Lecture 8 - Transport Security

MIT - 6.1600
Fall 2022
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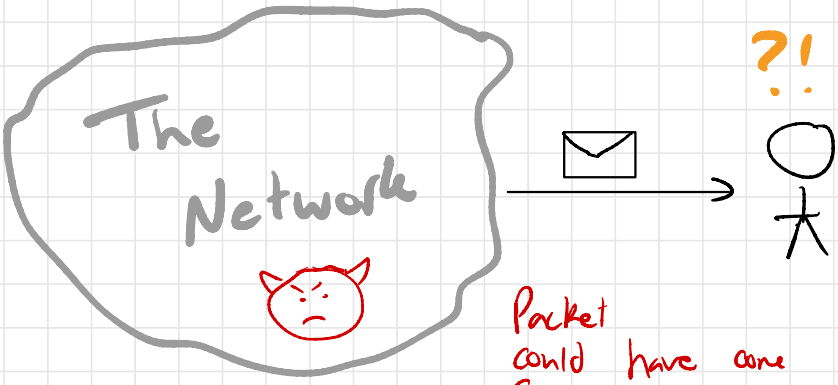
Plan

- Network (in)security
- Encryption
  * Weak defn (CPA)
  * One-time pad
  * Encryption from PRF
- What's missing

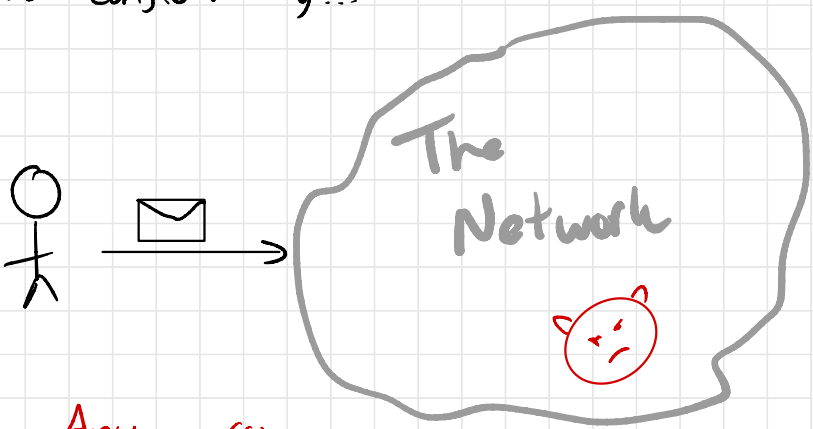
Background

Mental model for integrity...

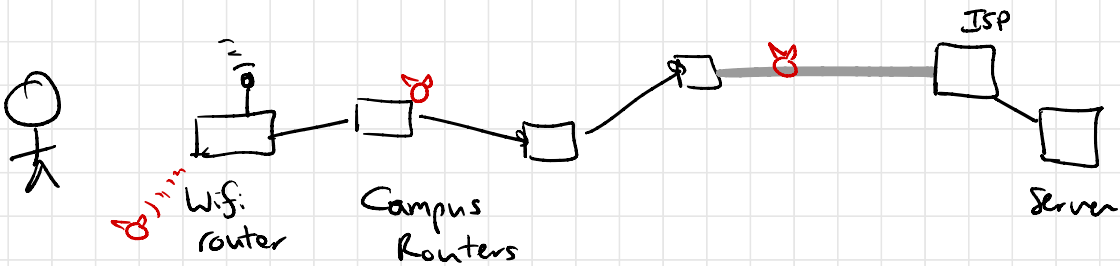


Packet could have come from anyone

For confidentiality...



Anyone can read the packets you send across a network.



Many network places for an adversary to see your traffic — every hop!

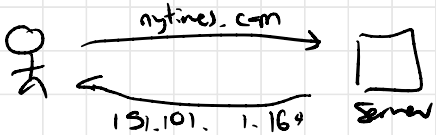
↳ Attacker doesn't need privilege — see tcpdump on LAN

Standard network protocols provide NO AUTH/ENC!

- Ethernet – LAN
- IP
- DNS
- email (SMTP, POP, IMAP)
- HTTP – web content

⟹ When you query a DNS server.

(a) Think of your query as being public
(b) Think of the answer as coming from an adversary.

