Transport Security

Lecture 12, Computer Networks (198:552)

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Why security?

- Malicious people share your network
  - People who want to snoop, corrupt, destroy, pretend, steal, …

- Problem made more severe as Internet becomes more commercialized

- Active and passive attacks

Key aspects of network security

confidentiality: only sender, intended receiver should "understand" message contents

- sender encrypts message
- receiver decrypts message

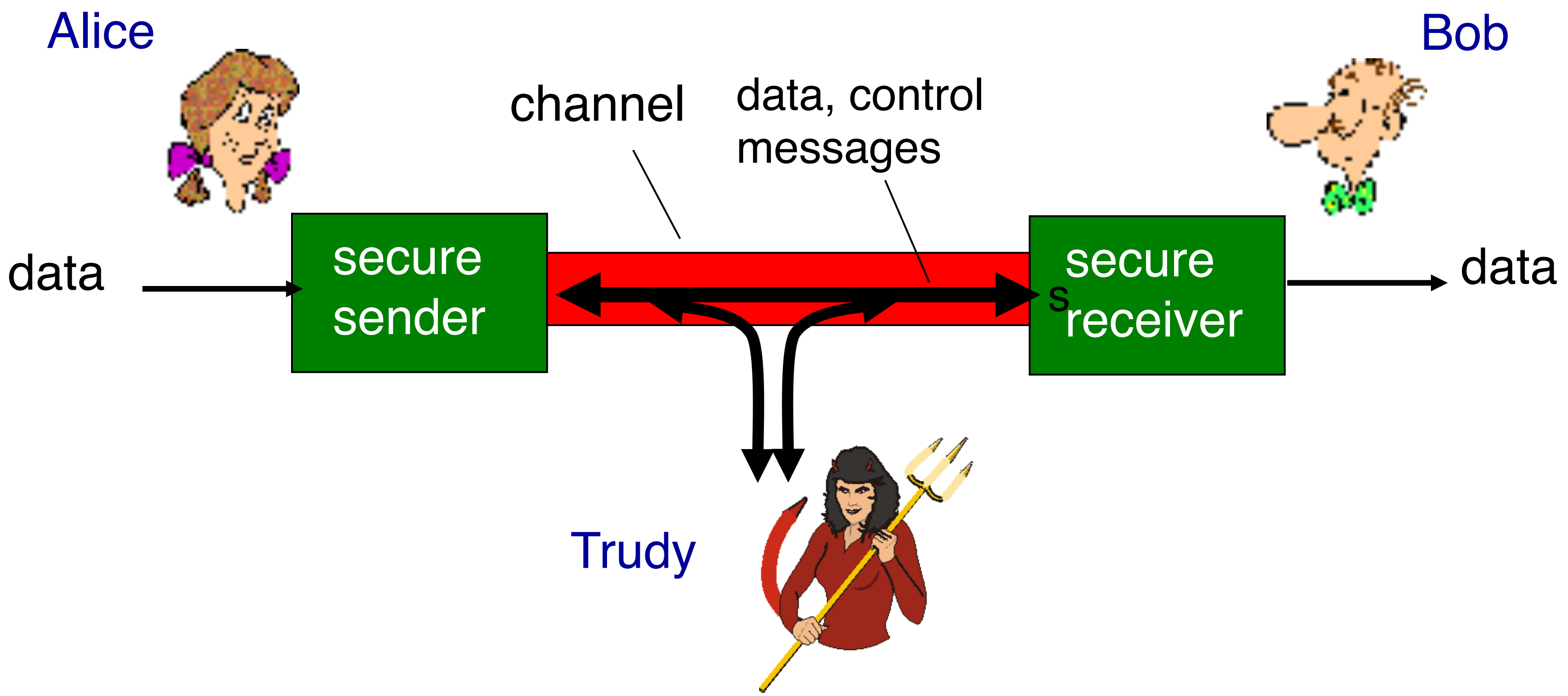
integrity*:* sender, receiver want to ensure message not altered (in transit, or afterwards) without detection

authentication*:* sender, receiver want to confirm identity of each other

non-repudiation*:* Once someone sends a message, or conducts a transaction, she can't later deny the contents of that message

Friends and enemies: Alice, Bob, Trudy

- well-known in network security world
- Bob and Alice want to communicate "securely"
- Trudy (intruder) may intercept, delete, add messages



Who might Bob and Alice be?

- Real humans ☺
- Web browser/server for electronic transactions (e.g., on-line purchases)
- on-line banking client/server
- DNS servers
- routers exchanging routing table updates

What can bad actors do?

