Four Attacks and a Proof for Telegram

Joint Latvian-Estonian Theory Days 2022
May 06, 2022

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ROYAL HOLLOWAY UNIVERSITY OF LONDON

ETH zürich

Based on a paper to appear at IEEE S&P 2022.
More information at https://mtpsym.github.io/

Telegram

Monthly active users in Jan 2022:

According to Statistica 2022.

WhatsApp	$2000 \cdot 10^6$
WeChat	$1263 \cdot 10^6$
FB Messenger	$988 \cdot 10^6$
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Collective Information Security in Large-Scale Urban Protests: the Case of Hong Kong

Martin R. Albrecht, Jorge Blasco, Rikke Bjerg Jensen, and Lenka Mareková, *Royal Holloway, University of London*

Predominant in Hong Kong protests.

Perceived more secure than competitors.

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Advantages of **Telegram**:

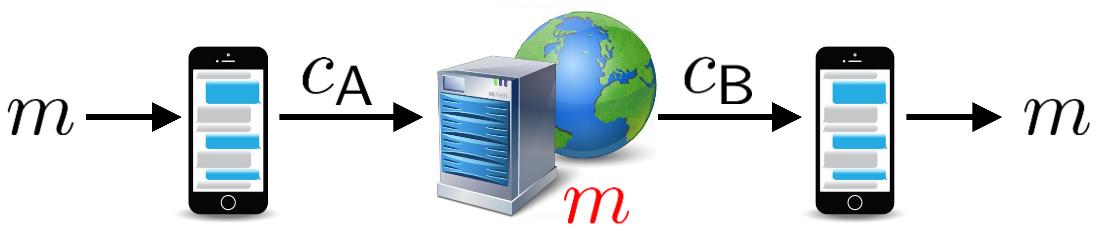
Group chats for up to 200000 people.

Support of pseudonyms in group chats.

Other features:

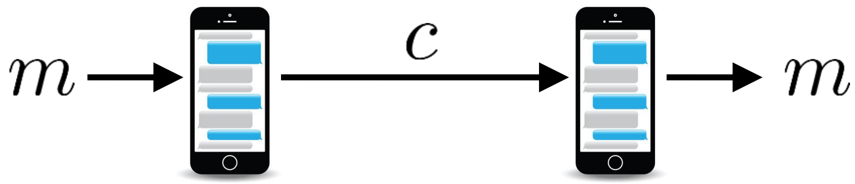
…, anonymous polls, disappearing messages, timed or scheduled messages, ability to delete messages sent by others, …

Cloud Chats



	Cloud Chats	Secret Chats
Encryption	client-server	end-to-end
Groups	✓	✗
1-on-1	✓	✓
Enabled by default	✓	✗

Secret Chats



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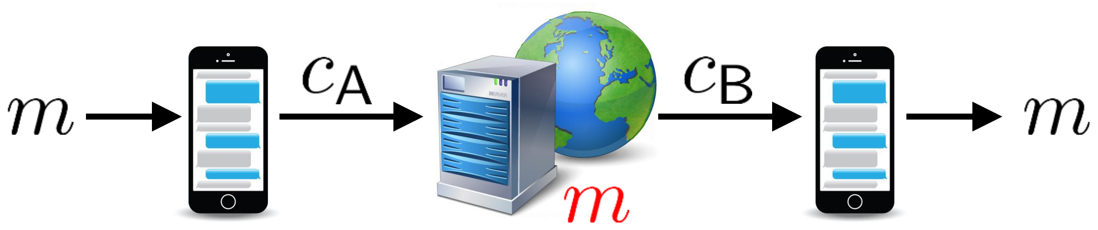

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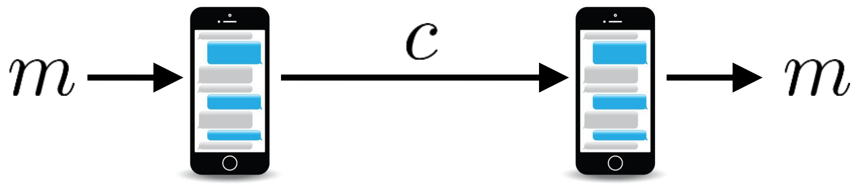

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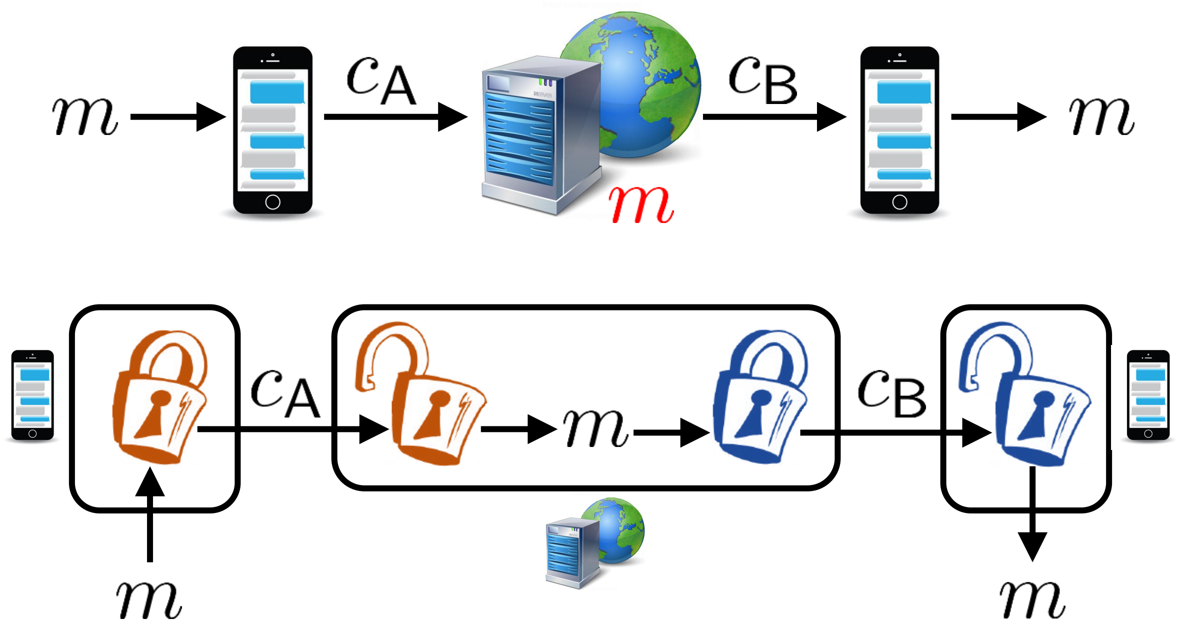
MTProto protocol

Encryption Decryption

Cloud Chats



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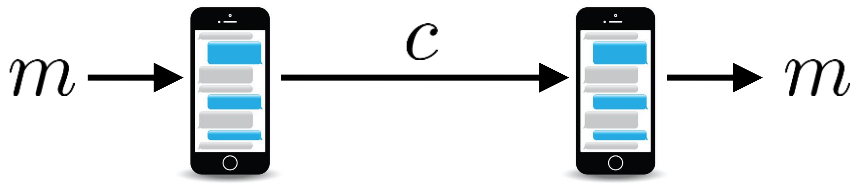

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MTProto protocol

 Encryption  Decryption

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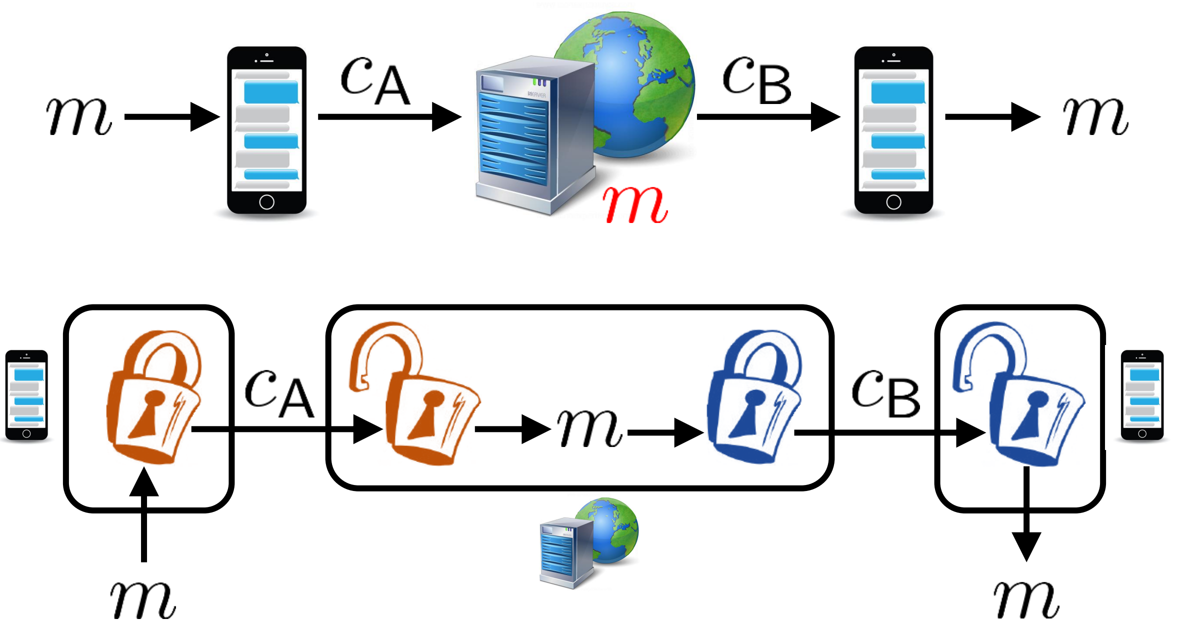

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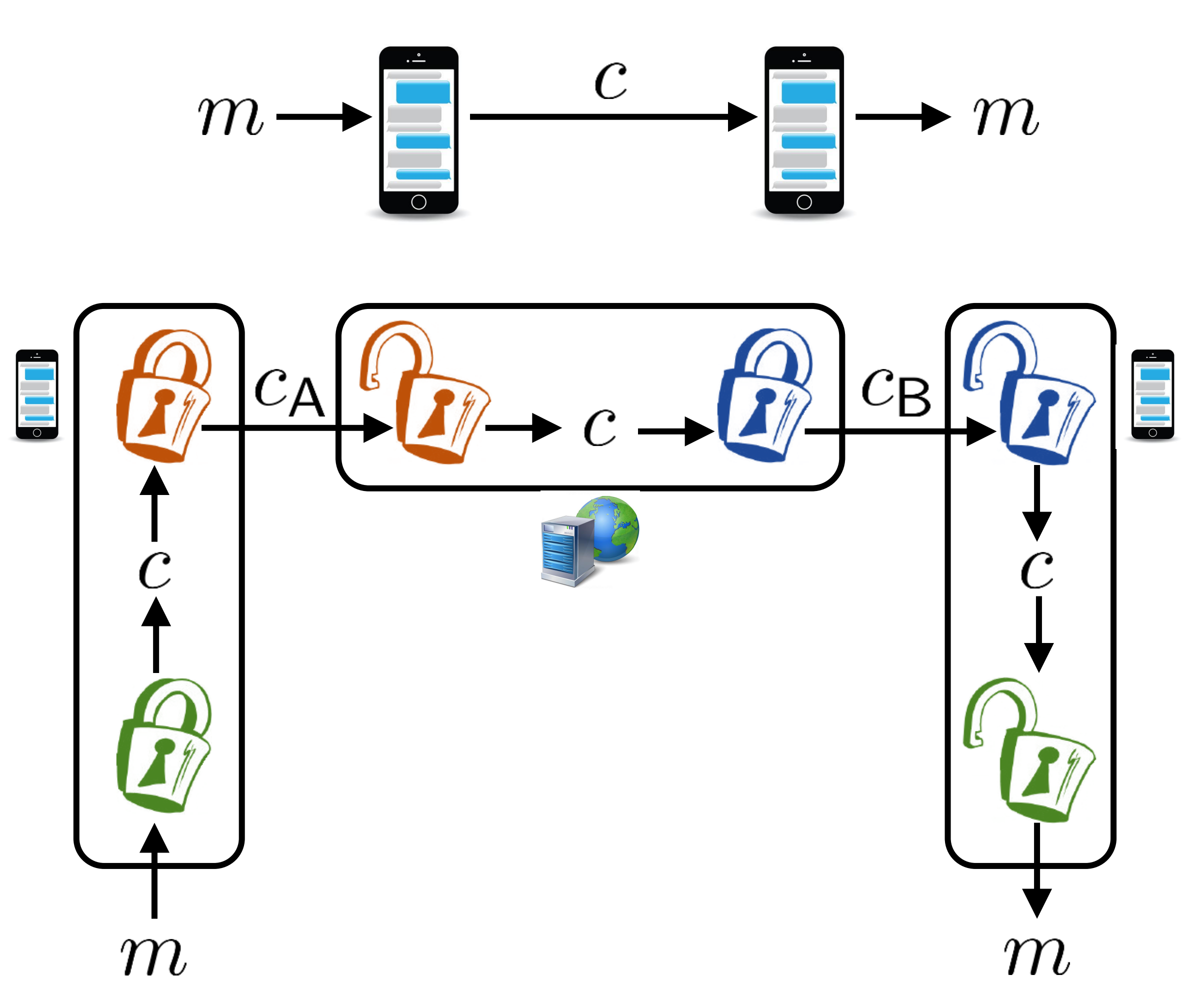

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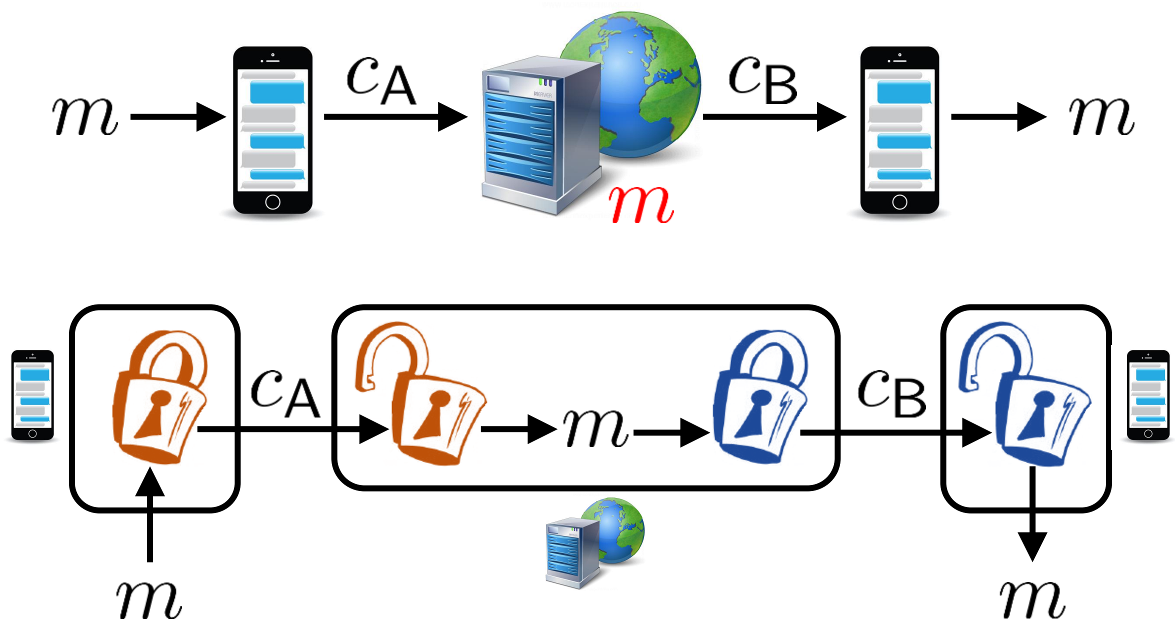

