Introduction to Information Security

—— Digital Signature, One-Way Hash & MAC

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Outlines

- Digital Signature
- One-way hash function
- Message Authentication Code, MAC
- PGP

Concepts of Digital Signature

What dose Cryptography do and not do?

- Cryptography solved the issue:
  - The communication of A and B can't be seen by others！
- However, encryption/decryption can't prevent deception:
  - If Alice has sent Bob a message, the dispute between them may be:
    - Bob fabricates a different message and declares that he has received for Alice；
    - Alice can deny sending the message, and Bob can't prove Alice has sent the message.
- How do we solve this problem in daily life？
  - How can the court accept a contract？
  - Doing something which needs the approval of the supervisor or the organization, how can we prove that we have got the approval?
- The Signature

Characters and Requirements of Digital Signature

- Handwritten signature features?
  - The signature is credible. The recipient believes that the signer signed the document carefully
  - A signature can't be fabricated
  - A signature can't be reusable
  - A signed document can't be changed
  - A signature is an undeniable
  - In some cases, the signature and time are bound
  - A signature can be legal evidence and can be proved
- Similar: the seal, fingerprint

Characters and Requirements of Digital Signature

- Obviously, we can’t use a handwritten signature on digital documents. So, we need the digital signature.
- Requirements of a digital signature system:
  - Can be bound with the signed document
  - The recipient can verify the signature, and any other person can not forge a signature
  - Signer can not deny his signature
  - A third party should be able to check and confirm the signature for the settlement of disputes
  - Verify the author, date and time, content of the signature

The requirements of digital signatures

- Digital signatures must rely on the signed message
  - Relate to the contents to prevent modification.
- The digital signature must use the unique information of the sender to prevent fabrication and denial.
  - Only known by the sender, so it can't be faked, and the sender can't deny it.
- Digital signature generation, identification, and authentication must be relatively simple.
  - The signature must be able to be generated and verified in a short time.
- Fabricate a digital signature is not feasible in the calculation
  - It can't be faked.
- Keep a backup of digital signatures is feasible
  - Can be stored(e.g., can't be larger than the original documents)

