CSC 580
Cryptography and Computer Security

Authenticated Encryption, Key Wrapping, and PRNGs
(Sections 12.6-12.9)

April 3, 2018

Goal: Protect both Confidentiality and Integrity

Some techniques that have been used:

- Encrypt with hash of message: $E(K, M \,||\, H(M))$
  - *E better be non-malleable!! (problem with WEP using RC4)*
- Encrypt with MAC: $E(K_1, M \,||\, MAC(K_2, M))$
  - *Used in SSL/TLS*
- Encrypt followed by MAC: $C = E(K_1, M)$; $T = MAC(K_2, C)$
  - *Used in IPSec*
- Encrypt and MAC: $C = E(K_1, M)$; $T = MAC(K_2, M)$
  - *Used in SSH*

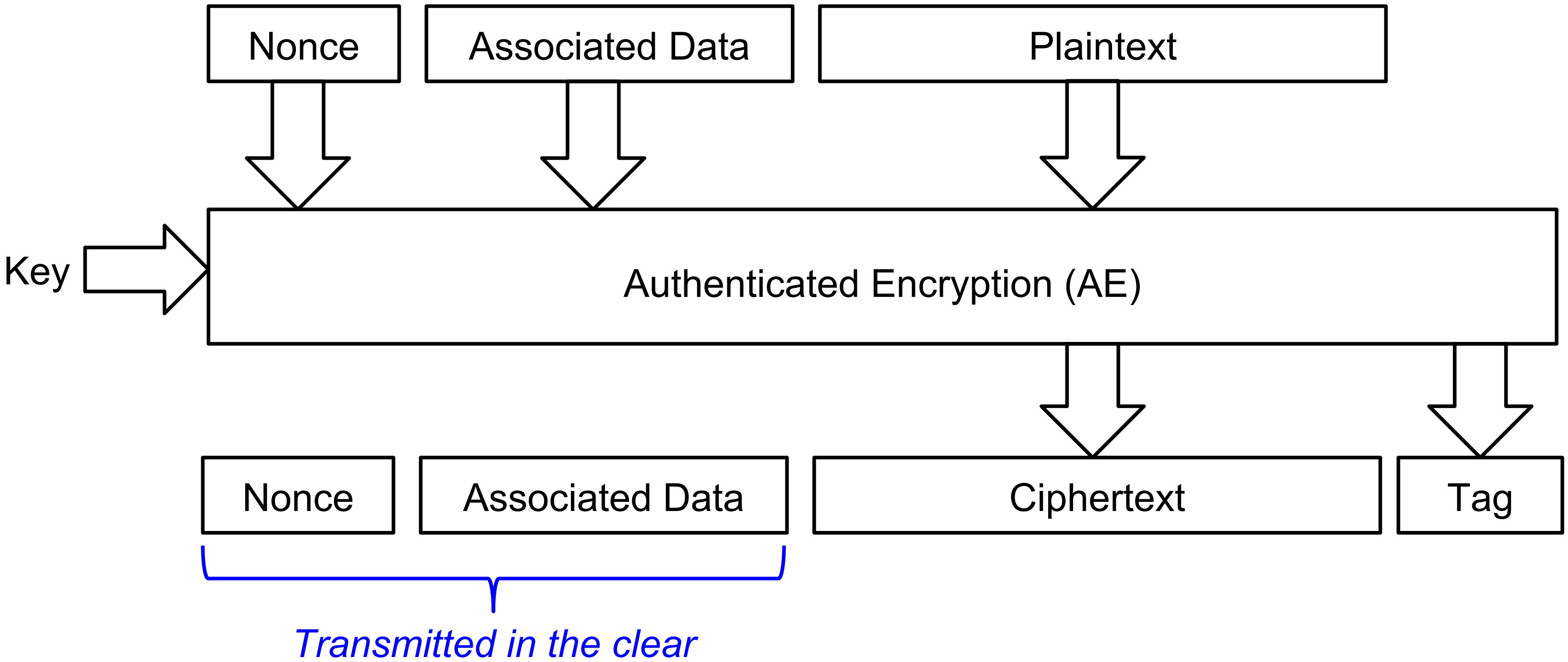
Notes:

- Important to use different keys for encryption and MAC (avoid interactions)
- All techniques have drawbacks

New and Improved! Authenticated Encryption
High-Level Idea

Ideas:

- Design for confidentiality and integrity together - use a single key!
- Allow some data to be transmitted in the clear, but still authenticated



JCA - Using Authenticated Encryption

Example using GCM (one AE mode)

```
GCMParameterSpec s = ...;
cipher.init(..., s);

// If the GCM parameters were generated by the provider, it can
// be retrieved by:
// cipher.getParameters().getParameterSpec(GCMParameterSpec.class);

cipher.updateAAD(...);  // AAD (optional - must be before plaintext)
cipher.update(...);     // Multi-part update
cipher.doFinal(...);    // conclusion of operation

// Use a different IV value for every encryption
byte[] newIv = ...;
s = new GCMParameterSpec(s.getTLen(), newIv);
cipher.init(..., s);
...
```

On encryption: Tag is embedded in output ciphertext (you don’t have to handle!)

