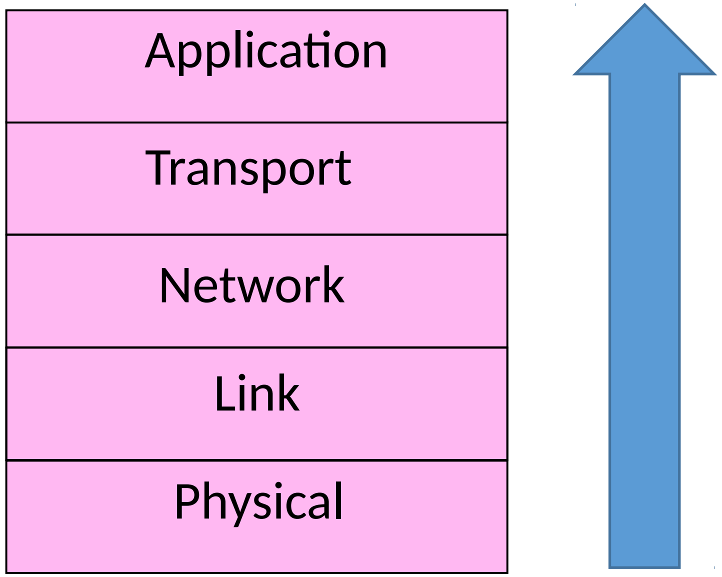
Network Security

Where we are in the Course

- Security crosses all layers



Application

Transport

Network

Link

Physical

Security Threats

- “Security” is like “performance”
  - Means many things to many people
  - Must define the properties we want
- Key part of network security is clearly stating the threat model
  - The dangers and attacker’s abilities
  - Can’t assess risk otherwise

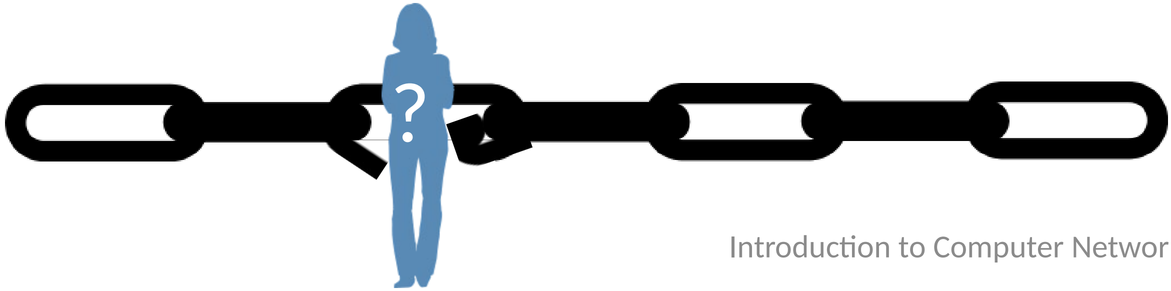
Security Threats (2)

- Some example threats
  - It’s not all about encrypting messages

Attacker	Ability	Threat
Eavesdropper	Intercept messages	Read contents of message
Observer	Inspect packet destinations	Collect conversations
Intruder	Compromised host	Tamper with contents of message
Impersonator	Remote social engineering	Trick party into giving information
Extortionist	Remote / botnet	Disrupt network services

Risk Management

- Security is hard as a negative goal
  - Try to ensure security properties and don't let anything bad happen!
- End-to-end principle in action (can't trust network!)
- Only as secure as the weakest link
  - Could be design flaw or bug in code
  - But often the weak link is elsewhere …



Risk Management (2)

- 802.11 security … early on, WEP:
  - Cryptography was flawed; can run cracking software to read WiFi traffic
- Today, WPA2/802.11i security:
  - Computationally infeasible to break!
- So that means 802.11 is secure against eavesdropping?

Risk Management (3)

- Many possible threats
  - We just made the first one harder!
  - 802.11 is more secure against eavesdropping in that the risk of successful attack is lower. But it is not “secure”.

Threat Model	**Old WiFi (WEP)**	**New WiFi (WPA2)**
Break encryption from outside	Very easy	Very difficult
Guess WiFi password	Often possible	Often possible
Get password from computer	May be possible	May be possible
Physically break into home	Difficult	Difficult

Cryptography

Cryptology

- Rich history, especially spies / military
  - From the Greek “hidden writing”
- Cryptography
  - Focus is encrypting information
- Cryptanalysis
  - Focus is how to break codes
- Modern emphasis is on codes that are “computationally infeasible” to break
  - Takes too long compute solution

Uses of Cryptography

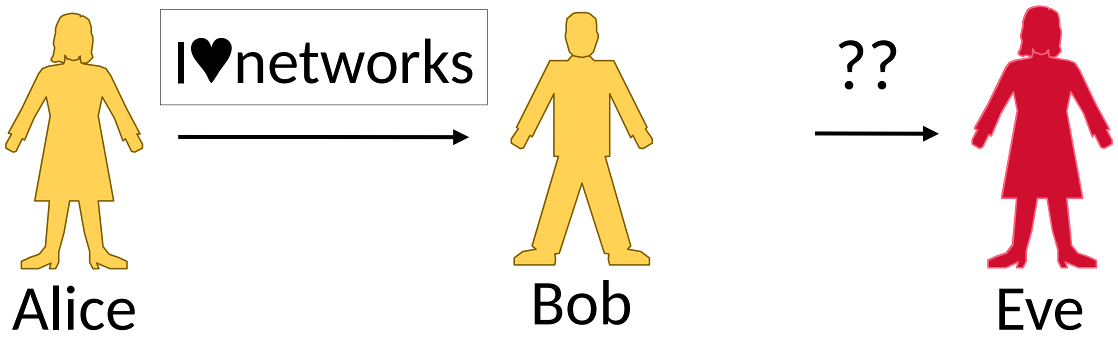
- Encrypting information is useful for more than deterring eavesdroppers
  - Prove message came from real sender
  - Prove remote party is who they say
  - Prove message hasn’t been altered
- Designing secure cryptographic scheme tricky!
  - Use approved design (library) in approved way

Internet Reality

- Most of the protocols were developed before the Internet grew popular
  - It was a smaller, more trusted world
  - So protocols lacked security …
- We have strong security needs today
  - Clients talk with unverified servers
  - Servers talk with anonymous clients
  - Security has been retrofitted
  - This is far from ideal!

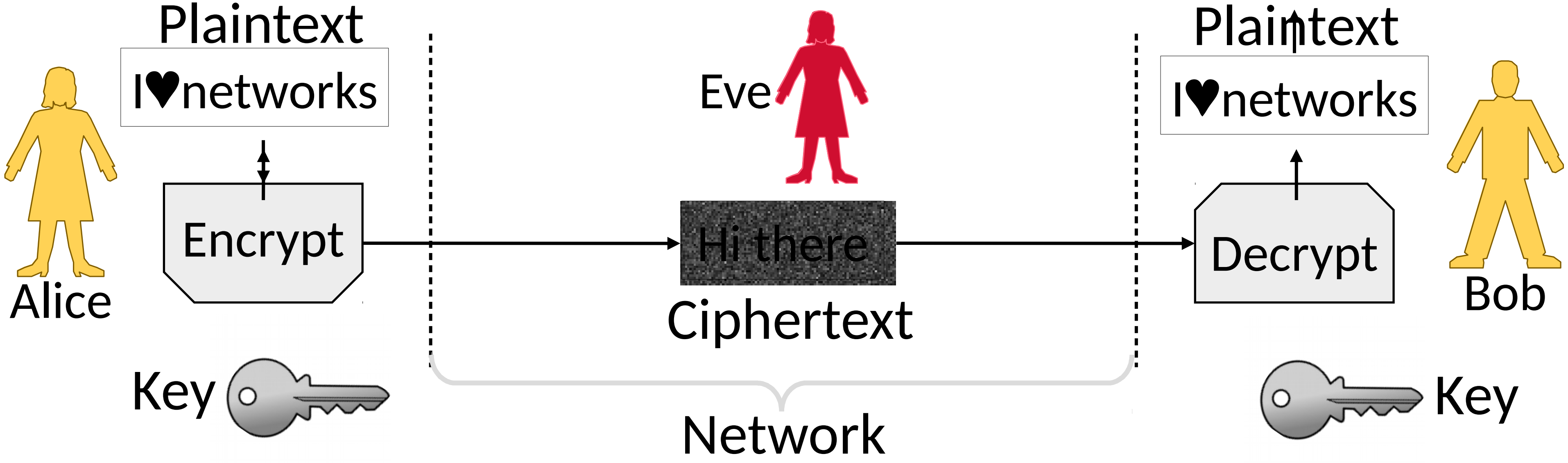
Goal and Threat Model

- Goal is to send a private message from Alice to Bob
  - This is called confidentiality
- Threat is Eve will read the message
  - Eve is a passive adversary (observes)



Encryption/Decryption Model

- Alice encrypts private message (plaintext) using key
- Eve sees ciphertext but not plaintext
- Bob decrypts using key to get the private message



Encryption/Decryption (2)

- Encryption is a reversible mapping
  - Ciphertext is encrypted plaintext
- Assume attacker knows algorithm
  - Security does not rely on its secrecy
- Algorithm is parameterized by keys
  - Security does rely on key secrecy
  - Must be distributed (Achilles' heel)

Encryption/Decryption (3)

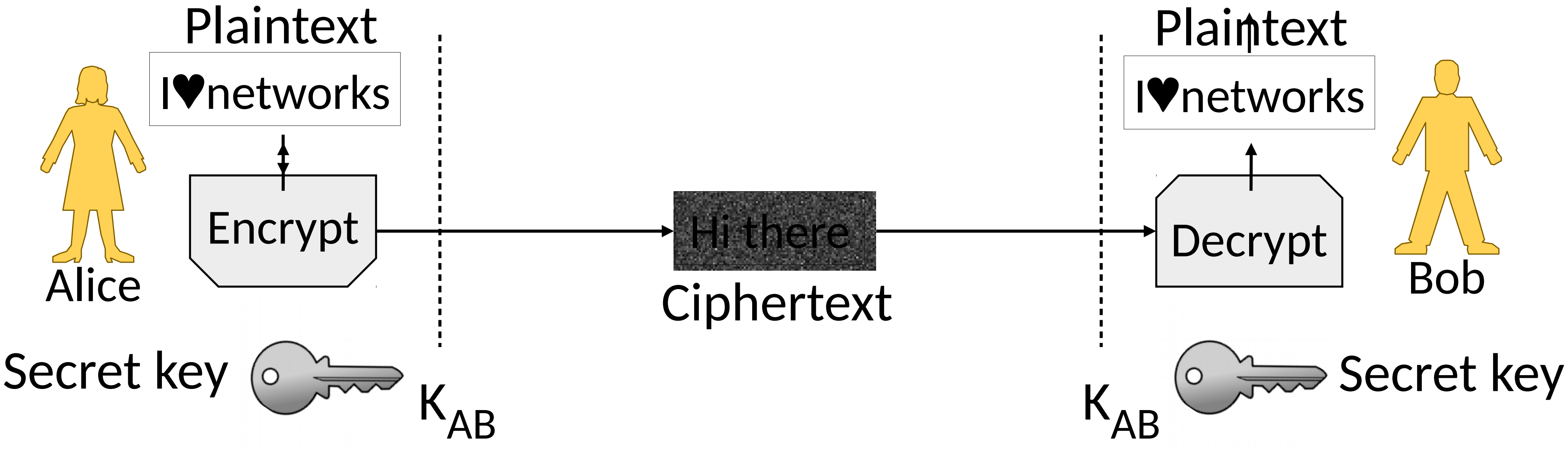
Two main kinds of encryption:

1. Symmetric key encryption », e.g., AES
   - Alice and Bob share secret key
   - Encryption is a bit mangling box

2. Public key encryption », e.g., RSA
   - Alice and Bob each have a key in two parts: a public part (widely known), and a private part (only owner knows)
   - Encryption is based on mathematics (e.g., RSA is based on difficulty of factoring)

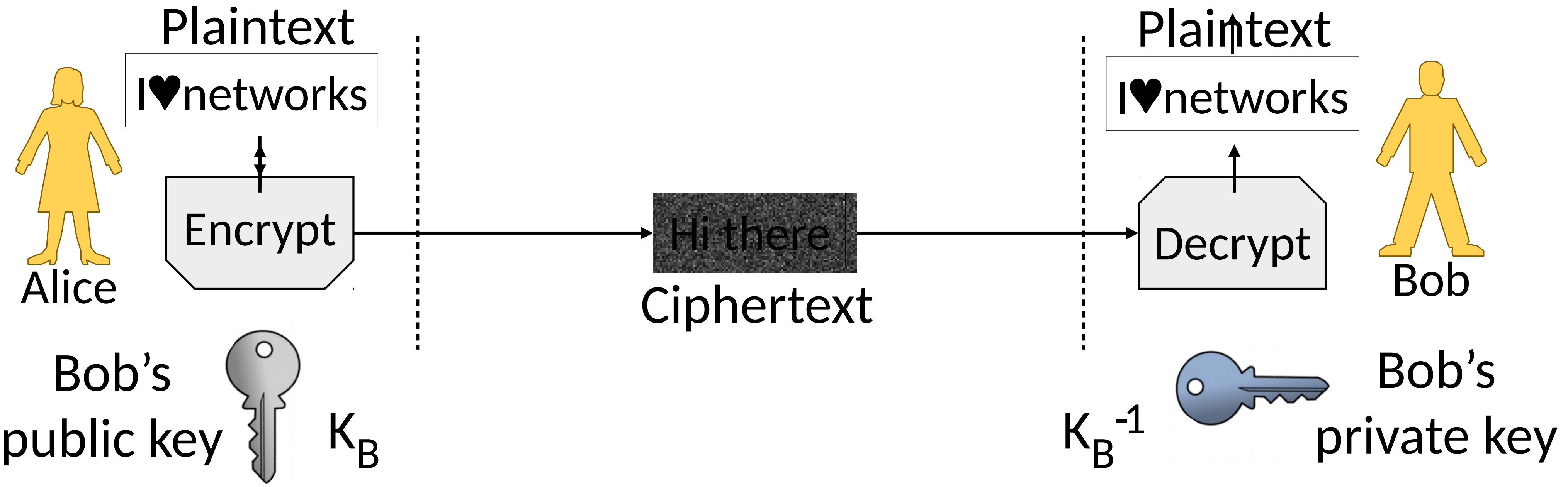
Symmetric (Secret Key) Encryption

- Alice and Bob have the same secret key, K_{AB}
  - Anyone with the secret key can encrypt/decrypt



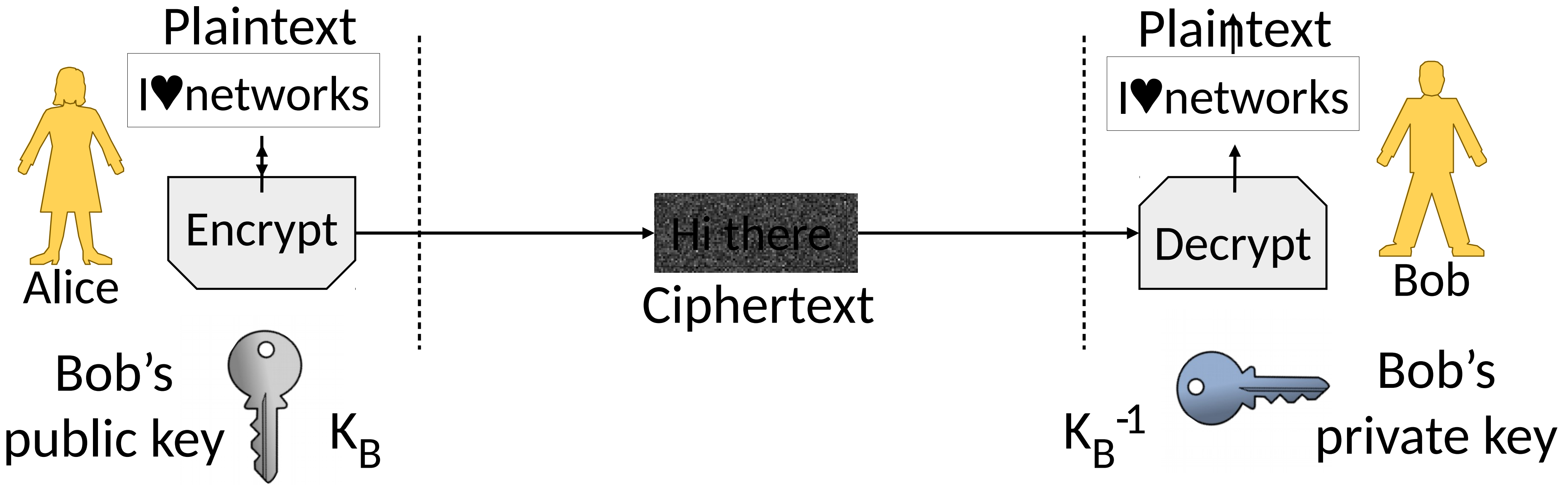
Public Key (Asymmetric) Encryption

- Alice and Bob have public/private key pairs (K_B / K_B^{-1})
  - Public keys are well-known, private keys are secret

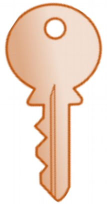


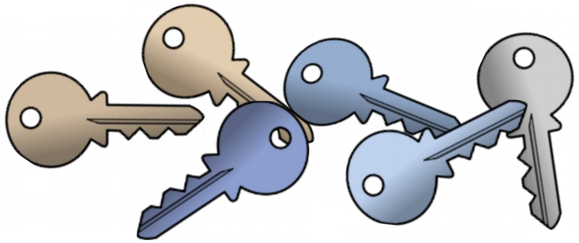
Public Key Encryption (2)

- Alice encrypts w/ Bob's pubkey K_B; anyone can send
- Bob decrypts w/ his private key K_B^{-1}; only he can



Key Distribution





- This is a big problem on a network!
  - Often want to talk to new parties
- Symmetric encryption problematic
  - Have to first set up shared secret
- Public key idea has own difficulties
  - Need trusted directory service
  - We'll look at <u>certificates</u> later

Symmetric vs. Public Key

- Have complementary properties
  - Want the best of both!