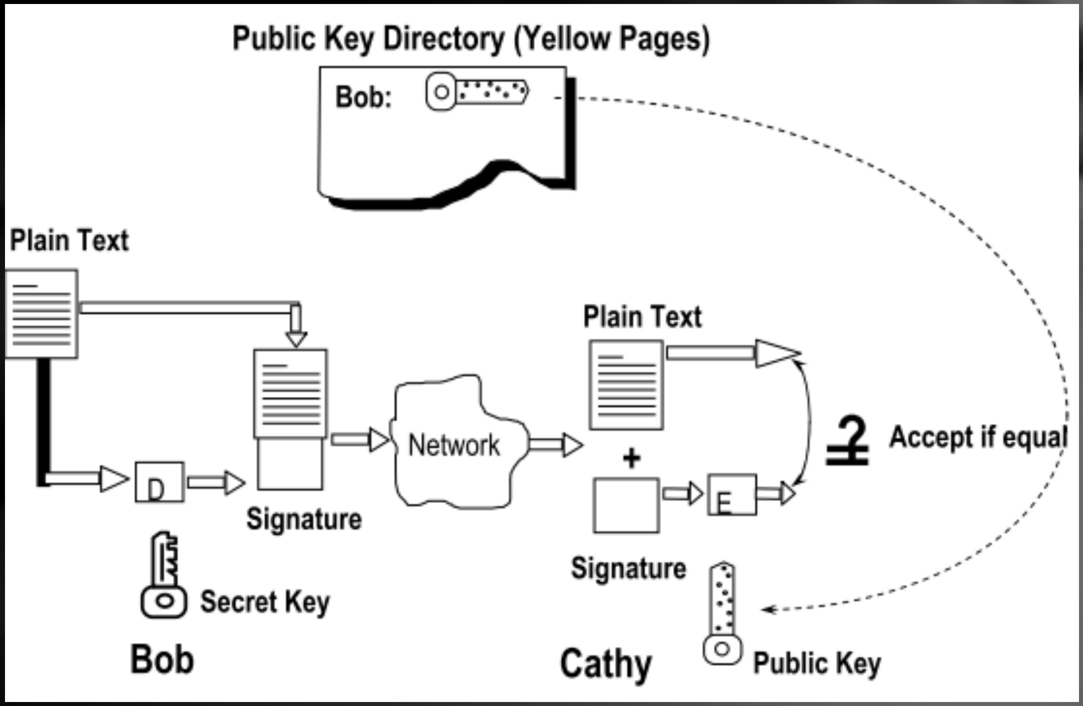
Digital Signature Algorithm

- **Public key cryptography supports the "Digital Signature" natively.**
- **DSS/DSA, Digital Signature Standard**
  - American National Standard, Digital Signature Standard (DSS), standardized in 1991
  - utilizing the difficulty of computing discrete logarithms
  - strongly promoted by the U.S. government
- **RSA**
  - RSA, widely supported by the industry, is the de facto industry standard
- **Elliptic curve**

Digital Signature Workflow

Attention:

- During encryption:
  - The sender encrypts using the receiver's public key
  - The receiver decrypts using his private key
- During signature
  - The sender signs using his private key
  - The receiver verifies the signature using the sender's public key



RSA signature example

- Key generation:
  - Bob:
    - Choose two prime numbers: $p = 5$, $q = 11$, $n=p*q=55$， $(p-1) * (q-1) = 40$
    - Find e=3 and d=27, so: $3 \times 27 \equiv 1 \pmod{40}$
  - Bob's key: public key: (3, 55)， private key: 27
- Bob is going to sign on a document where m = 19
  - He uses his private key d = 27 to calculate the digital signature of m = 19: $s = m^d \bmod n = 19^{27} \bmod 55 = 24$.
  - Attached 24 to the document, then : (m, s) = (19, 24), Representing that the document is 19 and Bob's signature is 24.
  - Bob sent this document to Alice
- Alice or a third party to verify the signature :
  - Receiving a plaintext and the signature (m, s) = (19, 24)
  - Check the public key directory to find Bob's public key(e, n) = (3, 55)
  - Computing : $t = s^e \bmod n = 24^3 \bmod 55 = 19$
  - Compare t and m whether they are equal; if equal, then (19, 24) must be the document signed by Bob.

Any problems?

- In the previous example, the document m must be an integer of [0 .. n-1]
  - If the document is very long, how to sign it?
- For a very long document, signing requires using the one-way hash algorithm.
  - We do not sign the document. Instead, we get the hash value of documents, and then we sign the hash value.

One-Way Hash Algorithm

Also called Cryptographic hash function

One-way hash algorithm

- A one-way hash algorithm hashes an input document to about 100-bit output
- Given a one-way hash algorithm H(.) we have:
  - Input: m —— Binary string of arbitrary length
  - Output: H(m) —— Binary string of size L
  - Given H(.), L is fixed:
    - In MD5, L=128
    - In SHA-1, L=160

One-way hash algorithm

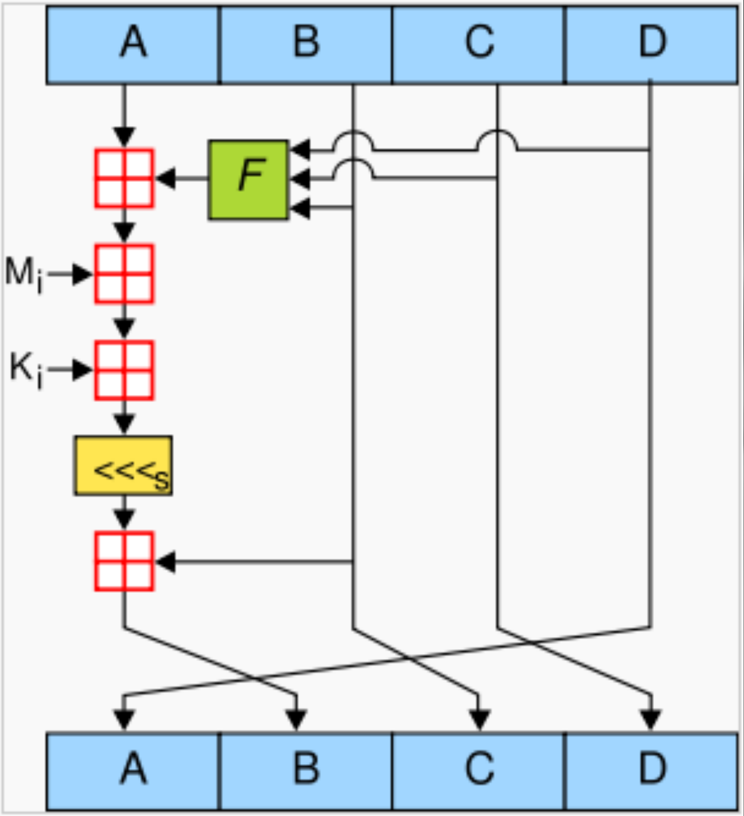
- A good one-way hash algorithm H (.) needs the following characteristics:
  - **Easy to compute**: Given any document m, H(m) can be calculated quickly;
  - **Difficult to reverse computing**
    - Namely, given any hash value h, find any document m, making H (m) = h is not feasible in computing.
  - Any algorithm meeting the above two requirements can be considered **"one-way"** ;
  - **Difficult to find a collision**
    - Finding any two documents, m1 and m2, to make H (m1) = H (m2) is computationally infeasible

