# Network Security (NetSec)

## IN2101 – WS 16/17

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Version: November 28, 2016

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# Chapter 7: Cryptographic Hash Functions and MACs Add-on

# Motivation

- Common practice in data communications: *error detection code*, to identify random errors introduced during transmission
  - Examples: Parity, Bit-Interleaved Parity, Cyclic Redundancy Check (CRC)

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  - Examples: Parity, Bit-Interleaved Parity, Cyclic Redundancy Check (CRC)
- Underlying idea of these codes: add redundancy to a message for being able to *detect*, or even *correct* transmission errors
- The error detection/correction code of choice and its parameters: trade-off between
  - Computational overhead
  - Increase of message length
  - Probability/characteristics of errors on the transmission medium

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- Outline:
  1. Repetition of Cryptographic Hash Functions
  2. Repetition of Message Authentication Codes

## Disclaimer

- Definition of Hash functions and MACs: Chapter 6 Modern Cryptography is authoritative.

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- Example: given a large prime number *p* and a primitive root *g* in $Z_p^*$
  Let $h(x) = g^x \mod p$
  Then *h* is a one-way function

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  3. *Collision resistance*:
     It is computationally infeasible to find any pair $(x, x')$ with $x \neq x'$ such that $H(x) = H(x')$

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- In networking there are codes for error detection.
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  - CRC is a fast compression function.
- Why not use CRC?
  - CRC is not a cryptographic hash function
  - CRC does not provide $2^{nd}$ pre-image resistance and collision resistance
  - CRC is additive
    - If $x' = x \oplus \triangle$, then $CRC(x') = CRC(x) \oplus CRC(\triangle)$
  - CRC is useful for protecting against noisy channels
  - But not against intentional manipulation

## Can Hashing ensure Integrity?

Case:
No attacker

Alice (A)

$m, H(m)$

Bob (B)

ok

Case:
With attacker

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- Applying a hash function is not sufficient to secure a message.
- $H(m)$ needs to be protected.

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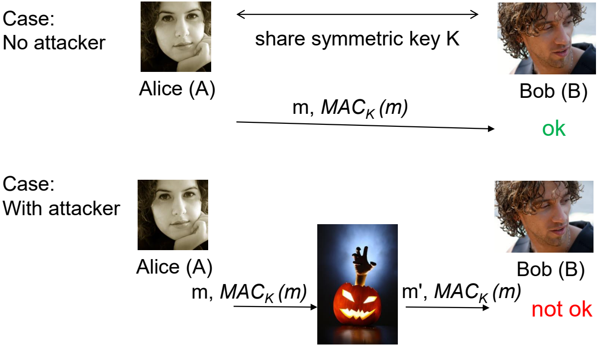


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- Simply hashing a message and appending the hash is not secure against intentional manipulation (compare with CRC)!
- Solution:
  - Include a secret in the hash.
  - Since the secret key $k$ is unknown to the attacker, the attacker cannot compute $MAC_K(m')$ (see next section).

# Other applications which require some caution:

- Pseudo-random number generation
  - The output of a cryptographic hash function is assumed to be uniformly distributed
  - Although this property has not been proven in a mathematical sense for common cryptographic hash functions, such as MD5, SHA-1, it is often used
  - Start with random seed, then hash
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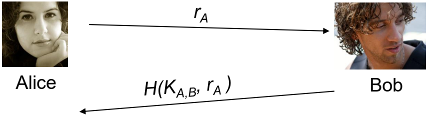
- Encryption
  - Remember: Output Feedback Mode (OFB) - encryption by generating a pseudo random stream, and performing XOR with plain text
  - Generate a key stream as follow:
  - $k_0 = H(K_{A,B} | IV)$
  - $k_{i+1} = H(K_{A,B} | k_i)$
  - The plain text is XORed with the key stream to obtain the cipher text.

# Applications

- Authentication with a *challenge-response* mechanism



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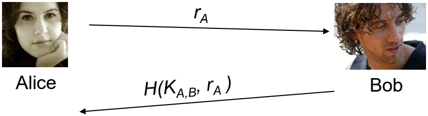


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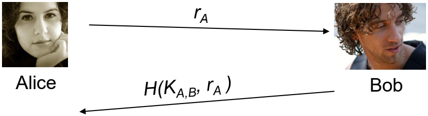


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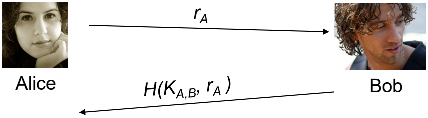


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  - It avoids transmitting the transport of the shared key (e.g. password) in clear text
- Another type of a challenge-response would be, e.g., if Bob signs the challenge "$r_A$" with his private key
- Note that this kind of authentication does not include negotiation of a session key.
- Protocols for key negotiation will be discussed in subsequent chapters.

