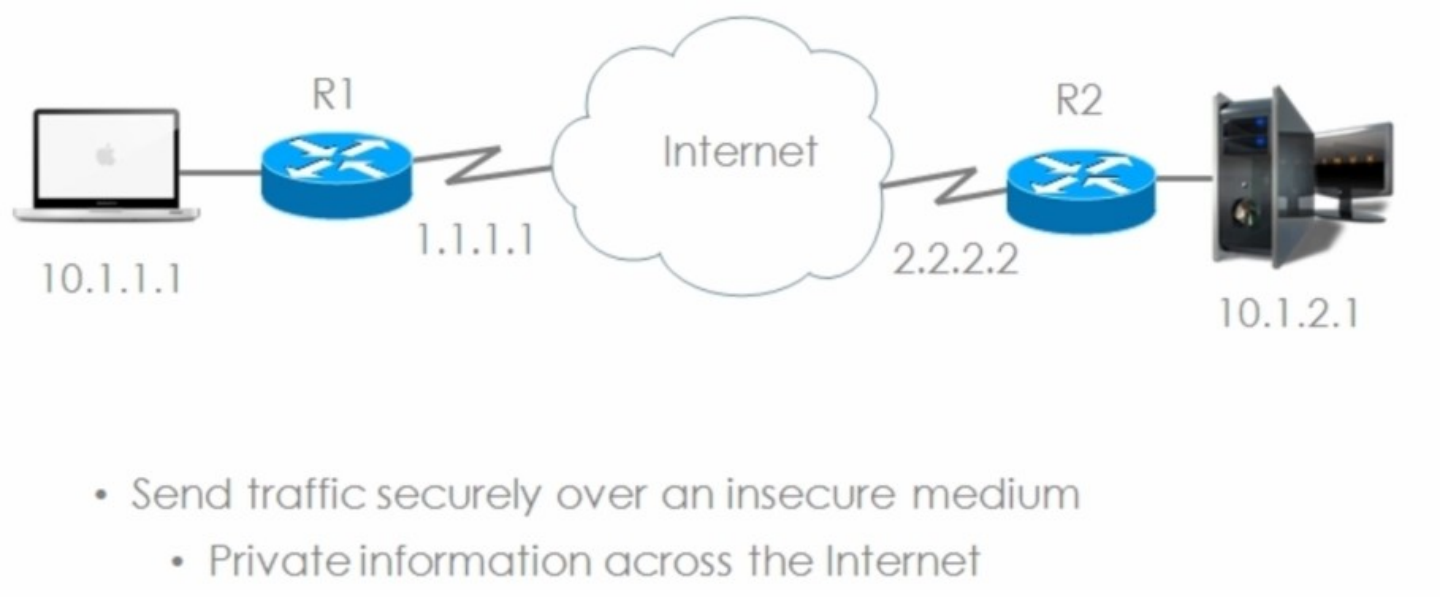
Virtual Private Networks (VPNs)
VPN solutions allow for secure access across insecure medium (e.g. the internet) allowing for the connection of branch offices, home offices, business partners, and remote tele-commuters to all or a part of a corporate network

VPNs have help reduce network costs by allowing for secure connections thru broadband technologies

These days VPNs can transport mission critical data, VOIP, client-server applications without compromising quality or security.



Instead of using a dedicated connection (leased line) we are able to use the public internet to send private data via an encrypted tunnel from one private network to another

Cryptography Terminology

- Algorithm
  - Detailed steps for performing a function
- Cipher
  - An encryption algorithm
- Asymmetric algorithm
  - An algorithm in which different keys are used for encryption and decryption.
  - Public key algorithms are asymmetric
- Symmetric algorithm
  - An algorithm in which the same key is used for encryption and decryption.
  - Secret key algorithms are symmetric

- A key
  - Is a bit of information that is required to decrypt the message, usually in the form of a value that is used with a cipher to encrypt the message
  - The key must be kept secret in order for the message to remain private

- The algorithm is well known
  - Can read about it in books, web etc
  - AES / 3DES / DES

- Key is secret

- Together they make the data unique

What are we trying to accomplish?

