Security I: Concepts and Applications

Lecture 20

COS 461: Computer Networks

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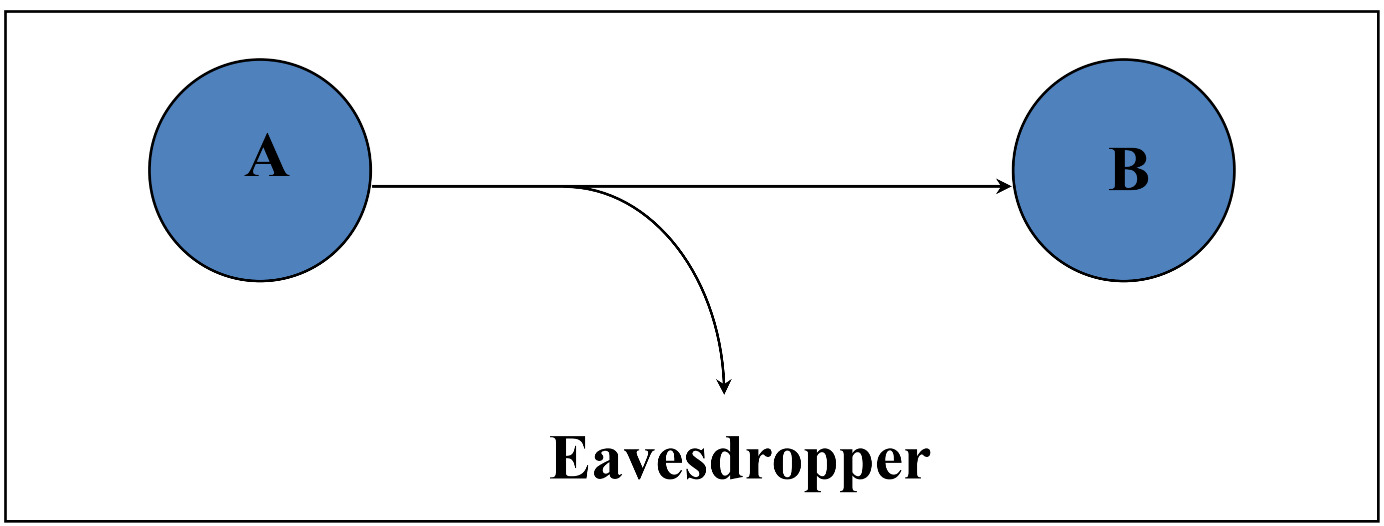
Internet's Design: Insecure

- Designed for simplicity
- "On by default" design

- Readily available zombie machines
- Attacks look like normal traffic
- Internet's federated operation obstructs cooperation for diagnosis/mitigation

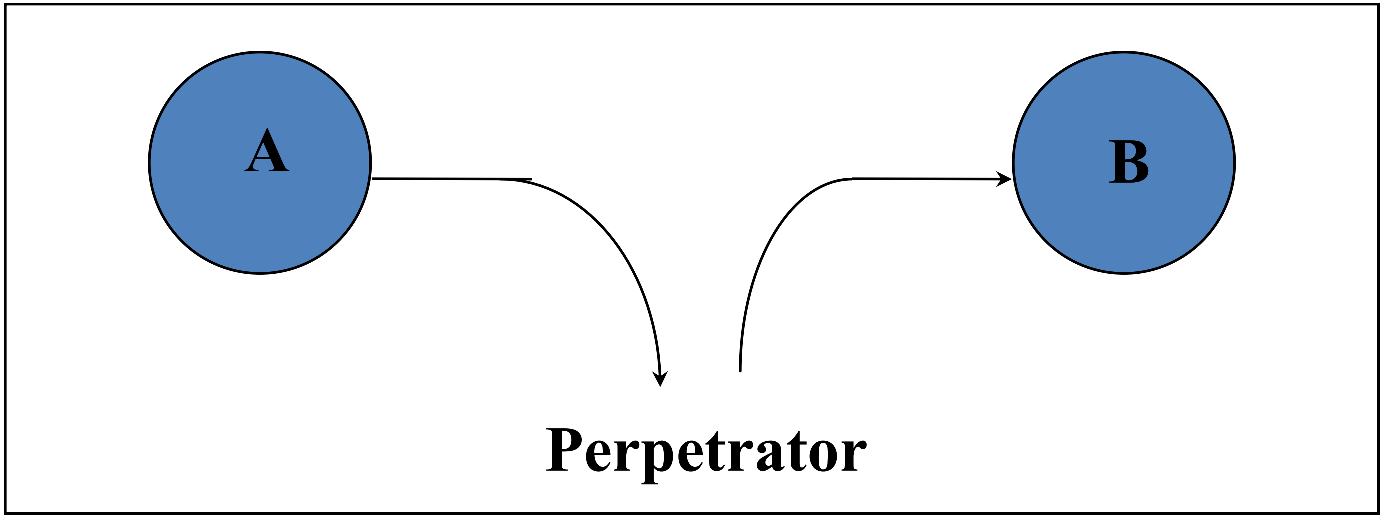
Eavesdropping - Message Interception (Attack on Confidentiality)

