CSCI-1680
Security

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Based on lecture notes by Scott Shenker and Mike Freedman

Today's Lecture

- Classes of attacks
- Basic security requirements
- Simple cryptographic methods
- Cryptographic toolkit (Hash, Digital Signature, …)
- DNSSec
- Certificate Authorities
- SSL / HTTPS

Basic Requirements for Secure Communication

- **Availability: Will the network deliver data?**
  - Infrastructure compromise, DDoS
- **Authentication: Who is this actor?**
  - Spoofing, phishing
- **Integrity: Do messages arrive in original form?**
- **Confidentiality: Can adversary read the data?**
  - Sniffing, man-in-the-middle
- **Provenance: Who is responsible for this data?**
  - Forging responses, denying responsibility
  - Not who sent the data, but who created it

Other Desirable Security Properties

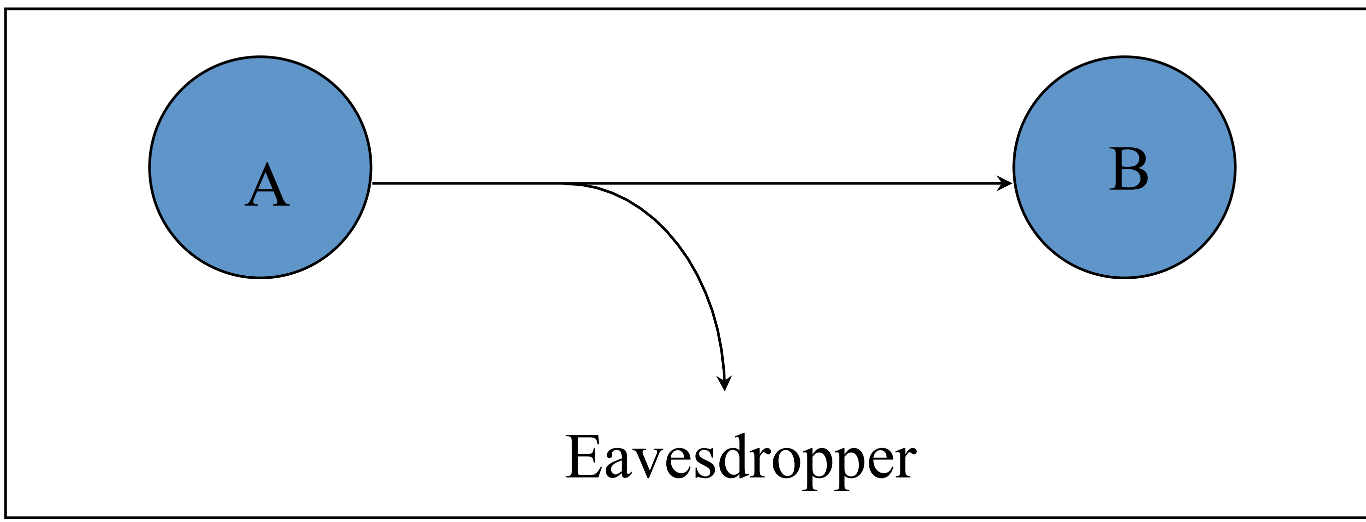
- **Authorization: is actor allowed to do this action?**
  - Access controls
- **Accountability/Attribution: who did this activity?**
- **Audit/Forensics: what occurred in the past?**
  - A broader notion of accountability/attribution
- **Appropriate use: is action consistent with policy?**
  - E.g., no spam; no games during business hours; etc.
- **Freedom from traffic analysis: can someone tell when I am sending and to whom?**
- **Anonymity: can someone tell I sent this packet?**

Internet's Design: Insecure

- Designed for simplicity in a naïve era
- "On by default" design
- Readily available zombie machines
- Attacks look like normal traffic
- Internet's federated operation obstructs cooperation for diagnosis/mitigation

Eavesdropping - Message Interception (Attack on Confidentiality)

- Unauthorized access to information
- Packet sniffers and wiretappers
- Illicit copying of files and programs



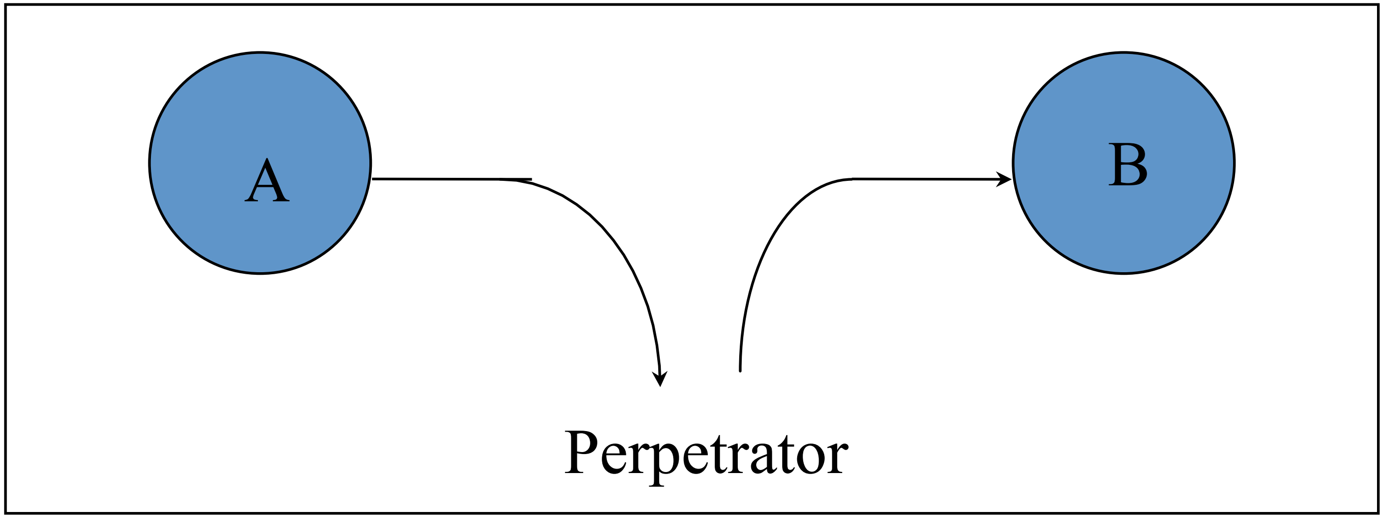
Eavesdropping Attack: Example

- **tcpdump with promiscuous network interface**
  - On a switched network, what can you see?

- **What might the following traffic types reveal about communications?**
  - DNS lookups (and replies)
  - IP packets without payloads (headers only)
  - Payloads

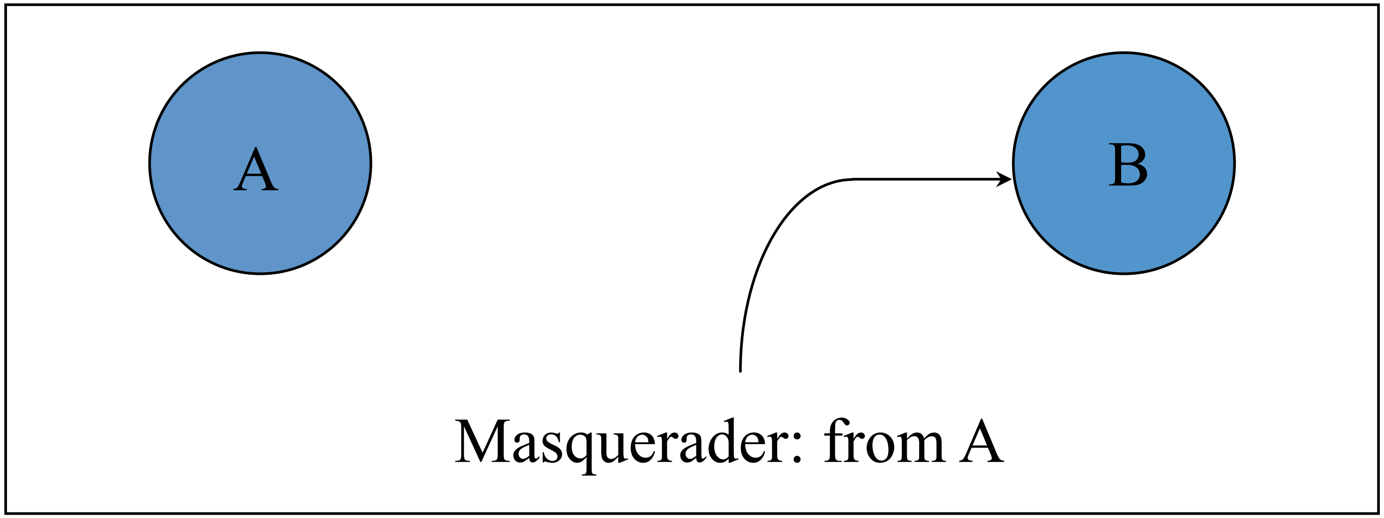
Integrity Attack - Tampering

- Stop the flow of the message
- Delay and optionally modify the message
- Release the message again