- Data Confidentiality
  - No one else should be able to read the information by manipulating the data
  - Provided by data encryption and keys
- Data Integrity
  - Know that the data has traversed unchanged between the two parties
- Data Origin Authentication
  - The receiver can verify that the protected data could only have originated from the sender
- Antireplay protection
  - Verify that each packet is unique and not duplicated

Keylength / Keyspace

- An algorithm's keyspace is the set of all possible values
- N-bit keys produce 2^n keyspace size
- Class A address = 32 bits
  - Network = 8 bits
  - Host = 24 bits
  - Gives you 2^{24} options = 16,777,216 hosts

Symmetrical algorithm

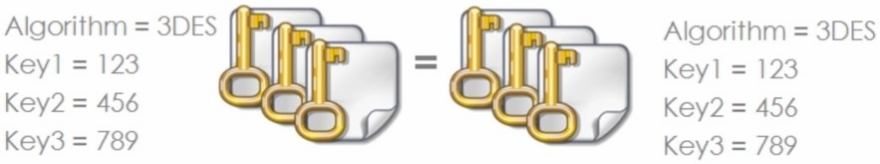
- The same key is used to encrypt and decrypt the message
- Both the sender and receiver must have the same key
  - We will need to communicate this out of band
- Good symmetric ciphers are fast, secure and easy to implement using modern microprocessors
- DES, 3DES, AES, Blowfish

Out of band means through a separate communication source / medium (like calling to say what the key will be)

DES

- IBM and the US National Security Agency cooperated to develop this cipher in 1975
- Fixed Key Length = 56bits
- The algorithm is very good, but the key length isn't (susceptible to brute force attacks)

3DES



- Encrypt with key 1
- Decrypt with key 2
- Encrypt with key 3
- K1 = K3, 112 bit key length
- K1 <> K3, 168 bit key length

AES

Algorithm = AES
Key = 123

=

Algorithm = AES
Key = 123

- AES 128
- AES 192
- AES 256

Asymmetrical algorithm

Algorithm = RSA
Key = 123

Algorithm = RSA
Key = 456

- Asymmetrical ciphers uses a different key to decrypt than was used to encrypt
- Solves many long standing problems like how to exchange the secret keys in the first place
  - Solves: How do we send the decided private key to each other without it being intercepted?
  - Solves: Without a secure channel, there is no way to establish a secure channel
- Long key lengths of 512 to 2048 bits

Asymmetrical algorithm

A

Algorithm = RSA
Key = 123

B

Algorithm = RSA
Key = 456

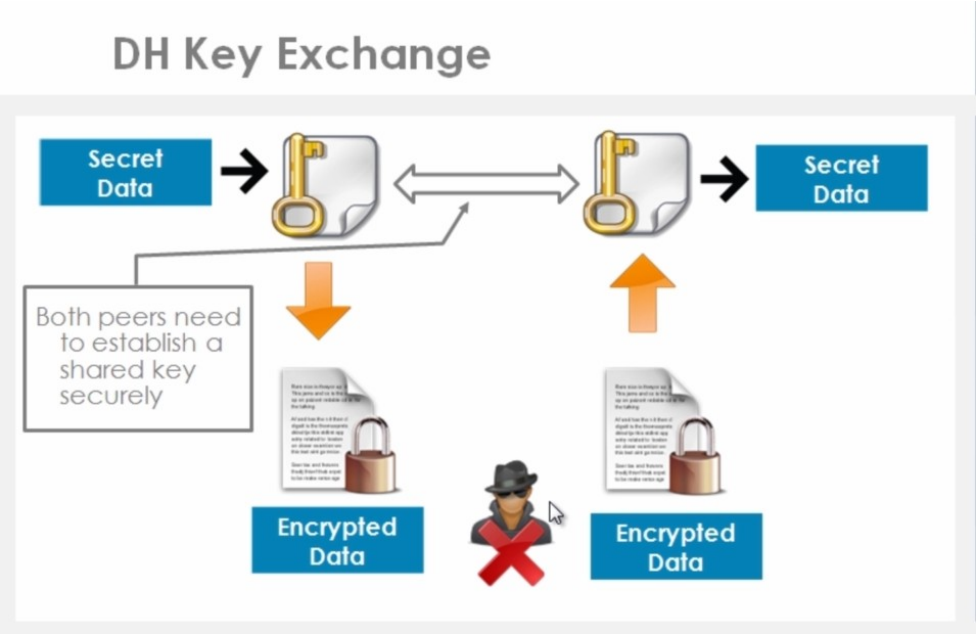
- You can tell the world your public key
- But you tell no one your private key
- Something encrypted with your private key can only be decrypted with your public key
- Something encrypted with your public key can only be decrypted with your private key

Diffie Hellman (DH)

- In 1976, Wilfred Diffie and Martin Hellman discovered a way out of the secure channel dilemma
- Found out that by using a different key, certain one-way functions could be undone
- Their solution called public key cryptography takes advantage of a characteristic of prime and almost prime number –specifically how hard it is to find the two factors of a large number that has only two factors, both of which are prime.