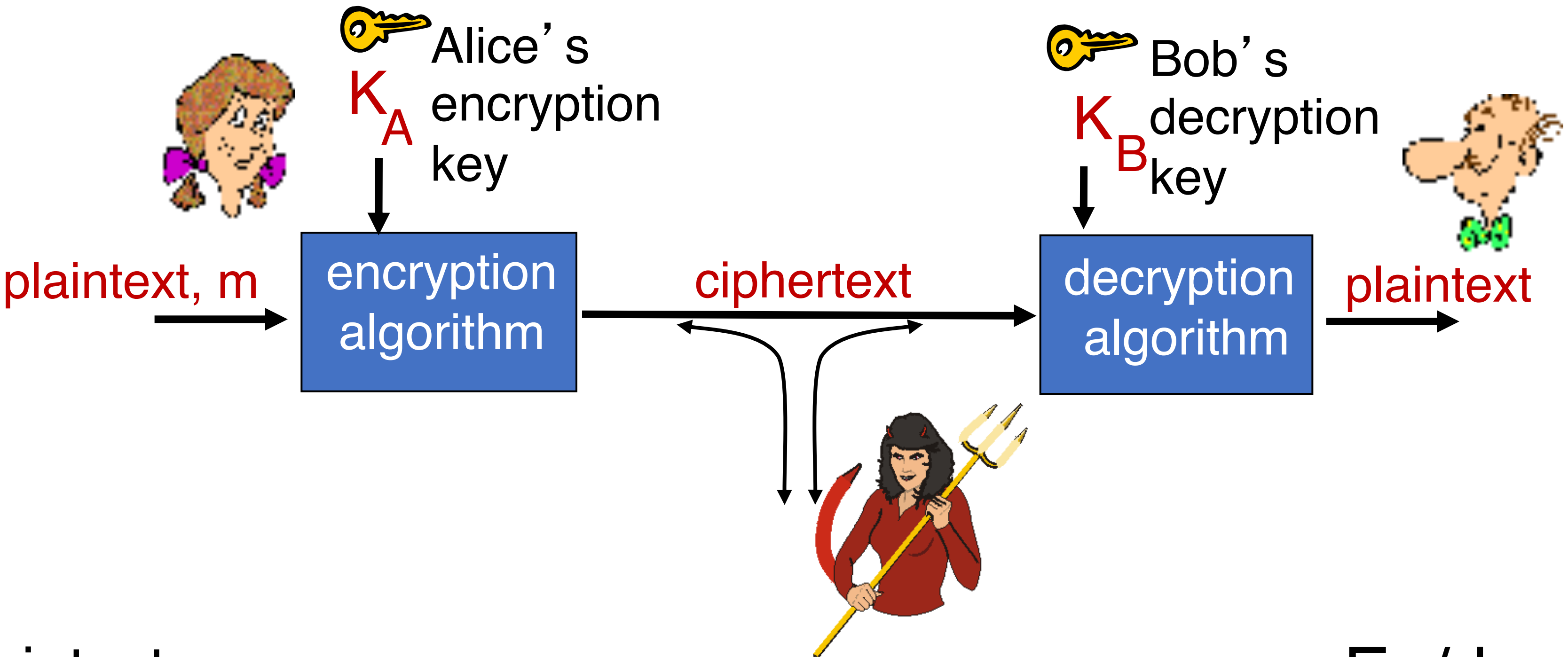
A lot!

- *eavesdrop:* intercept messages
- actively *insert* messages into connection
- *impersonation:* can fake (spoof) source address in packet (or any field in packet)
- *hijacking:* "take over" ongoing connection by removing sender or receiver, inserting itself in place
- *denial of service*: prevent service from being used by others (e.g., by overloading resources)

Confidentiality

Cryptography: preventing adversaries from reading private messages

Cryptography: Terminology



m plaintext message

$c = K_A(m)$, $K_A(m)$ ciphertext, encrypted with key K_A

$m' = K_B(c)$, $K_B(c)$ decrypted plaintext with key K_B

Want: $m = K_B(K_A(m))$

Want: $K_A(m)$ to be uncorrelated with m

En/decryption algorithms are also called ciphers.

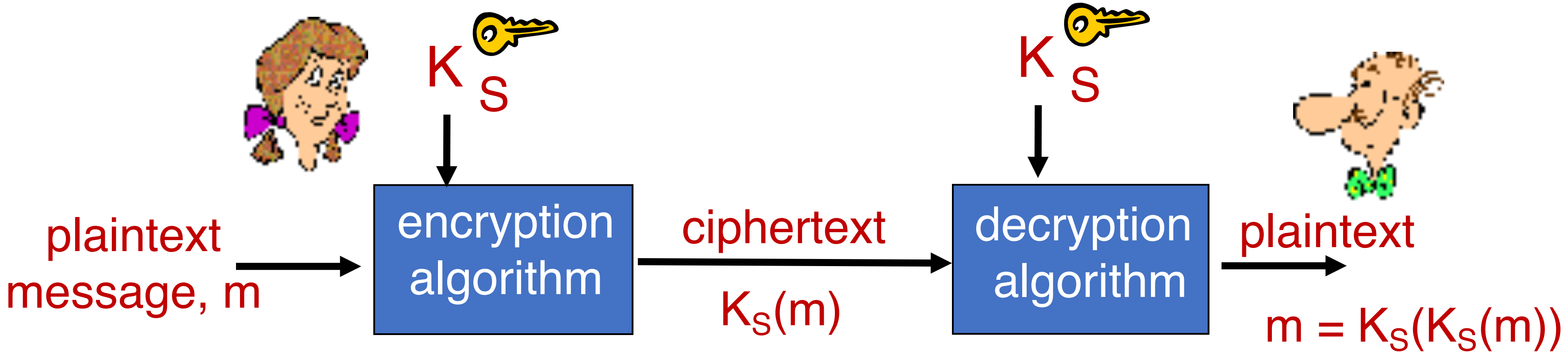
Cryptography: Algorithms and Keys

- Cryptography requires both an en-/decryption algorithm and keys
  - Key is a string known only to Alice and Bob, which controls how algorithm works

- Algorithm should be public and known to all
  - Inspires trust that the algorithm works

- Keys
  - Should be long enough to prevent easy breaking of the encryption
  - Should be short enough to keep algorithm efficient
  - Typical key lengths: 56-bit, 128-bit, 256-bit, 512-bit

Symmetric key cryptography



Symmetric keys: Bob and Alice share same (symmetric) key: S

Main techniques of symmetric key cryptography:
Substitution and Permutation

Q: how do Bob and Alice agree on key value?

How to agree on a shared secret key?

