Hash Functions, Message Authentication Codes

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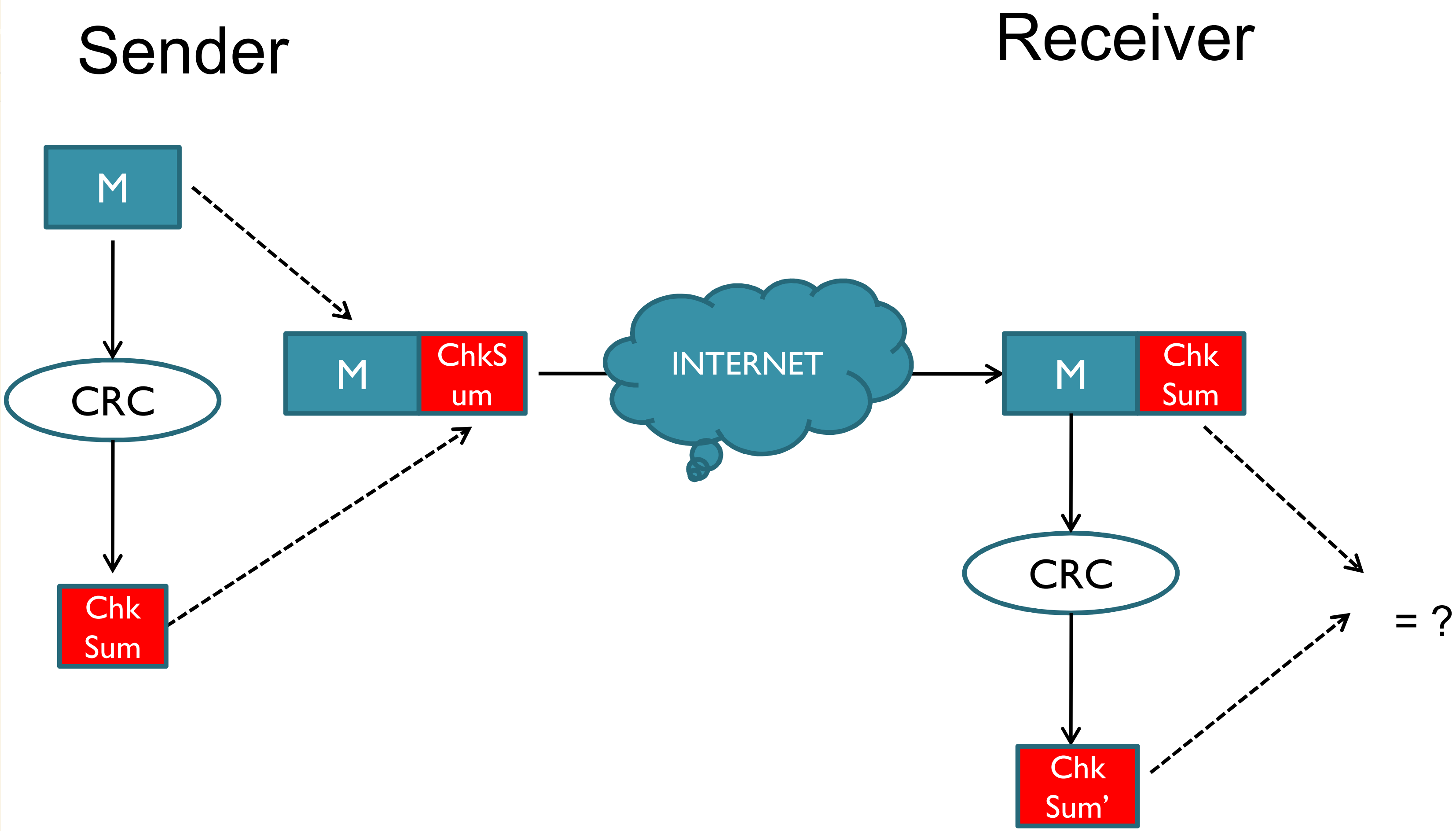
Security Services

- ✓ Confidentiality : Symmetric encryption solves
- Integrity
- Authentication
- Non-repudiation
- Access control
- Availability

Integrity in Networking

- Sender computes a CRC for the message
- Sender appends the CRC code to the message and sends them to the receiver
- The receiver computes the CRC of the message.
  - If the CRC appended to the message is equal to the computed one, the message is unchanged with a high probability.
  - If the CRCs do no match, the message is changed during the transmission.