On decryption: Bad tag results in throwing AEADBadTagException

Two AE modes: CCM and GCM

CCM (Counter with CBC-MAC)

- Ciphertext produced using CTR mode
- MAC produced using CBC-based MAC
- The good: Strong, provable security under certain assumptions
- The bad:
  - Encrypt/MAC require two independent block cipher calls
  - Inclusion of CBC means not parallelizable

GCM (Galois/Counter Mode)

- CTR mode encryption - *almost*… incr 32-bits → 2^{39}-bit limit on size
- GHASH to auth ***ciphertext*** - one Galois Field (GF) mult per block
- The good:
  - Strong, provable security under certain assumptions
  - Per block: 1 block cipher call, and one GF mult (Intel instruction) - fast!
  - Block cipher calls are parallelizable (just like CTR mode)
- The bad: ?

GCM - Algorithm Overview

Hash and Encryption Functions

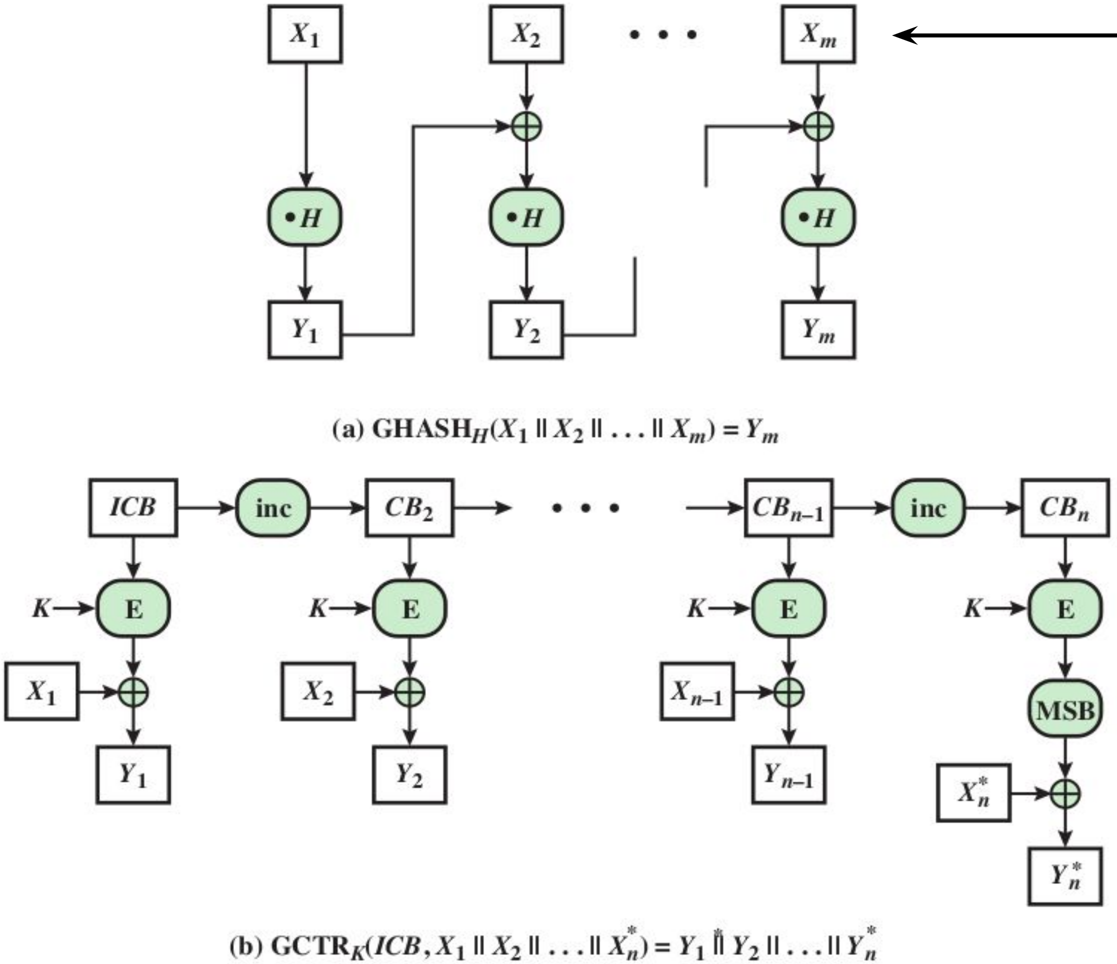


Figure 12.10 GCM Authentication and Encryption Functions

A little misleading: When combined, these X_i's are *ciphertext* blocks (called Y_i below)!

