15-441 15-641 Computer Networking

Lecture 21 – Security: Cryptography and key management

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www.cs.carnegiemellon.edu/~prs/15-441-F14

With slides from: Debabrata Dash, Nick Feamster, Vyas Sekar, and others

Announcements: P2

- Common problems that prevent interoperation with test software used in autolab tests
  1. The size of data in each data packet is not fixed
  2. Congestion control should always start with sequence number 1
  3. The code does not need to modify the has-chunk-file or get-chunk-file
  4. Not matching the packet format in Figure 2 in handout
- Can result in 0 grade although it "kind of" works
  - Might work in a system that only uses your software
  - Would not work in the Internet

Moving Forward

- The plan is:
  - TA will grade using Autolab as planned
  - Will post preliminary grades
  - Teams can meet with TA to adjust grade
- What we have learned:
  - You cannot use Autolab as a debugging tool
    - Limited I/O, limited tests, …
  - You must also develop your own test scripts
    - Remember that the Autolab tests are very limited – sanity check
  - Please ask us if something is unclear or other things that might help early

Normal Mindset

- No user would do that
- The odds of a router being misconfigured that way is too small to worry about

Security Mindset

- The **adversary** will do anything it can to break your system
- It will study your system and purposefully do the worse thing it can
- Might even disregard its own well being
- Will attack your implementation and your assumptions

5

Adversaries

- Possible adversaries include:
  - Competitors trying harm you
  - Governments trying to control you
  - Criminals who want to use your system
  - Disgruntled employees (the *insider threat*)
  - Hackers who find it fun to break stuff
  - Others we didn't even think of...
- Assumptions about the adversary
- Security is very hard

Unlimited resources

Knows your source code

Destructive with no "real" goals

6

Flashback .. Internet design goals

1. Interconnection
2. Failure resilience
3. Multiple types of service
4. Variety of networks
5. Management of resources
6. Cost-effective
7. Low entry-cost
8. Accountability for resources

Where is security?

Why did they leave it out?

- Designed for connectivity
- Network designed with implicit trust
  - Origin as a small and cooperative network
  - No "bad" guys (adversaries)
- Can't security be provided at the edge?
  - Encryption, Authentication etc
  - End-to-end arguments in system design

Internet Design Decisions and Security

- Global Addressing
  (=> every sociopath is your next-door neighbor*)
- Connection-less datagram service
  (=> can't verify source, hard to protect bandwidth)

* Dan Geer

9

Internet Usage and Security

- Anyone can connect
  (=> ANYONE can connect)
- Millions of hosts run nearly identical software
  (=> single exploit can create epidemic)
- Most Internet users know about as much as Senator Stevens aka "the tubes guy"
  (=> God help us all…)

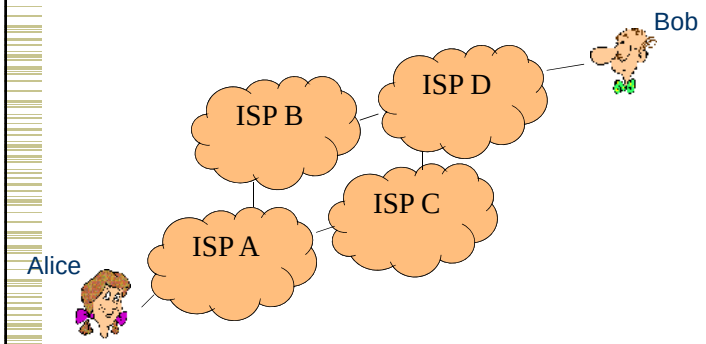
10

Our "Narrow" Focus

- Yes:
  - Creating a "secure channel" for communication (Part I)
    - End-to-end
  - Protecting network resources and limiting connectivity (Part II)
    - Accountability for resources (largely not end-to-end)
- No:
  - Preventing software vulnerabilities & malware, or "social engineering".