- Unauthorized access to information
- Packet sniffers and wiretappers (e.g. tcpdump)
- Illicit copying of files and programs



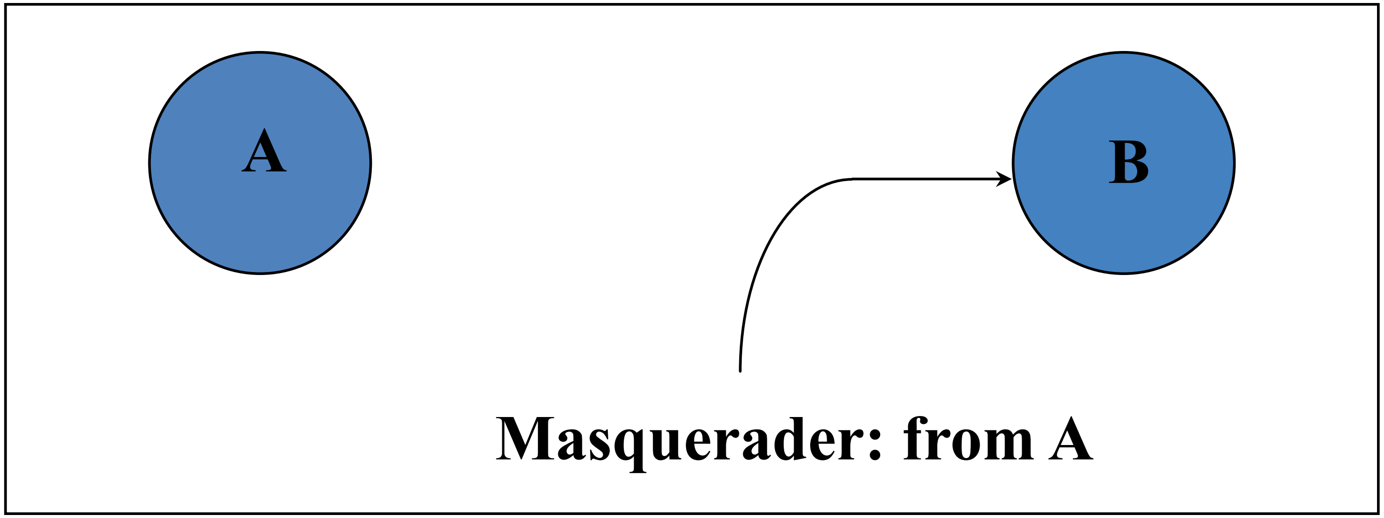
Integrity Attack - Tampering

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



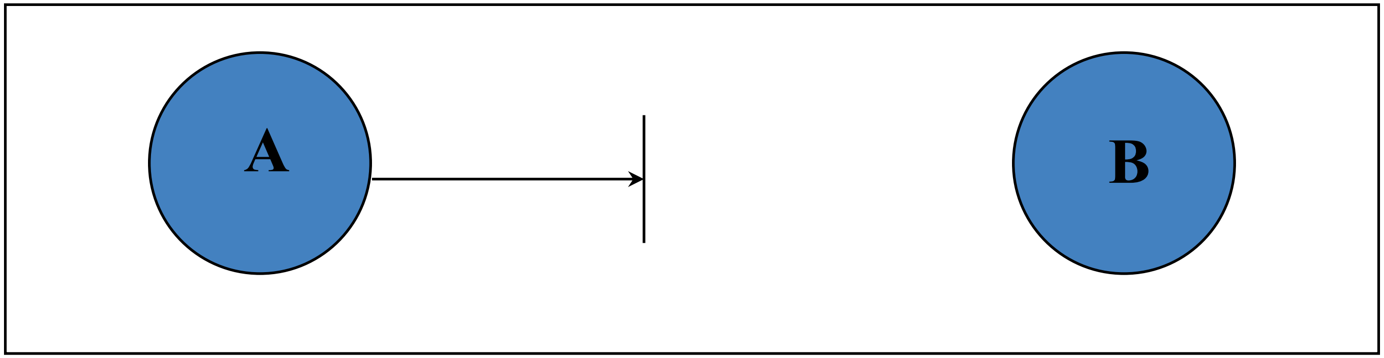
Authenticity Attack - Fabrication

- Unauthorized assumption of other’s identity
- Generate and distribute objects under 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 Security Properties

- **Confidentiality:** Concealment of information or resources
- **Authenticity:** Identification & assurance of origin of info
- **Integrity:** Trustworthiness of data/resources; preventing improper/unauthorized changes
- **Availability:** Ability to use desired information/resource
- **Non-repudiation:** Offer of evidence that a party indeed is sender or a receiver of certain information
- **Access control:** Facilities to determine and enforce who is allowed access to what resources (host, software, network, …)

Security protocols at many layers

- Application layer
  - E-mail: PGP, using a web-of-trust
  - Web: HTTP-S, using a certificate hierarchy
- Transport layer
  - Transport Layer Security/ Secure Socket Layer
- Network layer
  - IP Sec
- Network infrastructure
  - DNS-Sec and BGP-Sec

Introduction to Cryptography

Cryptographic Algorithms: Goal

