15-640/440: Distributed Systems

Lecture 23: Key Distribution and Management

Thanks to the many, many people who have contributed various slides to this deck over the years.

Key Distribution

- Have network with n entities
- Add one more
  - Must generate n new keys
  - Each other entity must securely get its new key
  - Big headache managing n^2 keys!
- One solution: use a central keyserver
  - Needs n secret keys between entities and keyserver
  - Generates session keys as needed
  - Downsides
    - Only scales to single organization level
    - Single point of failure

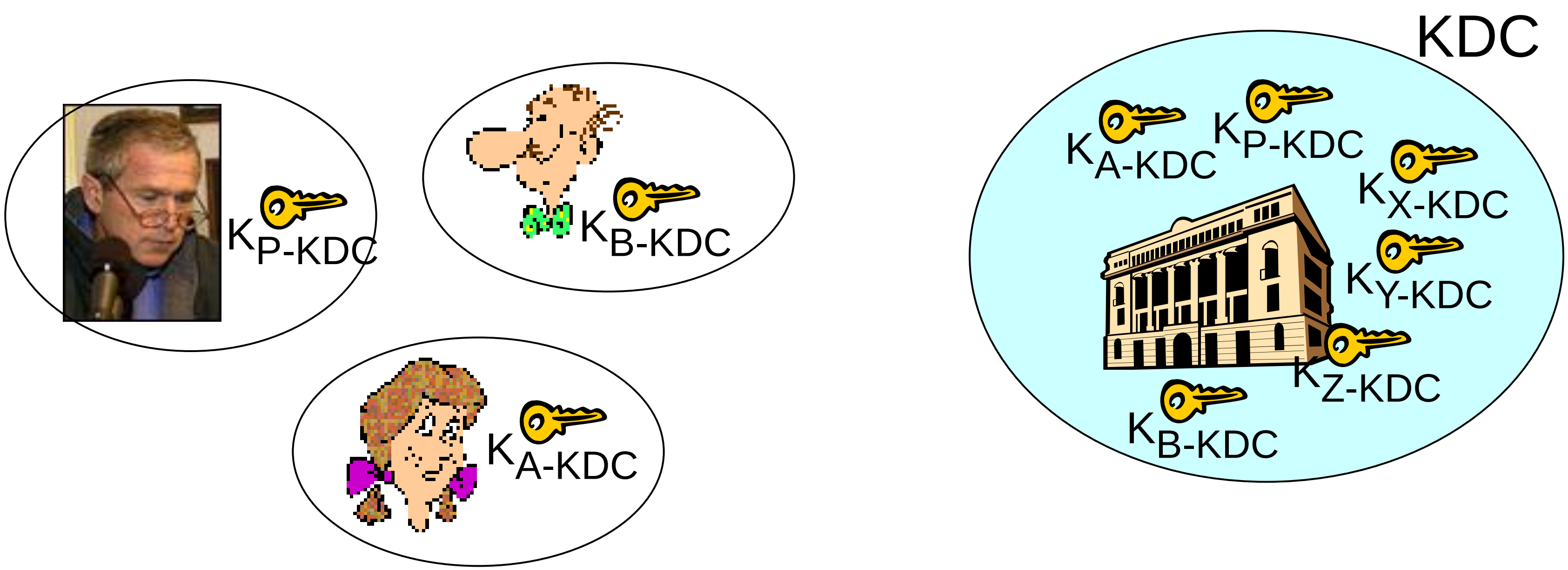
Symmetric Key Distribution

- How does Andrew do this?

Andrew Uses Kerberos, which relies on a Key Distribution Center (KDC) to establish shared symmetric keys.

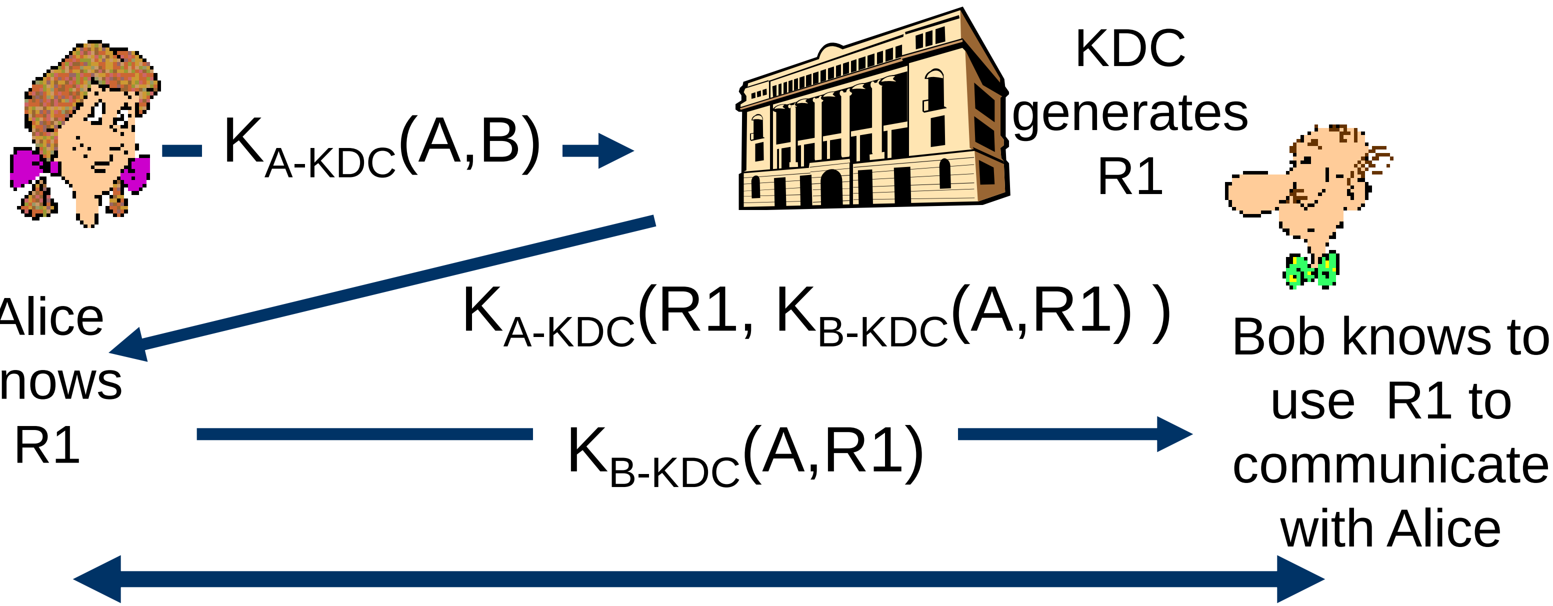
Key Distribution Center (KDC)

- Alice, Bob need shared <u>symmetric key</u>.
- KDC: server shares different secret key with *each* registered user (many users)
- Alice, Bob know own symmetric keys, K_{A-KDC} K_{B-KDC} , for communicating with KDC.