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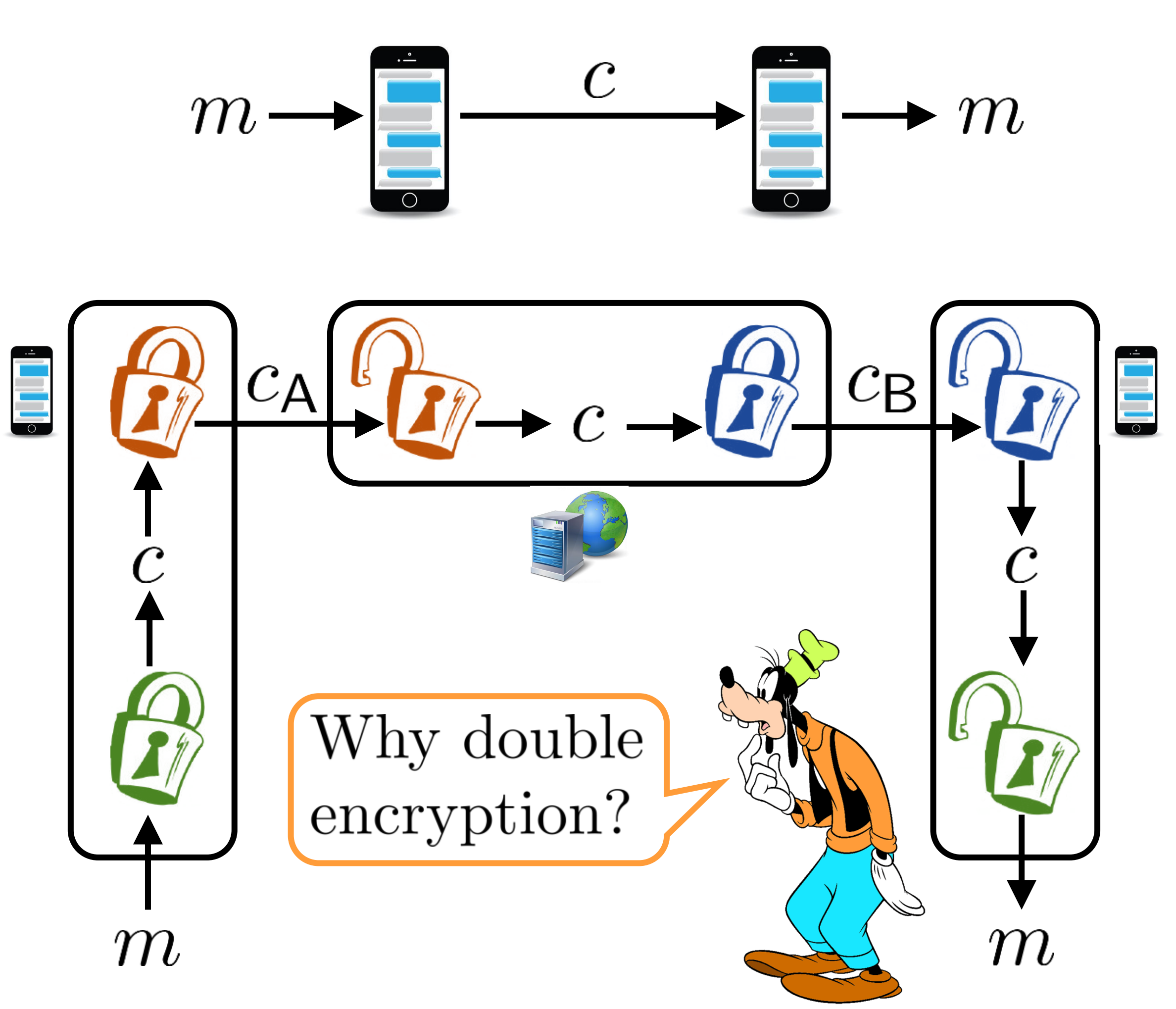

MTProto protocol

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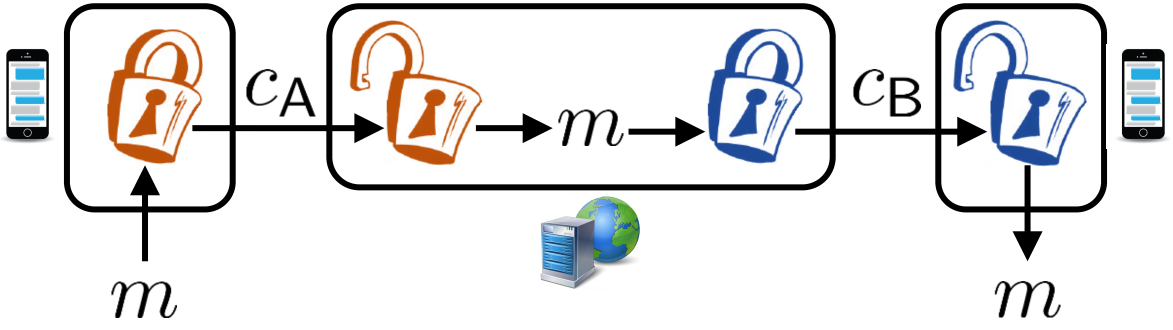

MTProto 2.0

MTProto 2.0 is **Telegram**'s equivalent of the TLS record protocol.

2013 **Telegram** launched with MTProto 1.0.

2016 MTProto 1.0 is not CCA-secure [JO16].

2017 Input validation bug (message replay) [SK17].
Telegram released MTProto 2.0.

2018 Input validation bug in key exchange [K18].

2020 MTProto 2.0 secure in symbolic model [MV20].
(assuming ideal building blocks)

MTProto 2.0 is not well-studied.

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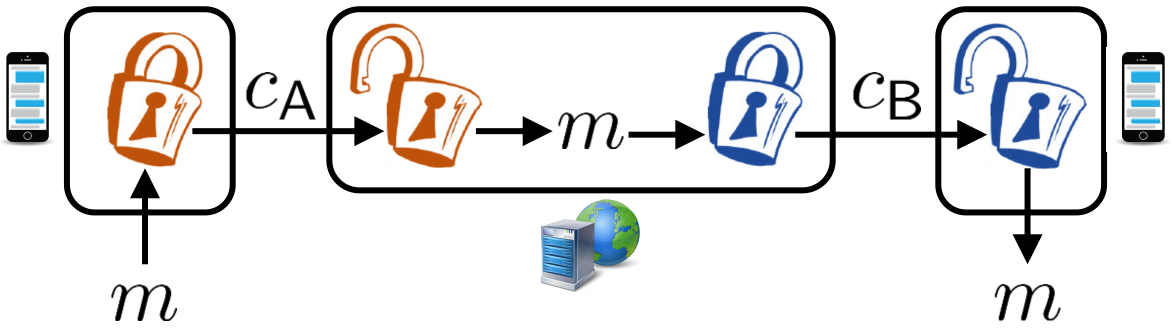

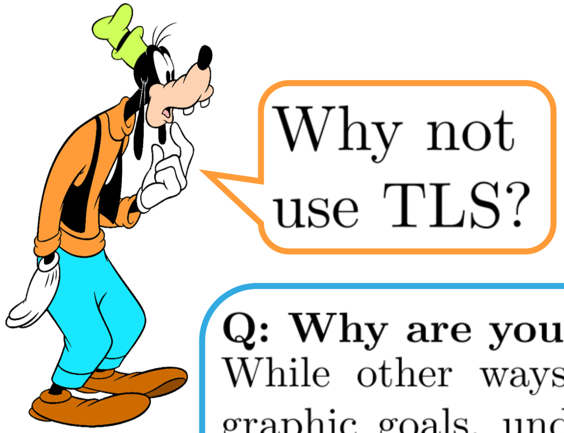

https://core.telegram.org/techfaq

Telegram FAQ

Q: Why are you not using X? (insert solution)
While other ways of achieving the same cryptographic goals, undoubtedly, exist, we feel that the present solution is both robust and also succeeds at our secondary task of beating unencrypted messengers in terms of delivery time and stability.

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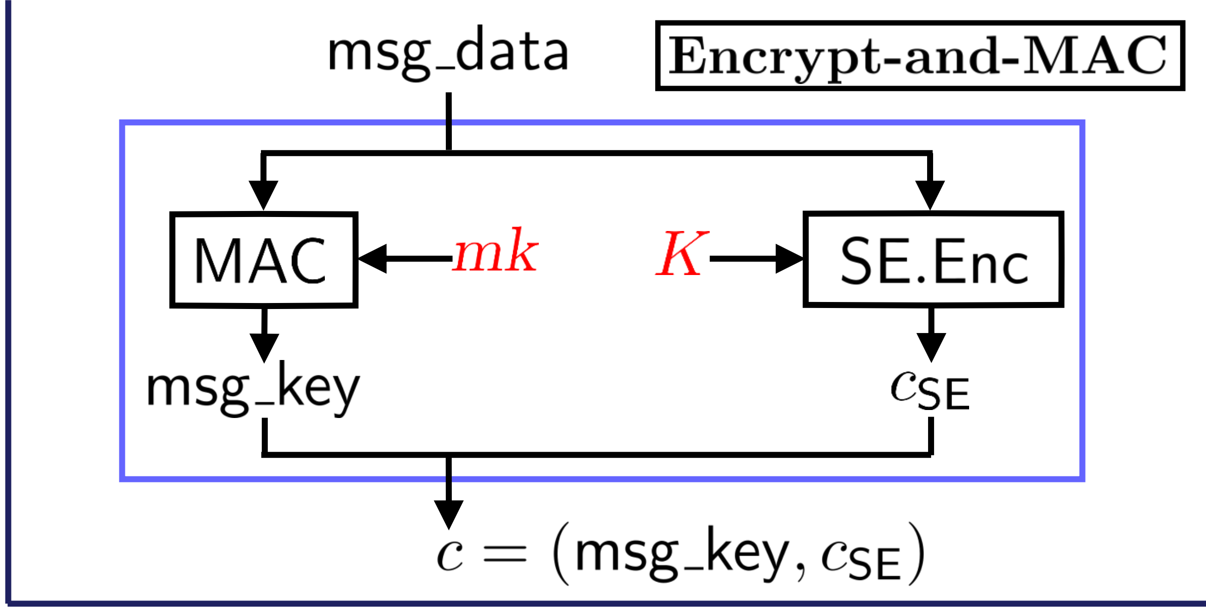
The Design of MTProto 2.0



MAC – Message Authentication Code
SE – Symmetric Encryption Scheme

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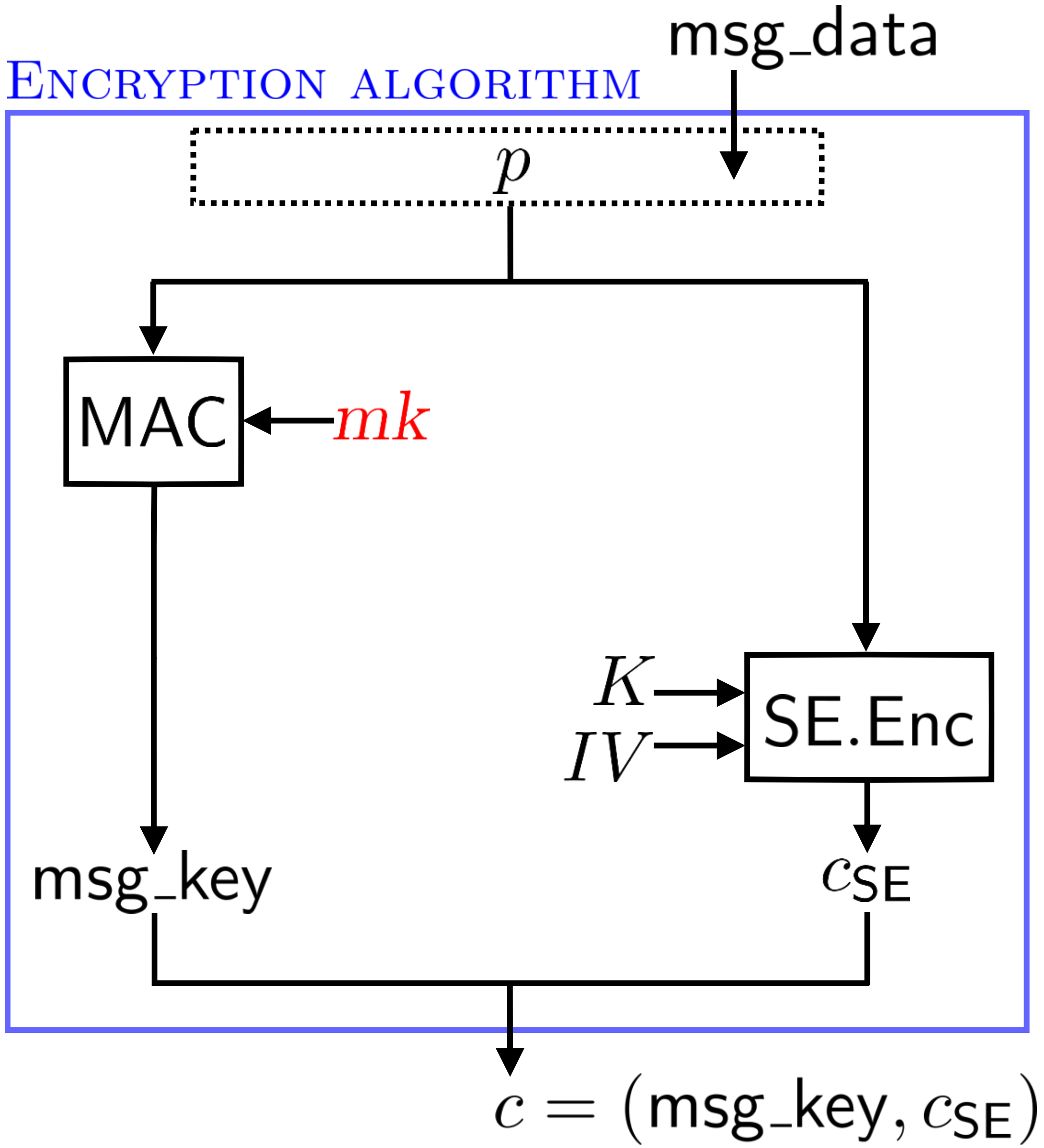

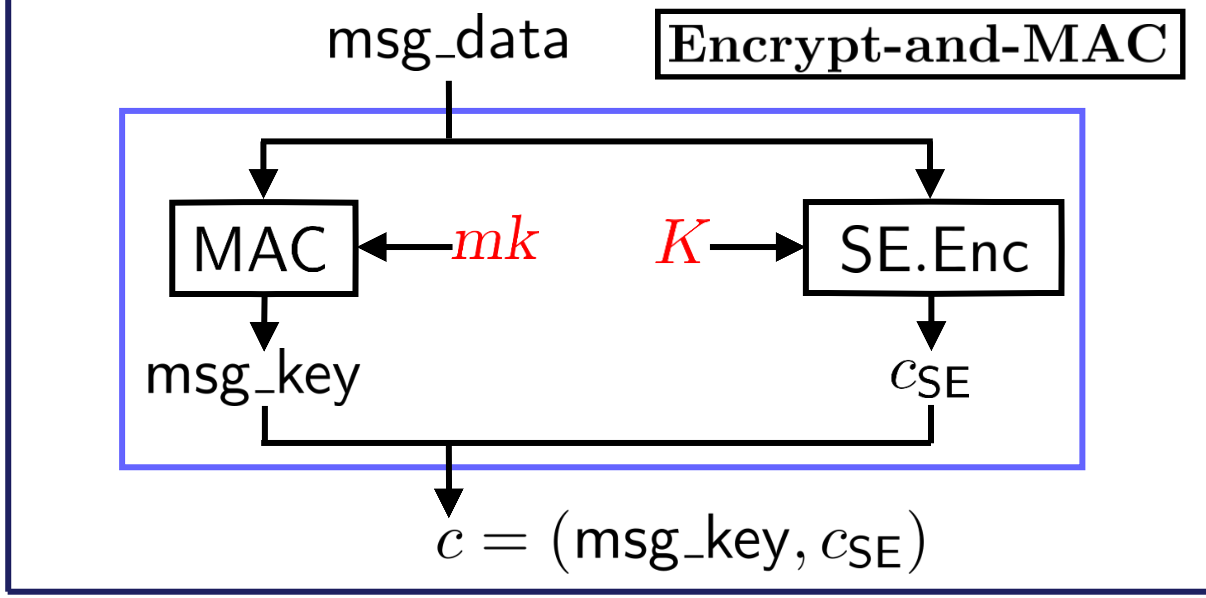

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payload p

Random values:	server_salt	64 bits
	session_id	64 bits
Message sequence number:	msg_seq_no	96 bits
Message length:	msg_length	32 bits
Message body:	msg_data	$\leq$ 16 MB
Random padding:	padding	12-1024 bytes