- One-way functions: cryptographic hash
  - Easy to compute hash
  - Hard to invert
- "Trapdoor" functions: encryption/signatures
  - Given ciphertext alone, hard to compute plaintext (invert)
  - Given ciphertext and key (the "trapdoor"), relatively easy to compute plaintext
  - "Level" of security often based on "length" of key

Encryption and MAC/Signatures

<u>Confidentiality (Encryption)</u>

Sender:

- Compute $C = Enc_K(M)$
- Send C

Receiver:

- Recover $M = Dec_K(C)$

<u>Auth/Integrity (MAC / Signature)</u>

Sender:

- Compute $s = Sig_K(Hash\ (M))$
- Send <M, s>

Receiver:

- Compute $s' = Ver_K(Hash\ (M))$
- Check $s' == s$

These are simplified forms of the actual algorithms

Symmetric vs. Asymmetric Crypto
a.k.a. Secret vs. Public Key Crypto

- Symmetric crypto (all crypto pre 1970s)
  - Sender and recipient share a common key
  - All classical encryption algorithms are private-key
  - Dual use: confidentiality or authentication/integrity
    - Encryption vs. msg authentication code (MAC)
- Public-key crypto
  - (Public, private) key associated w/ea. entity ("Alice")
  - Anybody can encrypt to Alice, anybody can verify Alice's message
  - Only Alice can decrypt, only Alice can "sign"
  - Developed to address "key distribution" problem and "digital signatures" (w/o prior establishment)

Why still both?

