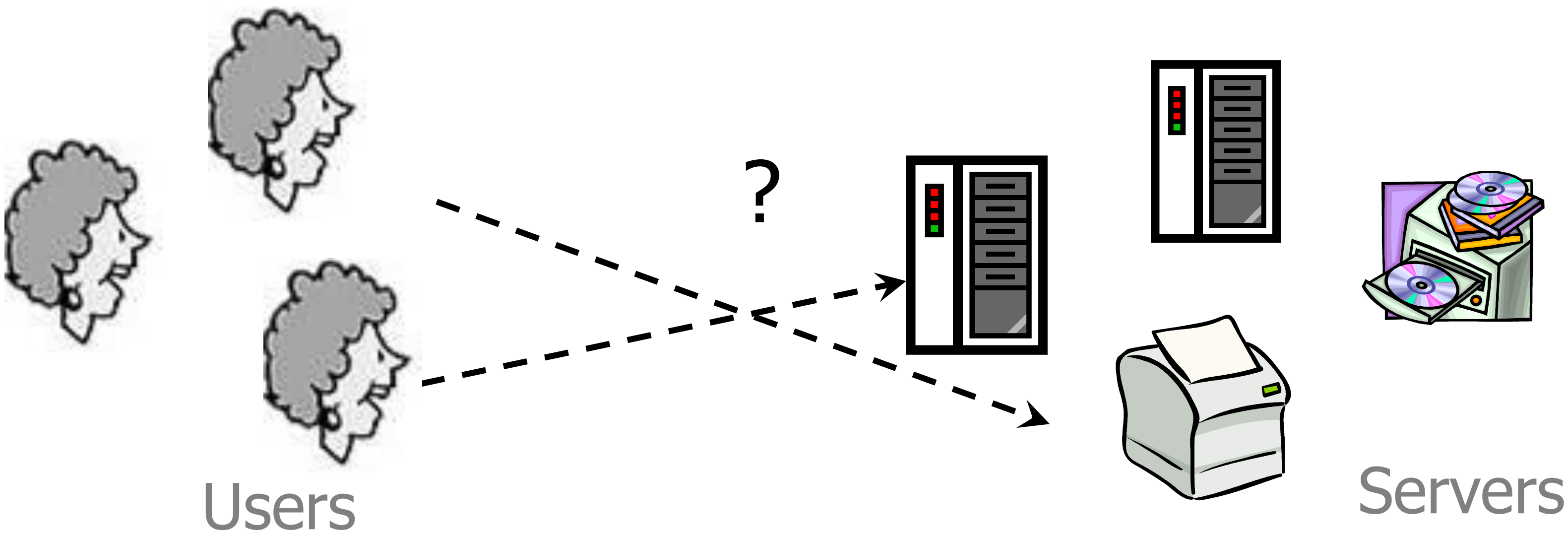
Network Security Standards

Key distribution

Kerberos

SSL/TLS

Many-to-Many Authentication



How do users prove their identities when requesting services from machines on the network?

Naïve solution: every server knows every user's password

- Insecure: compromise of one server is enough to compromise all users
- Inefficient: to change his password, user must contact every server

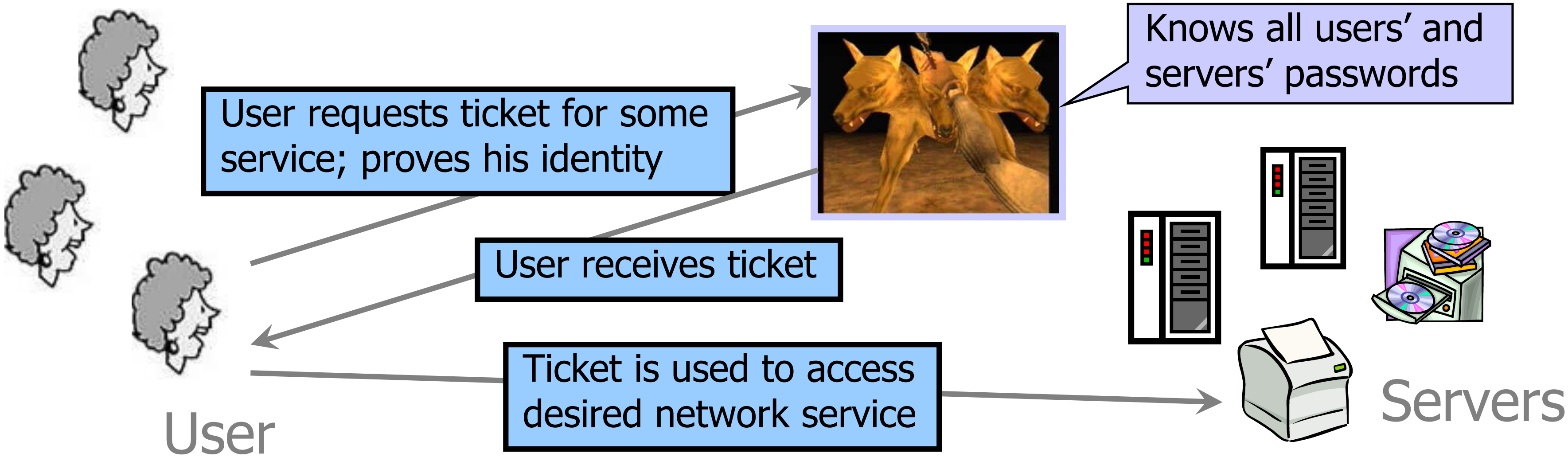
Key Distribution - Secret Keys

- What if there are millions of users and thousands of servers?
- Could configure n^2 keys for n users
- Better is to use a Key Distribution Center
  - Everyone has one key
  - The KDC knows them all
  - The KDC assigns a key to any pair who need to talk

Goals

- Requirements:
  - Security (sniffers and malicious users)
  - Reliability
  - Transparency
    - Users should not be aware of authentication action
    - Entering password is OK, if done rarely
  - Scalability
- Threats:
  - User impersonation:
    - can’t trust workstations to verify users’ identities
  - Network address impersonation: Spoofing
  - Eavesdropping, tampering and replay to gain unauthorized access

Solution: trusted third party



- Trusted authentication service on the network
  - Knows all passwords, can grant access to any server
  - Convenient, but also the single point of failure
  - Requires high level of physical security

Key Distribution - Secret Keys

KDC

Alice Bob

A wants to talk to B $\longrightarrow$

Randomly choose K_{ab}

$\longleftarrow \{\text{“B”}, K_{ab}\}_{Ka}$ $\{\text{“A”}, K_{ab}\}_{Kb} \longrightarrow$

$\{\text{Message}\}_{Kab} \longrightarrow$

A Common Variant

KDC

Alice

Bob

A wants to talk to B

Randomly choose K_{ab}

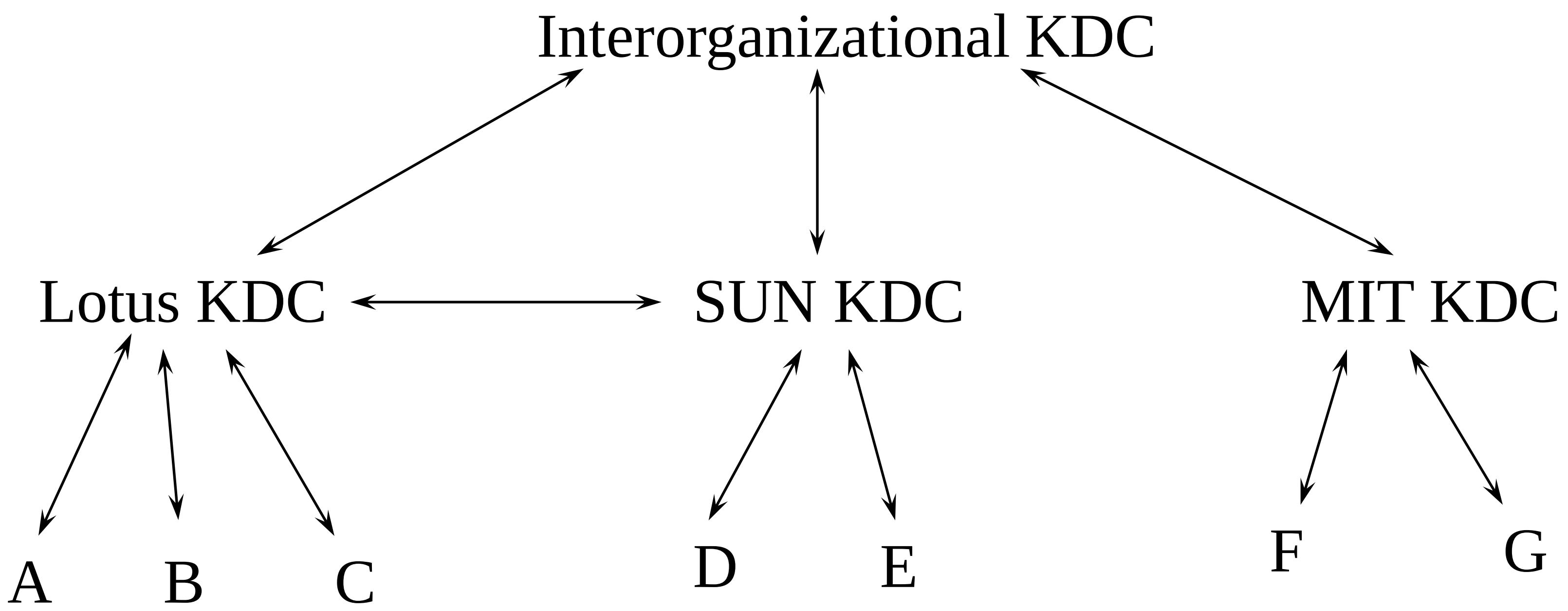
$\{$"B", $K_{ab}\}_{Ka}$, $\{$"A", $K_{ab}\}_{Kb}$

$\{$"A", $K_{ab}\}_{Kb}$, $\{Message\}_{Kab}$

KDC Realms

- KDCs scale up to hundreds of clients, but not millions
- There's no one who everyone in the world is willing to trust with their secrets
- KDC Realm: a KDC and the users of that KDC

KDC Realms



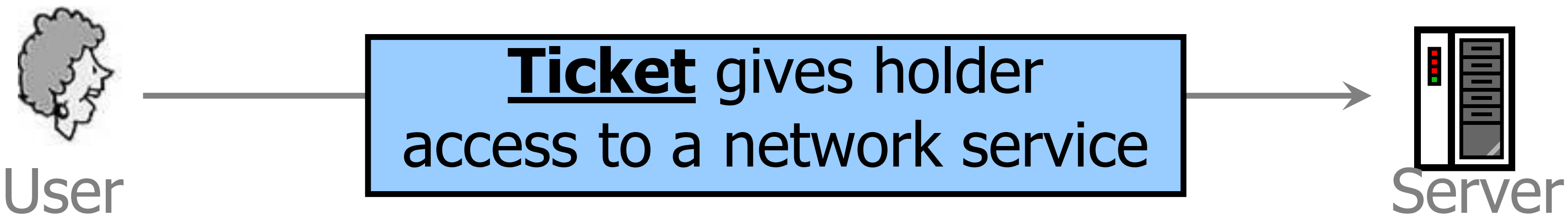
Interrealm KDCs

- How would you talk to someone in another realm?
- How would you know what realm?
- How would you know a path to follow?
- What can bad KDCs do?
- How do you know what path was used?
- Why do you care?

