Warnings….

- Format Warning:
  - Today's slides are borrowed from CSE473 ed to this class's without bei google slid
- Coverage Warning
  - Included are some det e have not covered the background material for so we will gloss over some areas.

CSE 523S: Systems Security

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Co

Systems

Spring 2018

Jon Shidal

(slides borrowed from CSE473)

Plan for Today

- Questions
- Assignment
- System Desi
  - erable? [x] Why are o
  - [x] Working with binaries an s
  - [x] Why are our networks v
  - Working with packets -- Next class
  - Network security revisited

Assignment

- For Monday
  - HW2 Due
  - Readings
    - HTAOE: Ch. 4 195-223

- For Wednesday
  - Readings

    - HTAOE: Ch. 3 115-132

- For Monday (2/19)
  - The following sections of [Metasploit Unleashed]
    - Introduction, Metasploit Fundamentals, Information Gathering, Vulnerability Scanning, Exploit Development

Principles of Network Security/ Internet Attacks and Defenses

- Basic principles
- Symmetric encry
- Public-key encry
- Signatures, authentication, mes ity
- Denial-of-Service & Distributed ervice

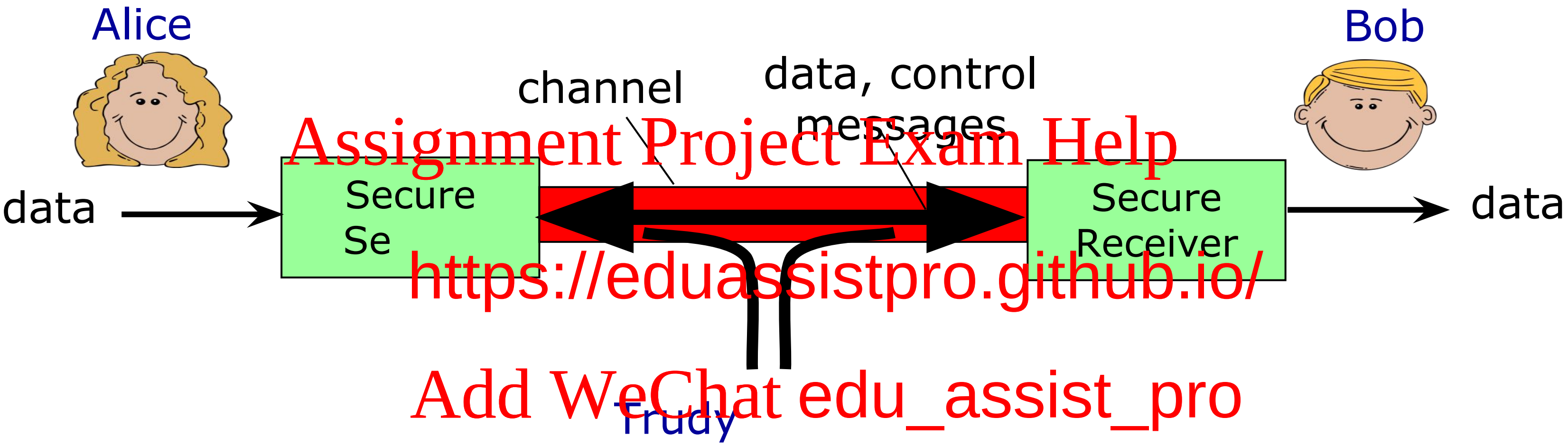
John DeHart

Based on material from Jon Turner, Roch Guerin and Kurose & Ross

Four Elements of Network Security

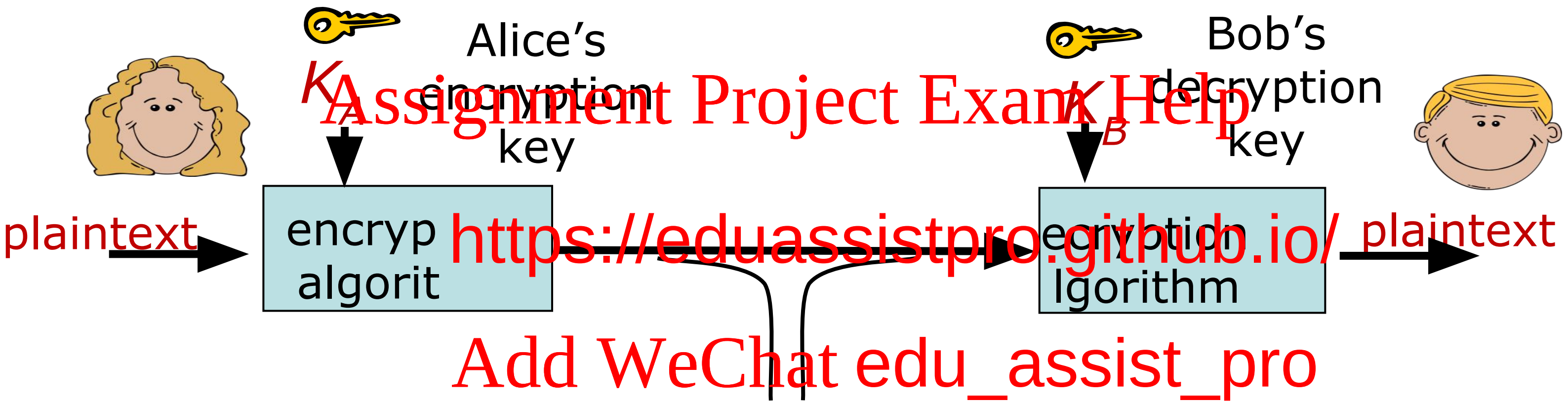
- ***Confidentiality***
  - » only sender, intended receiver should "understand" message
  - » sender encrypts m
- *Authentication*
  - » sender, receiver want to confirm id … other
  - » Use of "certification of authenticity" … sted entity
- *Message integrity*
  - » sender, receiver want to ensure message not altered (in transit, or afterwards) without detection
- *Access and availability*
  - » services must be accessible and available to users

