Goals of authenticated encryption

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More details, credits:
competitions.cr.yp.to
/features.html

Encryption

$$
\begin{tikzcd}
\boxed{\text{sender}} \arrow[d] & \\
m \arrow[d] & \\
c \arrow[d] & k \arrow[l] \\
\boxed{\text{network}} &
\end{tikzcd}
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k: secret key.

m: variable-length plaintext.

c: variable-length ciphertext.

Authenticated encryption

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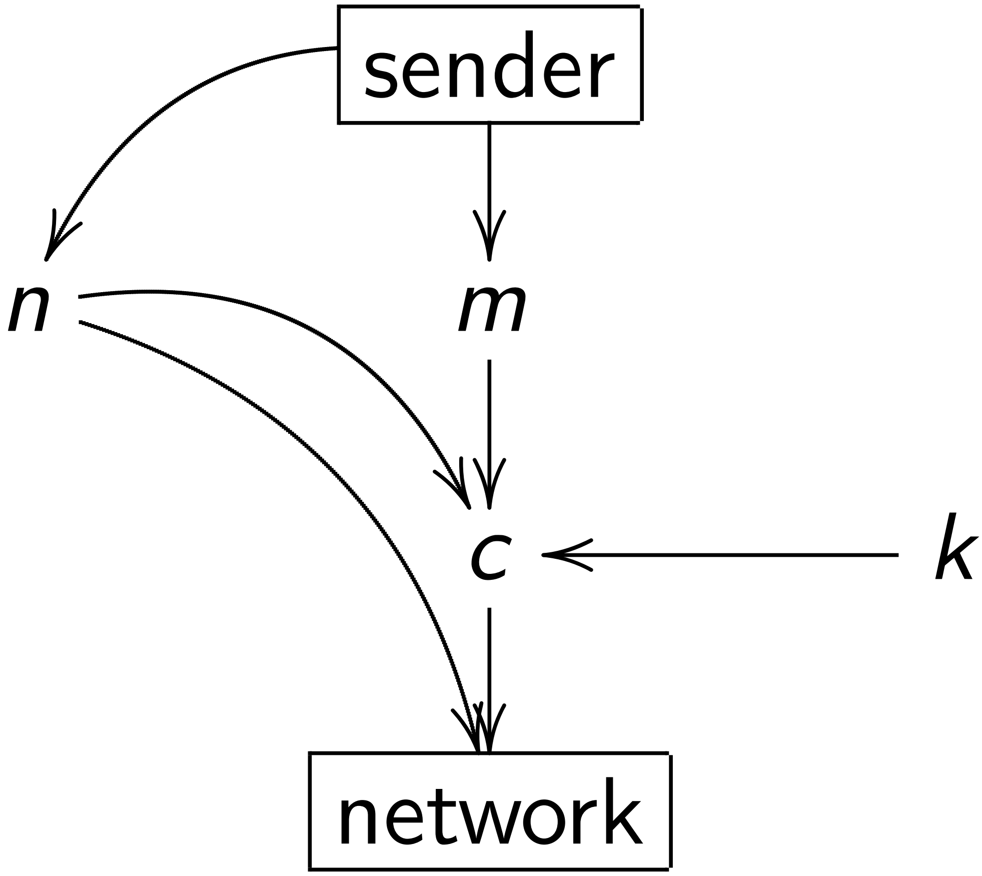
Same picture! But now
c is slightly longer than m:
includes an “authentication tag”.

Message numbers



k: secret key.