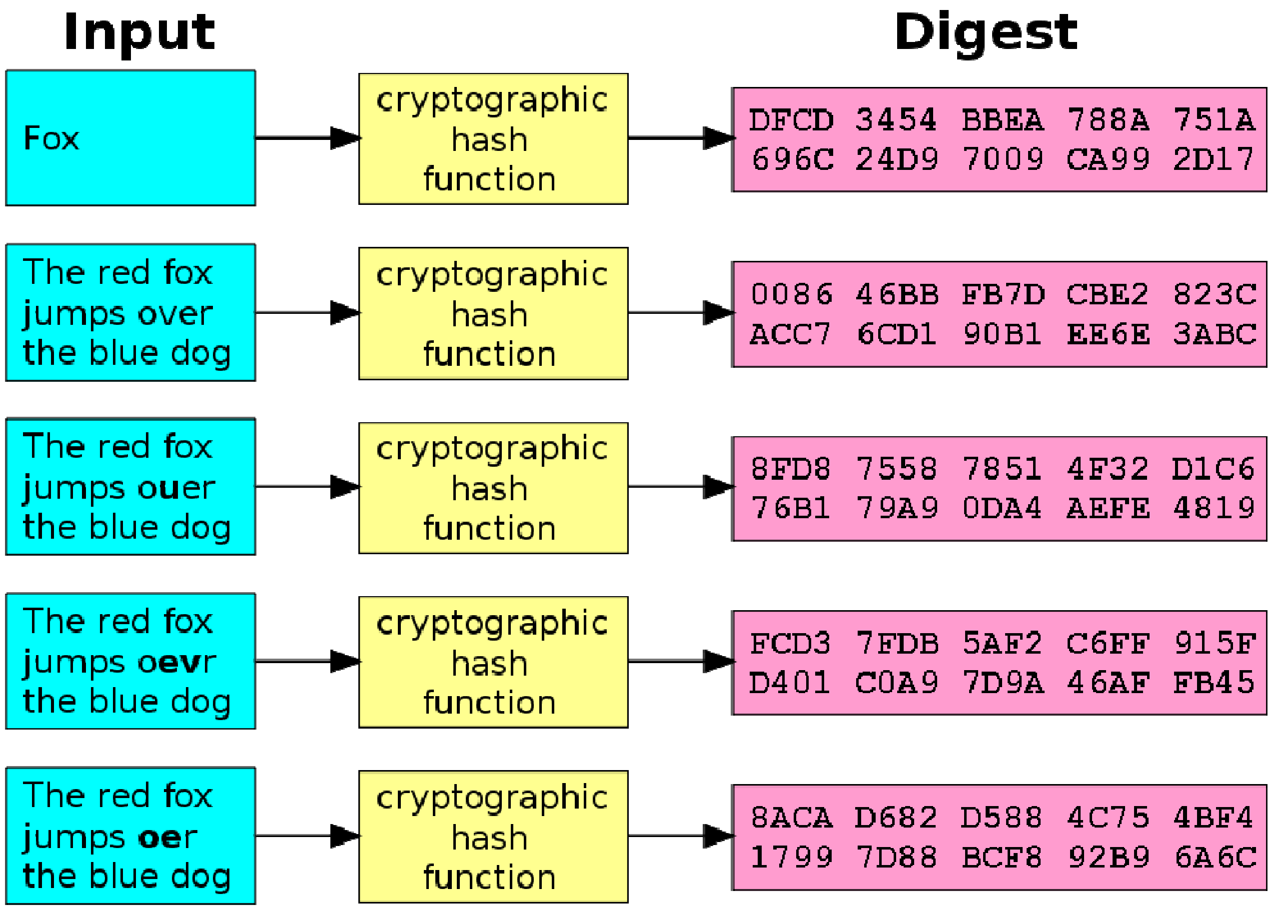
CRC Checksum in Networking



Cryptographic Hash Functions

- Maps an arbitrary length input to a fixed-size output.
  - If m is message, H is the hash function, H(m) is the output of hash function, also called message digest.
- Desirable features:
  - One-way: There should be no easy way to guess m from H(m)
  - Pseudorandom: If m and m' are two close values, H(m) and H(m') should not be close each other.
  - Collision resistant: It should be hard to find two inputs that hash to the same output
    - It should be hard to find two inputs *a* and *b* such that $H(a) = H(b)$