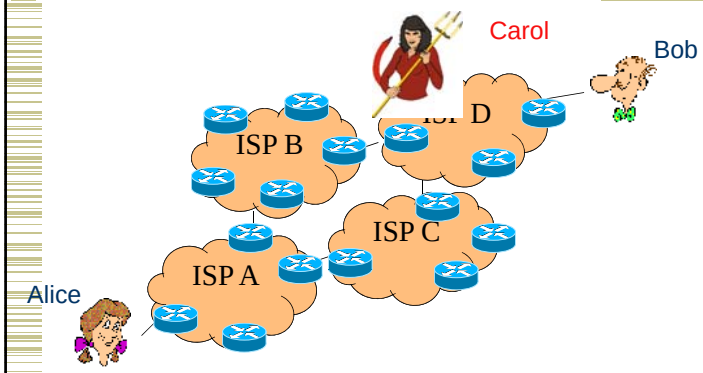
11

Secure Communication with an Untrusted Infrastructure



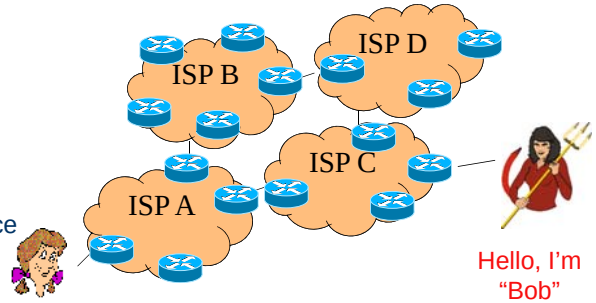
12

Secure Communication with an Untrusted Infrastructure



13

Secure Communication with an Untrusted Infrastructure



14

What do we need for a Secure Communication Channel?

- Authentication (Who am I talking to?)
- Confidentiality (Is my data hidden?)
- Integrity (Has my data been modified?)
- Availability (Can I reach the destination?)

15

What is cryptography?

"cryptography is about communication in the presence of adversaries."

- Ron Rivest

"cryptography is using math and other crazy tricks to approximate magic"

- Unknown 441 TA

16

What is cryptography?

Tools to help us build secure communication channels that provide:

1) Authentication
2) Integrity
3) Confidentiality

17

Cryptography As a Tool

- Using cryptography securely is not simple
- Designing cryptographic schemes correctly is near impossible.

Today we want to give you an idea of what can be done with cryptography.

Take a security course if you think you may use it in the future

18

The Great Divide

	Symmetric Crypto (Private key) (E.g., AES)	Asymmetric Crypto (Public key) (E.g., RSA)
Shared secret between parties?	Yes	No
Speed of crypto operations	Fast	Slow

19

Symmetric Key Cryptography: Confidentiality

Motivating Example:

You and a friend share a key K of L random bits, and want to secretly share message M also L bits long.

Scheme:

You send her the *xor(M,K)* and then she "decrypts" using *xor(M,K)* again.

1) Do you get the right message to your friend?
2) Can an adversary recover the message M?
3) Can adversary recover the key K?

20

Symmetric Key: Example

- One-time Pad (OTP) is proven "information-theoretically secure" (Claude Shannon, 1949)
  - No information provided about the message other than its length
- Impressive?
- Assumptions:
  - Perfectly random one-time pads
  - One-time pad at least the length of the message
  - Never can reuse a one-time pad
  - Adversary can never know the one-time pad

21

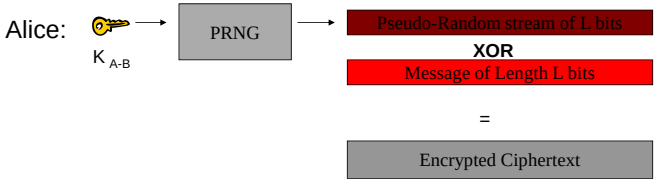
Symmetric Key: Reality

- All ciphers suffer from assumptions, but one-time pad's are impractical to maintain
  - Key is as long at the message
  - Keys cannot be reused
- In practice, two types of ciphers are used that require constant length keys:
  - **Stream Ciphers**
    Ex: RC4, A5
  - **Block Ciphers**
    Ex: DES, AES, Blowfish

22

Symmetric Key: Stream Ciphers

- Example: RC4

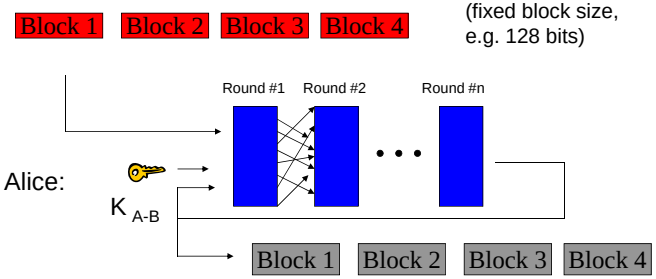


Bob uses K_{A-B} as PRNG seed, and XORs encrypted text to get the message back (just like OTP).

