Public key encryption

- **Three randomized algorithms:**
  - *Generate* – $G(1^k) \to K, K^{-1}$
  - *Encrypt* – $E(K, m) \to \{m\}_K$
  - *Decrypt* – $D(K^{-1}, \{m\}_K) \to m$
- **Provides secrecy, like conventional encryption**
  - Can't derive m from $\{m\}_K$ without knowing K^{-1}
- **Encryption key K can be made public**
  - Can't derive K^{-1} from K
  - Everyone can use the same public key to encrypt messages for one recipient.

Digital signatures

- **Three (randomized) algorithms:**
  - *Generate* – $G(1^k) \to K, K^{-1}$
  - *Sign* – $S\left(K^{-1}, m\right) \to \{m\}_{K^{-1}}$
  - *Verify* – $V\left(K, \{m\}_{K^{-1}}, m\right) \to \{\mathbf{true}, \mathbf{false}\}$
- **Provides integrity, like a MAC**
  - Cannot produce valid $\langle m, \{m\}_{K^{-1}} \rangle$ pair without K^{-1}
- **Many keys support both signing & encryption**
  - But Encrypt/Decrypt and Sign/Verify different algorithms!

Cost of cryptographic operations

Operation	msec
Encrypt	1.11
Decrypt	39.62
Sign	40.56
Verify	0.10

[1,280-bit Rabin-Williams keys on 550 MHz K6]

- **Cost of public key algorithms significant**
  - Encryption only on small messages (< size of key)
  - Signature cost relatively insensitive to message size
- **In contrast, symmetric algorithms must cheaper**
  - Symmetric can encrypt+MAC faster than 100Mbit/sec LAN

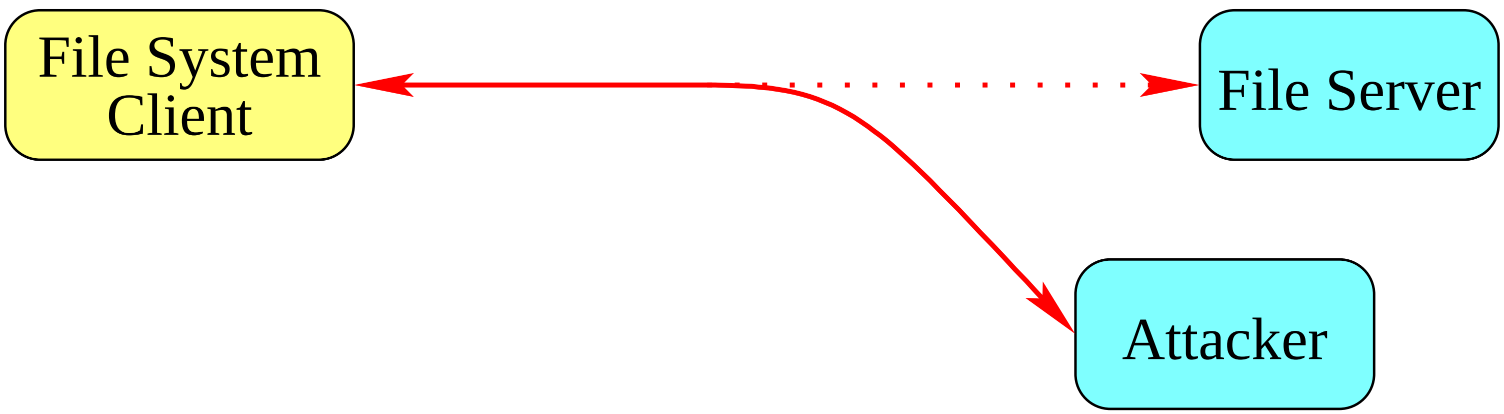
Hybrid schemes

- **Use public key to encrypt symmetric key**
  - Send message symmetrically encrypted: $\{\mathrm{msg}\}_{K_S}, \{K_S\}_{K_P}$
- **Use PK to negotiate secret session key**
  - E.g., Client sends server $\{K_1, K_2, K_3, K_4\}_{K_P}$
  - Client sends server: $\{m_1, \mathrm{MAC}(K_2, m_1)\}_{K_1}$
  - Server sends client: $\{m_2, \mathrm{MAC}(K_4, m_2)\}_{K_3}$
- **Often want mutual authentication (client & server)**
  - Or more complex, user(s), client, & server

Server authentication

- **An approach: Use public key cryptography**
  - Give client public key of server
  - Lets client authenticate secure channel to server
- **Problem: Key management problem**
  - How to get server's public key?
  - How to know the key is really server's?