Example Operation of Hash Functions

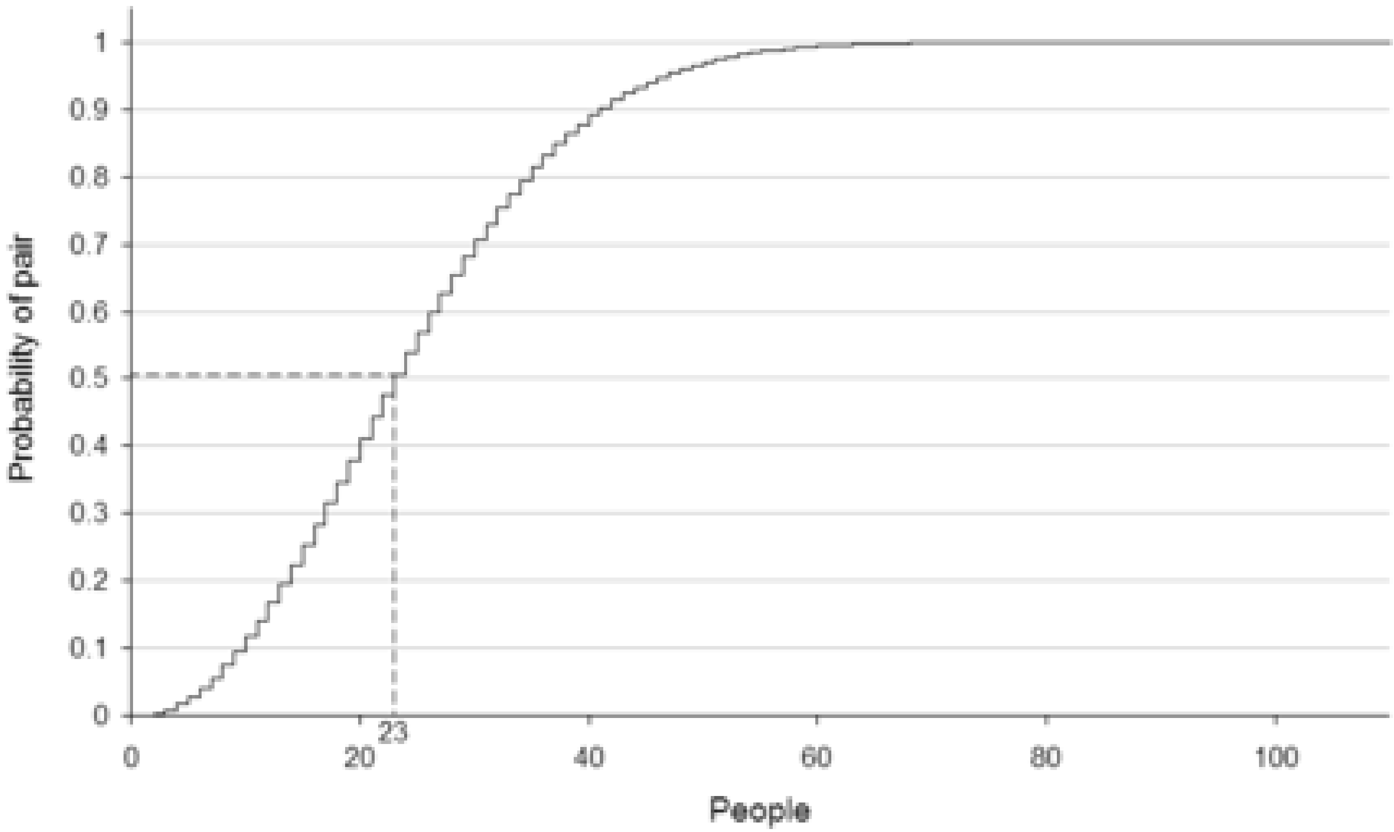


Birthday Paradox

- Birthday Problem ("paradox"): When √N or more are chosen randomly from a domain of N, there is a significant chance of collision.
- Probability of n persons having different birthdays:

$$p(n) = 1 \times (1 - \frac{1}{365}) \times (1 - \frac{2}{365}) \times \ldots \times (1 - \frac{n-1}{365})$$