Key Distribution Center (KDC)

Q: How does KDC allow Bob, Alice to determine shared symmetric secret key to communicate with each other?



Alice and Bob communicate: using R1 as *session key* for shared symmetric encryption

How Useful is a KDC?

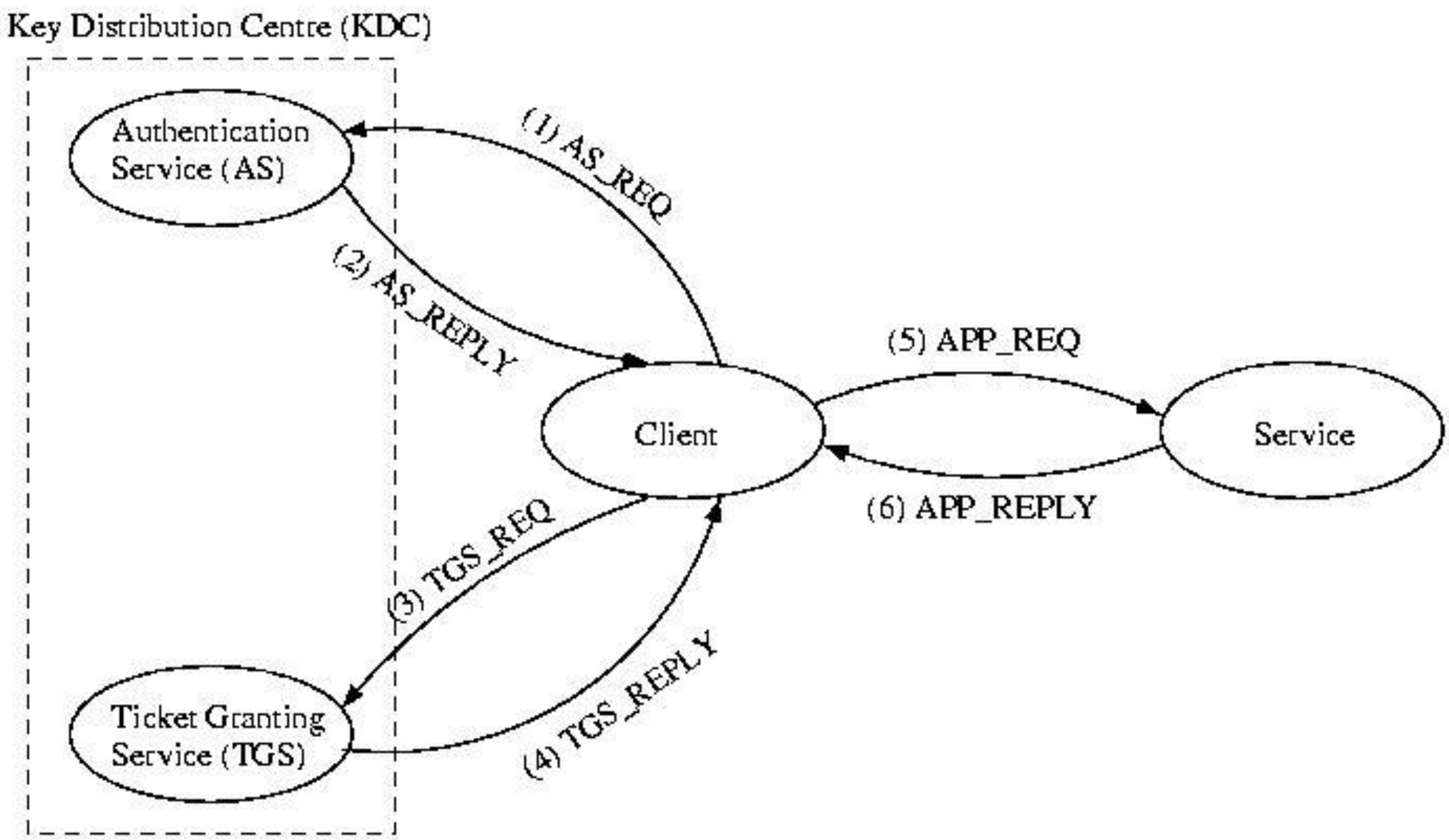
- Must always be online to support secure communication
- KDC can expose our session keys to others!
- Centralized trust and point of failure.

In practice, the KDC model is mostly used within single organizations (e.g. Kerberos) but not more widely.

Kerberos

- Trivia
  - Developed in 80's by MIT's Project Athena
  - Used on all Andrew machines
  - Mythic three-headed dog guarding the entrance to Hades
- Uses DES, 3DES
- Key Distribution Center (KDC)
  - Central keyserver for a Kerberos domain
  - Authentication Service (AS)
    - Database of all master keys for the domain
    - Users' master keys are derived from their passwords
    - Generates ticket-granting tickets (TGTs)
  - Ticket Granting Service (TGS)
    - Generates tickets for communication between principals
  - "slaves" (read only mirrors) add reliability
  - "cross-realm" keys obtain tickets in others Kerberos domains