KDC Hierarchies

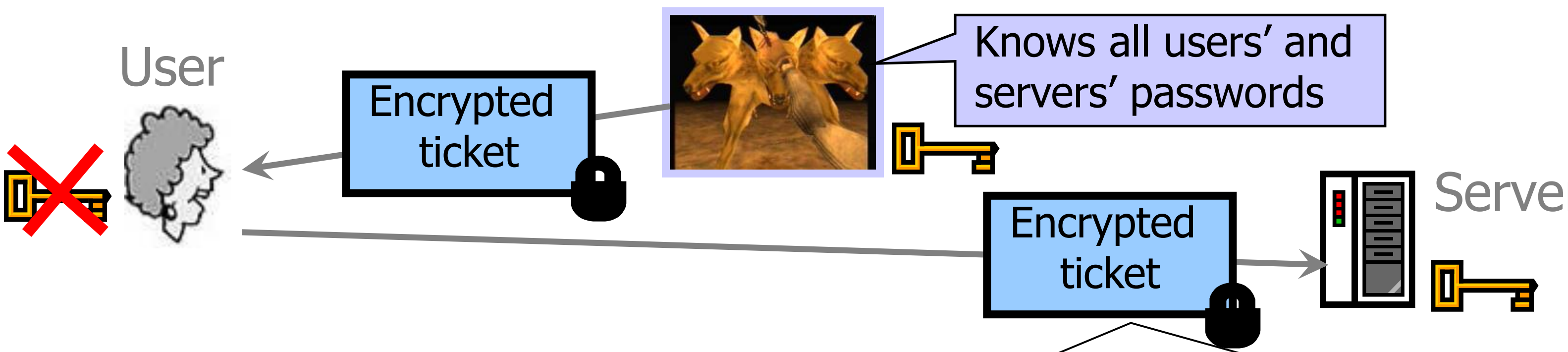
- In hierarchy, what can each compromised KDC do?
- What would happen if root was compromised?
- If it's not a name-based hierarchy, how do you find a path?

What should a ticket look like?



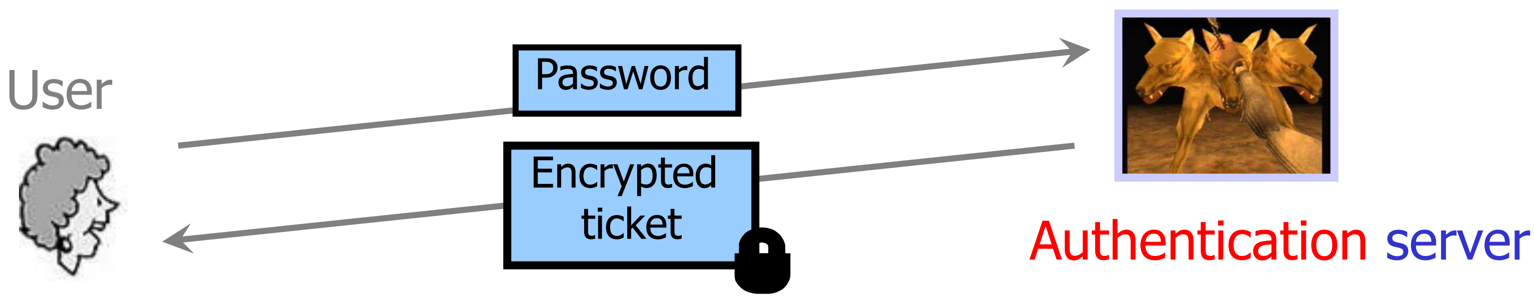
- Ticket cannot include server's plaintext password
  - Otherwise, next time user will access server directly without proving his identity to authentication service
- Solution: encrypt some information with a key derived from the server's password
  - Server can decrypt ticket and verify information
  - User does not learn server's password

What should a ticket include?



- User name
- Server name
- Address of user's workstation
  - Otherwise, a user on another workstation can steal the ticket and use it to gain access to the server
- Ticket lifetime
- A few other things (e.g., session key)

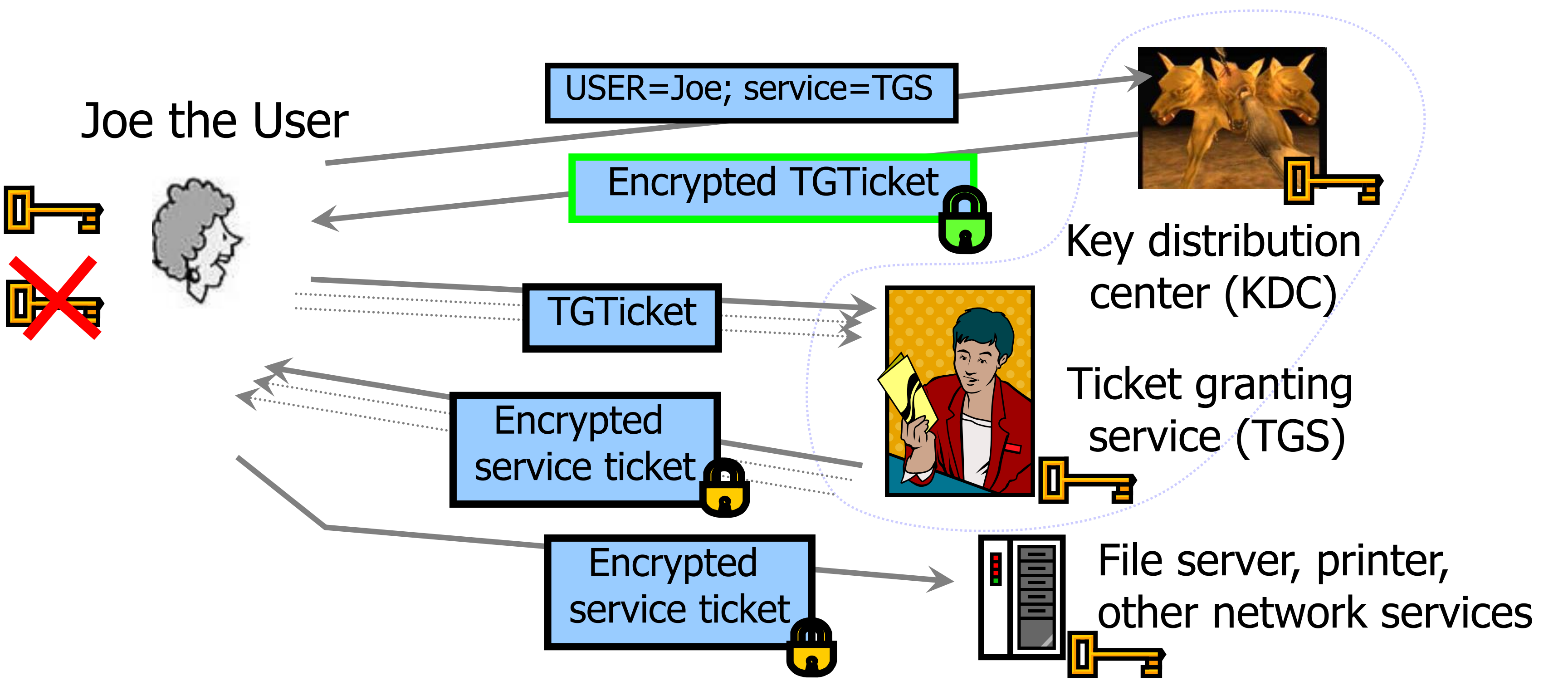
How is authentication done?



- Insecure: passwords are sent in plaintext
  - Eavesdropper can steal the password and later impersonate the user to the authentication server
- Inconvenient: need to send the password each time to obtain the ticket for any network service
  - Separate authentication for email, printing, etc.