GCM - Algorithm Overview

Overall GCM operation

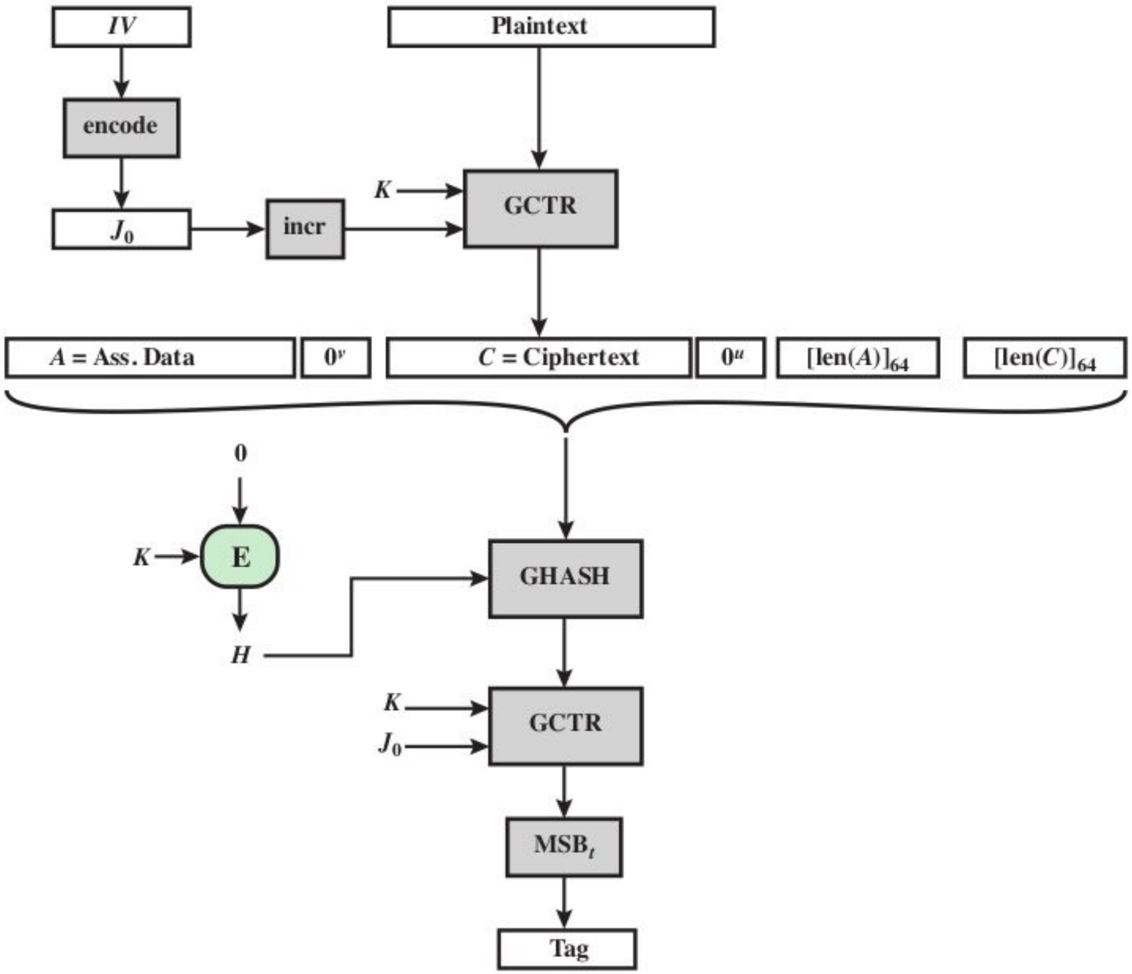


Figure 12.11 Galois Counter - Message Authentication Code (GCM)

Key Wrapping

Consider: In the JCA KeyStore, keys are stored in a file. How are they protected?