Kerberos Authentication Steps

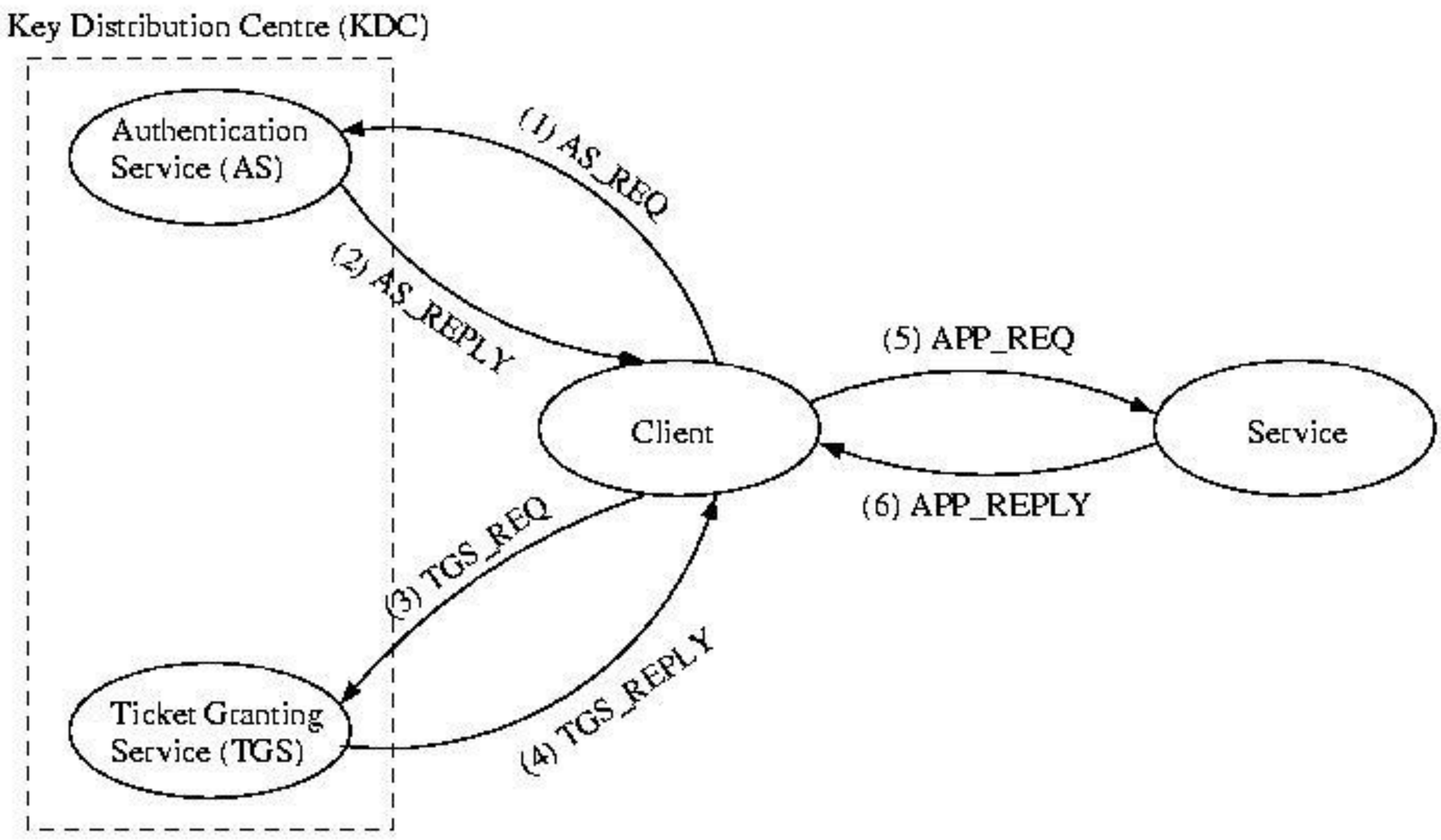


(1) AS_REQUEST

- The first step in accessing a service that requires Kerberos authentication is to obtain a *ticket-granting ticket*.

- To do this, the client sends a plain-text message to the AS:
  - <client id, KDC id, requested ticket expiration, nonce1>

Kerberos Authentication Steps



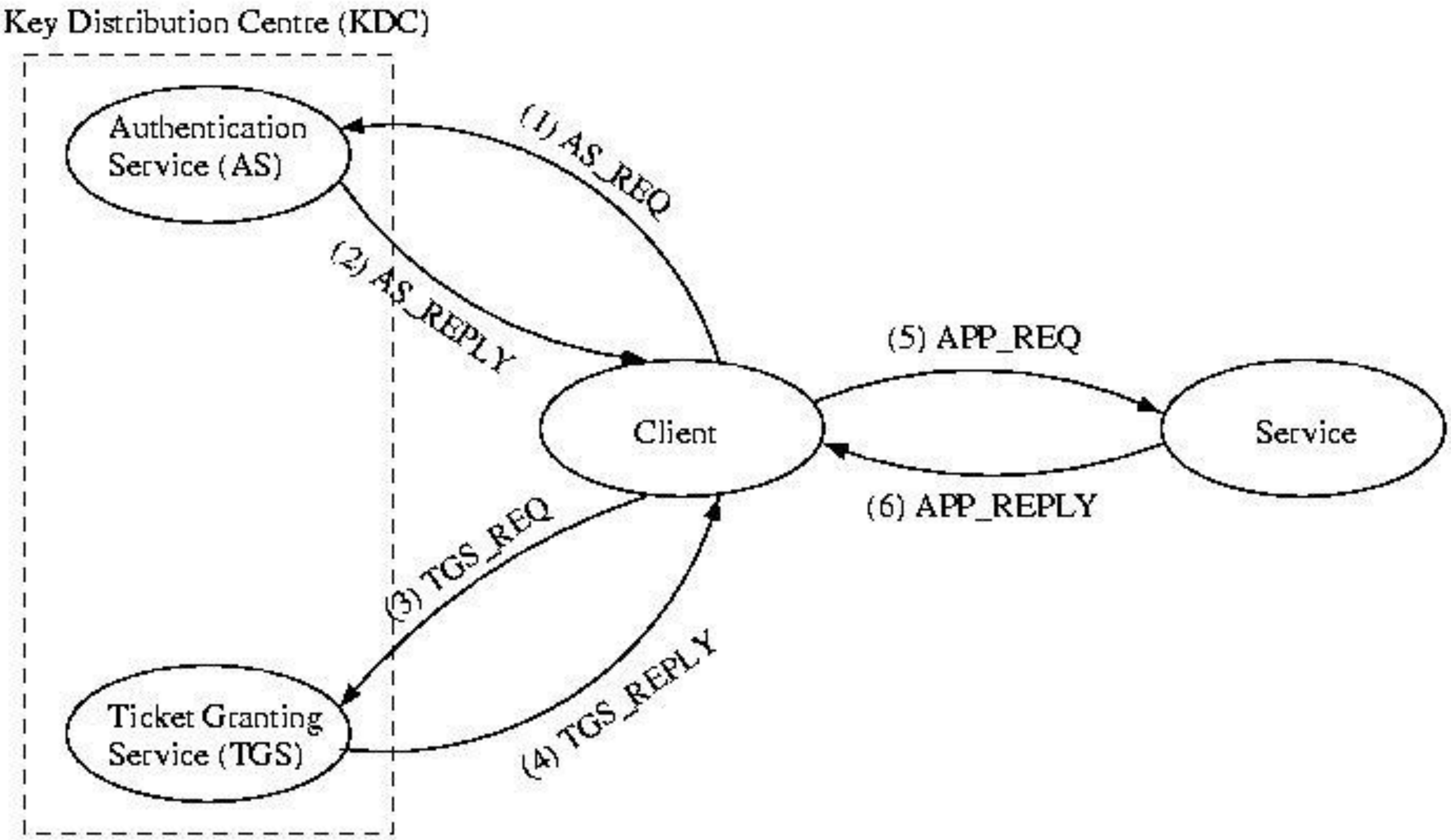
(2) AS_REPLY

- $<\{K_{c,TGS}, \text{none1}\}K_c, \{\text{ticket}_{c,tgs}\}K_{TGS}>$

- Notice the reply contains the following:
  - The nonce, to prevent replays
  - The new session key
  - A *ticket* that the client can’t read or alter

- A ticket:
  - $\text{ticket}_{x,y}$ = {x, y, beginning valid time, expiration time, $K_{x,y}$}