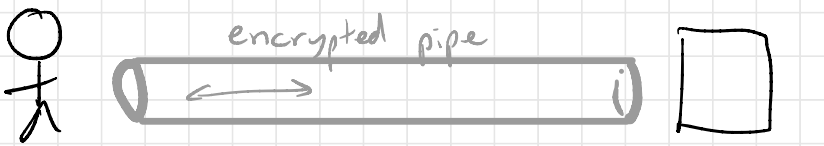


Really?! Yes.

How can we get any integrity/privacy?
↳ Crypto: encryption & authentication.

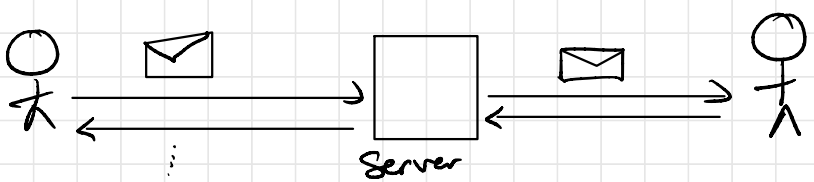
Systems in which encryption appears...

Encrypted interactive streams (web, SSH, email, ...)

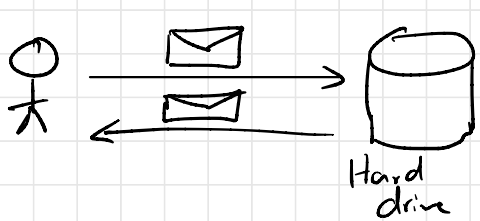


Like TCP (bidirectional stream)
+ encryption & auth... more later

High-latency encrypted (WhatsApp, Signal, iMsg, ...)



File encryption (PGP, pass mgr, ...)



Plan

* Begin with simplest form of encryption
* Build up to fancier / more powerful ones
* End module by seeing encryption in s:th

Roadmap

Today: Weak encryption for fixed-len msgs with shared key

Next time: Strong (authenticated encryption) encryption for var-len msgs "

Next week: " " without shared key

In two weeks: → " for streams "

↳ Encryption in applications (protocol-level attacks, extra properties)

Finally: Problems that encryption doesn't solve.

↳ e.g. hiding length of msg, recipient, ...

Note: You should almost never implement these things yourself! Better to use solid library when you can!

Encryption syntax

security parameter

		today:	
key space	$\mathcal{K}$	$\{0,1\}^n$	($n = 128, 256$)
msg space	$\mathcal{M}$	$\{0,1\}^n$	
ciphertext space	$\mathcal{C}$	$\{0,1\}^{2n}$	

$$\text{Enc}: \mathcal{K} \times \mathcal{M} \longrightarrow \mathcal{C}$$

$$\{0,1\}^n \times \{0,1\}^n \longrightarrow \{0,1\}^{2n}$$

$$\text{Dec}: \mathcal{K} \times \mathcal{C} \rightarrow \mathcal{M}$$

(we will see some schemes in which decrypt can also output "fail.")

What does it mean for an encryption scheme to be secure?

"Eavesdropper can't recover msg"
↳ Admits schemes that leak ½ of msg bits.

"Eavesdropper can't recover any bit of msg"
↳ Admits schemes that leak whether two ctext bits encrypt same plaintext bits

"Eavesdropper can't distinguish ctext from random string"
↳ Maybe too strong? Seems ok to have first bits of ctext always be 0000...

⇒ Not so easy to cook the right defn!

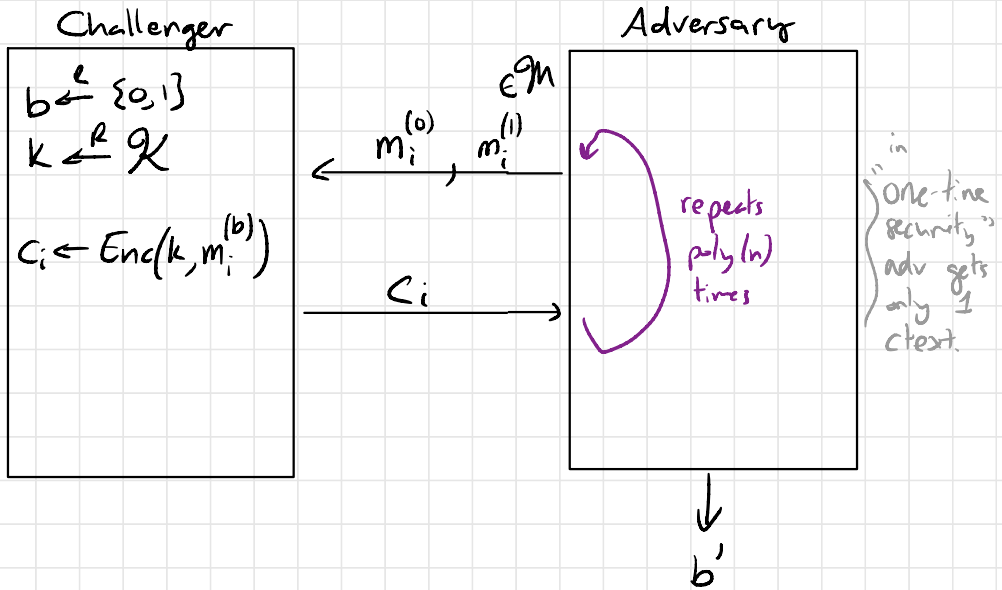
Weak security...