Property	Symmetric	Public Key
Key Distribution	Hard – share secret per pair of users	Easier – publish public key per user
Runtime Performanc e	Fast – good for high data rate	Slow – few, small, messages

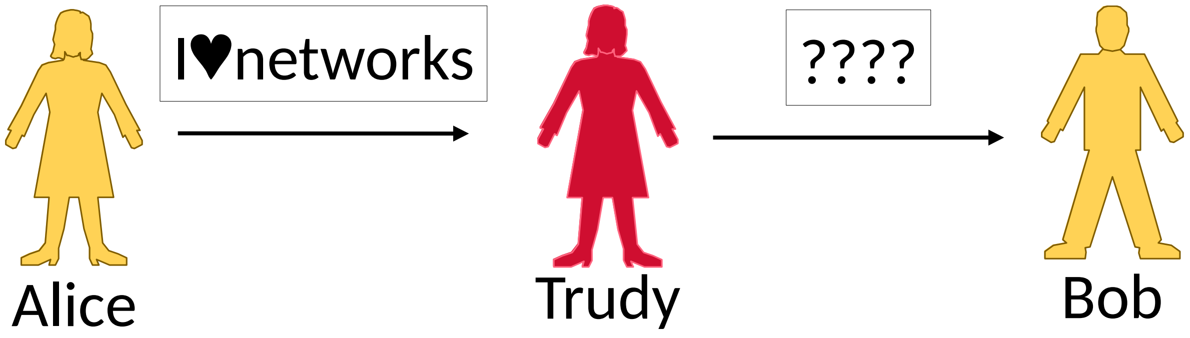
Winning Combination

- Alice uses public key encryption to send Bob a small private message
    - It’s a key! (Say 256 bits.)
- Alice/Bob send messages with symmetric encryption
    - Using the key they now share
- The key is called a <u>session key</u>
    - Generated for short-term use

Message Authentication

Goal and Threat Model

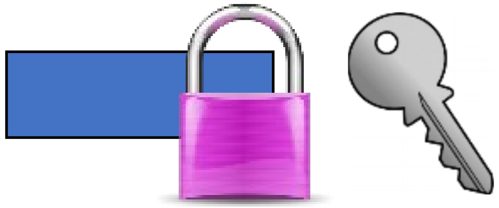
- Goal is for Bob to verify the message is from Alice and unchanged
  - This is called integrity/authenticity
- Threat is Trudy will tamper with messages
  - Trudy is an active adversary (interferes)



Wait a Minute!

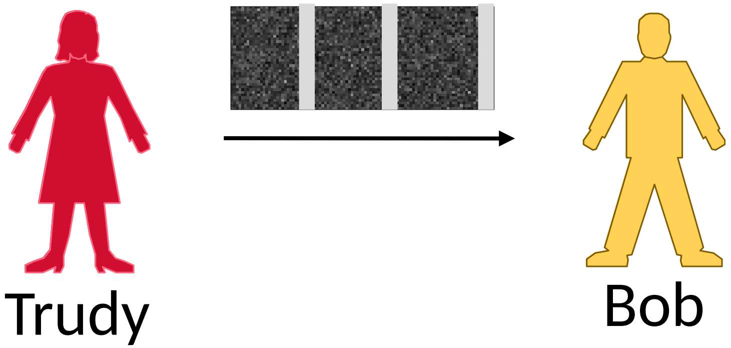
- We’re already encrypting messages to provide confidentiality

- Why isn’t this enough?



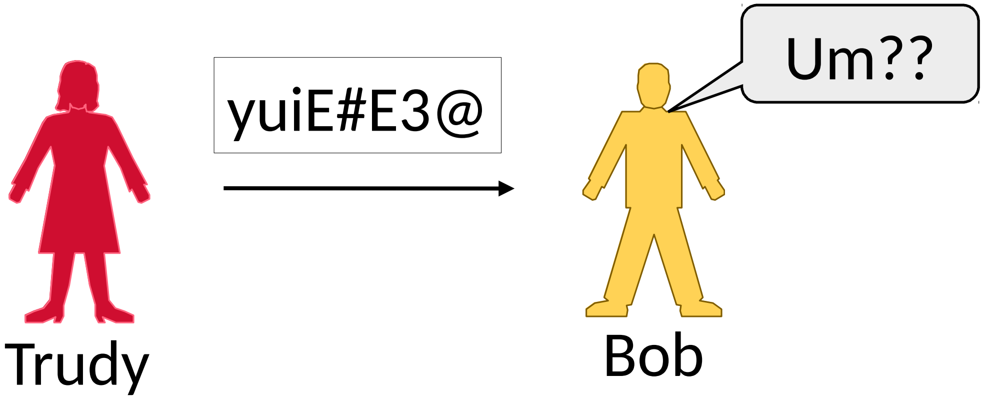
Encryption Issues

- What will happen if Trudy flips some of Alice’s message bits?
  - Bob will decrypt it, and …



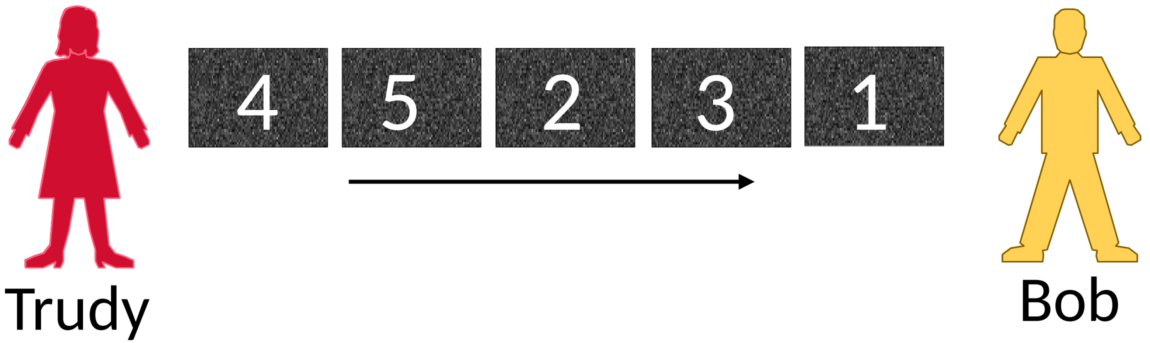
Encryption Issues (2)

- What will happen if Trudy flips some of Alice’s message bits?
  - Bob will receive an altered message



Encryption Issues (3)

- Typically encrypt blocks of data
- What if Trudy reorders message?
  - Bob will decrypt, and …



Encryption Issues (4)

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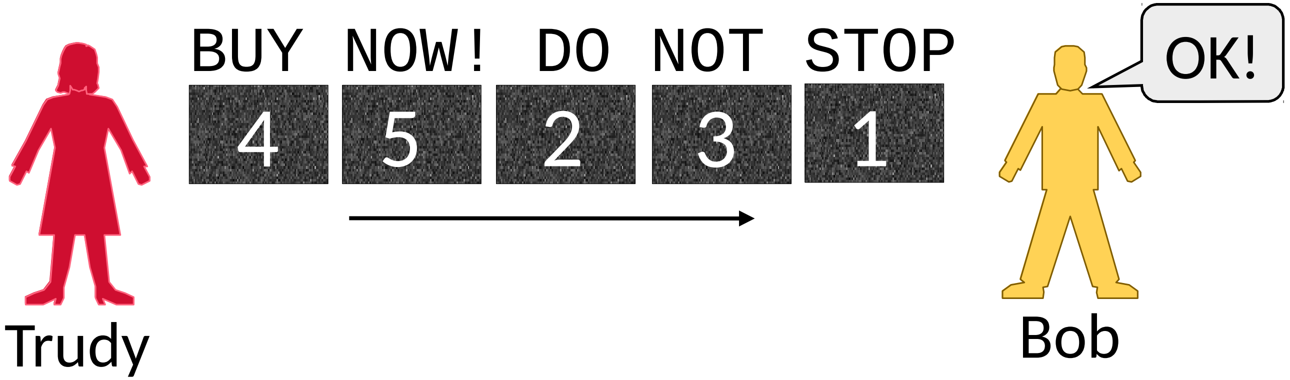
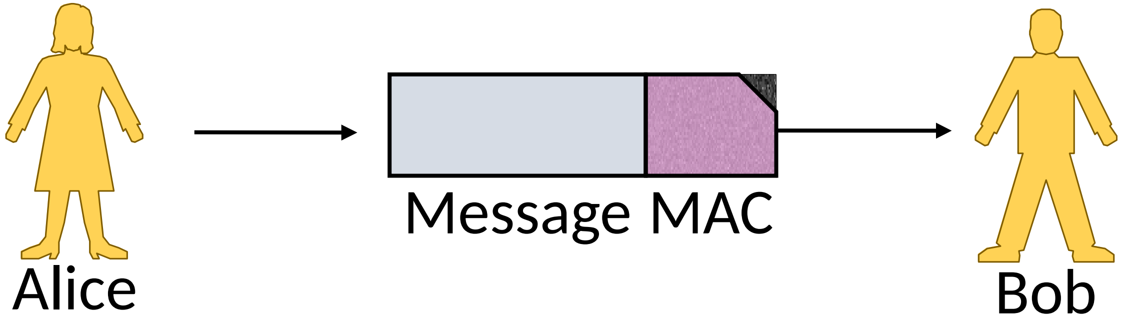


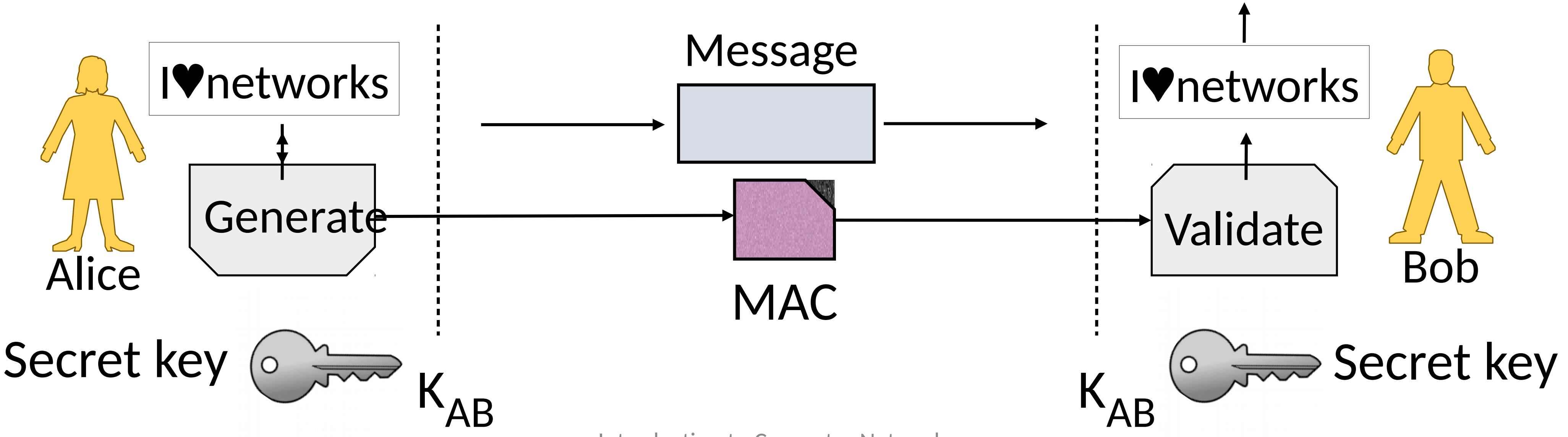
MAC (Message Authentication Code)

- MAC is a small token to validate the integrity/authenticity of a message
  - Conceptually ECCs again
  - Send the MAC along with message
  - Validate MAC, process the message
  - Example: HMAC scheme



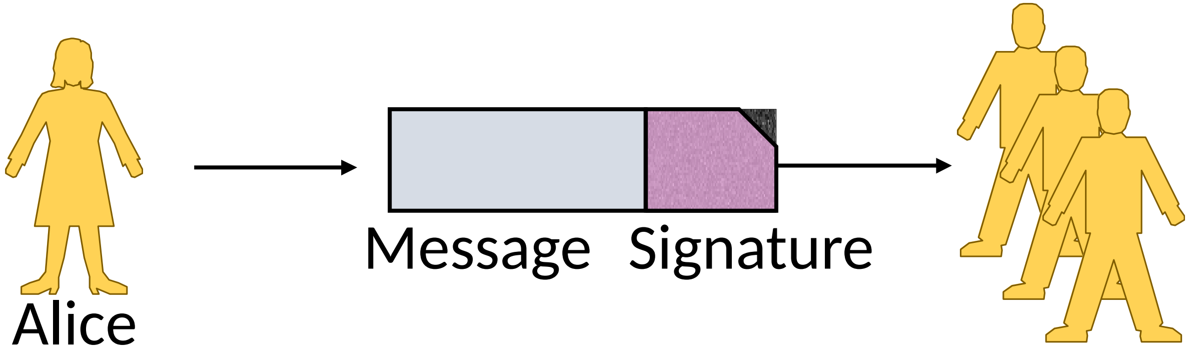
MAC (2)

- Sorta symmetric encryption operation – key shared
  - Lets Bob validate unaltered message came from Alice
  - Doesn’t let Bob convince Charlie that Alice sent the message



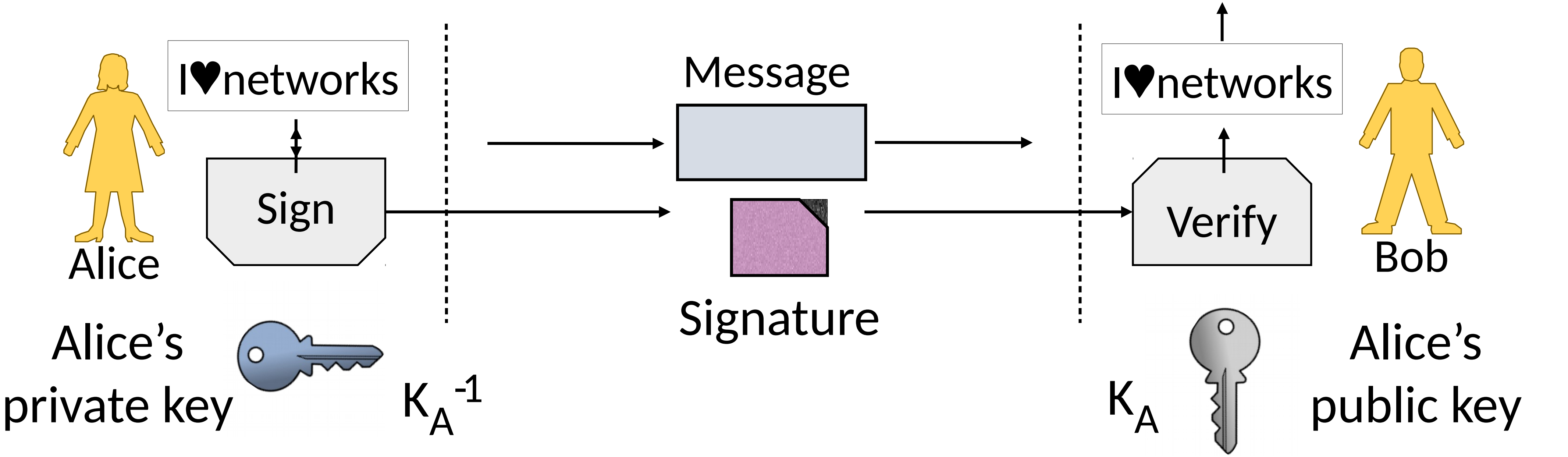
Digital Signature

- Signature validates the integrity/authenticity of message
  - Send it along with the message
  - Lets all parties validate
  - Example: RSA signatures



Digital Signature (2)

- Kind of public key operation – pub/priv key parts
  - Alice signs w/ private key, K_A^{-1}, Bob verifies w/ public key, K_A
  - Does let Bob convince Charlie that Alice sent the message

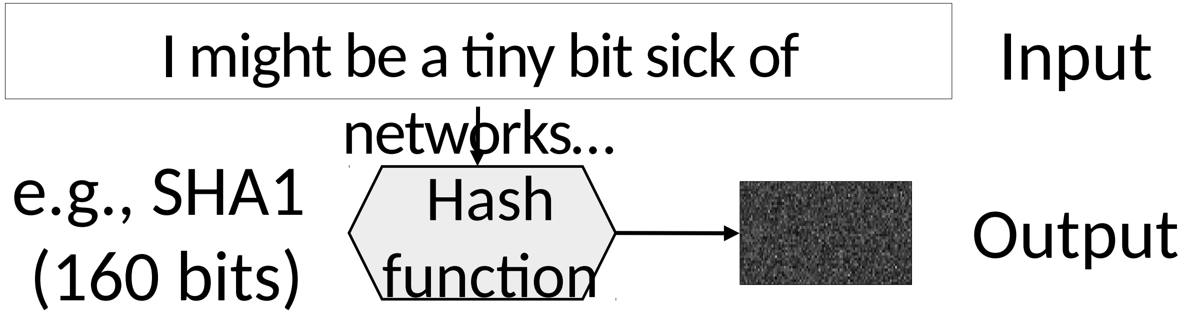


Speeding up Signatures

- Same tension as for confidentiality:
  - Public key has keying advantages
  - But it has slow performance!
- Use a technique to speed it up
  - Message digest stands for message
  - Sign the digest instead of full message

Message Digest or Cryptographic Hash

- Digest/Hash is a secure checksum
  - Deterministically mangles bits to pseudo-random output (like CRC)
  - Can’t find messages with same hash
  - Acts as a fixed-length descriptor of message – very useful!