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  - Secure Hash Algorithm 3 (SHA-3):
    - Current NIST standard (since October 2012).
    - Keccak algorithm by G. Bertoni, J. Daemen, M. Peeters und G. Van Assche.

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- (Cryptographic) hashes alone don't protect against tampering!
- MACs include a secret key $K$ in addition to the message $m$ they aim to protect.
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    - Sender s computes $MAC_K(m)$.
    - $<m,MAC_K(m)>$ is sent to the receiver r.
    - r receives $<m',MAC_K(m)>$.
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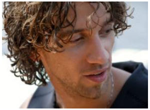
- MACs:
  - Prove message authenticity $\leftrightarrow$ integrity.
  - Do detect tampering.
  - Can't be forged.
  - Can be replayed.

# Application

Alice (A)

share symmetric key $K$



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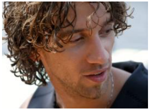

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- Alice protects/authenticates her message *m* with a MAC function
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- Examples for potential MAC constructions:
  - HMAC
  - CBC-MAC / CMAC
  - $Enc_K$ (h(m)) $\rightarrow$ NO!!

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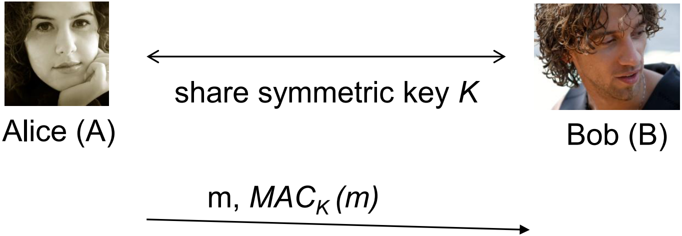


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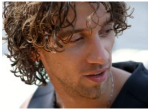

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  - Only Alice and Bob who know $K$ can do this.
- Take home message: for authenticity checks the receiver needs to know $m$ and a secure modification check value that it can compare.
  - Think about it: Why is $Enc_K(m)$ usually not sufficient?

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- Reasons for constructing MACs from cryptographic hash functions:
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- Reasons for constructing MACs from cryptographic hash functions:
  - Cryptographic hash functions generally execute faster than symmetric block ciphers (Note: with AES this isn't much of a problem today)
  - There are no export restrictions to cryptographic hash functions
- Basic idea: "mix" a secret key $K$ with the input and compute a hash value.
- The assumption that an attacker needs to know $K$ to produce a valid MAC nevertheless raises some cryptographic concern:
  - The construction $H(K \parallel m)$ is not secure
  - The construction $H(m \parallel K)$ is not secure
  - The construction $H(K \parallel p \parallel m \parallel K)$ with p denoting an additional padding field does not offer sufficient security

# Attack Against an Insecure MAC

- For illustrative purposes, consider the following MAC definition:
  - Input: message $m = (x_1, x_2, ..., x_n)$ with $x_i$ being 128-bit values, and key $K$
  - Compute $\triangle(m) := x_1 \oplus x_2 \oplus ... \oplus x_n$ with $\oplus$ denoting XOR
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  - Therefore, $MAC_k(m)$ is a valid MAC for m', since $\triangle m = \triangle m'$
  - When Bob receives ($m'$, $MAC_K(m)$) from Eve, he will accept it as being originated from Alice.

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  - Poly1305:
    - Standardized in RFC 7539.

# Common MAC Functions: Hash MACs (HMAC)

- The construction *H(K | m | K)*, called prefix-suffix mode, has been used for a while.
  - See for example RFC 1828
  - It has been also used in earlier implementations of the Secure Socket Layer (SSL) protocol (until SSL 3.0)
  - However, it is now considered vulnerable to attack by the cryptographic community.

# Common MAC Functions: Hash MACs (HMAC)

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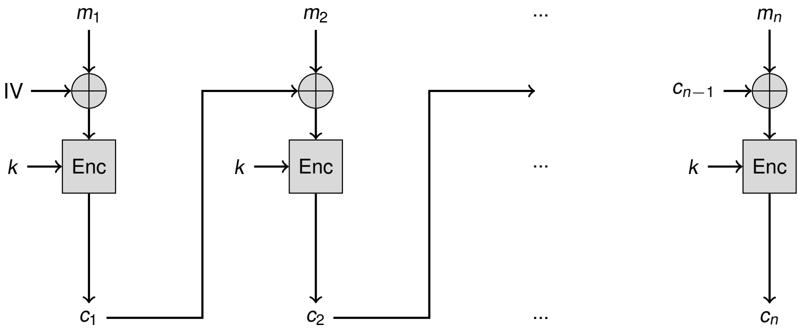
  - See for example RFC 1828
  - It has been also used in earlier implementations of the Secure Socket Layer (SSL) protocol (until SSL 3.0)
  - However, it is now considered vulnerable to attack by the cryptographic community.
- The most used construction is **HMAC**: $H(K \oplus opad \mid H(K \oplus ipad \mid m))$
  - The length of the key K is first extended to the block length required for the input of the hash function H by appending zero bytes.
  - Then it is xor'ed respectively with two constants opad and ipad
  - The hash function is applied twice in a nested way.
  - Currently no attacks have been discovered on this MAC function.

