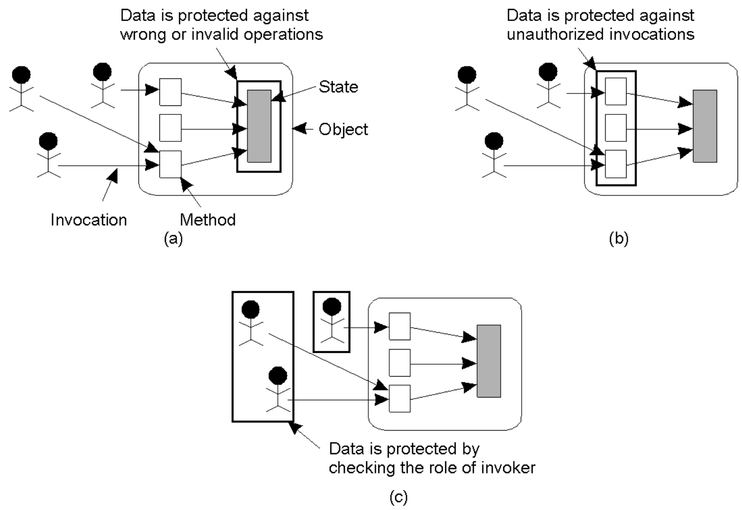
Distributed Systems Security

- Three approaches for protection against security threats

a) Protection against invalid operations

b) Protection against unauthorized invocations

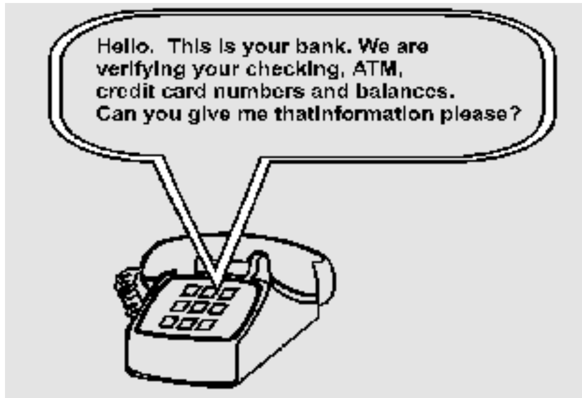
c) Protection against unauthorized users



Security and Privacy

- Related but different concepts
- Unauthorized access is a security issue
  - May cause sensitive data (e.g., credit card info, personal info) to be stolen
- Privacy violations can occur without any security violations
  - Mobile app collects location trace for advertising
    - can see visits to a doctor
  - Anonymous browsing history can be de-anonymized
  - Learn internal details of deep neural network from simple request patterns

Authentication



- **Question:** how does a receiver know that remote communicating entity is who it is claimed to be?

Authentication Protocol (ap)

- Ap 1.0
  - Alice to Bob: "I am Alice"
  - Problem: intruder "Trudy" can also send such a message
- Ap 2.0
  - Authenticate source IP address is from Alice's machine
  - Problem: IP Spoofing (send IP packets with a false address)
- Ap 3.0: use a secret password
  - Alice to Bob: "I am Alice, here is my password" (e.g., telnet)
  - Problem: Trudy can intercept Alice's password by sniffing packets

Authentication Protocol

Ap 3.1: use encryption

– encryption algorithms provide secrecy: use keys

use a symmetric key known to Alice and Bob

- Alice & Bob (only) know secure key for encryption/decryption

A to B: msg = encrypt("I am A")

B computes: if decrypt(msg)=="I am A"

then A is verified

else A is fradulent

- failure scenarios: playback attack
  - Trudy can intercept Alice's message and masquerade as Alice at a later time

Authentication Using Nonces

Problem with ap 3.1: same password is used for all sessions

Solution: use a sequence of passwords

pick a "once-in-a-lifetime-only" number (nonce) for each session

Ap 4.0

A to B: msg = "I am A" /* note: unencrypted message! */

B to A: once-in-a-lifetime value, n

A to B: msg2 = encrypt(n) /* use symmetric keys */

B computes: if decrypt(msg2)==n

then A is verified

else A is fradulent

- note similarities to three way handshake and initial sequence number choice
- problems with nonces?

