ĐẠI HỌC TÔN ĐỨC THẮNG
TON DUC THANG UNIVERSITY

Chapter 10.3
Public-Key Cryptography and Message Authentication

Book Reading: Computer Security Principles and Practice (3ed), 2015, p.669-692

Public-Key Cryptography and Message Authentication

- now look at technical detail concerning:
  - secure hash functions and HMAC
  - RSA & Diffie-Hellman Public-Key Algorithms

Simple Hash Functions

- a one-way or secure hash function used in message authentication, digital signatures
- all hash functions process input a block at a time in an iterative fashion
- one of simplest hash functions is the bit-by-bit exclusive-OR (XOR) of each block

$$C_i = b_{i1} \oplus b_{i2} \oplus \ldots \oplus b_{im}$$

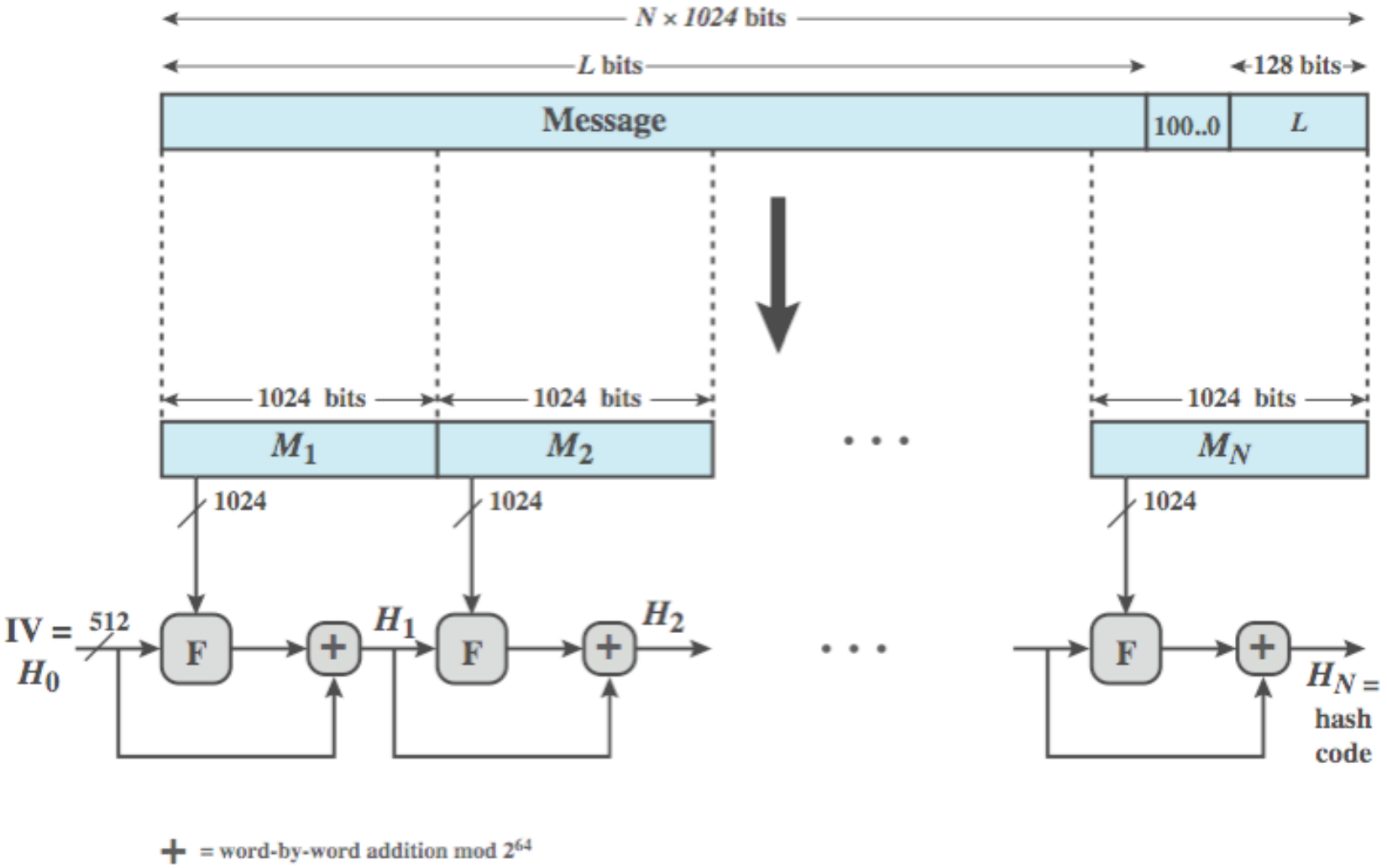
  - effective data integrity check on random data
  - less effective on more predictable data
  - virtually useless for data security

