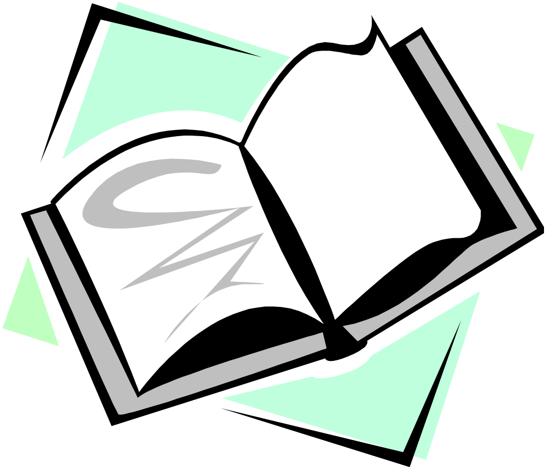
Cryptography
CS 555

Topic 15: HMAC, Combining Encryption & Authentication

Outline and Readings

- Outline
  - Hash Family
  - NMAC and HMAC
  - CCA-secure encryption
  - Combining encryption & authentication



- Readings:
  - Katz and Lindell: : 4.7,4.8,4.9

Hash Family (Called Hash Function in the Textbook)

- A hash family H is a function $K \times X \rightarrow Y$
  - X is a set of possible messages
  - Y is a finite set of possible message digests
  - K is the keyspace
  - For each $s \in K$, there is a hash function $h^s \in H$.
  - Here, it is typically assumed that s is made public
    - Unlike when we analyze a PRF

- Hash functions in practice (SHA-1, SHA-2) can be viewed as hash family, where the IV is viewed as the key

Collision Resistant Hash Family

- A Hash family is collision resistant if no adversary has negligible advantage in the following experiment:
  - A key s is generated.
  - Adversary is given s, and needs to find a collision on h^s ,that is find x1, x2 such that $h^s(x1)=h^s(x2)$
    - A random hash function is chosen, and the adversary needs to produce a collision on that
- Advantage of using the concept of collision resistant hash family instead of a collision resistant hash function
  - Now it makes sense to assume that there is no adversary algorithm can produce collision.
  - Why it does not make sense to say that there exists no algorithm to produce a collision on a fixed hash function?

Constructing MAC from Collision Resistant Hash Functions

- Let h be a collision resistant hash function

- $MAC_k(M) = h(k || M)$, where || denote concatenation
  - Okay as fixed-length MAC
  - Insecure when variable-length messages are allowed
  - Because of the Merkle-Damgard construction for hash functions, given M and t=h(K || M), adversary can compute M' by appending to M some new data blocks, and then h(K||M')

Idea of NMAC (Nested MAC)

- Given a compression function f, and a hash function h constructed with f using the Merkle-Damgard method, NMAC defines $MAC_{k1,k2}(m)=f(k1||\ h(k2||m))$.
  - Technically, both f and h are parameterized by a randomly chosen s, however, we ignore it
- NMAC is secure if both (1) h produces no collision, and (2) f(k||m) is a secure **fixed-length** MAC.
  - f(k||m) is a secure MAC means that adversary cannot compute f(k||m') even after obtaining $f(k||m_1)$, $f(k||m_2)$, …
    - Not implied by f being collision resistant, but in general safely assumed to be true for practical hash functions
  - Proof. A forgery against f(k1|| h(k2||m')) means that either h(k2||m') = $h(k2||m_i)$ for a queried m_i, which means h is not collision resistant; or one computes f(k1||d= h(k2||m')), for a new value d, which means that f is not a secure MAC.