A Traditional Model of Security



- Alice & Bob want to communicate “securely”
- Trudy (intruder) may intercept, delete, add, and modify messages

The Language of Cryptography



m plaintext message

$K_A(m)$ ciphertext, encrypted with key K_A

$m = K_B(K_A(m))$

Note that K_A and K_B need not be identical

i.e., symmetric vs. asymmetric encryption

Simple Encryption Scheme

- *Substitution cipher*
  - » substituting one thing for another
  - » Mono-alphabetic cipher: substitute one letter for another

plaintext: `abcdefghijklmnopqrstuvwxyz`

ciphertext: `mnbvcxzasdfghjklpoiuytrewq`

plaintext: `bob. i love you. alice`

ciphertext: `nkn. s gktc wky. mgsbc`

Encryption key: mapping from set of 26 letters to set of 26 letters (26! Possible mappings to choose from)

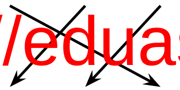
Breaking an Encryption Scheme

- Cipher-text only attack
  - » Trudy just has ciphertext she can analyze
  - » two approaches:
    - brute force: search through all keys
    - statistical analysis most common letter
- Known-plaintext a
  - » Trudy has at least some plaintext c to ciphertext
  - » *e.g.*, in mono-alphabetic cipher, Tru s pairings for a,l,i,c,e,b,o,
- Chosen-plaintext attack
  - » Trudy can get ciphertext for chosen plaintext
- Ideally, an encryption scheme should be resistant to even a chosen-plaintext attack

Block Cipher Encryption – (1)

- *Transposition block cipher*
  - Changing the order of the input
  - a.k.a. a scrambler

3-bit



3-bit transposed

input: 011 110 001 01

ciphertext: 110 101 010 100 000

Encryption key: permutation of *k*-bit blocks ($k!=6$ distinct permutations for $k=3$, *i.e.*, key of size $\lceil \log_2 k! \rceil$ or $\lceil \log_2 3! \rceil = 3$ bits)