- Symmetric Pros and Cons
  - Simple and very fast (1000-10000x faster than asymmetric)
  - Must agree/distribute the key beforehand
  - AES/CBC (256-bit) → 80 MB/s (*for 2048 bits, .003 ms*)
- Public Key Pros and Cons
  - Easier key pre-distro.: "Public Key Infrastructure" (PKI)
  - Much slower
  - 2048-RSA → 6.1ms Decrypt, 0.16ms Encrypt
- Common "engineering" approach:
  - Best of both worlds via "hybrid" scheme: Use public key to distribute a new random "session" key b/w sender and recipient, then symmetric crypto for remainder of session

Email Security: Pretty Good Privacy (PGP)

Sender and Receiver Keys

- If the receiver knows the sender's public key
  - Sender authentication
  - Sender non-repudiation
- If the sender knows the receiver's public key
  - Confidentiality
  - Receiver authentication

Sending an E-Mail Securely

- Sender digitally signs the message
  - Using the sender's private key
- Sender encrypts the data
  - Using a one-time session key
  - Sending the session key, encrypted with the receiver's public key
- Sender converts to an ASCII format
  - Converting the message to base64 encoding
  - (Email messages must be sent in ASCII)

Public Key Certificate

- Binding between identity and a public key
  - "Identity" is, for example, an e-mail address
  - "Binding" ensured using a digital signature
- Contents of a certificate
  - Identity of the entity being certified
  - Public key of the entity being certified
  - Identity of the signer
  - Digital signature
  - Digital signature algorithm id

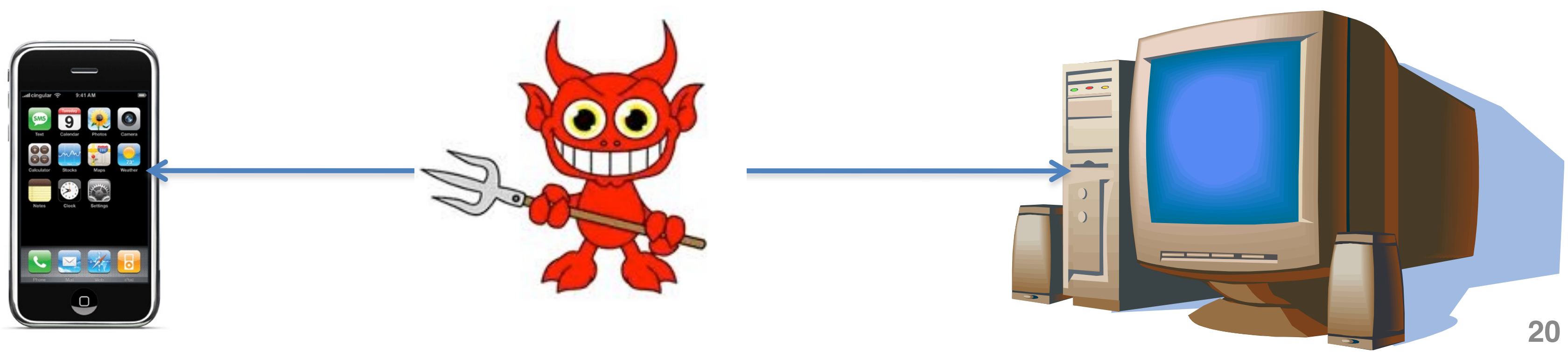
Web of Trust for PGP

- Decentralized solution
  - Protection against state actor intrusion
  - No central certificate authorities
- Customized solution
  - Individual decides whom to trust, and how much
  - Multiple certificates with different confidence levels
- Key-signing parties!
  - Collect and provide public keys in person
  - Sign other's keys, and get your key signed by others