I might be a tiny bit sick of networks…

Input

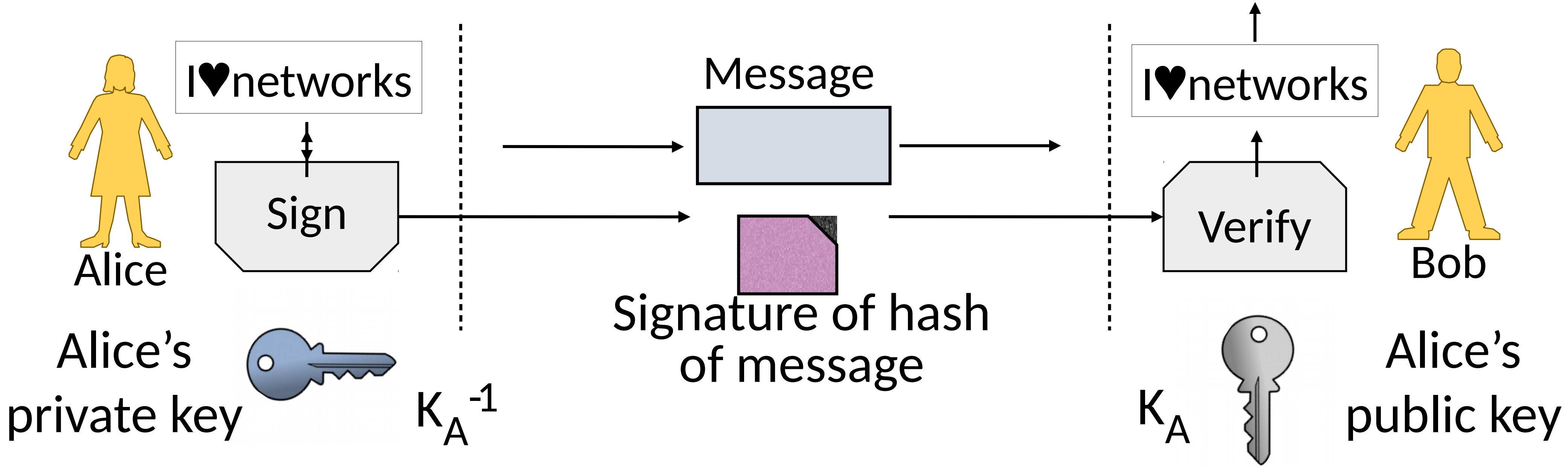
e.g., SHA1 (160 bits)

Hash function

Output

Speeding up Signatures (2)

- Conceptually similar except sign the hash of message
  - Hash is fast to compute, so it speeds up overall operation
  - Hash stands for msg as can’t find another w/ same hash

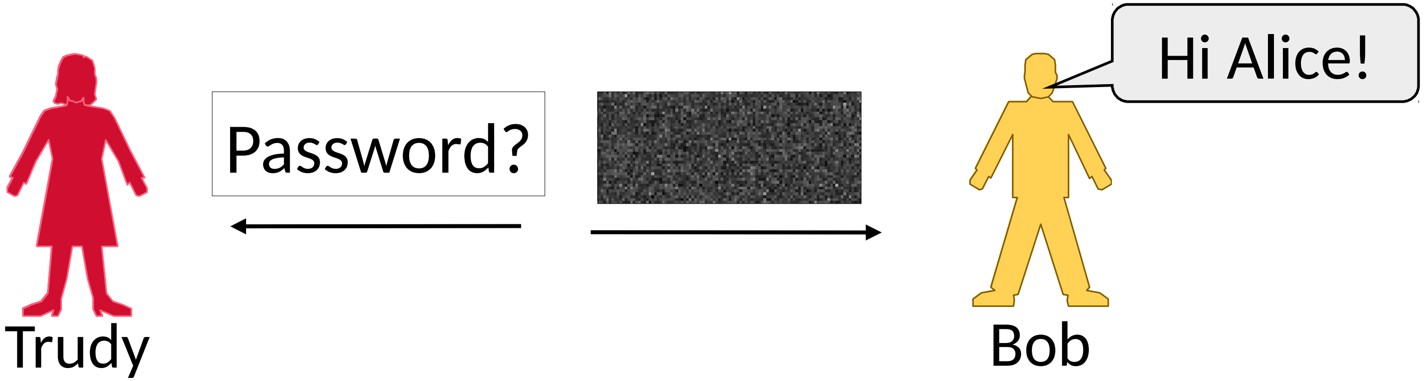


Preventing Replays

- We normally want more than confidentiality, integrity, and authenticity for secure messages!
  - Want to be sure message is fresh
- Need to distinguish message from replays
  - Repeat of older message
  - Acting on it again may cause trouble

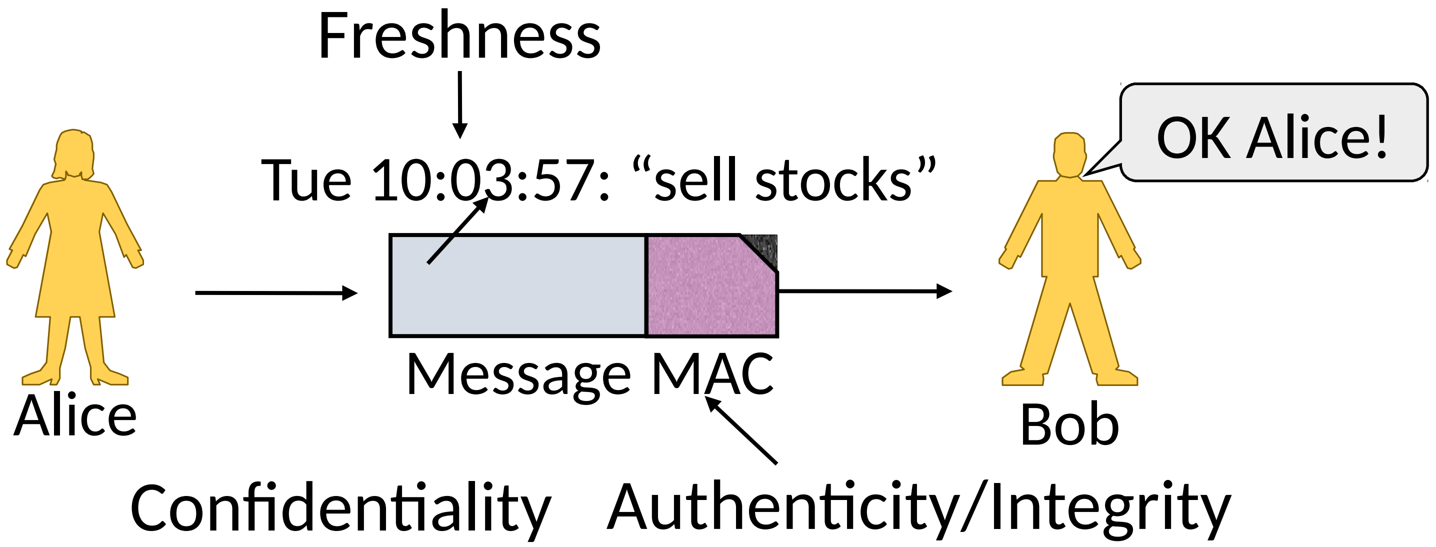
Preventing Replays (2)

- Replay attack:
  - Trudy records Alice’s messages to Bob
  - Trudy later replays them (unread) to Bob
    - She pretends to be Alice



Preventing Replays (3)

- To prevent replays, include a proof of freshness in the messages
  - Use a timestamp, or nonce



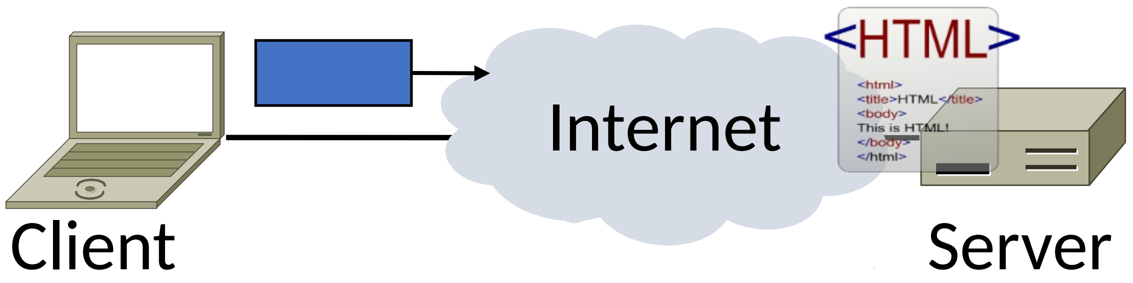
Takeaway

- Cryptographic designs can give us integrity, authenticity and freshness as well as confidentiality.
- Real protocol designs combine the properties in different ways
  - We’ll see some examples
  - Note many pitfalls in how to combine, as well as in the primitives themselves

Web Security

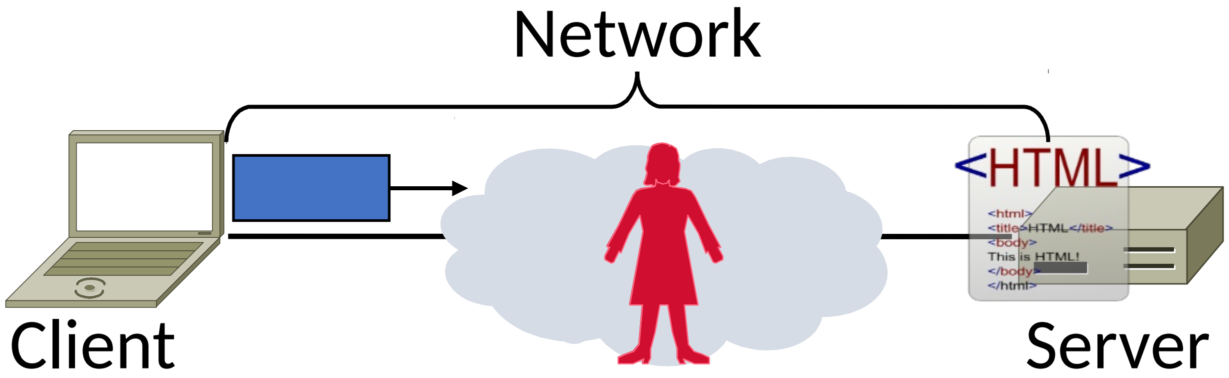
Goal and Threat Model

- Much can go wrong on the web!
  - Clients encounter malicious content
  - Web servers are target of break-ins
  - Fake content/servers trick users
  - Data sent over network is stolen …



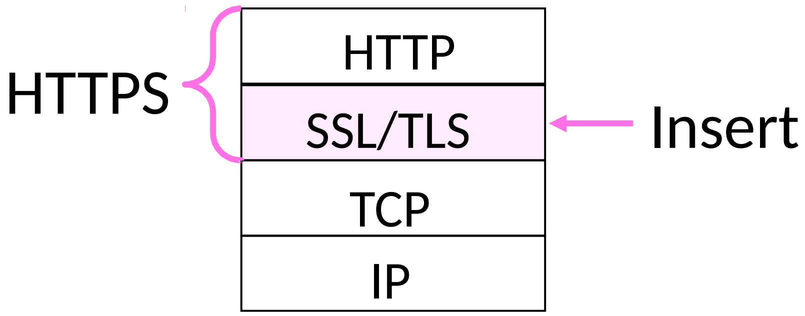
Goal and Threat Model (2)

- Goal of HTTPS is to secure HTTP
- We focus on network threats:
    1. Eavesdropping client/server traffic
    2. Tampering with client/server traffic
    3. Impersonating web servers



HTTPS Context

- HTTPS (HTTP Secure) is an add-on
  - Means HTTP over SSL/TLS
  - SSL (Secure Sockets Layer) precedes TLS (Transport Layer Security)



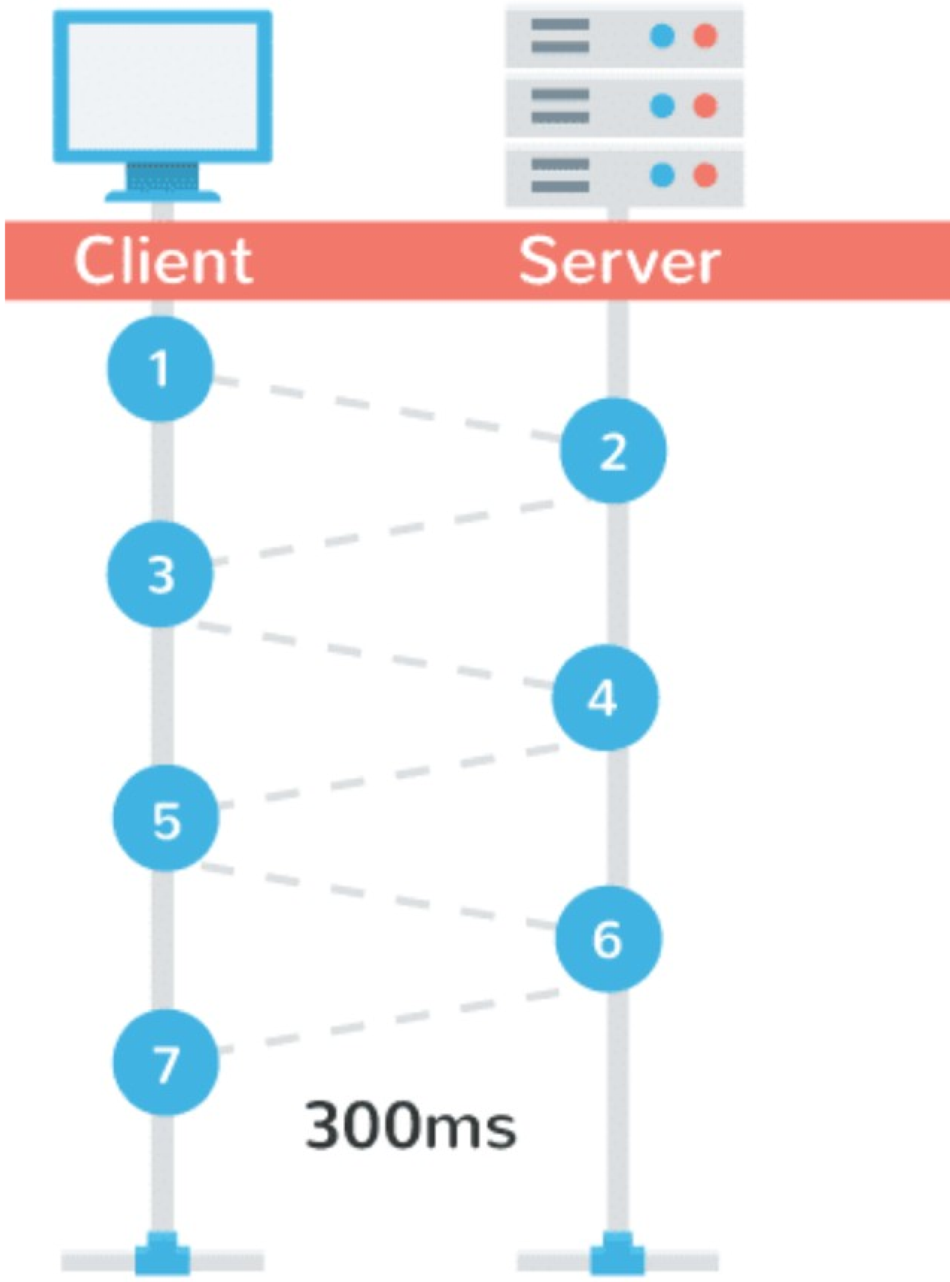
HTTPS Context (2)

- SSL came out of Netscape
  - SSL2 (flawed) made public in ‘95
  - SSL3 fixed flaws in ‘96
- TLS is the open standard
  - TLS 1.0 in ‘99, 1.1 in ‘06, 1.2 in ‘08, 1.3 in ‘18
- Motivated by secure web commerce
  - Slow adoption, now widespread use
  - Can be used by any app, not just HTTP

