Lecture 19
Security - Technology

Peter Steenkiste

School of Computer Science

Carnegie Mellon University

15-441 Networking

Mutilated by Dave Eckhardt, Fall 2004

Outline

- Textbook coverage
  - » Chapter 8
  - » Do not get bogged down in mathematics of DES, RSA
  - » Do understand how to use them to get jobs done
- Security threats and techniques.
- Encryption
  - » Private-key, public-key
- Hashing
- IP security (IPsec)

Security Threats

- **Impersonation.**
  - » **Pretend to be another user with the intent of getting access to information or services**
- **Secrecy.**
  - » **Get access to the contents of packets**
- **Message integrity.**
  - » **Change a message unbeknownst to the sender or receiver**
- **Repudiation**
  - » **Denying to have sent a message**
- **Breaking into systems.**
  - » **To steal or destroy contents**
- **Denial of service.**
  - » **Flooding the system so users with legitimate needs cannot get service**

Active Versus Passive Threats

Active Threats

- Denial of Service
- Masquerade
- Modifying of Message contents
- Replay

Passive Threats

- Traffic Analysis
- Release of Message Contents

Three Levels of Defense

- Using firewalls to limit access to the network.
  - » Packets that cannot enter the network cannot cause harm
  - » Packets that do not leave the network cannot leak secrets
- Securing the infrastructure at the network layer (IP).
  - » Host to host or at a finer grain
  - » Can be viewed as management tool: can be done without knowledge of applications
- Application level security.
  - » Communicating peers execute protocols to secure their communication channel
  - » Essential for critical applications: end-to-end security
  - » Requires effort from both application developers and users

Encryption

Ciphertext = E(plaintext, K_E)

Plaintext = D(ciphertext, K_D)

Algorithm = E(), D()

- Algorithm should generally be public
  - » Otherwise when (!!) it is cracked you won't hear about it
  - » Easier to get known-good software implementations
  - » Encourages fast hardware implementations
- Keys are generally kept private
  - » Easier to change a key than an algorithm
- Given the ciphertext, it must be "very difficult" to calculate the plaintext without K_D
  - » Difficult = computationally very expensive
  - » Resistant to known attacks

Special Cases

$$\text{Ciphertext} = E(\text{plaintext}, K_E)$$

$$\text{Plaintext} = D(\text{ciphertext}, K_D)$$

$$\text{Algorithm} = E(), D()$$

- **Details**
  - » E() and D() may be the same function
  - » K_E and K_D may be the same key

Perfect Encryption: One-Time Pad

- "Pad" = large nonrepeating set of truly random key letters

plaintext ONETIMEPAD

one-time pad TBFRGFARFM........................

ciphertext IPKLPSFHGQ

- Algorithm often simple
  - » K_E == K_D, E() == D() == XOR()
- Perfect <u>if and only if</u>
  - » Key bits are <u>truly random</u>
  - » Key bits are <u>never re-used</u>

Simple Applications

- Maintain secrecy of message

A:	m = “secret msg”
	m’ = E(m, K_E)
A⇒B:	m’
B:	m = D(m’, K_D)

- Prove identity by knowing a key
  - » two parties must have a shared secret

A:	m = “I am A”
	m’ = E(m, K_E)
A⇒B:	m, m’
B:	verify m = D(m’, K_D)

Public versus Private Key Cryptography

- Private key (symmetric, e.g., DES)
  - » Two parties share (keep private) a key k
  - » Encrypt plaintext using k
  - » Also decrypt ciphertext using k -- symmetric
- Public key (asymmetric, e.g. RSA)
  - » Keys come in pairs, $K_{private}$ and K_{public}
  - » $K_{private}$ is kept private by its owner
  - » K_{public} is published
  - » Sender encrypts with recipient's public key $C=E(M, K_{public})$
  - » Recipient uses private key to decrypt $M=D(C, K_{private})$
  - » Must be "impossible" to derive private key from public

Authentication Revisited

Private key			Public key	

Private key

A:	m = “I am A”
	m’ = $\{m\}k_{shared}$
A⇒B:	m, m’
B:	verify m’ = $\{m\}k_{shared}$

- Parties must share a secret before they can communicate.
- Need a separate channel to establish the shared key.

Public key

A:	m = “I am A”
	m’ = $\{m\}k_{private}$
A⇒B:	m, m’
B:	verify m = $\{m'\}k_{public}$

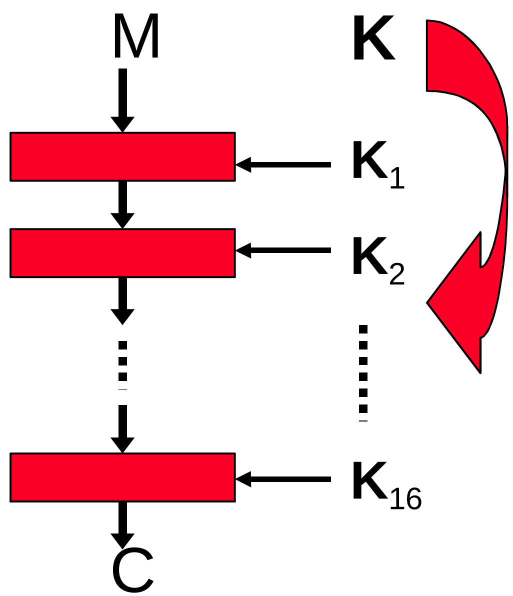
- Distribution of keys is easier.
- Still need a way to <u>reliably</u> distribute public keys.

