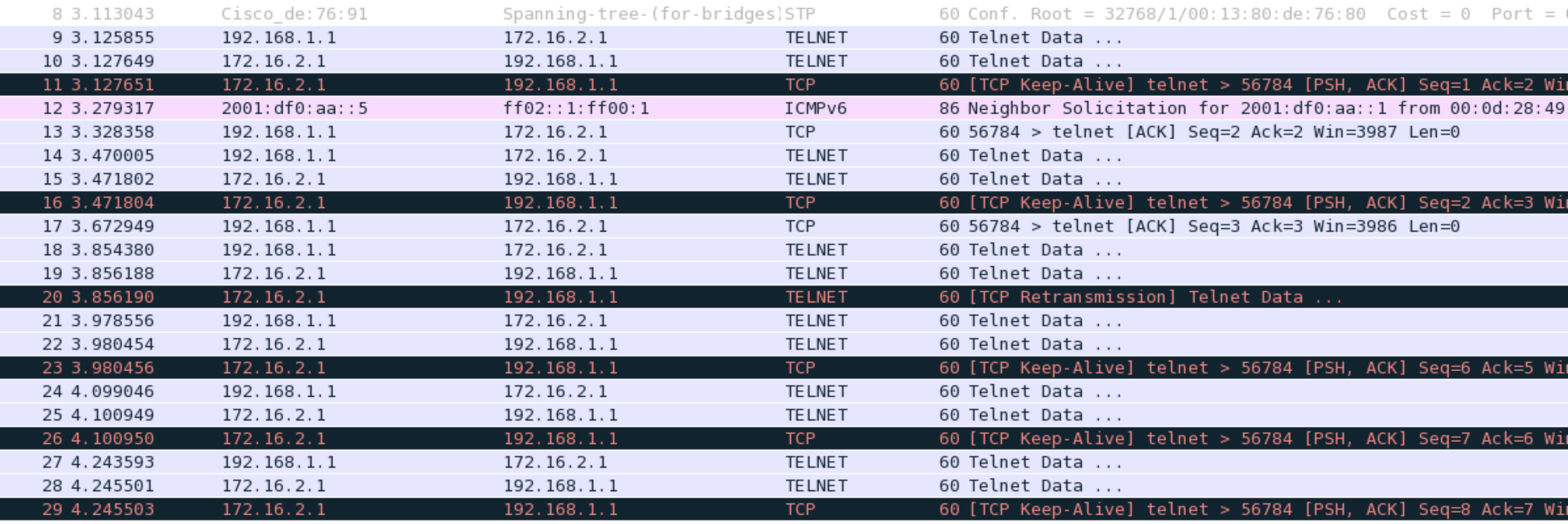
Apply on outbound interface

Define interesting VPN traffic

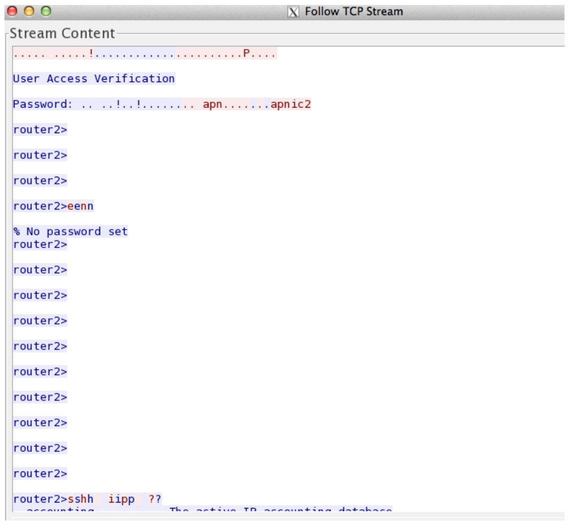
Help With Configuring IPsec

- http://www.vpnc.org/InteropProfiles/
- Documents for Cisco IPsec configuration:
  - http://www.cisco.com/en/US/tech/tk583/tk372/technologies_configuration_example09186a0080093f73.shtml
  - http://www.cisco.com/en/US/tech/tk583/tk372/technologies_configuration_example09186a0080093f86.shtml
- Document for Juniper IPsec configuration:
  - http://kb.juniper.net/InfoCenter/index?page=content&id=KB10128