Kerberos Authentication Steps



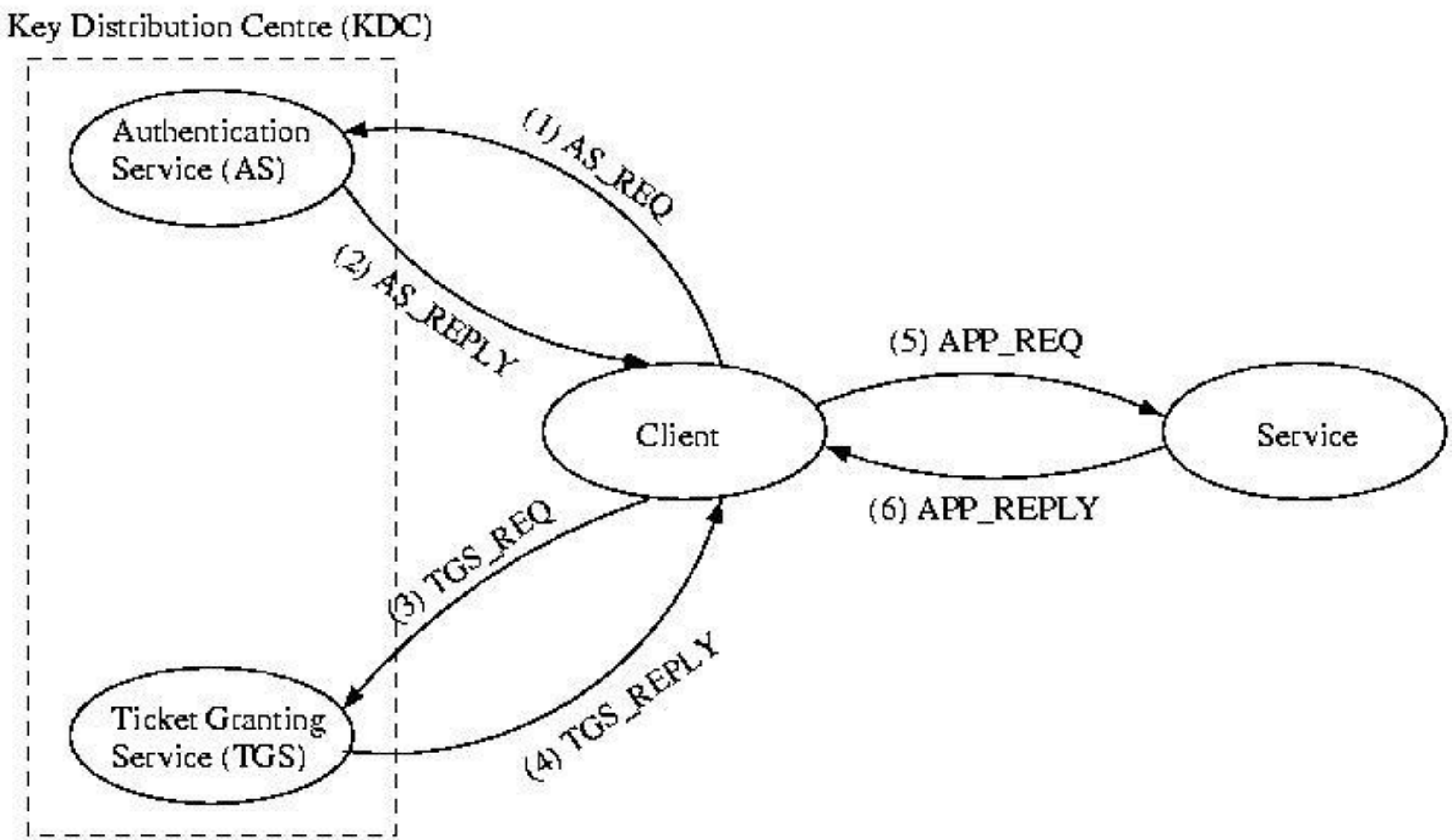
(3) TGS_REQUEST

- The TGS request asks the TGS for a ticket to communicate with a a particular service.

- $<\{auth_c\}_{Kc,\ TGS}, \{ticket_c, TGS\}K_{TGS}, service, nonce2>$

- $<\{auth_c\}$ is known as an *authenticator* it contains the name of the client and a timestamp for freshness

Kerberos Authentication Steps



(4) TGS_REPLY

- $<\{K_{c,service}, nonce2\}K_{c, TGS}, \{ticket_{c, service}\}K_{service} >$

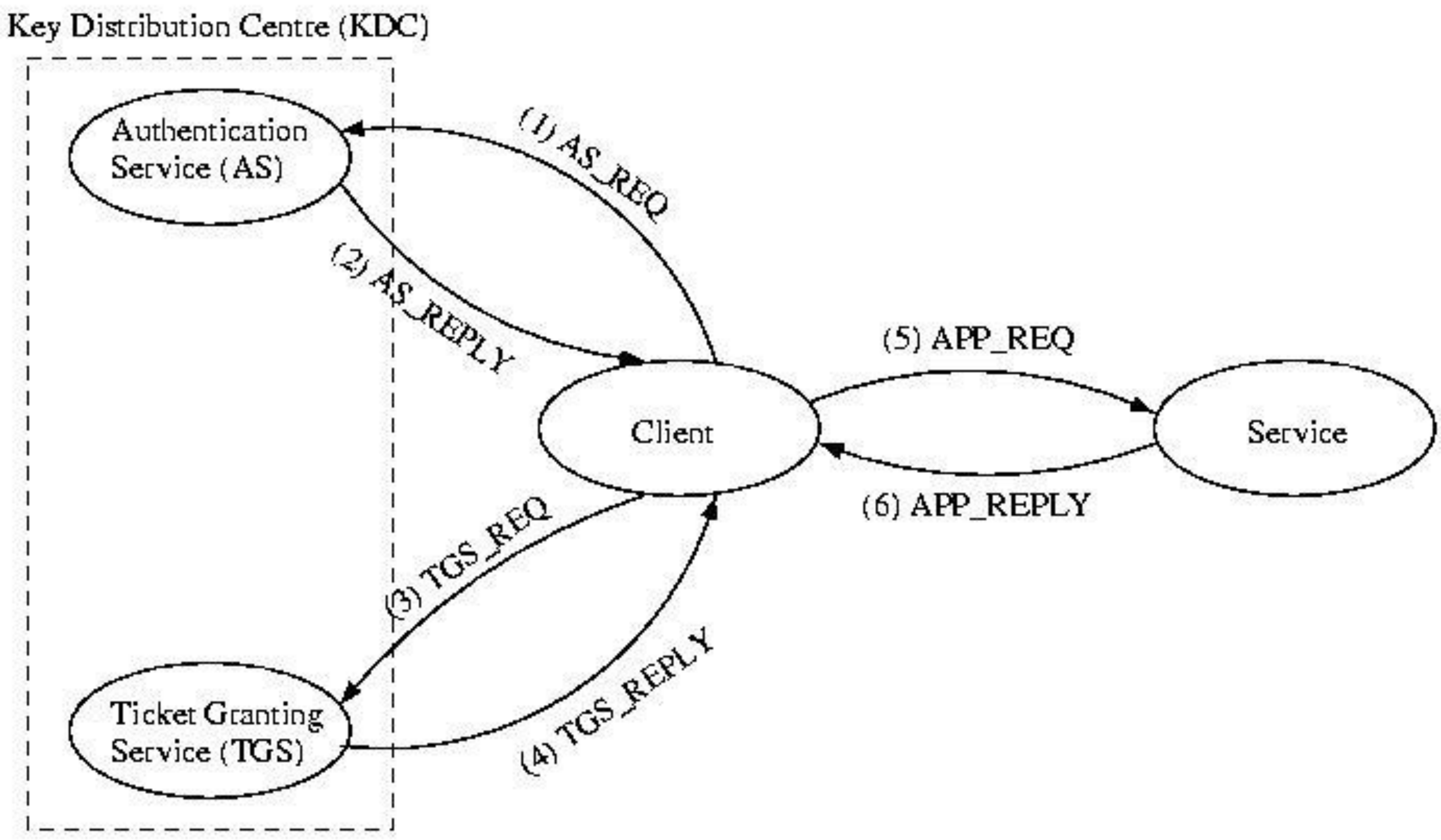
- Notice again that the client can’t read or alter the ticket
- Notice again the use of the session key and nonce between the client and the TGS