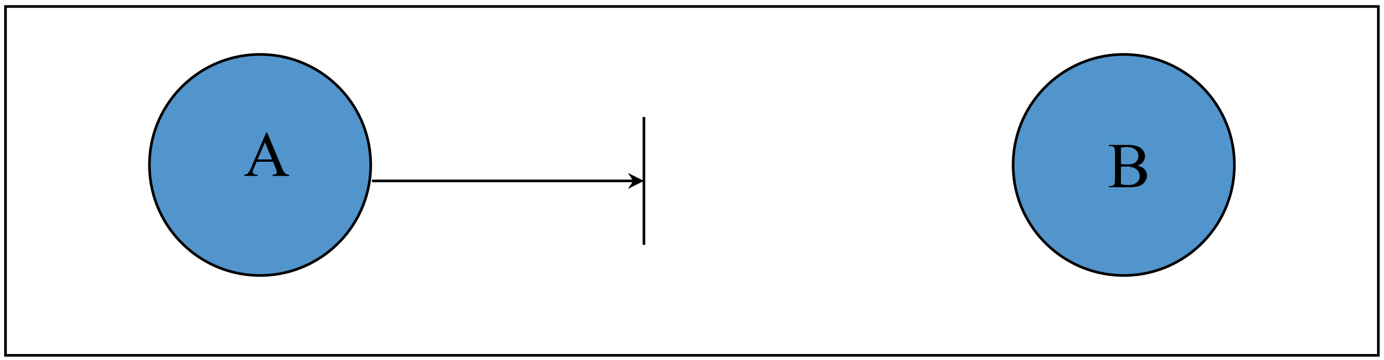
Authenticity Attack - Fabrication

- Unauthorized assumption of other's identity
- Generate and distribute objects under this identity



Attack on Availability

- **Destroy hardware (cutting fiber) or software**
- **Modify software in a subtle way**
- **Corrupt packets in transit**



- **Blatant *denial of service* (DoS):**
  - Crashing the server
  - Overwhelm the server (use up its resource)

Basic Forms of Cryptography

Confidentiality through Cryptography

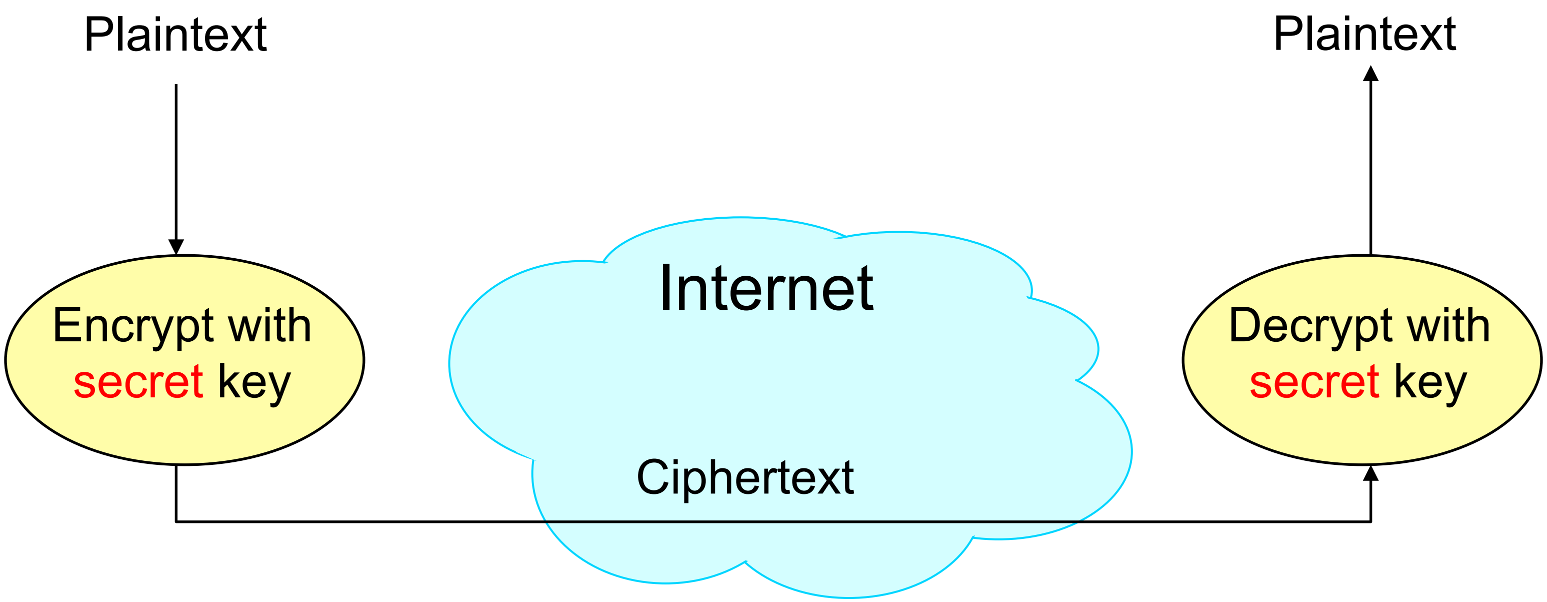
- **Cryptography:** *communication over insecure channel in the presence of adversaries*
- **Studied for thousands of years**
- **Central goal:** how to encode information so that an adversary can't extract it …but a friend can
- **General premise:** a ***key*** is required for decoding
  – Give it to friends, keep it away from attackers
- **Two different categories of encryption**
  – Symmetric: efficient, requires key distribution
  – Asymmetric (Public Key): computationally expensive, but no key distribution problem

Symmetric Key Encryption

- **Same key for encryption and decryption**
  - Both sender and receiver know key
  - But adversary does not know key
- **For communication, problem is key distribution**
  - How do the parties (secretly) agree on the key?
- **What can you do with a huge key? One-time pad**
  - Huge key of random bits
- **To encrypt/decrypt: just XOR with the key!**
  - Provably secure! …. provided:
    - You never reuse the key … and it really is random/unpredictable
  - Spies actually use these

Using Symmetric Keys

- **Both the sender and the receiver use the same secret keys**

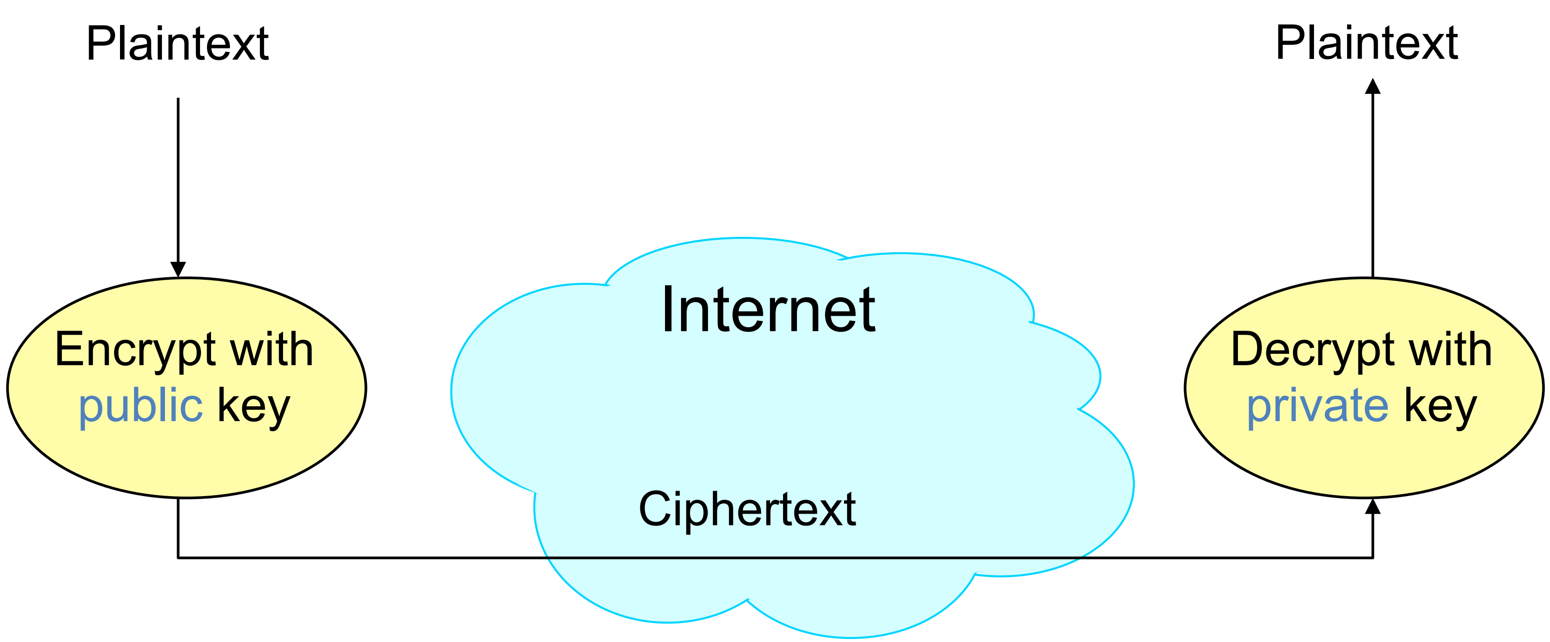


Asymmetric Encryption *(Public Key)*

- **Idea: use two *different* keys, one to encrypt (*e*) and one to decrypt (*d*)**
  - A key pair
- **Crucial property: knowing *e* does not give away *d***
- **Therefore *e* can be public: everyone knows it!**
- **If Alice wants to send to Bob, she fetches Bob's public key (say from Bob's home page) and encrypts with it**
  - Alice can't decrypt what she's sending to Bob …
  - … but then, neither can anyone else (except Bob)