- Password used to “unlock” the KeyStore
- Need to use encryption with one key to encrypt another key
- An AES 256-bit key spans multiple blocks of AES
- Can a specially designed mode help?
  - Advantage: Limited size plaintext (can have all in memory at once)
  - Speed isn’t as big an issue as it is with bulk encryption
  - Wrapped key is random - how do you know decryption is right - authentication!
  - Specially designed mode: Key Wrap (KW) mode

Related notions with different terminology:

- **Key Wrapping**: Encrypting a symmetric key using symmetric cipher
- **Key Encapsulation**: Encrypting a symmetric key using a public key algorithm (e.g., for hybrid encryption)

AES Key Wrap Mode
Pseudocode from NIST publication

Inputs: Plaintext, n 64-bit values $\{P_1, P_2, \ldots, P_n\}$,
Key, K (the KEK).
Outputs: Ciphertext, (n+1) 64-bit values $\{C_0, C_1, \ldots, C_n\}$.

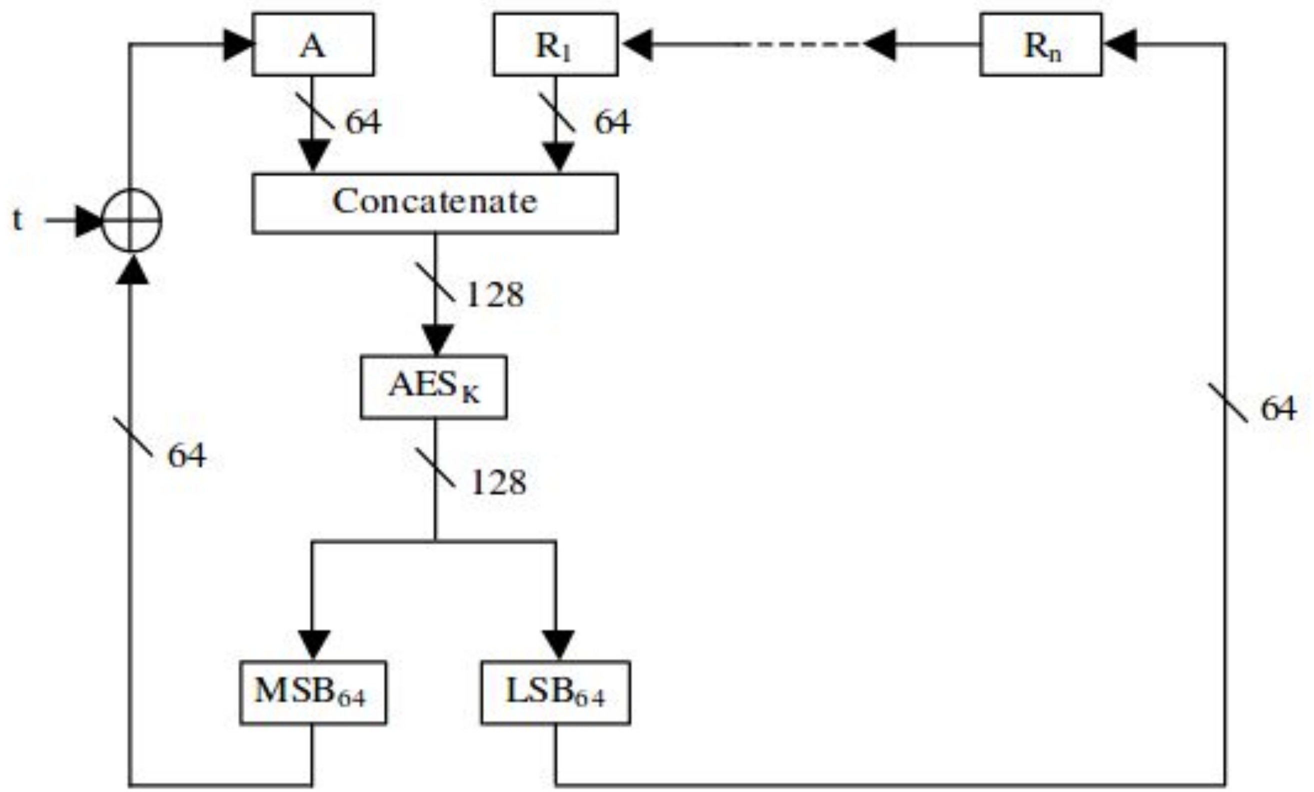
1) Initialize variables
   Set $A^0 = IV$, an initial value (see 2.2.3)
   For $i = 1, \ldots, n$
   $R_i^0 = P_i$
2) Calculate intermediate values
   For $t = 1, \ldots, s$, where $s = 6n$
   $A^t = \mathbf{MSB}_{64}\left(\mathbf{AES}_{\mathbf{K}}\left(A^{t-1} \mid R_1^{t-1}\right)\right) \oplus t$
   For $i = 1, \ldots, n-1$
   $R_i^t = R_{i+1}^{t-1}$
   $R_n^t = \mathbf{LSB}_{64}\left(\mathbf{AES}_{\mathbf{K}}\left(A^{t-1} \mid R_1^{t-1}\right)\right)$
3) Output the results
   Set $C_0 = A^t$
   For $i = 1, \ldots, n$
   $C_i = R_i^t$

Default IV is hex:
A6A6A6A6A6A6A6A6A6A6A6A6A6A6A6A6

Each 64-bit plaintext block gets “shifted through” encryption position 6 times.