Authentication Using Public Keys

Ap 4.0 uses symmetric keys for authentication

Question: can we use public keys?

symmetry: DA(EA(n)) = EA (DA(n))

AP 5.0

A to B: msg = "I am A"

B to A: once-in-a-lifetime value, n

A to B: msg2 = DA(n)

B computes: if EA (DA(n))== n

then A is verified

else A is fradulent

Problems with Ap 5.0

- Bob needs Alice's public key for authentication
  - Trudy can impersonate as Alice to Bob
    - Trudy to Bob: msg = "I am Alice"
    - Bob to Alice: nonce n (Trudy intercepts this message)
    - Trudy to Bob: msg2= DT(n)
    - Bob to Alice: send me your public key (Trudy intercepts)
    - Trudy to Bob: send ET (claiming it is EA)
    - Bob: verify ET(DT(n)) == n and authenticates Trudy as Alice!!
- Moral: Ap 5.0 is only as "secure" as public key distribution

Digital Signatures Using Public Keys

Goals of digital signatures:

- sender cannot repudiate message never sent ("I never sent that")
- receiver cannot fake a received message

Suppose A wants B to "sign" a message M

B sends DB(M) to A

A computes if EB (DB(M)) == M

then B has signed M

Question: can B plausibly deny having sent M?

Message Digests

- Encrypting and decrypting entire messages using digital signatures is computationally expensive
  - Routers routinely exchange data
    - Does not need encryption
    - Needs authentication and verify that data hasn’t changed
- Message digests: like a checksum
  - Hash function H: converts variable length string to fixed length hash
  - Digitally sign H(M)
  - Send M, DA(H(m))
  - Can verify who sent the message and that it has been changed!
- Property of H
  - Given a digest x, it is infeasible to find a message y such that H(y) = x
  - It is infeasible to find any two messages x and y such that H(x) = H(y)

Hash Functions

- MD5 not secure any more
- SHA hash functions   (SHA = Secure Hash Algorithm)
  - SHA-1 : 160-bit function that resembles MD5
  - SHA-2: family of two hash functions (SHA-256 and SHA-512)
  - Developed by NIST and NSA

Symmetric key exchange: trusted server

Problem: how do distributed entities agree on a key?

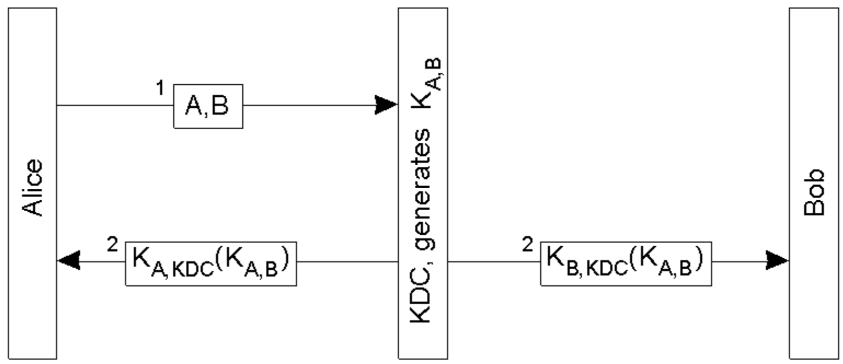
Assume: each entity has its own single key, which only it and trusted server know

Server:

- will generate a one-time session key that A and B use to encrypt communication
- will use A and B's single keys to communicate session key to A, B

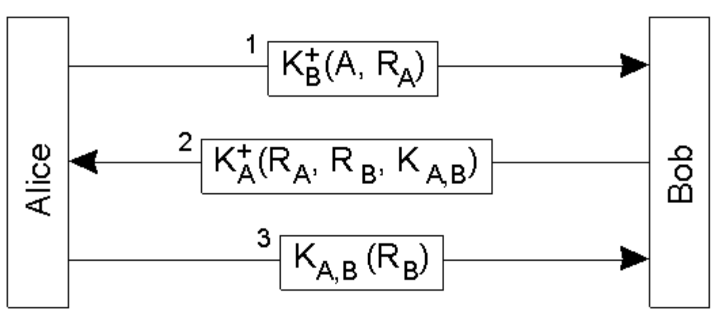
Key Exchange: Key Distribution Center (1)

- The principle of using a KDC.