Data Encryption Standard DES

- **Example of symmetric-key cryptography.**
- **Basically permutes the bits based on a 56 bit key.**
  - » **Substitution: reduce the relationship between plaintext and ciphertext**
  - » **Diffusion: move the bits around**
- **How secure is DES?**
  - » **It is becoming less secure as computers get faster**
  - » **DES has recently been "cracked" by teams of volunteers using both lots of idle workstations, and special-purpose hardware**
- **Security can be improved by running the algorithm several times, e.g. Triple-DES**
  - » **Odd fact: 2DES is <u>less safe</u> than DES!**

DES Algorithm

- **Use a 64-bit key to encrypt data in 64-bit blocks**
  - » **Actually 56-bit key: every 8th bit is parity**
- **16 "rounds"**
  - » **The 56-bit key** K **is used to generate 16 48-bit keys** $K_1 \ldots K_{16}$**, one for each round**
- **In each round:**
  - » **Substitution (S-boxes)**
  - » **Permutation (P-boxes)**



RSA Algorithm

- Example of a public key system.
  - » Name based on the names of its founders
- A key pair can be generated based on a pair of large prime numbers.
  - » Different key sizes can be used
  - » Larger key sizes are harder to crack but also result in more expensive encryption and decryption
- Encryption and decryption is based on exponentiation and remainder calculation.
- The security of RSA is based on the fact that there is no known algorithm for quickly factoring large numbers.

RSA Algorithm

- RSA: Rivest, Shamir, and Adleman
- Based on the difficulty of factoring large numbers
- How it works:
  1. Generate two large primes (100-200 digits) p and q
  2. $n = pq$
  3. Randomly find e such that it is relatively prime to $(p-1)(q-1)$
  4. $d = e^{-1} \bmod ((p-1)(q-1))$
  5. Public key: e and n
  6. Private key: d

Public vs. Private Key Systems

- **Scale of key management.**
  - » **If N users want to communicate securely, private key systems require Nx(N-1)/2 key pairs while public key systems require only N key pairs**
- **Computational cost.**
  - » **Public key cryptography is much more expensive than private key cryptography**
- **Compromise: use public key system to agree on temporary private keys**
- **Or: use an *authentication server* to reduce the key management complexity of private key systems.**
  - » **Authentication server versus public key server**

Cryptanalysis: Types of Attack

- **Goal: recover plaintext or key.**
- **Basic assumptions**
  - » **Attacker has complete access to the communications (ciphertext)**
  - » **Cryptanalyst knows the cryptographic algorithms (and protocols)**
- **Ciphertext-only**
  - » **Given** $C_1 = E_K(M_1), C_2 = E_K(M_2), \dots, C_N = E_K(M_N)$
  - » **Deduce** $M_1, M_2, \dots, M_N$, **or** K
- **Known-plaintext**
  - » **Given** $M_1, C_1 = E_K(M_1), M_2, C_2 = E_K(M_2), \dots, M_N, C_N = E_K(M_N)$
  - » **Deduce** K
- **Chosen-plaintext**
  - » **Attacker chooses** $M_1, \dots, M_N$ **and gets** $C_1 = E_K(M_1), \dots, C_N = E_K(M_N)$
  - » **Deduce** K

Hash Functions

- Usually operates on an arbitrary length message to generate a fixed length message digest.
- Properties of a good hash function:
  1. Pre-image Resistant: given f(x) cannot find x
  2. 2nd Pre-image Resistant: given x and f(x), it is difficult to find $x' \neq x$ such that that $f(x) = f(x')$
  3. Collision Resistant: it is difficult to find any x', x such that that $x' \neq x$ and $f(x) = f(x')$
- If 1,2 are satisfied, the function is said to be one way.
- Example uses:
  - » Message Authentication
  - » Password Storage
  - » Key Generation

