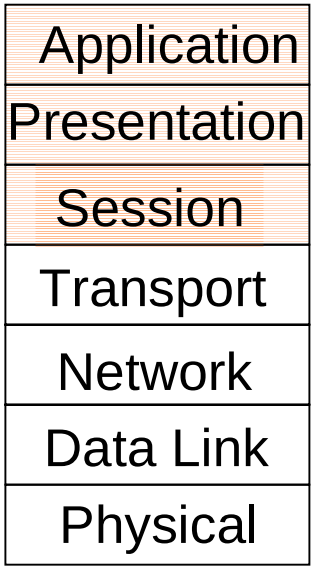
CSE/EE 461 – Lecture 15

David Wetherall

djw@cs.washington.edu

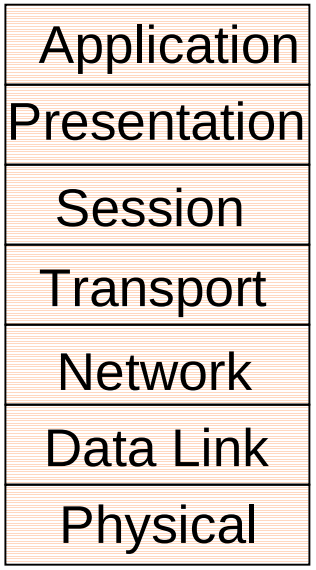
Last Time

- Naming
- Focus
  - How do we name hosts etc.?
- Topics
  - Domain Name System (DNS)
  - Email/URLs



This Time

- A whirlwind tour of network security
- Focus
  - How do we secure distributed systems?
- Topics
  - Privacy, integrity, authentication
  - Cryptography and key distribution
  - Firewalls and Denial-of-service
  - TCP/IP vulnerabilities



What do we mean by "Security"?

- Networks are fundamentally shared
  - Need means to protect legitimate participants in a distributed system from others with access to the network

- Privacy: messages can't be eavesdropped
- Integrity: messages can't be tampered with
- Authenticity: messages were sent by the right party

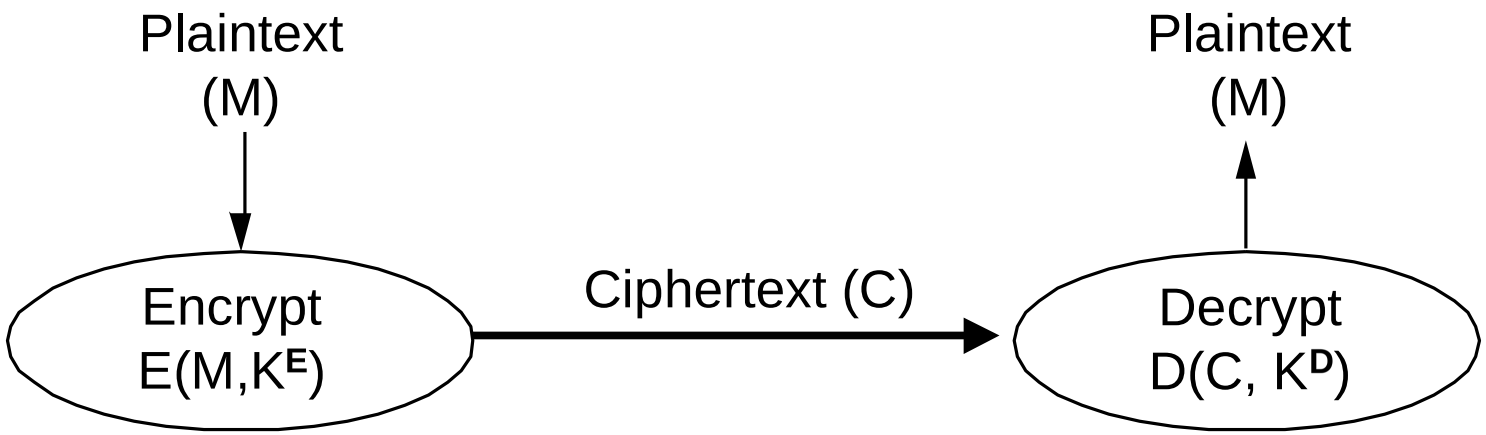
- Denial-of-Service: overwhelm system with bogus tasks causing service to be denied for legitimate tasks

Approaches at 10,000 ft

- Physical security
  - Tackle the problem of sharing directly
- "Security through obscurity"
  - Hope no-one will find out what you're doing!
- Throw math at the problem
  - Cryptography