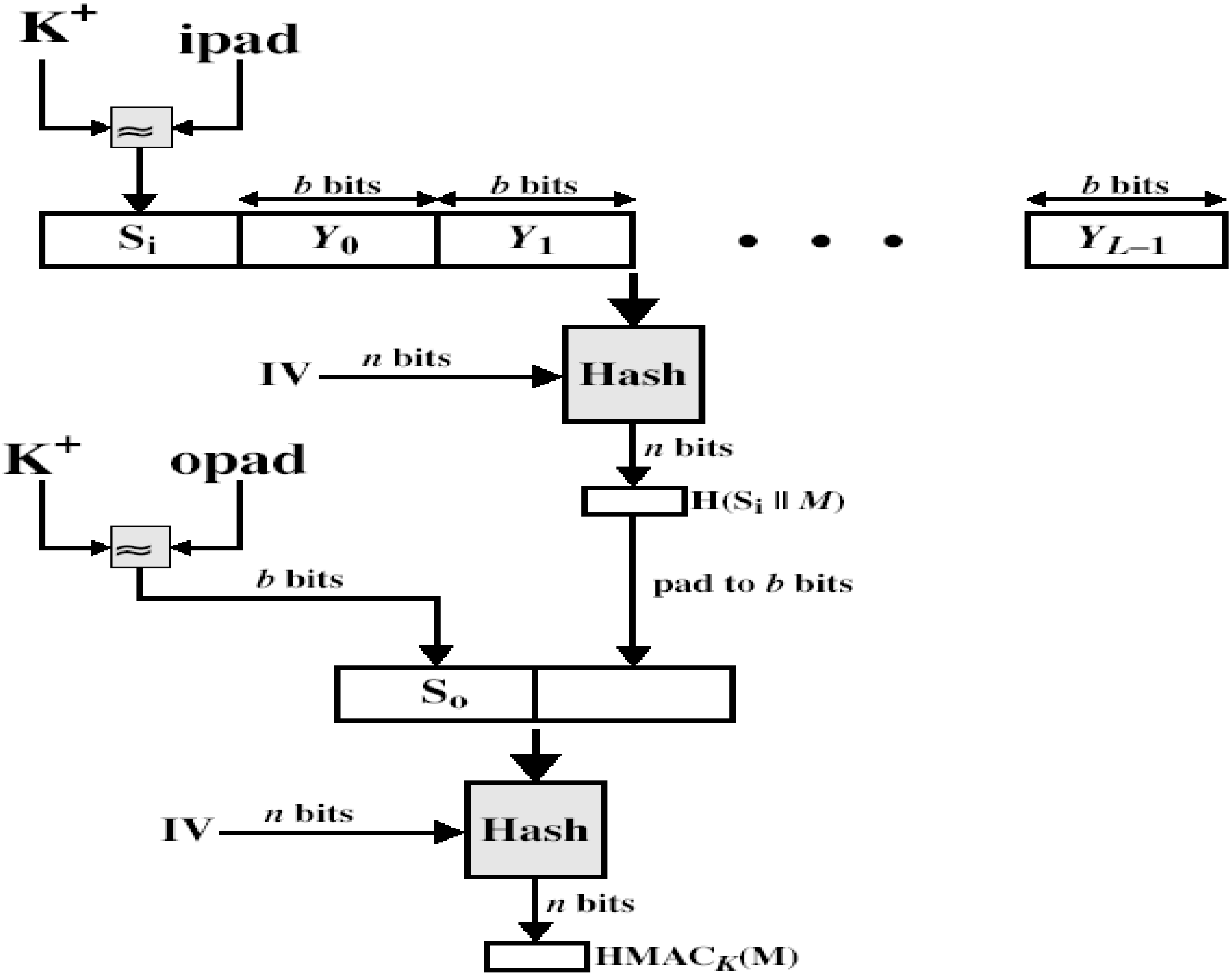
HMAC: A Derivative of NMAC

$HMAC_K[M] = Hash[(K^+ \oplus opad) \| Hash[(K^+ \oplus ipad) \| M)]]$

- K^+ is the key padded (with 0) to B bytes, the input block size of the hash function
- ipad = the byte 0x36 repeated B times
- opad = the byte 0x5C repeated B times.

- Essentially NMAC. Differs in that NMAC uses independent k1 and k2, HMAC uses two keys that are computed from one key
- Proven to be PRF if compression function is PRF.
- If used with a secure hash functions (e.g., SHA-256) and according to the specification (key size, and use correct output), no known practical attacks against HMAC exists

HMAC Overview



Constructing CCA-Secure Encryption

- Construction 4.19. CCA-secure encryption scheme.
  - Uses a CPA-secure encryption scheme, and a secure MAC.
  - In key generation, generates k_1 for encryption, and k_2 for MAC.
  - To encrypt a message m, computes ciphertext $\langle c=Enc_{k1}(m),\ \ t=MAC_{k2}(c_1)\rangle$
    - The ciphertext of the scheme is a pair (c,t)
  - To decrypt a ciphertext $\langle c, t\rangle$, first check whether $Vrfy_{k2}(c,t)=1$; if yes, outputs $Dec_{k1}(c)$; if not, outputs $\perp$
    - That is, decline to decrypt if the MAC does not verify
- This is CCA-secure because the adversary gets nothing from the decryption oracle, unless the adversary can break the MAC first

Encryption and Authentication

- Three ways for encryption and authentication
  - Authenticate-then-encrypt (AtE), used in SSL
    - a = MAC(x), C=E(x,a), transmit C
  - Encrypt-then-authenticate (EtA), used in IPSec
    - C=E(x), a=MAC(C), transmit (C,a)
  - Encrypt-and-authenticate (E&A), used in SSH
    - C=E(x), a=MAC(x), transmit (C,a)
- Which way provides secure communications when embedded in a protocol that runs in a real adversarial network setting?

Encryption Alone May Be Insufficient for Privacy

- If an adversary can manipulate a ciphertext such that the observable behavior (such as success or failure of decryption) differs depending on the content of plaintext, then information about plaintext can be leaked
- To defend against these, should authenticate ciphertext, and only decrypt after making sure ciphertext has not changed
- Encrypt-then-authenticate (EtA) is secure
  - C=E(x), a=MAC(C), transmit (C,a)

Encryption Alone May Be Insufficient for Privacy: An Artificial Example

- Given a secure stream cipher (or even one-time pad) E, Consider encryption E*
  - E*[x] = E[encode[x]]
    - encode[x] replaces 0 with 00, and 1 with either 01 or 10.
  - How to decrypt?
  - E*[x] is secure
- Using E* may not provide confidentiality in some usage
  - Consider the case an adversary flips the first two bits of E*[x]
  - When the bits are 01 or 10, flipping results in no change after decrypt
  - When the bits are 00, flipping result in decryption failure
  - Learning whether decryption succeeds reveal first bit

AtE and E&A are insecure

- Authenticate-then-encrypt (AtE) is not always secure
  - a = MAC(x), C=E(x,a), transmit C
  - As first step is decryption, its success or failure may leak information.
  - AtE, however, can be secure for some encryption schemes, such as CBC or OTP (or stream ciphers)
- Encrypt-and-authenticate (E&A) is not secure
  - C=E(x), a=MAC(x), transmit (C,a)
  - MAC has no guarantee for confidentiality

Coming Attractions …

- Private key management and the Public key revolution

- Reading: Katz & Lindell: Chapter 9