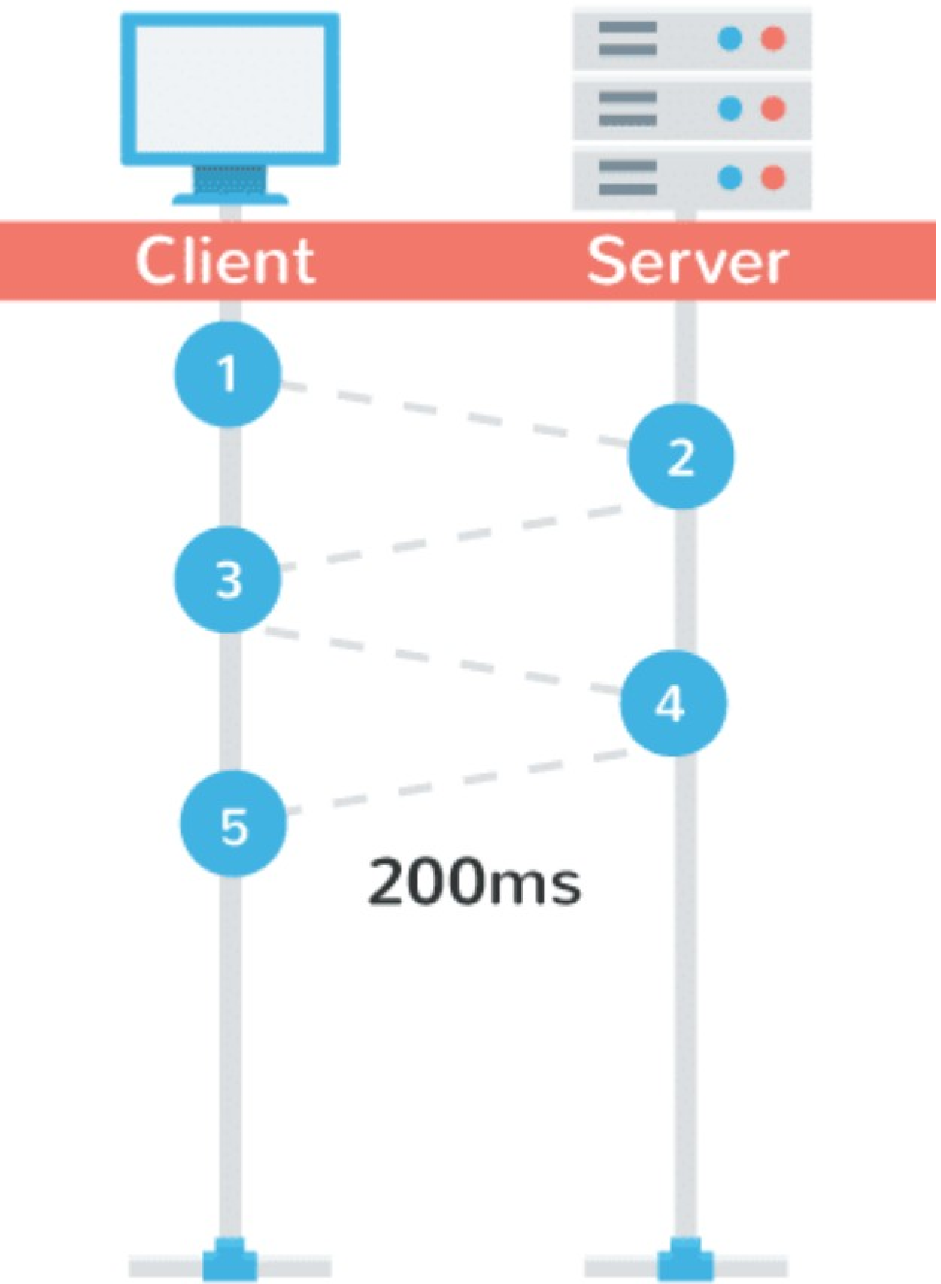
TLS 1.3

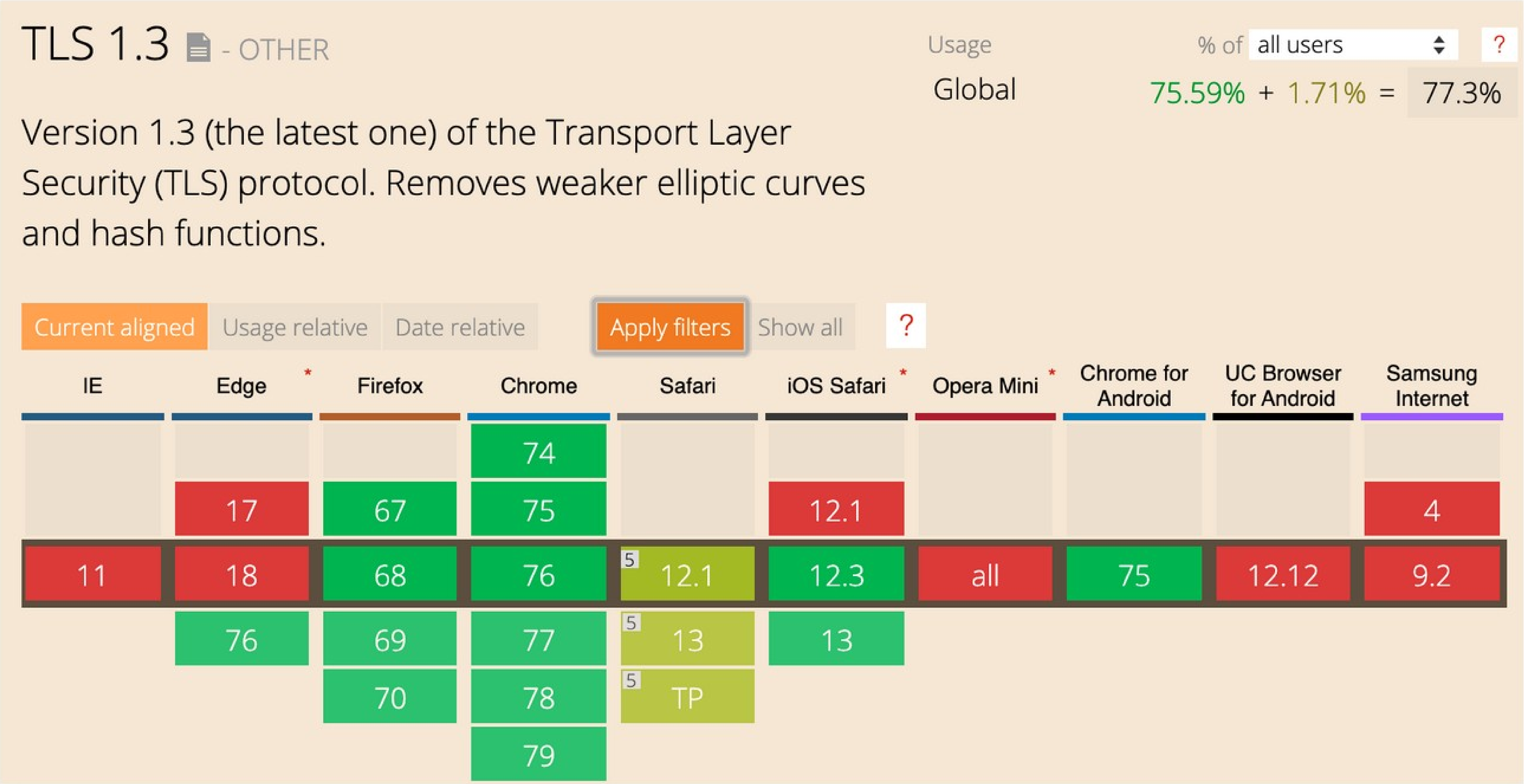
- Motivation 1: Strengthen security
  - Remove bad cyphers: SHA-1, RC4, DES, 3DES, AES-CBC, MD5, Arbitrary Diffie-Hellman groups, etc
  - Simplify configuration
- Motivation 2: Speed up protocol
  - 2 RTTs → 1 RTT
  - 0 RTT (resumption) possible if site has been recently been visited

TLS 1.2 Handshake



TLS 1.3 Handshake





TLS 1.3 - OTHER

Usage | % of all users | ?

Global 75.59% + 1.71% = 77.3%

Version 1.3 (the latest one) of the Transport Layer Security (TLS) protocol. Removes weaker elliptic curves and hash functions.

IE	Edge *	Firefox	Chrome	Safari	iOS Safari *	Opera Mini *	Chrome for Android	UC Browser for Android	Samsung Internet
			🟩 74						
	🟥 17	🟩 67	🟩 75		🟥 12.1				🟥 4
🟥 11	🟥 18	🟩 68	🟩 76	🟨 [5] 12.1	🟩 12.3	🟥 all	🟩 75	🟥 12.12	🟥 9.2
	🟩 76	🟩 69	🟩 77	🟨 [5] 13	🟩 13				
		🟩 70	🟩 78	🟨 [5] TP					
			🟩 79						

SSL Operation

- Protocol provides:
    1. Verification of identity of server (and optionally client)
    2. Message exchange between the two with confidentiality, integrity, authenticity and freshness
- Consists of authentication phase (that sets up encryption) followed by data transfer phase

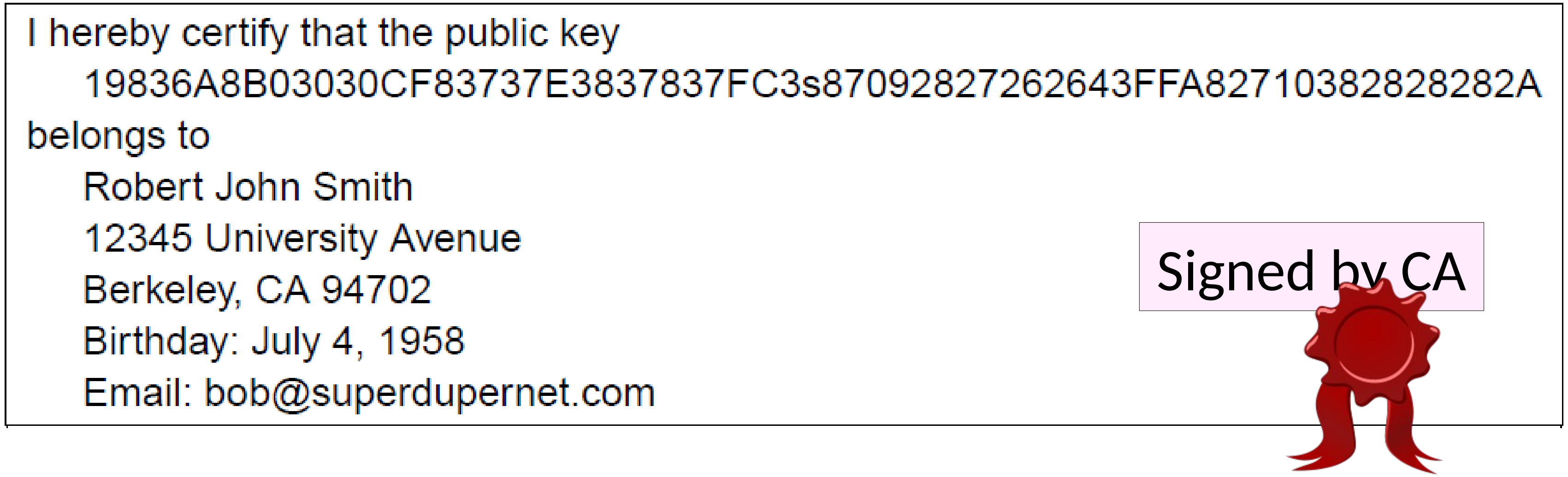
SSL/TLS Authentication

- Must allow clients to securely connect to servers not used before
  - Client must authenticate server
  - Server typically doesn’t identify client

- Uses public key authentication
  - But how does client get server’s key?
  - With certificates »

Certificates

- A certificate binds pubkey to identity, e.g., domain
  - Distributes public keys when signed by a party you trust
  - Commonly in a format called X.509

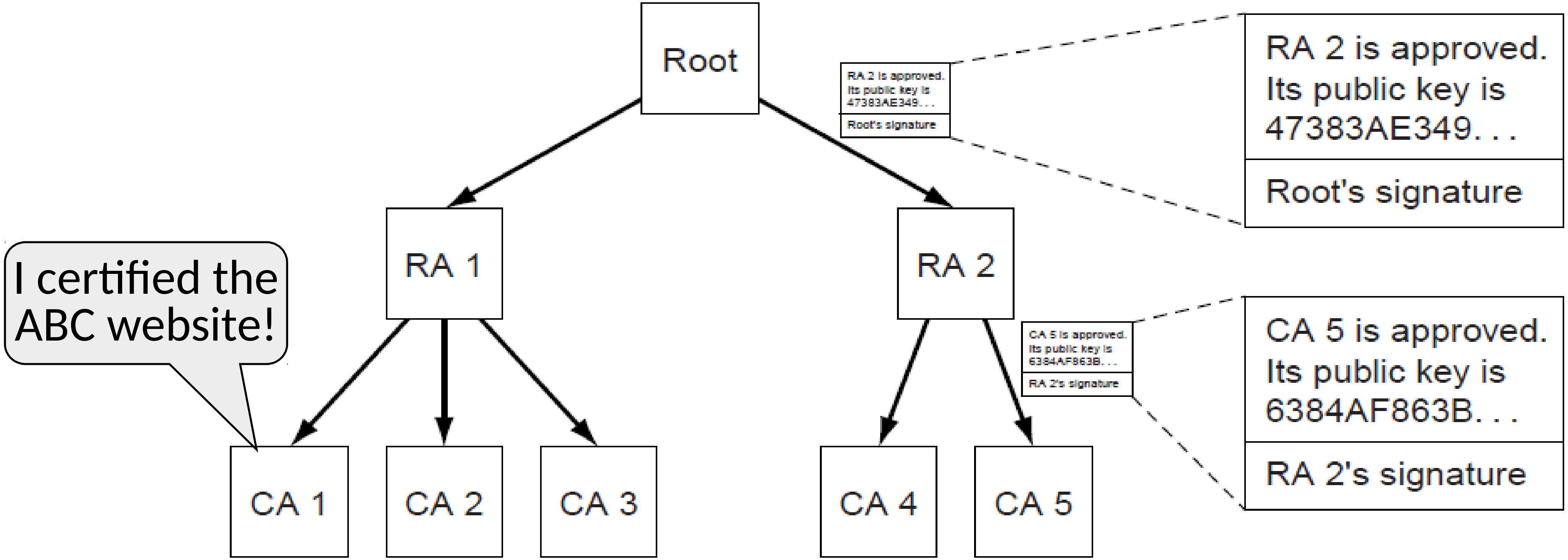


I hereby certify that the public key
    19836A8B03030CF83737E3837837FC3s87092827262643FFA82710382828282A
belongs to
    Robert John Smith
    12345 University Avenue
    Berkeley, CA 94702
    Birthday: July 4, 1958
    Email: bob@superdupernet.com

Signed by CA

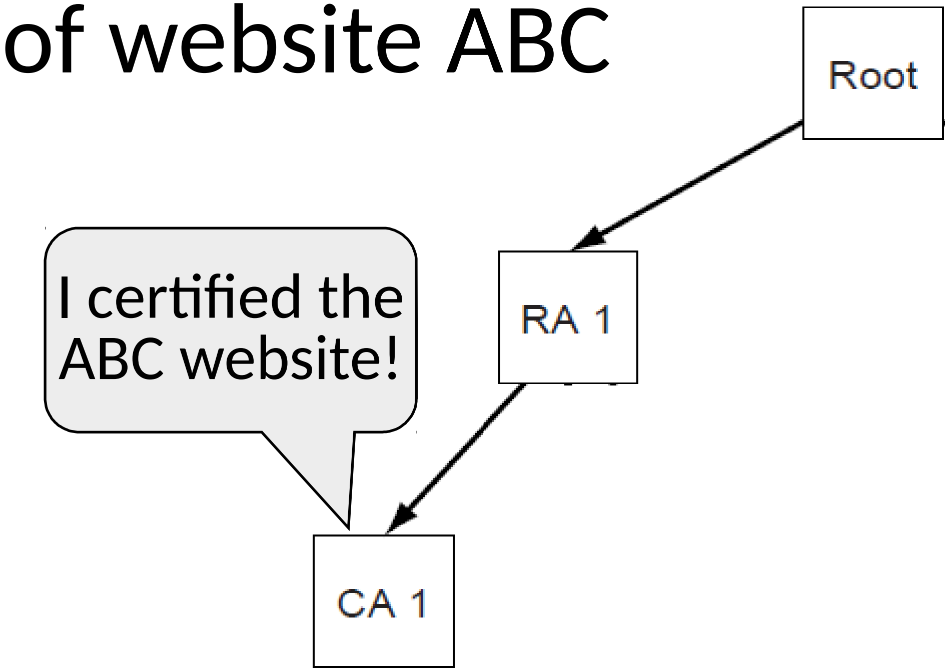
PKI (Public Key Infrastructure)

- Adds hierarchy to certificates to let parties issue
  - Issuing parties are called CAs (Certificate Authorities)


Root
RA 1
RA 2
CA 1
CA 2
CA 3
CA 4
CA 5
I certified the ABC website!
RA 2 is approved. Its public key is 47383AE349. . .
Root's signature
RA 2 is approved. Its public key is 47383AE349. . .
Root's signature
CA 5 is approved. Its public key is 6384AF863B. . .
RA 2's signature
CA 5 is approved. Its public key is 6384AF863B. . .
RA 2's signature