(5) APP_REPLY

- $<\{auth_c\}K_{c,service}, \{ticket_{c,service}\}K_{service}, request, nonce3>$

- Notice again the use of the session key as well as the protected ticket.

Kerberos Authentication Steps



(6) APP_REPLY

- <{nonce3}$K_{c,service}$, response>

- Because of the use of the encrypted nonce, the client is assured the reply came form the application, not an imposter.

Using Kerberos

- kinit
  - Get your TGT
  - Creates file, usually stored in /tmp
- klist
  - View your current Kerberos tickets

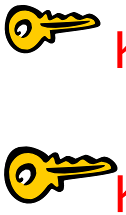
```
unix41:~ebardsle> klist
Credentials cache: FILE:/ticket/krb5cc_61189_9FTlN6
        Principal: ebardsle@ANDREW.CMU.EDU

  Issued           Expires          Principal
Apr 18 19:40:50  Apr 19 20:40:49  krbtgt/ANDREW.CMU.EDU@ANDREW.CMU.EDU
Apr 18 19:40:50  Apr 19 20:40:49  afs@ANDREW.CMU.EDU
Apr 18 19:40:51  Apr 19 20:40:49  imap/cyrus.andrew.cmu.edu@ANDREW.CMU.EDU
```

- kdestory
  - End session, destroy all tickets
- kpasswd
  - Changes your master key stored by the AS
- “Kerberized” applications
  - kftp, ktelnet, ssh, zephyr, etc
  - afslog uses Kerberos tickets to get AFS token

Asymmetric Key Crypto:

- Instead of shared keys, each person has a “key pair”



K_B Bob’s public key

K_B^{-1} Bob’s private key

- The keys are inverses, so: $K_B^{-1}(K_B(m)) = m$

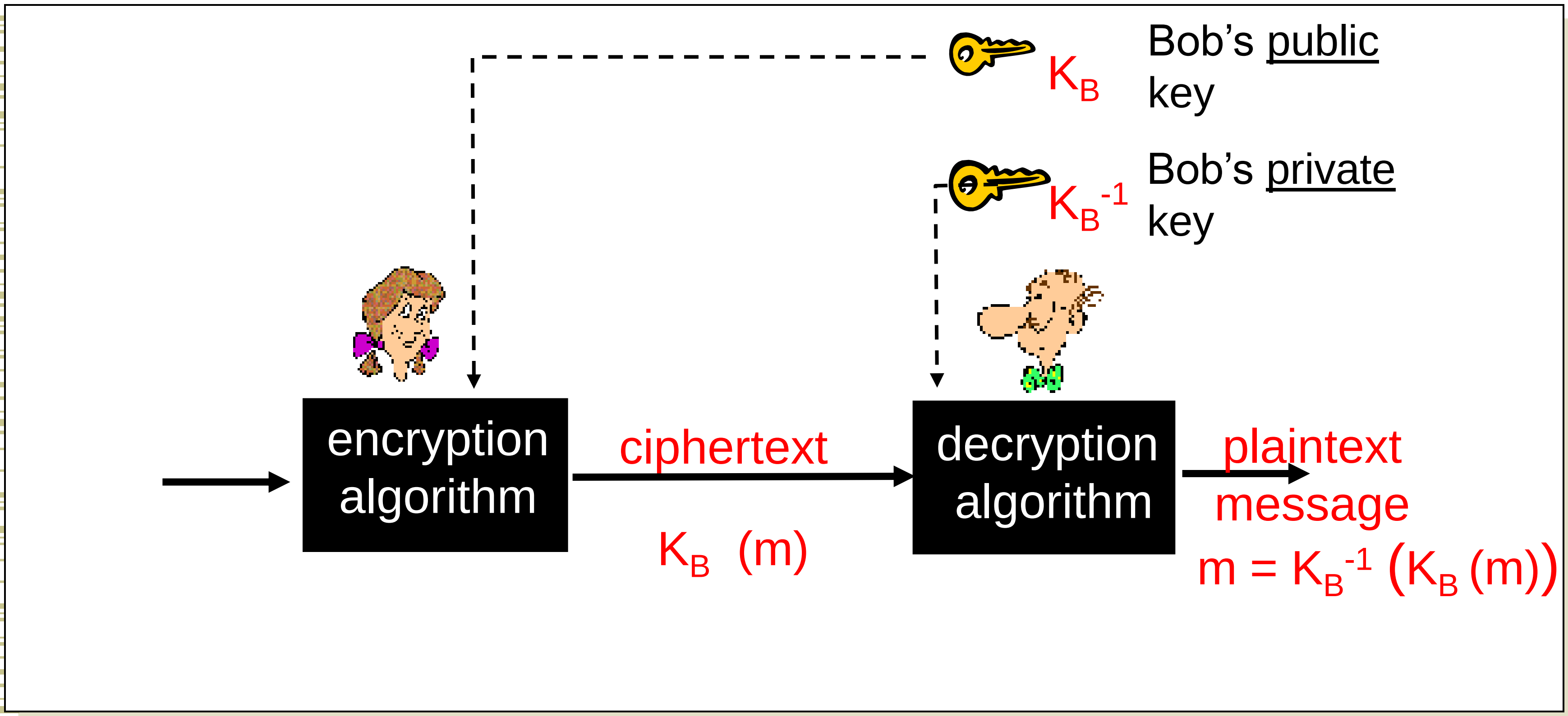
Asymmetric Key Crypto:

- It is believed to be computationally unfeasible to derive K_B^{-1} from K_B or to find any way to get M from $K_B(M)$ other than using K_B^{-1} .