ĐẠI HỌC TÔN ĐỨC THẮNG
TON DUC THANG UNIVERSITY

SHA Secure Hash Functions

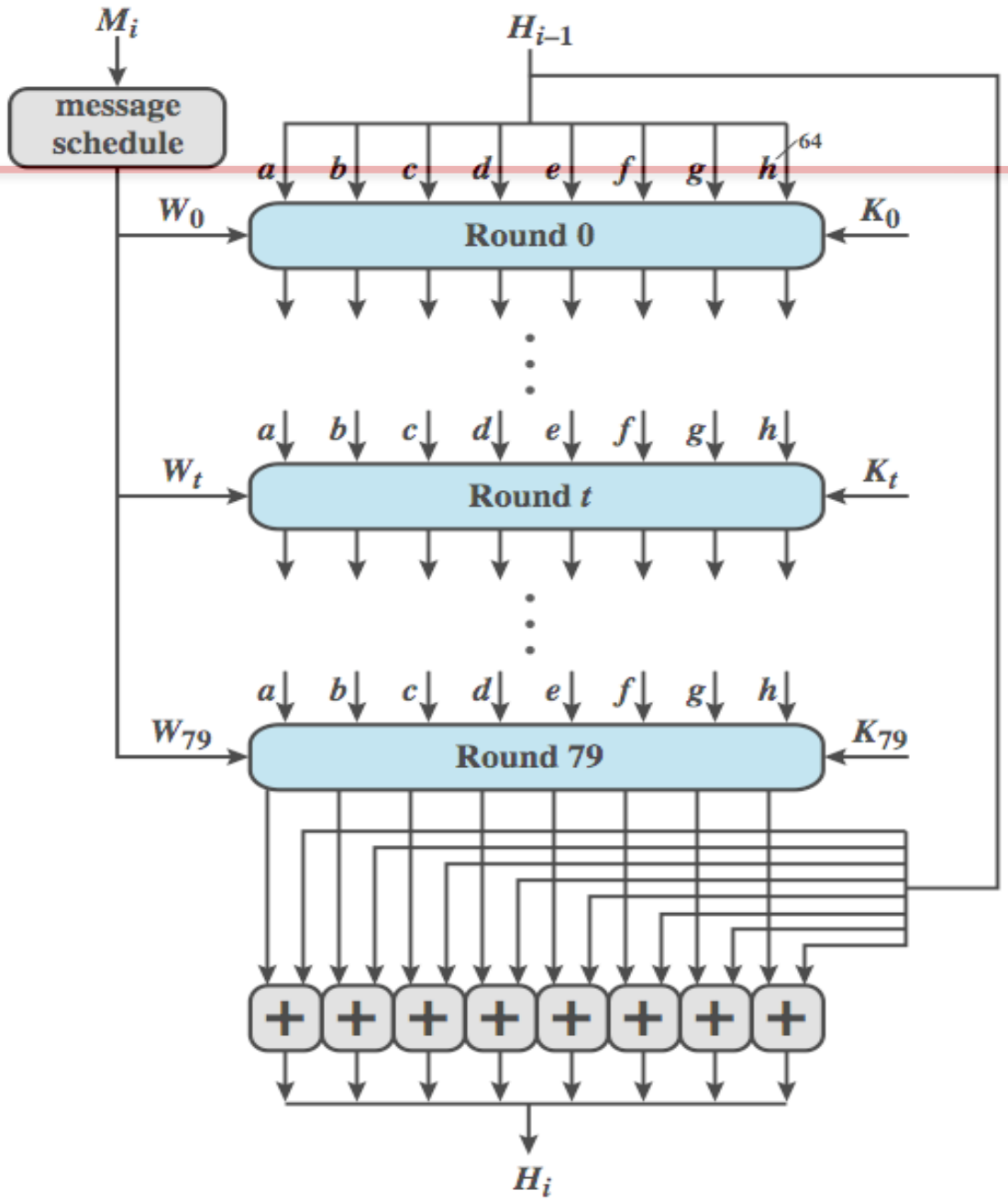
- SHA originally developed by NIST/NSA in 1993
- was revised in 1995 as SHA-1
  - US standard for use with DSA signature scheme
  - standard is FIPS 180-1 1995, also Internet RFC3174
  - produces 160-bit hash values
- NIST issued revised FIPS 180-2 in 2002
  - adds 3 additional versions of SHA
  - SHA-256, SHA-384, SHA-512
  - with 256/384/512-bit hash values
  - same basic structure as SHA-1 but greater security
- NIST intend to phase out SHA-1 use