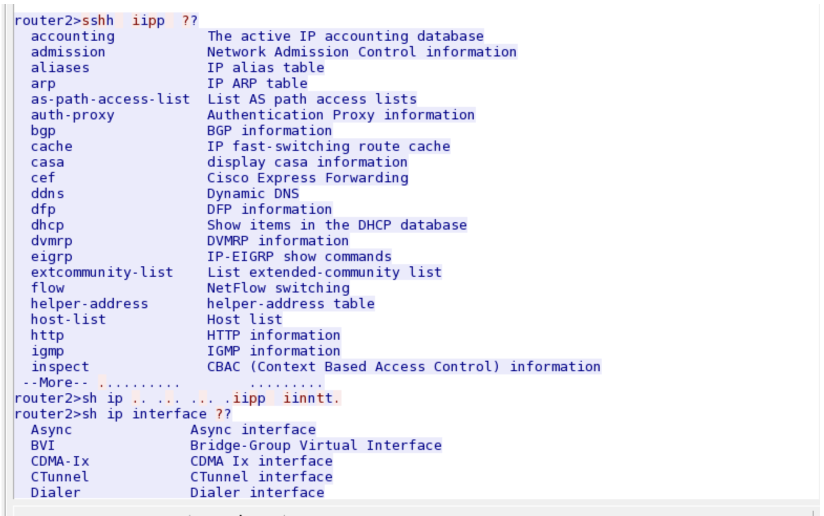
Capture: Telnet



```
 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   172.16.2.1       192.168.1.1               TCP      60 [TCP Keep-Alive] telnet > 56784 [PSH, ACK] Seq=7 Ack=6 Wi
27 4.243593   192.168.1.1      172.16.2.1                TELNET   60 Telnet Data ...
28 4.245501   172.16.2.1       192.168.1.1               TELNET   60 Telnet Data ...
29 4.245503   172.16.2.1       192.168.1.1               TCP      60 [TCP Keep-Alive] telnet > 56784 [PSH, ACK] Seq=8 Ack=7 Wi
```