Solution: Two-Step Authentication

- Prove identity **once** to obtain special TGTicket
  - Instead of password, use key derived from password
- Use TGT to get tickets for many network services



Still Not Good Enough

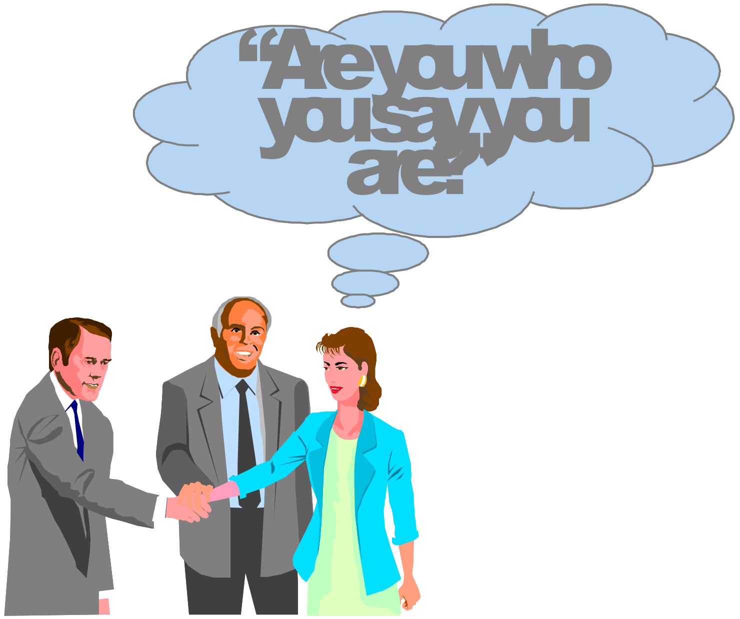
- Ticket hijacking
  - Malicious user may steal the service ticket of another user on the same workstation and use it
    - IP address verification does not help
  - Servers must be able to verify that the user who is presenting the ticket is the same user to whom the ticket was issued
- No server authentication
  - Attacker may misconfigure the network so that he receives messages addressed to a legitimate server
    - Capture private information from users and/or deny service
  - Servers must prove their identity to users

Key management

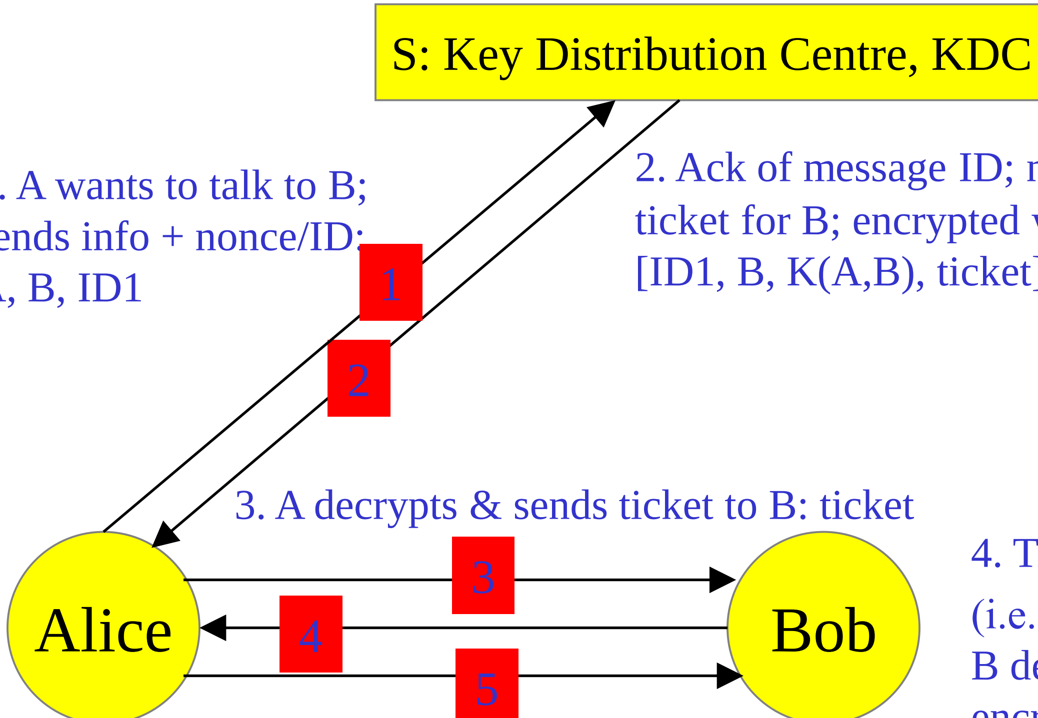
- Where do keys come from?
  - Symmetric Ciphers: Key Distribution Center (KDC)
  - Why?
    - Shared key for any communication pair does not scale and is cryptographically unwise – uses each key too much!
- Key lifetime / freshness?
  - Long-lived key for authentication and session key negotiation
  - Short-lived key for transfer
  - Why?
    - Long-lived keys are tempting/easy targets (stream ciphers!!!)
    - Compromised old keys

Needham-Schroeder Protocol (1978)

- Basis of Kerberos
- Relies on a key distribution centre (KDC)
- KDC is part of the trusted computing base
  - Knows secret keys of all participants
  - Manages *N* keys (instead of *N(N-1)/2*)
- Solves two key problems
  - Distribution of shared secret key
  - Mutual authentication



Needham and Schroeder's Protocol



1. A wants to talk to B; sends info + nonce/ID: A, B, ID1

2. Ack of message ID; new key for A ↔ B: K(A,B); ticket for B; encrypted with secret key of A: $[ID1, B, K(A,B), ticket]_{K(A)}$

3. A decrypts & sends ticket to B: ticket

4. Ticket contains $[K(A,B), A]_{K[B)}$ (i.e., encrypted with B's secret key). B decrypts it and sends A a unique ID encrypted in K(A, B): $[ID2]_{K(A,B)}$

5. A returns an agreed transformation of B's ID encrypted with K(A,B): $[ID2 - 1]_{K(A,B)}$

Alices proves that she can read nounce

Cryptographic protocol design is hard

- Bob never proved his identity to Alice
- If K(A,B) is compromised attacker can impersonate Alice forever
- Denning and Sacco proposed a fix in 1981
- Needham found a flaw in their fix in 1994
- Another flaw found in public key version in 1995 (it is actually only a 3-message protocol)

- Cryptographic protocol design is hard!!!

Kerberos [RFC4120,NeumanTs'94]

- Kerberos: ("der Höllenhund") The watch dog of Hades, whose duty it was to guard the entrance – against whom or what does not clearly appear; … it is known to have had three heads…

  - Ambrose Bierce, The Enlarged Devil's Dictionary
- Designed to authenticate users to servers
- Users use their password to authenticate themselves
- It is possible to protect the Kerberos server
- Assumption: The workstations have not been tampered with!

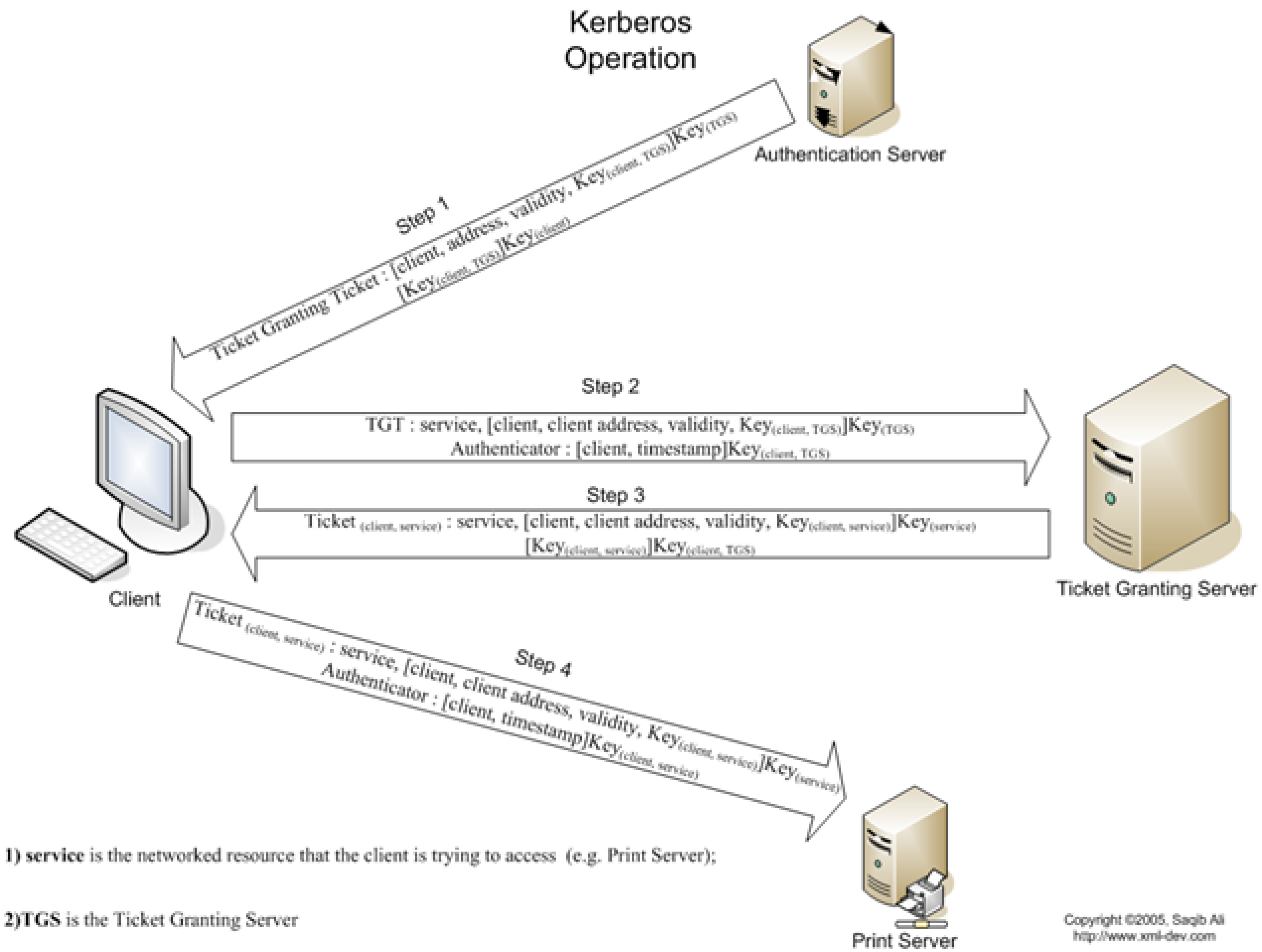
Kerberos lingua

- Principles: Kerberos entity
  - User or system service
  - Triples: (primary name, instance, realm)
    Realm: identifies Kerberos server
  - Examples:
    username@some.domain.name
    somehost/lpr@other.domaim
- Tickets: cryptographically sealed messages with session keys and identifiers
  - Used to obtain a service
- Ticket-Granting ticket (TGT)
  - Ticket to obtain other tickets