HTTP Security

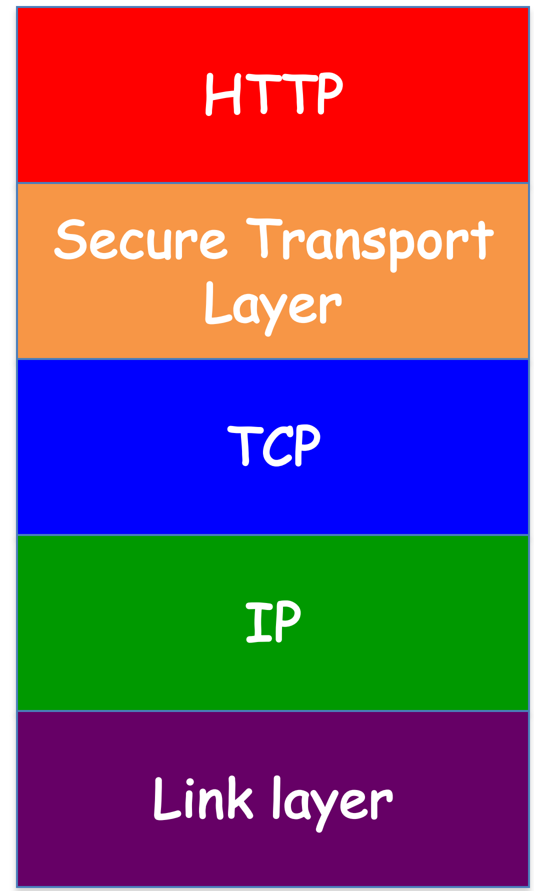
HTTP Threat Model

- Eavesdropper
  - Listening on conversation (confidentiality)
- Man-in-the-middle
  - Modifying content (integrity)
- Impersonation
  - Bogus website (authentication, confidentiality)

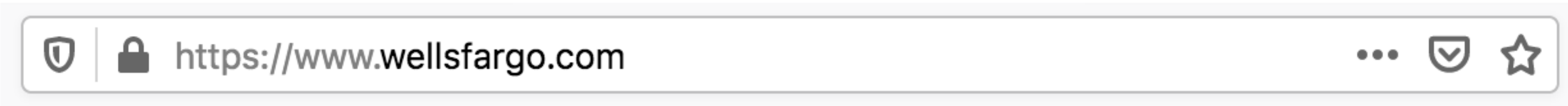


HTTP-S: Securing HTTP

- HTTP sits on top of secure channel (SSL/TLS)
  - https:// vs. http://
  - TCP port 443 vs. 80
- All (HTTP) bytes encrypted and authenticated
  - No change to HTTP itself!
- Where to get the key???