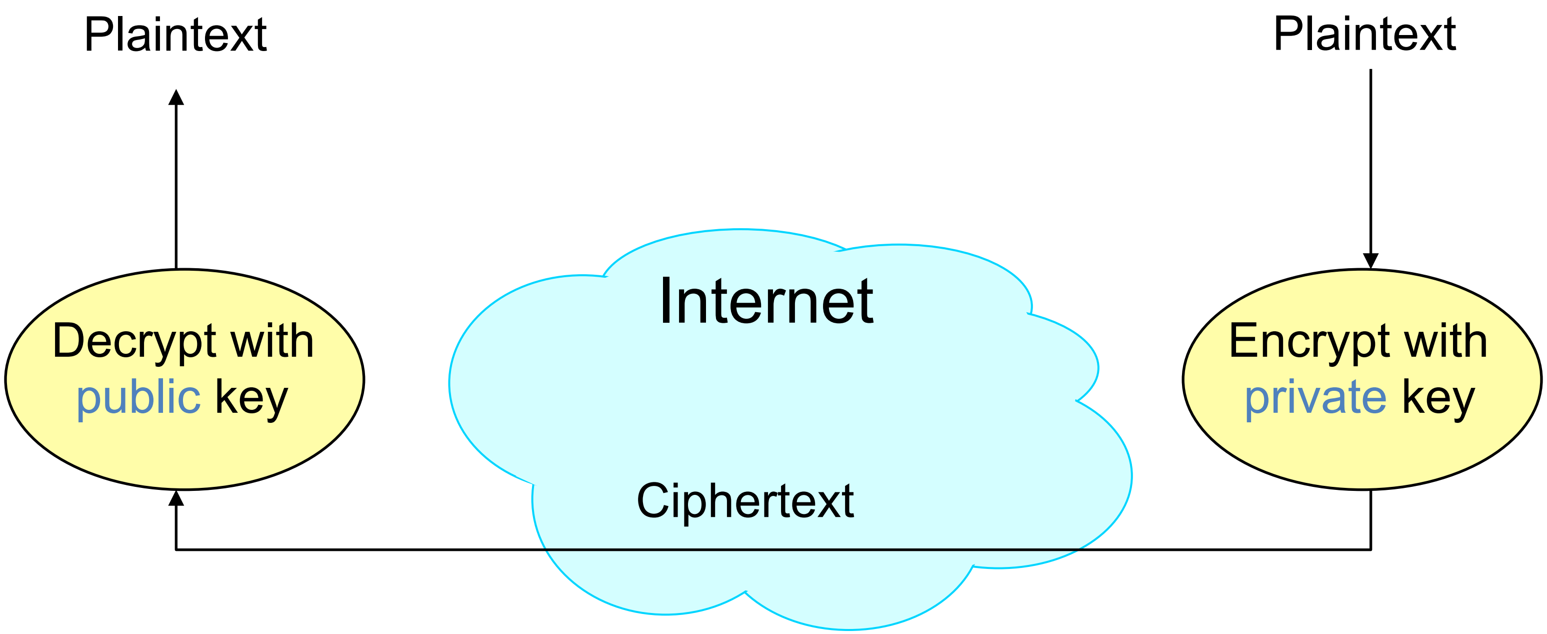
Public Key / Asymmetric Encryption

- **Sender uses receiver's public key**
  - Advertised to everyone
- **Receiver uses complementary private key**
  - Must be kept secret



Works in Reverse Direction Too!

- Sender uses his own private key
- Receiver uses complementary public key
- Allows sender to prove he knows private key



Realizing Public Key Cryptography

- **Invented in the 1970s**
  - *Revolutionized* cryptography
  - (Was actually invented earlier by British intelligence)
- **How can we construct an encryption/decryption algorithm with public/private properties?**
  - Answer: Number Theory
- **Most fully developed approach: RSA**
  - Rivest / Shamir / Adleman, 1977; RFC 3447
  - Based on modular multiplication of very large integers
  - Very widely used (e.g., SSL/TLS for **`https`**)

Cryptographic Toolkit

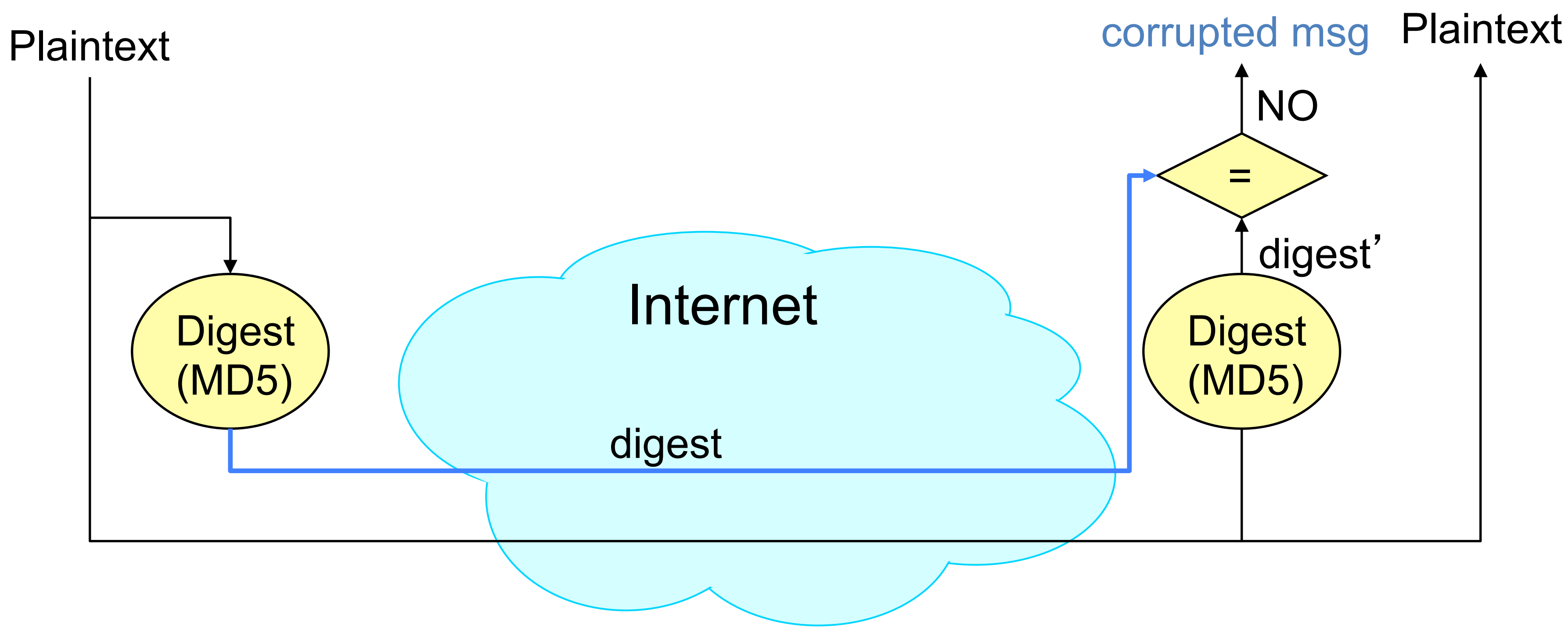
Cryptographic Toolkit

- **Confidentiality: Encryption**
- **Integrity: ?**
- **Authentication: ?**
- **Provenance: ?**