Indistinguishability under chosen plaintext attack (CPA)

also IND-CPA

Intuition: Scheme is CPA secure if attacker can't tell which of two chosen msgs are encrypted

Enc scheme (Enc, Dec) is CPA-secure if ∀ eff advs A, A wins game w prob $\leq \frac{1}{2}$ + negl.



Attacker wins if $b = b'$

Even if attacker gets to choose msgs being encrypted, still can't learn distinguish one from another.

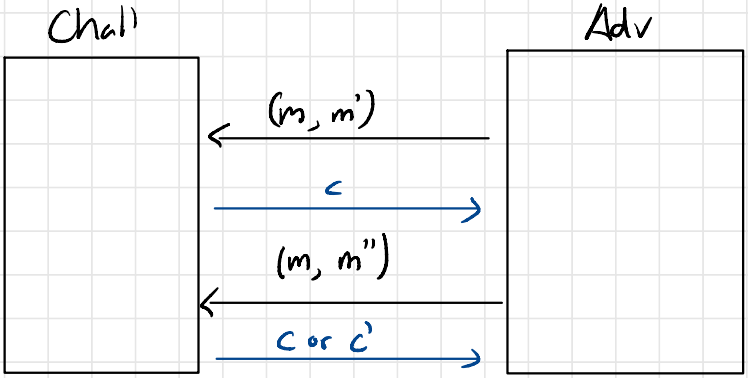
Non-obvious fact:

For encryption scheme to be CPA secure, it MUST be randomized.

If not, same msg → same ctext

↳ Attacker can detect when same msg was sent twice

↳ Enough to win in CPA game.



In practice, leaking duplicate msgs is often very problematic.

↳ Encrypt bytes of an image one by one...

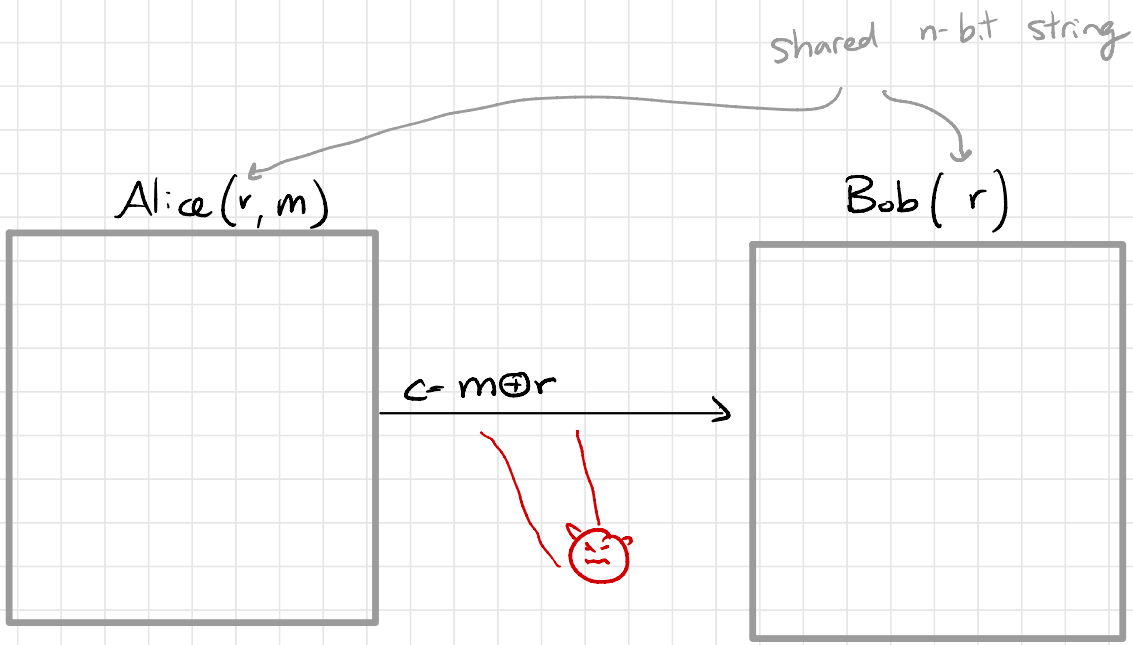
↳ Attacker can inject traffic into stream