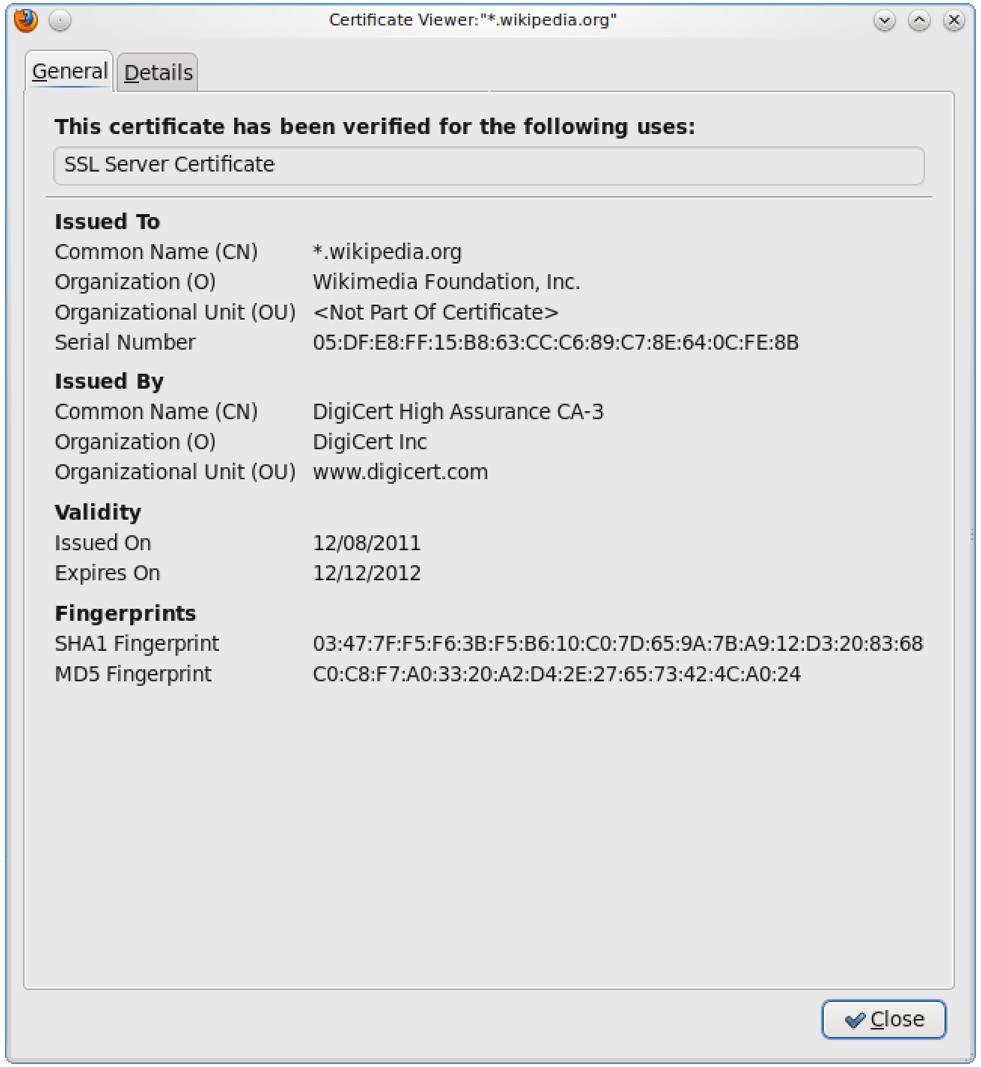
PKI (2)

- Need public key of PKI root and trust in servers on path to verify a public key of website ABC
  - Browser has Root’s public key
  - {RA1’s key is X} signed Root
  - {CA1’s key is Y} signed RA1
  - {ABC’s key Z} signed CA1



PKI (3)

- Browser/OS has public keys of the trusted roots of PKI
  - >100 root certificates!
  - Inspect your web browser



This certificate has been verified for the following uses:

SSL Server Certificate

Issued To

Common Name (CN)	*.wikipedia.org
Organization (O)	Wikimedia Foundation, Inc.
Organizational Unit (OU)	<Not Part Of Certificate>
Serial Number	05:DF:E8:FF:15:B8:63:CC:C6:89:C7:8E:64:0C:FE:8B

Issued By

Common Name (CN)	DigiCert High Assurance CA-3
Organization (O)	DigiCert Inc
Organizational Unit (OU)	www.digicert.com

Validity

Issued On	12/08/2011
Expires On	12/12/2012

Fingerprints

SHA1 Fingerprint	03:47:7F:F5:F6:3B:F5:B6:10:C0:7D:65:9A:7B:A9:12:D3:20:83:68
MD5 Fingerprint	C0:C8:F7:A0:33:20:A2:D4:2E:27:65:73:42:4C:A0:24

Certificate for wikipedia.org issued by DigiCert

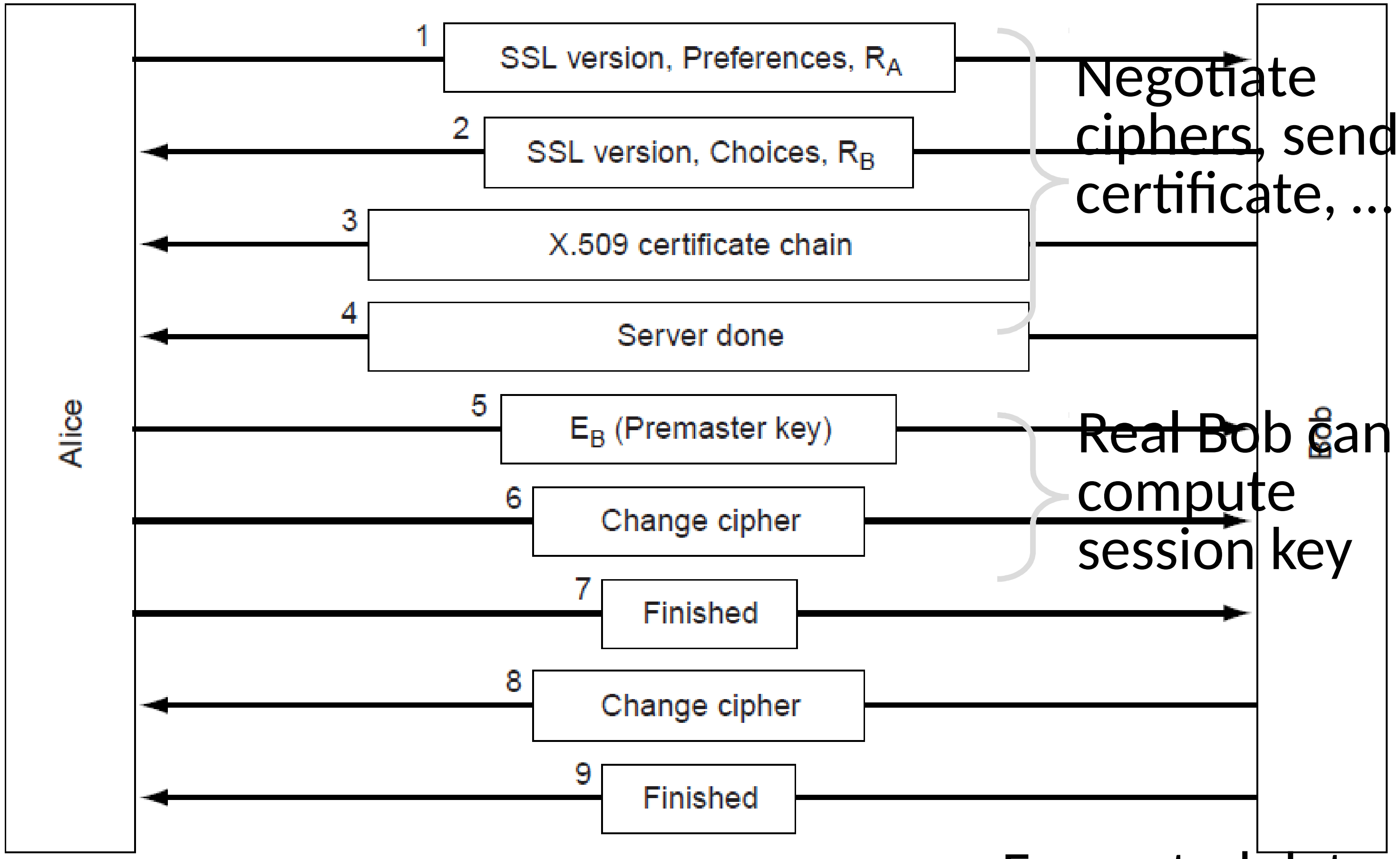
PKI (4)

- Real-world complication:
  - Public keys may be compromised
  - Certificates must then be revoked
- PKI includes a CRL (Certificate Revocation List)
  - Browsers use to weed out bad keys

SSL3 Authentication (2)

Certificate lets Alice check Bob

Switch to Alice’s session key



Negotiate ciphers, send certificate, …

Real Bob can compute session key

Encrypted data ⟷ Encrypted data

Cellular Security (1)

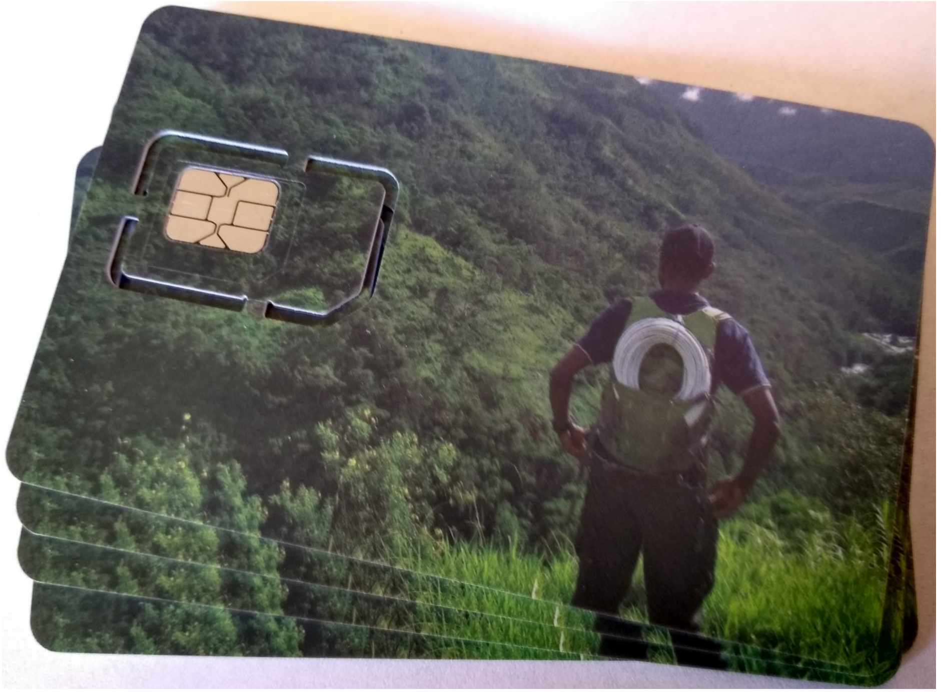
- Very different model
  - Need to encrypt traffic **and** authenticate user
  - Traffic is **not** end-to-end, you are talking to the core network
  - Plus we have a SIM card!

Cellular Security (2)

- Symmetric Key on SIM
  - Created when SIM is printed
  - Used for authentication and link-layer encryption

Absolutely no end-to-end encryption

- Actually illegal. Need to support “lawful intercept”



“Metadata”

- What can attacker (in the network) learn from a call?

“Metadata”

- What can attacker (in the network) learn from a call?
- What can attacker (in the network) learn from an HTTPS connection?

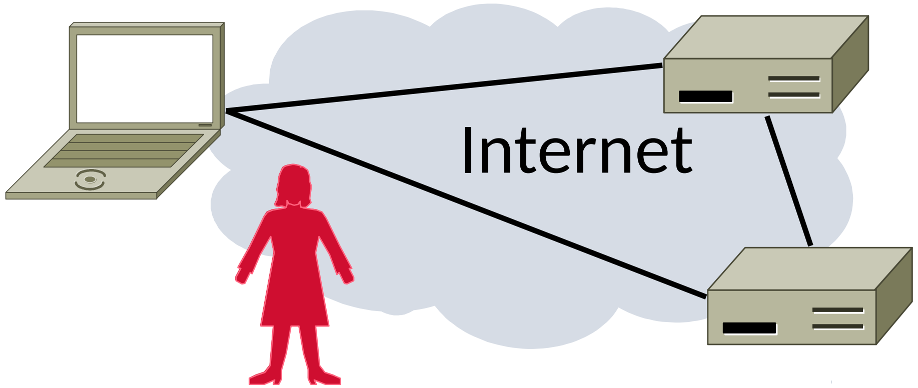
Takeaways

- SSL/TLS is a secure transport
    - For HTTPS and more, with the usual confidentiality, integrity / authenticity
- Client authenticates web server
    - Done with a PKI and certificates
    - Major area of complexity and risk
- Cellular networks are dumb
- “Metadata” leaks
    - Use other tools (Tor or VPN) if you want to hide that

Defenses

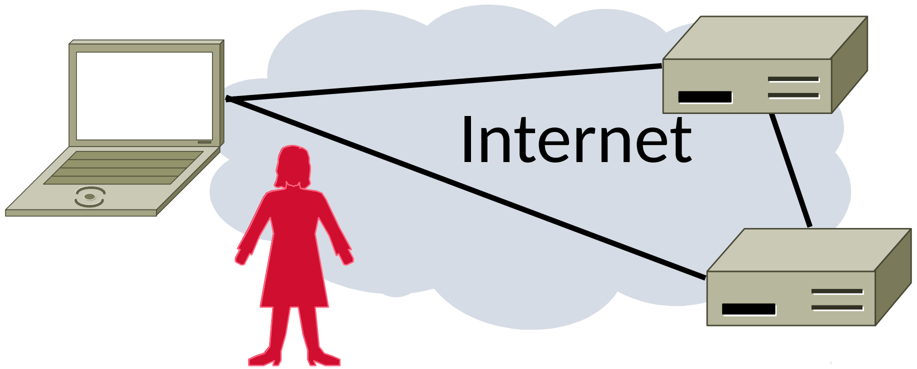
Topic

- Virtual Private Networks (VPNs)
  - Run as closed networks on Internet
  - Use IPSEC to secure messages



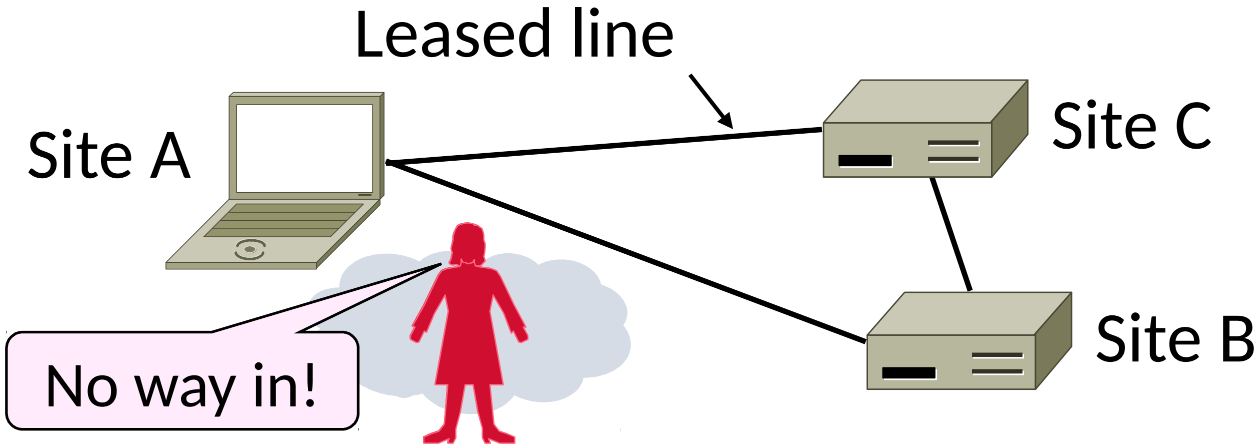
Motivation

- The best part of IP connectivity
  - You can send to any other host
- The worst part of IP connectivity
  - Any host can send packets to you!
  - There's nasty stuff out there …



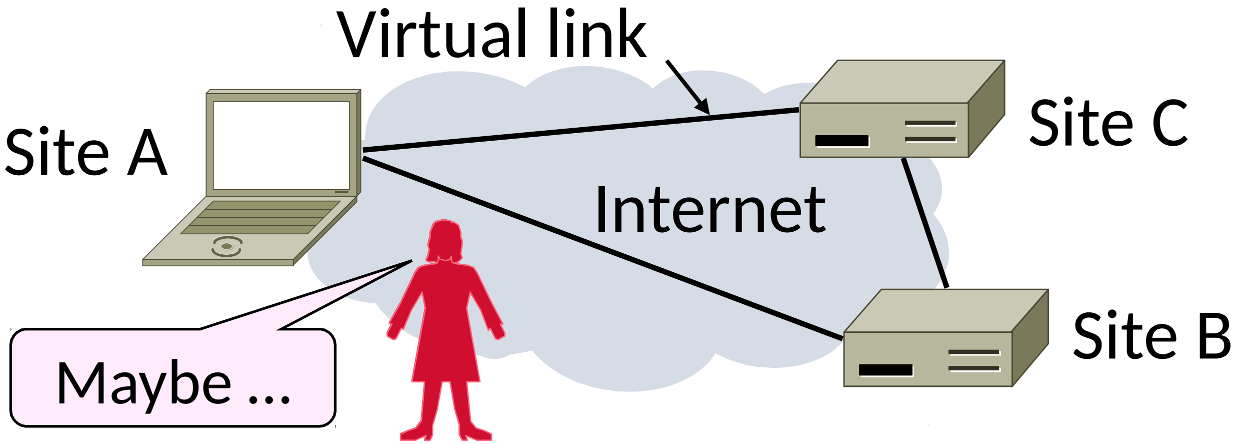
Motivation (2)