How Kerberos works

- Relies on
  - Kerberos key distribution center (KDC)
  - Ticket granting service (TGS)
- Users
  - Have to present a ticket to obtain a service
  - Request TGT from KDC via extended Needham-Schroeder (using their shared secret with the KDC)
  - Request tickets from TGS via extended Needham-Schroeder (using the TGT)

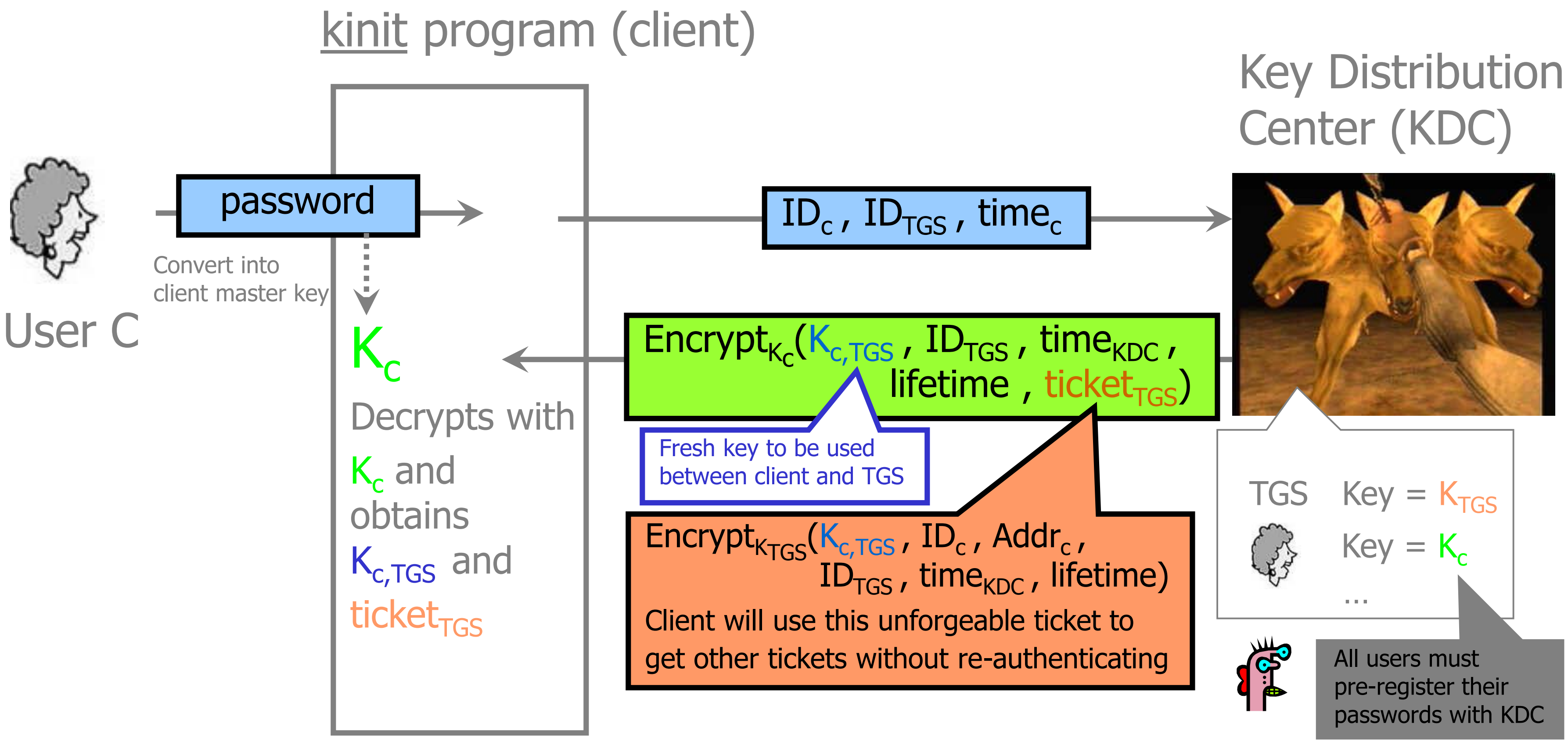
Kerberos picture



Symmetric keys in Kerberos

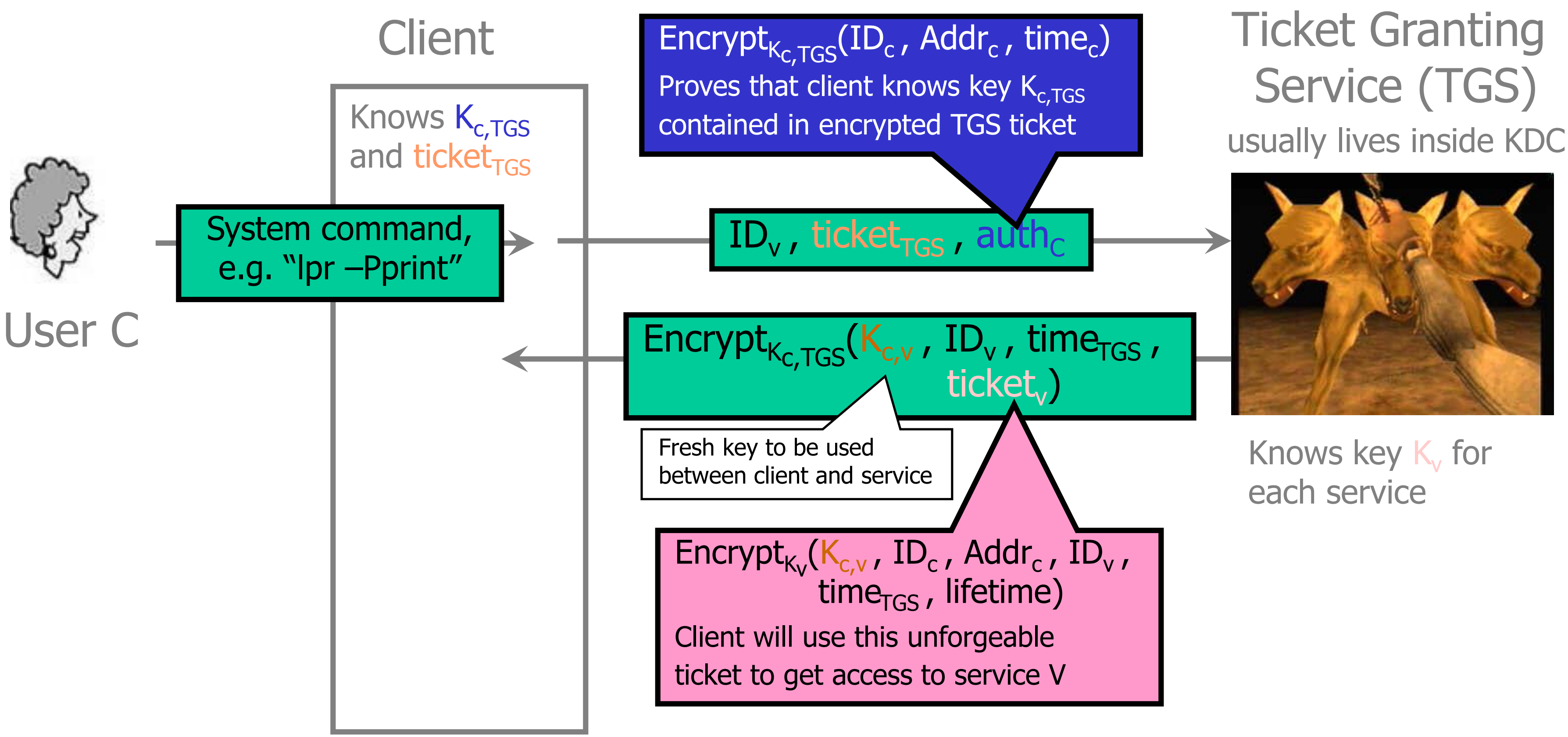
- K_c is long-term key for each client C
  - Derived from user's password
  - Known to client and key distribution center (KDC)
- K_{TGS} is long-term key of TGS
  - Known to KDC and ticket granting service (TGS)
- K_v is long-term key of each service V
  - Known to V and TGS; separate key for each service
- $K_{c,TGS}$ is short-term key between C and TGS
  - Created by KDC, known to C and TGS
- $K_{c,v}$ is short-term key between C and V
  - Created by TGS, known to C and V