Integrity: Cryptographic Hashes

- **Sender computes a *digest* of message *m*, i.e., *H(m)***
  - H() is a publicly known *hash function*
- **Send *m* in any manner**
- **Send digest *d = H(m)* to receiver in a secure way:**
  - Using another physical channel
  - Using encryption *(why does this help?)*
- **Upon receiving *m* and *d*, receiver re-computes *H(m)* to see whether result agrees with *d***

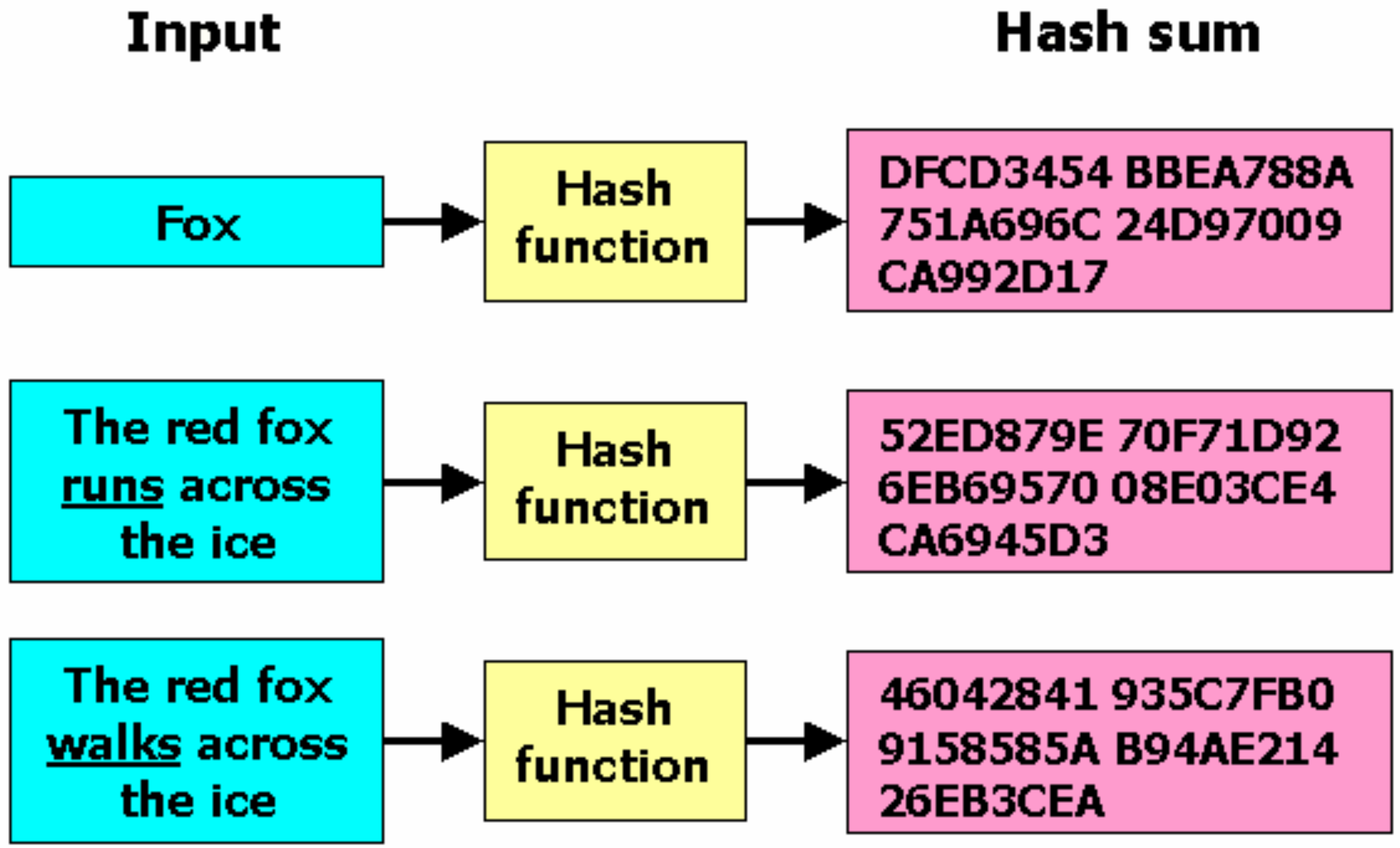
Operation of Hashing for Integrity



Cryptographically Strong Hashes

- **Hard to find collisions**
  - Adversary can't find two inputs that produce same hash
  - Someone cannot alter message without modifying digest
  - Can succinctly refer to large objects
- **Hard to invert**
  - Given hash, adversary can't find input that produces it
  - Can refer obliquely to private objects (e.g., passwords)
    - Send hash of object rather than object itself

Effects of Cryptographic Hashing

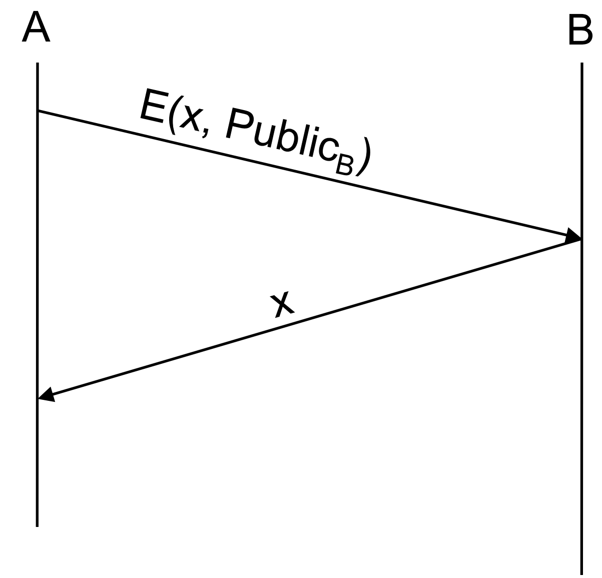


Cryptographic Toolkit

- **Confidentiality:** Encryption
- **Integrity:** Cryptographic Hash
- **Authentication:** ?
- **Provenance:** ?

Public Key Authentication

- **Each side need only to know the other side's public key**
  - No secret key need be shared
- **A encrypts a nonce (random number) *x* using B's public key**
- **B proves it can recover *x***
- **A can authenticate itself to B in the same way**