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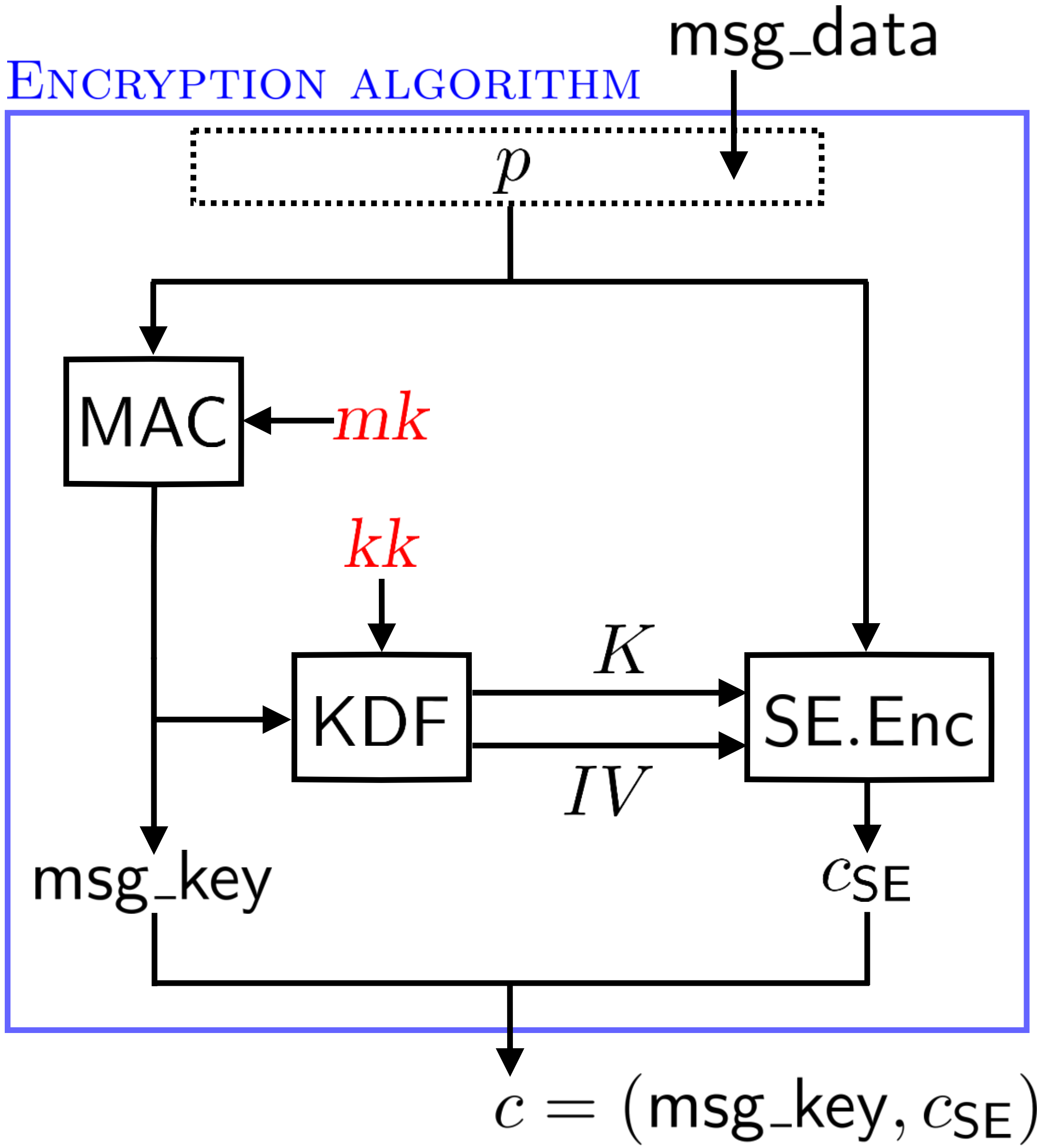

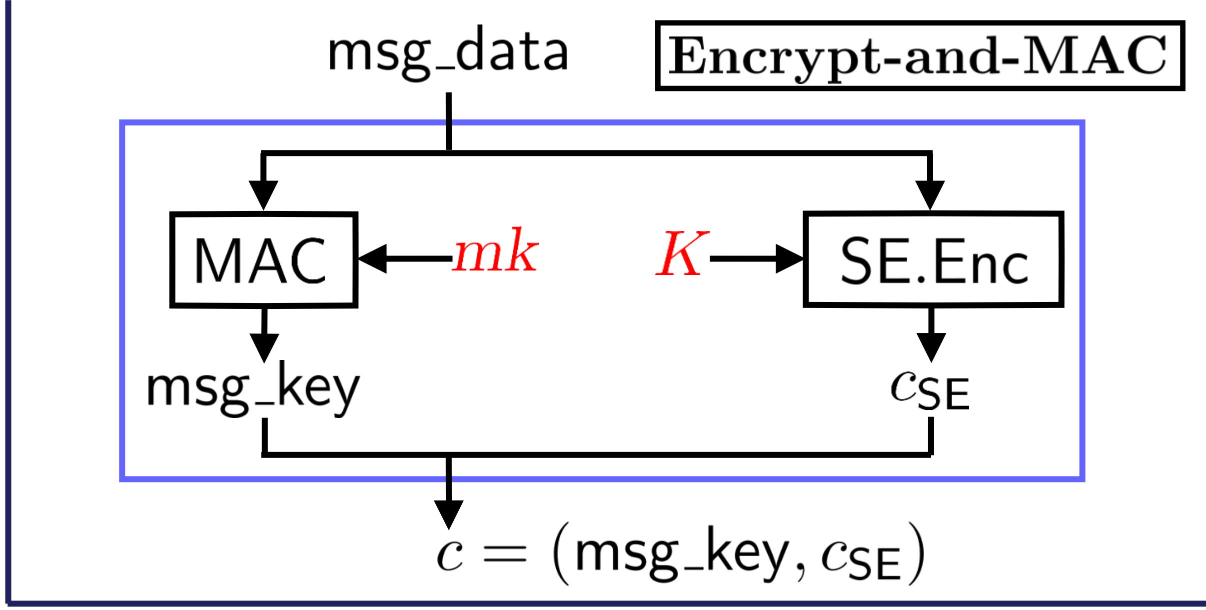

MAC – Message Authentication Code
SE – Symmetric Encryption Scheme
KDF – Key Derivation Function

payload p

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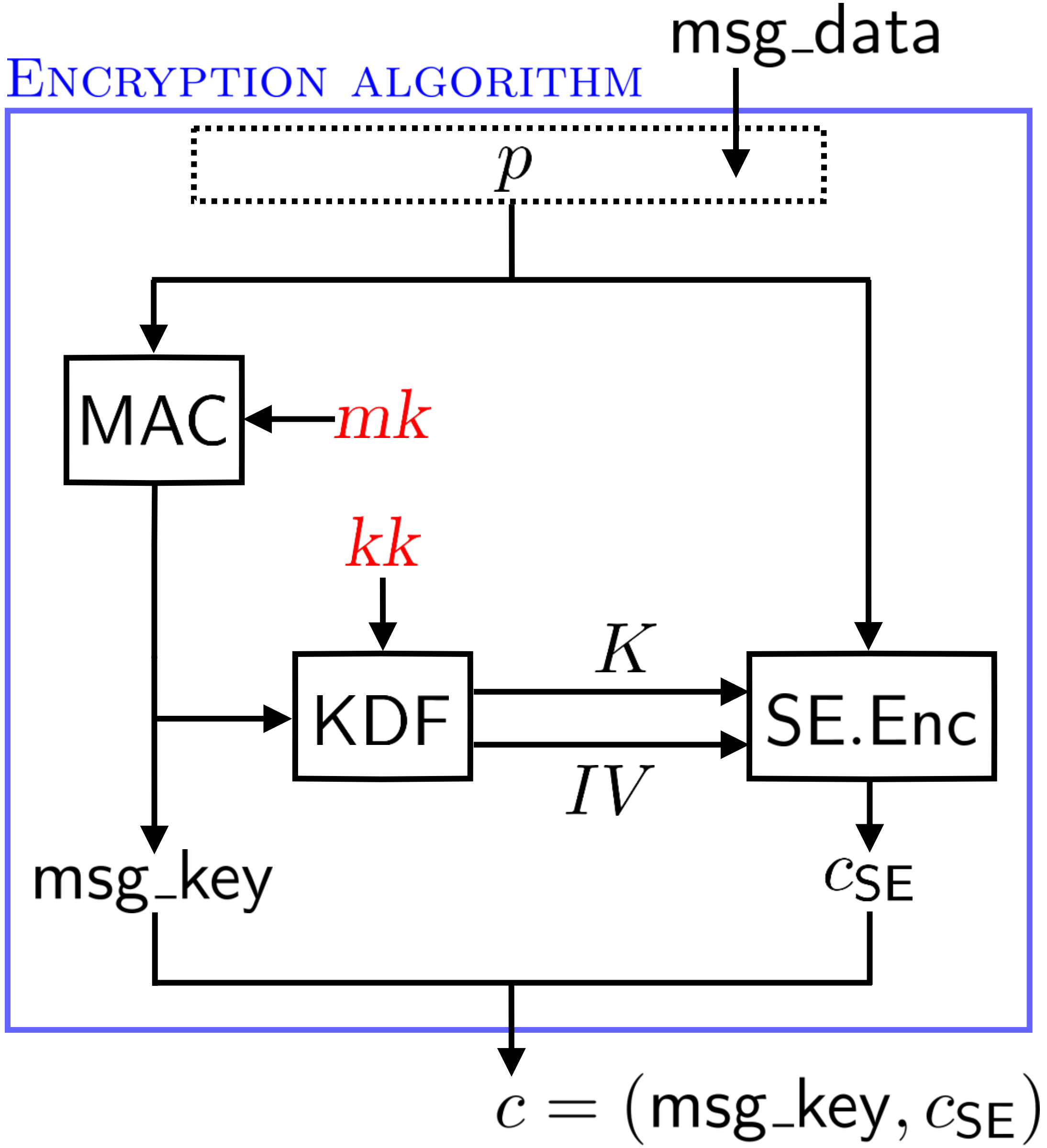


MTProto defines **ad-hoc** MAC and KDF schemes.

$\underline{\mathsf{MAC}(mk, p)}$

$\mathsf{msg\_key} \leftarrow \mathsf{SHA\text{-}256}(mk \| p)[64:192]$

Return $\mathsf{msg\_key}$

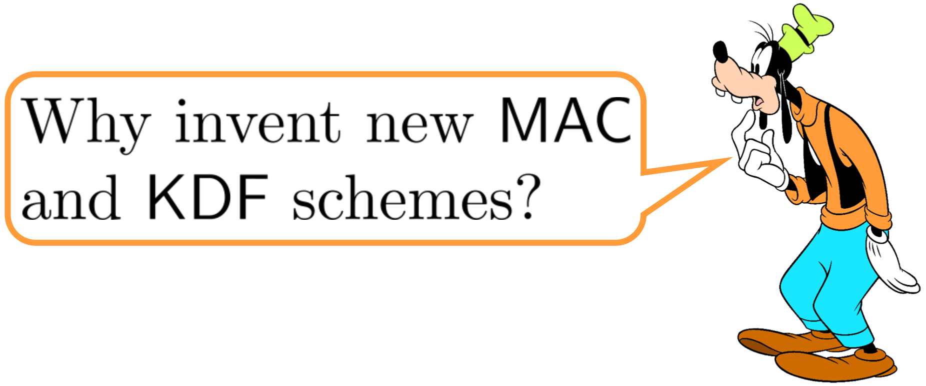
$\underline{\mathsf{KDF}(kk, \mathsf{msg\_key})}$