Birthday Paradox

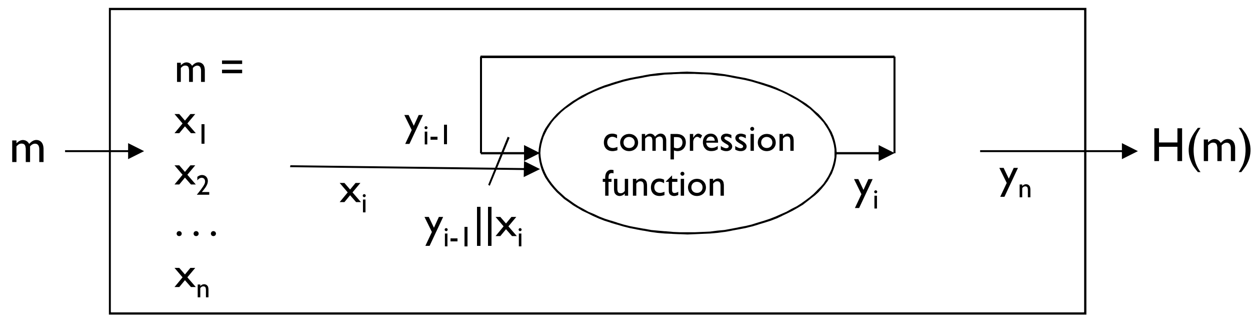


Collision Resistance

- If a hash function produces *N* bits of output, an attacker should not easily find a collision by performing less than (on average) $2^{N/2}$ hash operations.
  - If there is an easier method than this brute force attack, it is typically considered a flaw in the hash function
  - Therefore, hash output size ≥ 128 bits is desirable.
- But why "collision resistance"?
  - A chosen plaintext attack: Trudy is Alice's secretary. Generates two opposite messages.

Internals of a Hash Function

- A fixed-size "compression function".
  - Each iteration mixes an input block with the previous output.



- Design:
  - Lots of operations (rotations, $\oplus$, $\wedge$, $\vee$, +, ...) fast in s/w.
  - More of them are added if a weakness is found.

Some Popular Hash Algorithms

- MD5 (Rivest)
  - 128-bit output
  - Most popular
- SHA-1 (NIST-NSA)
  - US gov't standard
  - 160-bit output
- RIPEMD-160
  - Euro. RIPE project.
  - 160-bit output

Algorithm	Speed (MByte/s.)
MD5	205
SHA-1	72
RIPEMD-160	51

Crypto++ 5.1 benchmarks, 2.1 GHz P4

Message Authentication Codes (MAC)

- A simple message integrity checking method:
  - Compute H(m) and send (m, H(m))
  - The receiver computes H(m) and compares with the received H(m) value.
- What happens if an attacker changes both m and H(m) value and sends (m',H(m')) to receiver?

- A secret key system can be used to generate a cryptographic checksum known as a message authentication code (MAC).
  - It is also referred as MIC (Message Integrity Code).

MACs

- Let $MAC_K(m)$ be a message authentication code for m produced by using K.
- An attacker shouldn't be able to generate a valid (m, $MAC_K(m)$), even after seeing many valid message-MAC pairs.
- It aims to protect against undetected modifications on messages, not the contents.
  - Sender of a message m computes $MAC_K(m)$ and appends it to the message
  - Verification: The receiver also computes $MAC_K(m)$ & compares to the received value.

MACs from Hash Functions

- prefix: $MAC_K(m) = H(K \| m)$
  - not secure; extension attack.
- suffix: $MAC_K(m) = H(m \| K)$
  - mostly ok; problematic if H is not collision resistant.
- send half of the digest
- envelope: $MAC_K(m) = H(K_1 \| m \| K_2)$
- HMAC: $MAC_K(m) = H(K_2 \| H(K_1 \| m))$
  - provably secure; popular in Internet standards.