=> K_B can safely be made public.

Note: We will not detail the computation that $K_B(m)$ entails, but rather treat these functions as black boxes with the desired properties.

Asymmetric Key: Confidentiality



Asymmetric Key: Sign & Verify

- If we are given a message M, and a value S such that $K_B(S) = M$, what can we conclude?

- The message must be from Bob, because it must be the case that $S = K_B^{-1}(M)$, and only Bob has K_B^{-1}!

- This gives us two primitives:
  - Sign (M) = $K_B^{-1}(M)$ = Signature S
  - Verify (S, M) = test($K_B(S) == M$)

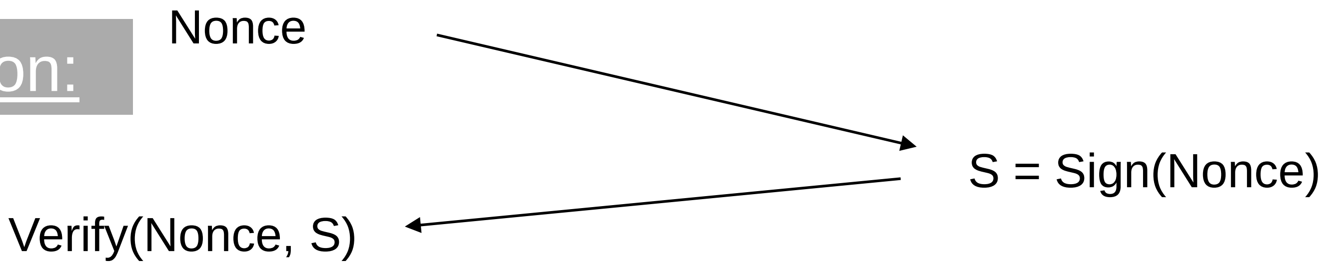
Asymmetric Key: Integrity & Authentication

- We can use Sign() and Verify() in a similar manner as our HMAC in symmetric schemes.

Integrity:

Receiver must only check Verify(M, S)

Authentication:



Asymmetric Key Review:

- Confidentiality: Encrypt with Public Key of Receiver
- Integrity: Sign message with private key of the sender
- Authentication: Entity being authenticated signs a nonce with private key, signature is then verified with the public key

But, these operations are computationally expensive*

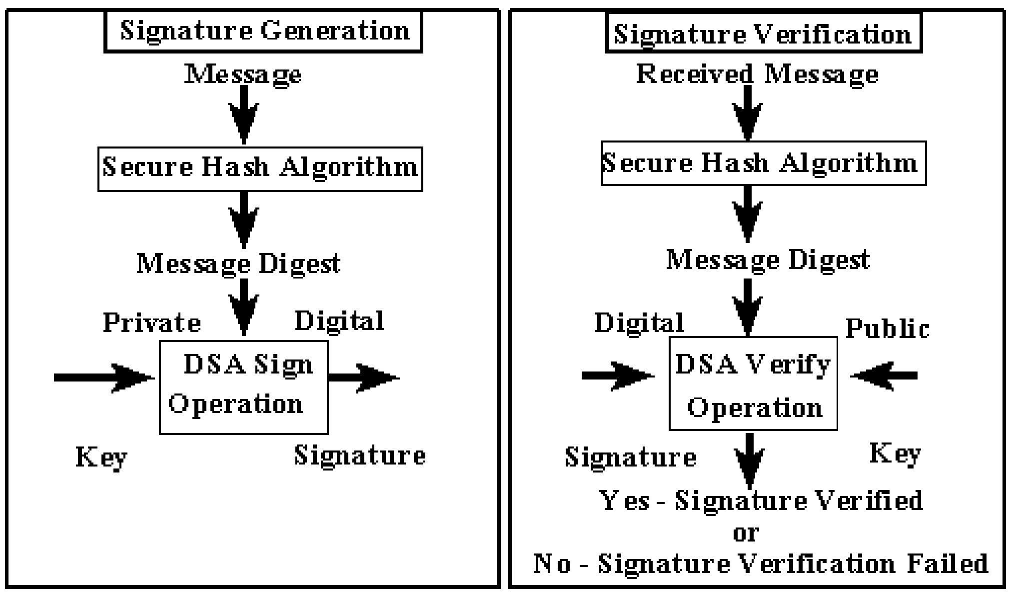
Cryptographic Hash Functions

- Given arbitrary length message m, compute constant length digest h(m)
- Desirable properties
  - h(m) easy to compute given m
  - Preimage resistant
  - 2nd preimage resistant
  - Collision resistant

- Crucial point : These are not inverted, they are recomputed
- Example use: file distribution (ur well aware of that!)
- Common algorithms: MD5, SHA

Digital Signatures

- Alice wants to convince others that she wrote message m
  - Computes digest d = h(m) with secure hash
  - Send <m,d>
- Digital Signature Standard (DSS)



The Dreaded PKI

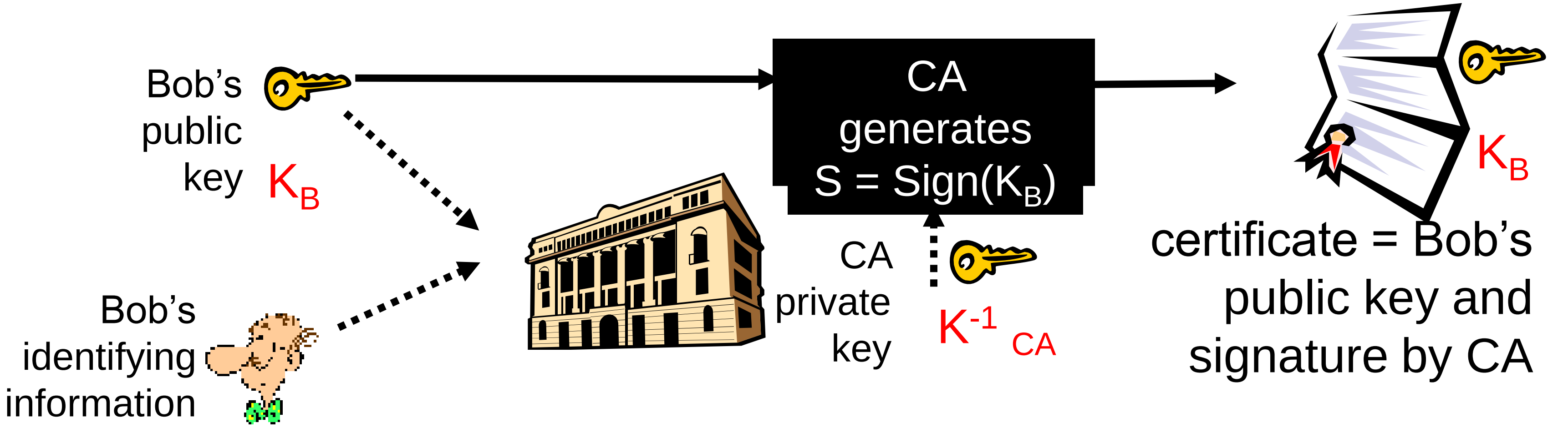
- Definition:

  Public Key Infrastructure (PKI)

1) A system in which "roots of trust" authoritatively bind public keys to real-world identities
2) A significant stumbling block in deploying many "next generation" secure Internet protocol or applications.