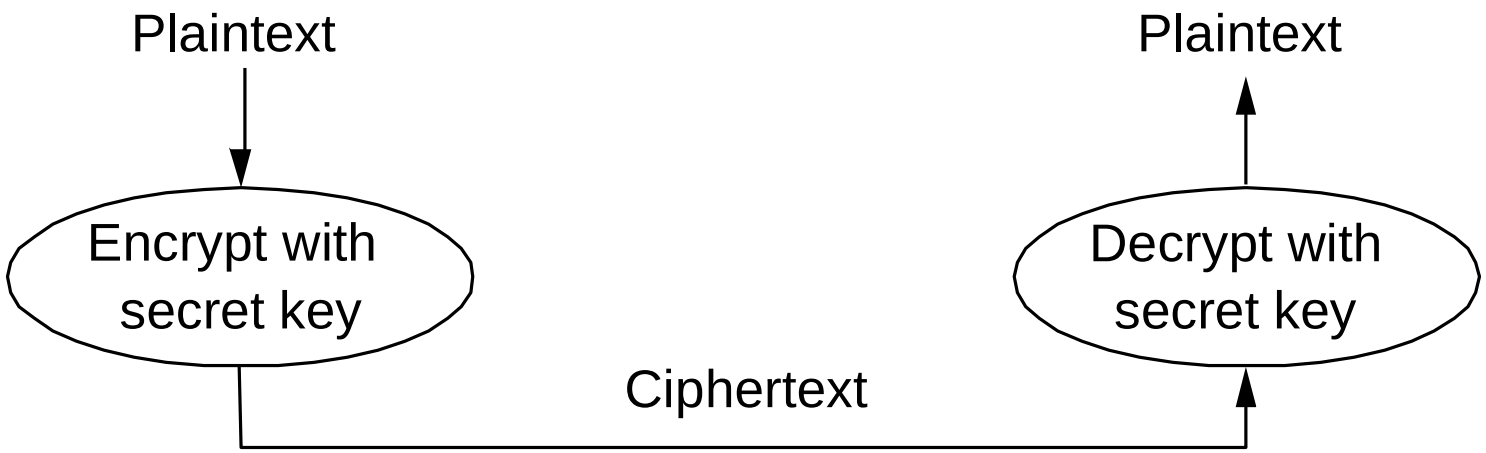
- Why is security difficult?
  - It's a negative goal: can you be sure there are no flaws?
  - Often assumptions turn out to be invalid, esp. randomness

Basic Cryptography



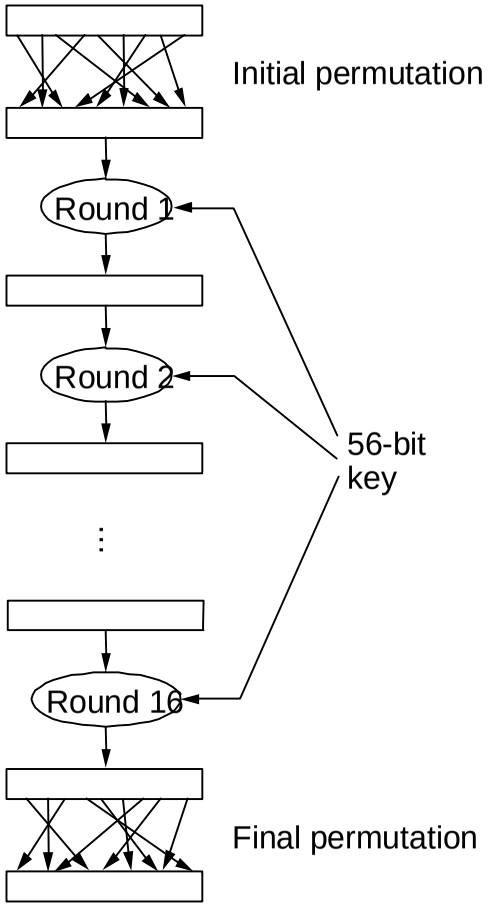
- Cryptographer chooses functions E, D and keys K^E, K^D
  - Mathematical basis
- Cryptanalyst try to “break”
  - Depends on what is known: E and D, M and C?
  - Attacks: traffic analysis, known plaintext, chosen plaintext

Secret Key Functions (DES, IDEA)