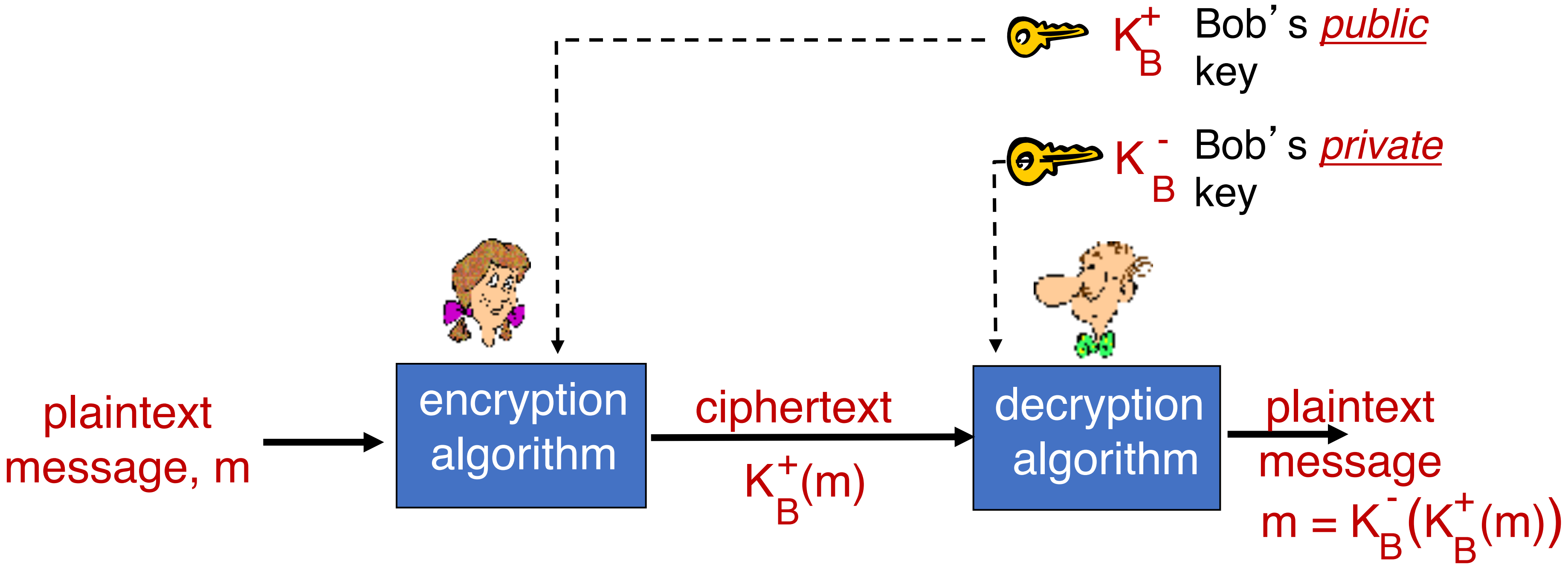
- In reality: two parties may meet in person or communicate “out of band” to exchange shared key
- But communicating parties may never meet in person
  - Example: An online retailer and customer
  - Much more common for a network ☺
- What if the shared secret is stolen?
  - All secret communications can now be decrypted and are visible
  - Including earlier ones that were encrypted using that secret
- How to communicate without necessitating key exchange?

Public key cryptography

Public Key Cryptography

- Sender and receiver do not share secret key
- public encryption key known to all
- private decryption key known only to the receiver

Public key cryptography (eg: RSA)



Diffie Hellman Merkle key exchange

- Alice and Bob agree on a modulus p and base g
- Alice chooses secret a, sends bob $A = g^a \bmod p$
- Bob chooses secret b, sends bob $B = g^b$ mob p
- Alice computes $B^a \bmod p$
- Bob computes $A^b \bmod p$

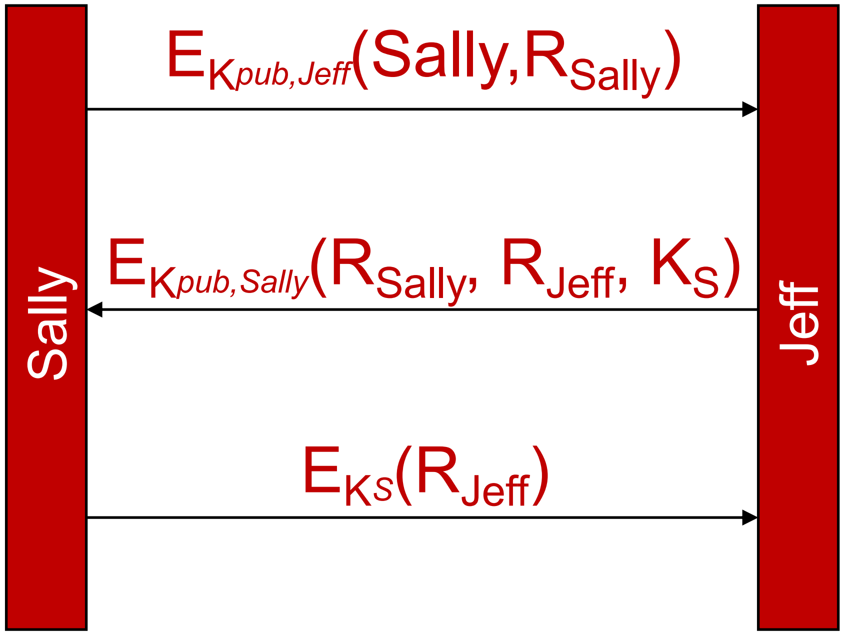
- Is the common key computed by Alice and Bob the same?
- In what sense is D-H-M key exchange secure?

Public vs. Symmetric key crypto

- Public key crypto
- Expensive to encrypt using just modular exponentiation operations
- No need to exchange keys

- Symmetric key crypto
- Encryption and decryption are fast
- But need to solve the key exchange problem

Crypto in practice: session keys



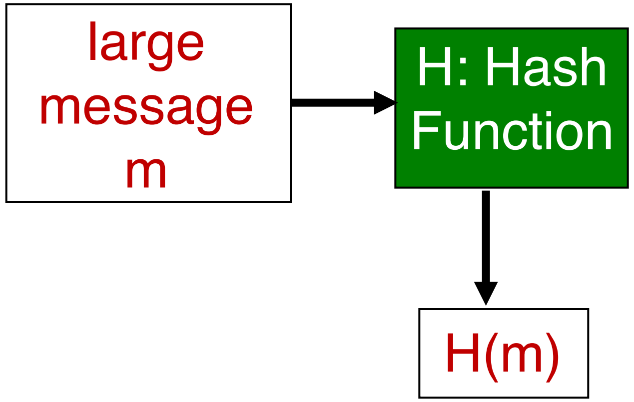
Use public key crypto or key exchange to agree on a symmetric session key

Use symmetric key to protect the rest of the session efficiently

Integrity

Did messages get across without tampering?