- Often desirable to separate network from the Internet, e.g., a company
  - Private network with leased lines
  - Physically separated from Internet



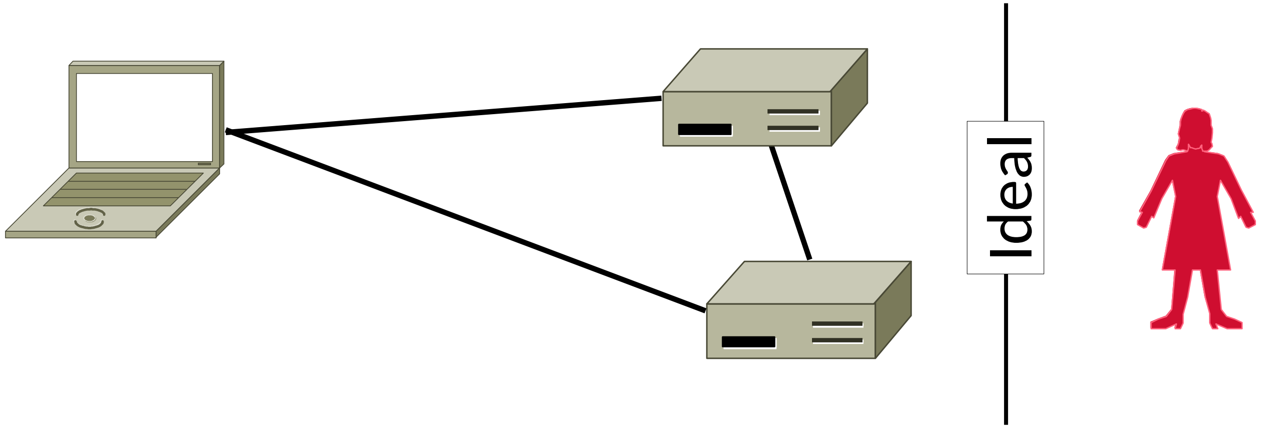
Motivation (3)

- Idea: Use the public Internet instead of leased lines – cheaper!
  - Logically separated from Internet …
  - This is a Virtual Private Network (VPN)



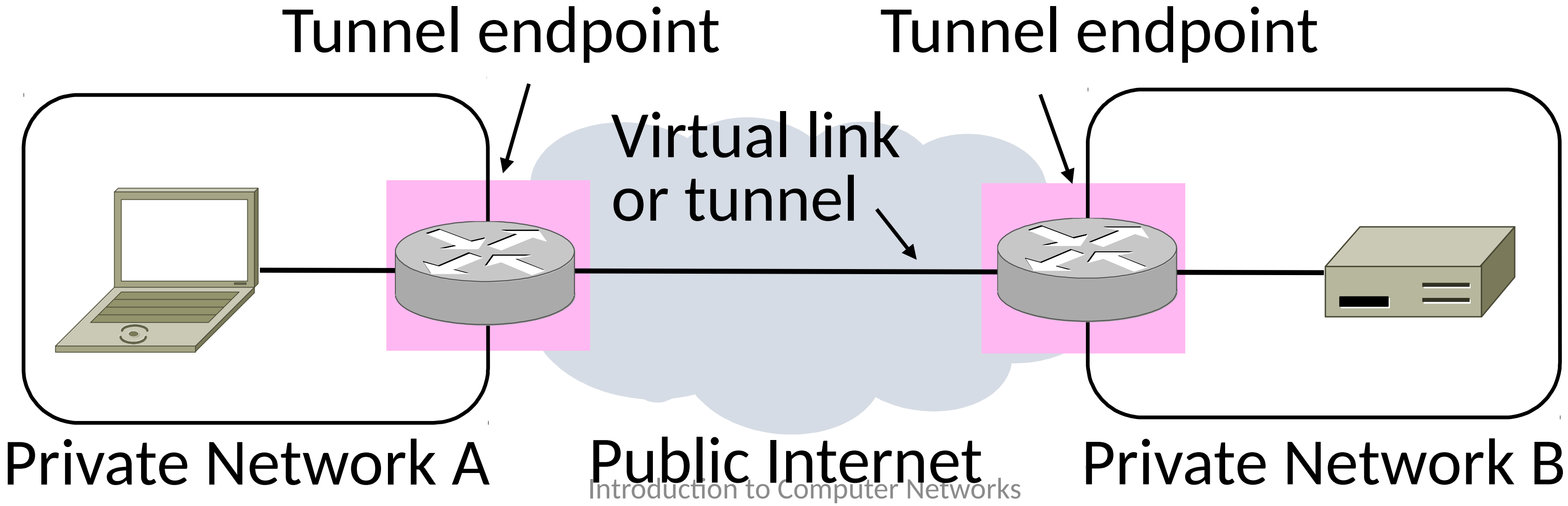
Goal and Threat Model

- Goal is to keep a logical network (VPN) separate from the Internet while using it for connectivity
  - Threat is Trudy may access VPN and intercept or tamper with messages



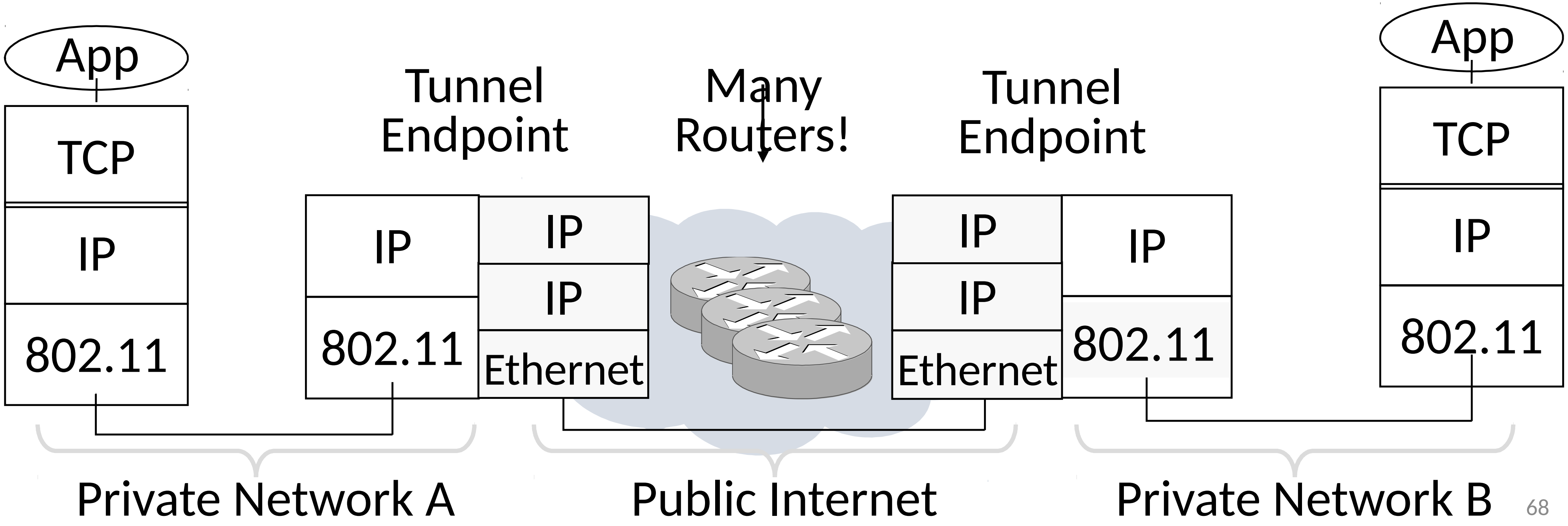
Tunneling

- How can we build a virtual link? With tunneling!
  - Hosts in private network send to each other normally
  - To cross virtual link (tunnel), endpoints encrypt and encapsulate packet



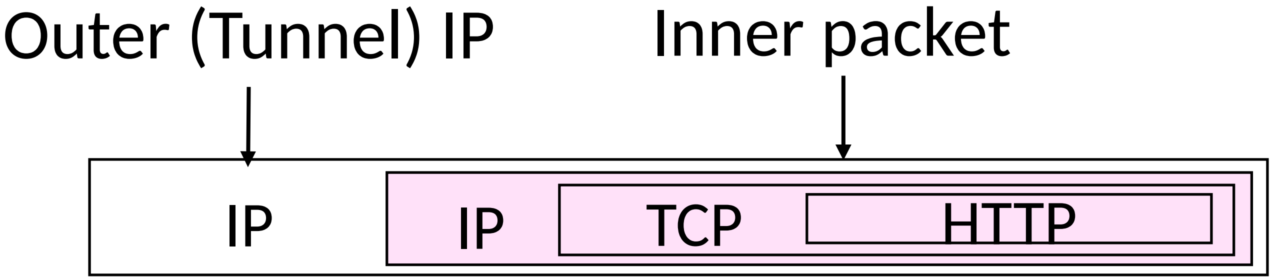
Tunneling (2)

- Tunnel endpoints encapsulate IP packets ("IP in IP")
    - Add/modify outer IP header for delivery



Tunneling (3)

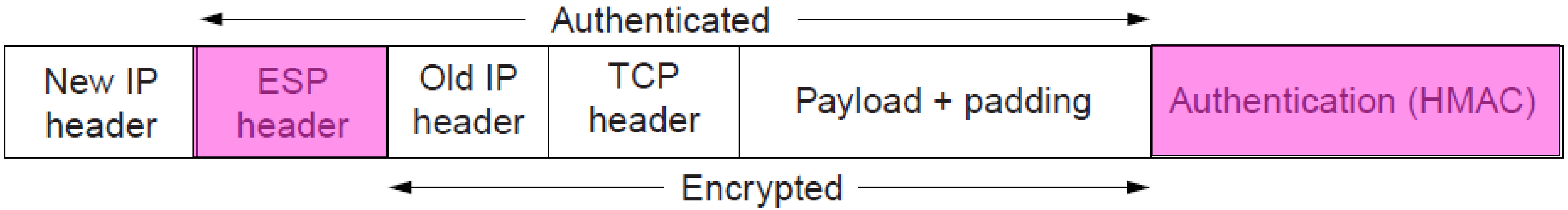
- Simplest encapsulation wraps packet with another IP header
  - Outer (tunnel) IP header has tunnel endpoints as source/destination
  - Inner packet is encrypted and has private network IP addresses as source/destination



IPSEC (IP Security)

- Longstanding effort to secure the IP layer
  - Adds confidentiality, integrity/authenticity
- IPSEC operation:
  - Keys are set up for communicating host pairs
  - Communication becomes more connection-oriented
  - Header and trailer added to protect IP packets

Tunnel Mode



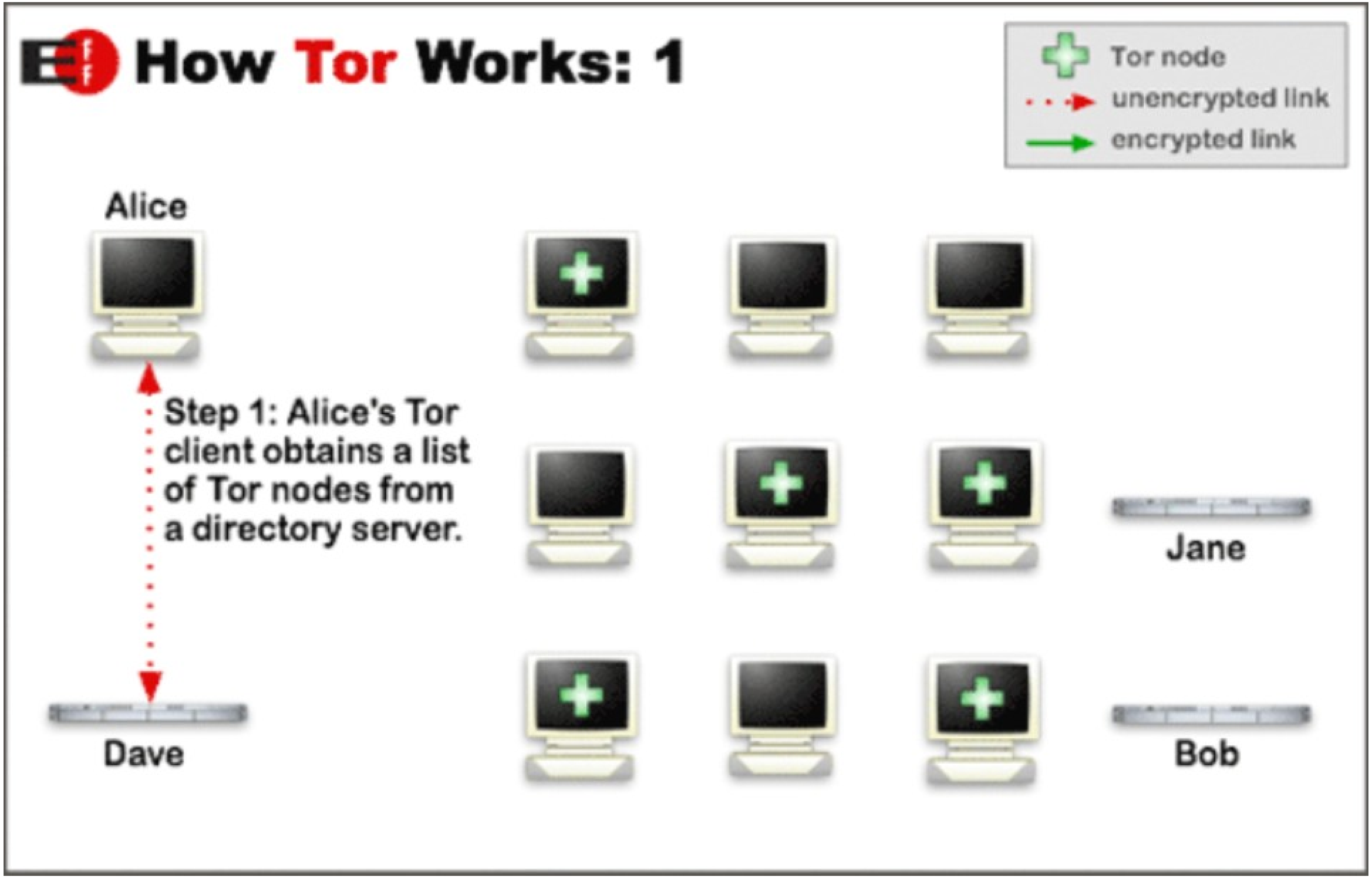
Takeaways

- VPNs are useful for building networks on top of the Internet
  - Virtual links encapsulate packets
  - Alters IP connectivity for hosts