Secure encryption schemes must always use randomness...

(Miller 1882, Vernam 1991, Mauborgne ...)

One-time pad

- The first encryption scheme with a strong theoretical foundation
- Widely used in practice through 1970s.



Benefit: * "Perfect" security — for any c, all ms are equally likely.
* Secure against comp. unbounded attacker

One-Time Pad

Problem: Need new r value for each msg.
↳ inherent for perfect info-theoretic security.
It's called the one-time pad for a reason.

TWO-TIME PAD ATTACK

$$c_1 = m_1 \oplus r$$
$$c_2 = m_2 \oplus r$$
$$\overline{c_1 \oplus c_2 = m_1 \oplus m_2}$$

From: henryc g@mit.edu ...
Subject: _____ ...

If attacker knows bits of m_1, gets plaintext of m_2.

⇒ OTP is maybe ok for embassys, not for high-b/w computer systems

Historical aside: Venona (1943, ...)
- USSR used OTP for mil & diplomatic comms
- Duplicated pads shipped to a number of embassies
⇒ Two-time pad attack!
- US got copies of all telegrams (network is insecure!)
- Decryption continued through 1980. (!)

Idea: Use pseudorandomness (PRF) to generate many pads from short keys.

Weak (CPA-secure) encryption for fixed-length msgs.

Uses PRF $F: \{0,1\}^n \times \{0,1\}^n \to \{0,1\}^n$

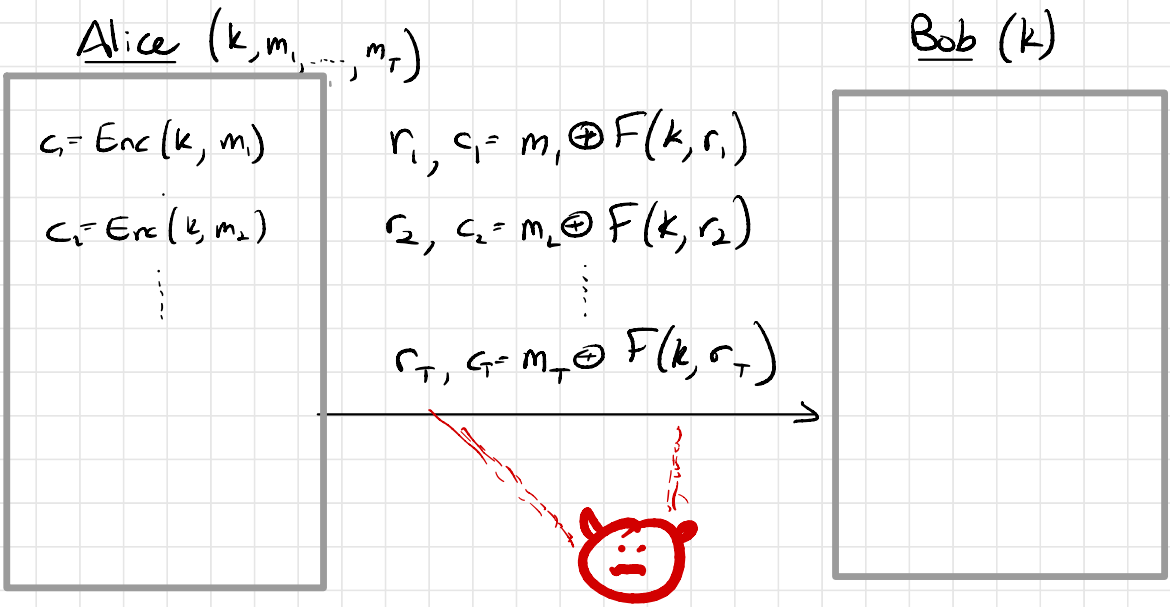
Enc (k, m):

$r \xleftarrow{R} \{0,1\}^n$ ("nonce")

output $(r, F(k,r) \oplus m)$

Dec $(k, (r,c))$:

output $c \oplus F(k,r)$



Notice: the block size n needs to be big enough to avoid repetitions of r values.