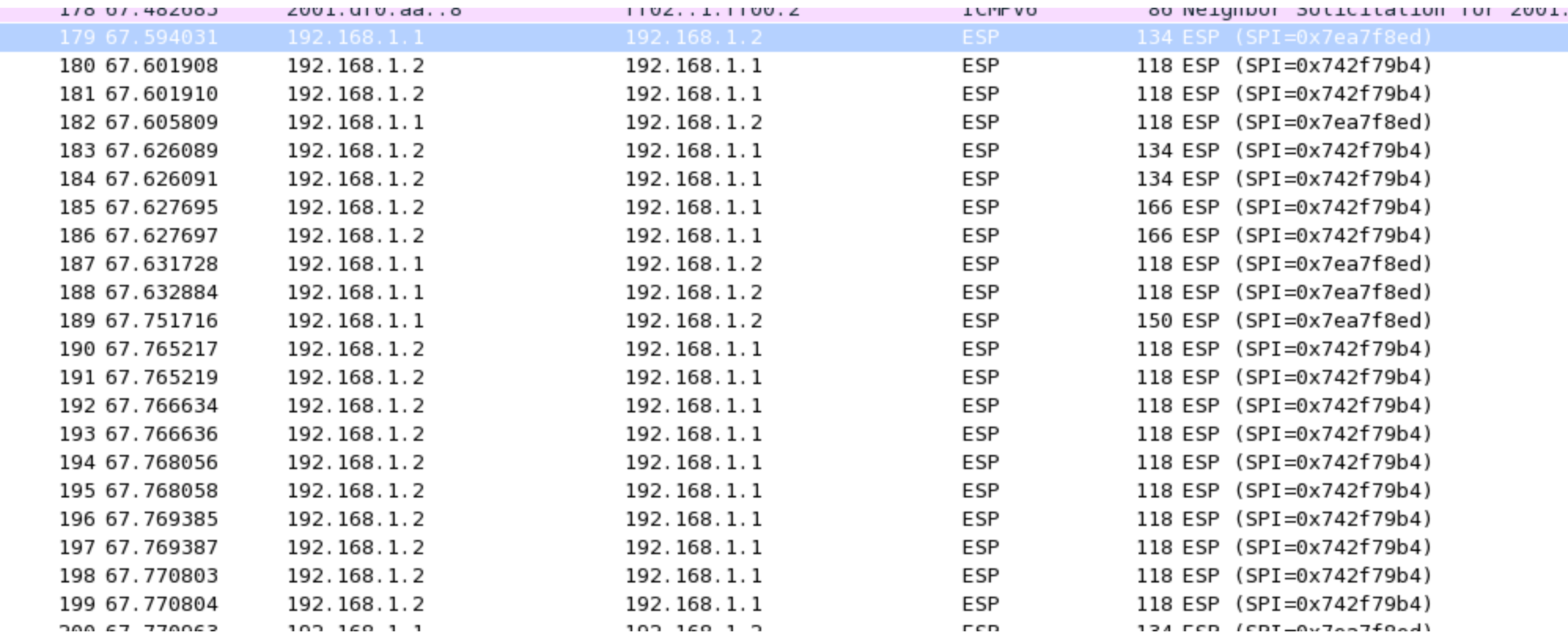


```
..... .....!.......................P....

User Access Verification

Password: .. ..!..!........ apn.......apnic2

router2>

router2>

router2>

router2>eenn

% No password set
router2>

router2>

router2>

router2>

router2>

router2>

router2>

router2>

router2>sshh  iipp  ??
  accounting              The active IP accounting database
```



```
router2>sshh  iipp  ??
  accounting              The active IP accounting database
  admission               Network Admission Control information
  aliases                 IP alias table
  arp                     IP ARP table
  as-path-access-list     List AS path access lists
  auth-proxy              Authentication Proxy information
  bgp                     BGP information
  cache                   IP fast-switching route cache
  casa                    display casa information
  cef                     Cisco Express Forwarding
  ddns                    Dynamic DNS
  dfp                     DFP information
  dhcp                    Show items in the DHCP database
  dvmrp                   DVMRP information
  eigrp                   IP-EIGRP show commands
  extcommunity-list       List extended-community list
  flow                    NetFlow switching
  helper-address          helper-address table
  host-list               Host list
  http                    HTTP information
  igmp                    IGMP information
  inspect                 CBAC (Context Based Access Control) information
 --More-- ..........        .........
router2>sh ip .. ... ... .iipp  iinntt.
router2>sh ip interface ??
  Async                 Async interface
  BVI                   Bridge-Group Virtual Interface
  CDMA-Ix               CDMA Ix interface
  CTunnel               CTunnel interface
  Dialer                Dialer interface
```

Capture: Telnet + IPsec



```
178 67.482683   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)
```

SSL/TLS

- Most widely-used protocol for security
- Encrypts the segments of network connections above the Transport Layer
- SSL and TLS
  - SSL v3.0 specified in an I-D in 1996 (draft-freier-ssl-version3-02.txt)
  - TLS v1.0 specified in RFC 2246 in 1999
  - TLS v1.0 = SSL v3.1 ≈ SSL v3.0
  - TLS v1.1 in 2006
  - TLS v1.2 in 2008
- Goals of protocol
  - Secure communication between applications
  - Data encryption
  - Server authentication
  - Message integrity
  - Client authentication (optional)

Some Applications Using TLS/SSL

- Securing WWW traffic (HTTPS)
- Browsers Apache
  - Apache_mod_ssl
- DNSSEC requires SSL
- Postfix, Sendmail, SMTP
- sTelnet
- OpenSSH
- SFTP
- SSL VPNs such as OpenVPN and OpenConnect
- VoIP and SIP signaling
- EAP-TLS for wifi