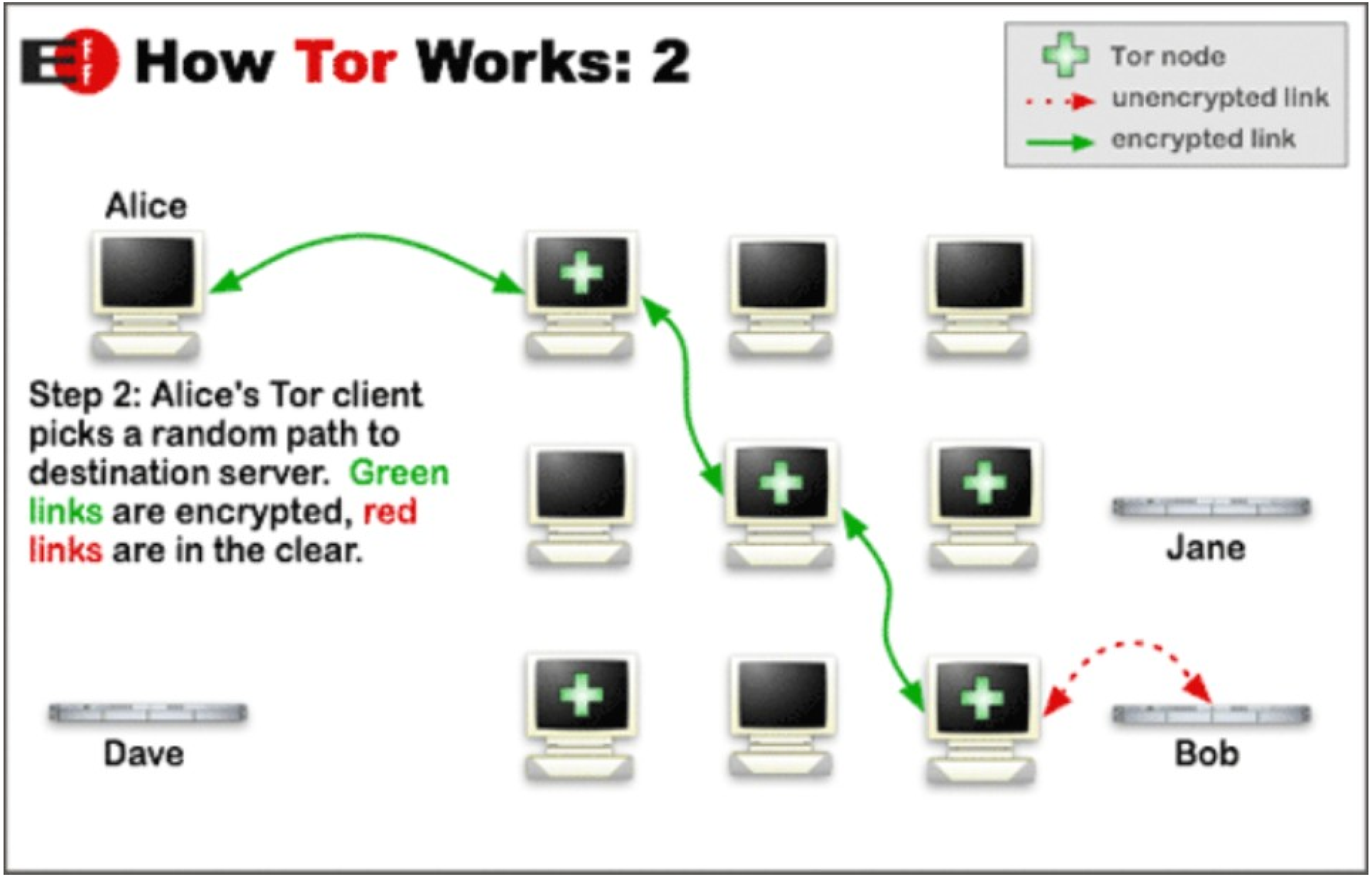
- VPNs need crypto to secure messages
  - Typically IPSEC is used for confidentiality, integrity/authenticity

Tor

- “The Onion Router”
- Basic idea:
  1. Generate circuit of routers that you know will send packet
  2. Encrypt the packet in layers for each router in circuit
  3. Send the packet
  4. Each router receives, decrypts their layer, and forwards based on new info
  5. Routers maintain state about circuit to route stuff back to sender
     - But again, only know the next hop

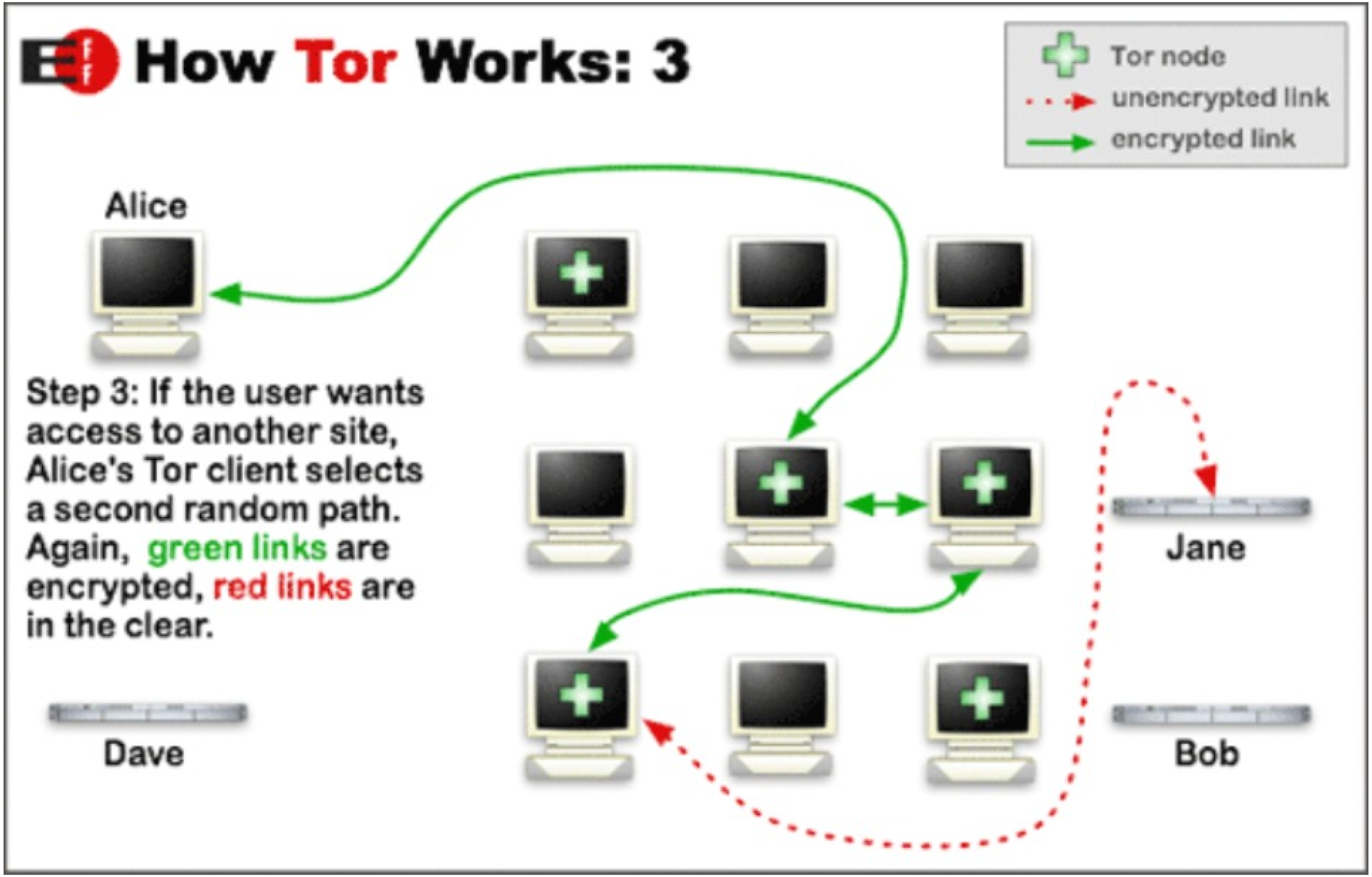


Step 1: Alice's Tor client obtains a list of Tor nodes from a directory server.



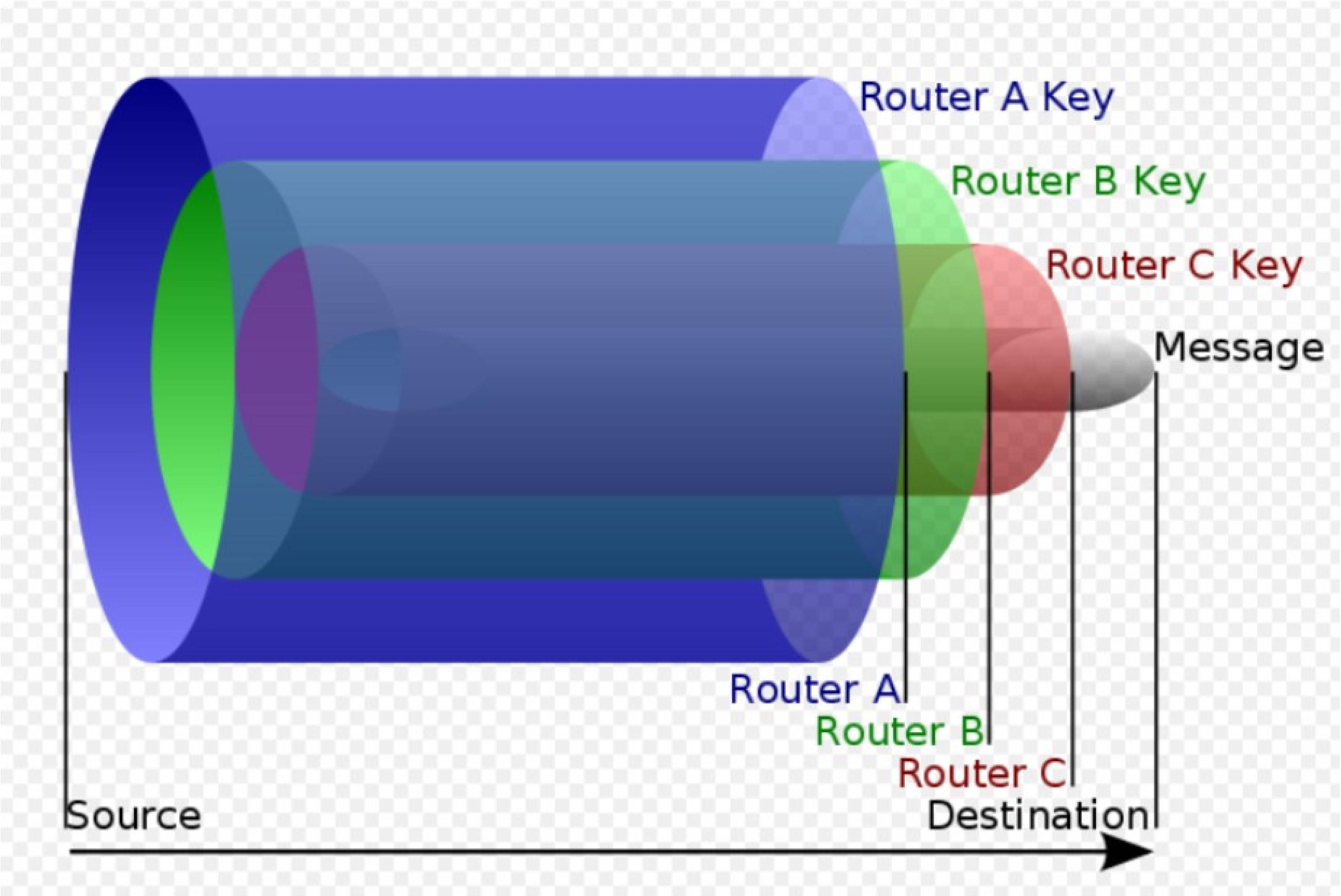
Step 2: Alice's Tor client picks a random path to destination server. Green links are encrypted, red links are in the clear.

- Image courtesy torproject.org



How Tor Works: 3

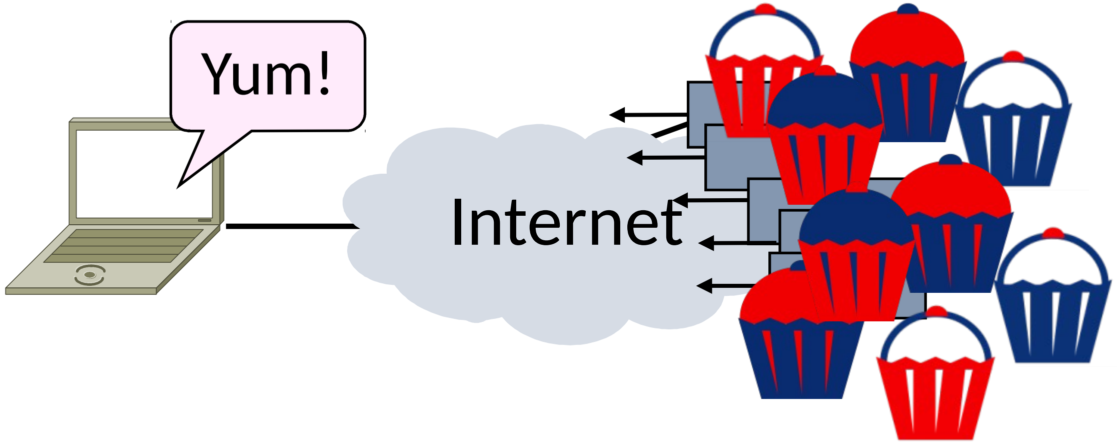
Step 3: If the user wants access to another site, Alice's Tor client selects a second random path. Again, green links are encrypted, red links are in the clear.


Router A Key
Router B Key
Router C Key
Message
Router A
Router B
Router C
Source
Destination

Other Attacks

Topic

- Distributed Denial-of-Service (DDOS)
  - An attack on network availability



Topic

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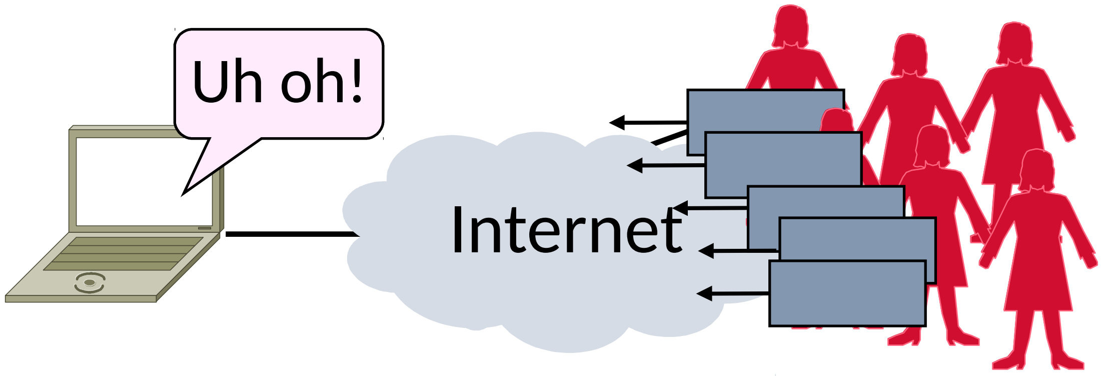

Motivation

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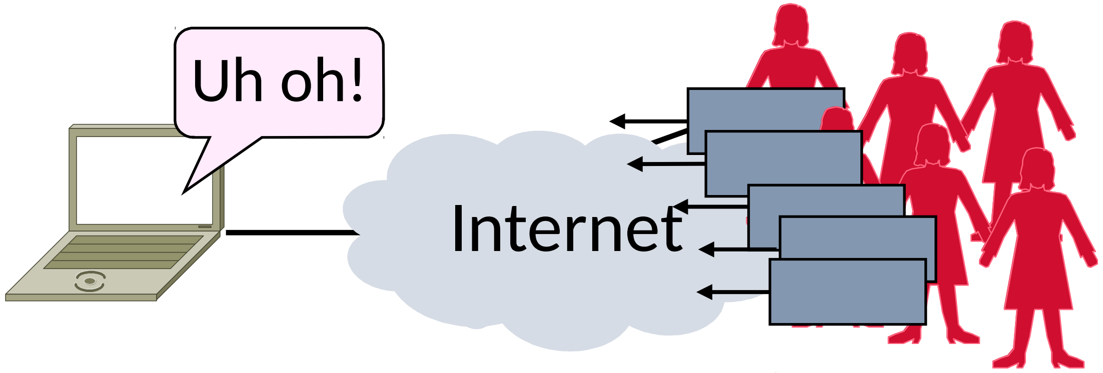
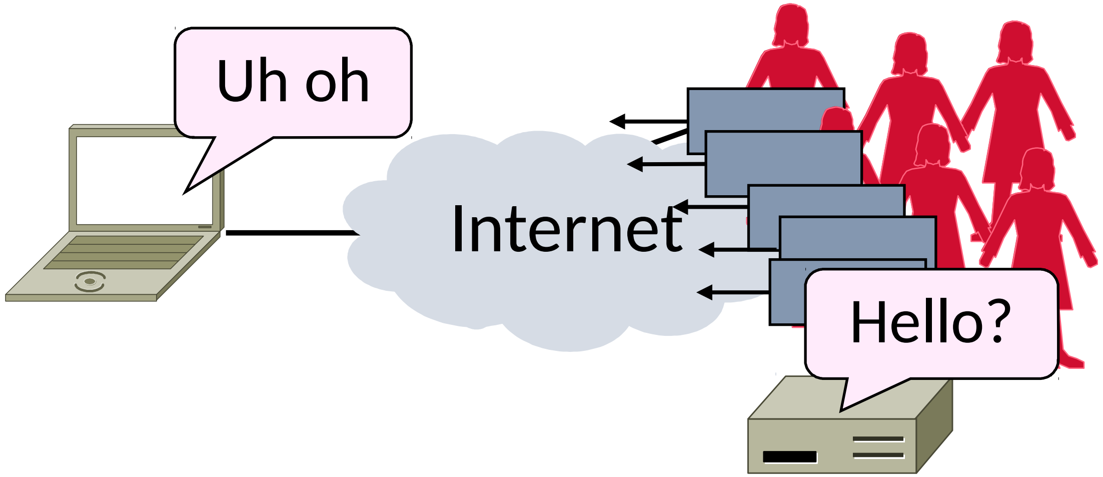