Message digests



Can we ensure that a receiver can detect message tampering?

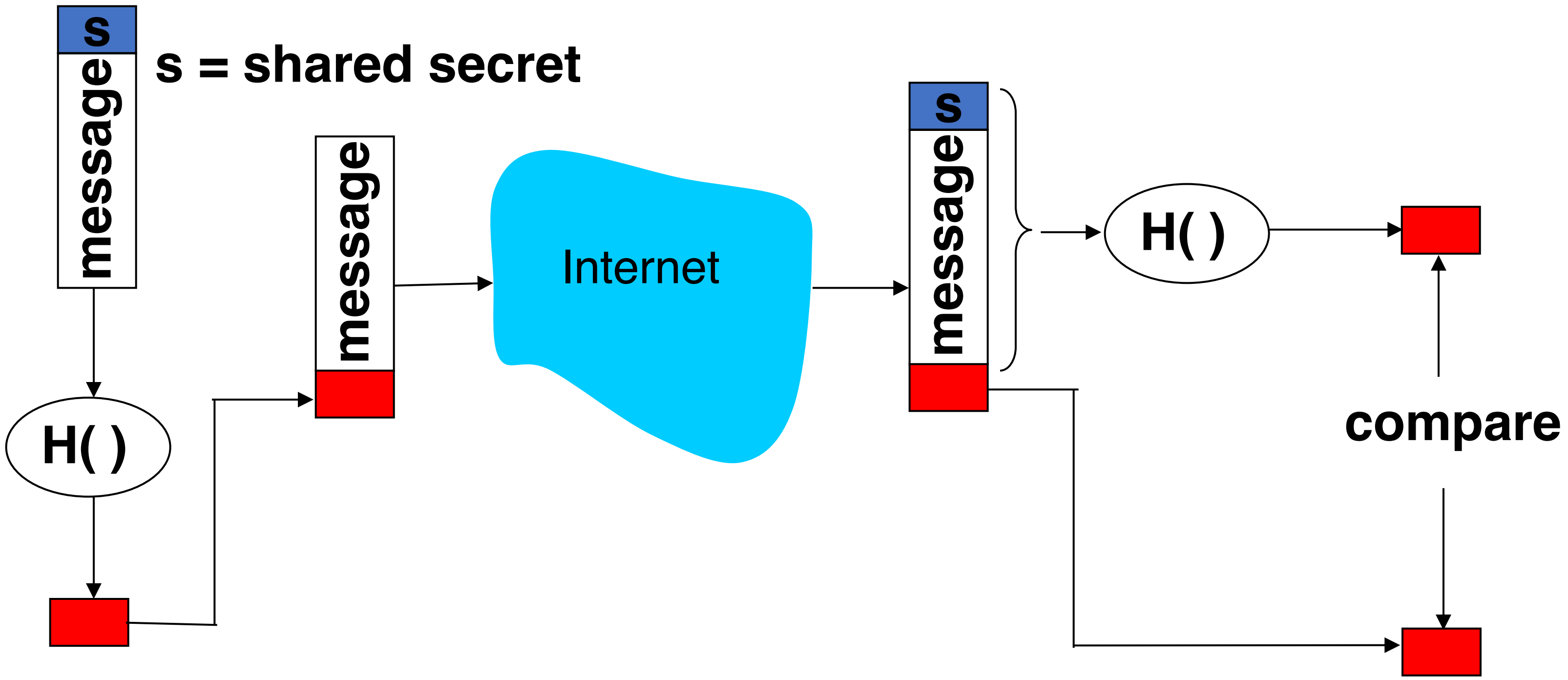
Idea: fixed-length, easy- to-compute digital "fingerprint" of a message

- apply hash function H to *m*, get fixed size message digest, *H(m).*

Cryptographic hash function properties:

- Easy to calculate
- Produces fixed-size msg digest (fingerprint)
- Hard to reverse: given msg digest x,
  - computationally infeasible to find m such that x = H(m)
  - Or another m' such that H(m) = H(m')

Using message digests for integrity



- Verifies message integrity
- Requires a secret shared key
- No encryption

Message digest algorithms

- You’ll see the term “MAC” or Message Authentication Codes
  - I find it confusing (medium access); I will avoid using it.

- MD5 hash function widely used (RFC 1321)
  - computes 128-bit message digest in 4-step process.
  - arbitrary 128-bit string x, appears difficult to construct msg m whose MD5 hash is equal to x

- SHA-1 is also used
  - US standard [NIST, FIPS PUB 180-1]
  - 160-bit message digest

Digital signatures

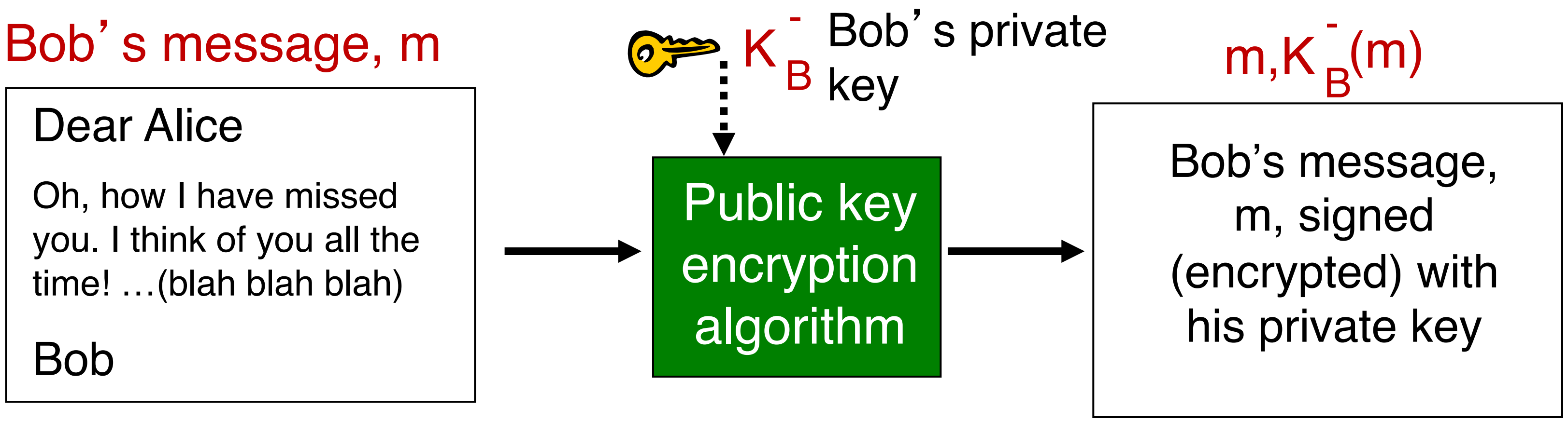
Cryptographic technique analogous to handwritten signatures:

- sender (Bob) digitally signs document, establishing he is document owner/creator.
- verifiable, nonforgeable: recipient (Alice) can prove to someone that Bob, and no one else (including Alice), must have signed document

Digital signatures

simple digital signature for message m:

- Bob signs m by encrypting with his private key K_B^-, creating "signed" message, $K_B^-(m)$

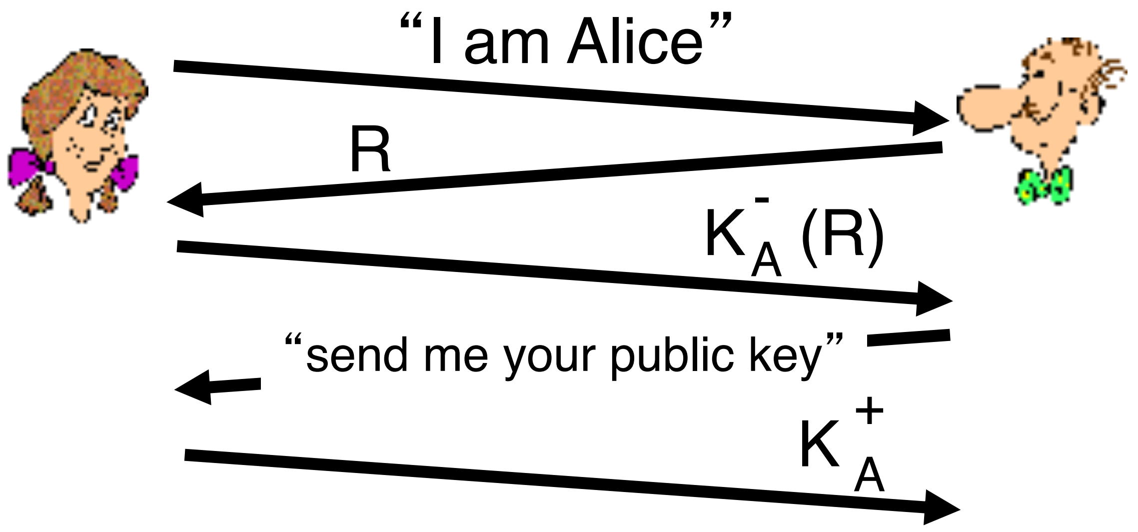


Authentication

How do I know you are who you say you are?