http://www.openssl.org/related/apps.html

Benefits of TLS

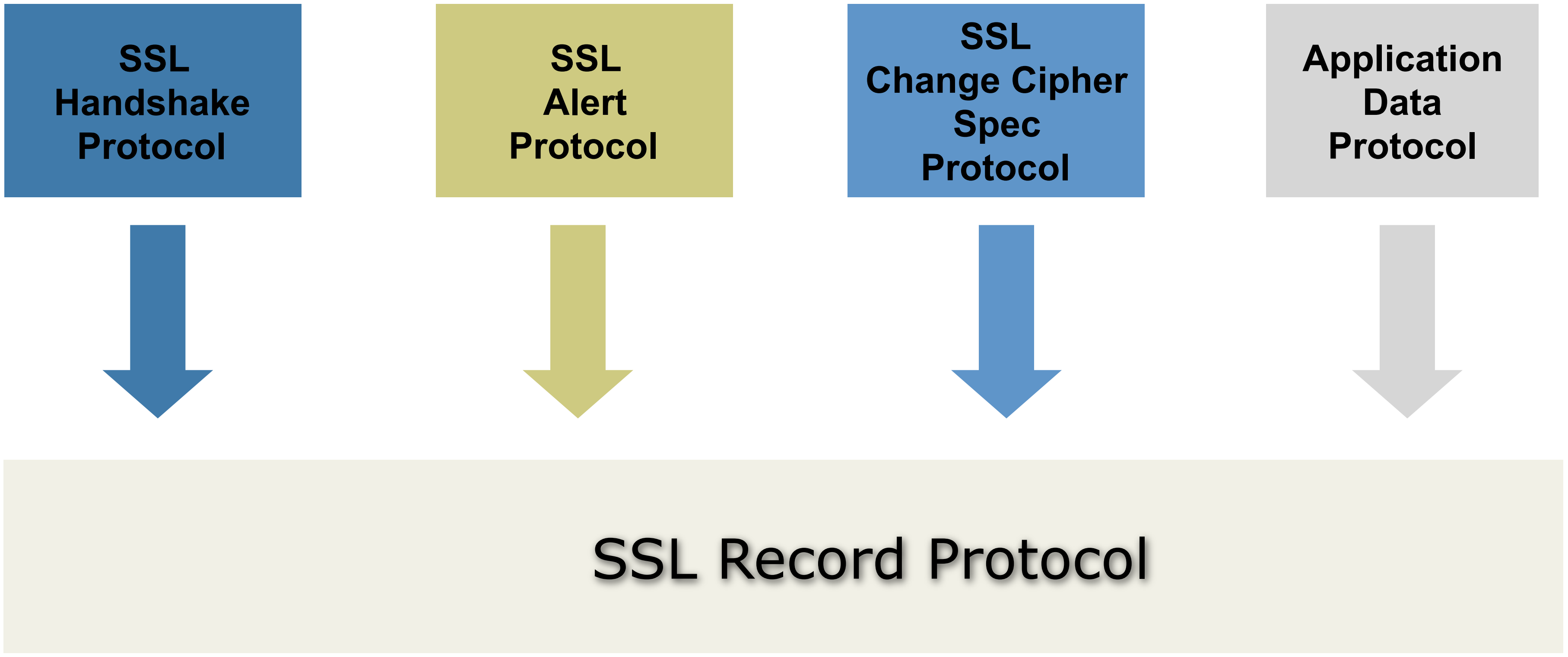
- Application-layer independent
  - can be implemented with any applications
  - a wide range of applications supporting it
- SSL makes use of both asymmetric and symmetric key cryptography.
  - performance reasons.
  - Only the initial "client key exchange message" is encrypted with asymmetric encryption.
  - Symmetric encryption is better in terms of performance/speed
- Uses X.509 certificates
  - Certificates and Public Key Infrastructure
- SSL protocol layers comes on top of TCP (transport Layer), and is below application layer.
  - no network infrastructure changes are required to deploy SSL
- Each and every connection that's made, through SSL has got one session information.
  - Session can also be reused or resumed for other connections to the server

SSL/TLS Properties

- Connection is private
  - Encryption is used after an initial handshake to define a secret key.
  - Symmetric cryptography used for data encryption
- Peer's identity can be authenticated
  - Asymmetric cryptography is used (RSA or DSS)
- Connection is reliable
  - Message transport includes a message integrity check using a keyed MAC.
  - Secure hash functions (such as SHA and MD5) are used for MAC computations.