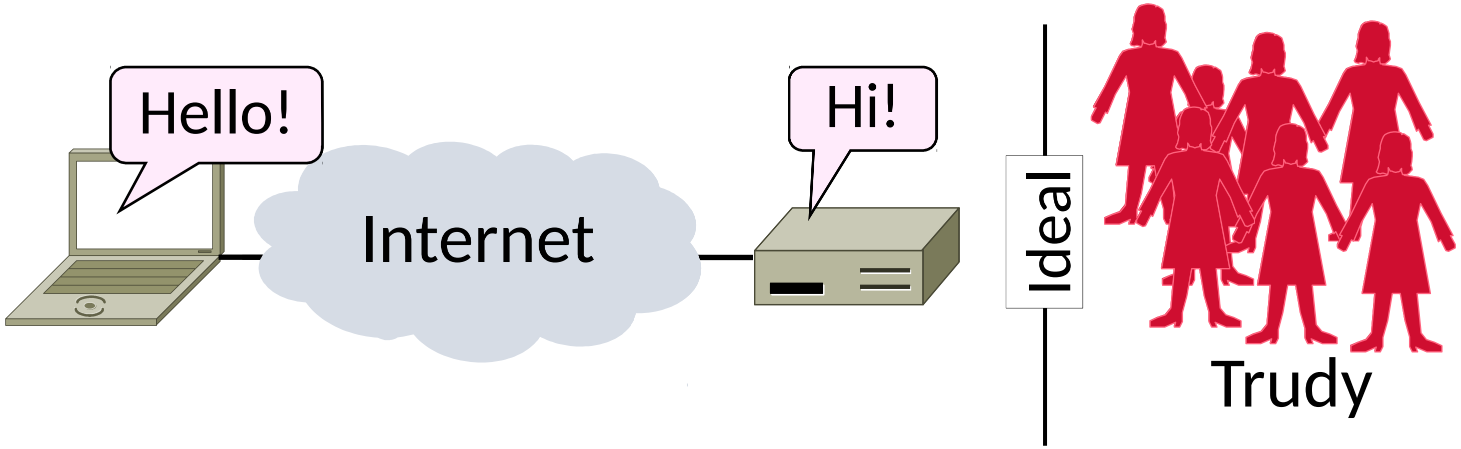
Motivation (2)

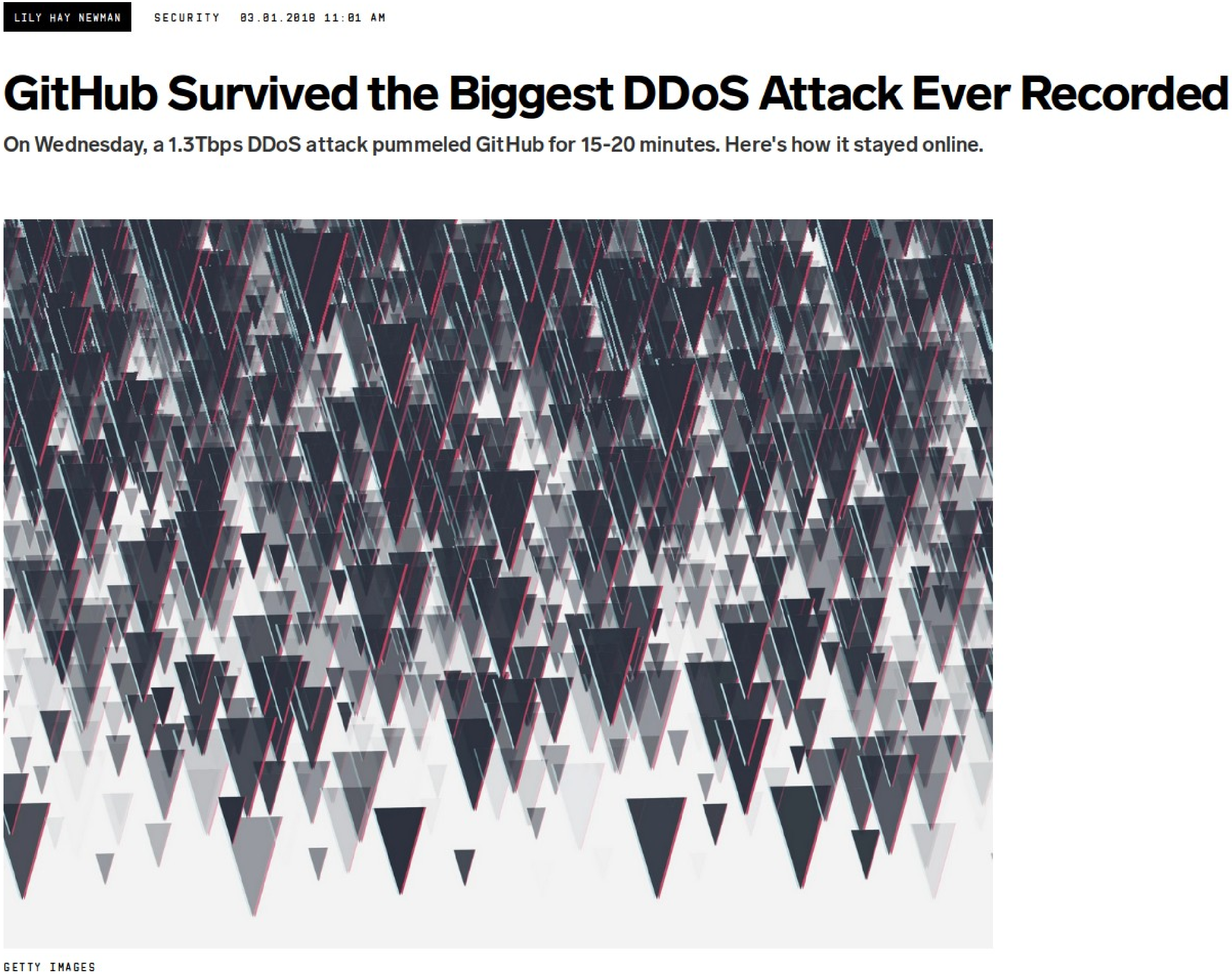
- Flooding a host with many packets can interfere with its IP connectivity
  - Host may become unresponsive
  - This is a form of denial-of-service



Goal and Threat Model

- Goal is for host to keep network connectivity for desired services
    - Threat is Trudy may overwhelm host with undesired traffic





LILY HAY NEWMAN SECURITY 03.01.2018 11:01 AM

GitHub Survived the Biggest DDoS Attack Ever Recorded

On Wednesday, a 1.3Tbps DDoS attack pummeled GitHub for 15-20 minutes. Here's how it stayed online.

GETTY IMAGES

Internet Reality

- Distributed Denial-of-Service is a huge problem today!
    - Github attack of 1tbps

- There are no great solutions
    - CDNs, network traffic filtering, and best practices all help

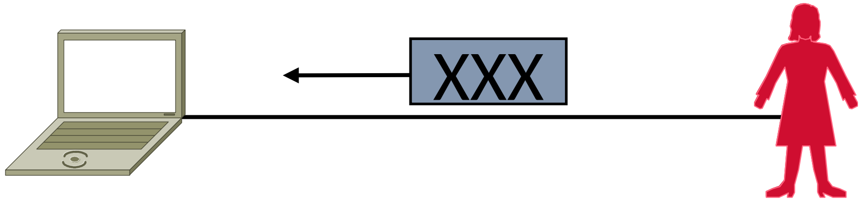
Denial-of-Service

- Denial-of-service means a system is made unavailable to intended users
  - Typically because its resources are consumed by attackers instead

- In the network context:
  - “System” means server
  - “Resources” mean bandwidth (network) or CPU/memory (host)

Host Denial-of-Service

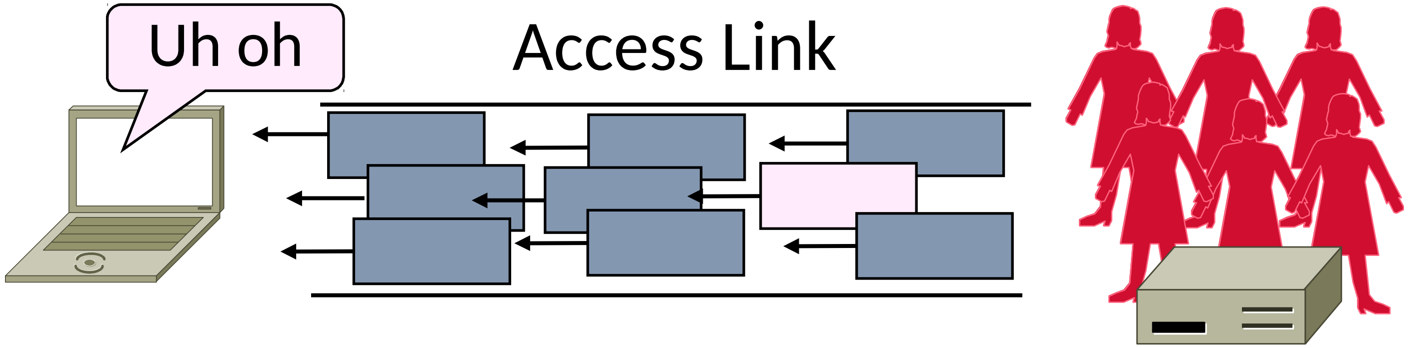
- Strange packets can sap host resources!
  - “Ping of Death” malformed packet
  - “SYN flood” sends many TCP connect requests and never follows up
  - Few bad packets can overwhelm host



- Patches exist for these vulnerabilities
  - Read about “SYN cookies” for interest

Network Denial-of-Service

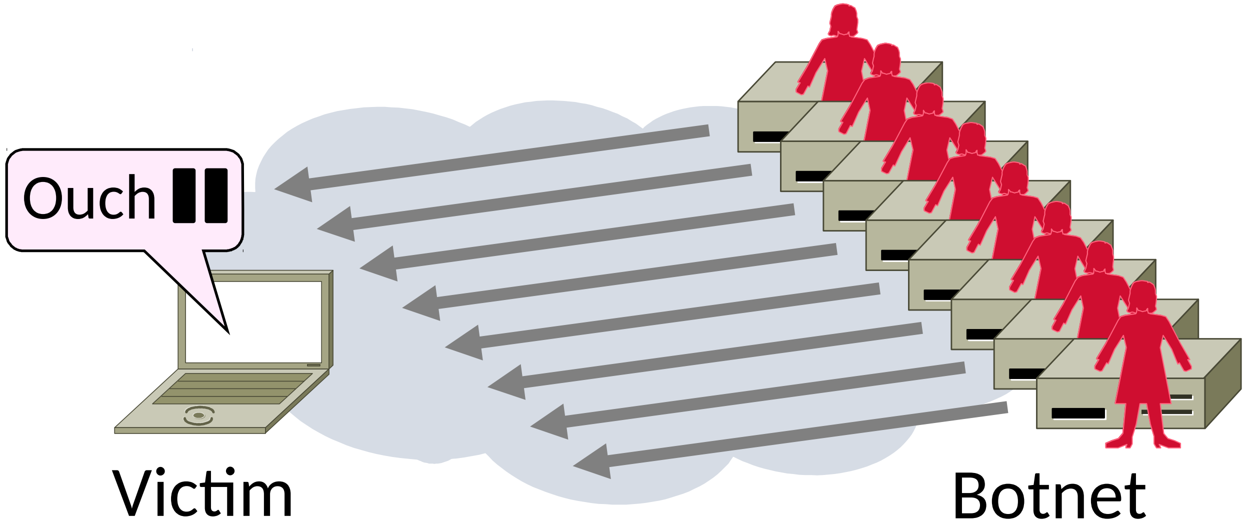
- Network DOS needs many packets
  - To saturate network links
  - Causes high congestion/loss



- Helpful to have many attackers … or Distributed Denial-of-Service

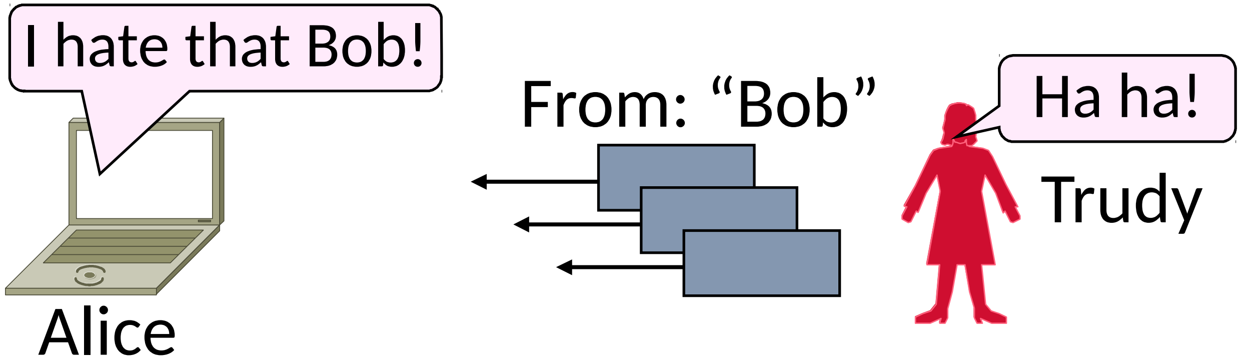
Distributed Denial-of-Service (DDOS)

- Botnet provides many attackers in the form of compromised hosts
  - Hosts send traffic flood to victim
  - Network saturates near victim



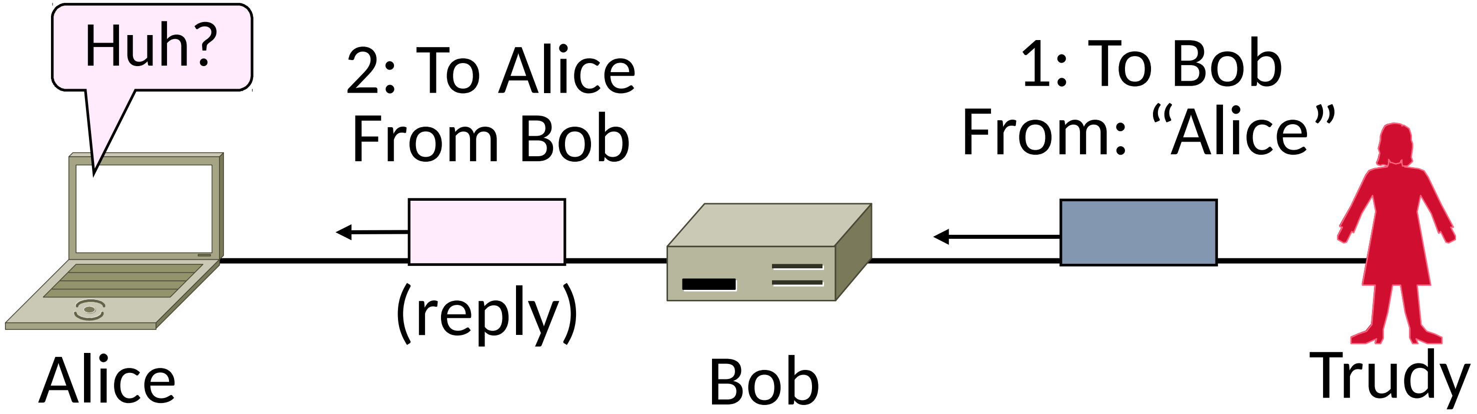
Complication: Spoofing

- Attackers can falsify their IP address
  - Put fake source address on packets
  - Historically network doesn't check
  - Hides location of the attackers
  - Called IP address <u>spoofing</u>



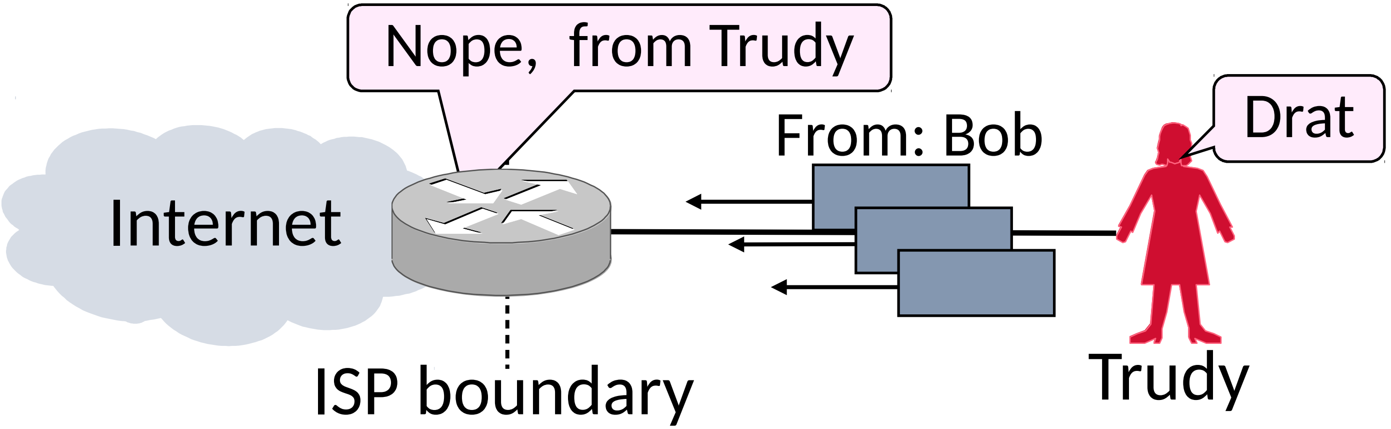
Spoofing (2)

- Actually, it’s worse than that
  - Trudy can trick Bob into really sending packets to Alice
  - To do so, Trudy spoofs Alice to Bob



Best Practice: Ingress Filtering

- Idea: Validate the IP source address of packets at ISP boundary (Duh!)
  - Ingress filtering is a best practice, but deployment has been slow



Flooding Defenses

1. Increase network capacity around the server; harder to cause loss
   - Use a CDN for high peak capacity

2. Filter out attack traffic within the network (at routers)
   - The earlier the filtering, the better
   - Ultimately what is needed, but ad hoc measures by ISPs today