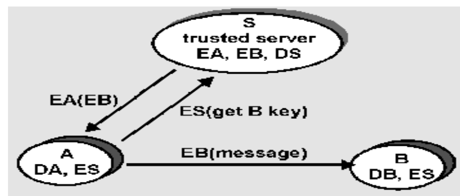
Public Key Exchange

- Mutual authentication in a public-key cryptosystem.



Public key exchange: trusted server

- public key retrieval subject to man-in-middle attack
- locate all public keys in trusted server
- everyone has server's encryption key (ES public)
- suppose A wants to send to B using B's "public" key
- use certificates: public keys signed by certification authority
  – certificates can be revoked as well
  –



Security in Enterprises

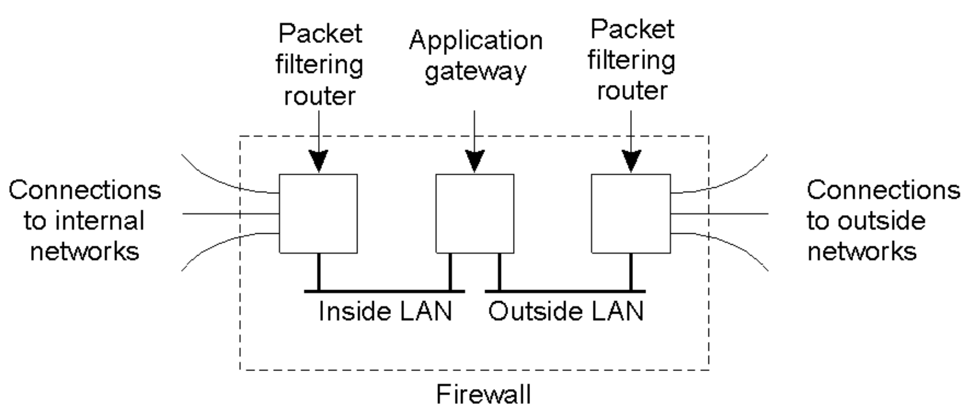
- Multi-layered approach to security in modern enterprises
  - Security functionality spread across multiple entities
- Firewalls (policies + ports)
- Deep Packet inspection
- Virus and email scanners
- VLANs
- Network radius servers
- Securing WiFi
- VPNs
- Securing services using SSL, cerificates, kerberos

Security in Internet Services

- Websites
  - SSL + authentication + captchas
- Challenge-response authentication
  - paypal
- Two factor authentication
  - Gmail: password + mobile phone
- One-time passwords
  - Hotmail one-time password
- Online merchant payments: paypal, amazon payments, google checkouts

Protection Against Intruders: Firewalls

- A common implementation of a firewall.



Firewalls

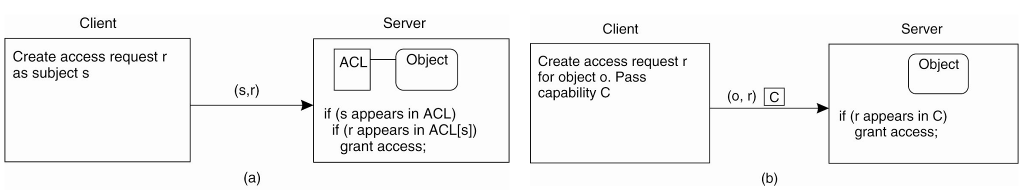
Firewall: network components (host/router+software) sitting between inside ("us") and outside ("them)