SSL Protocol Building Blocks

SSL is a Combination of a Primary Record Protocol with Four 'Client' Protocols



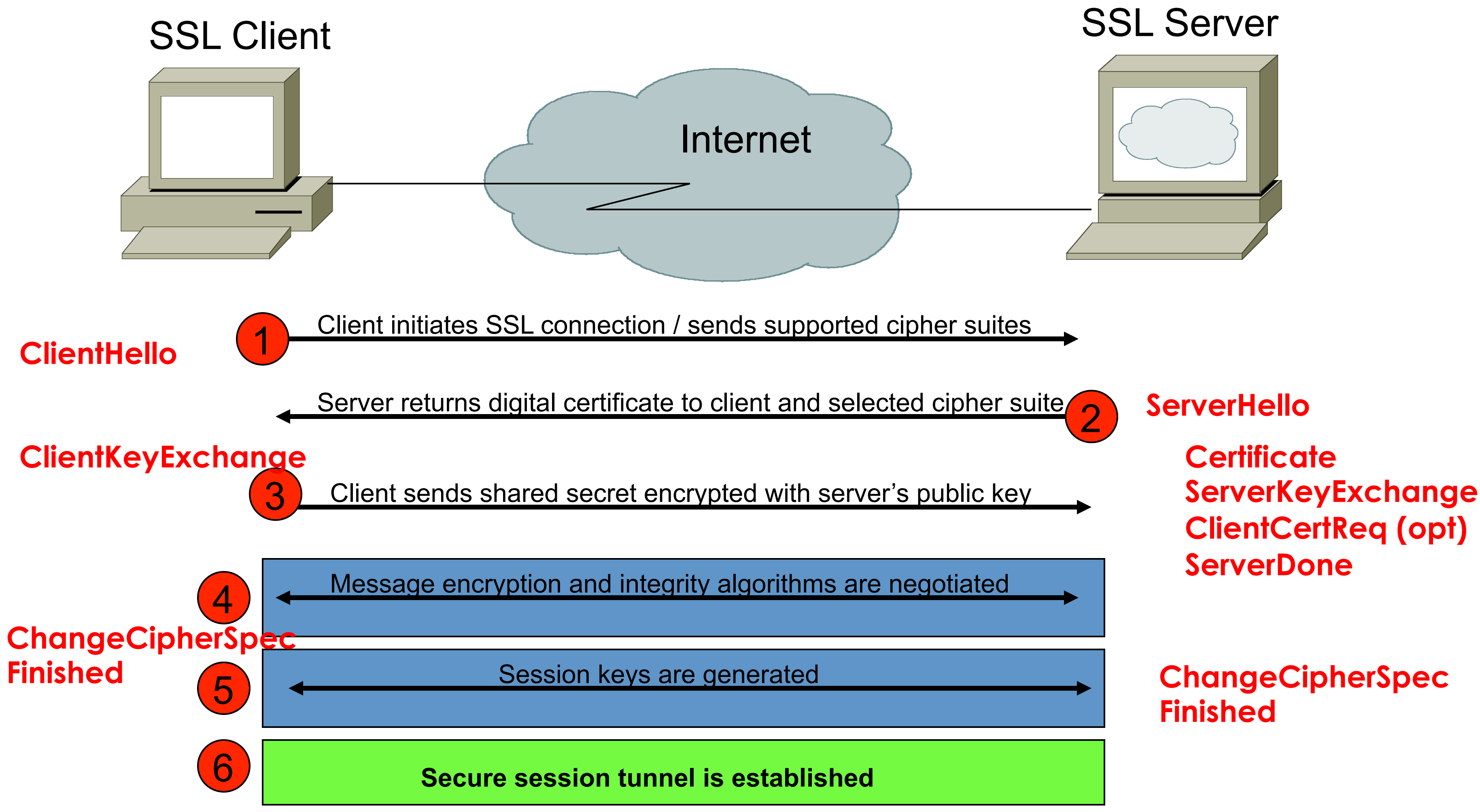
SSL Protocol Building Block Functions

SSL Handshake Protocol	Negotiates crypto algorithms and keys
SSL Alert Protocol	Indicates error or the end of a session
SSL Change Cipher Spec Protocol	Used to Signal Transition to New Cipher and Keys Generally Towards the End of a Handshake Negotiation
SSL Record Protocol	Indicates which encryption and integrity protection is applied to the data

SSL Record Layer

- provides fragmentation, compression, integrity protection, and encryption for data objects exchanged between clients and servers
- Maintains a <u>current</u> and a <u>pending</u> connection state
- Upper Layer ➔ TLSPlaintext ➔ TLSCompressed ➔ TLSCiphertext ➔ (send to transport)