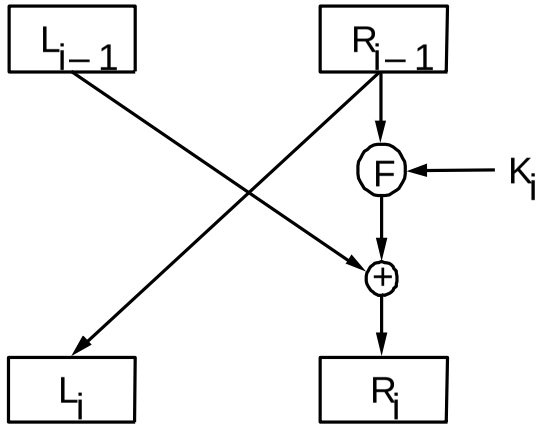


- Single key (symmetric) shared among parties
- Keys randomly chosen
  - But how do computers generate random numbers? Pitfall!
  - Ultimately need to tie to physical processes

Basics of DES

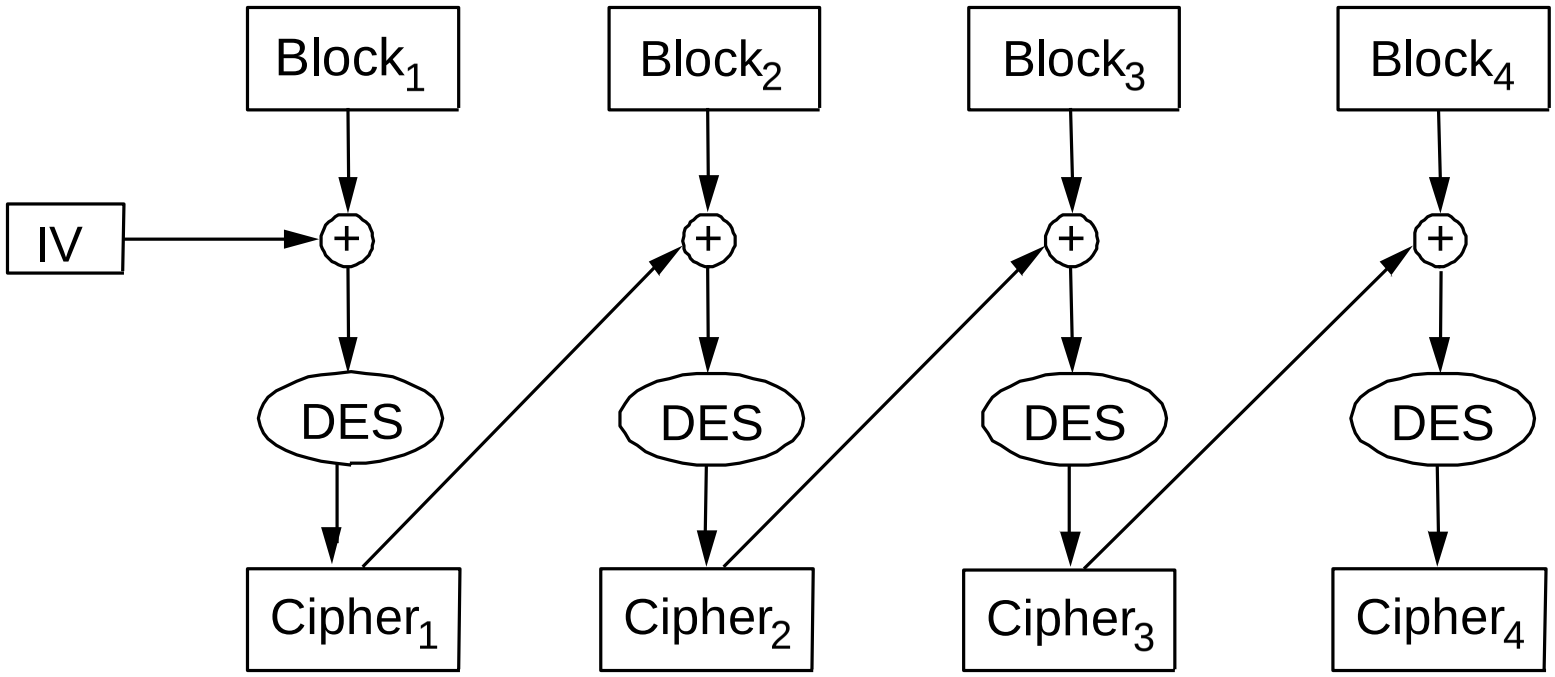


Each Round:



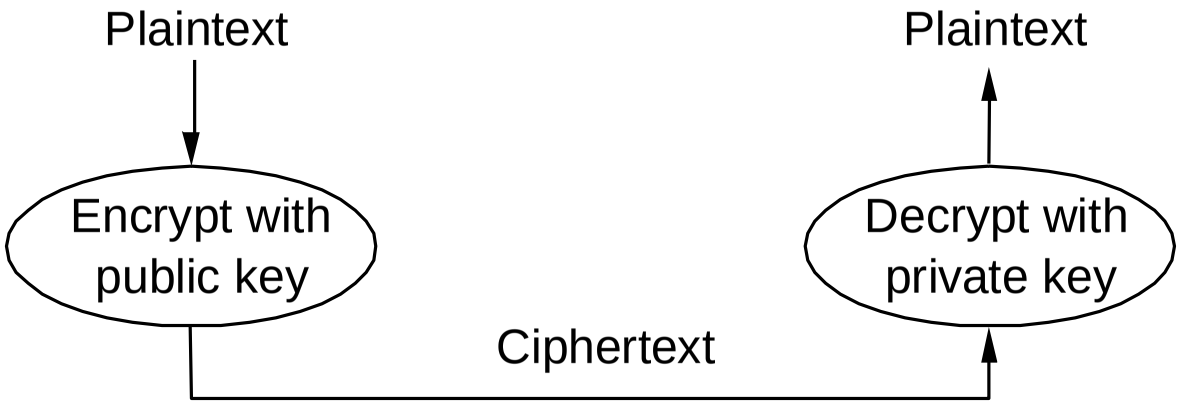
DES uses a 64 bit key (56 + 8)
Message encrypted 64 bits at a time
16 rounds in the encryption
Each round scrambles 64 bits

DES (cont.)



- Repeat process for larger messages with “chaining”

Public Key Functions (RSA)



- Public and private key related mathematically
  - Public key can be published; private is a secret

Basics of RSA

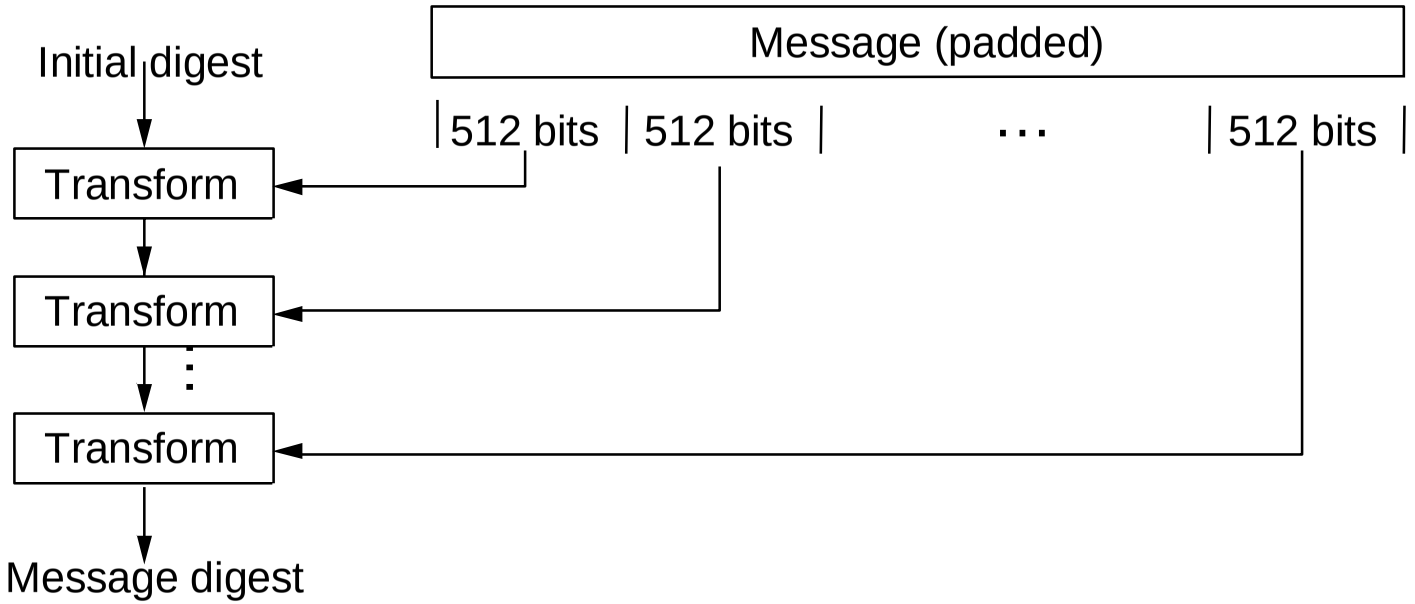
- To generate keys:
  - Choose two large prime numbers *p* and *q* (>=256 bits). Let *n*=*pq*
  - Choose key *e* such that *e* and (*p*-1) x (*q*-1) are relatively prime.
  - Compute key *d* such that *d* = 1/*e mod* ((*p*-1) x (*q*-1))
  - Public key (encryption) is (*e*, *n*), private key (decryption) is (*d*, *n*)