Common one-way hash algorithm

- MD4、MD5 (R. Rivest, 1992)
- SHS (secure hashing standard, USA, 1992， modified in 1995):
- SHS(SHA-0, SHA-1, SHA-2)
- HAVAL (Y. Zheng, 1992)
- RIPEMD (D. Hans, 1996)
- More info: http://en.wikipedia.org/wiki/Cryptographic_hash_function

MD5 Algorithm

Two steps: Padding and Hashing



Padding:

- MD5 handles segments of length 512 bits, so the input string should be padded to multiple-512-sized segments(16 32-bit little-endian integers).
  - Padding procedure :
    - Pad a bit '1'
    - Pad "0" until a multiple of 512 minus 64 bits
    - Pad the bit length of the original string to the last 64 bits

Hashing:

- MD5 handles a 128-bit string recursively; the initial value is the fixed constant, dividing the 128-bit string into four 32-bit-length integers(A, B, C, D)
- Using four different non-linear functions, F (downright) loops 16 times each.
  - : Addition (mod 2^{32})
  - 

: Shift left s bit
  - Mi: 32-bit substring in the 512-bit string
  - Ki: variant constant in each loop

$$F(X,Y,Z) = (X \wedge Y) \vee (\neg X \wedge Z)$$
$$G(X,Y,Z) = (X \wedge Z) \vee (Y \wedge \neg Z)$$
$$H(X,Y,Z) = X \oplus Y \oplus Z$$
$$I(X,Y,Z) = Y \oplus (X \vee \neg Z)$$

$\oplus, \wedge, \vee, \neg$ denote the XOR, AND, OR and NOT operations respectively.

Security of One-way Hash Algorithms

- Security evaluation of one-way hash algorithm:
  - **Preimage attack: tries to find a message that has a specific hash value**
    - Preimage resistance: for essentially all pre-specified outputs, it is computationally infeasible to find any input that hashes to that output; i.e., given y, it is difficult to find an x such that $h(x) = y$.
    - Second-preimage resistance: it is computationally infeasible to find any second input with the same output as a specified input; i.e., given x, it is difficult to find a second preimage $x' \neq x$ such that $h(x) = h(x')$.
  - **Collision attack: tries to find two inputs producing the same hash value**
    - Find two different messages , m1 and m2 , such that hash(m1) = hash(m2).
    - More generally, chosen-prefix collision attack: Given two different prefixes, p1, and p2, find two appendages, m1, and m2, such that hash(p1 || m1) = hash(p2 || m2), where || denotes the concatenation operation.

Attack of One-Way Hash Algorithm

- https: //en.wikipedia.org/wiki/Hash_function_security_summary
- 王小云（2004/2005）find the collide algorithm of MD5, HAVAL-128, MD4, RIPEMD, SHA-1

Preimage resistance [edit]

Main article: Preimage attack

Hash function	Security claim	Best attack	Publish date
MD5	2^{128}	$2^{123.4}$	2009-04-27
SHA-1	2^{160}	45 of 80 rounds	2008-08-17
SHA256	2^{256}	43 of 64 rounds ($2^{254.9}$ time, 2^{6} memory)	2009-12-10
SHA512	2^{512}	46 of 80 rounds ($2^{511.5}$ time, 2^{6} memory)	2008-11-25
SHA-3	Up to 2^{512}		
BLAKE2s	2^{256}	2.5 of 10 rounds (2^{241})	2009-05-26
BLAKE2b	2^{256}	2.5 of 12 rounds (2^{481})	2009-05-26