The SSL Handshake Process


SSL Client
SSL Server
Internet
ClientHello
1
Client initiates SSL connection / sends supported cipher suites
Server returns digital certificate to client and selected cipher suite
2
ServerHello
ClientKeyExchange
Certificate
ServerKeyExchange
ClientCertReq (opt)
ServerDone
3
Client sends shared secret encrypted with server's public key
4
Message encryption and integrity algorithms are negotiated
ChangeCipherSpec
Finished
5
Session keys are generated
ChangeCipherSpec
Finished
6
Secure session tunnel is established

<- Application Data ->

SSL version, Random data (ClientHello.random), sessionID, cipher suits, compression algorithm

Client computes the premaster key

SSL version, Cipher suits, Random data (ServerHello.random), session ID

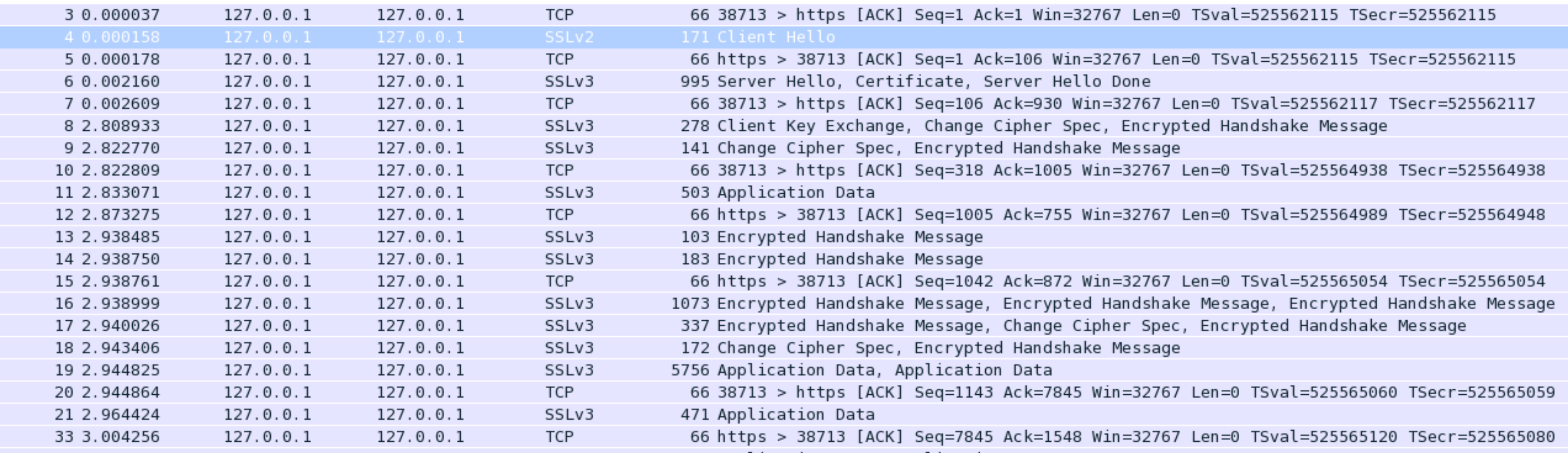
SSL Client Authentication

- Client authentication (certificate based) is optional and not often used
- Many application protocols incorporate their own client authentication mechanism such as username/password or S/Key
- These authentication mechanisms are more secure when run over SSL