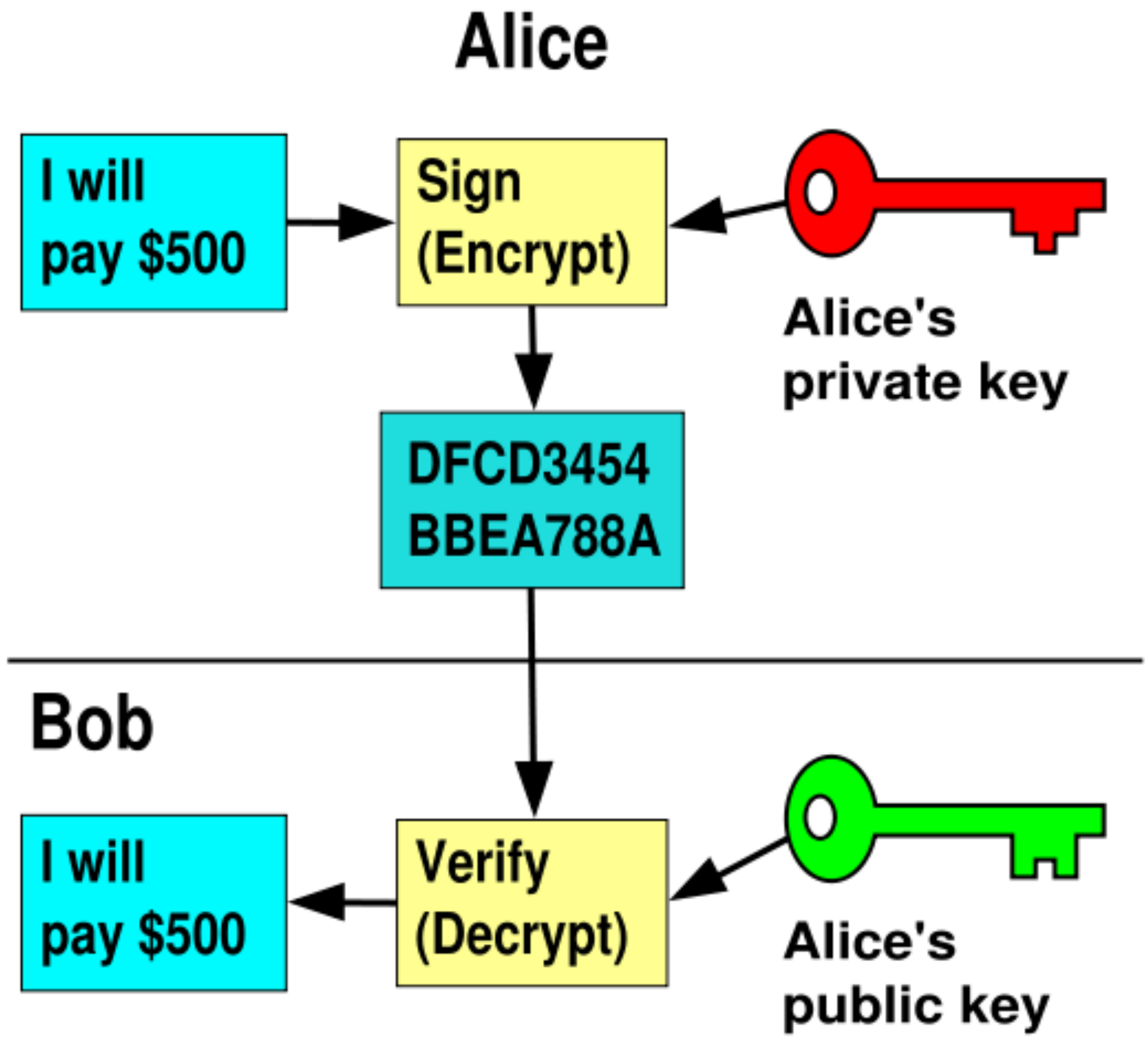
Cryptographic Toolkit

- **Confidentiality:** Encryption
- **Integrity:** Cryptographic Hash
- **Authentication:** Decrypting nonce
- **Provenance:** ?

Digital Signatures

- **Suppose Alice has published public key K_E**
- **If she wishes to prove who she is, she can send a message *x* encrypted with her private key K_D**
  - Therefore: anyone w/ public key K_E can recover *x*, verify that Alice must have sent the message
  - It provides a digital signature
  - Alice can't deny later deny it ⇒ non-repudiation

RSA Crypto & Signatures, con't



Summary of Our Crypto Toolkit

- **If we can securely distribute a key, then**
  - Symmetric ciphers (e.g., AES) offer fast, presumably strong confidentiality
- **Public key cryptography does away with problem of secure key distribution**
  - But not as computationally efficient
  - Often addressed by using public key crypto to exchange a session key
  - And not guaranteed secure
    - but **major** result if not

Summary of Our Crypto Toolkit, con't

- **Cryptographically strong hash functions provide major building block for integrity (e.g., SHA-1)**
  - As well as providing concise digests
  - And providing a way to prove you know something (e.g., passwords) without revealing it (non-invertibility)
  - But: worrisome recent results regarding their strength
- **Public key also gives us signatures**
  - Including sender non-repudiation
- **Turns out there's a crypto trick based on similar algorithms that allows two parties *who don't know each other's public key* to securely negotiate a secret key even in the presence of eavesdroppers**

PKIs and HTTPS

Public Key Infrastructure *(PKI)*

- **Public key crypto is *very* powerful …**
- **… but the realities of tying public keys to real world identities turn out to be quite hard**

- **PKI: *Trust distribution* mechanism**
  - Authentication via Digital Certificates
- **Trust doesn't mean someone is honest, just that they are who they say they are…**

Managing Trust

- **The most solid level of trust is rooted in our direct personal experience**
  - E.g., Alice's trust that Bob is who they say they are
  - Clearly doesn't scale to a global network!

- **In its absence, we rely on *delegation***
  - Alice trusts Bob's identity because Charlie attests to it ….
  - …. and Alice trusts Charlie

Managing Trust, con't

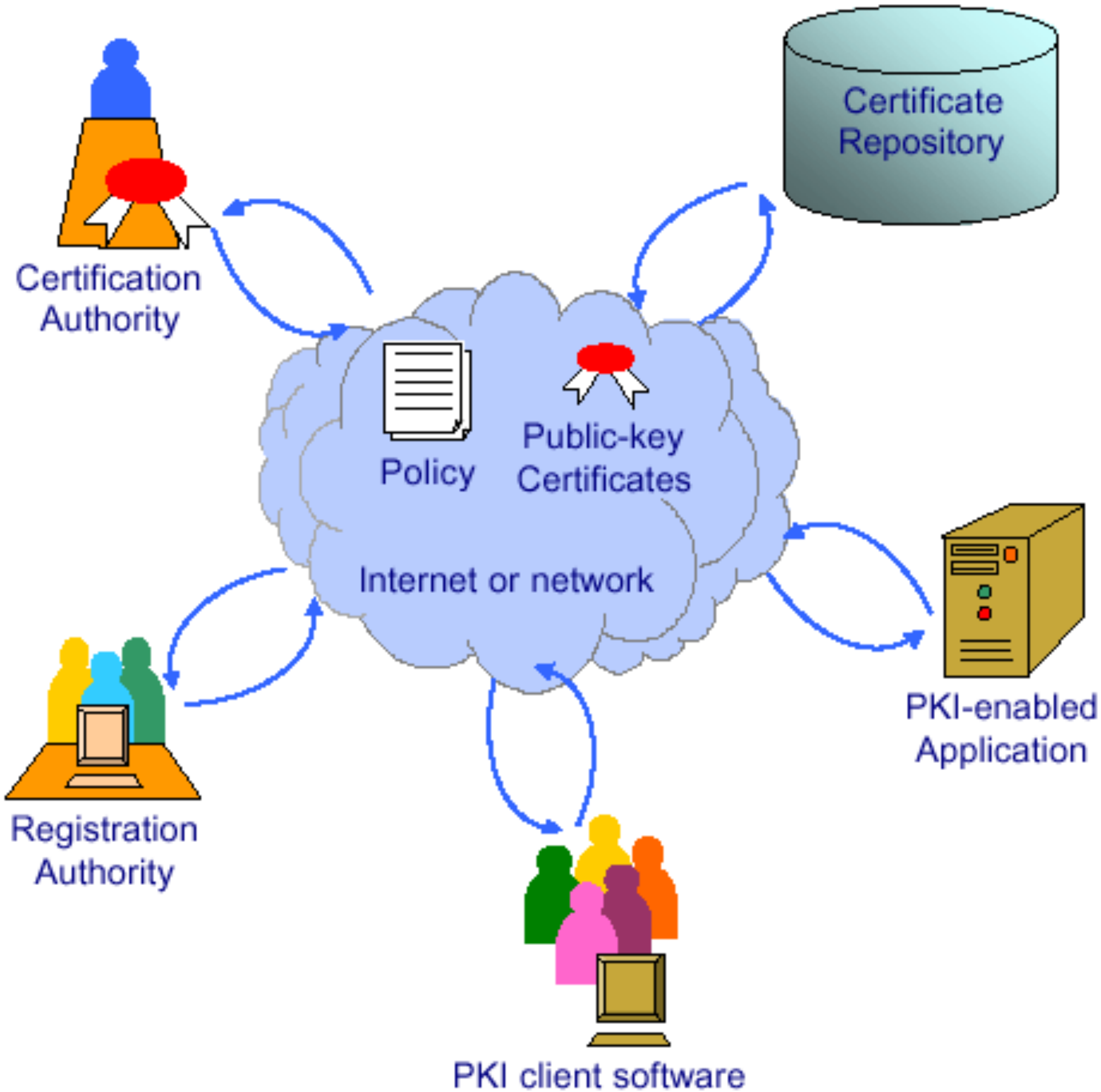
- **Trust is not particularly transitive**
  - Should Alice trust Bob because she trusts Charlie …
  - … and Charlie vouches for Donna …
  - … and Donna says Eve is trustworthy …
  - … and Eve vouches for Bob's identity?