“Single logon” authentication



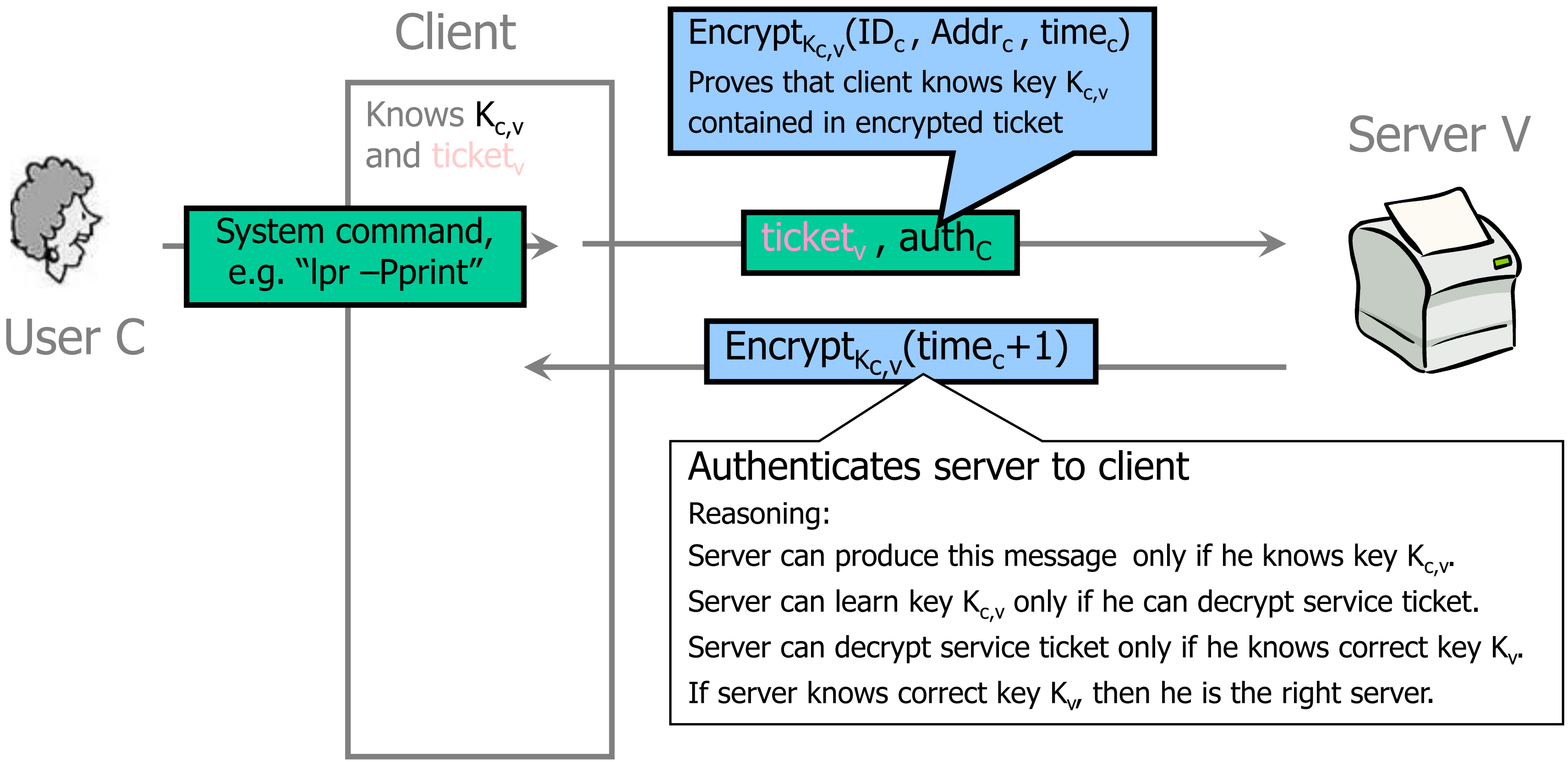
- Client only needs to obtain TGTicket **once** (say, every morning)
  - Ticket is encrypted; client cannot forge it or tamper with it

Obtaining a service ticket



- Client uses TGTicket to obtain a service ticket and a short-term key for each network service
  - One encrypted, unforgeable ticket per service (printer, email, etc.)

Obtaining service

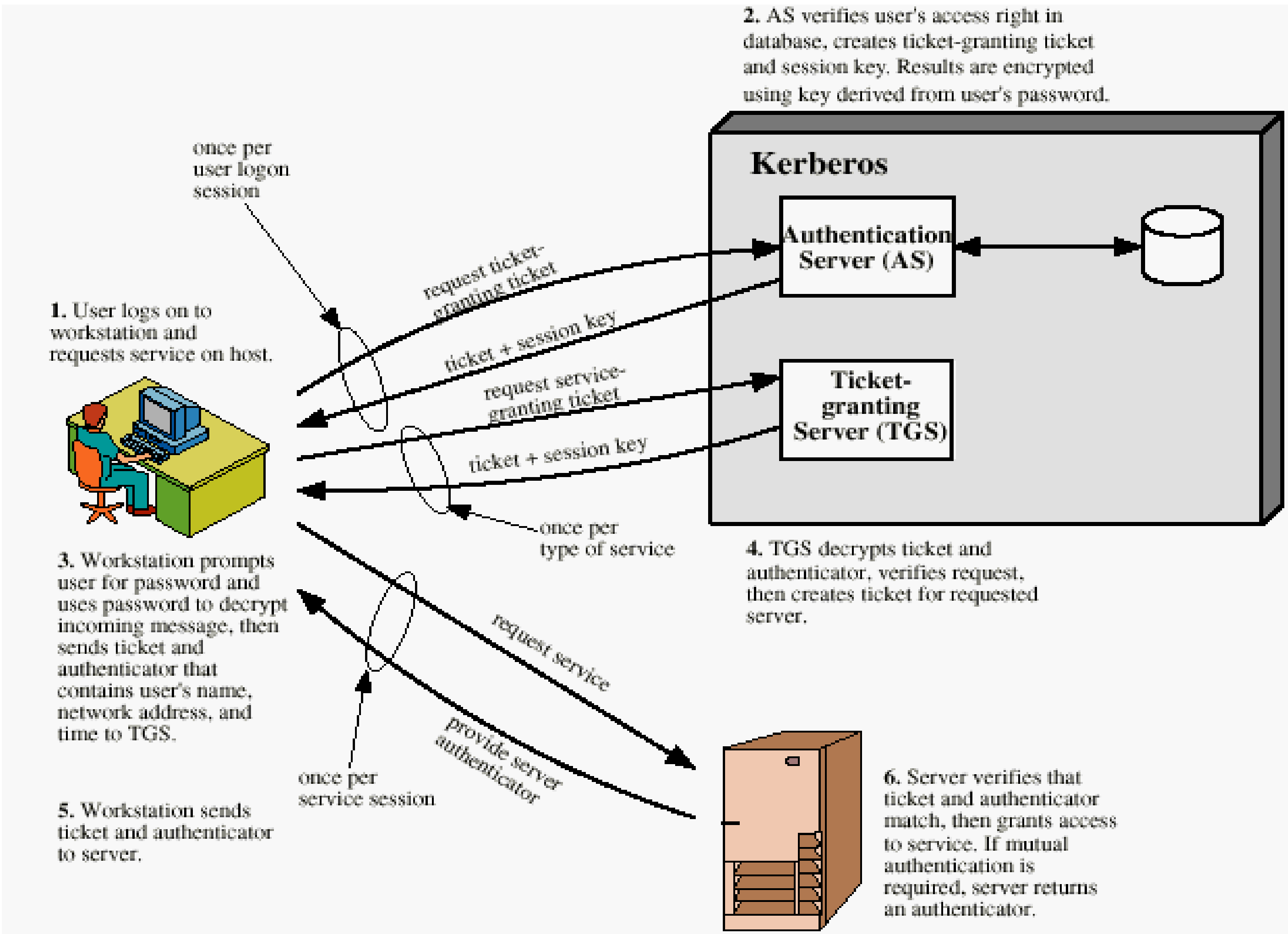


- For each service request, client uses the short-term key for that service and the ticket he received from TGS

Kerberos in large networks

- One KDC isn't enough for large networks (why?)
- Network is divided into realms
  - KDCs in different realms have different key databases
- To access a service in another realm, users must…
  - Get ticket for home-realm TGS from home-realm KDC
  - Get ticket for remote-realm TGS from home-realm TGS
    - As if remote-realm TGS were just another network service
  - Get ticket for remote service from that realm's TGS
  - Use remote-realm ticket to access service
  - N(N-1)/2 key exchanges for full N-realm interoperation

Summary of Kerberos



Important ideas in Kerberos

- Use of short-term session keys
  - Minimize distribution and use of long-term secrets; only used to derive short-term session keys
  - Separate short-term key for each user-server pair
    - But multiple user-server sessions reuse the same key!
- Proofs of identity are based on authenticators
  - Client encrypts his identity, address and current time using short-term session key
    - Also prevents replays (if clocks are globally synchronized)
  - Server learns this key separately (via encrypted ticket that client cannot decrypt) and verifies user’s identity
- Symmetric cryptography only

Problematic issues

- Password dictionary attacks on client master keys
- Ticket cache security
- Subverted login command
- Replay of authenticators
  - 5-minute lifetimes long enough for replay
  - Timestamps assume global, secure synchronized clocks
  - Challenge-response would be better
- Same user-server key used for all sessions
- Homebrewed mode of cipher encryption
  - Tries to combine integrity check with encryption
- Extraneous double encryption of tickets
- No ticket delegation
  - Printer cannot fetch email from server on your behalf

Kerberos Version 5

- Better user-server authentication
  - Separate subkey for each user-server session instead of re-using the session key contained in ticket
  - Authentication via subkeys, not timestamp increments
- Authentication forwarding
  - Servers can access other servers on user's behalf
- Realm hierarchies for inter-realm authentication
- Richer ticket functionality
- Explicit integrity checking + standard CBC mode
- Multiple encryption schemes, not just DES

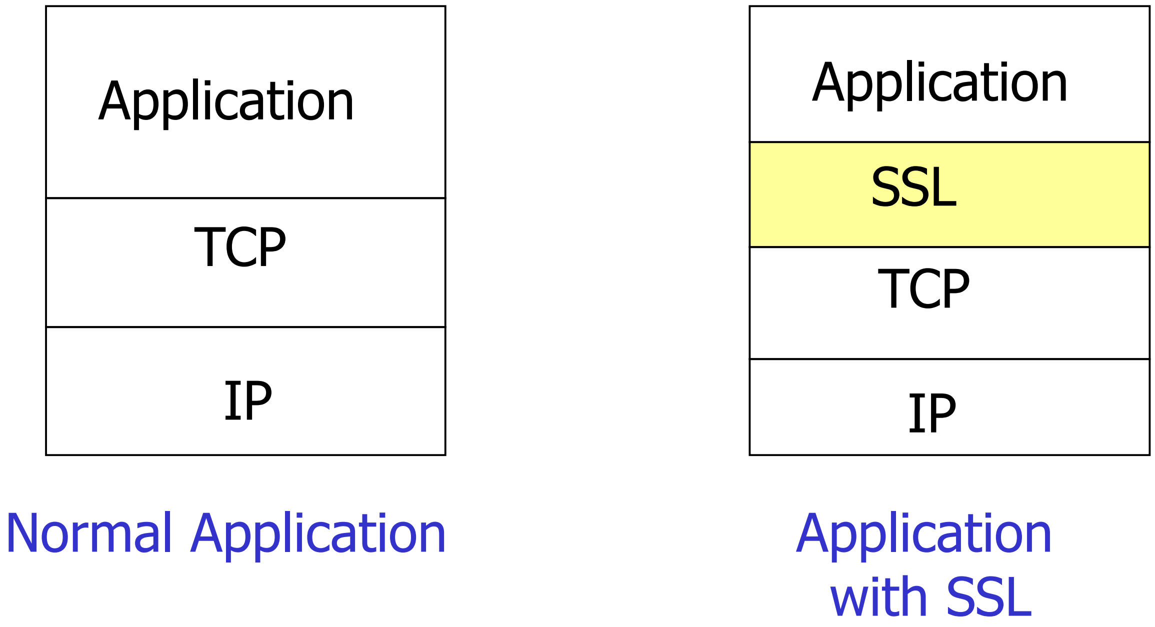
Practical Uses of Kerberos

- Email, FTP, network file systems and many other applications have been kerberized
  - Use of Kerberos is transparent for the end user
  - Transparency is important for usability!
- Standard authentication for Windows (since W2K)
- Local authentication
  - login and su in OpenBSD
- Authentication for network protocols
  - rlogin, rsh, telnet, afs
- Secure windowing systems
  - xdm, kx