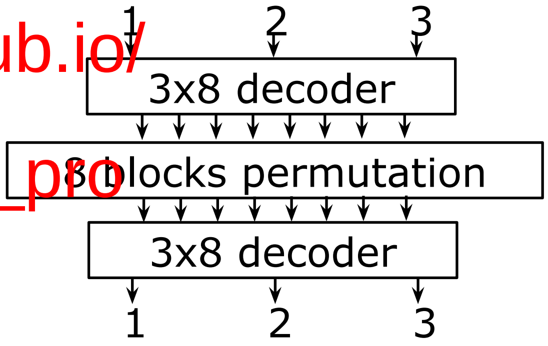
Why 3 bits? What do we use the 3 bits to identify?

Block Cipher Encryption – (2)

- *Substitution block cipher*
  - » Maps a *k*-bit block to another uniquely distinct *k*-bit block
  - » *k*-bit block input is one out of 2^k possible input
  - » Substitution applies permutation to all possible 2^k inputs

input: 011 110

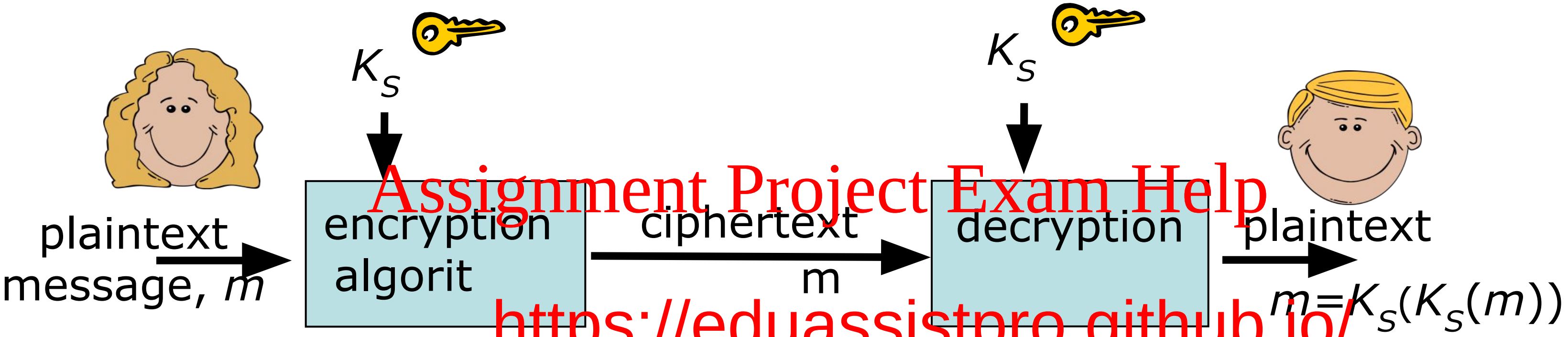
	01
	[illegible]
101	010
110	001
111	110



ciphertext: 111 001 011 100 101

Encryption key: permutation among 2^3=8 3-bit blocks (8!=40,320 distinct permutations, *i.e.*, key of size $\lceil \log_2 8! \rceil$ = 16 bits Why 16 bits? What do we use the 16 bits for?

Symmetric Key Cryptography



- Symmetric key crypt
  - Bob and Alice share same (symme
  - ***e.g.***, key might be knowing the su tern in mono alphabetic substitution cipher
- Main issue: how do Bob and Alice agree on key value?
  - need a separate, secure channel (to exchange key)
  - governments can use couriers, but that’s not a practical solution for individuals over the Internet

Block Ciphers

- DES (Data Encryption Standard) is an example of a *block cipher*
  - encrypts fixed length chunks separately (each chunk is a letter in an alphabet of size 2^k, where k is the chunk size in bits)
- Naive implementation can be vulnerable