Authentication using public key crypto

Idea: Use nonce and public key cryptography



Bob computes

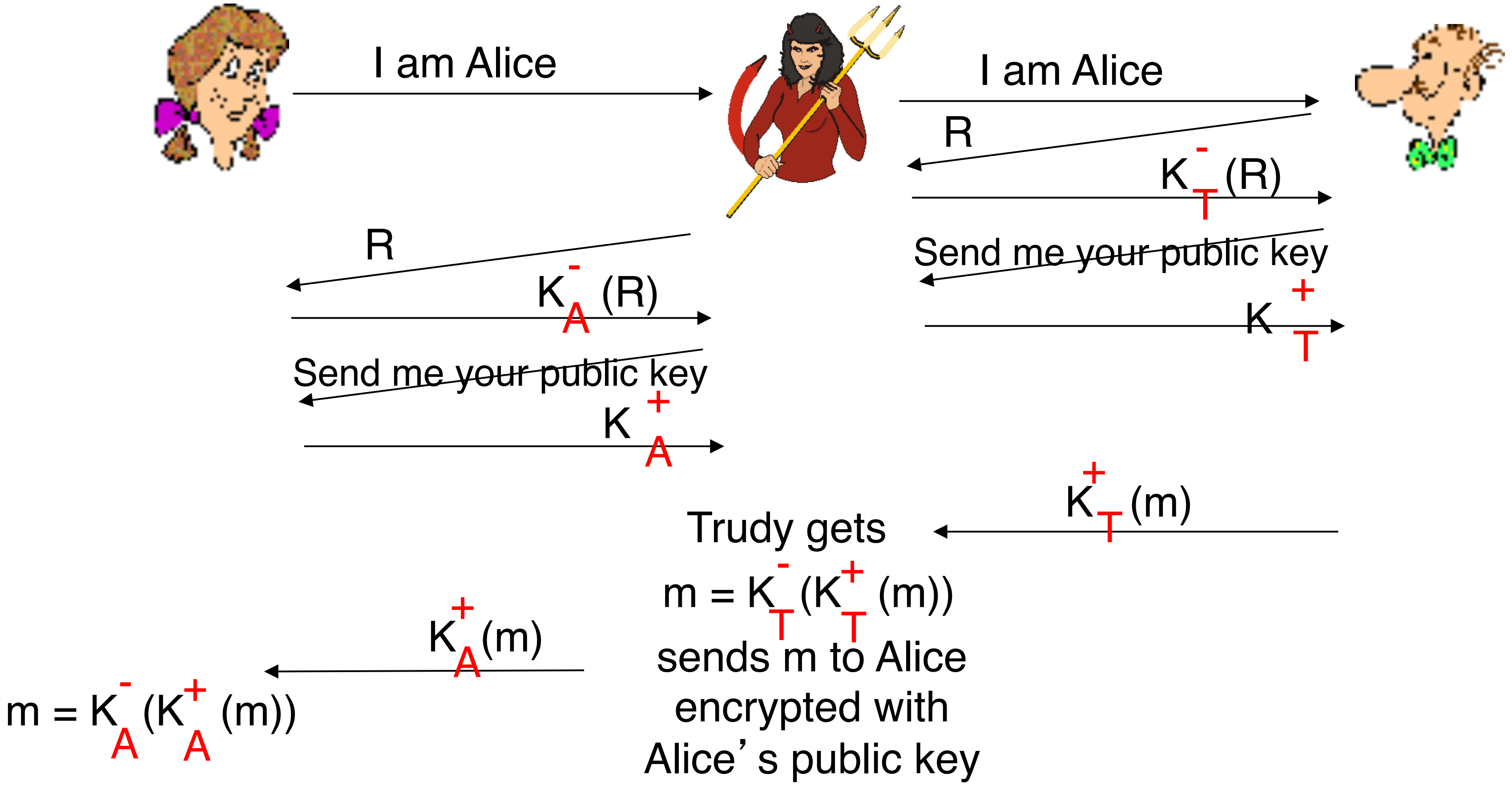
$K_A^+(K_A^-(R)) = R$

and knows only Alice could have the private key, that encrypted R such that

$K_A^+(K_A^-(R)) = R$

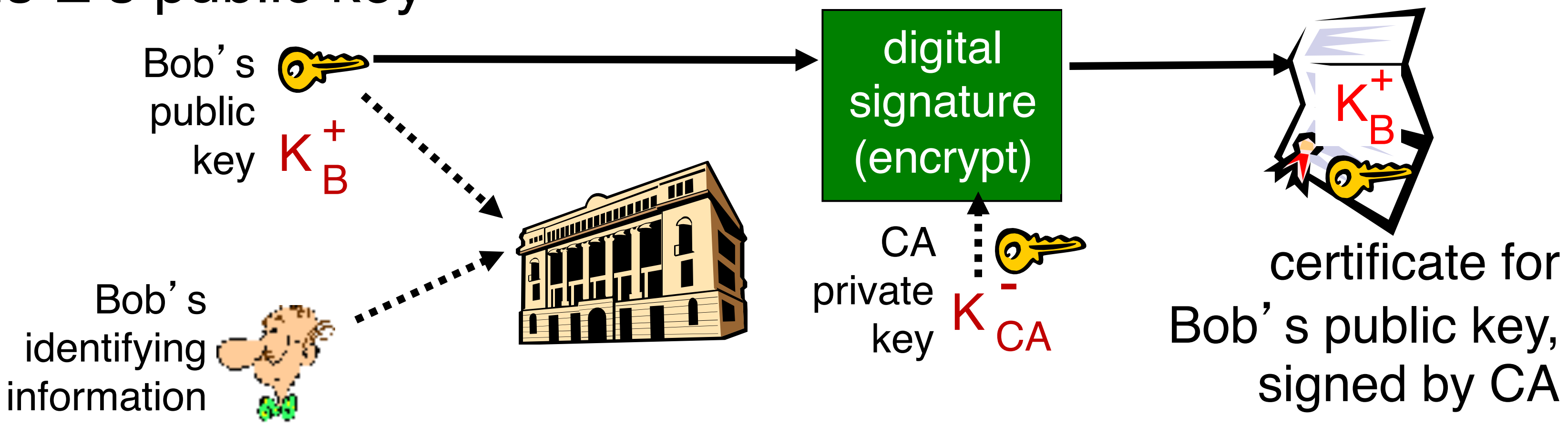
Security hole -- if you ask for public keys!

man (or woman) in the middle attack: Trudy poses as Alice (to Bob) and as Bob (to Alice)



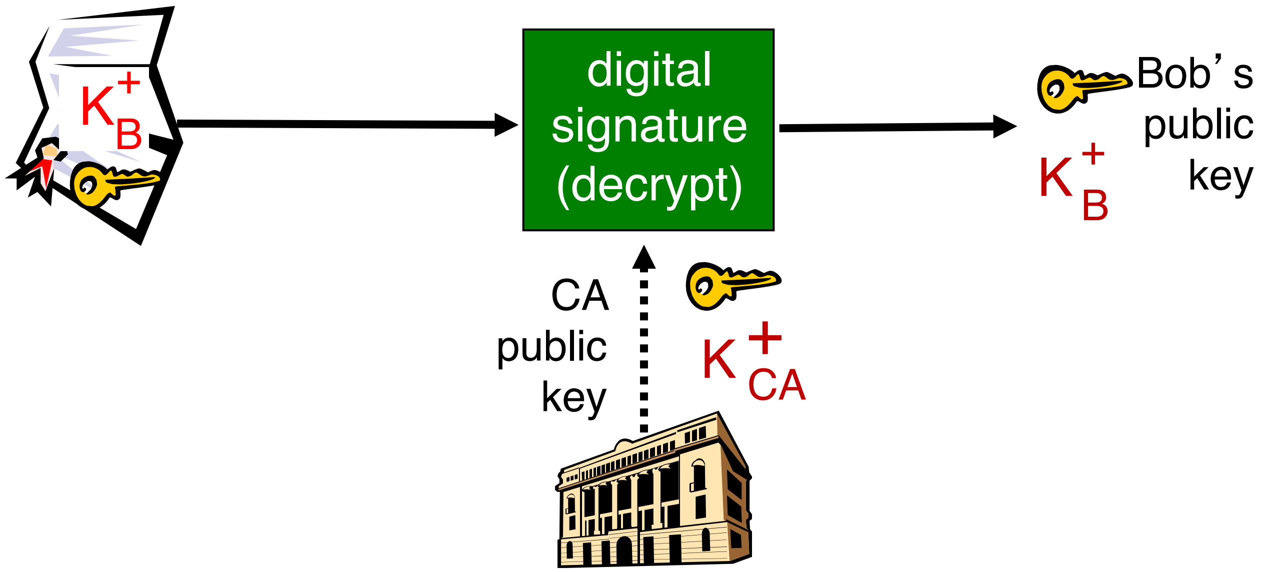
Certification authorities

- *certification authority (CA):* binds public key to particular entity, E.
- E (person, router) registers its public key with CA.
  - E provides “proof of identity” to CA.
  - CA creates certificate binding E to its public key.
  - certificate containing E’s public key digitally signed by CA – CA says “this is E’s public key”