Attack of One-Way Hash Algorithm

MD5 and SHA-1 were the most widely used one-way hash algorithms before 2009 and were used in many security-related computer products. The "cryptographic break" of them led to many severe security issues:

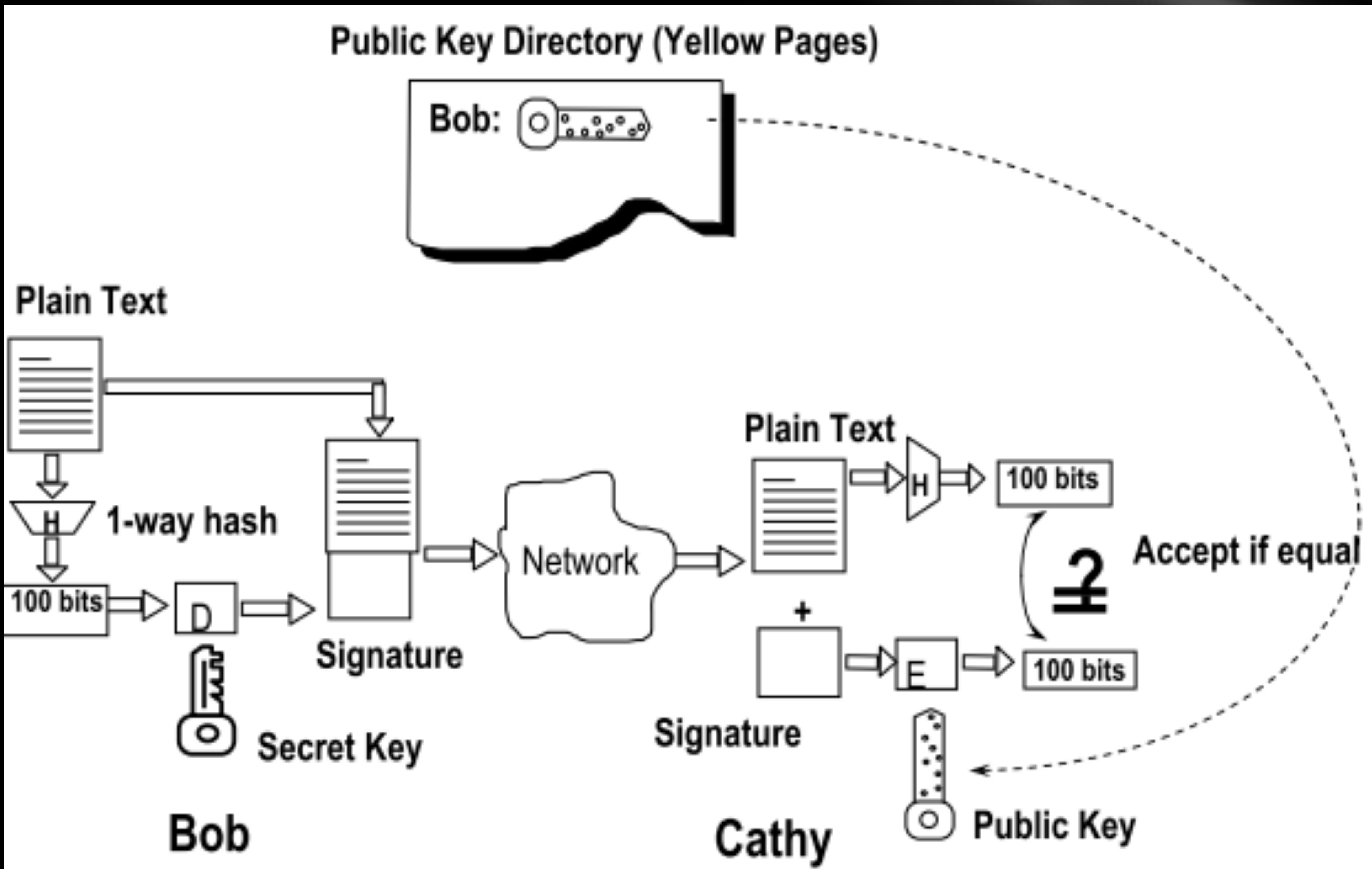
- In 2008, MD5 collision was used to attack SSL
  - http: //www.win.tue.nl/hashclash/rogue-ca/
  - Attackers aim at the security infrastructure, PKI and CA, of SSL and can forge SSL certificates.
  - Any services, including E-commerce, E-Bank, E-trading, and so on, using HTTPS/SSH protocol will be affected by the vulnerabilities.
- In 2009, US-CERT considered that MD5 "should be considered cryptographically broken and unsuitable for further use."
- The US government are mandated to use of SHA-2 from 2010