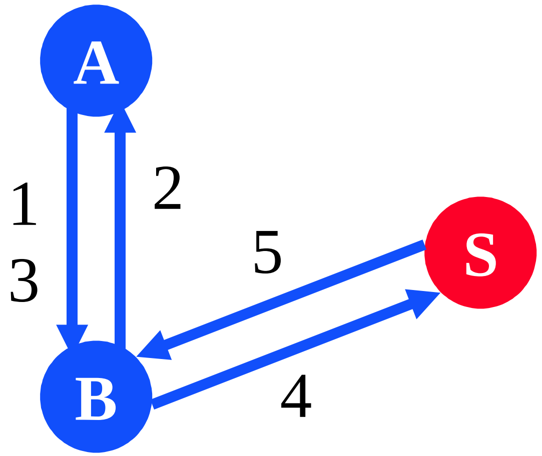
Hash Function Usage

- **Message Authentication**
  - » **A: “I have published the new OpenBSD CD-ROM image on lots of FTP servers.”**
  - » **B: “I have downloaded an image from ftp.asdfsdfa.org ... Is it the right one?”**
  - » **A: “Oh, the MD5 hash of the image I published is d41d8cd98f00b204e9800998ecf8427e.”**
- **Password Storage**
  - » **Storing passwords in a file makes the file very attractive to thieves...**
  - » **Solution: store MD5(password) instead. When user types in password, compute MD5(typed), compare to MD5(password).**

Using an Authentication Server

- Avoid n^2 key problem: each principal shares a key with server.
  - » Server S helps in authenticating A to B

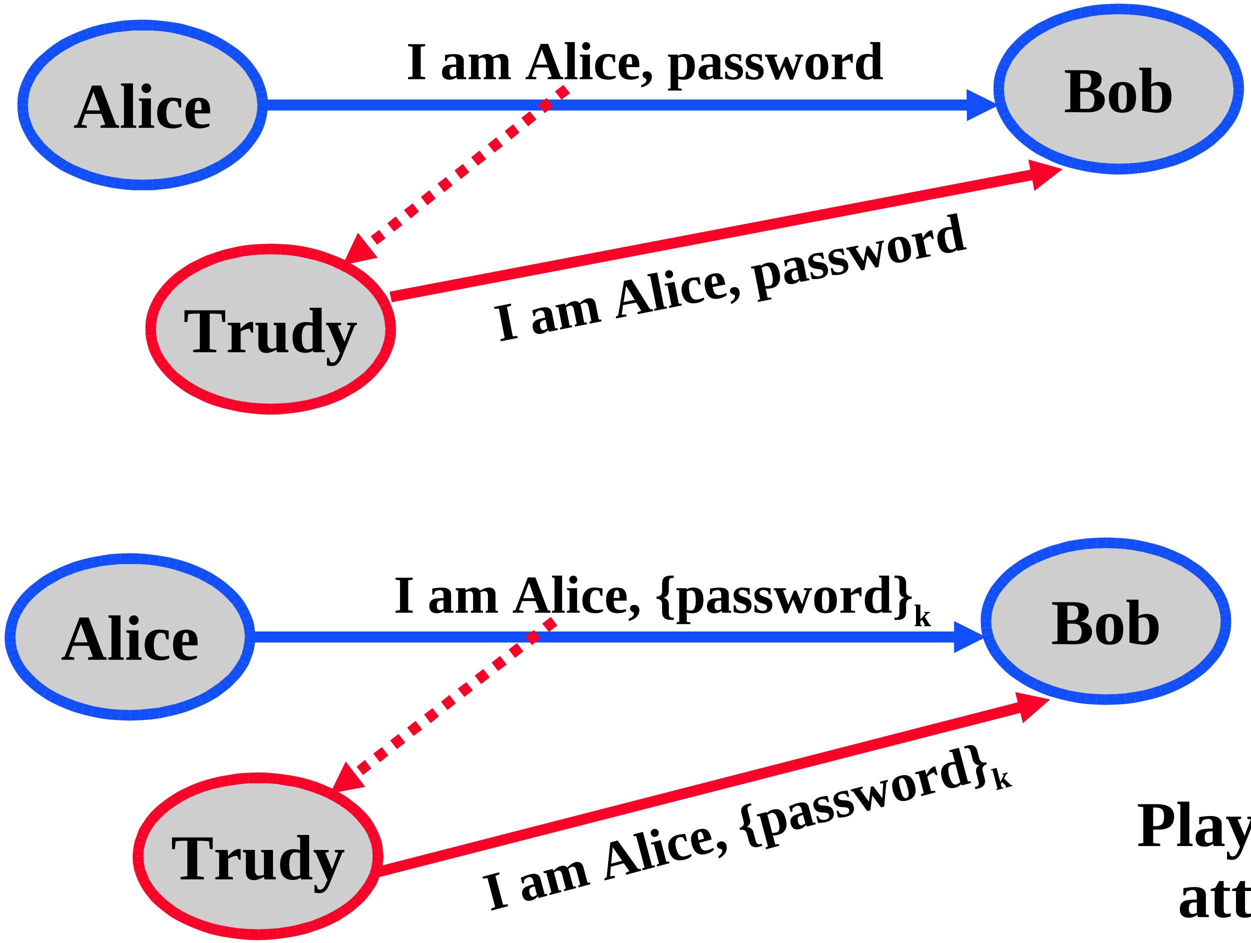
A⇒B:	"I am A"
B⇒A:	n
A:	$n' = \{n\}k_A$
A⇒B:	n'
B:	$n'' = \{A,n'\}k_B$
B⇒S:	n''
S:	recover P, n'
	$n = \{n'\}k_A$
	$m = \{n\}k_B$
S⇒B:	m
B:	verify $m = \{n\}k_B$