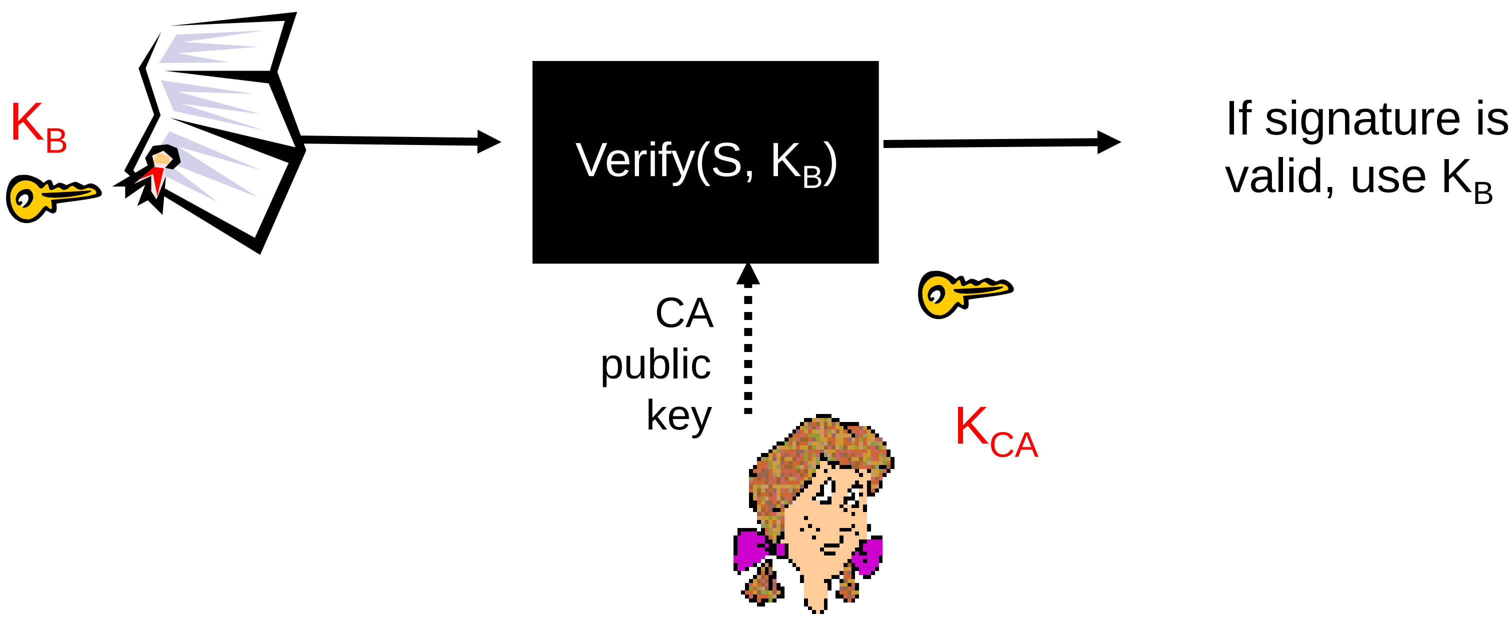
Certification Authorities

- Certification authority (CA): binds public key to particular entity, E.
- An entity E registers its public key with CA.
  - E provides "proof of identity" to CA.
  - CA creates certificate binding E to its public key.
  - Certificate contains E's public key AND the CA's signature of E's public key.



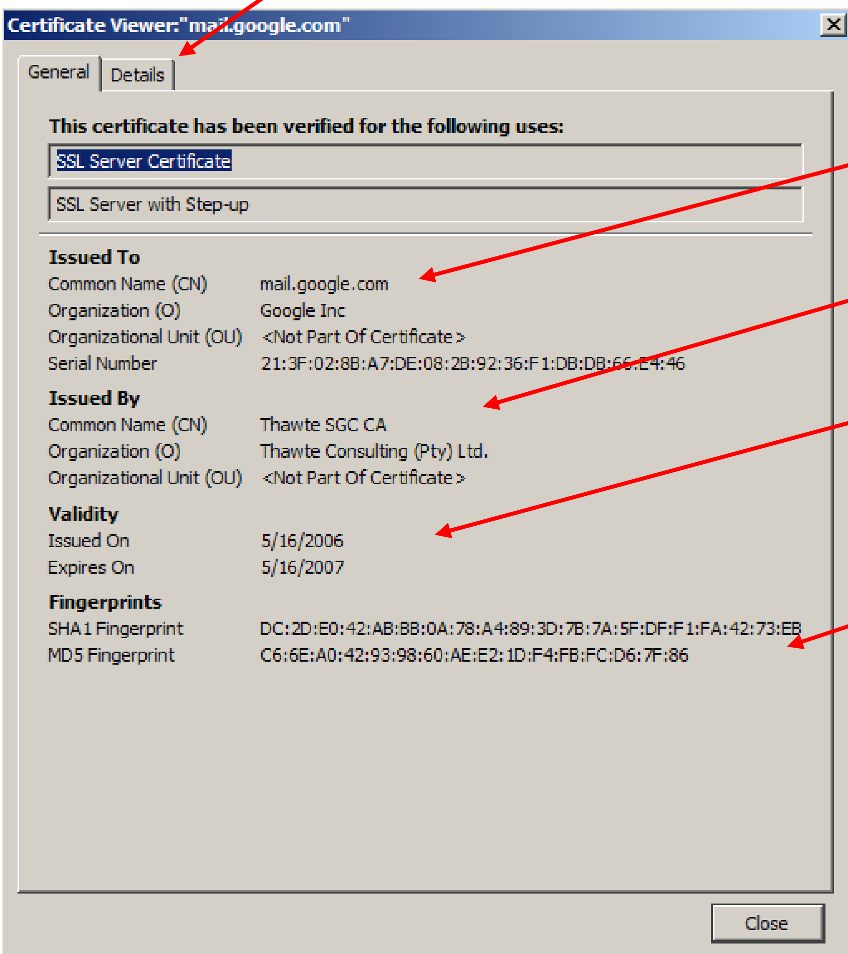
Certification Authorities

- When Alice wants Bob's public key:
  - Gets Bob's certificate (Bob or elsewhere).
  - Use CA's public key to verify the signature within Bob's certificate, then accepts public key



Certificate Contents

- info algorithm and key value itself (not shown)



- Cert owner
- Cert issuer
- Valid dates
- Fingerprint of signature

Pretty Good Privacy (PGP)