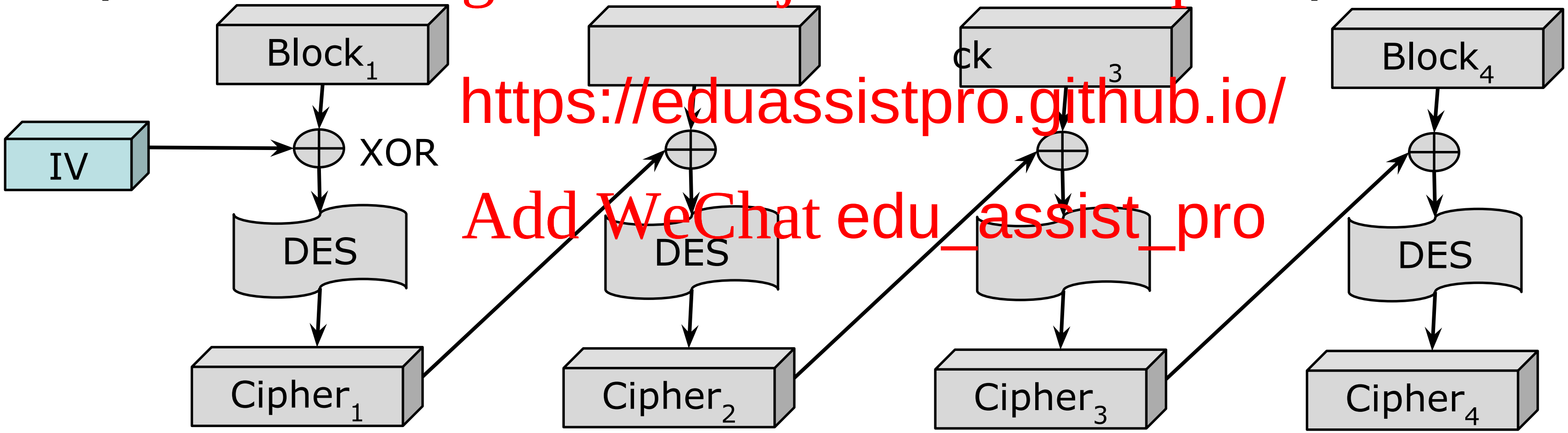
  - If each block is … ar-text blocks produce encry… repeated cipher-text

  - statistics of repeated blocks can aid atta…
- Cipher Block Chaining (CBC) used to a…

  - makes identical clear-text blocks look di… …ncrypted
  - example: each clear-text block m is xor-ed with a different "random" value before encryption
    - start with random *Initialization Vector* (IV) and xor this with first block before encrypting (IV sent to receiver, but need not be secret)
    - before encrypting each subsequent block, xor it with the ciphertext of the previous block

General Cipher Block Chaining

- Repeat across independent blocks
  (IV = Initial Vector – can be sent in the clear)



- Any other cipher block encryption can be used in lieu of DES

Data Encryption Standard (DES)

- Block cipher with cipher block chaining
  - 56-bit symmetric key, 64-bit plaintext input
- How secure is it?
  - DES Challenge: 56-bit-key-encrypted phrase decrypted (brute force) in less than a day in January 1999

  - no known good anal

  - Has been withdrawn
- More secure variant

  - 3DES: encrypt 3 times with 3 different
  - Advanced Encryption Standard (AES)
    - replaced DES in 2001
    - processes data in 128 bit blocks
    - 128, 192, or 256 bit keys
    - a computer that could break DES in one second (by brute force) would need 149 trillion years to break AES