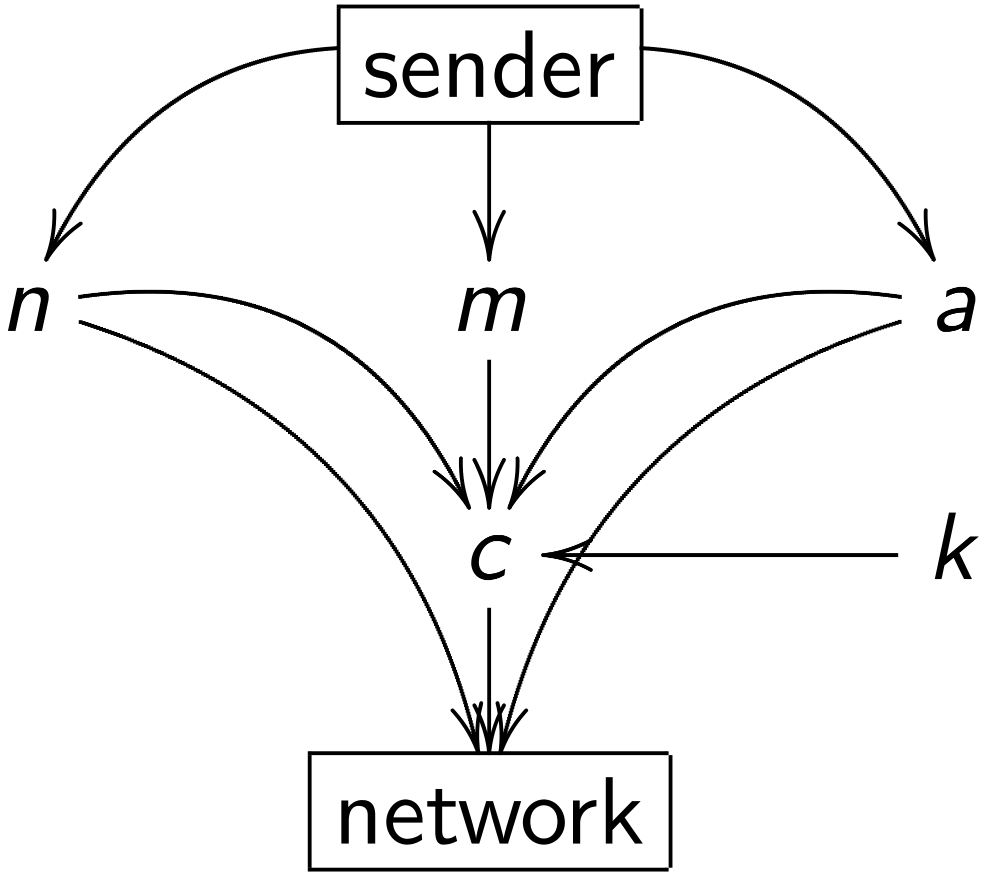
n: public message number.

m: variable-length plaintext.

c: variable-length ciphertext.

Changes in message number hide repetitions of plaintext.

Associated data



k: secret key.

n: public message number.

a: variable-length associated data.

m: variable-length plaintext.

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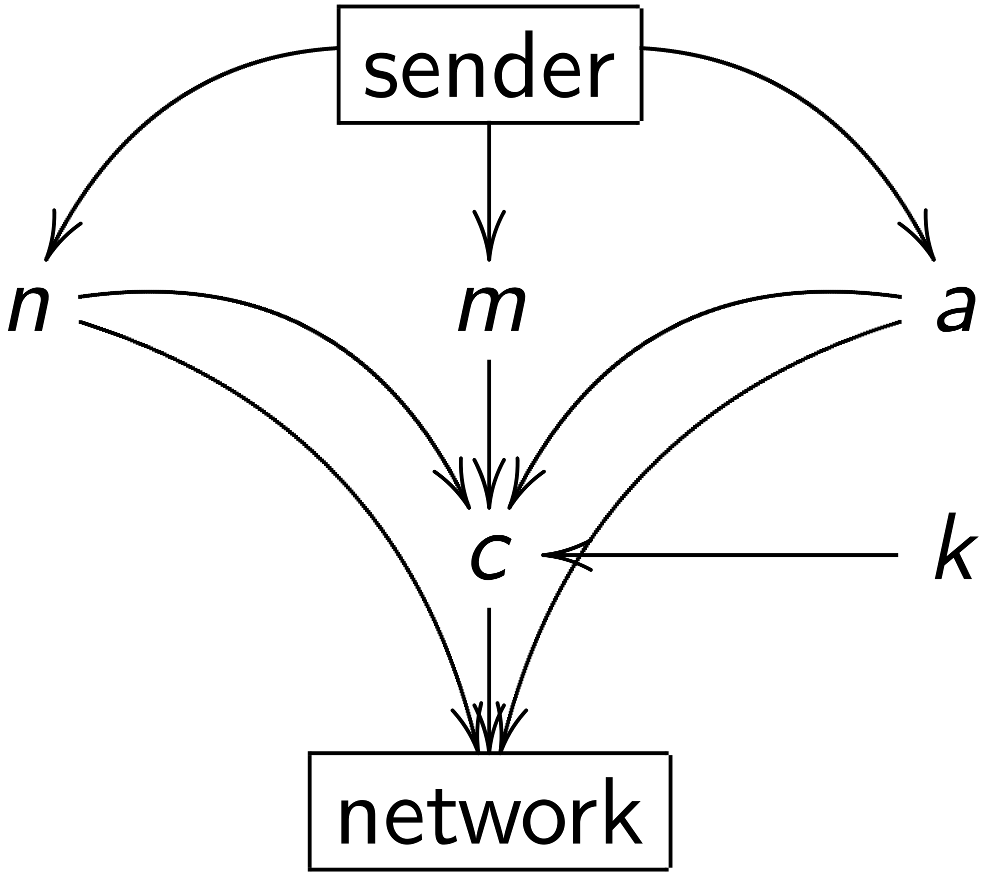