NIST hash function competition

http: //en.wikipedia.org/wiki/NIST_hash_function_competition

- Started @2007.11.2
- During 2008: 64 algorithms were submitted before 2008.10, and 51 of them were selected as the 1^{st} round candidates.
- During 2009: 14 algorithms were selected as the 2^{nd} round candidates, and those algorithm were publicly reviewed for one year
- During 2010: 5 algorithms were selected for the 3^{rd}, i.e., the last round in 2010.12
- On 2012.10.2, the Keccak algorithm was selected as the competition winner.
- On 2015.8.5, A version of this algorithm became a FIPS standard under the name SHA-3.

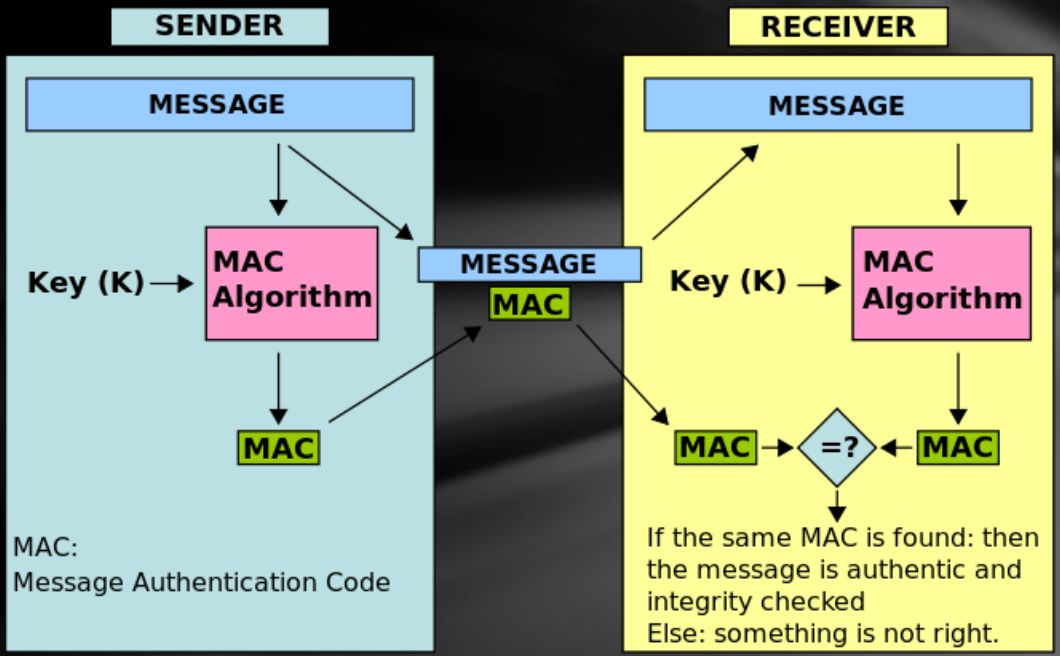
The procedure of signature for long plain text



MAC

Message Authentication Code

- MAC, Message authentication code, also called “keyed hash function.”
- Message Integrity Service
- Normal MAC algorithms:
  - HMAC
  - CBC-MAC
  - UMAC
  - CMAC
  - VMAC
  - Poly1305-AES
  - MMH-Badger MAC