The danger: Attackers impersonating servers



- **File system example:**
  - Attacker pretends to be server, gives its own public key
  - Attacker substitutes modified data for file
  - User writes sensitive file to fake server

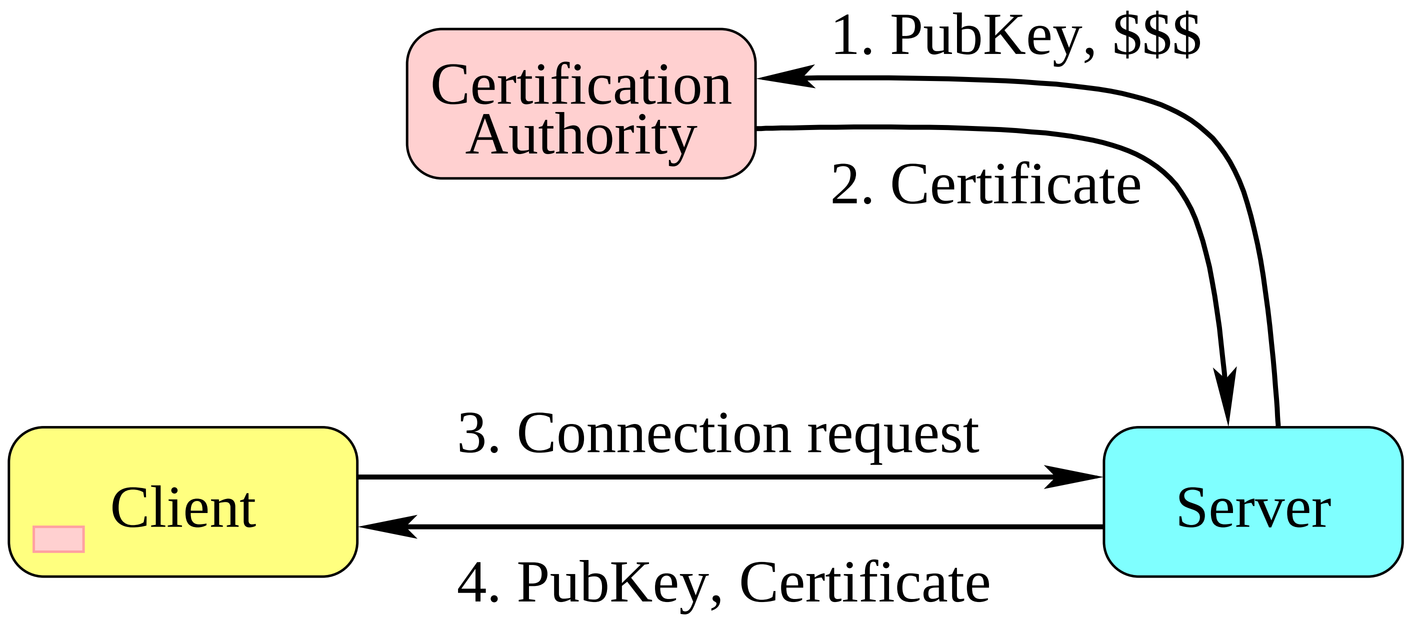
Man in the middle attacks

- **Attacker might not look like server**
  - User would notice if file system didn't contain right files
- **Man in the middle attack foils user:**
  - Attacker emulates server when talking to client
  - Attacker emulates client when talking to server
  - Attacker passes most messages through unmodified
  - Attacker substitutes own public key for client's & server's
  - Attacker records secret data, or tampers to cause damage

Key management

- **Put public keys in the phone book**
  - How do you know you have the real phone book?
  - How is a program supposed to use phone book www.phonebook.com? (are you talking to real web server)
- **Exchange keys with people in person**
- **“Web of trust” – get keys from friends you trust**

Certification authorities



- **Everybody trusts some certification authority**
- **Everybody knows authority's public key**
  - E.g., built into web browser

Hierarchy with local trust

- **To get from cs.nyu.edu to mit.edu:**
  - cs.nyu.edu knows key for nyu.edu
  - nyu.edu knows key for edu/root
  - root knows key for mit.edu
- **To get within cs.nyu.edu:**
  - No need to trust outside authorities