k: secret key.

n: public message number.

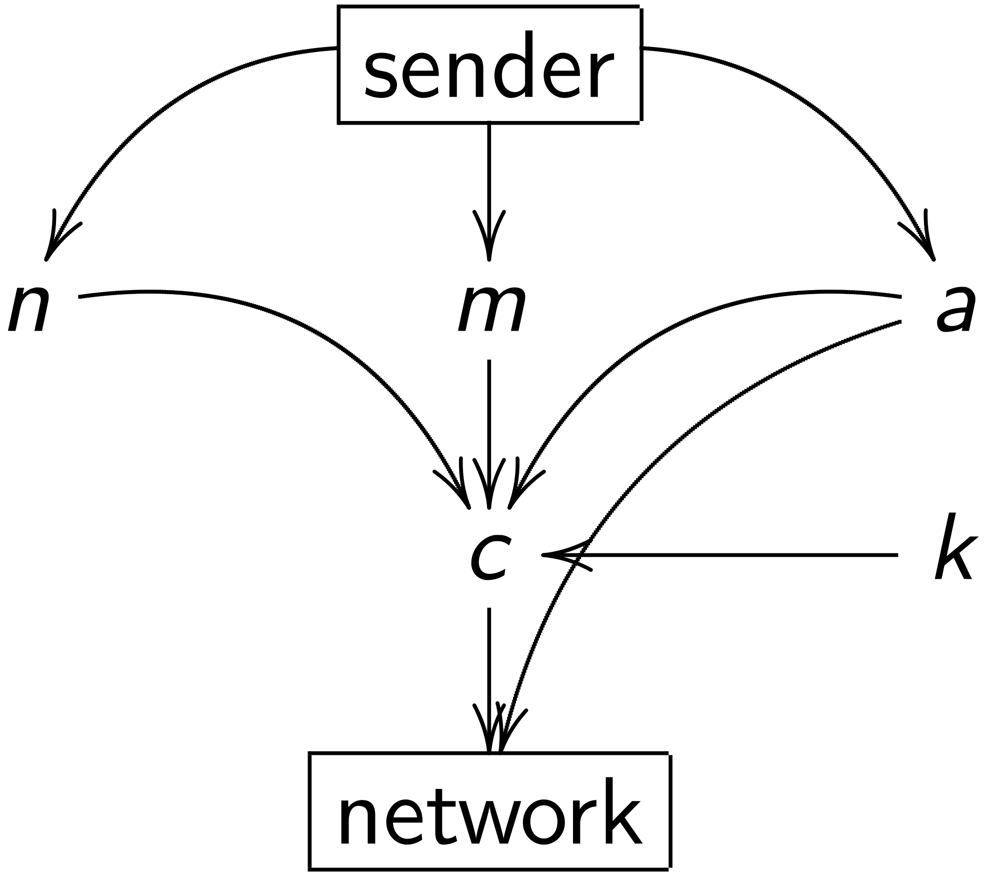
a: variable-length associated data.

m: variable-length plaintext.

c: variable-length ciphertext.

No problem repeating a.

Secret message numbers



k: secret key.

n: secret message number.

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m: variable-length plaintext.

c: variable-length ciphertext.

What is the attacker's goal?

Plaintext corruption,
associated-data corruption,
message-number corruption.
Forge (n, m, a) that receiver accepts but that legitimate sender never encrypted.