Why Diffie Hellman Works

- Peers yield a shared secret based on other peer's public value and own secret
  - You need at least one secret value to perform this calculation
- Attacker has no secret values and needs to perform a discrete logarithm of a public value
  - This is computationally infeasible



Both peers need to establish a shared key securely and Diffie Hellman gives us a secure way to do this. By using Public Key Cryptography (Private + Public Keys) we can work out a shared secret, securely, without others being able to see that. When two peers want to setup their VPN, they use Diffie Hellman to work out a shared key. They use a shared key because symmetric key algorithms (DES,3DES,AES) require that the same key be used on both sides. The reason we use AES is that it is good for bulk encryption. Once a Diffie Hellman key exchange has taken place, we can create a shared secret for AES and therefore AES and the shared key can be used for bulk encryption of our data, which can be sent across the insecure internet securely and only be decrypted by the receiving party.

Diffie Hellman types/forms

DH1 – 768 bits
DH2 – 1024 bits
DH5 – 1536 bits

The longer the key length the more secure the algorithm, down to this is more CPU required

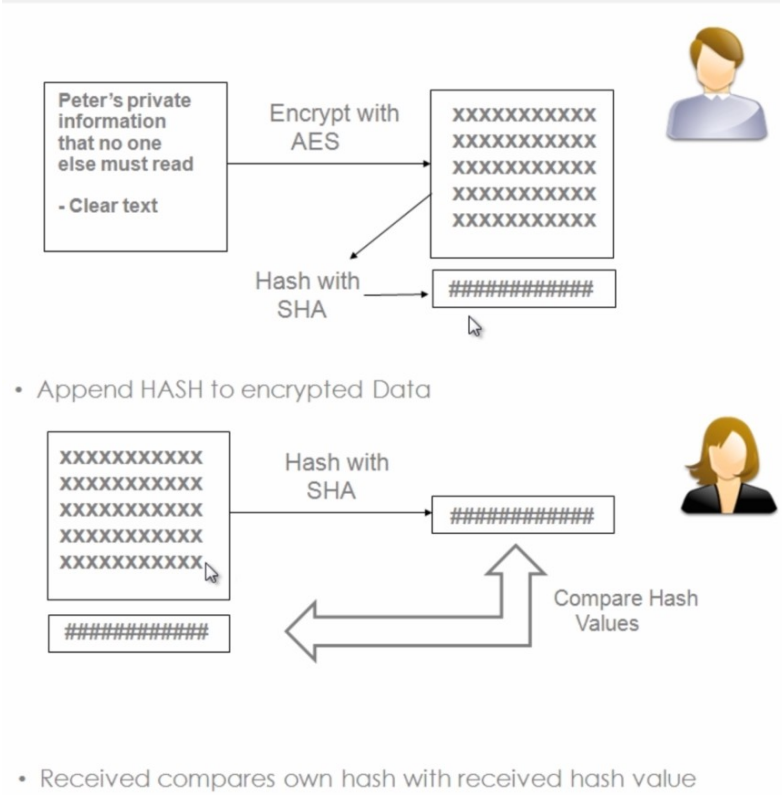
Integrity

- Ensure that data has not been tampered with
- Know that the data has traversed unchanged between the two parties
- Hash, trap-door, digest
- One way
- Converts to a fixed length hash – MD5 = 128 bits
- Not reversible – lost value
- Hash will change if input value changes

When hashing, you take data of an arbitrary length, run it through MD5 hashing algorithm, and yield a 128 bit value (MD5). The process cannot be reversed (thus it is a one-way function)

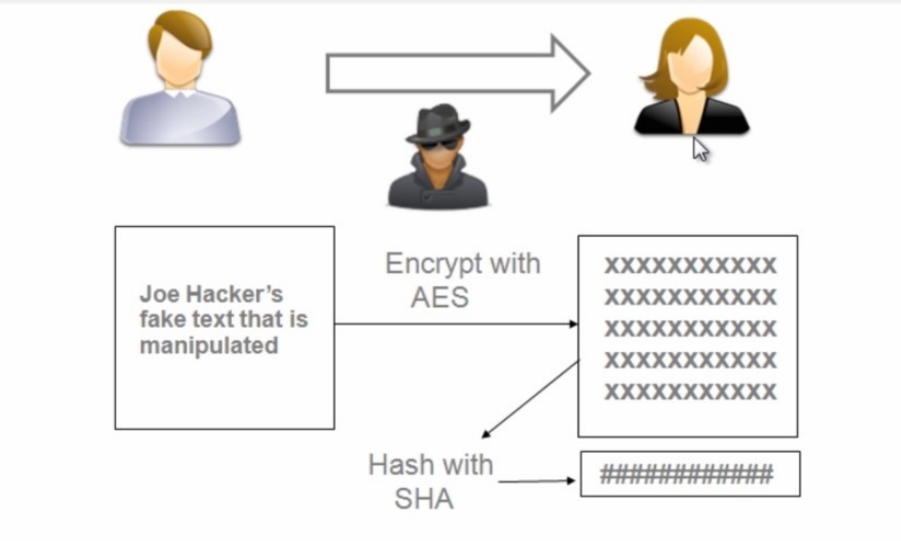
Hashing Algorithms
MD5 – 128 bits
SHA-1 = 160 bits
SHA-2 – 256 / 512 bits
SHA-3 – released in 2015