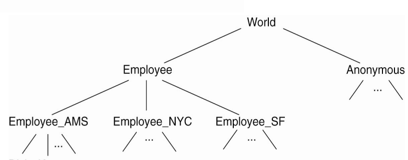
Packet filtering firewalls: drop packets on basis of source or destination address (i.e., IP address, port)

Application gateways: application specific code intercepts, processes and/or relays application specific packets

- e.g., email of telnet gateways
- application gateway code can be security hardened
- can log all activity

Access Control





- Access control lists
- Capabilities
- Protection domains

Secure Email

- Requirements:
  - Secrecy
  - Sender authentication
  - Message integrity
  - Receiver authentication
- Secrecy
  - Can use public keys to encrypt messages
    - Inefficient for long messages
  - Use symmetric keys
    - Alice generates a symmetric key K
    - Encrypt message M with K
    - Encrypt K with E_B
    - Send K(M), E_B(K)
    - Bob decrypts using his private key, gets K, decrypts K(M)

Secure Email

- Authentication and Integrity (with no secrecy)
  - Alice applies hash function H to M (H can be MD5 or SHA)
  - Creates a digital signature D_A(H(M))
  - Send M, D_A(H(M)) to Bob
- Putting it all together
  - Compute H(M), D_A(H(M))
  - M'= { M, D_A(H(M)) }
  - Generate symmetric key K, compute K(M')
  - Encrypt K as E_B(K)
  - Send K(M'), E_B(K)
- Used in PGP (pretty good privacy)

Secure Sockets Layer (SSL)

- SSL: Developed by Netscape
  - Provides data encryption and authentication between web server and client
  - SSL lies above the transport layer
  - Useful for Internet Commerce, secure mail access (IMAP)
  - Features:
    - SSL server authentication
    - Encrypted SSL session
    - SSL client authentication

Secure Socket Layer

- Protocol: https instead of http
  - Browser -> Server: B's SSL version and preferences
  - S->B: S's SSL version, preferences, and certificate
    - Certificate: server's RSA public key encrypted by CA's private key
  - B: uses its list of CAs and public keys to decrypt S's public key
  - B->S: generate K, encrypt K with with E_S
  - B->S: "future messages will be encrypted", and K(m)
  - S->B: "future messages will be encrypted", and K(m)
  - SSL session begins…

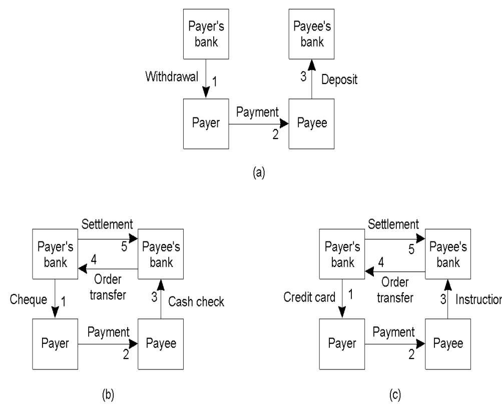
Electronic Payment Systems (1)

- Payment systems based on direct payment between customer and merchant.

a) Paying in cash.

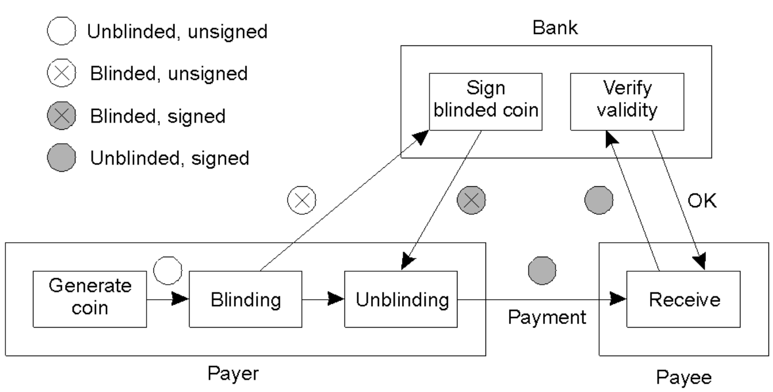
b) Using a check.

c) Using a credit card.