SSL/TLS IANA Assigned Port #s

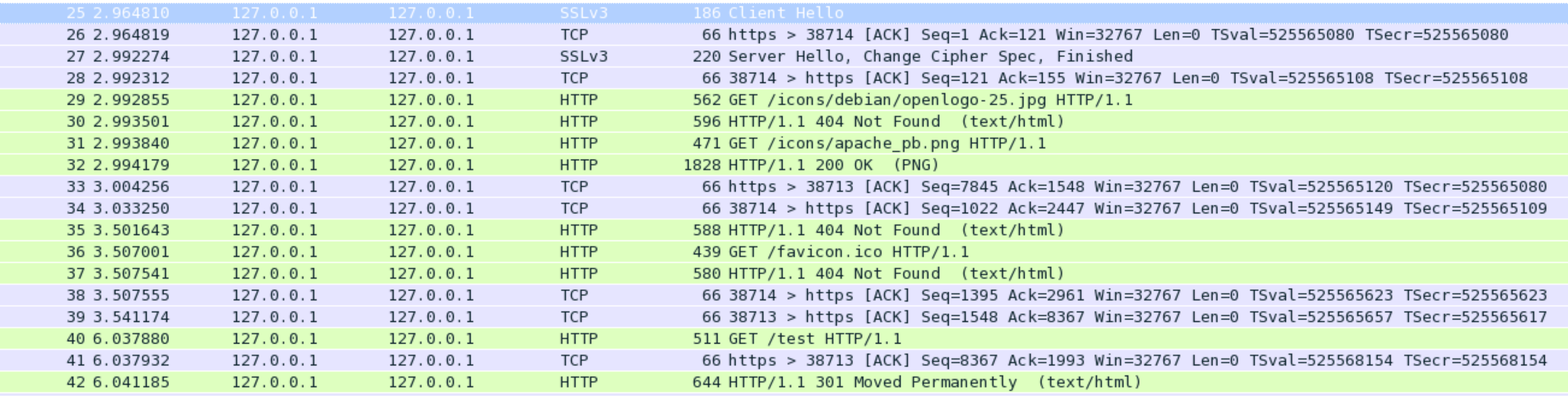
Protocol	Defined Port Number	SSL/TLS Port Number
HTTP	80	443
NNTP	119	563
POP	110	995
FTP-Data	20	989
FTP-Control	21	990
Telnet	23	992

Capture: SSL Decryption (easy)



```
 3 0.000037   127.0.0.1   127.0.0.1   TCP      66 38713 > https [ACK] Seq=1 Ack=1 Win=32767 Len=0 TSval=525562115 TSecr=525562115
 4 0.000158   127.0.0.1   127.0.0.1   SSLv2   171 Client Hello
 5 0.000178   127.0.0.1   127.0.0.1   TCP      66 https > 38713 [ACK] Seq=1 Ack=106 Win=32767 Len=0 TSval=525562115 TSecr=525562115
 6 0.002160   127.0.0.1   127.0.0.1   SSLv3   995 Server Hello, Certificate, Server Hello Done
 7 0.002609   127.0.0.1   127.0.0.1   TCP      66 38713 > https [ACK] Seq=106 Ack=930 Win=32767 Len=0 TSval=525562117 TSecr=525562117
 8 2.808933   127.0.0.1   127.0.0.1   SSLv3   278 Client Key Exchange, Change Cipher Spec, Encrypted Handshake Message
 9 2.822770   127.0.0.1   127.0.0.1   SSLv3   141 Change Cipher Spec, Encrypted Handshake Message
10 2.822809   127.0.0.1   127.0.0.1   TCP      66 38713 > https [ACK] Seq=318 Ack=1005 Win=32767 Len=0 TSval=525564938 TSecr=525564938
11 2.833071   127.0.0.1   127.0.0.1   SSLv3   503 Application Data
12 2.873275   127.0.0.1   127.0.0.1   TCP      66 https > 38713 [ACK] Seq=1005 Ack=755 Win=32767 Len=0 TSval=525564989 TSecr=525564948
13 2.938485   127.0.0.1   127.0.0.1   SSLv3   103 Encrypted Handshake Message
14 2.938750   127.0.0.1   127.0.0.1   SSLv3   183 Encrypted Handshake Message
15 2.938761   127.0.0.1   127.0.0.1   TCP      66 https > 38713 [ACK] Seq=1042 Ack=872 Win=32767 Len=0 TSval=525565054 TSecr=525565054
16 2.938999   127.0.0.1   127.0.0.1   SSLv3  1073 Encrypted Handshake Message, Encrypted Handshake Message, Encrypted Handshake Message
17 2.940026   127.0.0.1   127.0.0.1   SSLv3   337 Encrypted Handshake Message, Change Cipher Spec, Encrypted Handshake Message
18 2.943406   127.0.0.1   127.0.0.1   SSLv3   172 Change Cipher Spec, Encrypted Handshake Message
19 2.944825   127.0.0.1   127.0.0.1   SSLv3  5756 Application Data, Application Data
20 2.944864   127.0.0.1   127.0.0.1   TCP      66 38713 > https [ACK] Seq=1143 Ack=7845 Win=32767 Len=0 TSval=525565060 TSecr=525565059
21 2.964424   127.0.0.1   127.0.0.1   SSLv3   471 Application Data
33 3.004256   127.0.0.1   127.0.0.1   TCP      66 https > 38713 [ACK] Seq=7845 Ack=1548 Win=32767 Len=0 TSval=525565120 TSecr=525565080
```