$(kk_0, kk_1) \leftarrow kk$

$K \leftarrow \mathsf{SHA\text{-}256}(\mathsf{msg\_key} \| kk_0)$

$IV \leftarrow \mathsf{SHA\text{-}256}(kk_1 \| \mathsf{msg\_key})$

Return K, IV



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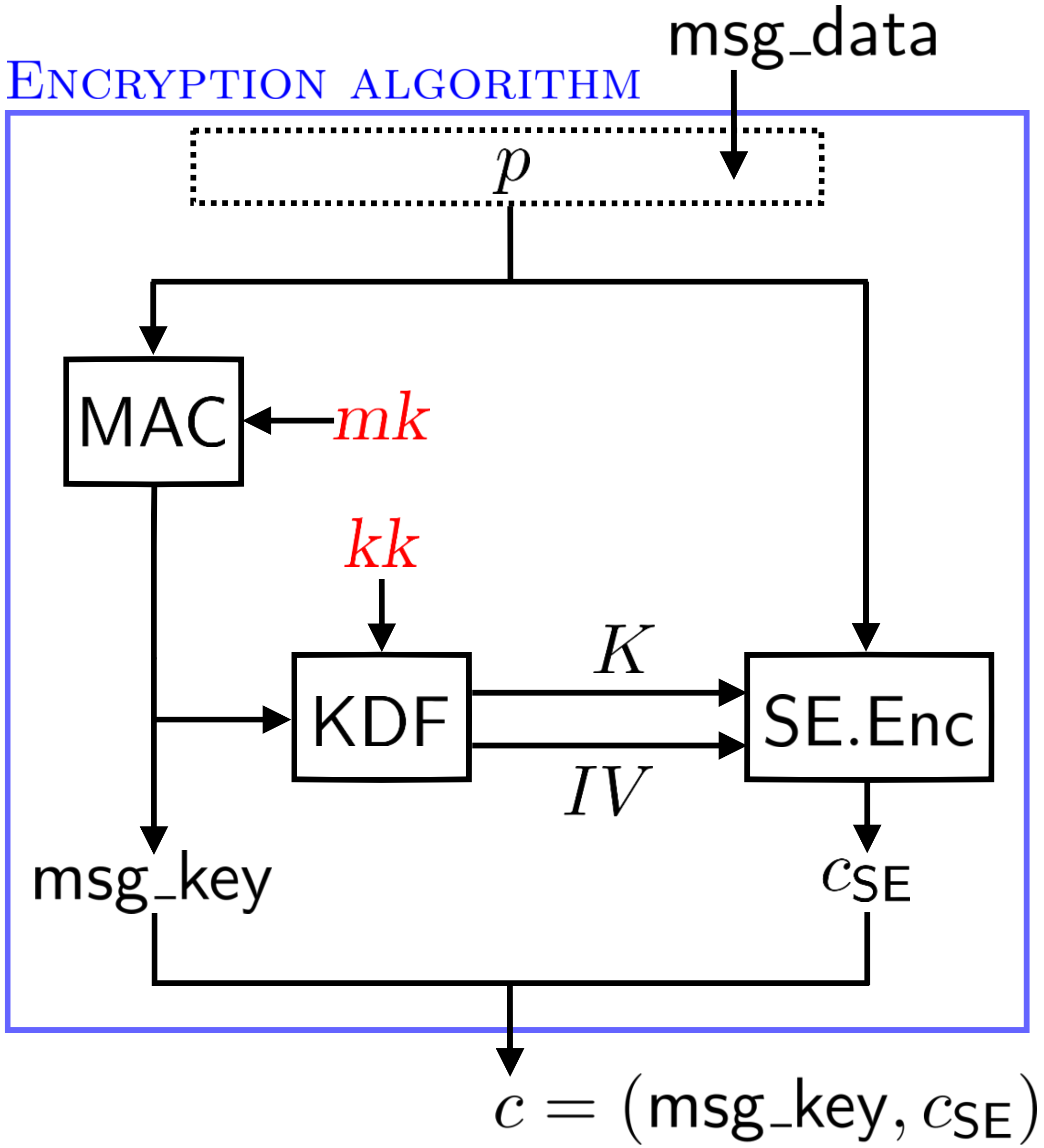
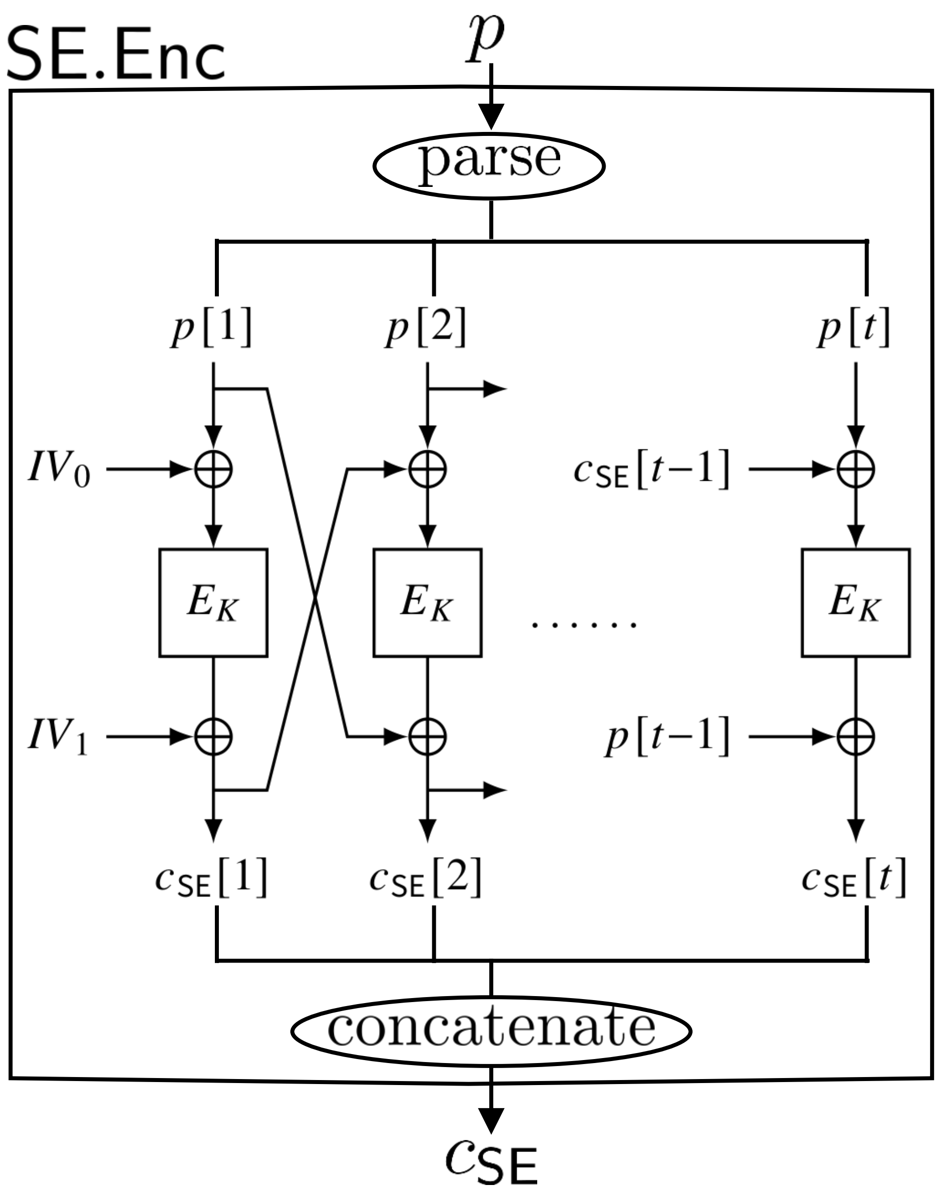


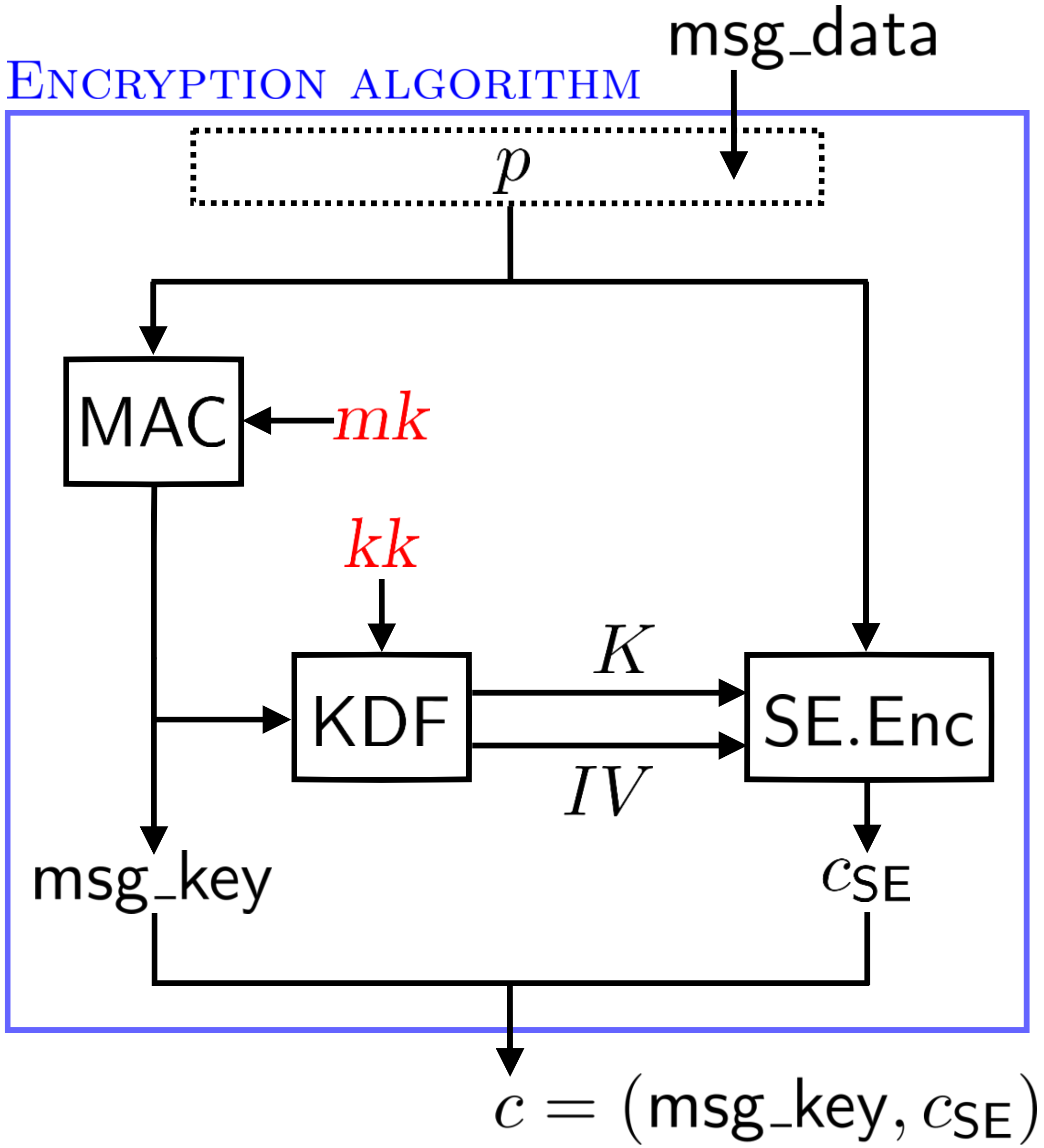
Infinite Garble Extension (IGE)

block cipher mode of operations



Not commonly used and not well studied.

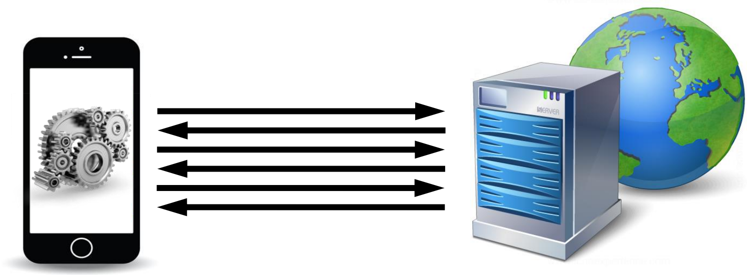
The Design of MTProto 2.0



How are mk and kk derived?

The Design of MTProto 2.0

MTProto uses Diffie-Hellman key exchange to agree on a raw shared secret g^{xy}.



raw g^{xy} value (2048-bit long)

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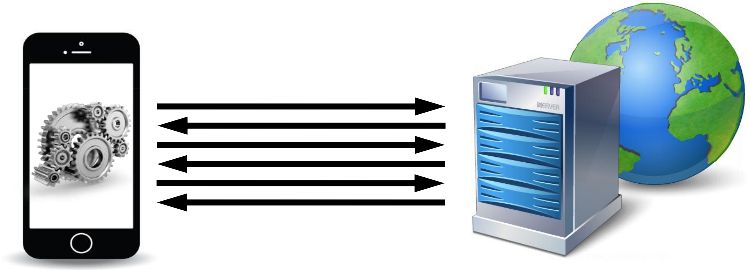
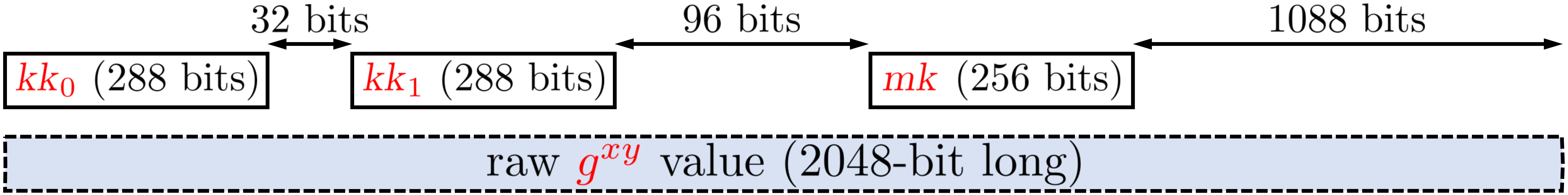


Keys used for **client** → **server** encryption.



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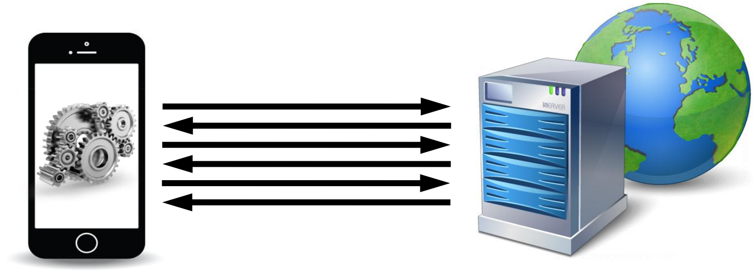

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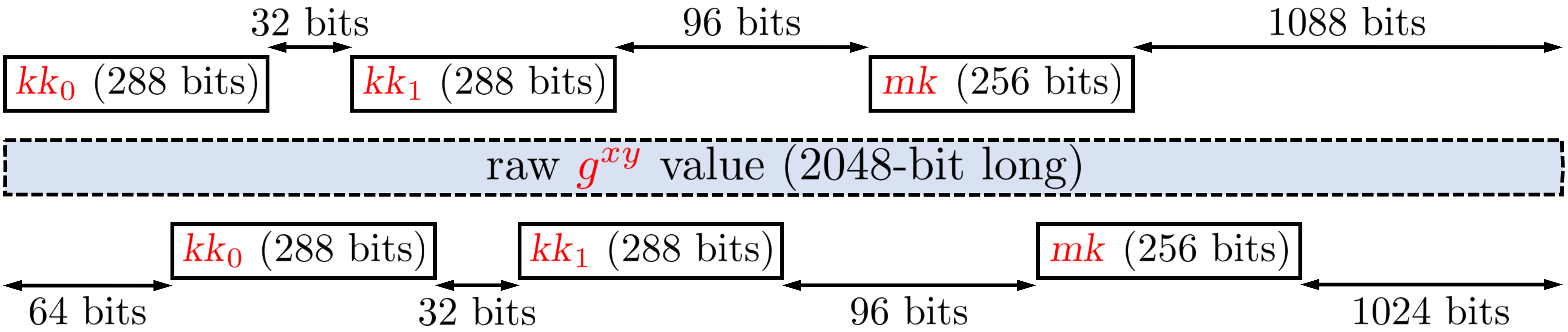