Certification authorities

- When Alice wants Bob's public key:
  - gets Bob's certificate (from Bob or elsewhere).
  - apply CA's public key to Bob's certificate, get Bob's public key



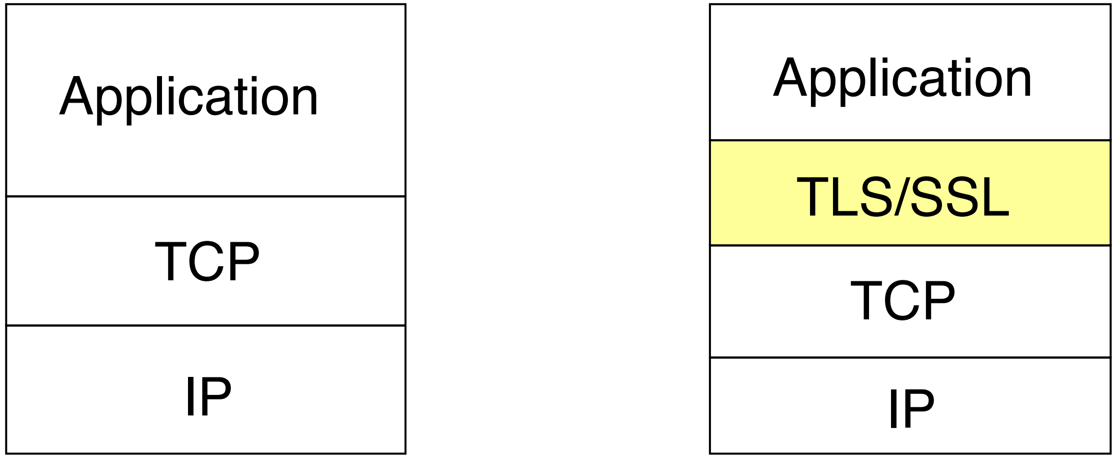
Transport Layer Security (TLS)

Providing security properties in a practical protocol

Goals of TLS

- Confidentiality
- Message integrity
- Server authentication (optionally, client authentication)
- Must work in the context of the existing network protocol stack

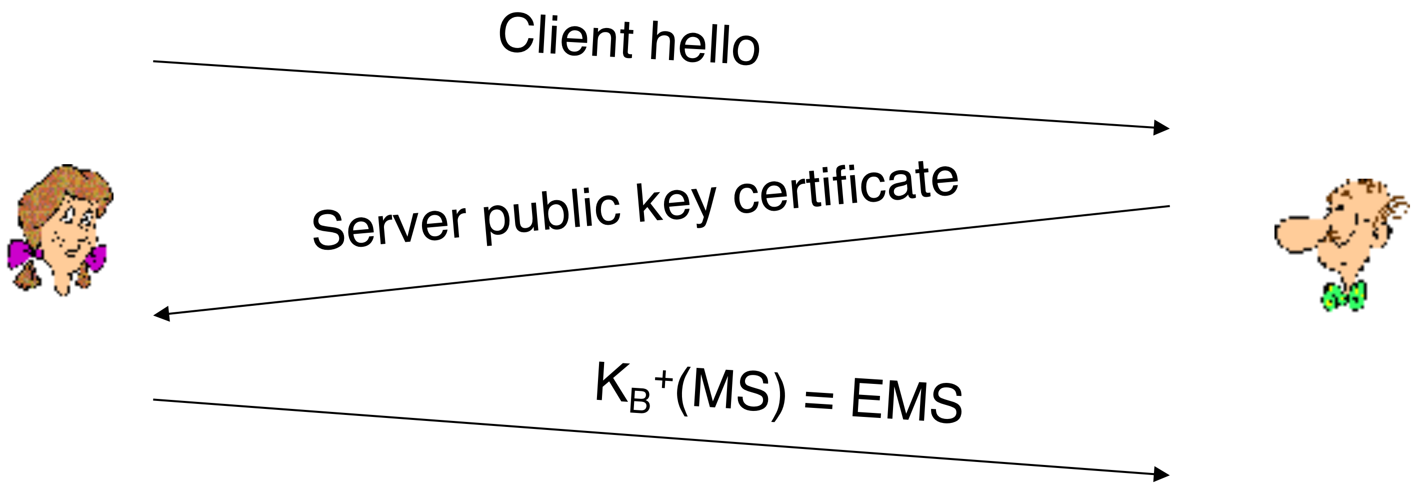
TLS/SSL and the rest of the protocol stack



normal application *application with TLS/SSL*

- TLS/SSL provides application programming interface (API) to applications
- C and Java libraries/classes readily available
  - Ex: OpenSSL

Step (1): a simple handshake



MS: master secret

EMS: encrypted master secret

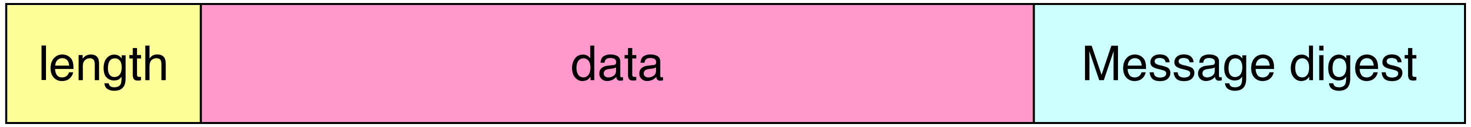
Q: What all might the “master secret” be used for?

