Preview question
Which of the following would have to be completely abandoned if scalable quantum computers become widely available?
A. one-time pads
B. RSA
C. AES
D. ROT13
E. SHA-3

Outline
Public key primitives, cont'd
Good technical writing (pt. 1)
Brief introduction to networking
Some classic network attacks
Cryptographic protocols

General description
Public-key encryption (generalizes block cipher)
- Separate encryption key EK (public) and decryption key DK (secret)
Signature scheme (generalizes MAC)
- Separate signing key SK (secret) and verification key VK (public)

Hybrid encryption
Public-key operations are slow
In practice, use them just to set up symmetric session keys
+ Only pay RSA costs at setup time
- Breaks at either level are fatal

Padding, try #1
Need to expand message (e.g., AES key) size to match modulus
PKCS#1 v. 1.5 scheme: prepend 00 01 FF FF .. FF
Surprising discovery (Bleichenbacher'98): allows adaptive chosen ciphertext attacks on SSL
Variants recurred later (c.f. “ROBOT” 2018)

Modern “padding”
Much more complicated encoding schemes using hashing, random salts, Feistel-like structures, etc.
Common examples: OAEP for encryption, PSS for signing
Progress driven largely by improvement in random oracle proofs

Simpler padding alternative
“Key encapsulation mechanism” (KEM)
For common case of public-key crypto used for symmetric-key setup
- Also applies to DH
Choose RSA message $r$ at random mod $n$,
symmetric key is $H(r)$
- Hard to retrofit, RSA-KEM insecure if $e$ and $r$ reused with different $n$
Post-quantum cryptography

- One thing quantum computers would be good for is breaking crypto
- Square root speedup of general search
  - Countermeasure: double symmetric security level
- Factoring and discrete log become poly-time
  - DH, RSA, DSA, elliptic curves totally broken
  - Totally new primitives needed (lattices, etc.)
- Not a problem yet, but getting ready

Box and locks revisited

- Alice and Bob's box scheme fails if an intermediary can set up two sets of boxes
  - Middleperson (man-in-the-middle) attack
- Real world analogue: challenges of protocol design and public key distribution

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Writing in CS versus other writing

- Key goal is accurately conveying precise technical information
- More important: careful use of terminology, structured organization
- Less important: writer's personality, persuasion, appeals to emotion

Still important: concise expression

- Don't use long words or complicated expressions when simpler ones would convey the same meaning.
  - Negative examples:
    - necessitate
    - utilize
    - due to the fact that
  - Beneficial for both clarity and style

Precise explanations

- Don't say "we" do something when it's the computer that does it
  - And avoid passive constructions
- Don't anthropomorphize (computers don't "know")
- Use singular by default so plural provides a distinction:
  - The students take tests
  - Each student takes a test
  - Each student takes two tests

Provide structure

- Use plenty of sections and sub-sections
- It's OK to have some redundancy in previewing structure
- Limit each paragraph to one concept, and not too long
  - Start with a clear topic sentence
- Split long, complex sentences into separate ones
Know your audience: Project 1

- For projects in this course, assume your audience is another student who already understands general course concepts
  - Up to the current point in the course
  - I.e., don’t need to define “buffer overflow” from scratch
- But you need to explain specifics of a vulnerable program
  - Make clear what part of the program you’re referring to
  - Explain all the specific details of a vulnerability

Inclusive language

- Avoid words and grammar that implies relevant people are male
- My opinion: avoid using he/him pronouns for unknown people
- Some possible alternatives
  - “he/she”
  - Alternating genders
  - Rewrite to plural and use “they” (may be less clear)
  - Singular “they” (least traditional, but spreading)

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The Internet

- A bunch of computer networks voluntarily interconnected
- Capitalized because there’s really only one
- No centralized network-level management
  - But technical collaboration, DNS, etc.

Layered model (OSI)

1. Physical (10BASE-T)
2. Data-link (PPP)
3. Network (IP)
4. Transport (TCP)
5. Session (SSL?)
6. Presentation (MIME?)
7. Application (HTTP)

Layered model: TCP/IP

<table>
<thead>
<tr>
<th>Layer</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Application</td>
<td>Application protocol (e.g., HTTP)</td>
</tr>
<tr>
<td>Transport</td>
<td>TC(P)</td>
</tr>
<tr>
<td>Network</td>
<td>IP</td>
</tr>
<tr>
<td>Link</td>
<td>802.11 (WiFi)</td>
</tr>
<tr>
<td>Physical</td>
<td>Ethernet</td>
</tr>
</tbody>
</table>

Packet wrapping

- Segments
  - application data
- TCP data
- IP data
- Frames
  - Ethernet
- IP
- TCP data

IP(v4) addressing

- Interfaces (hosts or routers) identified by 32-bit addresses
  - Written as four decimal bytes, e.g., 192.168.10.2
- First k bits identify network, 32 − k host within network
  - Can’t (anymore) tell k from the bits
- We’ll run out any year now
IP and ICMP
- Internet Protocol (IP) forwards individual packets
- Packets have source and destination addresses, other options
- Automatic fragmentation (usually avoided)
- ICMP (I Control Message P) adds errors, ping packets, etc.