Data Confidentially – through encryption algorithm (AES)
Data Integrity – through hashing algorithm (SHA-1) and HMAC (Hashing Message Auth Code)



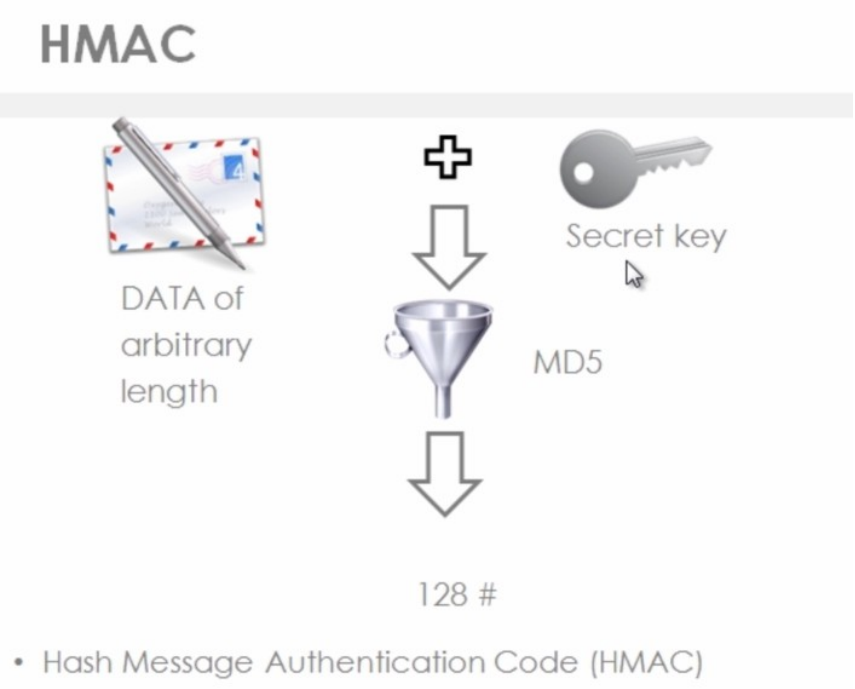
- Received compares own hash with received hash value

If hashes are the same – confirmed data integrity
Only after verifying the hash would recipient decrypt



What would prevent an attacker between the parties from removing the appended hash and replacing the encrypted message and hash with their own data? Should the 2nd party hash the data and compare values, they would have no way of knowing the data integrity was not correct, as the hash would match.

To fix this issue, we use HMAC (Hash Message Authentication Code)



Two Variants of HMAC

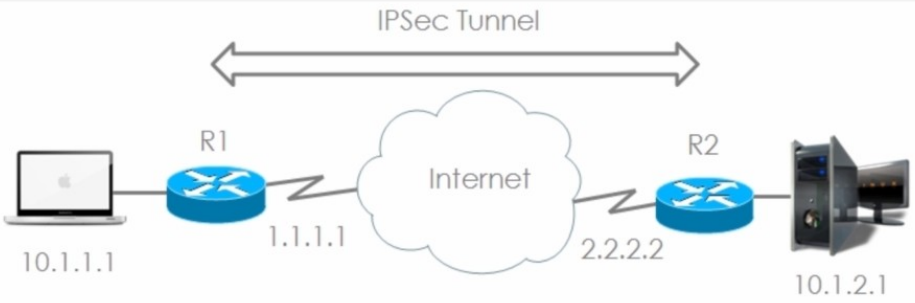
1. HMAC-MD5
2. HMAC-SHA

Sender 1 takes the data (of arbitrary length) and a "secret key". The hacker will not know what the secret key is, as such when he hashes the data, the Receipt will know the data has been manipulated as the hashes will not match unless hashed with the same HMAC key.