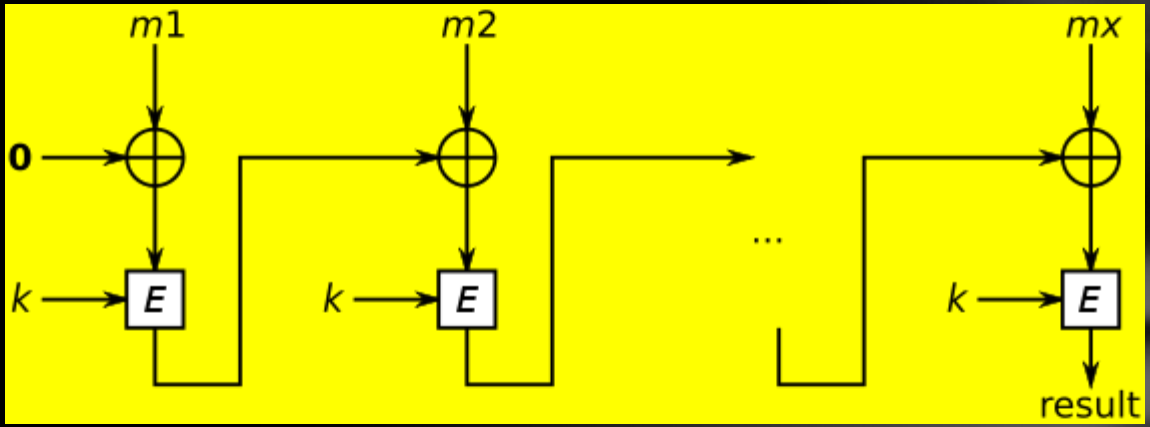
More info: [http: //en.wikipedia.org/wiki/Message_authentication_code](http://en.wikipedia.org/wiki/Message_authentication_code)

HMAC

- Hash-based message authentication code
- Definition（RFC 2014）：
  - H(): one-way hash function
  - K: Pad "0" until the key with the size of H() input block
  - m: message want to be authenticated
  - || : connect， $\oplus$: XOR
  - opad: outer padding (0x5c5c5c…5c5c, const in a block size)
  - ipad: inner padding (0x363636…3636, const in a block size)
  - So : HMAC (K, m) = H ((K $\oplus$ opad) || H ((K $\oplus$ ipad) || m)).
- Use different one-way hash functions to construct different HMAC algorithms:
  - HMAC-MD5
  - HMAC-SHA1
  - HMAC-SHA256
- HMAC is more difficult to occur a collision than a one-way hash function, so HMAC-MD5 and HMAC-SHA1 don't have security problems due to the vulnerability of MD5 and SHA1.
  - Until now, HMAC-MD5 and HMAC-SHA1 are safe enough and are the core components of IPSec and TLS.

CBC-MAC

- cipher block chaining message authentication code



- CBC-MAC computing:
  - Encryption algorithm E() uses key k to encrypt plaintext m;
  - Divide plaintext m into x parts (m_1, .., m_x); the length of every part equals the input size of E()
  - O_0 = 0x00000000....00
  - For i = 1..x:
    - $O_i = E_k(O_{i-1}$ XOR $m_i)$
  - O_x is the final authentication code MAC