DES Cipher

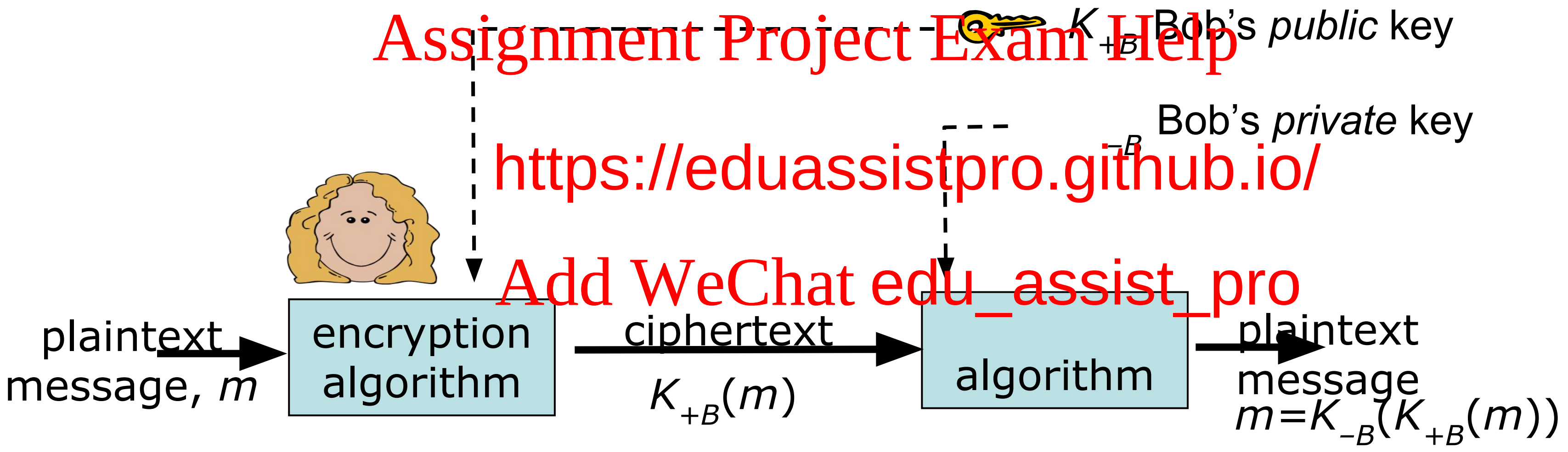
DES operation
(encryption by obfuscation)

- encrypt 64 bit chunks
- initial permutatio
- 16 identical "roun function application, each using different 48 bits of key = F(56 bit key)
- final permutation

Public Key Cryptography

- The problem with symmetric keys
  - They require sender & receiver to know a shared secret key
  - ok for governments perhaps, but no good for public internet
- Public key cryptography
  - radically different ap
  - built around idea of “ to compute, but computationally diffic
  - uses two keys
    - public key known to all (used to encr
    - private key known only to message recipient (used to decrypt)
  - since no common shared key, allows communication with strangers over insecure network
  - drawback: computationally expensive for large messages
    - in practice, used to encrypt and share symmetric keys

Public Key Cryptography



One-Way Functions

- Function that is easy to compute, hard to invert
  - example: easy to multiply two large prime numbers, but hard to find prime factors of a large composite number
    - no known method that is substantially better than trial-and error
    - a 300 digit numbe tors 150
- Key idea leading to prac
  - compute product of t public, while keeping prime factors private
  - product can be used to encrypt message pt it, you must know the prime factors
- RSA method based on this idea
  - named for its inventors **R**ivest, **S**hamir and **A**delman
- Alternate one-way functions have been proposed
  - based on variety of hard (NP-complete) computational problems

Background: Modulo Arithmetic

- $x \bmod n$ = remainder of x when divided by n
- Basic properties

  $[(a \bmod n) + (b \bmod n)] \bmod n = (a+b) \bmod n$

  $[(a \bmod n) - (b \bmod n)] \bmod n = (a-b) \bmod n$

  $[(a \bmod n) * (b$ mo

- Consequently,

$(a \bmod n)^d \bmod n = a^d$

$= [(a \bmod n)^l \bmod n]*[($ … $od\ n] \bmod n$

- Example: a=14, n=10, d=3:

  $(a \bmod n)^d \bmod n = (14 \bmod 10)^3 \bmod 10$

  $= 4^3 \bmod 10$

  $= 64 \bmod 10 = 4$

  $a^d = 14^3 = 2744 \quad a^d \bmod 10 = 4$

Creating an RSA Key Pair

1. Choose two large prime numbers p, q (say, 1024 bits long) and compute $n=pq$
2. Choose a number $e<(p-1)(q-1)$ with no common factor >1 with $(p-1)(q-1)$, *i.e.*, e and $(p-1)(q-1)$ are ***relatively prime***
3. Choose a number d such that $ed-1$ is a multiple of $(p-1)(q-1)$

equivalently, $d = (k$ itive integer k

4. Public key $K_+=(n,e)$, pri

close)

5. Advertise K_+ but keep K_- p and q (if p and q are known, e and d can be easily inferred)

Example with small numbers:

$$p=5,\ q=7,\ n=35,\ (p-1)(q-1)=24,\ e=5,\ d=29$$

$$(d = (6*4*6+1)/5 = 29 \quad \text{for} \quad k=6,\ p-1=4,\ q-1=6,\ e=5\ )$$

Dependent on having an efficient way to generate large prime numbers and efficient ways to select e and d

RSA Encryption/Decryption

Sending encrypted message <u>to</u> owner of $(K_+ \ K_-)$

- Given (n,e), (n,d) as discussed, and message ***<u>m<n</u>***
  - » m MUST be less than n
- Encrypt by computing $K_+(m) = c = m^e \bmod n$
- Decrypt by computing K d to know d to successfully decrypt a message)
- This works because

$$c^d \bmod n = (m^e \bmod n)^d \bmod n$$
$$= m^{ed} \bmod n$$
$$= m^{ed \bmod (p-1)(q-1)} \bmod n \ *$$
$$= m^1 \bmod n = m \ **$$

* by the magic of number theory (details on next slide)
** since $ed \bmod (p\text{-}1)(q\text{-}1) = 1$ by construction of d and $m<n$

From **number theory**, *p* & *q* prime with *n* = *pq* implies

$$a^b \bmod n = a^{b \bmod [(p-1)(q-1)]} \bmod n$$

So that

Since $ed=1 \bmod (p\text{-}1)(q\text{-}1)$
by construction of *d*

Simple RSA Example

1. Pick p=7, q=11 prime
   » $n = pq = 77$, $z = (p-1)(q-1) = 60$
2. Choose Encryption key $e<z$ such that e & z are relatively prime:
   » $e = 17$
3. pick Decryption key
   » $d = 53$ (53 x 17
4. Pub. Key: $(n,e)=(77,17)$; Priv. Key:)

- Assume message value of $m = 9$

  encode it as $c = 9^{17}$ [mod 77] = 4,

  decode this as 4^{53} [mod 77] = 9

Note: If too big, compute x^y mod v progressively,

i.e., $(x \bmod v)^y \bmod v$

Washington University in St.Louis

Engineering

Simple RSA Example

encode it as $c = 9^{17}$ [mod 77] = 4,

decode this as 4^{53} [mod 77] = 9

Note: If too big, compute x^y mod v progressively,

i.e., (x mod v)^y mod v

$c = 9^{17}$ [mod 77] = ((9^2

= ((81

= ((4 mod 77)^8 * 9) mod

= ((256 mod 77) * (256 m od 77

= (25 * 25 * 9) mod 77

= ((125 mod 77) * (5 * 9 mod 77)) mod 77

= (48 * 5 * 9) mod 77

= ((240 mod 77) * (9 mod 77)) mod 77

= (9 * 9) mod 77

= 4

Simple RSA Example

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i.e., (x mod

$c = 9^{17}$ [mod 77] = ((9^2

= ((81 mod 77)^8 * 9) m

= ((4 mod 77)^8 * 9) mo

= ((4^6 mod 77) * (4^2 * 9 mod 77)) mod 77

= ((4096 mod 77) * (16 * 9 mod 77)) mod 77

= (15 * 16 * 9) mod 77

= (3 * 80 * 9) mod 77

= (3 * 3 * 9) mod 77

= 4

More About RSA Operation

- To break RSA, need to find *d*, given *e* and *n*
  - » this can be done if we know (p–1)(q–1), but that requires knowing p and q