$\{r_1, \ldots, r_T\}$ should be distinct

What happens if not? Attacker sees:

$$(r, c_1 = m_1 \oplus F(k, r))$$
$$(r, c_2 = m_2 \oplus F(k, r))$$
$$\Rightarrow c_1 \oplus c_2 = m_1 \oplus m_2$$

"Two-time pad attack"

By Birthday Paradox...

Need: $\frac{T^2}{2^n} \ll 1$

AES has $n = 128 \Rightarrow$ After 2^{30} msgs or so, need to change keys. ("rekey")

Security intuition

Attacker sees pairs

where $k \xleftarrow{R} \mathcal{K}$ is a random secret key.

$$(r_1, \; m_1 \oplus F(k, r_1))$$
$$\vdots$$
$$(r_T, \; m_T \oplus F(k, r_T))$$

By PRF security property (& provided that all r's distinct)

$$\Downarrow$$

$$(r_1, \; m_1 \oplus \text{random}_1)$$
$$\vdots$$
$$(r_T, \; m_T \oplus \text{random}_T)$$

$$\Downarrow$$

One-time pad security. ✓

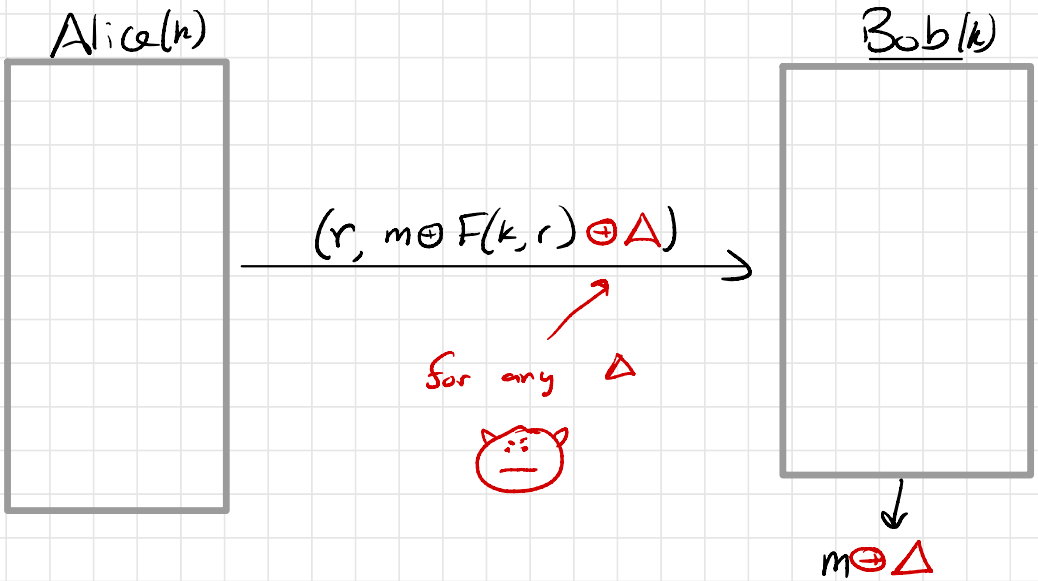
Note:

* Security argument here only uses the fact that $(r_1, \ldots, r_T)$ are distinct whp.

* If sender and receiver can have state, can set $r_1 = 1, r_2 = 2, r_3 = 3, \ldots$
  → Then, no need to send r values.

Why do we call CPA-secure encryption "weak"?

PROBLEM 1: CPA security definition guarantees nothing about integrity/authentication.



m = "Send $100 to Srini"

Δ =  ← "Srini" ⊕ "Yael!"

m⊕Δ "Send $100 to Yael!"

Why do we call CPA-secure encryption "weak"?

PROBLEM 2: When used in the context of a larger system, can create all sorts of security problems.

(More generally, security defn says nothing about what happens if Bob decrypts an adv chosen ct.)

↳ Might have an example on the next theory lab!

Enc(k, "date ||