- To use:
  - Encrypt: C = M^*e* mod *n*
  - Decrypt: M = C^*d* mod *n*

- Why it works:
  - M^*ed* = M in modulo arithmetic
  - Believe need to factor *n* into *p* and *q* to break and this is hard

Message Digests (MD5, SHA)

- Act as a cryptographic checksum or hash
  - Typically small compared to message (MD5 128 bits)
  - "One-way": infeasible to find two messages with same digest

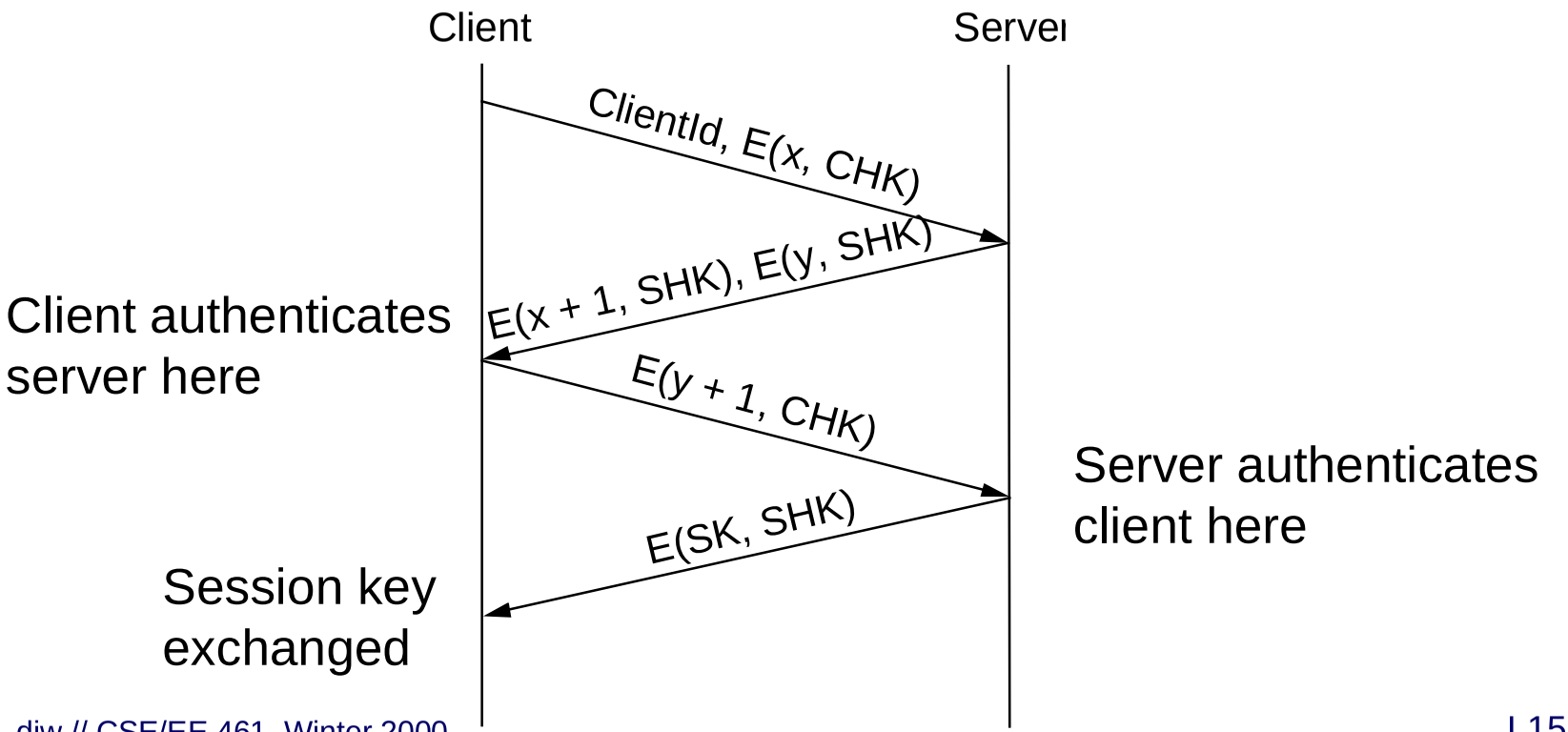


Some Tradeoffs

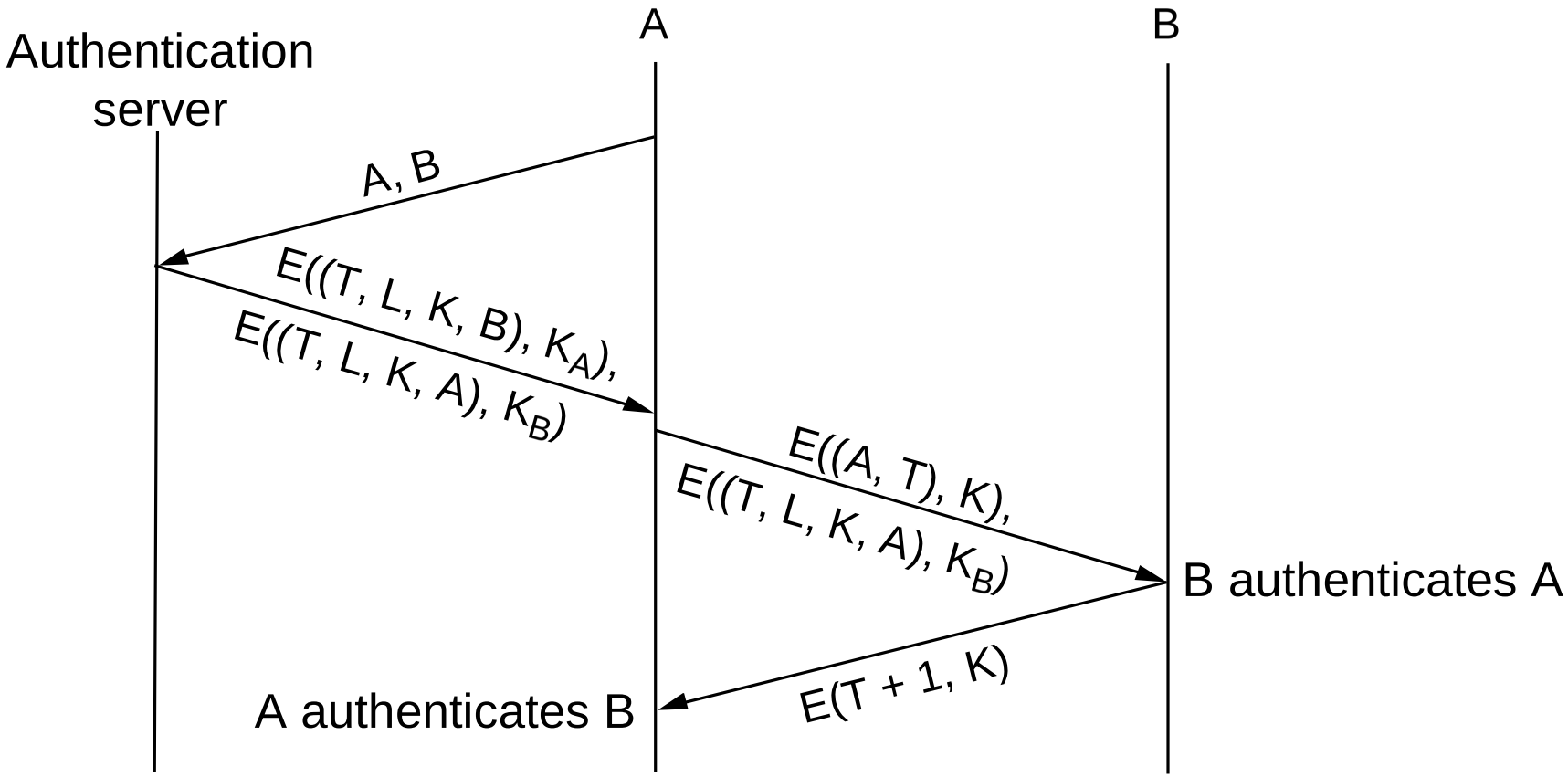
- Number of brute force operations to crack depend on size of key
  - DES marginal now, 3DES used, RSA used with 1024 bit keys
  - 1977 RSA challenge solved after 17 years using the Internet ☺
- Message digests and private key encryption typically much faster than public key encryption
  - e.g., Peterson says MD5 100Mbps, DES 40Mbps, RSA 1Kbps
  - Can improve system performance by using RSA to transfer DES keys for use in a session, or RSA to authenticate digests only
- Also, compress before encrypting ☺