SHA-512 Structure



ĐẠI HỌC TÔN ĐỨC THẮNG
TON DUC THANG UNIVERSITY

SHA-512 Round



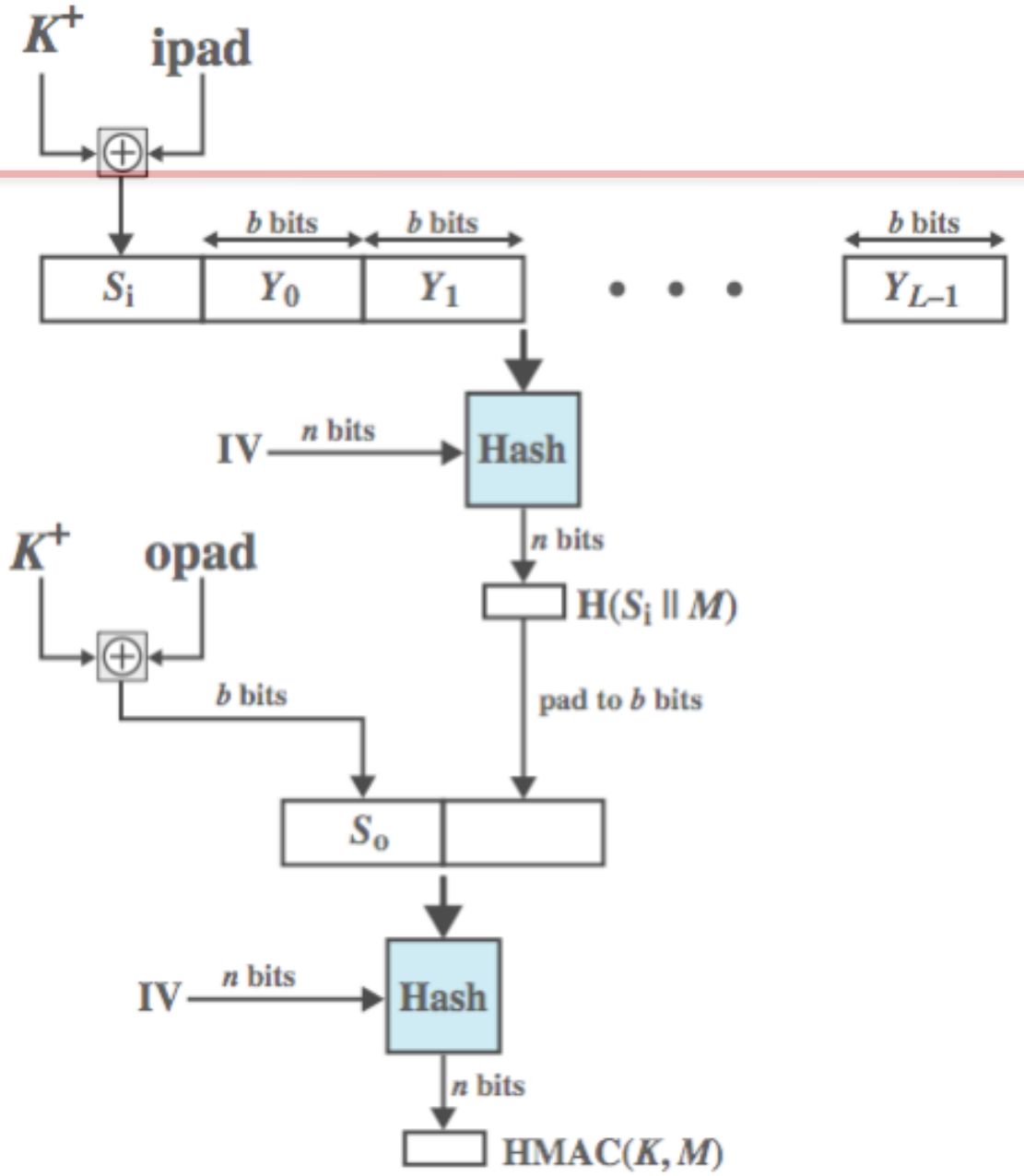
Other Secure Hash Functions

- most based on iterated hash function design
  - if compression function is collision resistant
  - so is resultant iterated hash function
- MD5 (RFC1321)
  - was a widely used hash developed by Ron Rivest
  - produces 128-bit hash, now too small
  - also have cryptanalytic concerns
- Whirlpool (NESSIE endorsed hash)
  - developed by Vincent Rijmen & Paulo Barreto
  - compression function is AES derived W block cipher
  - produces 512-bit hash

HMAC

- interest a MAC using a cryptographic hash
  - due to speed and code availability
- must incorporate key into use of hash alg
- HMAC (RFC2104) widely supported
  - used in IPsec, TLS & SET
- HMAC treats hash as “black box”
- HMAC proven secure if embedded hash function has reasonable cryptographic strength

HMAC Structure



Security of HMAC

- security based on underlying hash strength
- have prob given time and no msg-MAC's
- either attacker computes output even with random secret IV