Step (2): key derivation

- considered bad to use same key for more than one cryptographic operation
  - use different keys for message integrity and encryption
- four keys:
  - K_c = encryption key for data sent from client to server
  - M_c = integrity digest key for data sent from client to server
  - K_s = encryption key for data sent from server to client
  - M_s = integrity digest key for data sent from server to client
- keys derived from key derivation function (KDF)
  - Takes master secret and (possibly) some additional random data and creates the keys

Step (3): Data records

- why not encrypt data in constant stream as we write it to TCP?
  - where would we put the message digest? If at end, no message integrity until all data processed.
  - e.g., with instant messaging, how can we do integrity check over all bytes sent before displaying?
- instead, break stream in series of records
  - each record carries a message digest
  - receiver can act on each record as it arrives
- How does receiver distinguish the digest from data within a record?
  - want to use variable-length records



TLS/SSL "Cipher Suite"

- Cipher suite
  - public-key algorithm
  - symmetric encryption algorithm
  - Integrity hashing algorithm

- TLS/SSL supports several cipher suites

- Negotiation: client, server agree on cipher suite
  - client offers choices
  - server picks one

Common symmetric ciphers

- AES – Advanced Encryption Standard
- DES – Data Encryption Standard: block
- 3DES – Triple strength: block
- ChaCha: stream
- RC4 – Rivest Cipher 4: stream

SSL Public key encryption

- RSA with DH

Integrity hashing algorithms

- HMAC-MD5 and others

Improved Handshake with Negotiation

1. server authentication
2. negotiation: agree on cipher suite
3. establish necessary keys
4. client authentication (optional)

All this takes a few round trip times to accomplish!

QUIC handshake

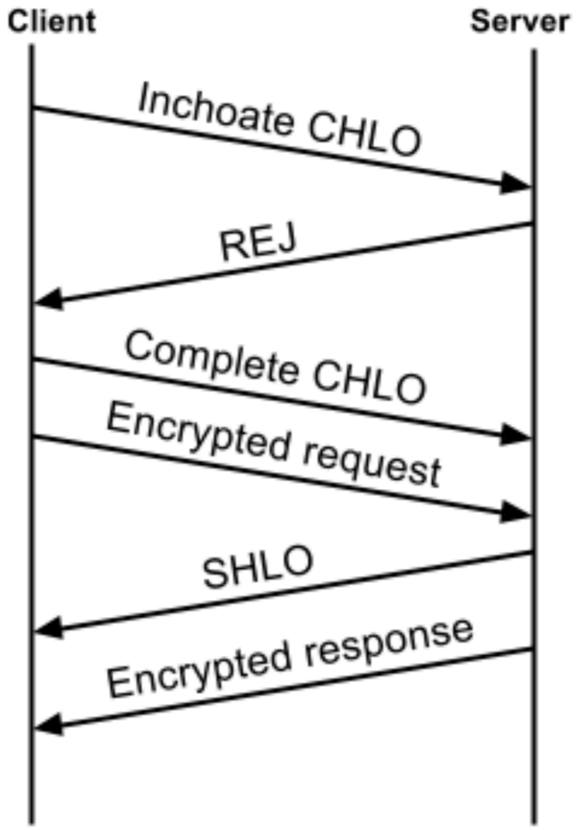
Adding security in one shot to a handshake

Goals of QUIC handshake

- Reduce round-trip times to get set up with secure connection
- Initial handshake takes 1 RTT, starting from the first byte received from the client, before server can send data
- Later, server can send data immediately upon receiving the first byte from the client (“0-RTT” handshake)

Initial 1-RTT handshake

- Client first sends an “inchoate” (incomplete) client hello message



Initial 1-RTT Handshake

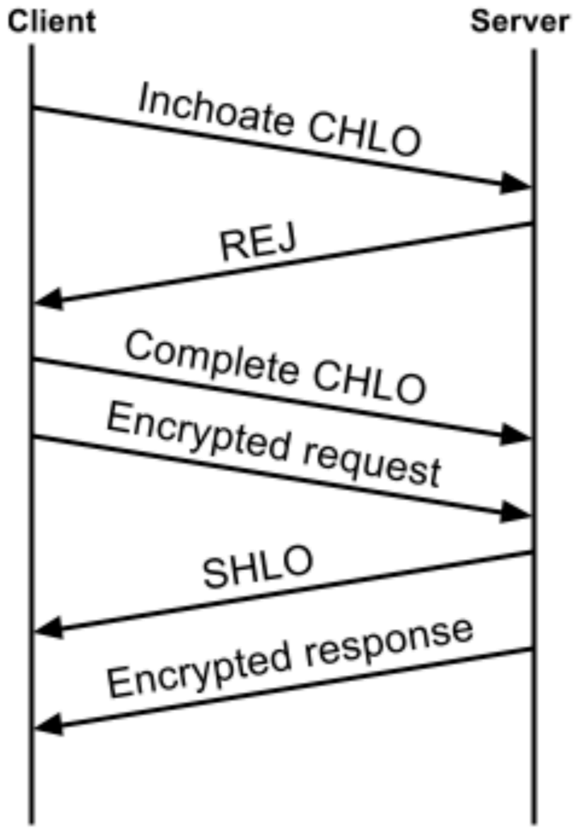
Server REJ message contains:

(1) server’s long-term DHM public value
(2) Certificate chain authenticating the server
(3) Signature of DHM public value using the certified (private) key
(4) Client source address token signed by server

What properties does each of these (help) establish?

Initial 1–RTT handshake

- Finish the handshake



Initial 1-RTT Handshake

Client sends its ephemeral DHM public value to server in a complete CHLO.

Server then responds with its ephemeral DHM public value.

Ephemeral DH values provide forward secrecy

Other handshake details

- In later handshakes, client optimistically sends its source address token to the server

- Optimistic version negotiation: client proposes a cipher suite and encrypts first request with that cipher suite
  - If server can't speak that cipher suite, it forces version renegotiation, similar to TLS

- Both techniques optimize the common case when clients speak to a known server with an agreed-upon cipher suite