Authentication

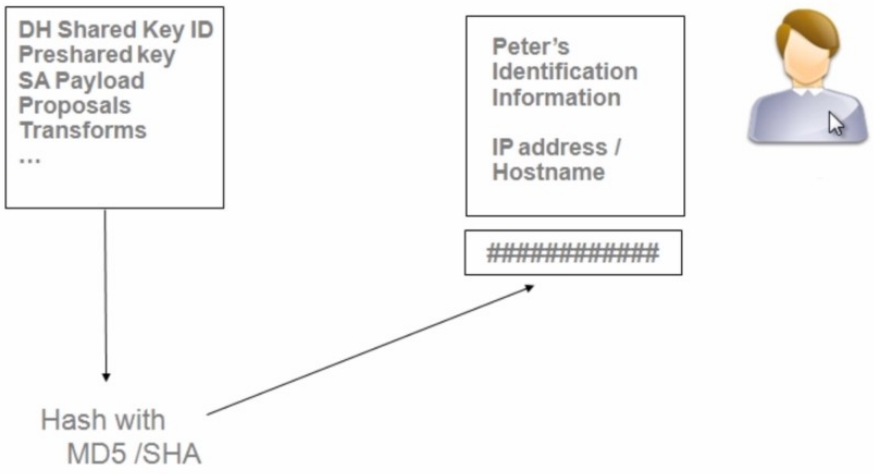
- Knowing that data received is the same data that was sent and that the claimed sender is in fact the actual sender
- Goes beyond validating the source attempting to access a service during initial logon
- You should also validate that the source has not been replaced by an attacking host in the course of the conversation (session hijacking)

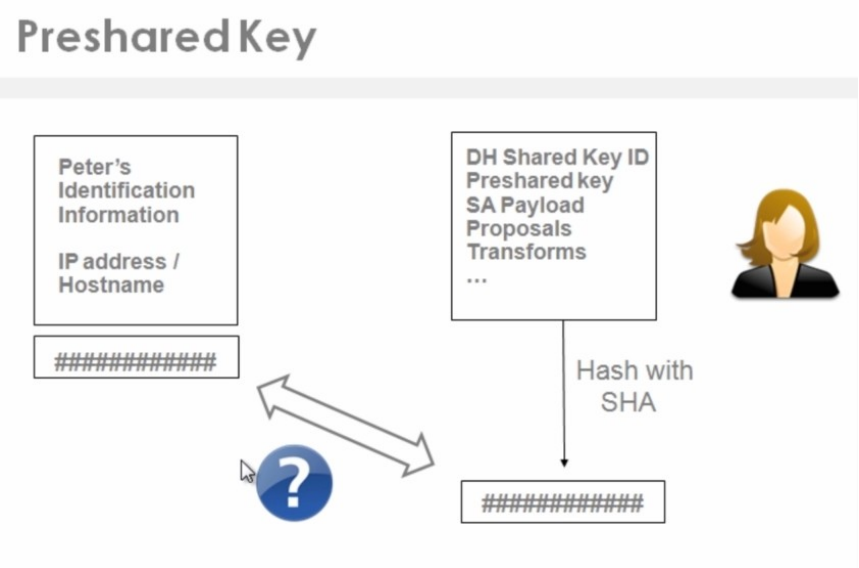
Authentication

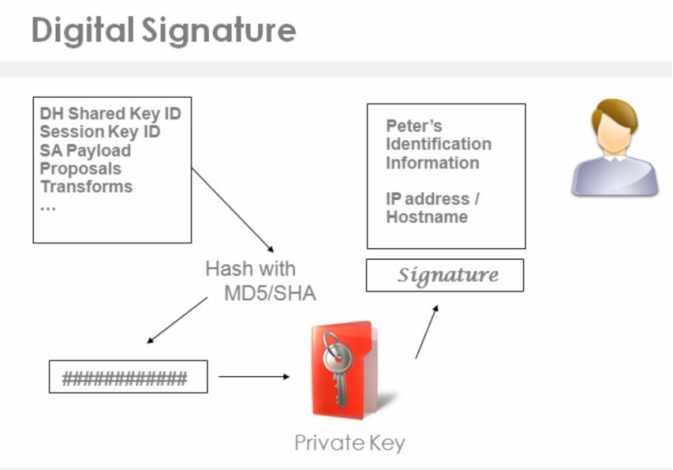


- Pre shared Key (PSK)
  - A secret key value is entered into each peer manually and is used to authenticate the peer
- RSA Signatures
  - Encrypt the hash with a private key