  - brute force key $O(2^n)$, or use birthday attack
- or attacker finds collisions in hash function even when IV is random and secret
  - ie. find *M* and *M*' such that H(*M*) = H(*M*')
  - birthday attack $O(2^{n/2})$
  - MD5 secure in HMAC since only observe

ĐẠI HỌC TÔN ĐỨC THẮNG
TON DUC THANG UNIVERSITY

RSA Public-Key Encryption

- by Rivest, Shamir & Adleman of MIT in 1977
- best known & widely used public-key alg
- uses exponentiation of integers modulo a prime
- encrypt: $C = M^e \bmod n$
- *decrypt:* $M = C^d \bmod n = (M^e)^d \bmod n = M$
- both sender and receiver know values of *n* and *e*
- only receiver knows value of *d*
- public-key encryption algorithm with
  - public key $PU = \{e, n\}$ & private key $PR = \{d, n\}$.

ĐẠI HỌC TÔN ĐỨC THẮNG
TON DUC THANG UNIVERSITY

RSA Algorithm

Key Generation

Select p, q	p and q both prime, $p \neq q$
Calculate $n = p \times q$	
Calculate $\phi(n) = (p-1)(q-1)$	
Select integer e	$\gcd(\phi(n), e) = 1;\ 1 < e < \phi(n)$
Calculate d	$de \bmod \phi(n) = 1$
Public key	$KU = \{e, n\}$
Private key	$KR = \{d, n\}$