UDP
- User Datagram Protocol: thin wrapper around IP
- Adds source and destination port numbers (each 16-bit)
- Still connectionless, unreliable
- OK for some small messages

TCP
- Transmission Control Protocol: provides reliable bidirectional stream abstraction
- Packets have sequence numbers, acknowledged in order
- Missed packets resent later

Flow and congestion control
- Flow control: match speed to slowest link
  - “Window” limits number of packets sent but not ACKed
- Congestion control: avoid traffic jams
  - Lost packets signal congestion
  - Additive increase, multiplicative decrease of rate

Routing
- Where do I send this packet next?
  - Table from address ranges to next hops
- Core Internet routers need big tables
- Maintained by complex, insecure, cooperative protocols
  - Internet-level algorithm: BGP (Border Gateway Protocol)

Below IP: ARP
- Address Resolution Protocol maps IP addresses to lower-level address
  - E.g., 48-bit Ethernet MAC address
- Based on local-network broadcast packets
- Complex Ethernets also need their own routing (but called switches)

DNS
- Domain Name System: map more memorable and stable string names to IP addresses
- Hierarchically administered namespace
  - Like Unix paths, but backwards
  - .edu server delegates to .umn.edu server, etc.

DNS caching and reverse DNS
- To be practical, DNS requires caching
  - Of positive and negative results
- But, cache lifetime limited for freshness
- Also, reverse IP to name mapping
  - Based on special top-level domain, IP address written backwards
Classic application: remote login

- Killer app of early Internet: access supercomputers at another university
- Telnet: works cross-OS
  - Send character stream, run regular login program
- rlogin: BSD Unix
  - Can authenticate based on trusting computer connection comes from
  - (Also rsh, rcp)

Packet sniffing

- Watch other people's traffic as it goes by on network
- Easiest on:
  - Old-style broadcast (thin, "hub") Ethernet
  - Wireless
- Or if you own the router

Forging packet sources

- Source IP address not involved in routing, often not checked
- Change it to something else!
- Might already be enough to fool a naive UDP protocol

TCP spoofing

- Forging source address only lets you talk, not listen
- Old attack: wait until connection established, then DoS one participant and send packets in their place
- Frustrated by making TCP initial sequence numbers unpredictable
  - Fancier attacks modern attacks are "off-path"

ARP spoofing

- Impersonate other hosts on local network level
- Typical ARP implementations stateless, don’t mind changes
- Now you get victim's traffic, can read, modify, resend

rlogin and reverse DNS

- rlogin uses reverse DNS to see if originating host is on whitelist
- How can you attack this mechanism with an honest source IP address?
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A couple more security goals

- Non-repudiation: principal cannot later deny having made a commitment
  - i.e., consider proving fact to a third party
- Forward secrecy: recovering later information does not reveal past information
  - Motivates using Diffie-Hellman to generate fresh keys for each session

Abstract protocols

- Outline of what information is communicated in messages
  - Omit most details of encoding, naming, sizes, choice of ciphers, etc.
  - Describes honest operation
  - But must be secure against adversarial participants
  - Seemingly simple, but many subtle problems

Protocol notation

\[ A \rightarrow B : N_B, (T_0, B, N_B)_{K_B} \]

- \( A \rightarrow B \): message sent from Alice intended for Bob
- \( B \) (after \( : \)): Bob’s name
- \( \cdot \cdot \cdot )_{K_B} \): encryption with key \( K_B \)

Example: simple authentication

\[ A \rightarrow B : A, (A, N)_{K_A} \]

- E.g., Alice is key fob, Bob is garage door
- Alice proves she possesses the pre-shared key \( K_A \)
  - Without revealing it directly
- Using encryption for authenticity and binding, not secrecy

Nonce

\[ A \rightarrow B : A, (A, N)_{K_A} \]

- \( N \) is a nonce: a value chosen to make a message unique
- Best practice: pseudorandom
- In constrained systems, might be a counter or device-unique serial number

Replay attacks

- A nonce is needed to prevent a verbatim replay of a previous message
- Garage door difficulty: remembering previous nonces
  - Particularly: lunchtime/roommate/valet scenario
- Or, door chooses the nonce: challenge-response authentication

Middleperson attacks

- Older name: man-in-the-middle attack, MITM
- Adversary impersonates Alice to Bob and vice-versa, relays messages
- Powerful position for both eavesdropping and modification
- No easy fix if Alice and Bob aren’t already related
Chess grandmaster problem

- Variant or dual of middleperson
- Adversary forwards messages to simulate capabilities with his own identity
- How to win at correspondence chess
- Anderson's MiG-in-the-middle

Anti-pattern: "oracle"

- Any way a legitimate protocol service can give a capability to an adversary
- Can exist whenever a party decrypts, signs, etc.
- "Padding oracle" was an instance of this at the implementation level