- **Two models of delegating trust**
  - Rely on your set of friends and their friends
    - "Web of trust" -- e.g., PGP
  - Rely on trusted, well-known authorities (*and their minions*)
    - "Trusted root" -- e.g., HTTPS

PKI Conceptual Framework

- **Trusted-Root PKI:**
  - Basis: well-known public key serves as root of a hierarchy
  - Managed by a Certificate Authority (CA)
- **To publish a public key, ask the CA to digitally sign a statement indicating that they agree ("certify") that it is indeed your key**
  - This is a certificate for your key (*certificate* = bunch of bits)
    - Includes both your public key and the signed statement
  - Anyone can verify the signature
- **Delegation of trust to the CA**
  - They'd better not screw up (duped into signing bogus key)
  - They'd better have procedures for dealing with stolen keys
  - Note: can build up a hierarchy of signing

Components of a PKI



Digital Certificate

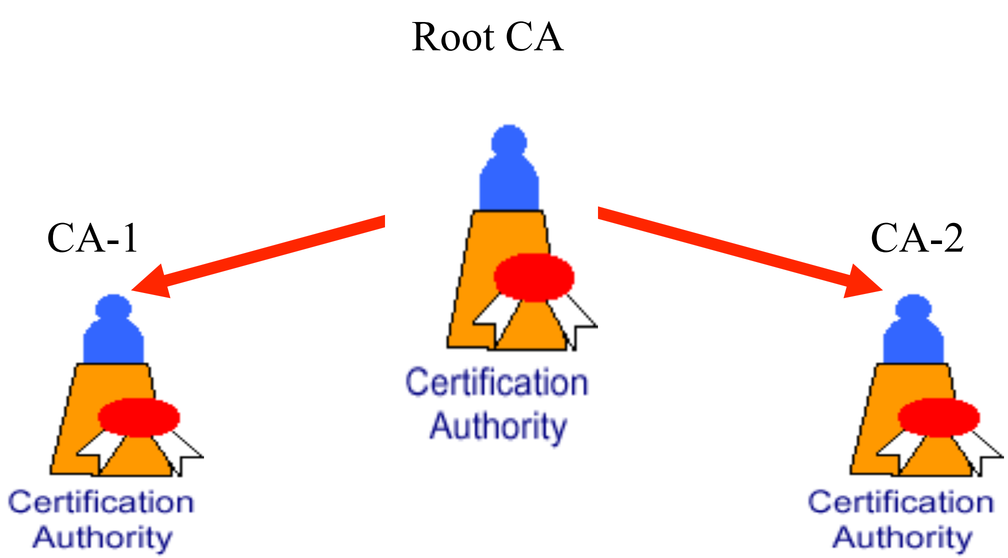
- **Signed data structure that binds an entity with its corresponding public key**
  - Signed by a *recognized* and *trusted* authority, i.e., Certification Authority (CA)
  - Provide assurance that a particular public key belongs to a specific entity
- **Example: certificate of entity Y**

  $$\textbf{Cert} = \textbf{E}(\{\textbf{name}_Y, \textbf{KY}_{\textbf{public}}\}, \textbf{KCA}_{\textbf{private}})$$

  - $KCA_{private}$: private key of Certificate Authority
  - $name_Y$: name of entity Y
  - KY_{public}: public key of entity Y
    - In fact, they may sign whatever glob of bits you give them
- **Your browser has a bunch of CAs wired into it**

Certification Authority

- **People, processes responsible for creation, delivery and management of digital certificates**
- **Organized in an hierarchy**
  - To verify signature chain, follow hierarchy up to root



Registration Authority

- **People & processes responsible for:**
  - Authenticating the identity of new entities (users or computing devices), e.g.,
    - By phone, or physical presence + ID
  - Issuing requests to CA for certificates
- **The CA must trust the Registration Authority**
  - This trust can be misplaced

Certificate Repository

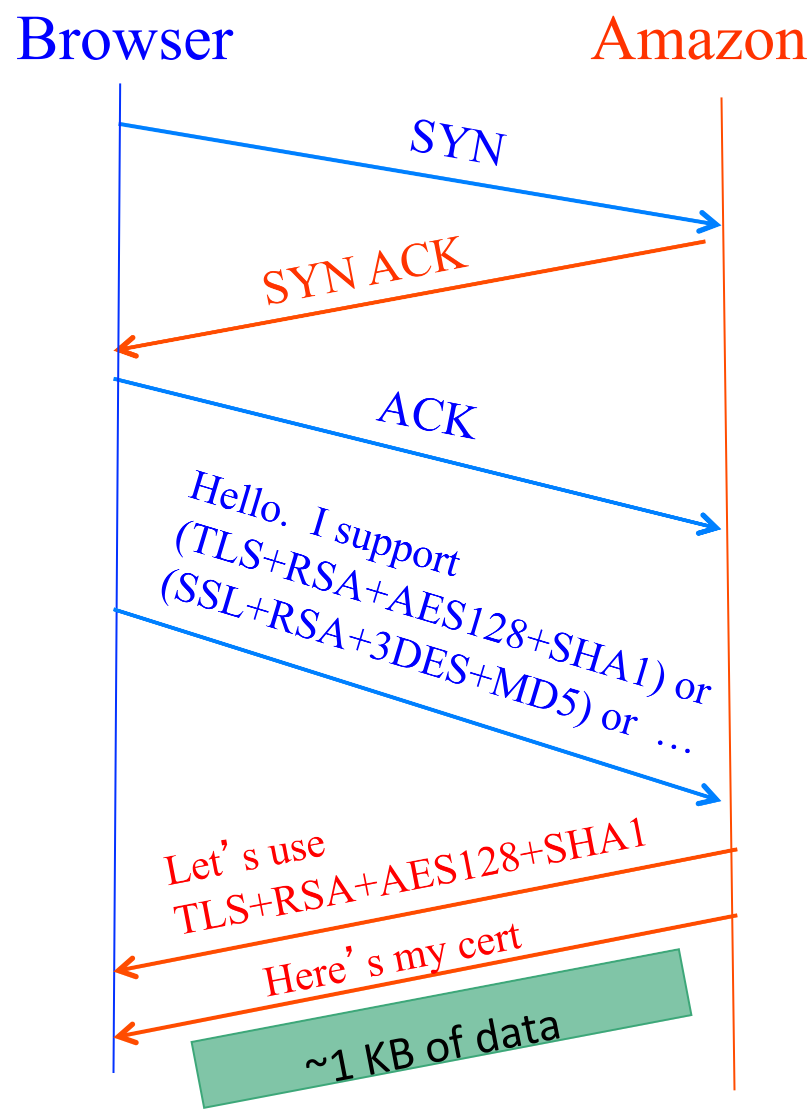
- **A database accessible to all users of a PKI**
- **Contains:**
  - Digital certificates
  - Policy information associated with certs
  - Certificate revocation information
    - Vital to be able to identify certs that have been compromised
    - Usually done via a *revocation list*

Putting It All Together: HTTPS

- **Steps after clicking on https://www.amazon.com**
- **https = "Use HTTP over SSL/TLS"**
  - SSL = Secure Socket Layer
  - TLS = Transport Layer Security
    - Successor to SSL, and compatible with it
  - RFC 4346
- **Provides security layer (authentication, encryption) on top of TCP**
  - Fairly transparent to the app

HTTPS Connection (SSL/TLS), con't

- Browser (client) connects via TCP to Amazon's `HTTPS` server
- Client sends over list of crypto protocols it supports
- Server picks protocols to use for this session
- Server sends over its certificate
- (all of this is in the clear)



Inside the Server's Certificate

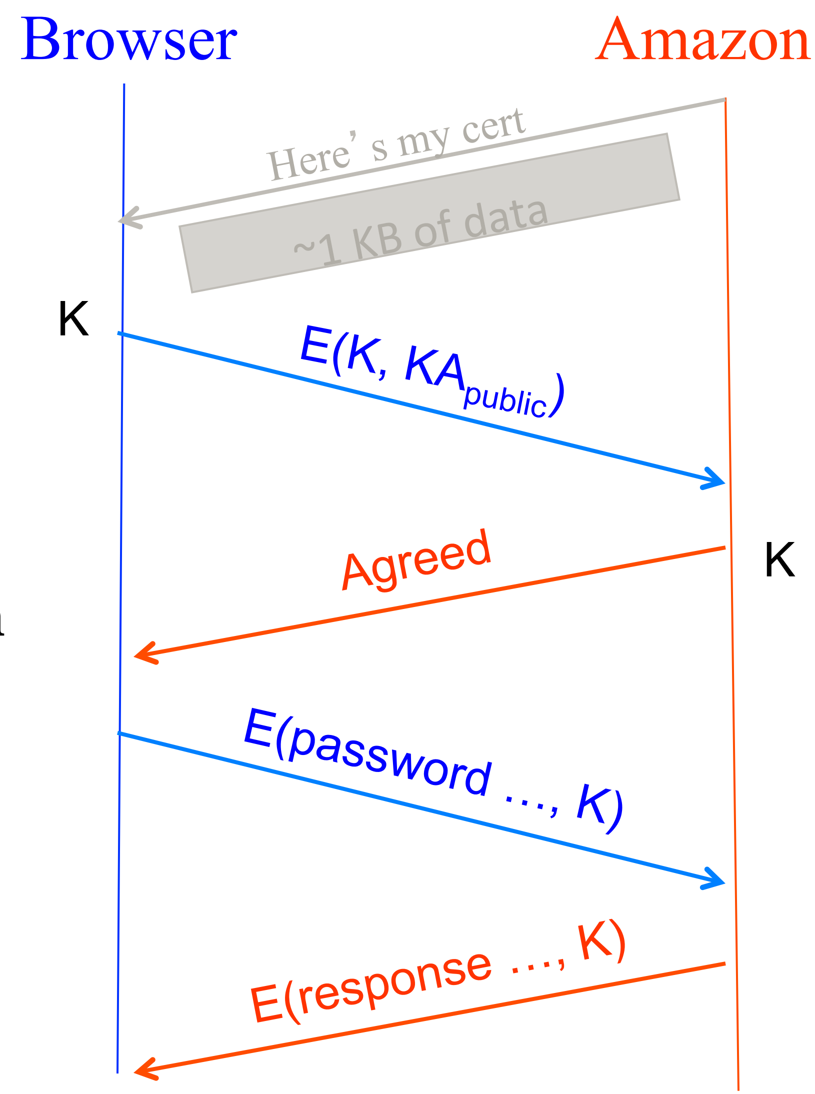
- **Name associated with cert (e.g., Amazon)**
- **Amazon's public key**
- **A bunch of auxiliary info (physical address, type of cert, expiration time)**
- **URL to *revocation center* to check for revoked keys**
- **Name of certificate's signatory (who signed it)**
- **A public-key signature of a hash (MD5) of all this**
  - Constructed using the signatory's private RSA key