Learning a Valid Public Key

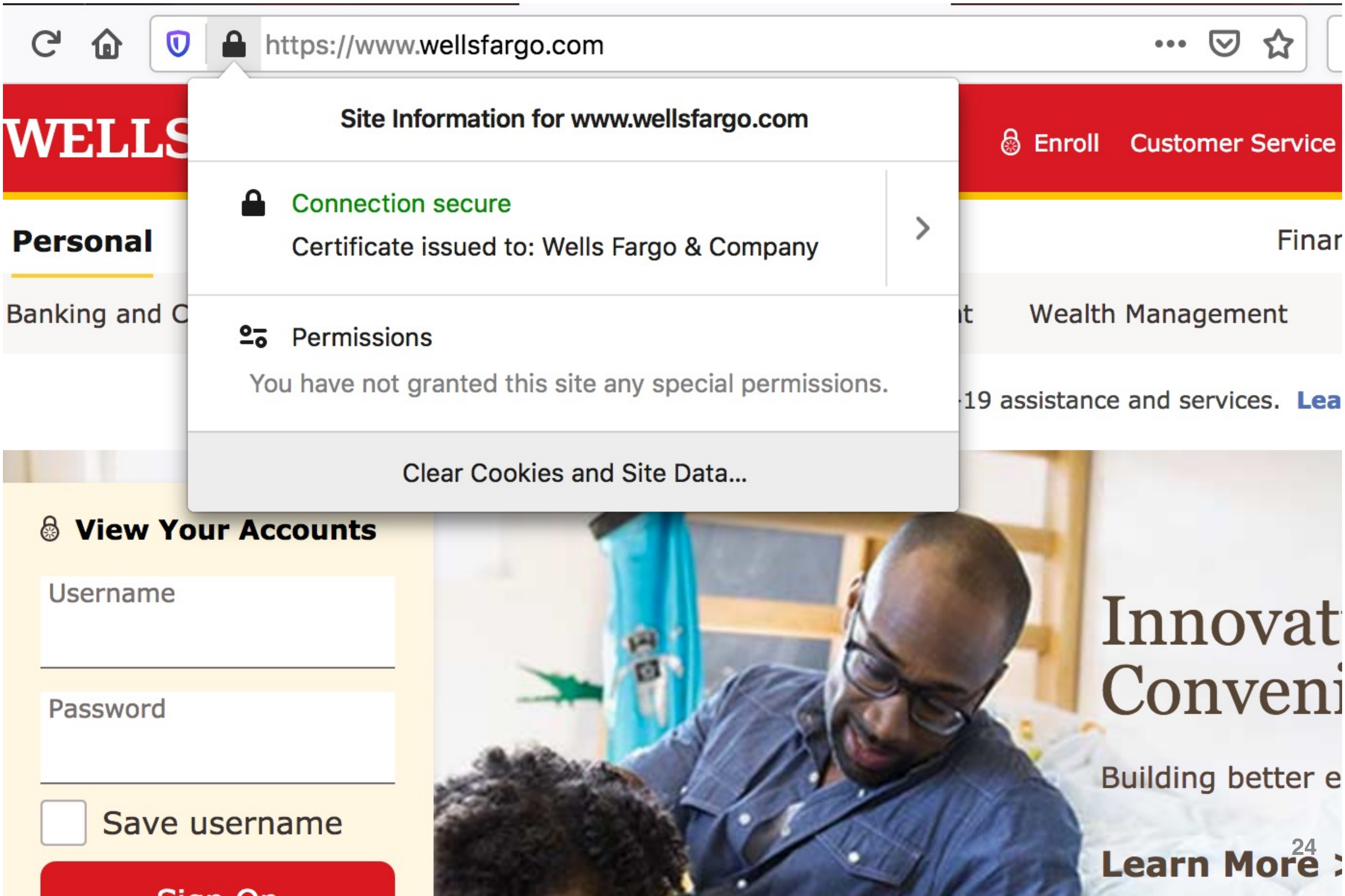


- What is that lock?
  - Securely binds domain name to public key (PK)
    - If PK is authenticated, then any message signed by that PK cannot be forged by non-authorized party
  - Believable only if you trust the attesting body
    - Bootstrapping problem: Who to trust, and how to tell if this message is actually from them?

Hierarchical Public Key Infrastructure

- Public key certificate
  - Binding between identity and a public key
  - "Identity" is, for example, a domain name
  - Digital signature to ensure integrity
- Certificate authority
  - Issues public key certificates and verifies identities
  - Trusted parties (e.g., VeriSign, GoDaddy, Comodo)
  - Preconfigured certificates in Web browsers

Public Key Certificate



Certificate

www.wellsfargo.com	DigiCert Global CA G2	DigiCert Global Root G2

Subject Name	
Business Category	Private Organization
Inc. Country	US
Inc. State/Province	Delaware
Serial Number	251212
Country	US
State/Province	California
Locality	San Francisco
Organization	Wells Fargo & Company
Organizational Unit	DCG-PSG
Common Name	www.wellsfargo.com
Issuer Name	
Country	US
Organization	DigiCert Inc
Common Name	DigiCert Global CA G2
Validity	
Not Before	2/7/2019, 7:00:00 PM (Eastern Daylight Time)
Not After	2/8/2021, 7:00:00 AM (Eastern Daylight Time)
Subject Alt Names	
DNS Name	www.wellsfargo.com

Certificate

www.wellsfargo.com	DigiCert Global CA G2	DigiCert Global Root G2

Subject Name	
Country	US
Organization	DigiCert Inc
Common Name	DigiCert Global CA G2
Issuer Name	
Country	US
Organization	DigiCert Inc
Organizational Unit	www.digicert.com
Common Name	DigiCert Global Root G2
Validity	
Not Before	8/1/2013, 8:00:00 AM (Eastern Daylight Time)
Not After	8/1/2028, 8:00:00 AM (Eastern Daylight Time)
Public Key Info	
Algorithm	RSA
Key Size	2048
Exponent	65537
Modulus	D3:48:7C:BE:F3:05:86:5D:5B:D5:2F:85:4E:4B:E0:86:AD:15:AC:61:CF:5B:AF:3E:6A:0A:47:FB:9A:76:91:60:0...
Miscellaneous	
Serial Number	0C:8E:E0:C9:0D:6A:89:15:88:04:06:1E:E2:41:F9:AF
Signature Algorithm	SHA-256 with RSA Encryption
Version	3
Download	PEM (cert) PEM (chain)