  - » and that requires being able to factor n, which is hard
- Session keys

  - » large values exponentiation req
    - • because multiplication time grow of the number of bits

  - » in practice, use RSA to exchange "s for use with symmetric encryption method like AES
- Keys can also be "reversed" – useful for authentication (coming next…)
  - » Sign with K_- (private) and verify signature with K_+ (public)

$$K_-(K_+(m)) = m^{ed} \bmod n = m = m^{de} \bmod n = K_+(K_-(m))$$

Elements of Network Security

- *Confidentiality*
  - » only sender, intended receiver should "understand" message
  - » sender encrypts message, receiver decrypts

- ***Authentication***
  - » sender, receiver w … other

  - » Use of "certification of authenticity" … sted entity

- *Message integrity*
  - » sender, receiver want to ensure message not altered (in transit, or afterwards) without detection
- *Access and availability*
  - » services must be accessible and available to users

Digital Signatures

- **Authentication**
- Digital signatures allow user to "sign" a document in a way that can't be forged
  - » this ensures that u
- *A* can sign a mess *A*'s private key
  - » message can then be "decrypted" u ic key
  - » so long as no one but *A* has access key, the message must have come from *A*
- *A* can also encrypt message using *B*'s public key to provide privacy
  - » $K_{+B}(K_{-A}(m))=c \;\; => \;\; K_{+A}(K_{-B}(c))=m$
  - » Only B can decrypt it and B can confirm it came from A.

Certificate Authorities

- Public-key systems require a secure way of making public keys available
  - » can't simply start by exchanging public keys in the clear, as this allows a "man-in-the-middle" attack
    - intruder, sitting between *A* and *B*, can substitute its own public key, causing *A* to enc ...'s public key
    - intruder can the ... encrypt using *B*'s public key, so *B* can't

- Certificate Authority (CA) vouches for ... n between a user and their public key
  - » CA provides Bob with *signed certificate* of Bob's identity
    - CA encrypts Bob's identifier and public key using CA's private key
  - » so, Alice decrypts certificate using CA's public key
    - public keys for "reputable" CAs "built in" to browsers
  - » security depends on trustworthiness/reliability of CAs

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Verifying Message **Integrity**

- How do we prevent an intruder from tampering with messages?
  - » can encrypt and sign messages, but is this necessary?
- Use a *hash function h* to produce *message digest*
  - » sender computes *h* +*s*)=*MAC*)
    - *s* is a ***shared se*** *uthentication* ***C****ode*
  - » receiver computes received value
  - » requires hash function that is hard t
    - MD5, SHA-1, SHA-2, SHA-3 are co "cryptographic hash functions"
- Can also use this to reduce effort for digital signatures
  - » sender encrypts *h*(*m*) and sends pair (*m*, *K*_(*h*(*m*)))
  - » receiver computes *h*(*m*) and compares it to received value, after decrypting it using sender's public key

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Traffic Attacks & Defenses Overview

- **Access and Availability**
- Traffic attacks: The goal is to overwhelm the target's resources at either the network or host/application level
  - » Network attacks
    - DNS amplification attack: Requires access to open DNS server and use of spoofed addresses (that of the target)
    - Bandwidth flooding: If … rate lots of traffic without resorting to address spo
  - » Application attacks
    - TCP SYN attack: Seeks to exhaust server state re … g lots of fake connections
    - HTTP GET flood: Same concept but with HTTP
    - TCP "shrew" attacks: takes advantage of TCP's o … on later slide)
- Defenses: Aimed at detecting, redirecting, and preventing attacking packets from reaching their target (or the target's network)
  - » Address filtering: Primarily aimed at countering address spoofing
  - » Unicast Reverse Path Filtering (uRPF): Discards traffic arriving from incorrect or invalid interface (only works when routing is symmetric)
  - » Black holes and sink holes: Used to attract unwanted traffic (backscatter) or redirect traffic for attack target