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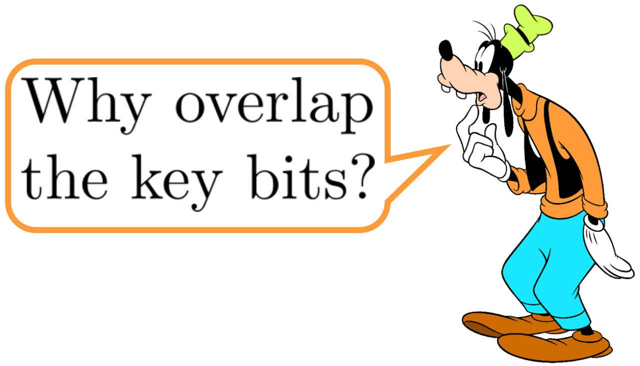
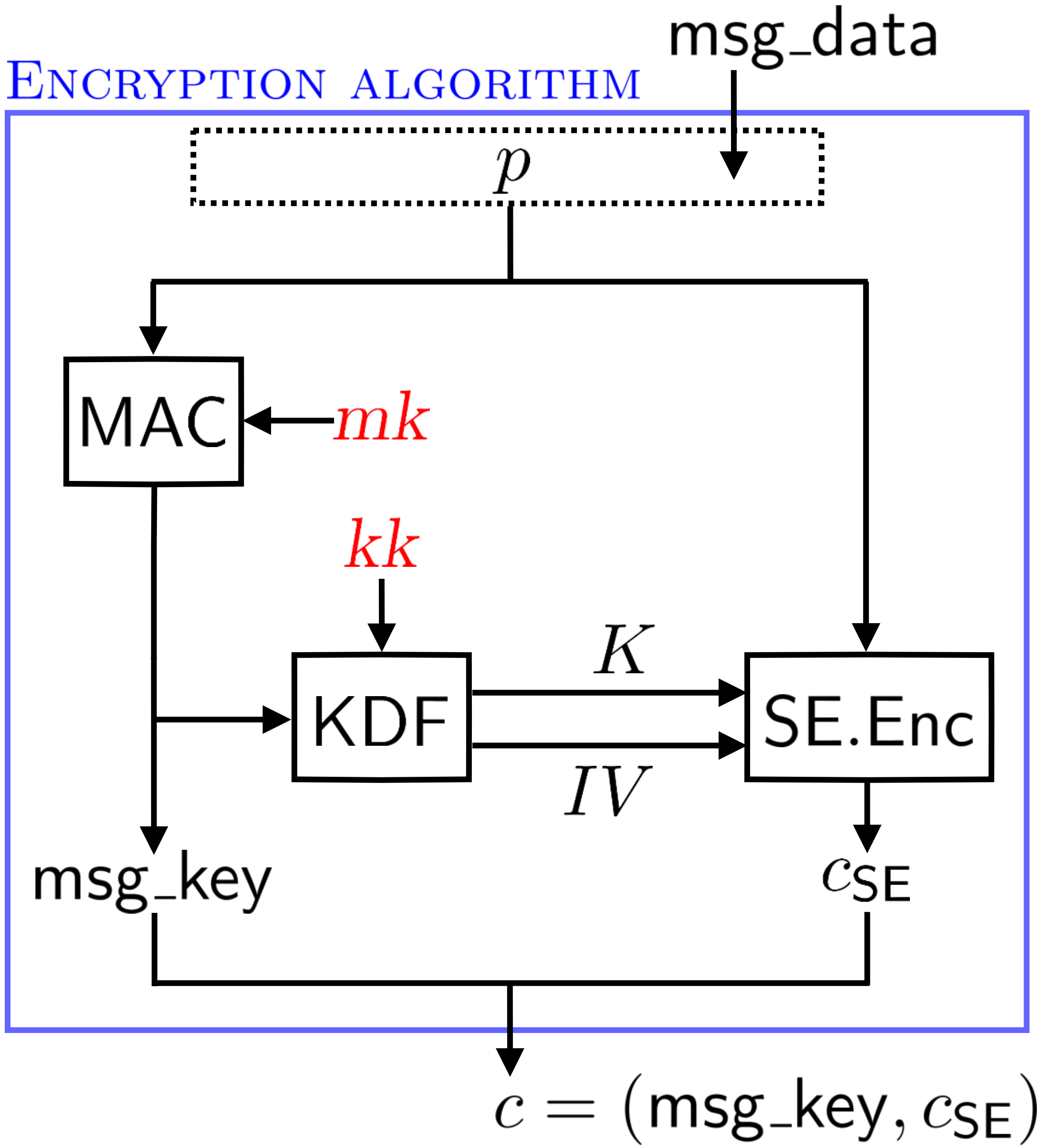
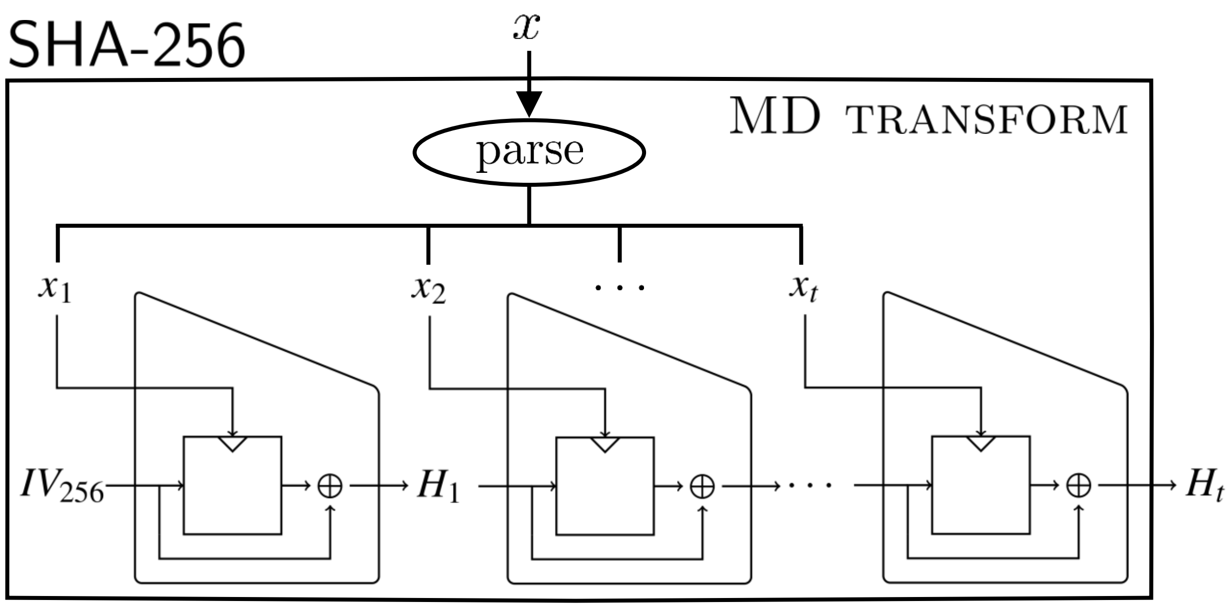
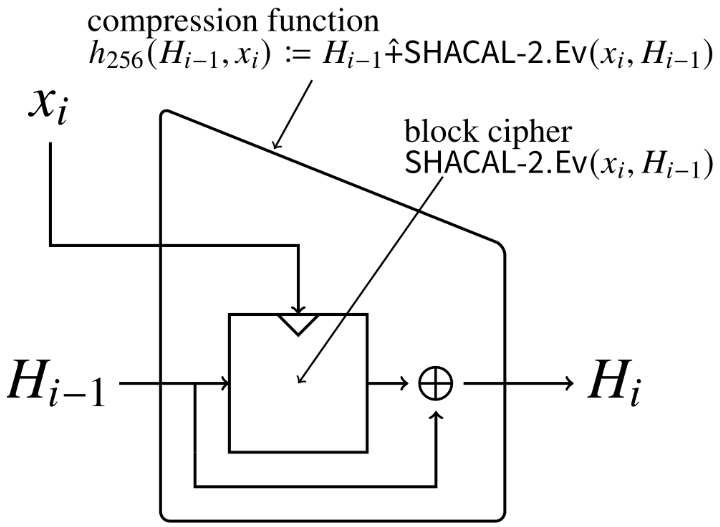


The Design of MTProto 2.0

We proved a variant of MTProto 2.0 is secure.
This comes with many caveats.







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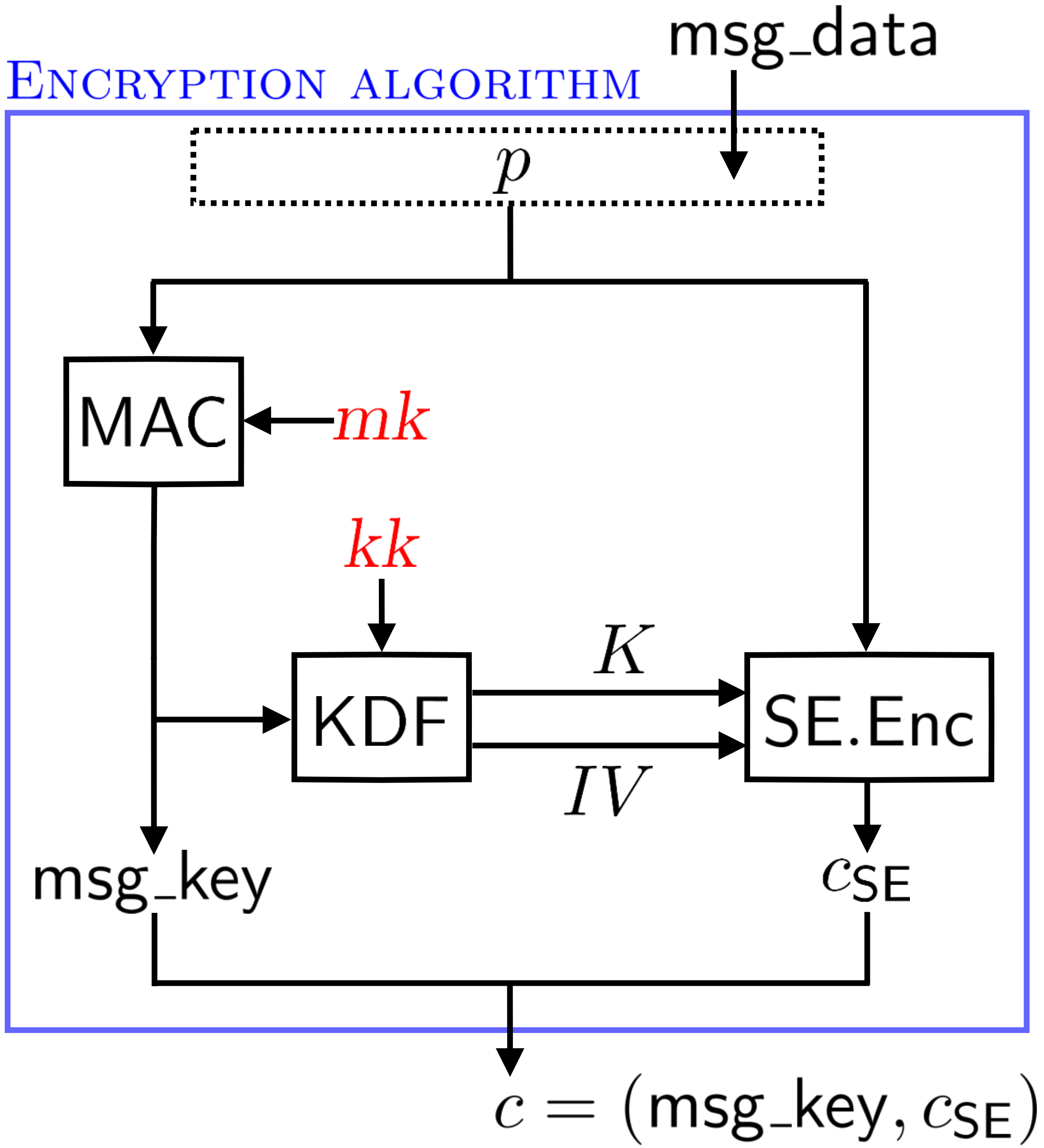
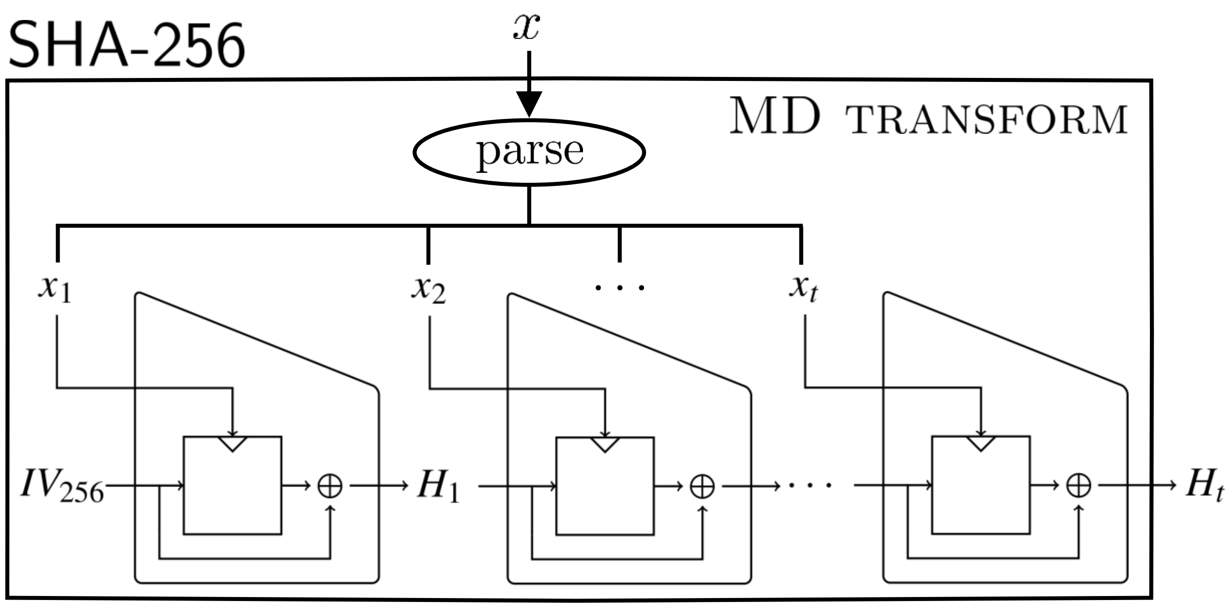
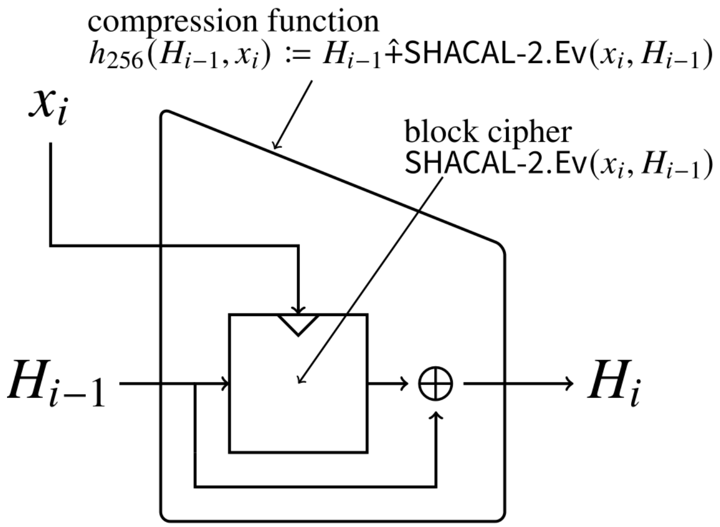




We rely on several assumptions about SHACAL-2.

Our novel SHACAL-2 assumptions need further study.



Four Attacks Against Telegram

- April 16, 2021 — We reported 4 vulnerabilities to **Telegram**.
- April 22, 2021 — **Telegram** confirmed the receipt of our e-mail.
- June 08, 2021 — **Telegram** acknowledged the reported behaviours.
- July 16, 2021 — Public disclosure (mutually agreed date).
- 2021 — **Telegram** awarded bug bounty for attacks and analysis.

All vulnerabilities fixed as of
7.8.1 for **Android**
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2.8.8 for **Desktop**

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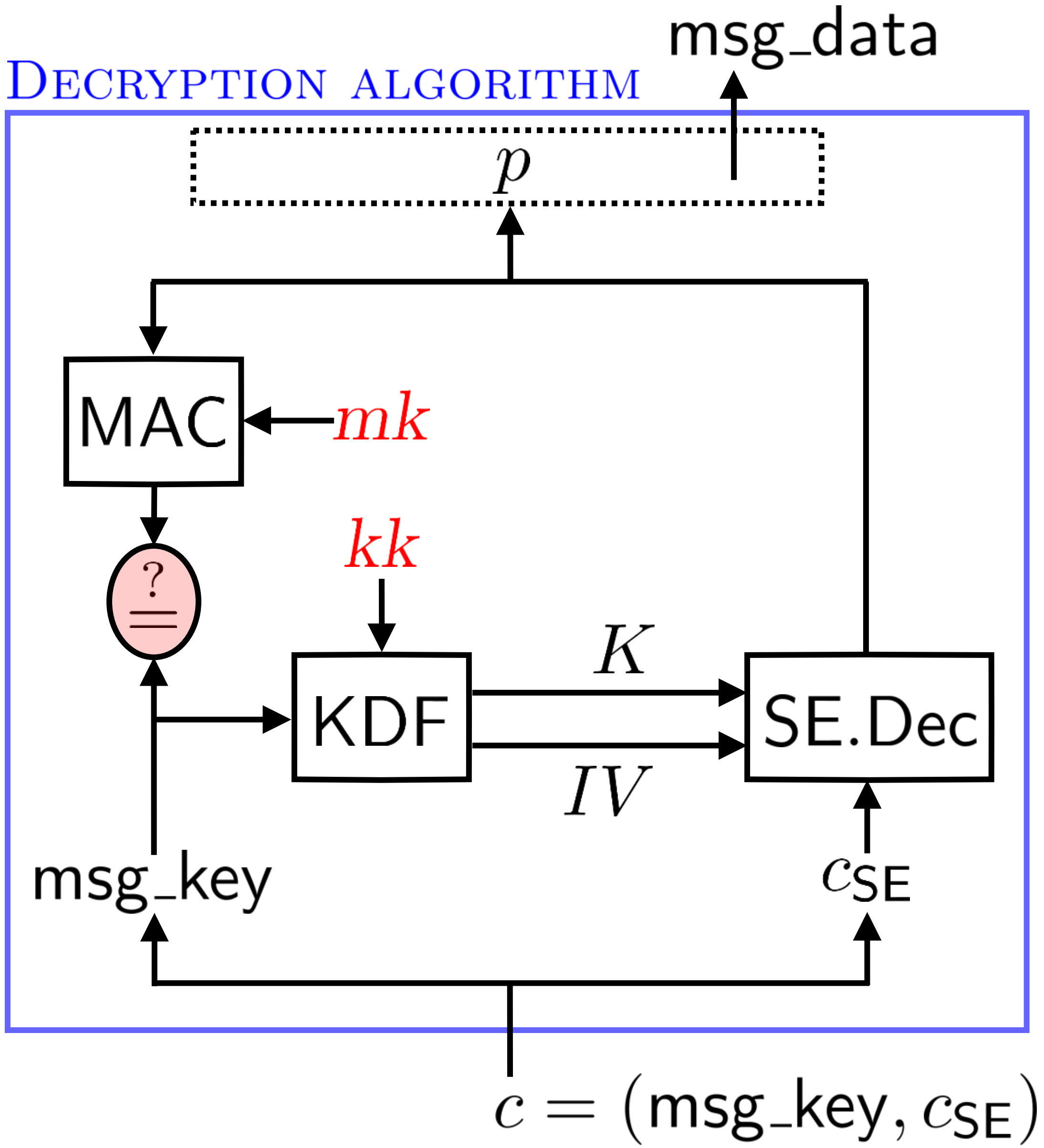
Telegram informed us that they

... do no security/bugfix releases except for post-release crash fixes.
(could not commit to release dates for specific fixes)
(fixes were rolled out as part of regular updates)

... did not wish to issue security advisories at the time of patching.