Authentication

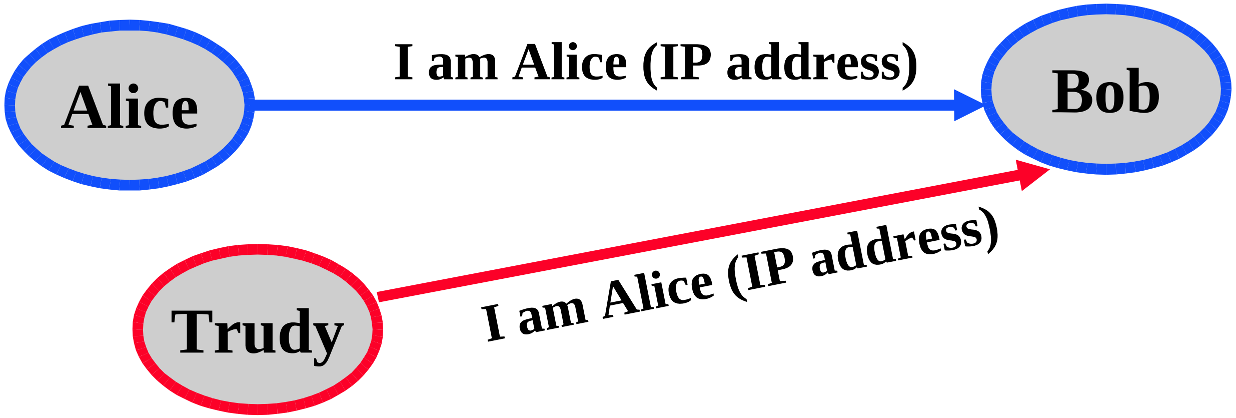
- Use authentication to illustrate some of the pittfalls of using cryptography to address security threats.
  - » Goal is for Alice to authenticate herself to Bob
- Passwords.
- Encrypted passwords.
- Use of a nonce.
- A challenge-based approach.

Plain or Encrypted Passwords



Playback attack

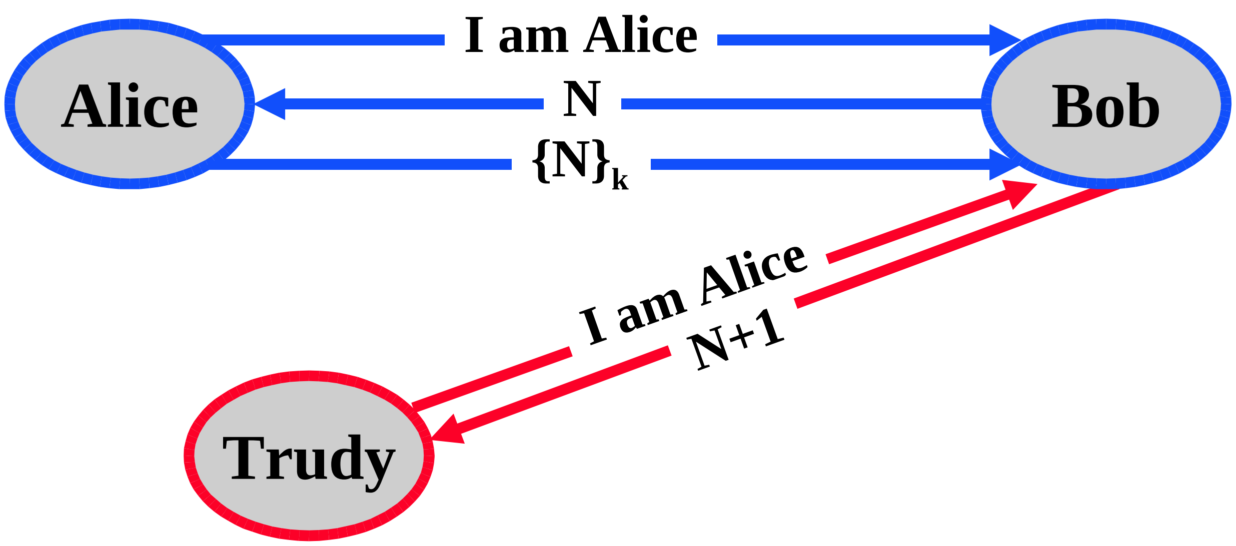
IP Spoofing



- Fairly easy to generate packets with arbitrary IP source addresses.
  - Certainly when you have access to the operating system
- Bob will send reply back to (the real) Alice.
  - But Trudy could intercept these replies

Preventing Replay Attack

- Include a *nonce*, a value that is used only once, in the message.
  - » Can be timestamp, random number, …
  - » Prevents a simple replay of requests or responses



Digital Signatures

- How can you prove somebody sent you a specific message?
  - » Prove identify of sender and exact message contents
- Digital signature: Bob sends Alice a plaintext message plus a cyphertext encrypted with his private key.
  - » Alice can verify that they are the same
  - » Alice has proof that only Bob could have sent this message
    - – since only Bob could have encrypted the message
  - » If either Bob or Alice modify the message, the other party can prove it
- Catch: what happens if Bob advertises his private key?