AES Key Wrap Mode

Diagram of one stage (from NIST)



PRNGs from Hash Functions and MACs

Observations:

- PRNGs need uniformly distributed output
  - Good hash functions and MACs have uniformly distributed outputs
- PRNGs need to be one-way so seed/state can't be derived
  - Good hash functions and MACs are preimage resistant (one-way)
- PRNGs need output to be computationally uncorrelated (independent)
  - Good hash functions and MACs have collision resistance

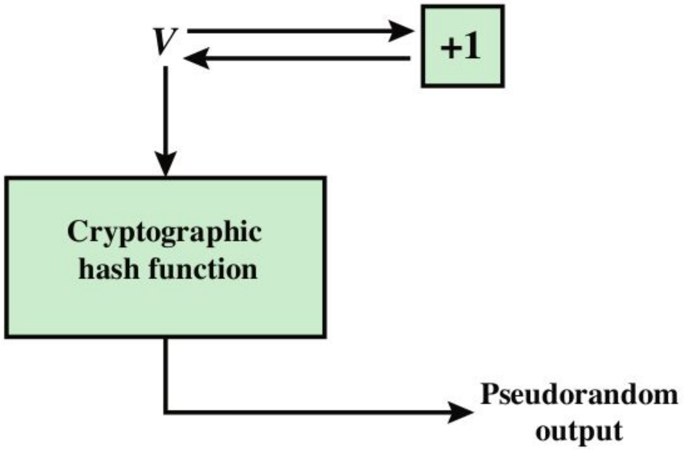
And in addition: Hash functions and MACs tend to be fast

So…. Can we use hash functions and MACs to make good PRNGs?

PRNGs from hash functions

Idea: Concatenate seed and counter, and run through hash fn

So: Initialize V = seed || 0



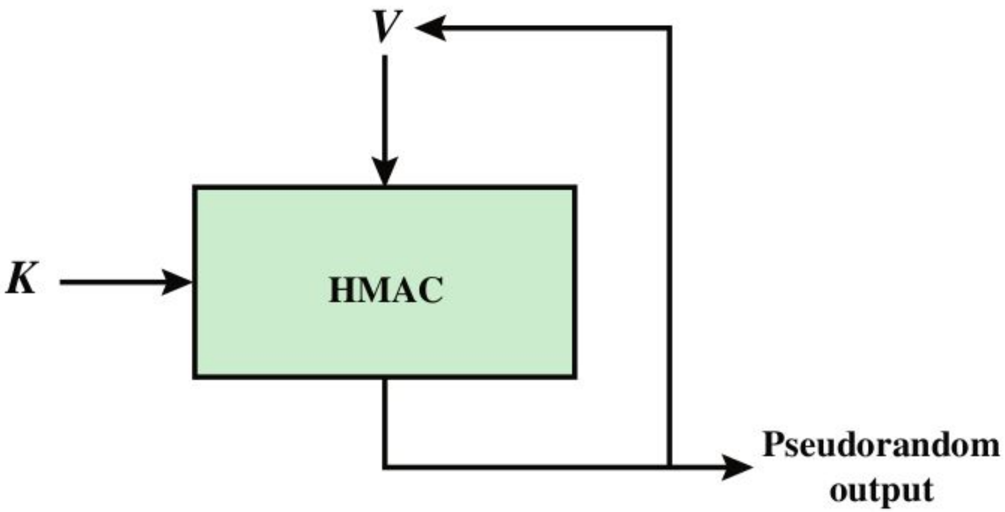
(a) PRNG using cryptographic hash function

From Figure 12.14 in the textbook

This is essentially how the standard Java SHA1PRNG instance of SecureRandom works (generally the default)

PRNGs from MACs

Can use a simple feedback loop with a MAC (NIST SP 800-90)



(b) PRNG using HMAC

Some other options

- Can use a MAC with a counter, like previous slide (IEEE 802.11i does this)
- Can do feedback, but concatenate a constant (the seed) each iteration (TLS)