Transport Layer Security (TLS)

Based on the earlier Secure Socket Layer (SSL) originally developed by Netscape

TLS Handshake Protocol

- Send new random value, list of supported ciphers
- Send pre-secret, encrypted under PK
- Create shared secret key from pre-secret and random
- Switch to new symmetric-key cipher using shared key

- Send new random value, digital certificate with PK
- Create shared secret key from pre-secret and random
- Switch to new symmetric-key cipher using shared key

TLS Record Protocol

- Messages from application layer are:
  - Fragmented or coalesced into blocks
  - Optionally compressed
  - Integrity-protected using an HMAC
  - Encrypted using symmetric-key cipher
  - Passed to the transport layer (usually TCP)
- Sequence #s on record-protocol messages
  - Prevents replays and reorderings of messages

Comments on HTTPS

- HTTPS authenticates server, not content
  - If CDN (Akamai) serves content over HTTPS, customer must trust Akamai not to change content
- Symmetric-key crypto after public-key ops
  - Handshake protocol using public key crypto
  - Symmetric-key crypto much faster (100-1000x)
- HTTPS on top of TCP, so reliable byte stream
  - Can leverage fact that transmission is reliable to ensure: each data segment received exactly once
  - Adversary can't successfully drop or replay packets

IP Security

IP Security

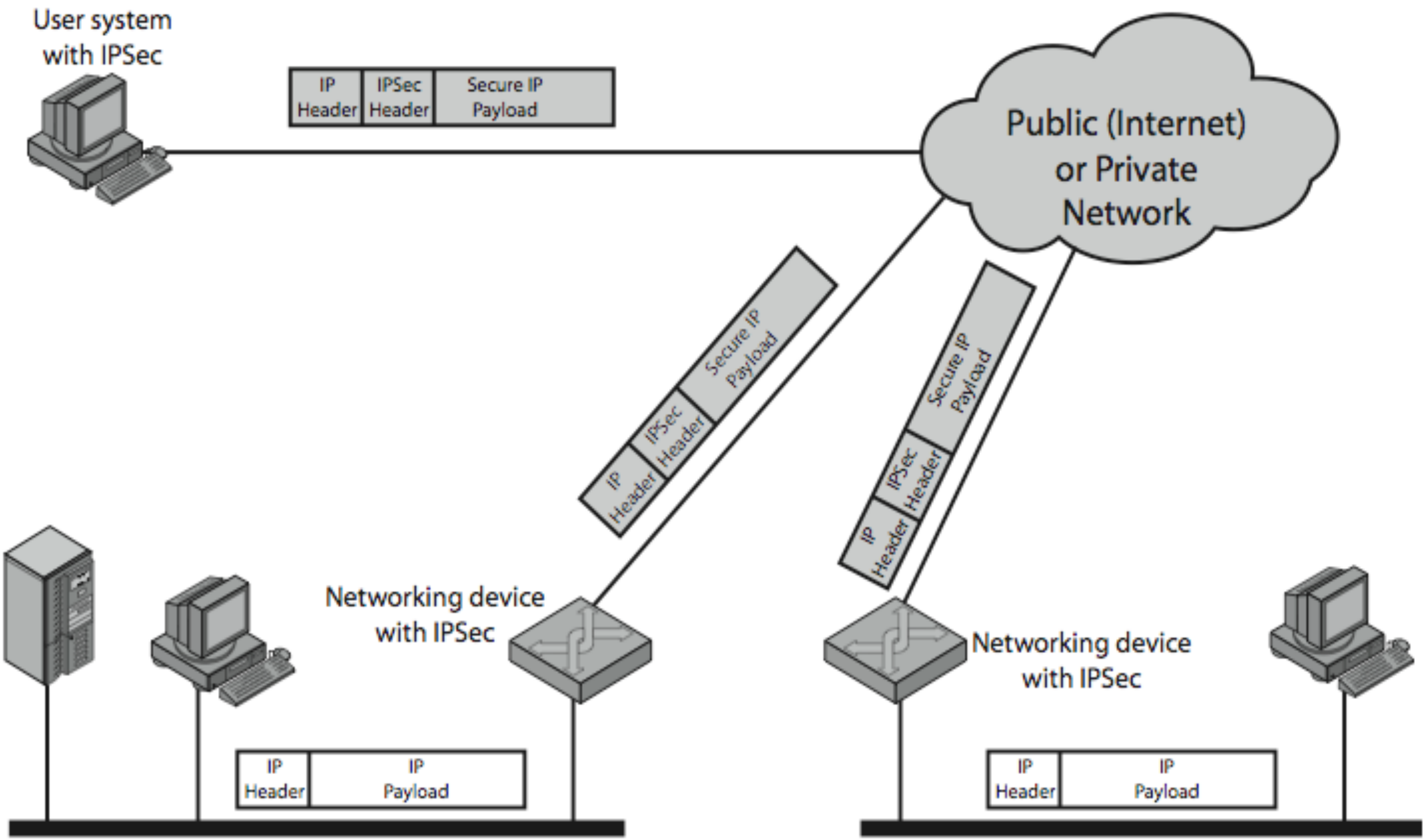
- There are range of app-specific security mechanisms
  - eg. TLS/HTTPS, S/MIME, PGP, Kerberos, …
- But security concerns that cut across protocol layers
- Implement by the network for all applications?