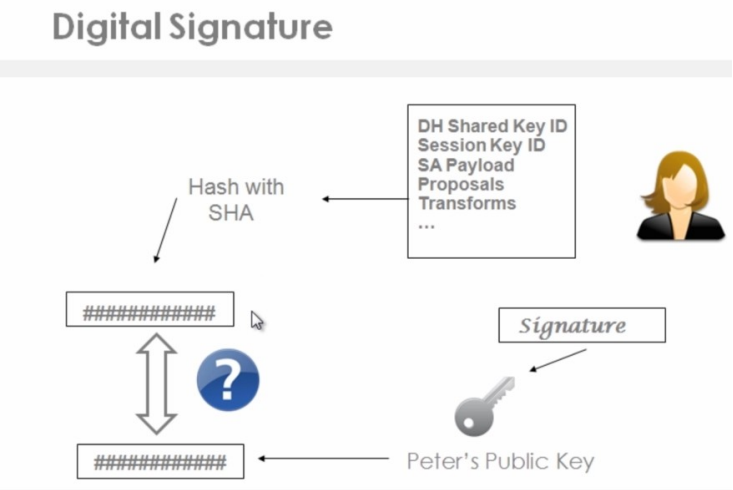
Preshared Key



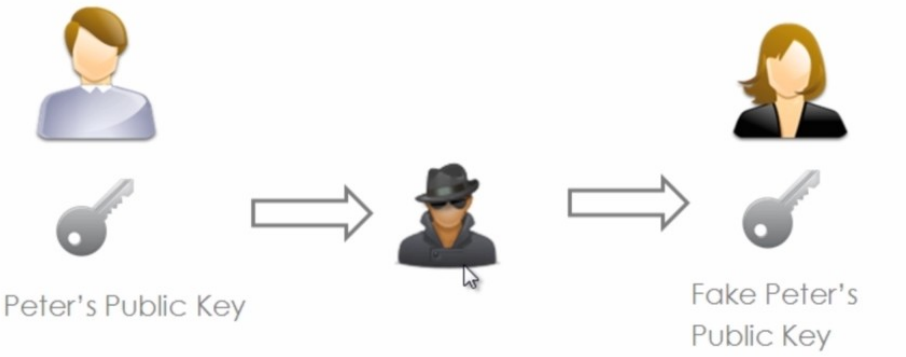




A digital signature is created when info is encrypted with a private key. Remember when something is encrypted with a private key, only that person's public key is able to decrypt it



Certificate of authority



IPSec

IP Security is a network layer protocol (actually a suite of protocols) that protects and authenticates IP Packets

It is a Framework of open standards that is algorithm independent. (thus can use multiple algorithms)

IPsec requires dedicated software installed on client hosts.

3 Main IPSec Protocols

- IKE (Internet Key Exchange)
  - Provides a framework for negotiating security parameters and establishing authenticated keys
- AH (Authentication Header)
  - No encryption
  - Provides Authentication
  - Provides Integrity
- ESP (Encapsulating Security Payload)
  - Encryption
  - Authentication
  - Integrity

IPSec uses two distinct protocols:

Authentication Header (AH) and Encapsulating Security Payload (ESP), which are defined by the IETF.

AH: Only offers **a*uthentication*** (data integrity, data origin authentication, and optional replay protection).

- Data integrity is ensured by using a message digest algorithm (HMAC-MD5 / HMAC-SHA)
- Data origin authentication is ensured by using a shared secret key to create the message digest
- Replay protection is provided by using a sequence number field within the AH header.
- AH-style authentication authenticates the entire IP packet
- AH authenticates IP headers and their payloads.

ESP: ***Data confidentiality*** (encryption) and ***authentication*** (data integrity, data origin, and replay protection)

- ESP can be used with confidentiality only, authentication only, or both
- Authentication functions use the same algorithms as AH, but the coverage is different
- ESP authentication mechanism authenticates only the IP datagram portion of the IP packet