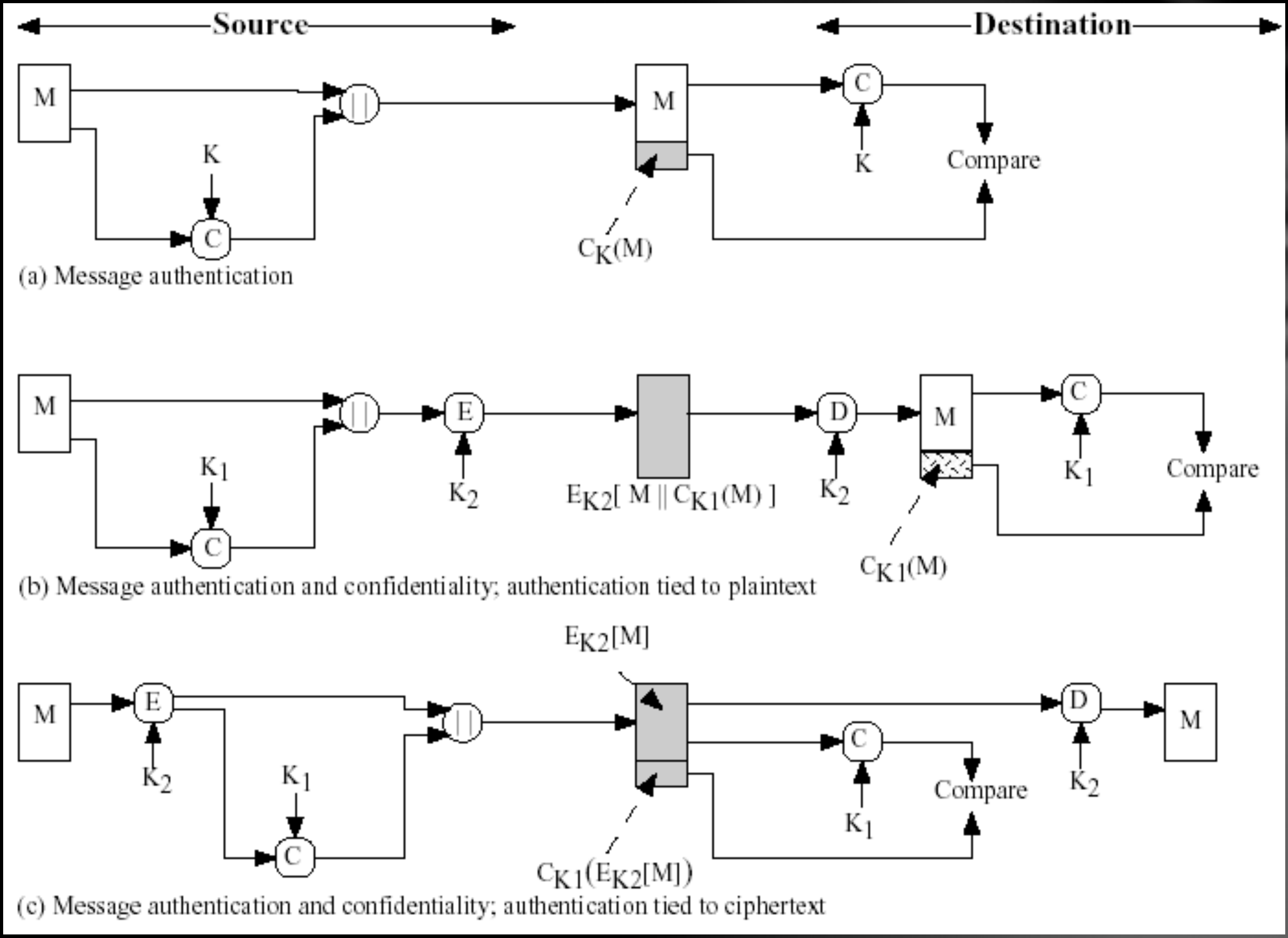
Difference of MAC & Digital Signature

- MAC: the sender and receiver need to share a “secret” key
  - MAC can only be verified by a special receiver.
  - MAC doesn’t provide the service of “Undeniable”: all the people who can verify the confidentiality of a message can also generate a MAC.

- Digital Signature: needn’t share any “secret” information
  - Digital Signature can be verified by all the receivers who have the sender’s public key;
  - Digital Signature provides the service of ” Undeniable.”

- Why not always DS? When do we use MAC?
  - MAC is much faster than DS
  - Undeniability is not always required.