Message Digests

- Public key cryptography can be used to sign documents, but it is computationally expensive.
  - » Makes message nonforgeable, verifiable, nonrepudiable
- Message digests save on computation costs by computing a small digest of the message, which can then be signed.
  - » Uses a many-to-one hash function H, i.e., m = H(M)
  - » Given m, it is infeasible to find an N so m=H(N)
  - » It is infeasible to find an M and N so H(M)=H(N)
- Example: MD5.
  - » Computes a 128 bit digest
  - » Alternative: SHA-1, a US federal standard; creates a 160 bit digest

2004 Update

- This summer was fun
  - » ...in terms of cryptography...
  - » ...where “fun” means “horror movie”...
- MD5 is probably blown
  - » A Chinese group can come up with (m_1,m_2) pairs which hash to the same value...
  - » ...fast.
- SHA-1 is “in trouble”
  - » SHA-1's “little brother” SHA-0 is under pressure
  - » Same technique might end up working for SHA-1
- So much for cryptographic hashing? Unknown!

IP Security Goals

- Provide a set of protocols that offer security at the network layer.
  - » Ideally every datagram sent over the Internet would be protected by IP Sec
  - » Analogy: almost all letters travel in an envelope
- Security is supported from source host to destination host.
  - » Can cover all end-to-end information in the packet
    - – Layers 4 and up
    - – Raises some issues with regard to classification
  - » IP Sec may not be sufficient for some applications
    - – May want to create a secure between two applications (instead of two hosts)
- Defined for both IPv4 and IPv6.

IP Security Components

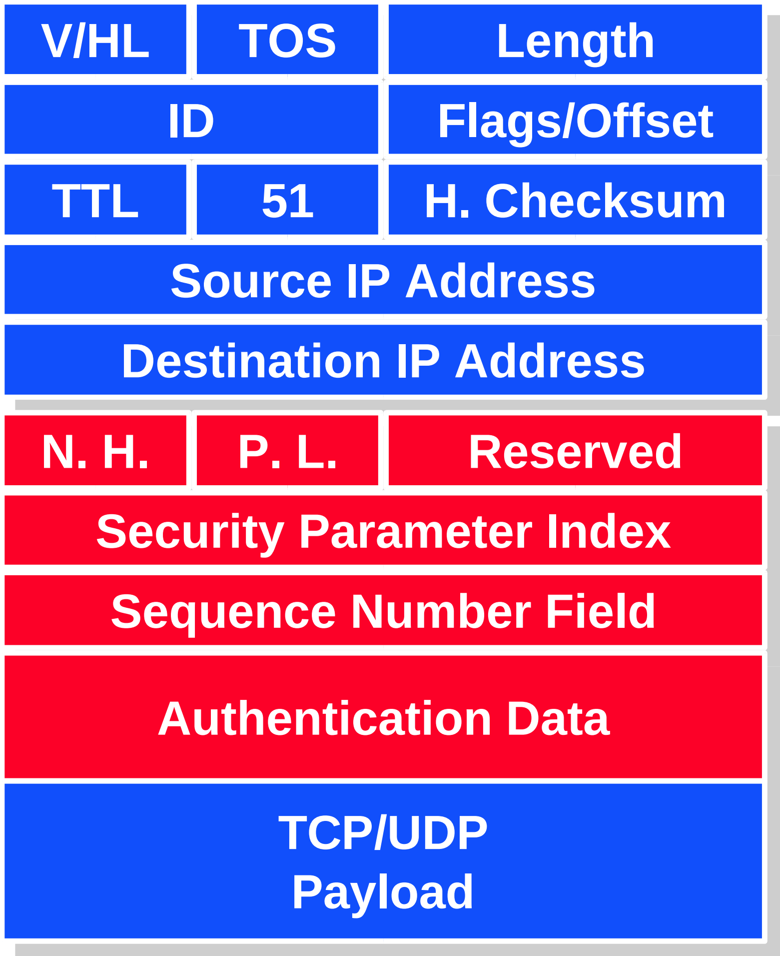
- IP "Authentication Header" protocol supports authentication and integrity.
  - » Based on cryptographic authentication function that is computed using a secret authentication key
- IP "Encapsulating Security Payload" protocol supports authentication, integrity, and confidentiality.
  - » Encrypt entire IP datagram or upper-layer protocol data
  - » New clear-text IP header is used to carry packet through the network
- Based on a "security association".
  - » Identified through Security Parameter Index and source address
  - » Stores information used to encrypt/decrypt/....