Validating Amazon's Identity

- **Browser retrieves cert belonging to the signatory**
  - These are hardwired into the browser
- **If it can't find the cert, then warns the user that site has not been verified**
  - And may ask whether to continue
  - Note, can still proceed, just without authentication
- **Browser uses public key in signatory's cert to decrypt signature**
  - Compares with its own MD5 hash of Amazon's cert
- **Assuming signature matches, now have high confidence it's indeed Amazon …**
  - … assuming signatory is trustworthy

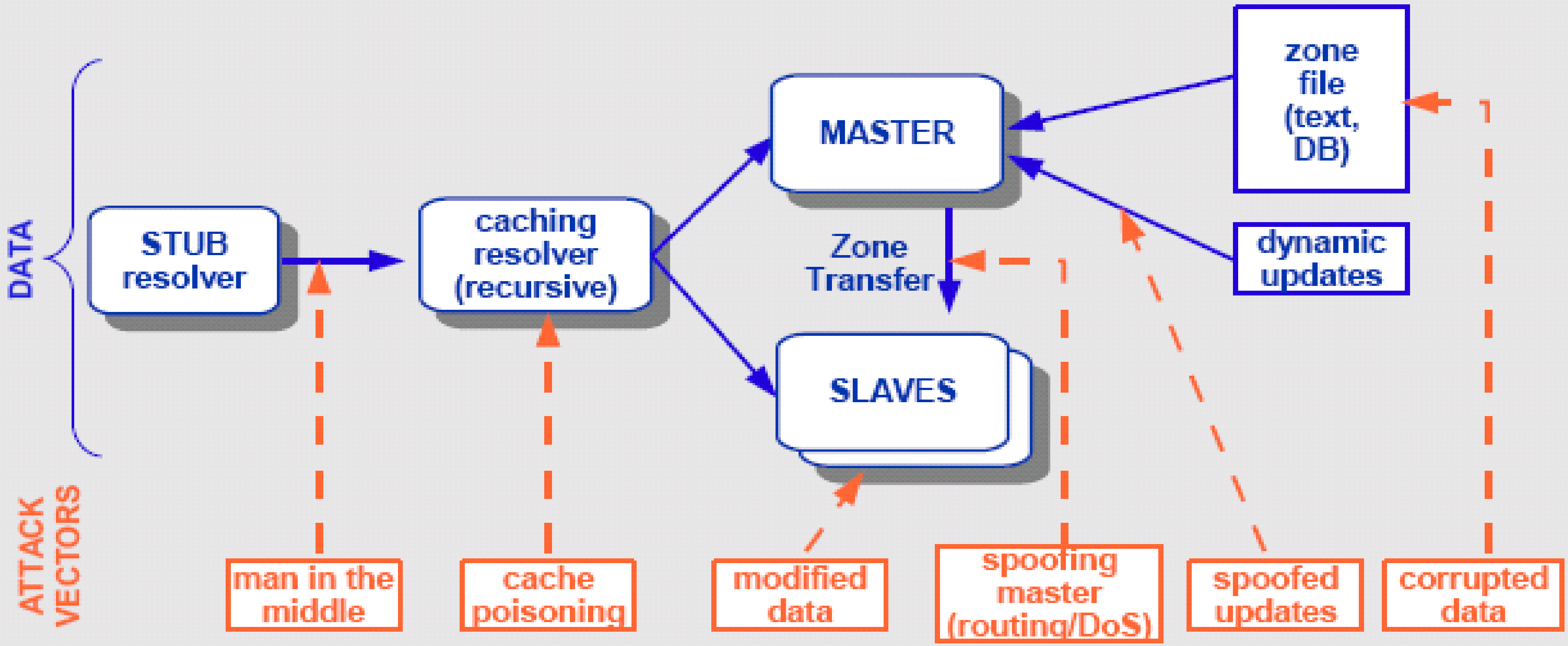
HTTPS Connection (SSL/TLS), con't

- **Browser constructs a random *session key* K**
- **Browser encrypts K using Amazon's public key**
- **Browser sends E(K, KA_{public}) to server**
- **Browser displays** 
- **All subsequent communication encrypted w/ symmetric cipher using key K**
  - E.g., client can authenticate using a password



DNS Security

DNS Data Flow
Points of attack



Source: http://nsrc.org/tutorials/2009/apricot/dnssec/dnssec-tutorial.pdf

Root level DNS attacks

- **<u>Feb. 6, 2007</u>:**
  - Botnet attack on the 13 Internet DNS root servers
  - Lasted 2.5 hours
  - None crashed, but two performed badly:
    - g-root (DoD), l-root (ICANN)
    - Most other root servers use anycast

Do you trust the TLD operators?

- **Wildcard DNS record for all .com and .net domain names not yet registered by others**
  - September 15 – October 4, 2003
  - February 2004: Verisign sues ICANN
- **Redirection for these domain names to Verisign web portal: "to help you search"**
  - and serve you ads…and get "sponsored" search

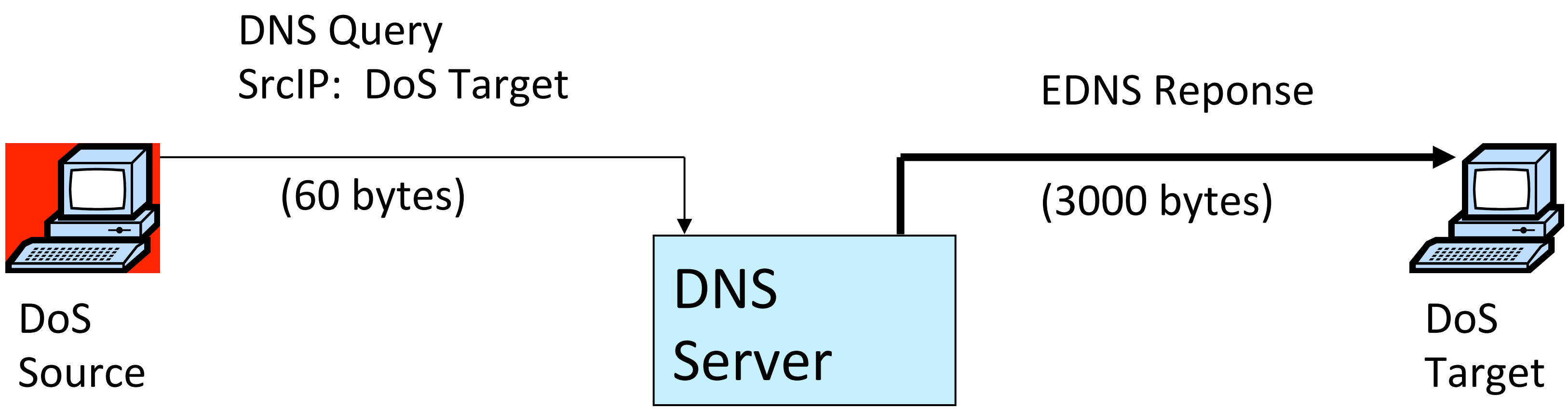
Defense: Replication and Caching

Letter	Old name	Operator	Location
A	ns.internic.net	VeriSign	Dulles, Virginia, USA
B	ns1.isi.edu	ISI	Marina Del Rey, California, USA
C	c.psi.net	Cogent Communications	distributed using anycast
D	terp.umd.edu	University of Maryland	College Park, Maryland, USA
E	ns.nasa.gov	NASA	Mountain View, California, USA
F	ns.isc.org	ISC	distributed using anycast
G	ns.nic.ddn.mil	U.S. DoD NIC	Columbus, Ohio, USA
H	aos.arl.army.mil	U.S. Army Research Lab	Aberdeen Proving Ground, Maryland, USA
I	nic.nordu.net	Autonomica	distributed using anycast
J		VeriSign	distributed using anycast
K		RIPE NCC	distributed using anycast
L		ICANN	Los Angeles, California, USA
M		WIDE Project	distributed using anycast