Timing Side-Channel Attacks



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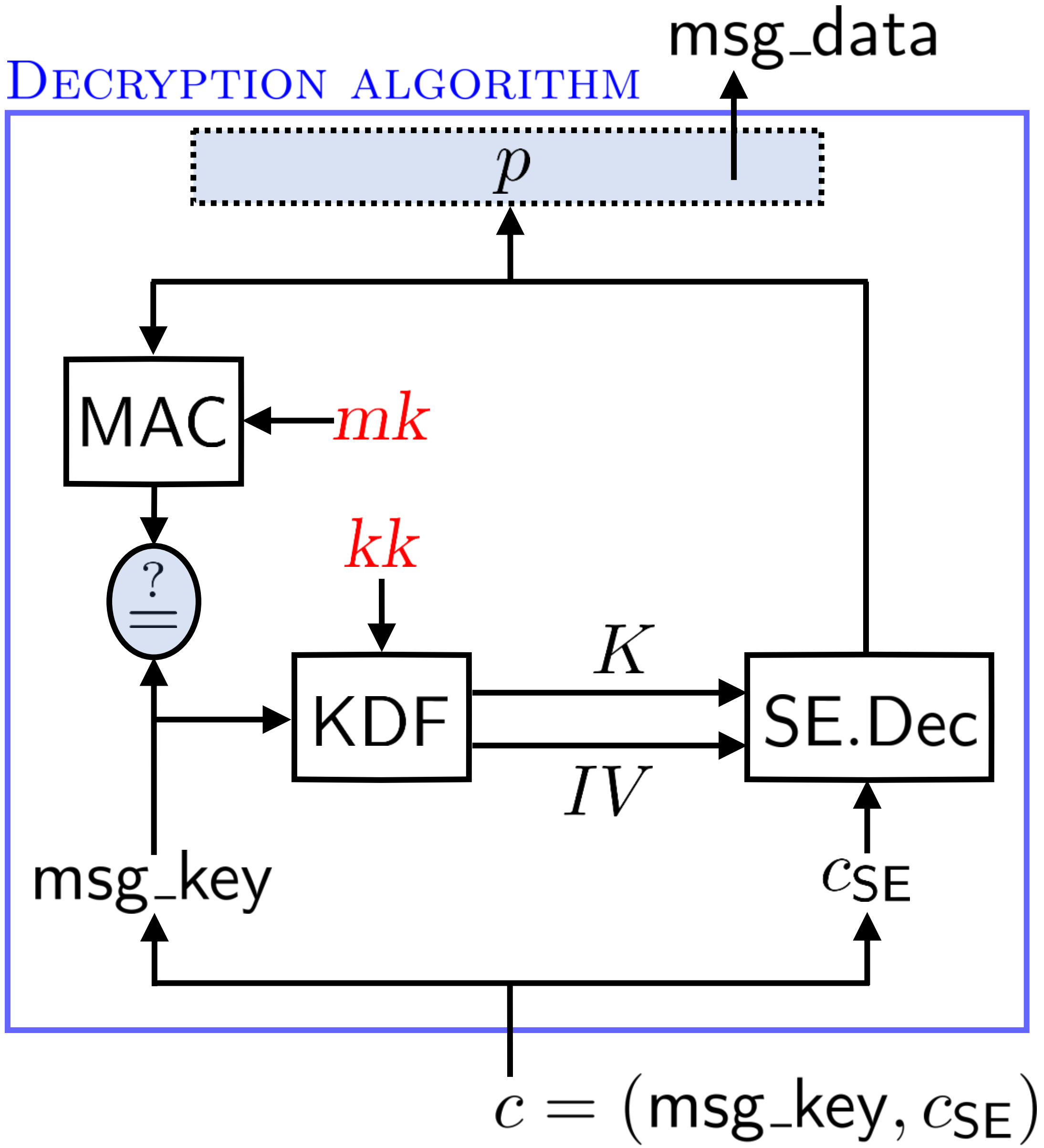

Telegram Desktop

if (msg_length $> 2^{24}$) then
// MAC verification skipped

payload p

server_salt	64 bits
session_id	64 bits
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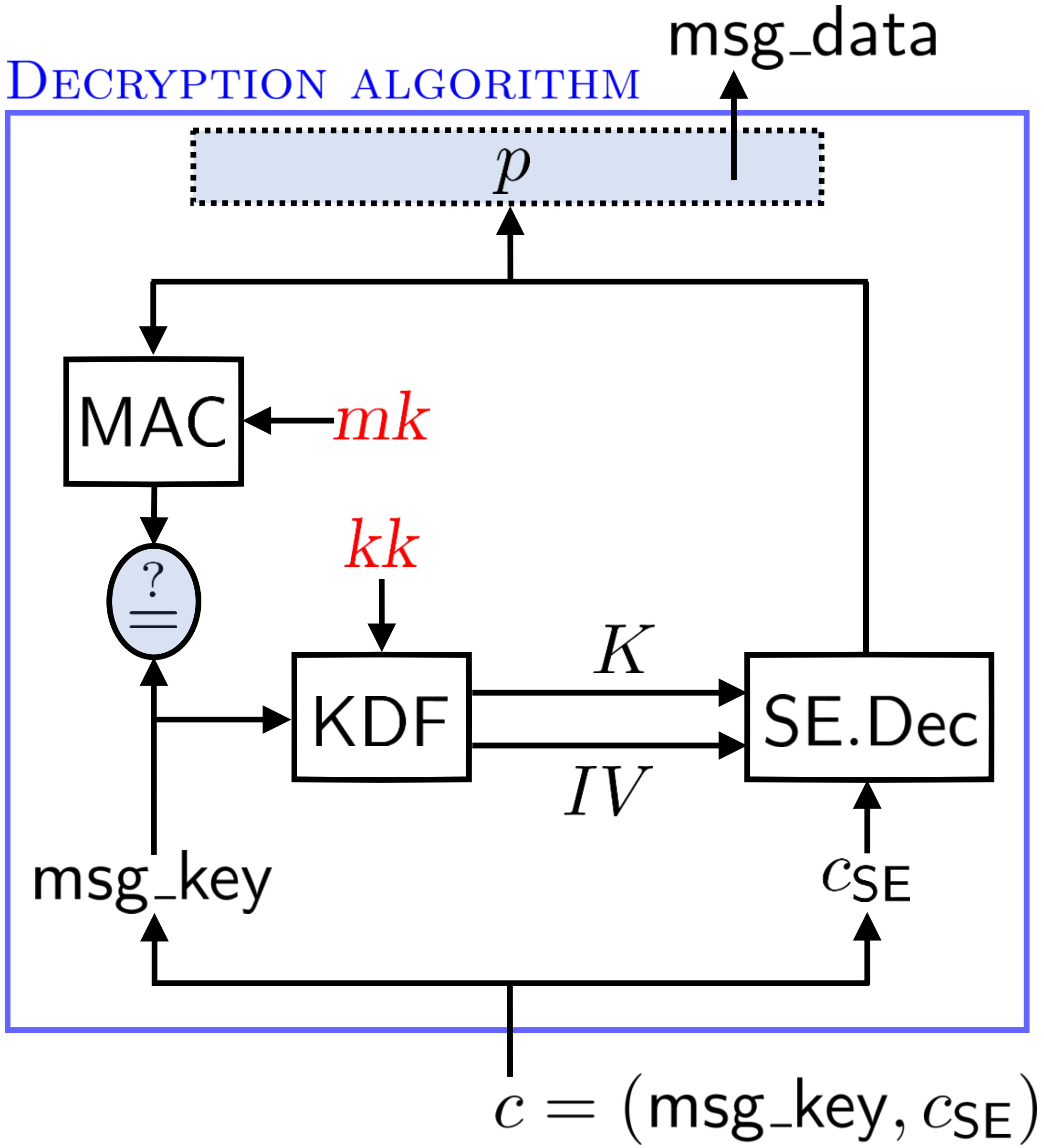
msg_length	32 bits
msg_data	...
padding	...

Timing Side-Channel Attacks



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Remote observer learns up to 8 bits.

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8 upper bits	**24 lower bits**

Timing Side-Channel Attacks

We adapt the attack from:

Plaintext Recovery Attacks Against SSH

Martin R. Albrecht, Kenneth G. Paterson and Gaven J. Watson

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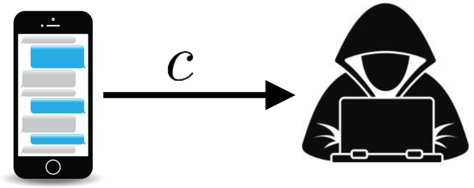

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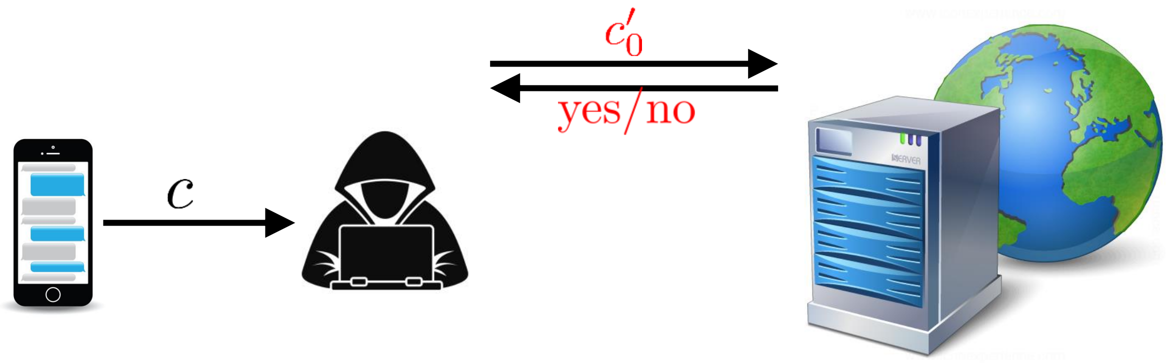

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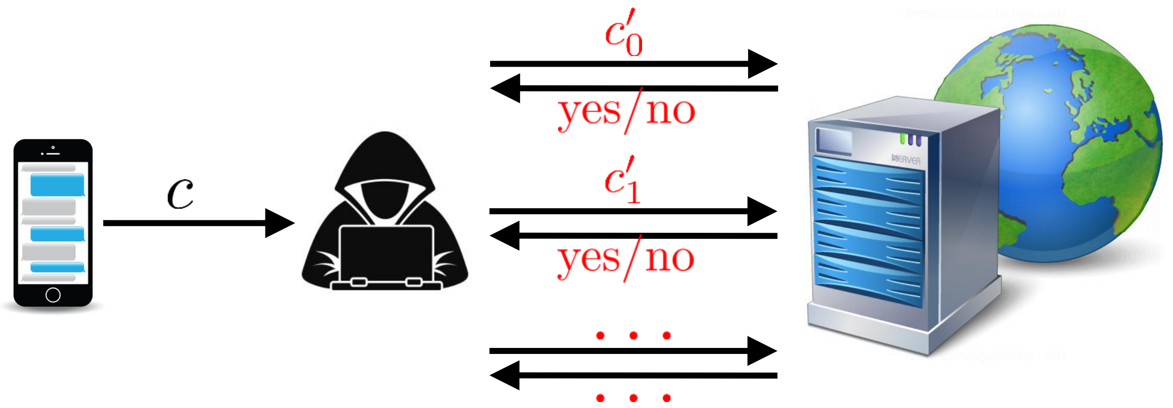

"Are the upper 8 bits of msg_length (encrypted in c'_i) equal to 00000000?"

We recover (up to) 8 bits of msg_data per query!

Telegram Desktop

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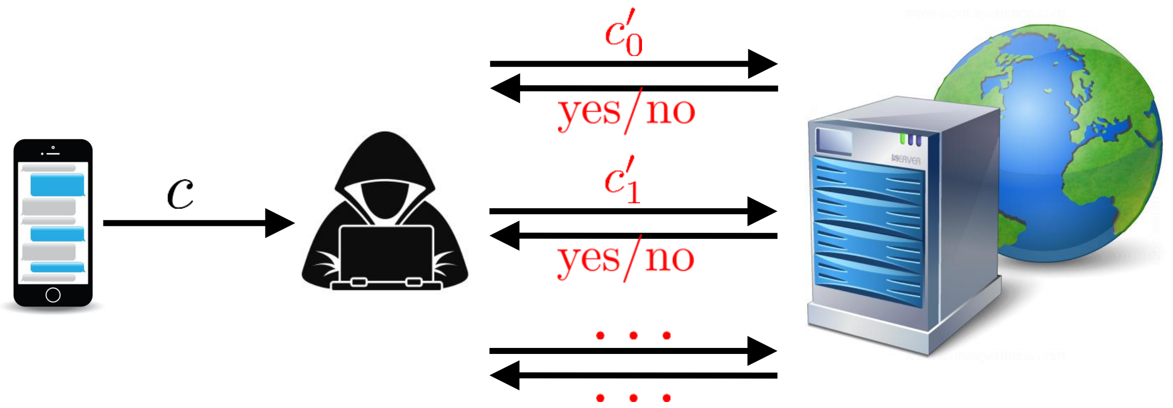

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msg_data	. . .
padding	. . .

msg_length

8 upper bits	24 lower bits

Three official clients checked p before MAC.

Telegram Desktop
Telegram Android
Telegram iOS

Each client did it in a different way.
Each client presented a timing side-channel.