First Some Definitions

- Bogon prefix
  - » route that should never appear in an internet routing table.
    - Private, reserved, unallocated, etc.
  - » Often used by atta
  - tains bogon list
  - » IANA (Internet Ass
  - » IPv4 bogon list is shrinking as addr sed up.
- Internet Background Noise (IBN)
  - » Packets addressed to addresses or ports where there is no network device to receive them.
- Backscatter
  - » IBN resulting from DDoS attack using spoofed addresses

Network Ingress Filtering

- Defeating Denial of Service Attacks which employ IP Source Address Spoofing – BCP 38 (RFC 2827)
  - » BCP: Internet **B**est **C**urrent **P**ractices
- Covers as well as invol valid addresses
  - » The latter can translate into a "dou *e.*, the spoofed source may now be filtered by the domain , or the response traffic may swamp the unwitting source, *e.g.*, as with a DNS amplification attack
- Filter traffic entering router from a known domain to ensure that source address is from that domain.

Black-Hole Router

- Helps identify attacks when they start, including on the network infrastructure itself

- Also called Networ
  t.
  - Targets the dark/u

- Advertise reachability to prefix in ress space

- Inferring DDoS attacks from bac asurements
  - Assumes that attackers use randomly selected spoofed addresses, with “responses” from victims sent back to those random source addresses
  - Extrapolates frequency, magnitude, and types of attacks from backscatter responses sent to address located in a “quiet” /8 network ($1/256^{th}$ of the Internet address space)

Sink Holes

- The network equivalent of a honey pot: One or more dedicated network/router that seeks to attract or divert attack traffic and support its analysis
  - » A double monitoring and defense role
  - » Advertise host route for server under attack
    - Diverts all attack t
  - » Advertise default rou
    - Pulls in all internal (and external) "ju ., to bogon address space
- Other uses
  - » Monitoring scanning of infrastructure addresses (pre-attack)
    - By advertising default route of routed for bogon IPs
  - » Monitoring activity on dark space (worms for locally infected clients)
  - » Capture backscatter, *i.e.*, responses (from attack victims) to bogon address space and addresses spoofed by attackers

DNS Attacks

- Redirecting traffic to an attacker by hijacking DNS replies
  - » Faking a response to a query requires only spoofing a source address and guessing an ID field value (DNS has no authentication)
  - » This together with TTL value of the reply to a high value will ensure tha eep the fake answer for a long time)
  - » The scope of cache poisoning can range from a single client to a slave primary server handling an entire zone (the attack then targets the zone transfer messages)
  - » DNSSEC (RFCs 4033, 4035) adds one-way authentication to DNS responses, *i.e.*, provides data integrity and origin authentication

easy to implement

ng the various DoS attack

DNS Attacks (continued)

- DNS Amplification Attack
  - » Attacker issues DNS request with source address spoofed to target machine

NY”.
    - Request asks fo

es that can be directed
  - » Amplification a f

to the host under attack, **and** the si eplies (creating fake DNS records that can be used durin significantly augment the size of the DNS replies)

- DNSSEC does not prevent DNS amplification attacks
  - » They only require spoofing the source address of DNS queries, but depend on access to open DNS servers

Application Layer attacks: Low-Rate TCP-Targeted Denial of Service Attacks

- Most servers now have mechanisms to defend against TCP SYN attacks, so attackers need to be a bit more creative
- Rather than blast traffic to swamp a server, take advantage of TCP's behavior to mount effective atta ow rate)
- Relies on sending prop of packets
  - » Packet bursts induce mu s for RTO
    - RTO: Retransmission TimeOut
  - » Another burst after another RTO can result in s experiencing repeated time-outs
- Effective even in the presence of flows with heterogeneous RTO and RTT values
  - » Select appropriate intermediate RTO value
  - » Can actually force the time-out synchronization of heterogeneous flows
- Neither router based schemes (RED-PD) nor end-host based schemes (RTO randomization) are able to successfully detect or diffuse the attacks

The End.