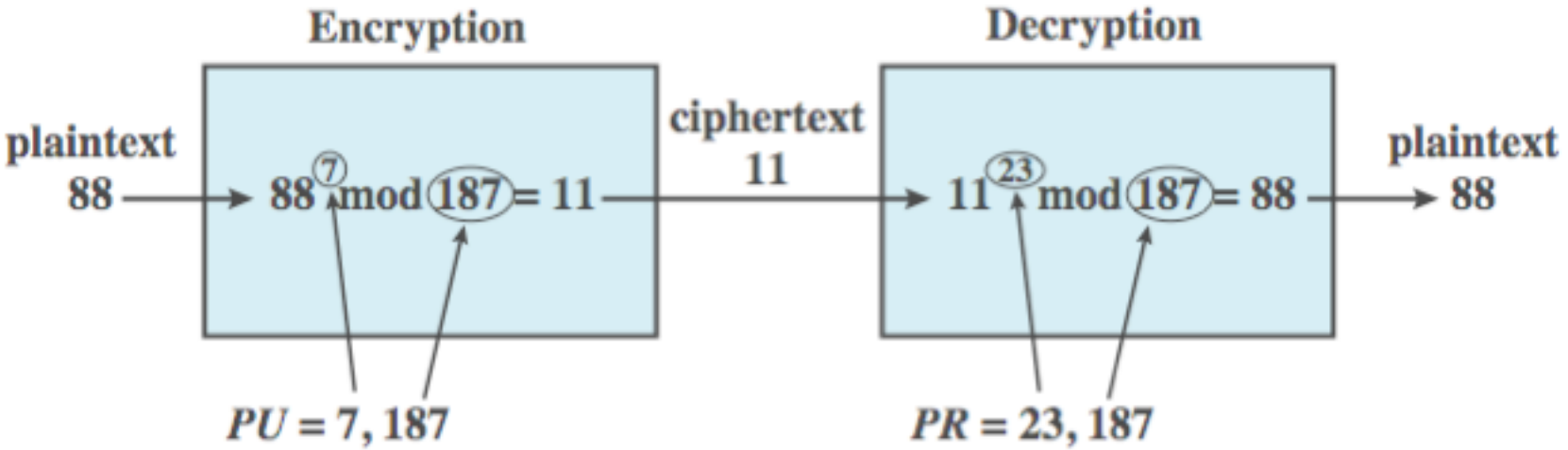
Encryption

Plaintext:	$M < n$
Ciphertext:	$C = M^e \pmod{n}$

Decryption

Ciphertext:	C
Plaintext:	$M = C^d \pmod{n}$

RSA Example


Encryption
Decryption
plaintext
88
88 7 mod 187 = 11
ciphertext
11
11 23 mod 187 = 88
plaintext
88
PU = 7, 187
PR = 23, 187

Attacks on RSA

- brute force
  - trying all possible private keys
  - use larger key, but then slower
- mathematical attacks (factoring n)
  - see improving algorithms (QS, GNFS, SNFS)
  - currently 1024-2048-bit keys seem secure
- timing attacks (on implementation)
  - use - constant time, random delays, blinding
- chosen ciphertext attacks (on RSA props)

ĐẠI HỌC TÔN ĐỨC THẮNG
TON DUC THANG UNIVERSITY

Diffie-Hellman Key Exchange

- first public-key type scheme proposed
- by Diffie & Hellman in 1976 along with the exposition of public key concepts
  - note: now know that Williamson (UK CESG) secretly proposed the concept in 1970
- practical method to exchange a secret key
- used in a number of commercial products
- security relies on difficulty of computing discrete logarithms