SSL: Secure Sockets Layer

- Widely deployed
  - Supported by almost all Web browsers and servers
  - **https**
  - Lots $ spent over SSL
- Originally designed by Netscape in 1993
- Proposed standard:
  - TLS: transport layer security (RFC 4346)
- Provides
  - Confidentiality
  - Integrity
  - Authentication
- Original goals:
  - Secure Web e-commerce transactions
  - Encryption (especially credit-card numbers)
  - Web-server authentication
  - Optional client authentication
  - Minimum hassle for business with new merchant
- Available to all TCP applications
  - Secure socket interface

SSL and TCP/IP

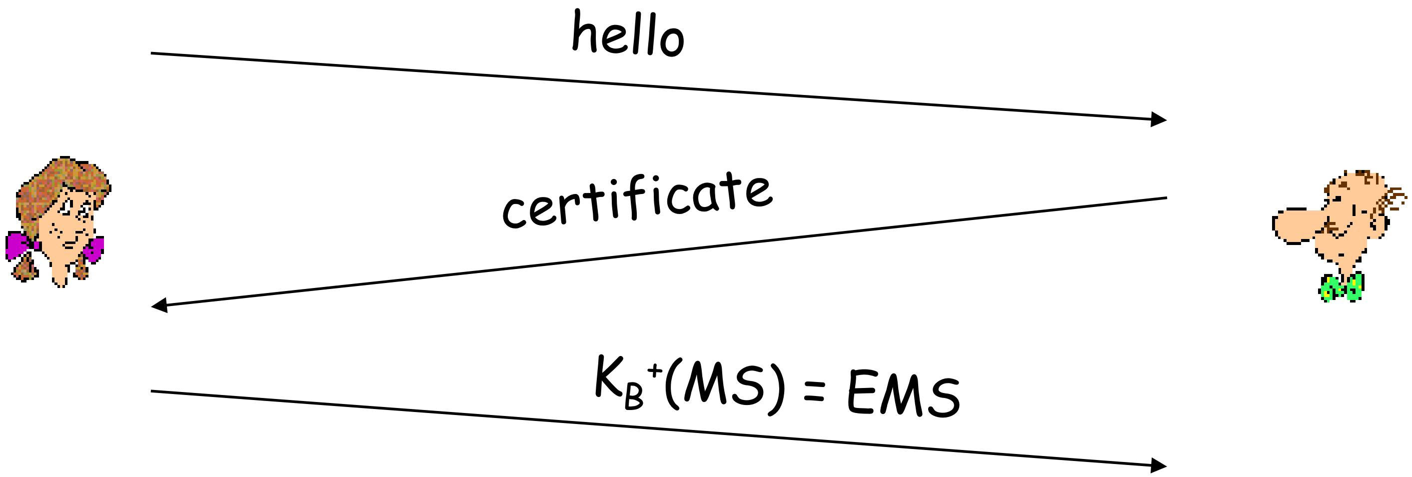


- SSL provides application programming interface (API) to applications
- Many SSL libraries/classes readily available, including C, C++, Java, Perl, ...

Toy SSL: a simple secure channel

- Handshake: Alice and Bob use their certificates and private keys to authenticate each other and exchange shared secret
- Key Derivation: Alice and Bob use shared secret to derive set of keys
- Data Transfer: Data to be transferred is broken up into a series of records
- Connection Closure: Special messages to securely close connection

Toy: simple handshake

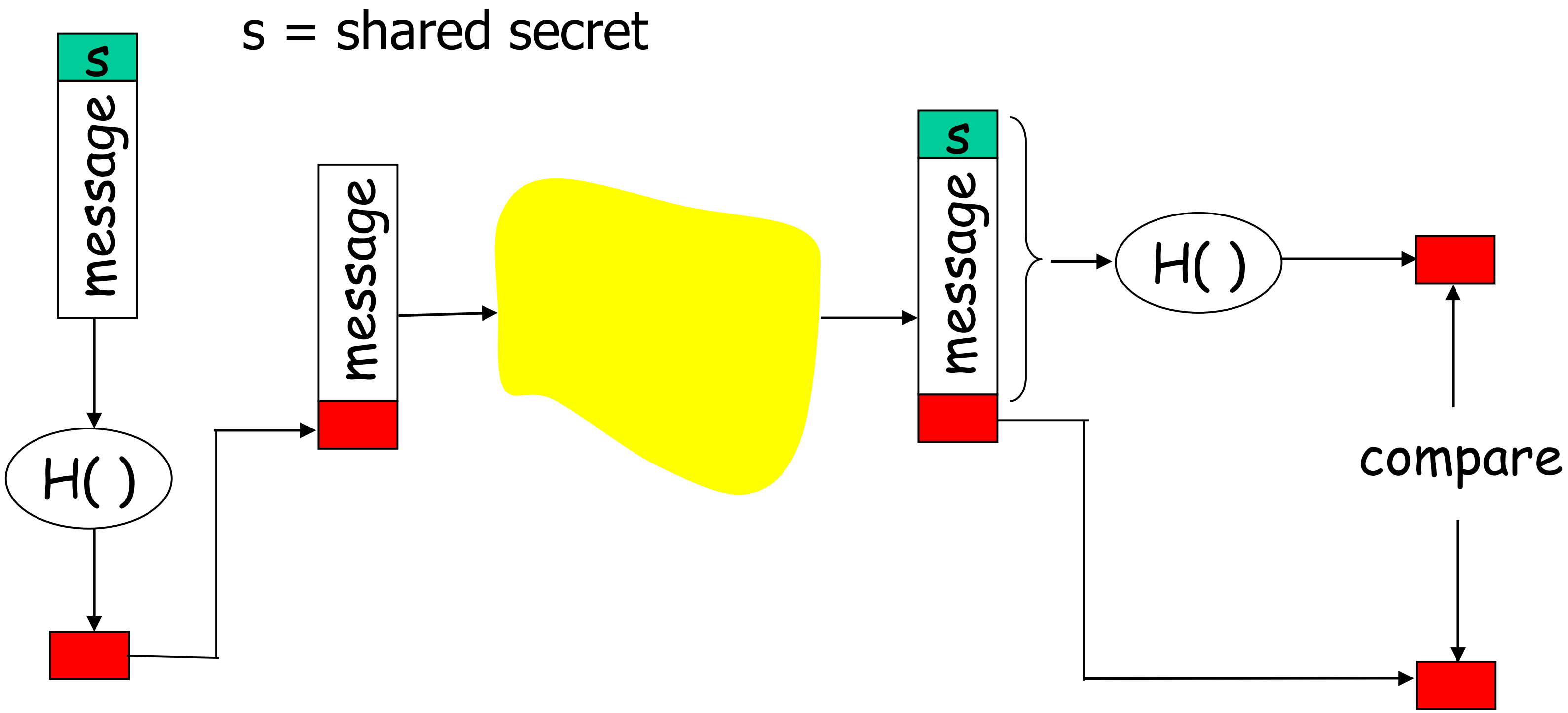


- MS = master secret
- EMS = encrypted master secret

Toy: key derivation

- Bad to use same key for >1 cryptographic op.
  - Different keys for message authentication code (MAC) and encryption
- Four keys:
  - K_c = encryption key for data sent from client to server
  - M_c = MAC key for data sent from client to server
  - E_s = encryption key for data sent from server to client
  - M_s = MAC key for data sent from server to client
- Keys derived via key derivation function (KDF)
  - Takes master secret and (possibly) some additional random data and creates the keys

Recall MAC



- Recall that HMAC is a standardized MAC algorithm
- SSL uses a variation of HMAC
- TLS uses HMAC

Toy: data records

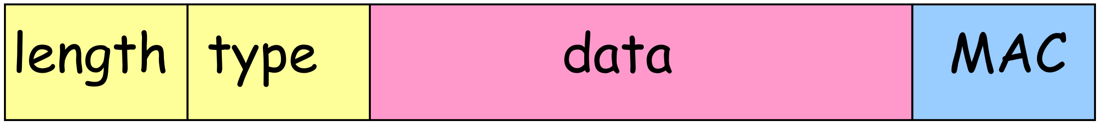
- Why not encrypt data in stream as we write it to TCP?
  - Where to put MAC?
    At end? No message integrity until all data processed.
  - E.g.: instant messaging: how to do integrity check over all bytes before displaying?
- Break stream in series of records
  - Each record carries a MAC
  - Receiver can act on each record as it arrives
- Issue for receiver: how to distinguish MAC from data
  - Want to use variable-length records