Using stolen key file



```
25 2.964810   127.0.0.1   127.0.0.1   SSLv3   186 Client Hello
26 2.964819   127.0.0.1   127.0.0.1   TCP      66 https > 38714 [ACK] Seq=1 Ack=121 Win=32767 Len=0 TSval=525565080 TSecr=525565080
27 2.992274   127.0.0.1   127.0.0.1   SSLv3   220 Server Hello, Change Cipher Spec, Finished
28 2.992312   127.0.0.1   127.0.0.1   TCP      66 38714 > https [ACK] Seq=121 Ack=155 Win=32767 Len=0 TSval=525565108 TSecr=525565108
29 2.992855   127.0.0.1   127.0.0.1   HTTP    562 GET /icons/debian/openlogo-25.jpg HTTP/1.1
30 2.993501   127.0.0.1   127.0.0.1   HTTP    596 HTTP/1.1 404 Not Found  (text/html)
31 2.993840   127.0.0.1   127.0.0.1   HTTP    471 GET /icons/apache_pb.png HTTP/1.1
32 2.994179   127.0.0.1   127.0.0.1   HTTP   1828 HTTP/1.1 200 OK  (PNG)
33 3.004256   127.0.0.1   127.0.0.1   TCP      66 https > 38713 [ACK] Seq=7845 Ack=1548 Win=32767 Len=0 TSval=525565120 TSecr=525565080
34 3.033250   127.0.0.1   127.0.0.1   TCP      66 38714 > https [ACK] Seq=1022 Ack=2447 Win=32767 Len=0 TSval=525565149 TSecr=525565109
35 3.501643   127.0.0.1   127.0.0.1   HTTP    588 HTTP/1.1 404 Not Found  (text/html)
36 3.507001   127.0.0.1   127.0.0.1   HTTP    439 GET /favicon.ico HTTP/1.1
37 3.507541   127.0.0.1   127.0.0.1   HTTP    580 HTTP/1.1 404 Not Found  (text/html)
38 3.507555   127.0.0.1   127.0.0.1   TCP      66 38714 > https [ACK] Seq=1395 Ack=2961 Win=32767 Len=0 TSval=525565623 TSecr=525565623
39 3.541174   127.0.0.1   127.0.0.1   TCP      66 38713 > https [ACK] Seq=1548 Ack=8367 Win=32767 Len=0 TSval=525565657 TSecr=525565617
40 6.037880   127.0.0.1   127.0.0.1   HTTP    511 GET /test HTTP/1.1
41 6.037932   127.0.0.1   127.0.0.1   TCP      66 https > 38713 [ACK] Seq=8367 Ack=1993 Win=32767 Len=0 TSval=525568154 TSecr=525568154
42 6.041185   127.0.0.1   127.0.0.1   HTTP    644 HTTP/1.1 301 Moved Permanently  (text/html)
```

Attacks on SSL (a little harder…)

- BEAST Attack (2011)
  - Browser Exploit Against SSL/TLS
  - CBC vulnerability discovered in 2002
  - Fixed in TLS 1.1
- CRIME Attack (2012)
  - Compression Ratio Info-leak Made Easy
  - Exploit against TLS compression
  - ‘fixed’ by disabling TLS Compression
- BREACH Attack (2013)
  - Browser Reconnaissance and Exfiltration via Adaptive Compression of Hypertext
  - Presented at BlackHat 2013 (Aug)
  - Attacks HTTP responses using HTTP Compression

Encrypted Communications

- Use encrypted communications whenever you need to keep information confidential
- Verify via network sniffer (e.g. wireshark) that your communication is indeed encrypted
- An important aspect is credential management (creating, distributing, storing, revoking, renewing)
- Understand if/when credentials are lost that you may not be able to recover the data
- Have a plan in place in case you forget your password that protects your private keys

Thank You. Questions?