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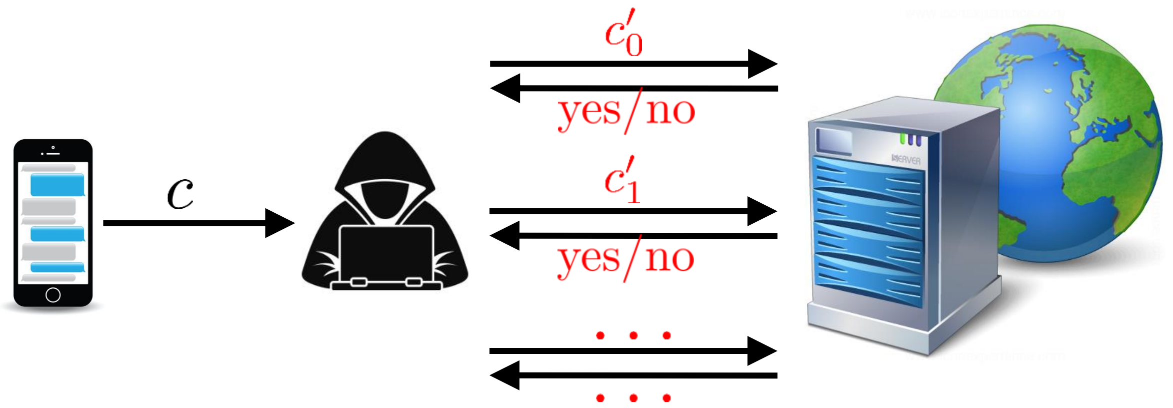

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// MAC verification skipped

Introduces 3 microsecond difference.
Remote observer learns up to 8 bits.

payload p

server_salt	64 bits
session_id	64 bits
msg_seq_no	96 bits
msg_length	32 bits
msg_data	...
padding	...

msg_length

8 upper bits	24 lower bits

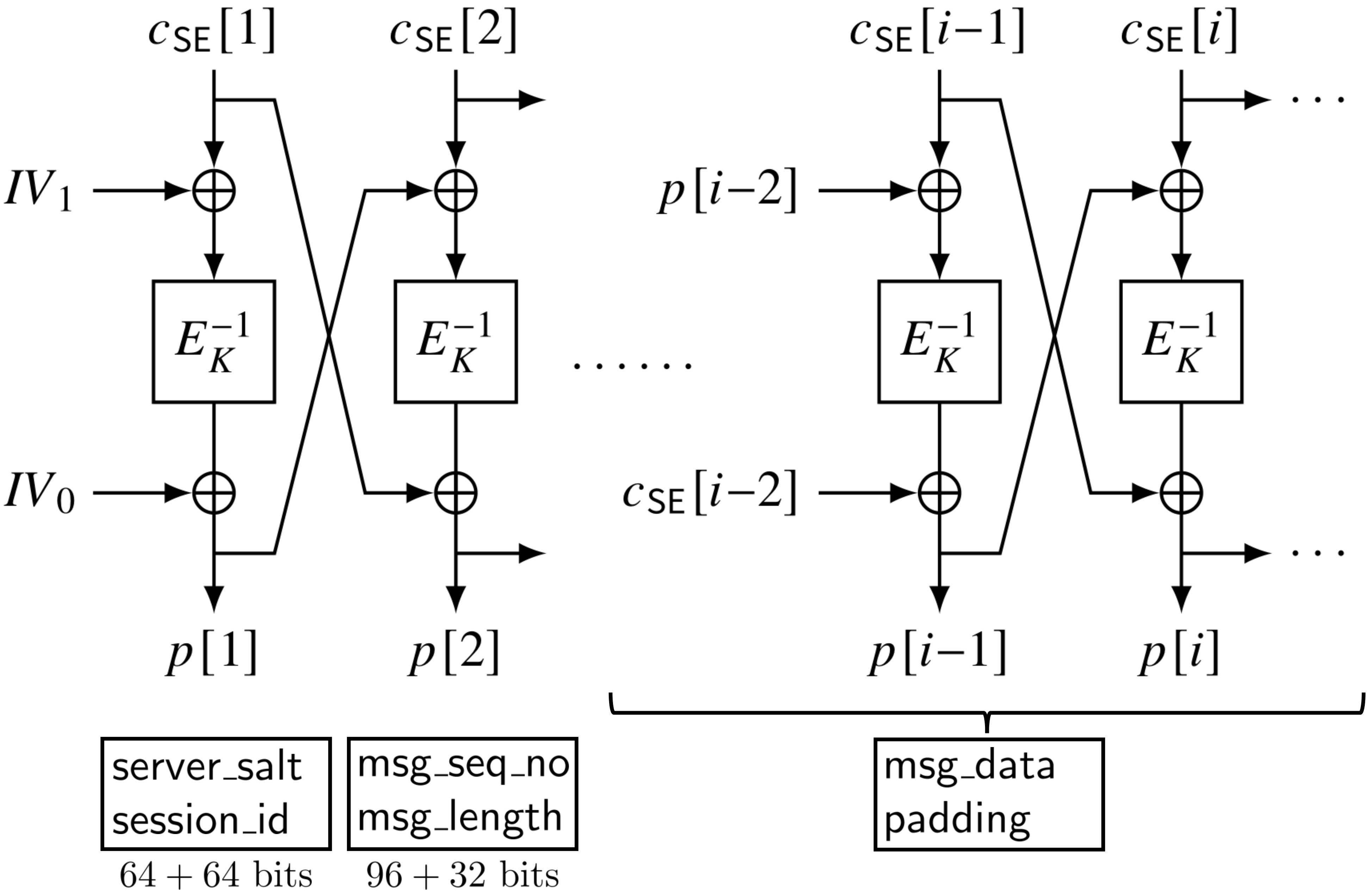
Three official clients checked p before MAC.

Telegram Desktop
Telegram Android
Telegram iOS

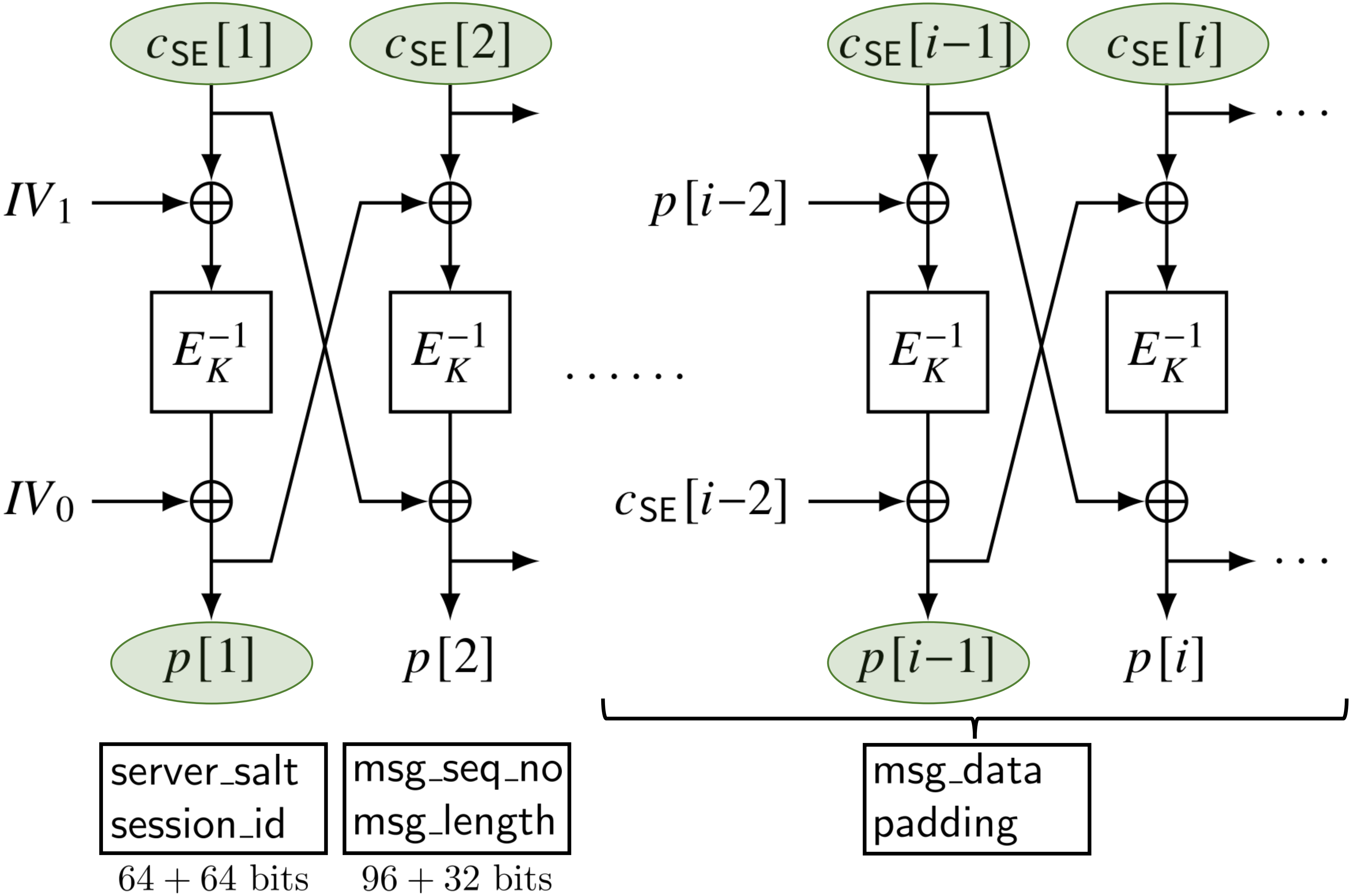
Each client did it in a different way.
Each client presented a timing side-channel.

This highlights a **brittle design**.
Encrypt-and-MAC requires to decrypt untrusted data.
Would be safer to protect integrity of ciphertext.

Timing Side-Channel Attacks

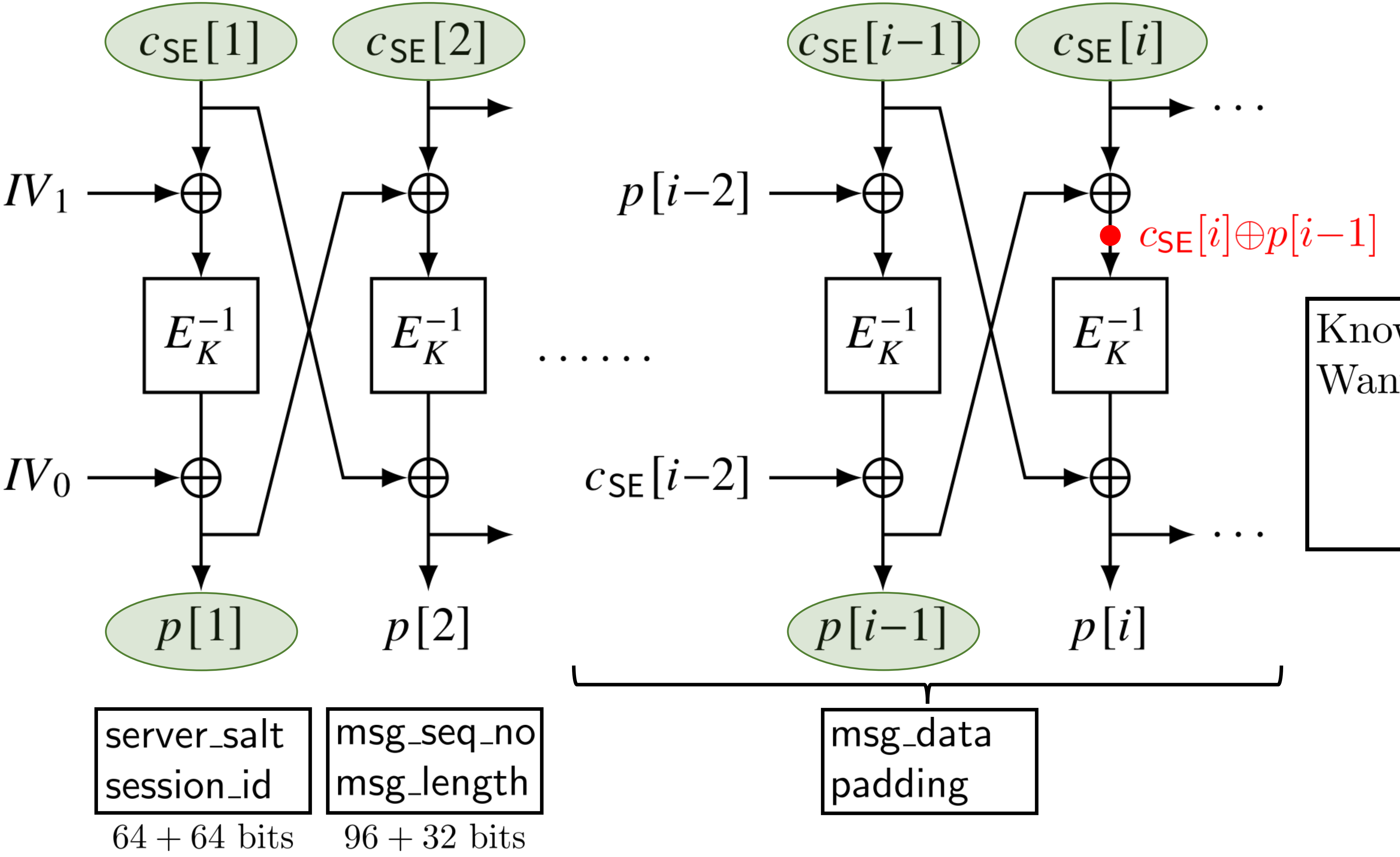


Timing Side-Channel Attacks



Know $p[1]$, $p[i-1]$.
Want to learn $p[i]$.

Timing Side-Channel Attacks



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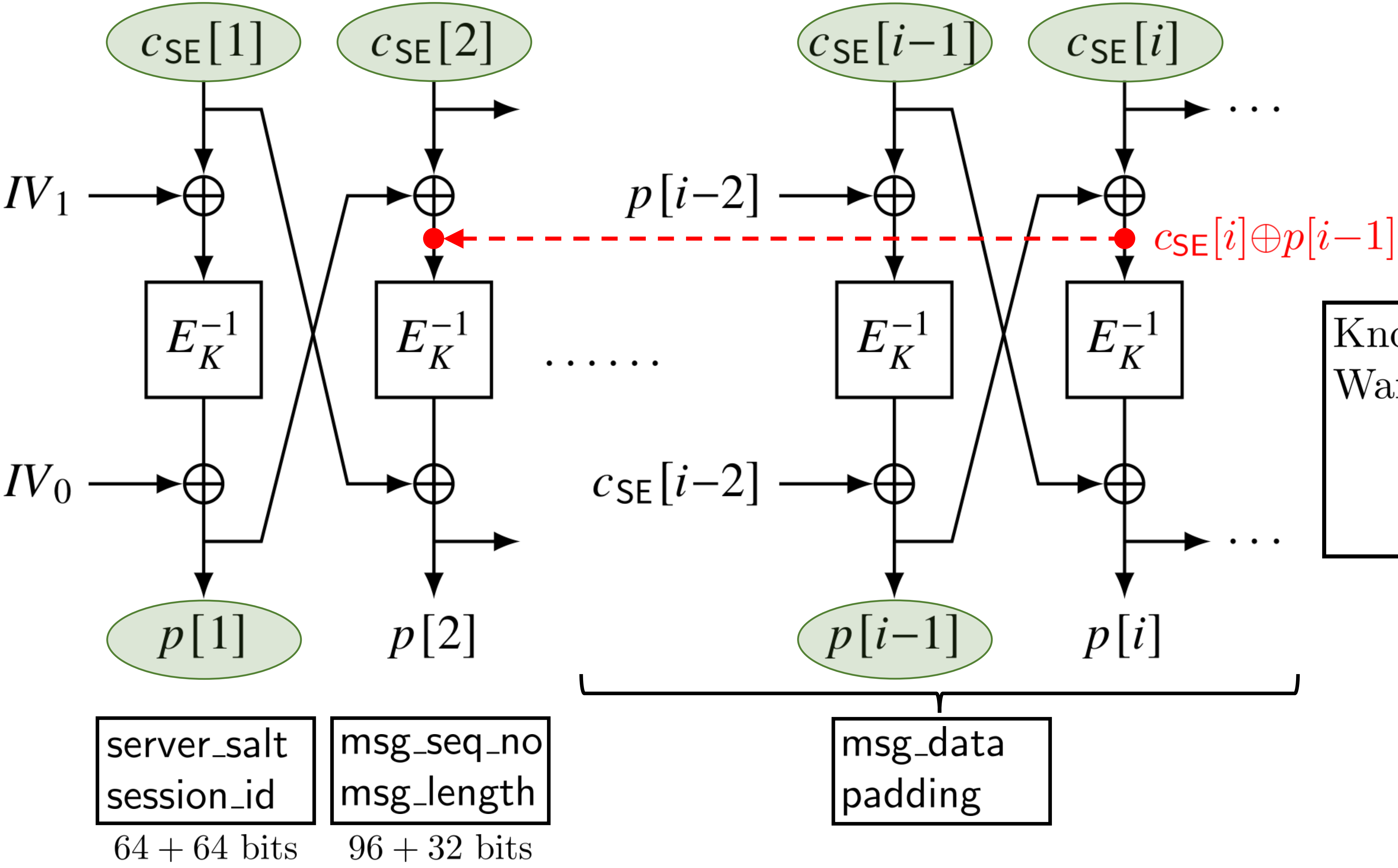