Toy: sequence numbers

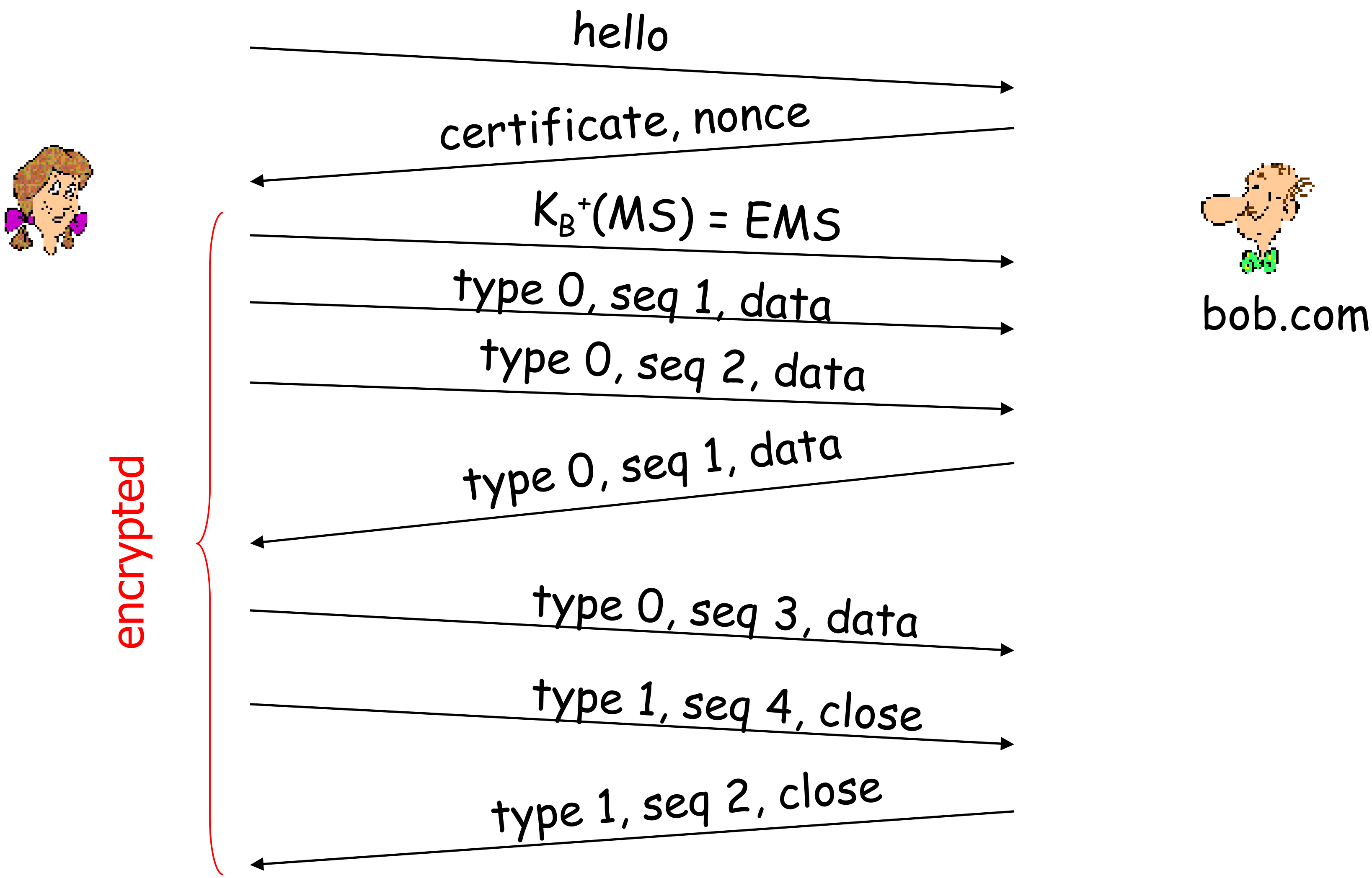
- Attacker can capture and replay record or re-order records
- Solution: put sequence number into MAC:
  - MAC = MAC(M_x, sequence||data)
  - Sequence number serves as nonce for record
  - Note: no sequence number field
- Attacker could still replay all of the records
  - Use session nonce as well

Toy: control information

- Truncation attack:
  - Attacker forges TCP connection close segment
  - One or both sides thinks there is less data than there actually is.
- Solution: record types, with special type for closure
  - Type 0 for data; type 1 for closure
- MAC = MAC(M_x, sequence||type||data)



Toy SSL: summary



Toy SSL is not complete

- How long are the fields?
- What encryption protocols?
- No negotiation
  - Allow support for different encryption algorithms
  - Allow client and server to choose together specific algorithm before data transfer

Most common symmetric ciphers in SSL

- DES – Data Encryption Standard: block
- 3DES – Triple strength: block
- RC2 – Rivest Cipher 2: block
- RC4 – Rivest Cipher 4: stream

Public key encryption

- RSA

SSL cipher suite

- Cipher suite
  - Public-key algorithm
  - Symmetric encryption algorithm
  - MAC algorithm
- SSL supports a variety of cipher suites
- Negotiation:
  - Client offers choice; server picks one

Real SSL: handshake (1)

Purpose

1. Server authentication
2. Negotiation: agree on crypto algorithms
3. Establish keys
4. Client authentication (optional)

Real SSL: handshake (2)

1. Client sends list of algorithms, along with client nonce
2. Server chooses algorithms from list;
   sends back: choice + certificate + server nonce
3. Client verifies certificate,
   extracts server's public key,
   generates pre_master_secret,
   encrypts with server's public key,
   sends to server
4. Client and server independently compute encryption and MAC keys from pre_master_secret and nonces

5. Client sends MAC of all handshake messages
6. Server sends MAC of all handshake messages

Real SSL: handshaking (3)

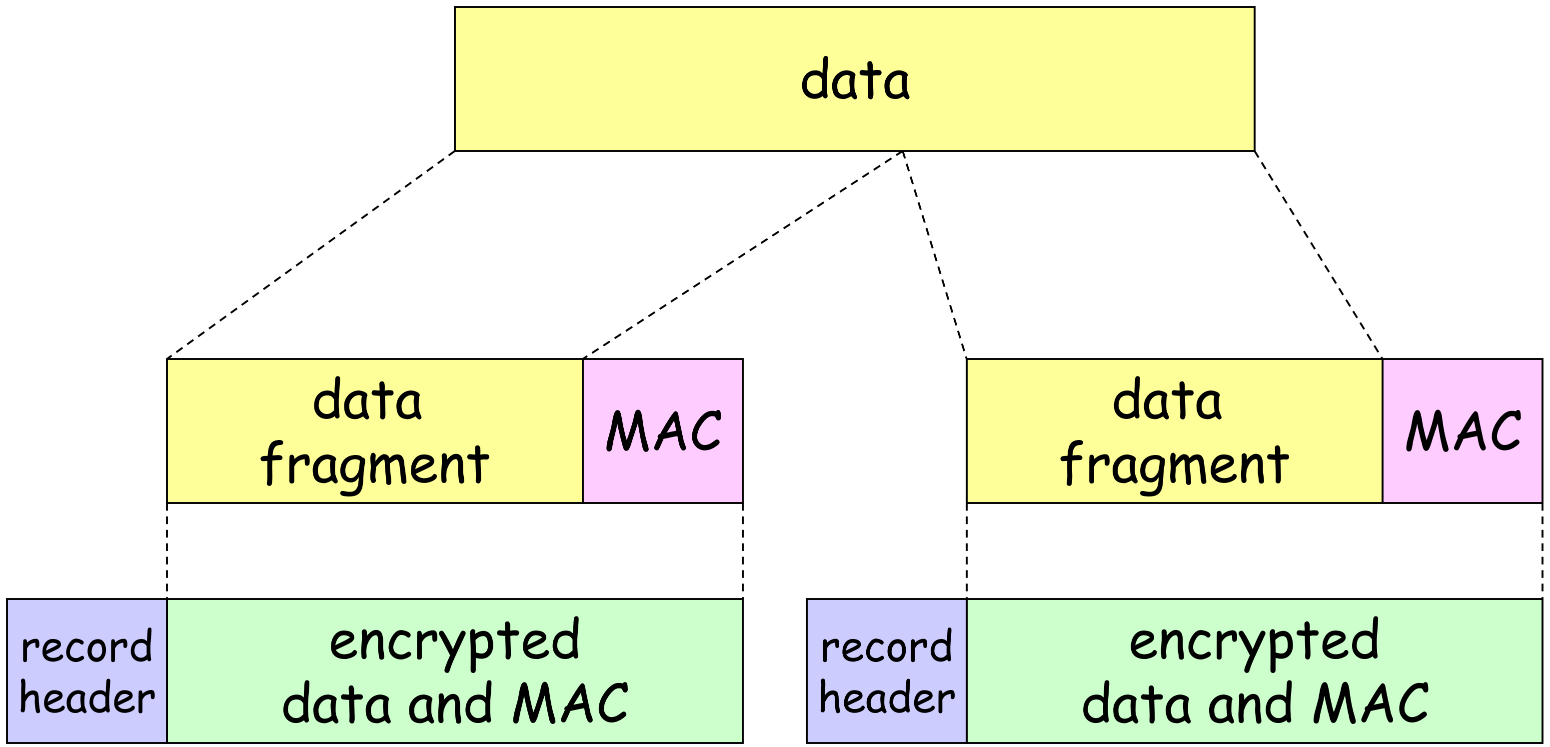
Last 2 steps protect against tampering of handshake

- Client typically offers range of algorithms: some strong, some weak
- Man-in-the-middle can delete stronger algorithms
- Last 2 steps prevent this
  - Note: last two messages are encrypted!