23

Symmetric Key: Block Ciphers

- Example: AES

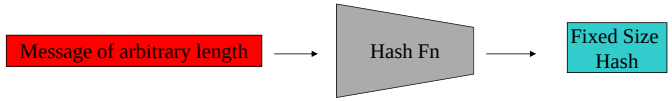


Bob breaks the ciphertext into blocks, feeds it through decryption engine using K_{A-B} to recover the message.

24

Cryptographic Hash Functions

- Consistent
  - hash(X) always yields same result
- One-way
  - given Y, can't find X s.t. hash(X) = Y
- Collision resistant
  - given hash(W) = Z, can't find X such that hash(X) = Z



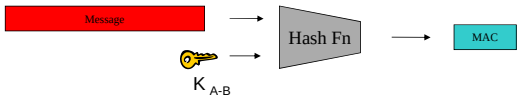
25

Symmetric Key: Integrity

- Hash Message Authentication Code (HMAC)

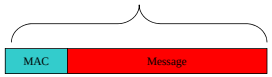
Step #1:

Alice creates MAC



Step #2

Alice Transmits Message & MAC



Step #3

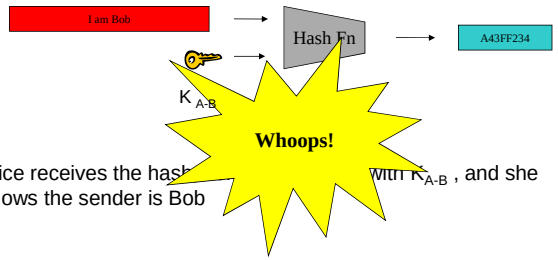
Bob computes MAC with message and K_{A-B} to verify.

Why is this secure?
How do properties of a hash function help us?

26

Symmetric Key: Authentication

- You already know how to do this!
  (hint: think about how we showed integrity)

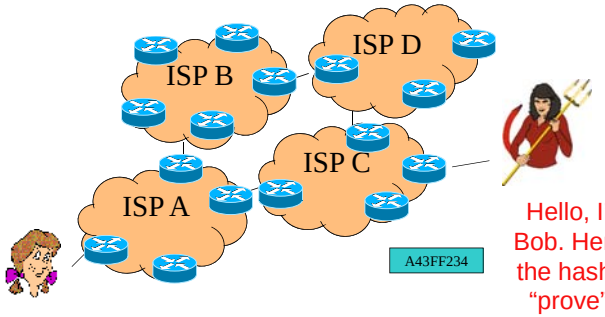


Alice receives the hash with K_{A-B}, and she knows the sender is Bob

27

Symmetric Key: Authentication

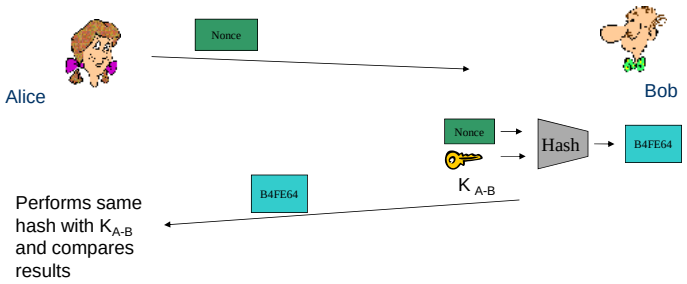
What if Mallory overhears the hash sent by Bob, and then "replays" it later?



28

Symmetric Key: Authentication

- A "Nonce"
  - A random bitstring used only once. Alice sends nonce to Bob as a "challenge". Bob Replies with "fresh" MAC result.



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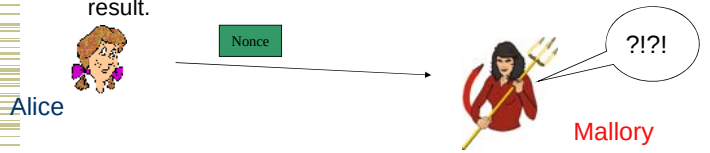


If Alice sends Mallory a nonce, she cannot compute the corresponding MAC without K_{A-B}

Symmetric Key Crypto Review

- Confidentiality: Stream & Block Ciphers
- Integrity: HMAC
- Authentication: HMAC and Nonce

Questions??

Are we done? Not Really:

1) Number of keys scales as $O(n^2)$

2) How to securely share keys in the first place?