Diffie-Hellman Algorithm

Global Public Elements

q	prime number
α	$\alpha < q$ and α a primitive root of q

User A Key Generation

Select private X_A	$X_A < q$
Calculate public Y_A	$Y_A = \alpha^{X_A} \bmod q$

User B Key Generation

Select private X_B	$X_B < q$
Calculate public Y_B	$Y_B = \alpha^{X_B} \bmod q$

Generation of Secret Key by User A

$K = (Y_B)^{X_A} \bmod q$

Generation of Secret Key by User B

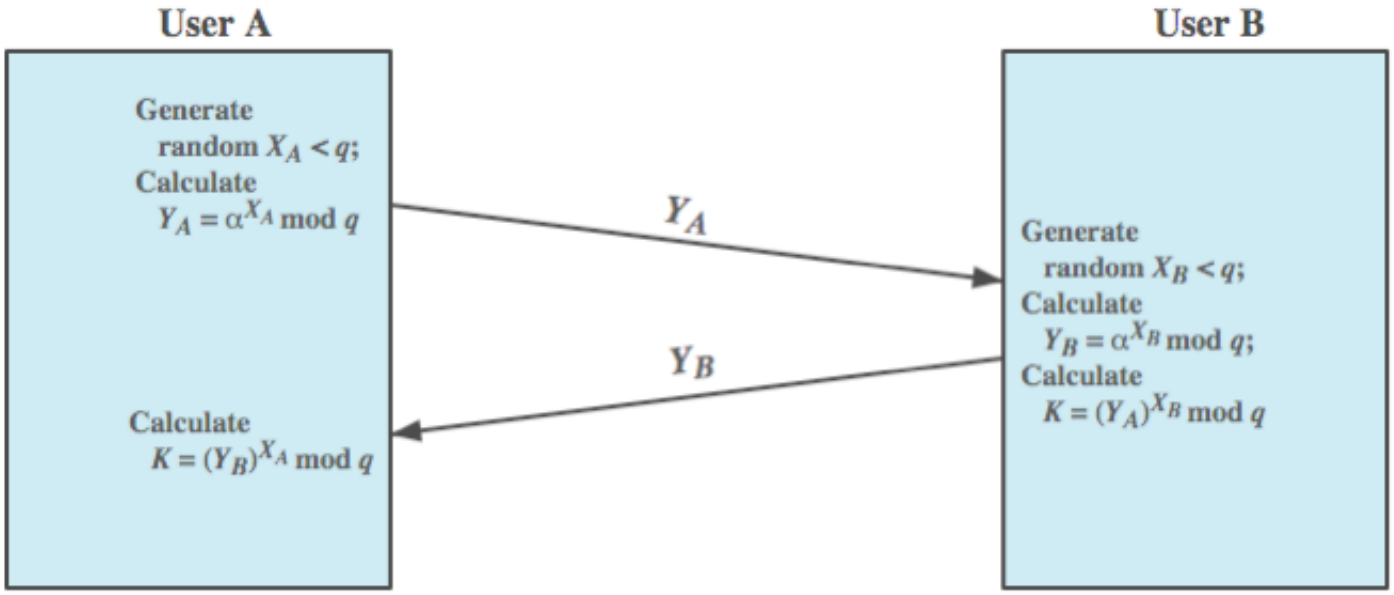
$K = (Y_A)^{X_B} \bmod q$

Diffie-Hellman Example

- have
  - prime number $q = 353$
  - primitive root ✔ = 3
- A and B each compute their public keys
  - A computes $Y_A = 3^{97} \bmod 353 = 40$
  - B computes $Y_B = 3^{233} \bmod 353 = 248$
- then exchange and compute secret key:
  - for A: $K = (Y_B)^{XA} \bmod 353 = 248^{97} \bmod 353 = 160$
  - *for B:* $K = (Y_A)^{XB} \bmod 353 = 40^{233} \bmod 353 = 160$
- attacker must solve:
  - $3^q \bmod 353 = 40$ which is hard
  - desired answer is 97, then compute key as B does

ĐẠI HỌC TÔN ĐỨC THẮNG
TON DUC THANG UNIVERSITY

Key Exchange Protocols



Man-in-the-Middle Attack

- attack is:
  1. Darth generates private keys X_{D1} & X_{D2}, and their public keys Y_{D1} & Y_{D2}
  2. Alice transmits Y_A to Bob
  3. Darth intercepts Y_A and transmits Y_{D1} to Bob. Darth also calculates K2
  4. Bob receives Y_{D1} and calculates K1
  5. Bob transmits X_A to Alice
  6. Darth intercepts X_A and transmits Y_{D2} to Alice. Darth calculates K1
  7. Alice receives Y_{D2} and calculates K2
- all subsequent communications compromised

ĐẠI HỌC TÔN ĐỨC THẮNG
TON DUC THANG UNIVERSITY

Other Public-Key Algorithms

- Digital Signature Standard (DSS)
  - FIPS PUB 186 from 1991, revised 1993 & 96
  - uses SHA-1 in a new digital signature alg
  - cannot be used for encryption
- elliptic curve cryptography (ECC)
  - equal security for smaller bit size than RSA
  - seen in standards such as IEEE P1363
  - still very new, but promising
  - based on a mathematical construct known as the elliptic curve (difficult to explain)

ĐẠI HỌC TÔN ĐỨC THẮNG
TON DUC THANG UNIVERSITY

Summary

- discussed technical detail concerning:
  - secure hash functions and HMAC
  - RSA & Diffie-Hellman Public-Key Algorithms