Handshake types

- All handshake messages (with SSL header) have 1 byte type field: Types
  - ClientHello
  - ServerHello
  - Certificate
  - ServerKeyExchange
  - CertificateRequest
  - ServerHelloDone
  - CertificateVerify
  - ClientKeyExchange
  - Finished

SSL record protocol

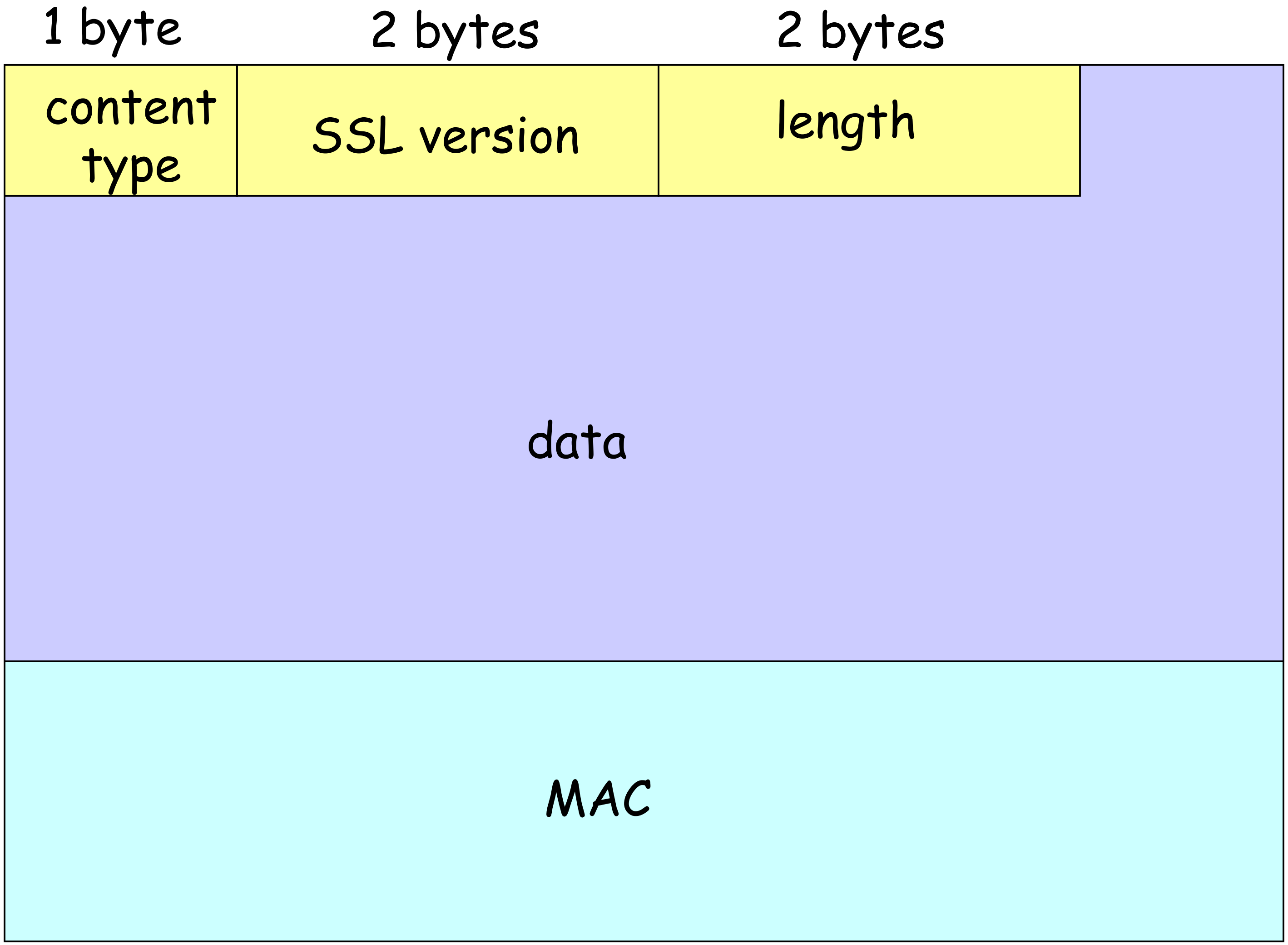


Record header: content type; version; length

MAC: includes sequence number, MAC key M_x

Fragment: each SSL fragment 2^{14} bytes (~16 Kbytes)

SSL record format

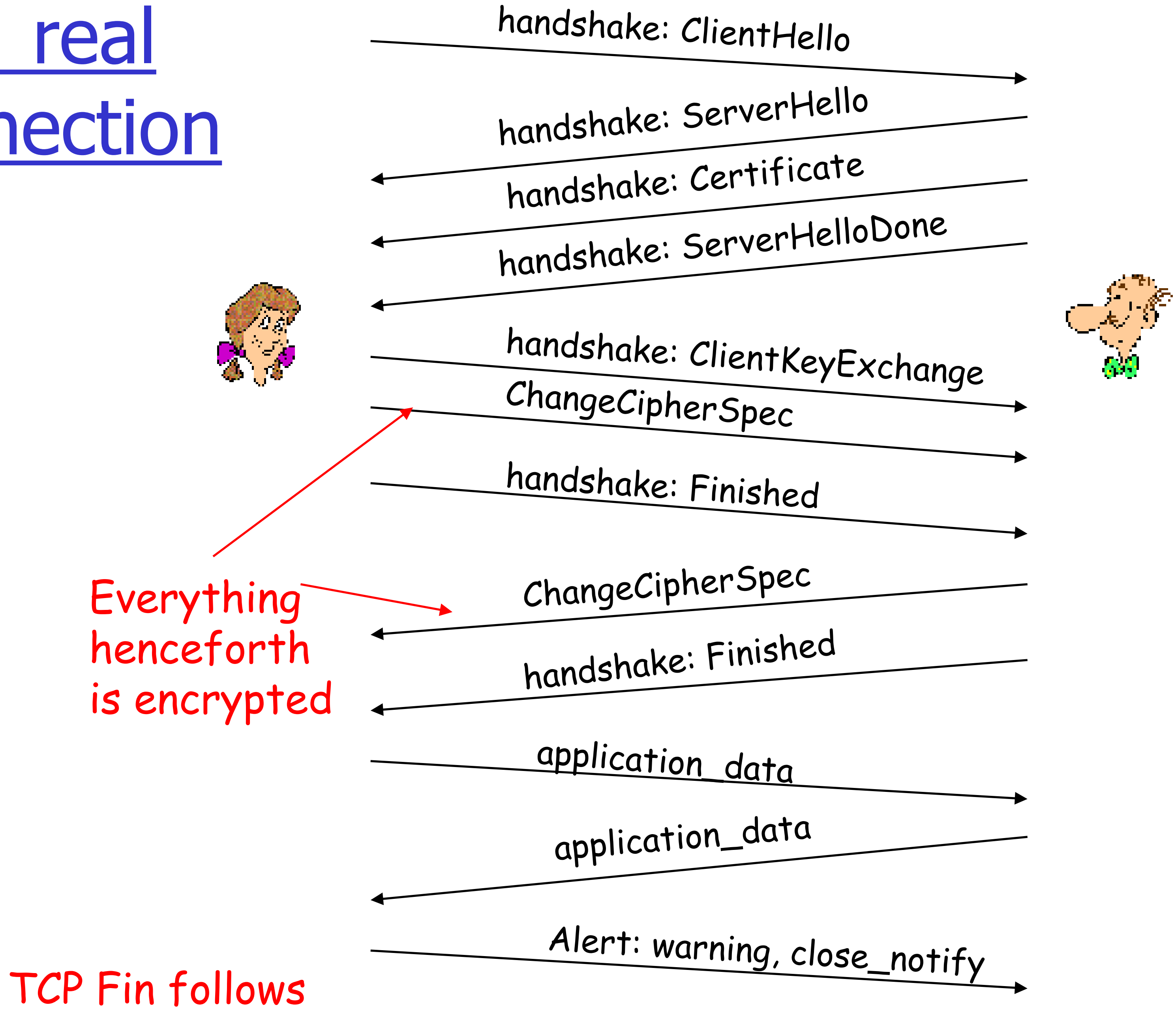


Data and MAC encrypted (symmetric key algorithm)

Content types in record header

- Application_data
- Alert
  - Signaling errors during handshake
- Handshake
  - Initial handshake messages are carried in records of type “handshake”
  - Handshake messages in turn have their own types
- Change_cipher_spec
  - Indicates change in encryption and authentication algorithms

SSL: real connection



Comments about trace messages

ClientHello

- Random: 32-byte nonce

ServerHello

- Cipher suite: RSA key exchange, DES-CBC message encryption, SHA digest
- Random: 32-byte nonce
- Session_id: used for session resumption

Certificate

- X.509 format
- Subject: company info
- Issuer: CA
- Certificate = public key

ClientKeyExchange

- Includes encrypted PreMasterSecret

Finished

- MAC of concatenation of handshake messages

Key derivation

- Client random, server random, and pre-master secret input into pseudo random-number generator.
  - Produces master secret
- Master secret, client and server random numbers into another random-number generator
  - Produces "key block"
- Key block sliced and diced:
  - Client MAC key
  - Server MAC key
  - Client encryption key
  - Server encryption key
  - Client initialization vector (IV)
  - Server initialization vector (IV)

SSL performance

- Recall: big-number operations in public-key crypto are CPU intensive
- Server handshake
  - Typically over half SSL handshake CPU time goes to RSA decryption of the encrypted pre_master_secret
- Client handshake
  - Public key encryption is less expensive
  - Server is handshake bottleneck
- Data transfer
  - Symmetric encryption
  - MAC calculation
  - Neither is as CPU intensive as public-key decryption

Session resumption

- Full handshake is expensive: CPU time
- If the client and server have already communicated once, they can skip handshake and proceed directly to data transfer
  - Session caching
  - For a given session, client and server store session_id, master_secret, negotiated ciphers
- Client sends session_id in ClientHello
- Server then agrees to resume in ServerHello
  - New key_block computed from master_secret and client and server random numbers

Client authentication

- SSL can also authenticate client
- Server sends a CertificateRequest message to client

Who issues Web certificates?

- Browser comes with list of built-in certificate authorities
- Firefox: 138(?) certificate authorities!
- Do you trust them all to be honest and competent?
- Do you even know them?

E.g.: Baltimore Cybertrust

- Sold its PKI in 2003
- What about the new owners?

Mountain America Credit Union

- Reputable CA issued certificate for Mountain America
- DNS name: www.mountain-america.net
- Looks OK
- But „real" site at www.mtnamerica.org

- Which site is intended by the user?

Technical attack

- Scenario:
  - Usually: shoping via unencrypted pages
  - Click on „Checkout" (or „Login" on bank Web site)
  - Next page – downloaded without SSL protection – has login link, which uses SSL
- Attack:
  - Tamper with that page
  - Will anyone notice
  - Note some sites outsource payment processing!

SSL summary

- Cryptography itself seems correct
  - Indeed is formally verified after many iterations
- Human factors are dubious
- Most users don‘t know what a certificate is, or how to verify one

  Moreover: hard to know what it should say!
- No rational basis for deciding whether or not to trust a CA