Asymmetric Key Crypto:

- Instead of shared keys, each person has a "key pair"

K_B Bob's public key

K_B^{-1} Bob's private key

- The keys are inverses, so: $K_B^{-1}(K_B(m)) = m$

Asymmetric Key Crypto:

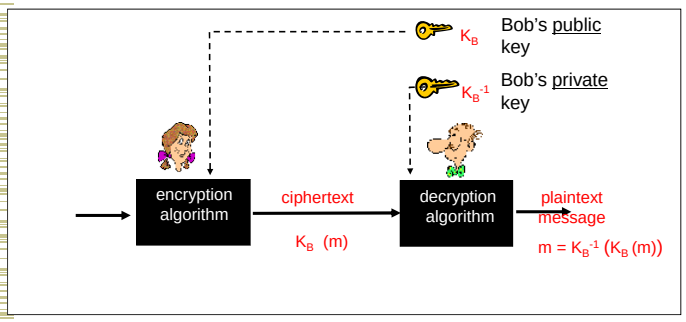
- It is believed to be computationally unfeasible to derive K_B^{-1} from K_B or to find any way to get M from $K_B(M)$ other than using K_B^{-1} .

=> K_B can safely be made public.

Note: We will not explain the computation that $K_B(m)$ entails, but rather treat these functions as black boxes with the desired properties.

33

Asymmetric Key: Confidentiality



34

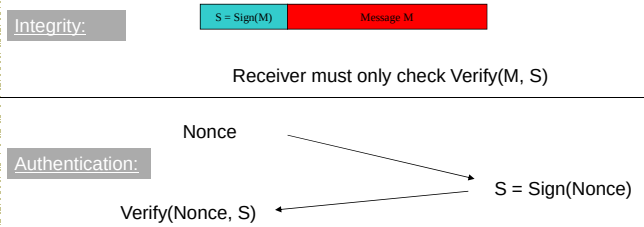
Asymmetric Key: Sign & Verify

- If we are given a message M, and a value S such that $K_B(S) = M$, what can we conclude?
- The message must be from Bob, because it must be the case that $S = K_B^{-1}(M)$, and only Bob has K_B^{-1} !
- This gives us two primitives:
  - $Sign(M) = K_B^{-1}(M)$ = Signature S
  - Verify(S, M) = test($K_B(S) == M$)

35

Asymmetric Key: Integrity & Authentication

- We can use Sign() and Verify() in a similar manner as our HMAC in symmetric schemes.



36

Asymmetric Key Review:

- Confidentiality: Encrypt with Public Key of Receiver
- Integrity: Sign message with private key of the sender
- Authentication: Entity being authenticated signs a nonce with private key, signature is then verified with the public key

But, these operations are computationally expensive*

One last "little detail"…

How do I get these keys in the first place??
Remember:

- Symmetric key primitives assumed Alice and Bob had already shared a key.
- Asymmetric key primitives assumed Alice knew Bob's public key.

This may work with friends, but when was the last time you saw Amazon.com walking down the street?

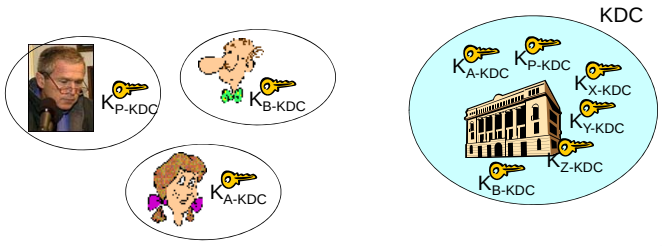
Symmetric Key Distribution

- How does Andrew do this?

Andrew Uses Kerberos, which relies on a Key Distribution Center (KDC) to establish shared symmetric keys.

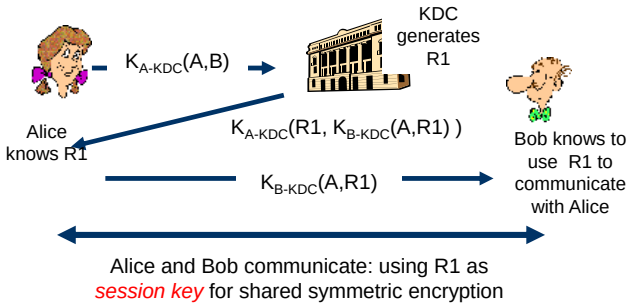
Key Distribution Center (KDC)

- Alice, Bob need shared symmetric key.
- KDC: server shares different secret key with *each* registered user (many users)
- Alice, Bob know own symmetric keys, $K_{A\text{-}KDC}$ $K_{B\text{-}KDC}$, for communicating with KDC.