"INT-PTXT" (integrity of plaintexts) means protection against such attacks.

Stronger goal:
Forge at least f messages.

Ciphertext corruption.

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Is it better to
randomly pad or *zero-pad* a
strong 112-bit MAC to 128 bits?

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Convince receiver to accept legitimate (n, m, a) more times than legitimate sender sent it.

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Typically delegate solutions to higher-level protocols, but is this optimal?

Plaintext espionage.

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Counterarguments:
Did attacker see everything?
Maybe timestamp is better, but how much does it leak?
Should encrypt by default.

What are the attacker's resources?

Extensive computation.

Are 80-bit keys adequate?

Are 128-bit keys adequate?

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Main arguments for small keys:

1. Smaller keys are cheaper.

2. Attack cost outweighs economic benefit of breaking key, so no sensible attacker will carry out a 2^{80} attack.

Maybe 64-bit keys are enough.

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2. Attacker's cost-benefit ratio is improved by multiple-user attacks, multiple forgeries, etc.

3. Some attackers carry out attacks that are feasible but not economically rational.

What attacks are feasible?

Back-of-the-envelope figures:

2^{57} watts: received by Earth's atmosphere from the Sun.

2^{44} watts: world power usage.

2^{26} watts: one computer center costing 2^{30} dollars.

1 watt: power for
2^{68} bit operations per year
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Scalable quantum computers.
2^{64} simple quantum operations
to find a 128-bit key
using Grover's algorithm.

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Chosen plaintexts, chosen ciphertexts, chosen message numbers.
Consensus: Unacceptable to blame the user. All ciphers must be safe against chosen-plaintext attacks and against chosen-ciphertext attacks.

Many users. How does security degrade with number of keys?

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Repeated message numbers. Minimum impact: Attacker sees whether (n, m, a) is repeated.

Examples of larger impact for many ciphers:

Leak number of shared initial blocks of plaintext.

Leak xor of first non-shared block.

Allow forgery under this n.

Allow forgery under any n'.

Software side channels.

Typical culprits:
secret branches,
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Thefts and monitors.
Attacker steals secret keys.
Can we still protect
past communication?

What performance is measured?

Typical performance metrics for ASICs:

Low energy (joules) per byte.

Low power (watts).

Low area (square micrometers; loosely predicted by "gate equivalents").

High throughput (bytes per second).

Low latency (seconds; very loosely predicted by cycles).

Similar metrics for
FPGAs and software.

For ASICs and FPGAs,
throughput per se
is not a useful metric
without limit on area (or power).

Parallelize across blocks
or across independent messages
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Fix: measure
ratio of area and throughput, i.e.,
product of area and time per byte.

What operations are measured?

Authenticate only, or encrypt and authenticate?

Cost per byte of a can be far below cost per byte of m.

Send valid data, receive valid data, or receive invalid data?

"Encrypt then MAC" skips cost of decryption for forgeries.

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Different area targets: encryption/authentication circuit; verification/decryption circuit; circuit that can dynamically select either operation.

Plaintext length and associated-data length.

Huge impact on performance.

Warning: Do not solely compare "overhead" of two ciphers. Cipher with larger "overhead" can be consistently faster.

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Number of inputs.
e.g. reduce latency by processing several AES-CBC messages in parallel. Simplest if many messages have the same length.

Number of times a key is used.

Most (not all) ciphers
expect precomputation of
"expanded keys".

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General input scheduling.
Reduce latency by processing key and nonce before seeing associated data; associated data before plaintext.

Scheduling within plaintext; scheduling within ciphertext.

Typically receive data from left to right. Reduce *latency* by processing earlier parts first.

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Also save *area* if large plaintext does not need large buffer. Warning: Large ciphertext needs large buffer or analysis of security impact of releasing unverified plaintext.

Intermediate tags.

Higher-level protocol splits long plaintext into packets, each separately authenticated. $\Rightarrow$ small buffer is safe.

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Single circuit for, e.g., hash and authenticated cipher; for different key sizes; etc.

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Cache context.
How well does the system fit into fast memory?

Support for cryptanalysis

Simplicity.
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Proofs.
The phrase "proof of security" is almost always fraudulent.
Proof says that attacks *meeting certain constraints* are difficult, or *as difficult as another problem*.
Can be useful for cryptanalysts.