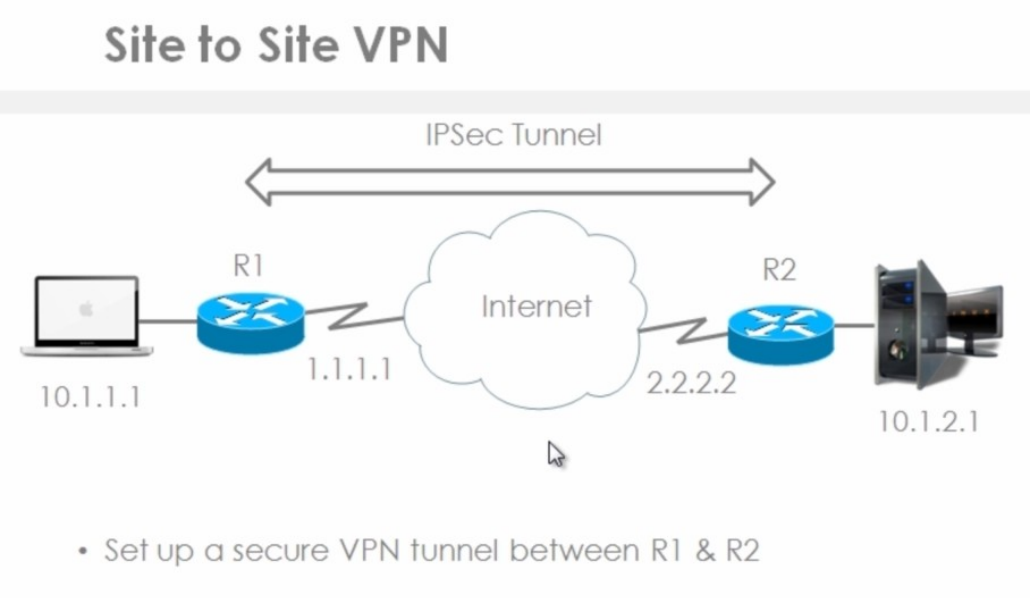
IPSec Modes

Transport Mode

- The original IP header of the packet being encrypted is used to transport the packet

Tunnel Mode

- The original IP header is not used to transport the packet
- A new IP header is tagged in front
  - IP addresses of peer devices, not originating host and destination host



This an example of a Site-to-site VPN and we are going to use ESP with Tunnel Mode.

The IPSec tunnel goes between two internet facing routers (R1 and R2)

IP Headers for Macbook (the left) SA: 10.1.1.1 DA: 10.1.2.1

When that traffic is sent through the IPSec Tunnel, the data and IP headers are encrypted (thus non-readable across the open internet). An ESP header is tagged onto the front, as well as a new SA and DA (SA = R1's IP and DA = R2's IP)

When Router 2 receives those encypted packets, R2 will strip off the outside headers, then decrypt the packet, and then send the original packet on to the Server at 10.1.2.1

IPSec Framework

IPSec Protocol

- ESP or AH or ESP and AH

IPSec Mode

- Transport or Tunnel
  (If the devices setting up the VPN are not the actual devices communicating, you need to use Tunnel Mode)
  In the example above R1 and R2 are not the source and destination of the actual traffic, therefore use Tunnel

Encryption

- DES or 3DES or AES (use AES, much stronger)

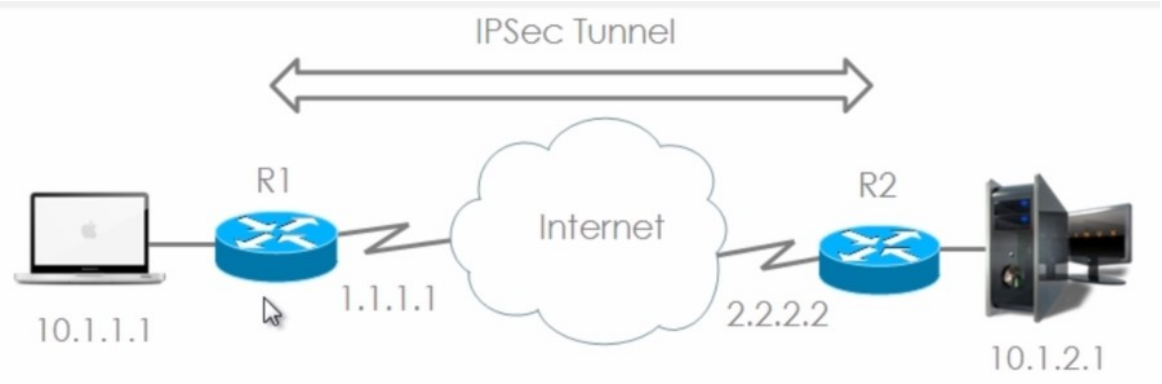
Authentication / Integrity

- MD5 or SHA
- Pre-Shared Keys or Digital Signatures (i.e. Certificates)
- Digital Certificates are harder to implement, but provide much better scalability

Diffie Hellman (DH)