Enter IPSec!

IPSec

- General IP Security framework
- Allows one to provide
  - Access control, integrity, authentication, originality, and confidentiality
- Applicable to different settings
  - Narrow streams: Specific TCP connections
  - Wide streams: All packets between two gateways

IPSec Uses


User system
with IPSec
IP Header
IPSec Header
Secure IP Payload
Public (Internet)
or Private
Network
IP Header
IPSec Header
Secure IP Payload
IP Header
IPSec Header
Secure IP Payload
Networking device
with IPSec
Networking device
with IPSec
IP Header
IP Payload
IP Header
IP Payload

Benefits of IPSec

- If in a firewall/router:
  - Strong security to all traffic crossing perimeter
  - Resistant to bypass
- Below transport layer
  - Transparent to applications
  - Can be transparent to end users
- Can provide security for individual users

IP Security Architecture

- Specification quite complex
  - Mandatory in IPv6, optional in IPv4
- Two security header extensions:
  - Authentication Header (AH)
    - Connectionless integrity, origin authentication
      - MAC over most header fields and packet body
    - Anti-replay protection
  - Encapsulating Security Payload (ESP)
    - These properties, plus confidentiality

Encapsulating Security Payload (ESP)

- Transport mode: Data encrypted, but not header
  - After all, network headers needed for routing!
  - Can still do traffic analysis, but is efficient
  - Good for host-to-host traffic

- Tunnel mode ("IP-in-IP")
  - Encrypts entire IP packet
  - Add new header for next hop
  - Good for VPNs, gateway-to-gateway security

Replay Protection is Hard

- Goal: Eavesdropper can't capture encrypted packet and duplicate later
  - Easy with TLS/HTTP on TCP: Reliable byte stream
  - But IP Sec at packet layer; transport may not be reliable
- IPSec solution: Sliding window on sequence #'s
  - All IPSec packets have a 64-bit sequence number
  - Receiver keeps track of which seqno's seen before
    - [latest – window + 1 , latest] ; window ~64 packets
  - Accept packet if
    - seqno > latest (and update latest)
    - Within window but has not been seen before
  - If reliable, could remember last, and accept iff last + 1

Conclusions

- Security at many layers
  - Application, transport, and network layers
  - Customized to the properties and requirements
- Exchanging keys
  - Public key certificates
  - Certificate authorities vs. Web of trust
- Next time
  - Network security: DNS, BGP