# Common MAC Functions: Cipher Block Chaining MACs (CBC-MAC)

- A CBC-MAC is computed by encrypting a message in CBC Mode and taking the last ciphertext block or a part of it as the MAC:



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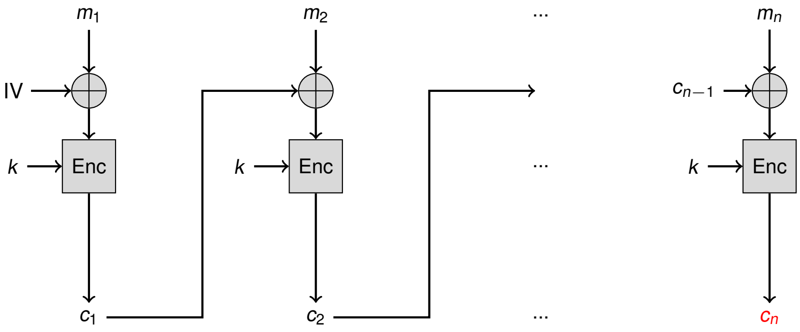


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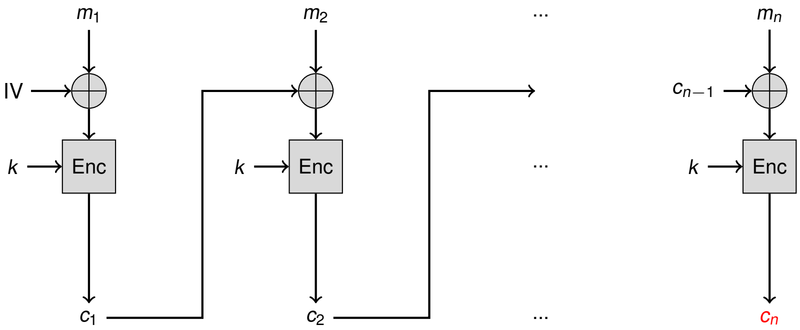


- $\mathrm{MAC}_k(m) = c_n$ for some publicly known, fixed, $IV$.
- This MAC needs not to be mixed with a secret any further, as it has already been produced using a shared secret $K$.
- This scheme works with any block cipher (AES, Twofish, 3DES, ...)
- It is used, e.g., for IEEE 802.11 (WLAN) WPA2, many modes in SSL / IPSec use some CBC-MAC construction.

# Common MAC Functions: Cipher Block Chaining MACs (CBC-MAC)

- CBC-MAC security
  - CBC-MAC must NOT be used with the same key as for the encryption
  - In particular, if CBC mode is used for encryption, and CBC-MAC for authenticity with the same key, the MAC will be equal to the last cipher text block
  - If the length of a message is unknown or no other protection exists, CBC-MAC can be prone to length extension attacks. CMAC resolves the issue.

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  - If the length of a message is unknown or no other protection exists, CBC-MAC can be prone to length extension attacks. CMAC resolves the issue.
- CBC-MAC performance
  - Older symmetric block ciphers (such as DES) require more computing effort than dedicated cryptographic hash functions, e.g. MD5, SHA-1 therefore, these schemes are considered to be slower.
  - However, newer symmetric block ciphers (AES) is faster than conventional cryptographic hash functions.
  - Therefore, AES-CBC-MAC is becoming popular.

# Common MAC Functions: Cipher-based MACs (CMAC)

- CMAC is a modification of CBC-MAC
  - Compute keys $k_1$ and $k_2$ from shared key $k$.
  - Within the CBC processing
    - XOR complete blocks before encryption with $k_1$
    - XOR incomplete blocks before encryption with $k_2$
    - $k$ is used for the block encryption
  - Output is the last encrypted block or the l most significant bits of the last block.
- XCBC-MAC (e.g. found in TLS) is a predecessor of CMAC where $k_1$ and $k_2$ are input to algorithm and not derived from $k$.

# Literature

(Beyond the scope of examination)


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