- History
  - Written in early 1990s by Phil Zimmermann
  - Primary motivation is email security
  - Controversial for a while because it was too strong
    - Distributed from Europe
  - Now the OpenPGP protocol is an IETF standard (RFC 2440)
  - Many implementations, including the GNU Privacy Guard (GPG)
- Uses
  - Message integrity and source authentication
    - Makes message digest, signs with public key cryptosystem
    - Webs of trust
  - Message body encryption
    - Private key encryption for speed
    - Public key to encrypt the message's private key

Secure Shell (SSH)

- Negotiates use of many different algorithms
- Encryption
- Server-to-client authentication
  - Protects against man-in-the-middle
  - Uses public key cryptosystems
  - Keys distributed informally
    - kept in ~/.ssh/known_hosts
  - Signatures not used for trust relations
- Client-to-server authentication
  - Can use many different methods
  - Password hash
  - Public key
  - Kerberos tickets

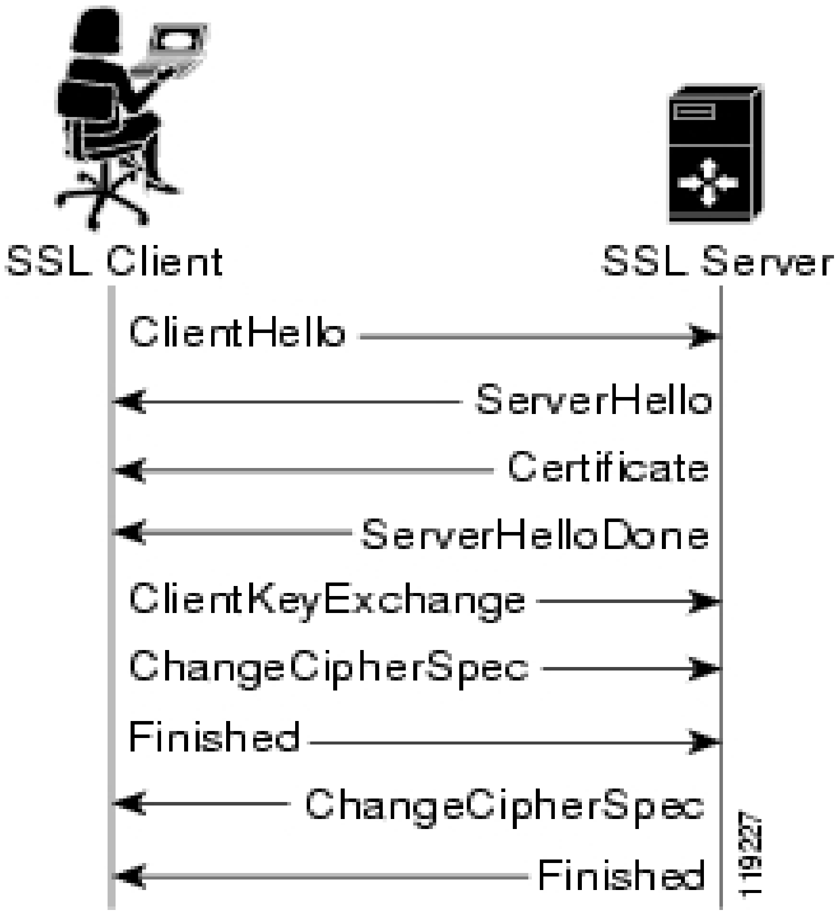
SSL/TLS

- History
  - Standard libraries and protocols for encryption and authentication
  - SSL originally developed by Netscape
    - SSL v3 draft released in 1996
  - TLS formalized in RFC2246 (1999)
- Uses public key encryption
- Uses
  - HTTPS, IMAP, SMTP, etc

Transport Layer Security (TLS) aka Secure Socket Layer (SSL)

- Used for protocols like HTTPS
- Special TLS socket layer between application and TCP (small changes to application).
- Handles confidentiality, integrity, and authentication.
- Uses “hybrid” cryptography.

Setup Channel with TLS "Handshake"

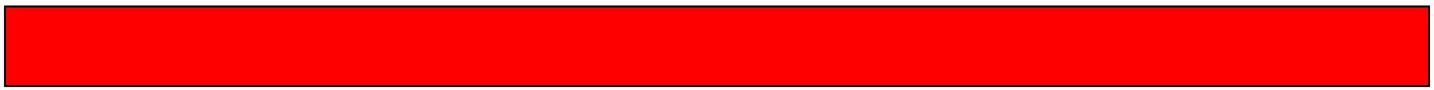


Handshake Steps:

1) Clients and servers negotiate exact cryptographic protocols
2) Client's validate public key certificate with CA public key.
3) Client encrypt secret random value with servers key, and send it as a challenge.
4) Server decrypts, proving it has the corresponding private key.
5) This value is used to derive symmetric session keys for encryption & MACs.

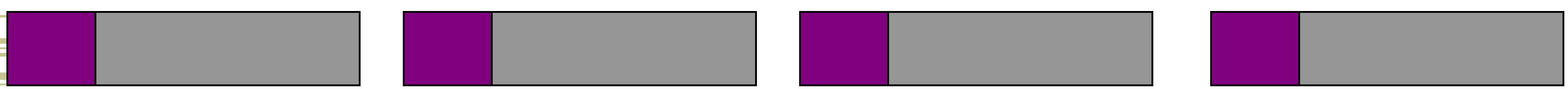
How TLS Handles Data

1) Data arrives as a stream from the application via the TLS Socket

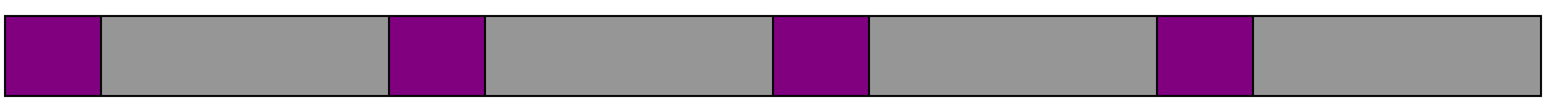


2) The data is segmented by TLS into chunks

3) A session key is used to encrypt and MAC each chunk to form a TLS “record”, which includes a short header and data that is encrypted, as well as a MAC.



4) Records form a byte stream that is fed to a TCP socket for transmission.



Works Cited/Resources

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- http://en.wikipedia.org/wiki/One-time_pad
- http://www.iusmentis.com/technology/encryption/des/
- http://en.wikipedia.org/wiki/3DES
- http://en.wikipedia.org/wiki/AES
- http://en.wikipedia.org/wiki/MD5Textbook: 8.1 – 8.3

- Wikipedia for overview of Symmetric/Asymmetric primitives and Hash functions.
- OpenSSL (www.openssl.org): top-rate open source code for SSL and primitive functions.
- "Handbook of Applied Cryptography" available free online: www.cacr.math.uwaterloo.ca/hac/