Key Distribution Center (KDC)

Q: How does KDC allow Bob, Alice to determine shared symmetric secret key to communicate with each other?



41

How Useful is a KDC?

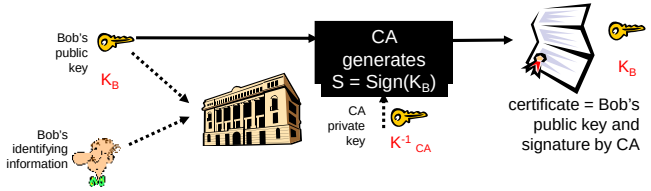
- Must always be online to support secure communication
- KDC can expose our session keys to others!
- Centralized trust and point of failure.

In practice, the KDC model is mostly used within single organizations (e.g. Kerberos) but not more widely.

42

Certification Authorities

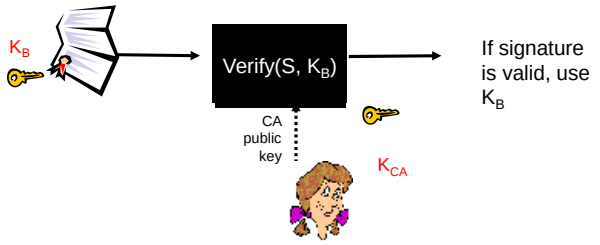
- Certification authority (CA): binds public key to particular entity, E.
- An entity E registers its public key with CA.
  - E provides "proof of identity" to CA.
  - CA creates certificate binding E to its public key.
  - Certificate contains E's public key AND the CA's signature of E's public key.



43

Certification Authorities

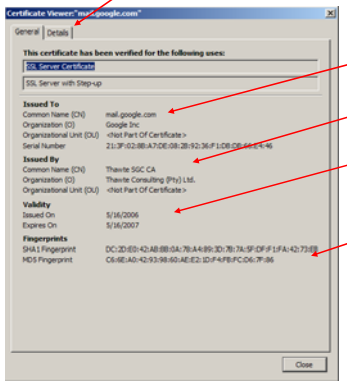
- When Alice wants Bob's public key:
  - Gets Bob's certificate (Bob or elsewhere).
  - Use CA's public key to verify the signature within Bob's certificate, then accepts public key



44

Certificate Contents

- info algorithm and key value itself (not shown)

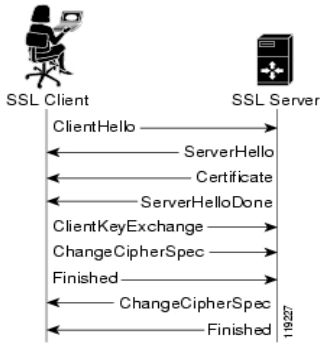


- Cert owner
- Cert issuer
- Valid dates
- Fingerprint of signature

Transport Layer Security (TLS) aka Secure Socket Layer (SSL)

- Used for protocols like HTTPS
- Special TLS socket layer between application and TCP (small changes to application).
- Handles confidentiality, integrity, and authentication.
- Uses “hybrid” cryptography.

Setup Channel with TLS “Handshake”



Handshake Steps:

1) Client and server negotiate exact cryptographic protocols
2) Client validates public key certificate with CA public key.
3) Client encrypts secret random value with server’s key, and sends it as a challenge.
4) Server decrypts, proving it has the corresponding private key.
5) This value is used to derive symmetric session keys for encryption & MACs.

Summary – Part I

- Internet design and growth => security challenges
- Symmetric (pre-shared key, fast) and asymmetric (key pairs, slow) primitives provide:
  - Confidentiality
  - Integrity
  - Authentication
- “Hybrid Encryption” leverages strengths of both.
- Great complexity exists in securely acquiring keys.
- Crypto is hard to get right, so use tools from others, don’t design your own (e.g. TLS).

Resources

- Textbook: 8.1 – 8.3
- Wikipedia for overview of Symmetric/Asymmetric primitives and Hash functions.
- OpenSSL (www.openssl.org): top-rate open source code for SSL and primitive functions.
- “Handbook of Applied Cryptography” available free online: www.cacr.math.uwaterloo.ca/hac/

49