Security Associations

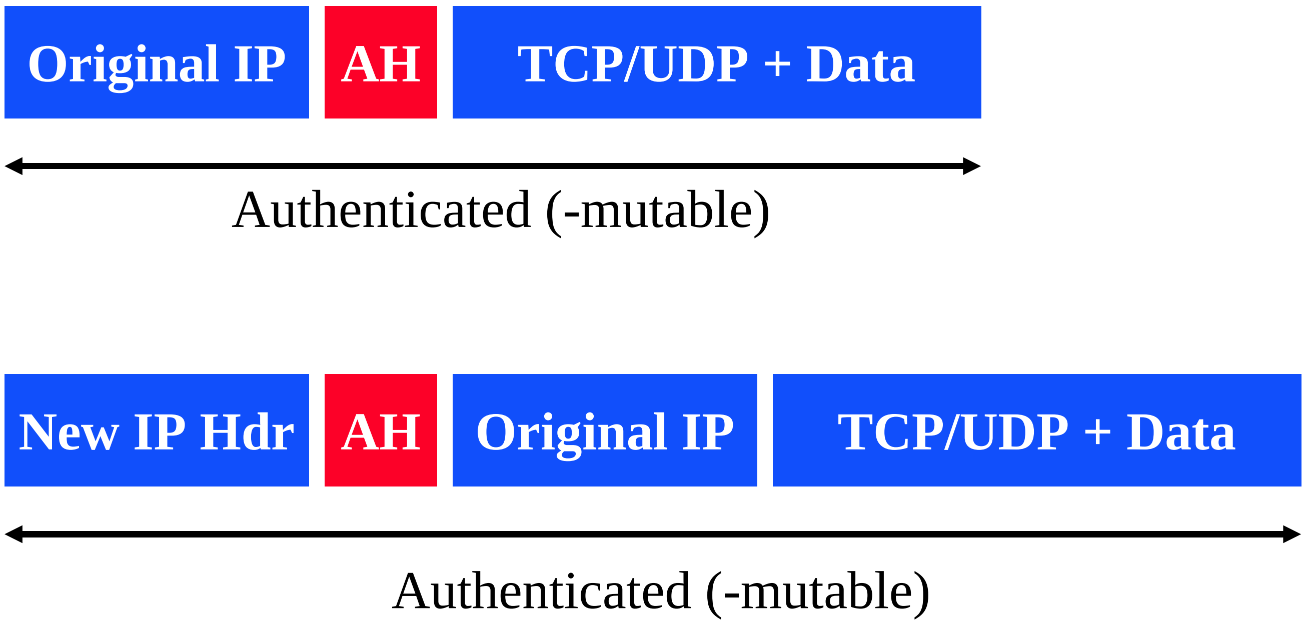
- A security association supports a simplex connection that can support security.
- Defined by a Security Parameter Index, an IP destination address, and a security protocol identifier.
- The Security Policy Database defines policies applicable to the node.
  - » Specifies policy (discard, bypass IPsec, apply IPsec) for inbound and outbound traffic
  - » Selectors identify flows: host-host or more fine grain
- The Security Association Database keeps track of the state of active connections.
  - » Protocols selected, keys, sequence numbers, ..
  - » Keys can be managed manually or using IKE

Authentication Header (AH) Protocol

- AH sits between IP header and the payload.
  - » Protocol 51
- Next header: from old IP header.
- Payload length: length of AH in words (-2).
- Security parameter index identifies the session.
- Sequence number field can be used against replay attacks.
- Authentication data: Integrity Check Value.
  - » Signed digest, e.g. DES, keyed MD5, ...