- DH1 or DH2 or DH5

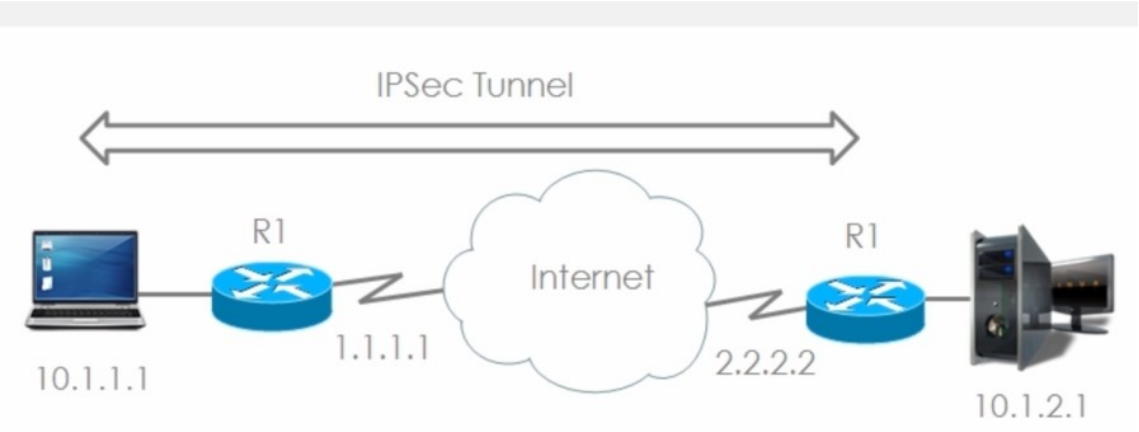
Site to Site VPN



Set up a secure VPN tunnel between R1 and R2, the advantage of this is that the devices (MacBook and server) do not need to run any encryption software. From the point of view of the MacBook (10.1.1.1) and Server (10.1.2.1), it is as if a leased-line exists, directly connecting the two LANs.

Because IPsec runs at the network level of the OSI model, it can encrypt all higher layer protocols.

Remote Access IPSec VPN



Sett up a secure VPN tunnel between PC and R2

PC uses software (such as Cisco VPN Client) IPsec requires dedicated software installed on client hosts.

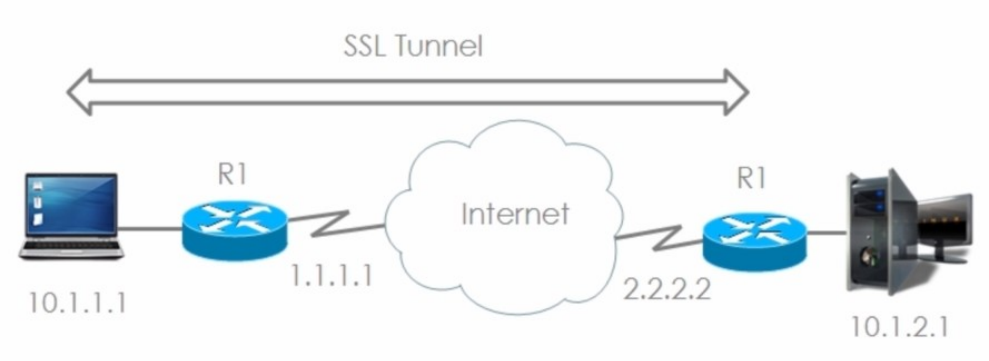
Advantage

User can be roaming, does not need to be on R1's LAN (as would be required in a site to site VPN), rather the user can be on any network and has the information necessary to call home to R2 and join R2's LAN.

Disadvantage

You would have to install the VPN client on the remote device, so it is not clientless

Remote Access TLS/SSL VPN



Set up as a secure VPN tunnel between the PC and R2

No PC software is required TLS can just use your browser

Advantage: Allows you to connect to the HQ router (R2) without installing any software.

Which devices Support VPNs

- Cisco Routers
- ASA
- Certicom client
- VPN 3002 hardware client (legacy)
- Cisco VPN software Client
- AnyConnect Client (can be downloaded automatically when connecting via an SSL VPN)

VPN Benefits

- Cost savings
- Security (encryption, authentication, data integrity, non-repudiation, anti-replay protection)
- Scalability
- Compatibility with Broadband

IPSEC vs TLS

IPsec can encrypt the entire IP packet, while TLS encrypts only the application level data

IPsec employs Internet Key Exchange (IKE) version 1 or version 2, using digital certificates or preshared secrets for two-way authentication.

Preshared secrets is the single most secure way to handle secure communications but is also the most management-intensive.

TLS is newer

SSL/TLS web servers always authenticate with digital certificates, no matter what method is used to authenticate the user.

IPsec requires a software client installed, as well as a specific configuration on the VPN server, which makes it a worse choice than TLS to encrypt traffic to resources external to the organization. TLS needs only the browser.