Authentication Protocols

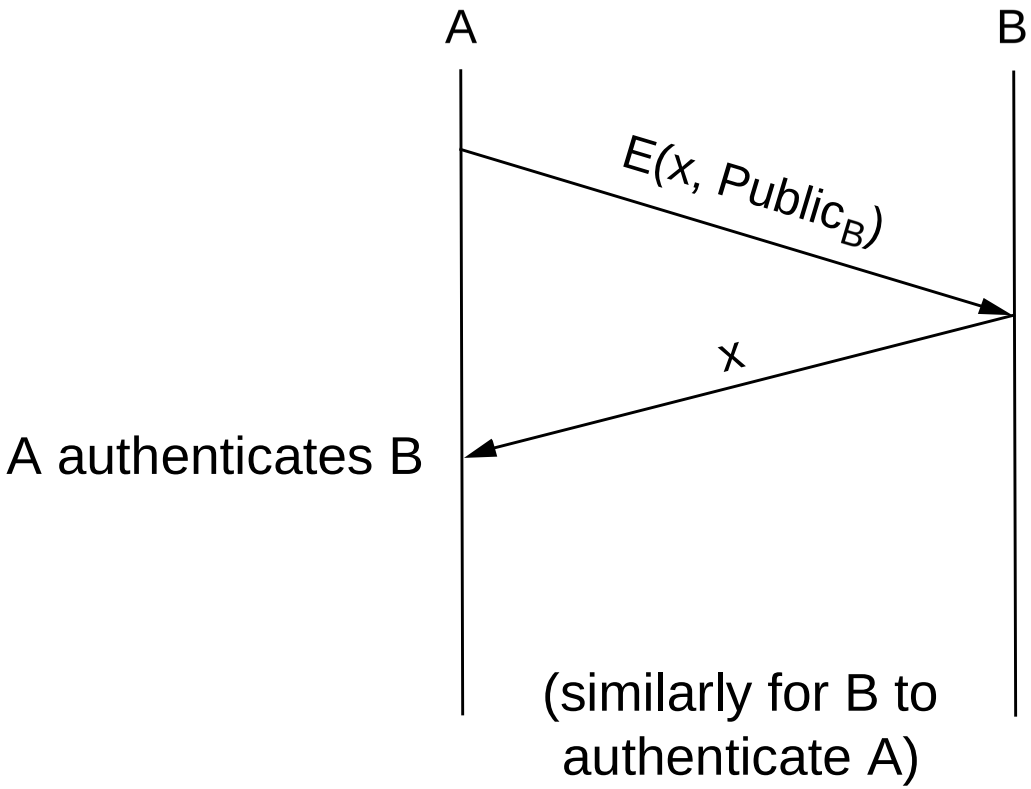
- Three-way handshake for mutual authentication
  - Client and server share secrets, e.g., login password



Via Trusted Third Party (Kerberos)



Public Key Authentication



Message Integrity Protocols

- Sometimes we don't care about privacy but do care about integrity/authenticity

- Digital signatures (RSA)
  - Sign message with private key (encrypt); others verify with public key (decrypt)
- MD5 with RSA
  - Send signed digest of message along with message
- Keyed MD5
  - Send digest of message plus shared secret along with message
- Last two methods increase performance

Key Distribution

- Public key systems depend on the distribution of keys!
  - Public Key Infrastructures (PKIs), e.g., Verisign
  - An Achilles heel?
- Certificates (X.509)
  - Distribute keys by trusted certification authority (CA)
    - "I swear X's public key is Y", signed by CA
  - Still requires bootstrapping ...
  - Also allows us to can build chains of trust
    - e.g., public keys for a domain name so that ".edu" (root) certifies "washington.edu"s key, they certify "cs..."'s key ...
  - Certificate Revocation Lists needed to "undo" associations!

Example Systems

- Pretty Good Privacy (PGP)
  - For authentic and confidential email
- Secure Sockets (SSL) and Secure HTTP (HTTPS)
  - For secure Web transactions
- IP Security (IPSEC)
  - Framework for encrypting/authenticating IP packets

PGP

- Application level system
- Based on public keys and a “grass roots” Web of trust
- Sign messages for integrity/authenticity
  - Encrypt with private key of sender
- Encrypt messages for privacy
  - Could just use public key of receiver ...
  - But encrypt message with secret key, and secret key with public key of receiver to boost performance