Combination of MAC & Cryptography



Introduction of PGP

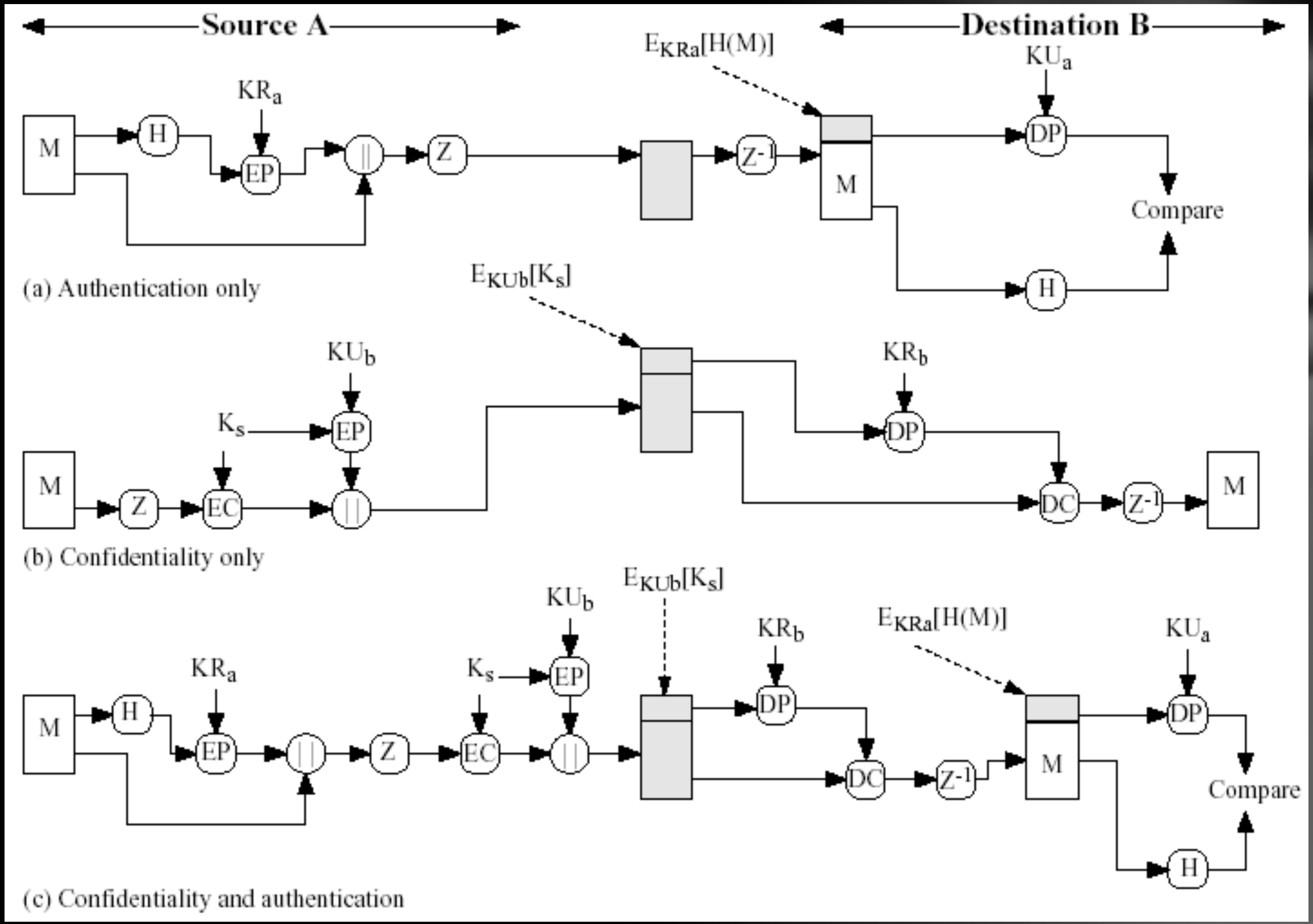
PGP —— Pretty Good Privacy

- Widely used in e-mail and file storage security applications, it provides the following services:
  - Digital signature; integrity verification; information encryption
  - Data compression; email format compatibility; data striping
- Support multiple platforms （DOS/Windows、Unix、Macintosh etc.）
  - It used to be free in early versions, but you need to pay for use now
  - The source code is free ...
- Based on proven security-related algorithms
  - RSA、DSS、Diffie-Hellman、CAST-128、IDEA、3DES、SHA－1、MD5
  - PGP integrates these algorithms and forms common applications independent of the OS and hardware.
- Father of PGP —— Phil Zimmermann
- Reference:
  - http: //www.philzimmermann.com/ZH/faq/index.html
  - http: //www.symantec.com/pgp
  - https: //www.gnupg.org

History of PGP

- In 1991, Phil Zimmermann wrote the first PGP encryption software, providing the commercial version, free non-commercial version, and containing all the source code.
- In February 1993, PGP encryption software was investigated by the U.S. government for violations of export control laws --At that time, the United States export control laws did not allow software with an encryption key of more than 40 bits to be exported -- PGP never used encryption whose key less than 128 bit.
- In 1995, "PGP Source Code and Internals," MIT Press
- In July 1997, Zimmermann and the company PGP Inc. Submitted the OpenPGP standard to the IETF. In December 1997, PGP Inc. was purchased by NAI（Network Associates, Inc.）, and NAI refused to continue opening the source code
- In February 2002, NAI stopped technical support for PGP products; NAI is now McAfee
- In August 2002, the early members of the PGP development team formed a new company, PGP Corporation, and the purchased intellectual property rights of PGP from NAI
- In April 2010, PGP Corporation was acquired by Symantec for a price of U.S. $ 370 million. PGP no longer provides separate software. Its functionality is integrated into Symantec's security software.

PGP Secure Mode



Reviews

- The concepts, characteristics and method of digital signatures
- Concepts of one-way hash algorithm
  - MD5 Algorithm
  - Attack of One-way hash algorithm
- Concepts of MAC
  - CBC-MAC
  - HMAC
- PGP