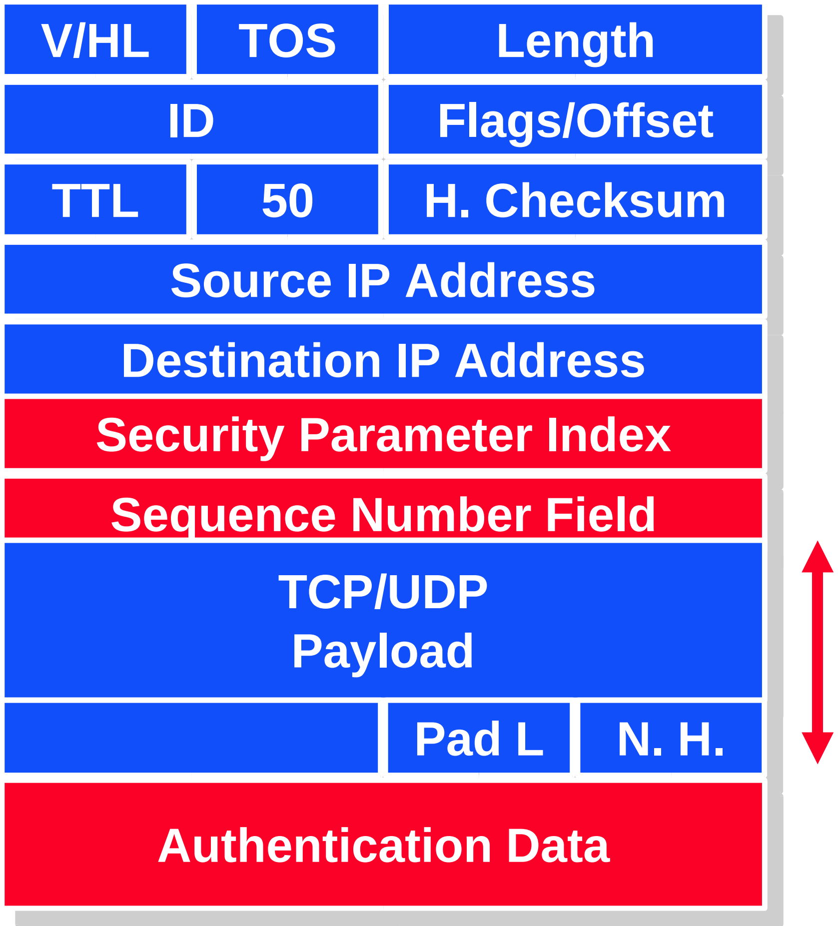


Transport versus Tunnel Mode AH

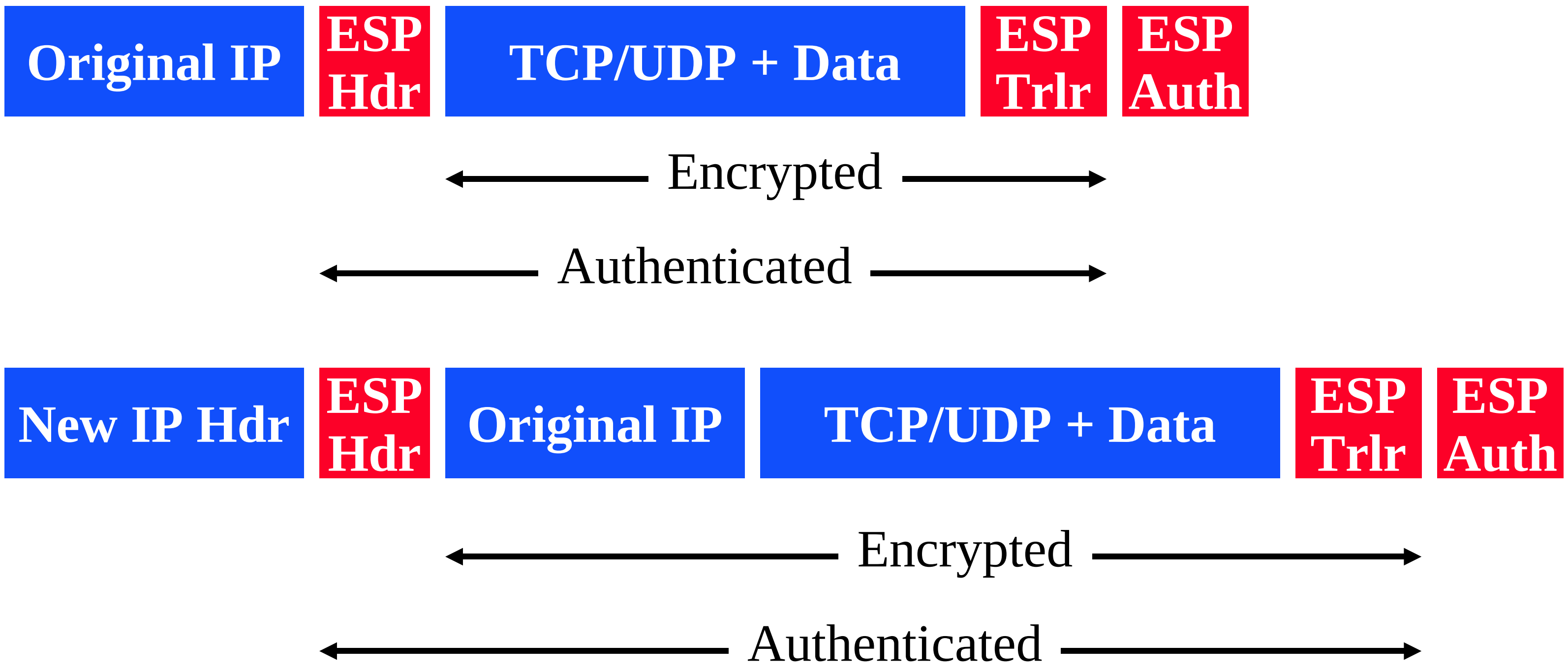


Encryption Support

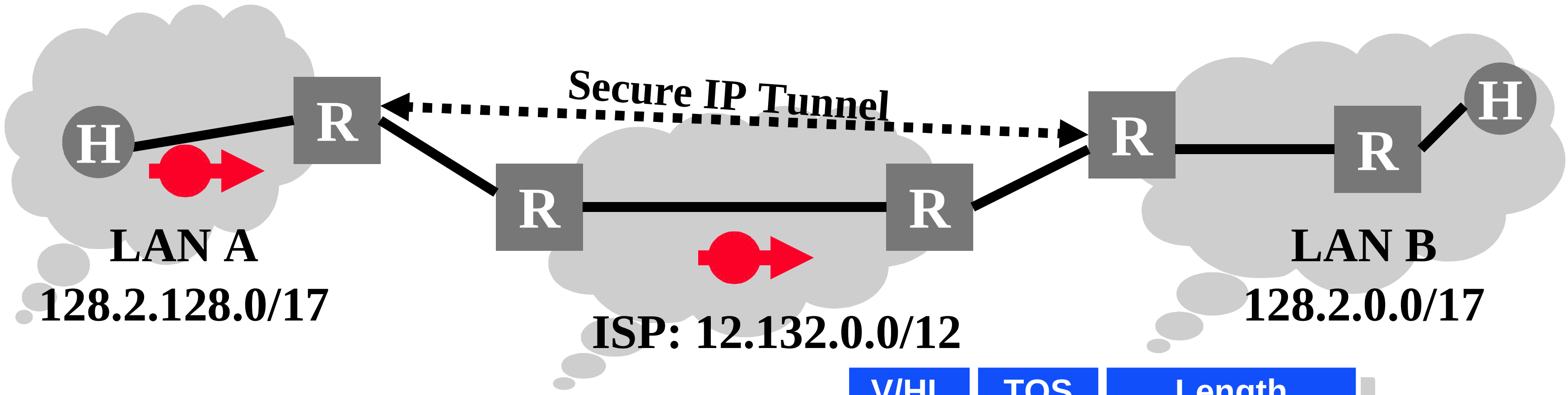
- ESP header follows IP header.
  - Protocol Id = 50
- SPI and sequence number have same role as in AH.
- Padding is used to have make sure encrypted data is a multiple of 4 bytes, and is aligned on a 4 byte boundary.