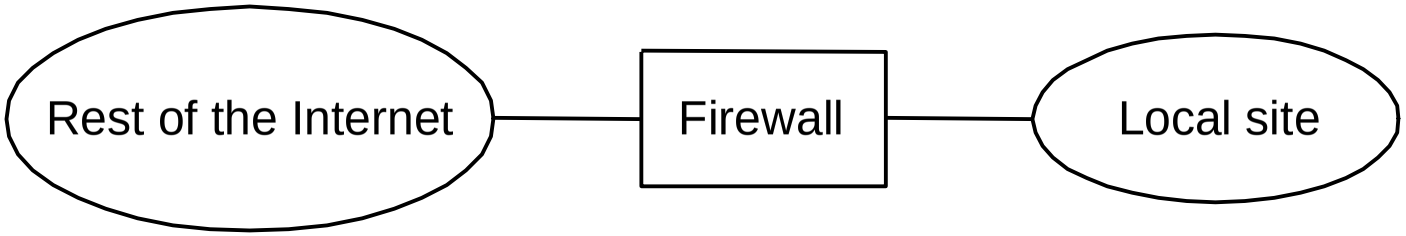
SSL/TLS and HTTPS

- Secure transport layers targeted at Web transactions
  - SSL/TLS inserted between TCP and HTTP to make secure HTTP
- Extra handshake phase to authenticate and exchange shared session parameters
  - Such as secret keys used for encryption
  - Client might authenticate Web server but not vice-versa
    - Certificate Authority embedded in Web browser
- Performance optimization
  - Refer to shared state with session id
  - Can use same parameters across connections
    - Client sends session id, allowing server to skip handshake

IPSEC

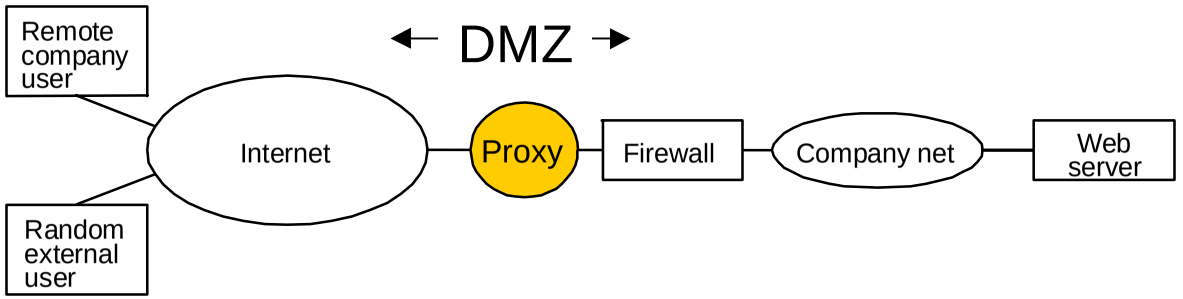
- Framework for encrypted and authenticated IP packets
  - Choice of algorithms not specified
- Uses new protocol headers inside IPv4 packets
  - Authentication header
    - For message integrity and origin authenticity
    - Optionally “anti-replay” protection (via sequence number)
  - Encapsulating Security Payload
    - Adds encryption for privacy
- Depends on key distribution (ISAKAMP)
  - Sets up security associations
- Example use: secure tunnels between corporate offices

Filter-based Firewalls



- Sit between site and rest of Internet, filter packets
  - Enforce site policy in a manageable way
  - e.g. pass (*,*, 128.7.6.5, 80), then drop (*, *, *, 80)
  - Rules may be added dynamically to pass new connections
- Sometimes called a “level 4” switch
  - Acts like a router (accepts and forwards packets)
  - But looks at information up to TCP port numbers (layer 4)

Proxy-Based Firewalls



- Problem: Filter ruleset can be complex/insufficient
  - Adequate filtering may require application knowledge
- Run proxies for Web, mail, etc. just outside firewall
  - In the "de-militarized zone" DMZ
  - External requests go to proxies, only proxies connect inside
    - External user may or may not know this is happening
  - Proxies filter based on application semantics

Denial-of-Service Attacks

- Attacker can deny service to legitimate users if they can overwhelm the system providing the service
  - System has limited bandwidth, CPU, memory, etc. resources
  - Just sent it too many packets to handle ...
- Made more devastating by focusing on specific, limited resources and distributed nature of attacks
  - e.g., How many TCP connections can be open?
  - Today, build implementation to tolerate DOS
  - Tomorrow, design protocols to tolerate better, possibly network support for shutting down attack?

TCP/IP Vulnerabilities

- Low-level specifics in TCP/IP used to wreak havoc, especially if implementation is weak or buggy
- Many incidents of buffer over-runs
  - Attacker can send packet to crash or compromise host
- IP fragmentation:
  - End-system hangs on to fragments hoping to re-assemble ...
  - But for how long? Attacker can exhaust memory
  - Similarly, state created for TCP SYN packet
- Smurfing:
  - Send ICMP echo request to broadcast address with fake source address; source gets hosed
- These are just some representative examples ... many more (CERT)

Key Concepts

- Privacy, message integrity, origin authenticity
- Cryptographic mechanisms are used to support these properties: private key, public key and digests

- Firewalls are in widespread use today
- Denial-of-service consumes system resources