E-cash

- The principle of anonymous electronic cash using blind signatures.



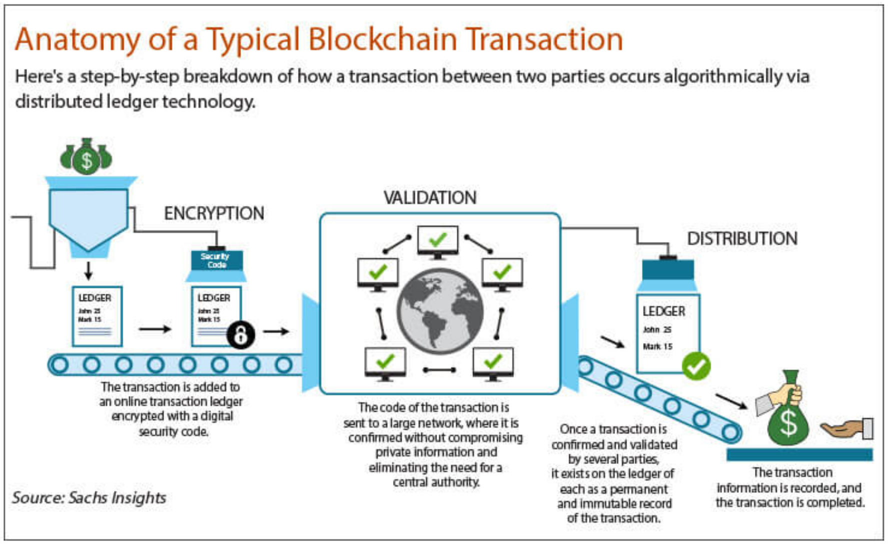
BitCoin

- Digital currency: P2P electronic cash, Decentralized
  - Open source crypto protocol
  - Satoshi Nakamoto
- New coins made by bitcoin servers
  - expend resources to generate a coin
  - 25 coins generated every 10 minutes
- Uses digital signatures to pay to “public keys”
- Bitcoin blockchain: distributed transaction ledger

Blockchain: Distributed Ledger

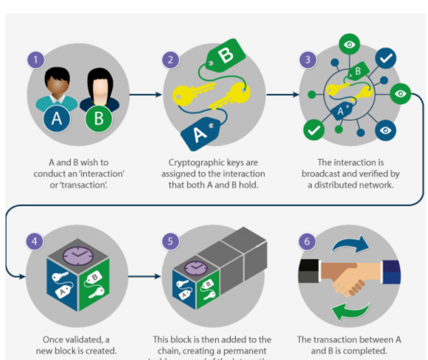
- Blockchain: distributed public ledger of transactions
  - Lists all financial transactions, distributed DB
  - Generic protocol for transactions based on public key cryptography
- **Applications**: stock register, land transactions, marriage records, smart contracts
- **Sign** a transaction with private key and insert in the ledger
- Every block contains multiple transactions
- Massively duplicated; shared using **P2P** file transfer protocol
- Updated by special nodes “miners” to append blocks
- All Network nodes perform validation and clearing
  - Miners perform “settlement” using **distributed consensus**

How Blockchain works



Bitcoin

- Bitcoin: use blockchain to track financial transactions
- Hold bitcoins in a digital wallet, pay for goods & services
- Payment transactions are recorded in the Bitcoin blockchain



Security: conclusion

key concerns:

- encryption
- authentication
- key exchange

also:

- increasingly an important area as network connectivity increases
- digital signatures, digital cash, authentication, increasingly important
- an important social concern
- further reading:
  - Crypto Policy Perspectives: S. Landau et al., Aug 1994 CACM
  - Internet Security, R. Oppliger, CACM May 1997
  - www.eff.org