- Authentication data: as in AH, but optional.

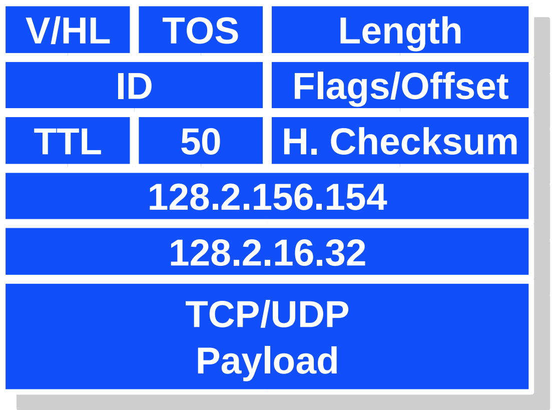


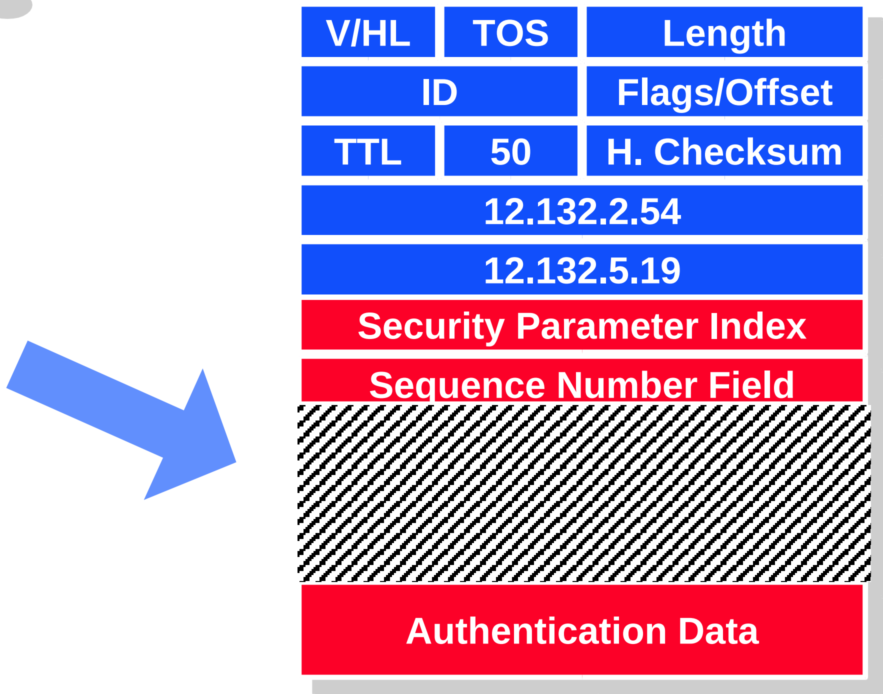
Transport versus Tunnel Mode ESP



Example: Virtual Private Networks







Summary

- Security threats and techniques
- Encryption
  - » Private-key, public-key
    - – Understand how to plug the parts together
    - – Who gets which keys?
    - – What do you encrypt and why?
- Hashing
- IP security (IPsec)