source: wikipedia

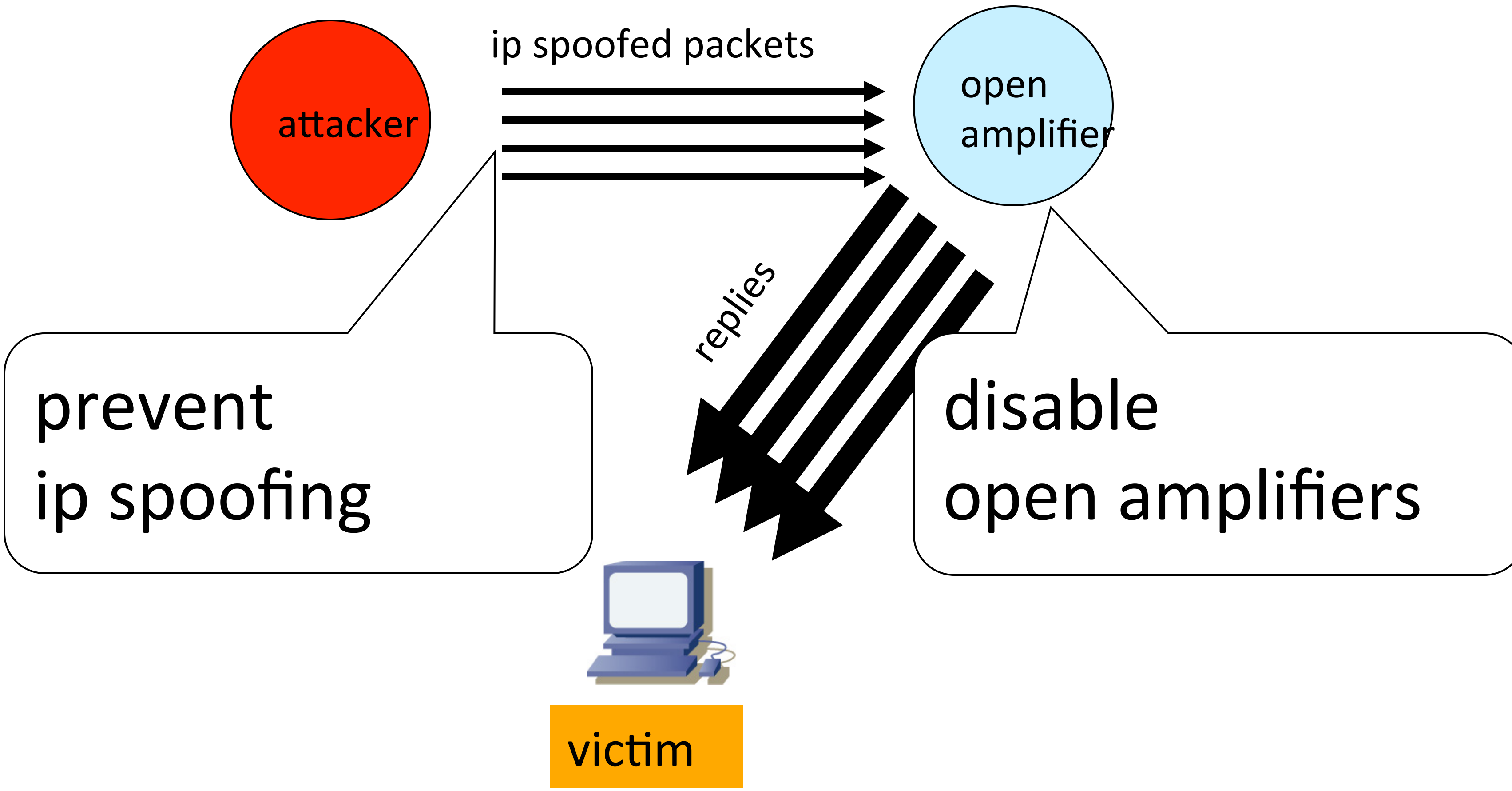
DNS Amplification Attack

DNS Amplification attack: (×40 amplification)



580,000 open resolvers on Internet (Kaminsky-Shiffman'06)

Solutions


attacker
ip spoofed packets
open amplifier
replies
prevent ip spoofing
disable open amplifiers
victim

But should we believe it?
Enter DNSSEC

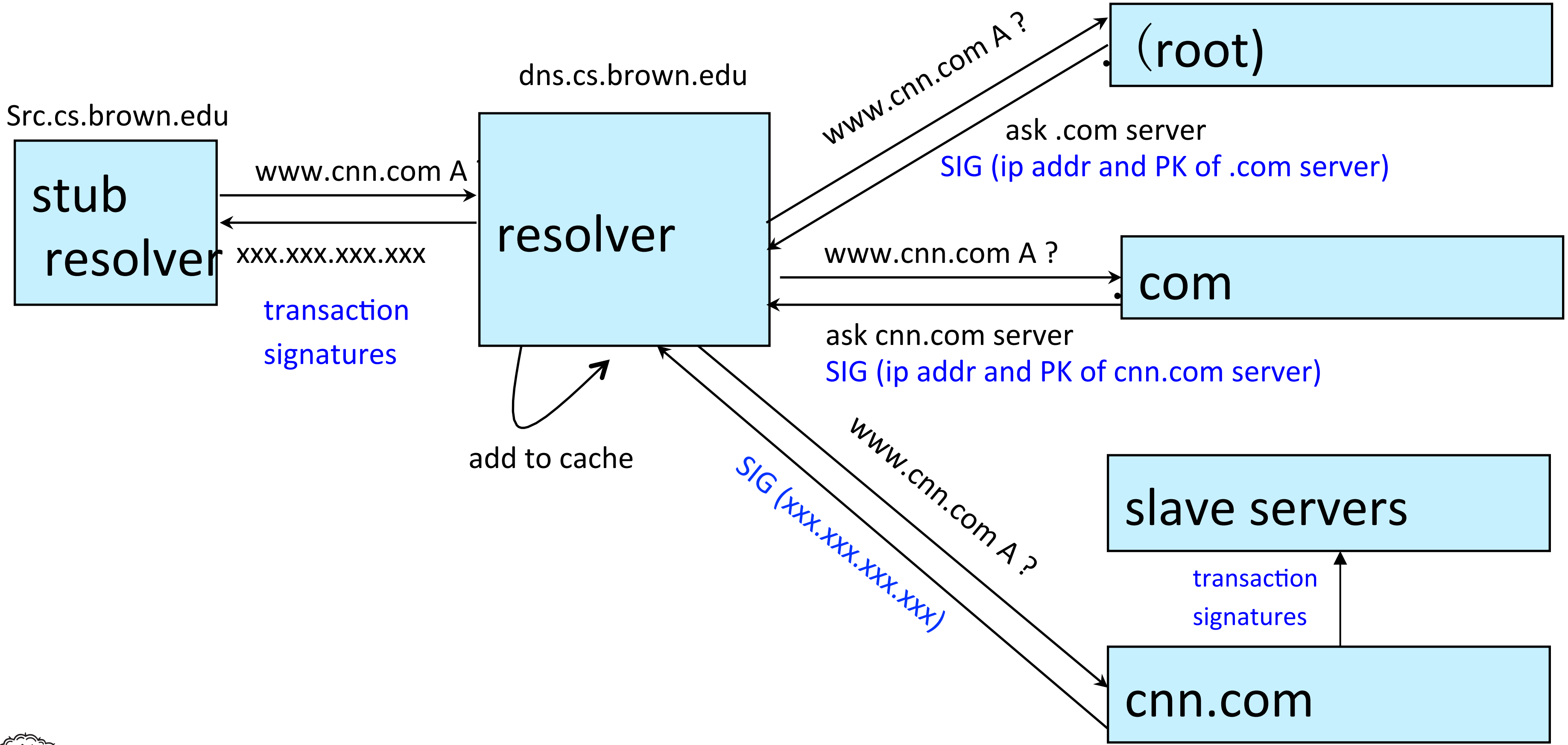
- **DNSSEC protects against data spoofing and corruption**
- **DNSSEC also provides mechanisms to authenticate servers and requests**
- **DNSSEC provides mechanisms to establish authenticity and integrity**

PK-DNSSEC (Public Key)

- **The DNS servers sign the hash of resource record set with its private (signature) keys**
- **Public keys can be used to verify the SIGs**
- **Leverages hierarchy:**
  - Authenticity of nameserver's public keys is established by a signature over the keys by the parent's private key
  - In ideal case, only roots' public keys need to be distributed out-of-band

Verifying the tree

Question: www.cnn.com ?



Next Class

- Some new trends, Software-Defined Networking
- Second-to-last class!
- No class on Tuesday, Dec 4