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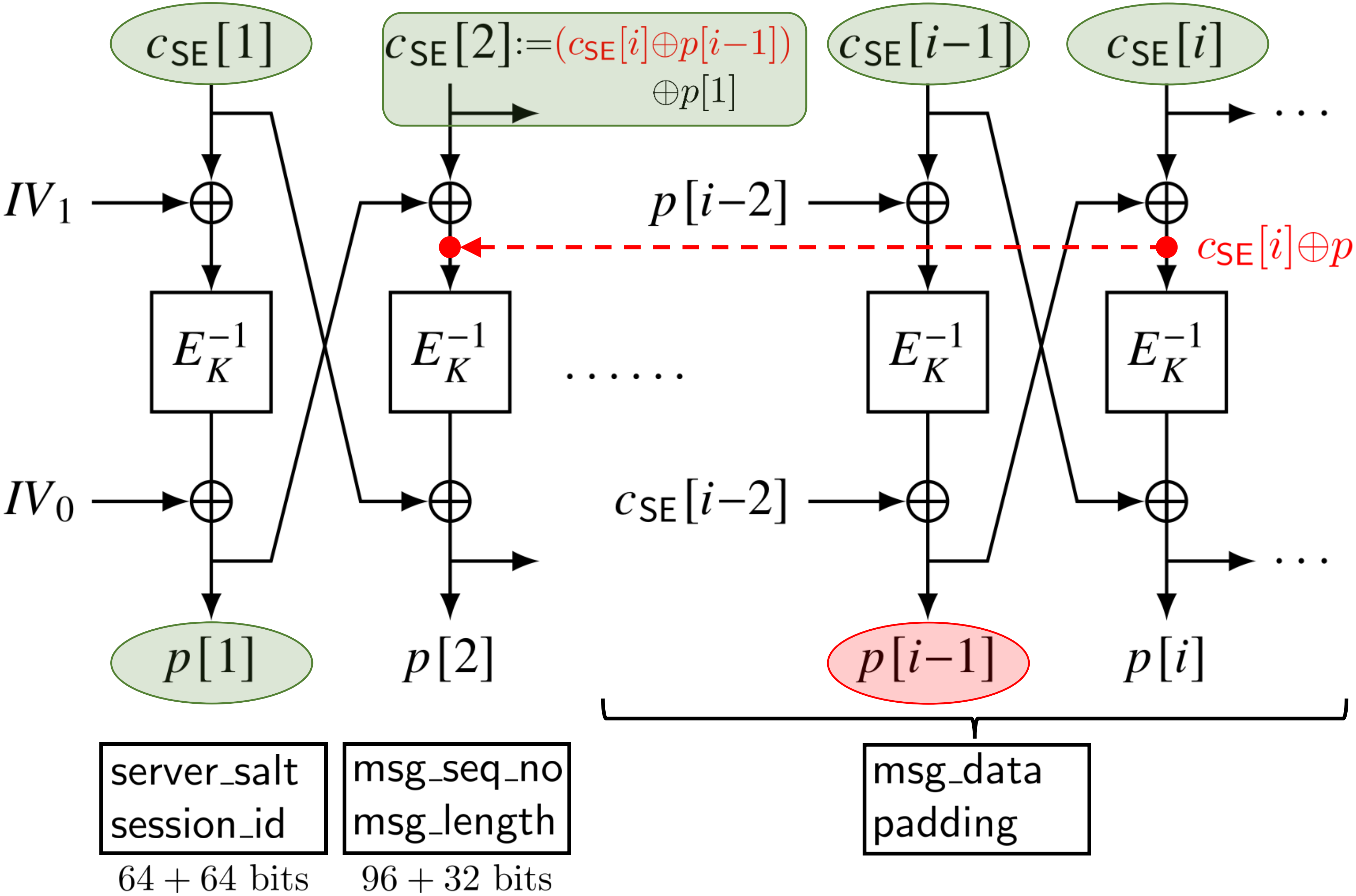

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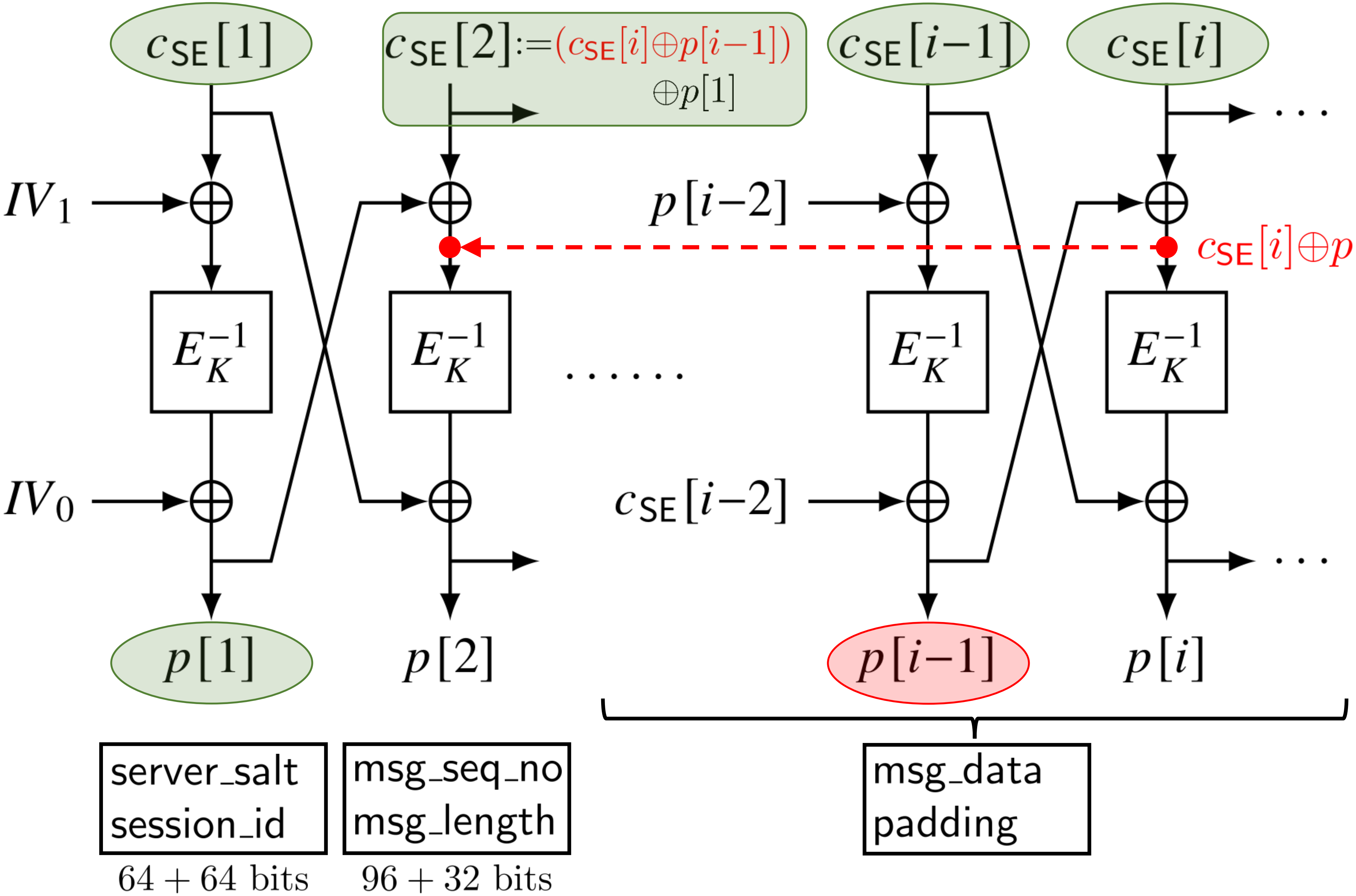

Know $p[1]$, $p[i-1]$.
Want to learn $p[i]$.

Infer bits of $p[2]$.
Derive bits of $p[i]$.

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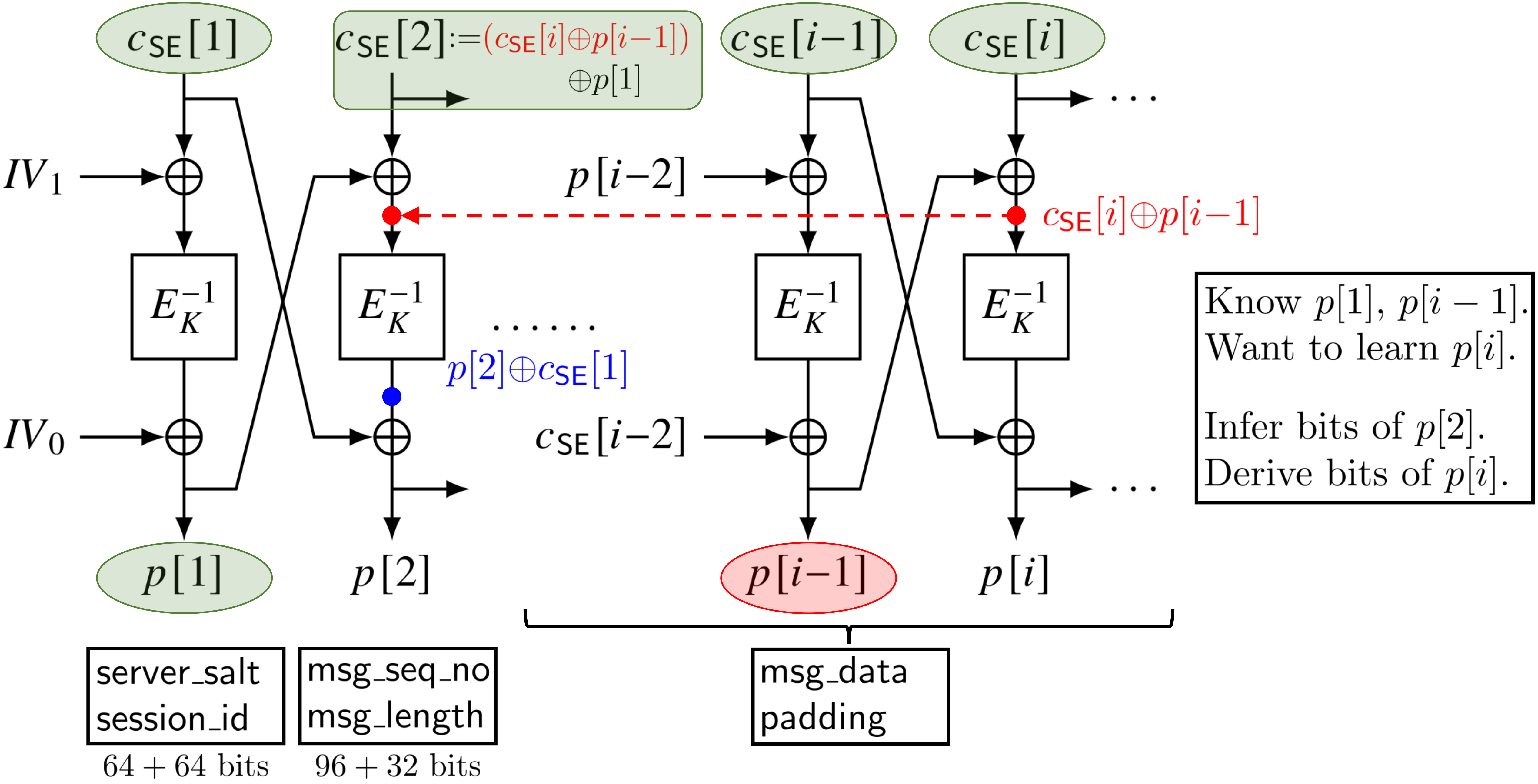

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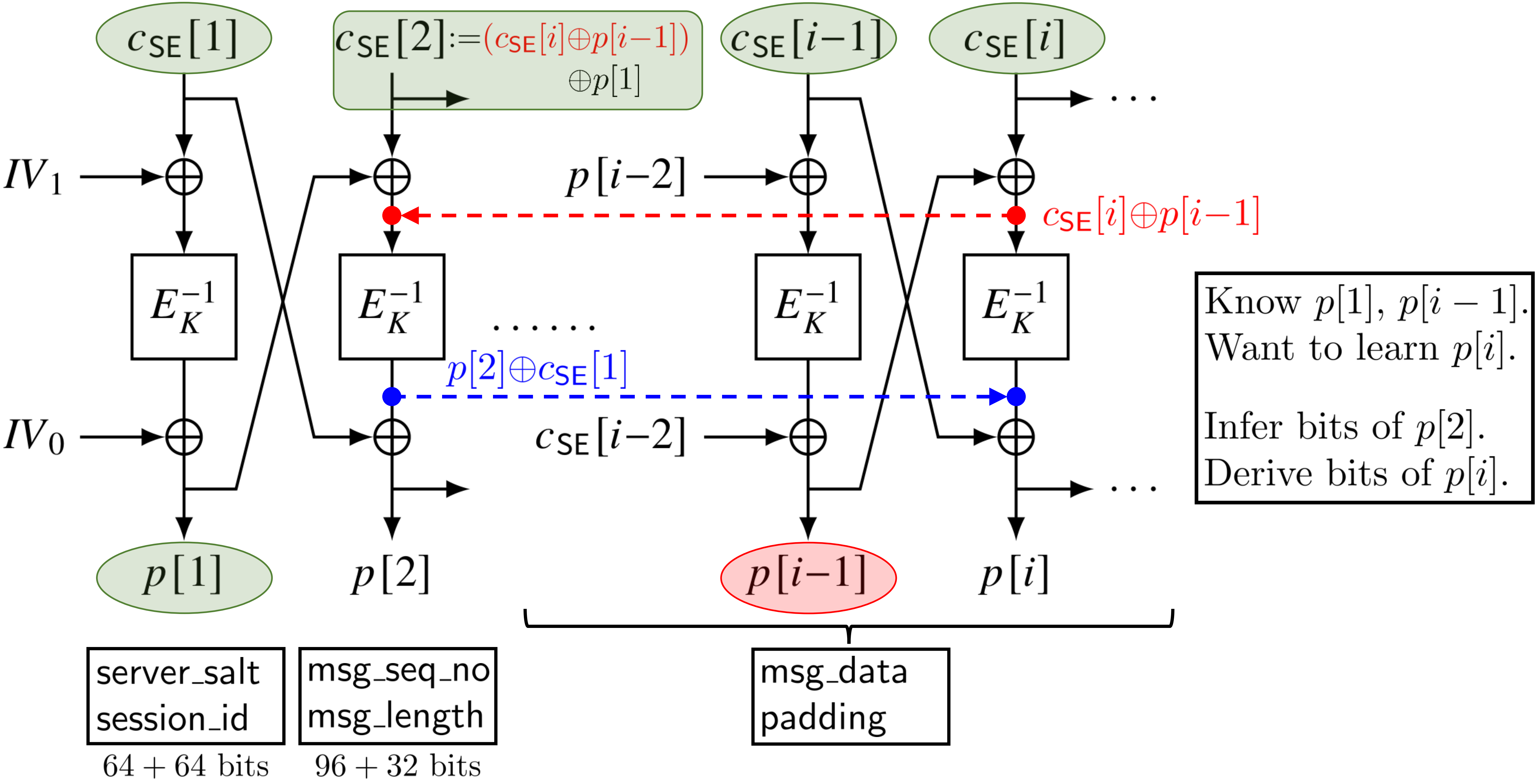

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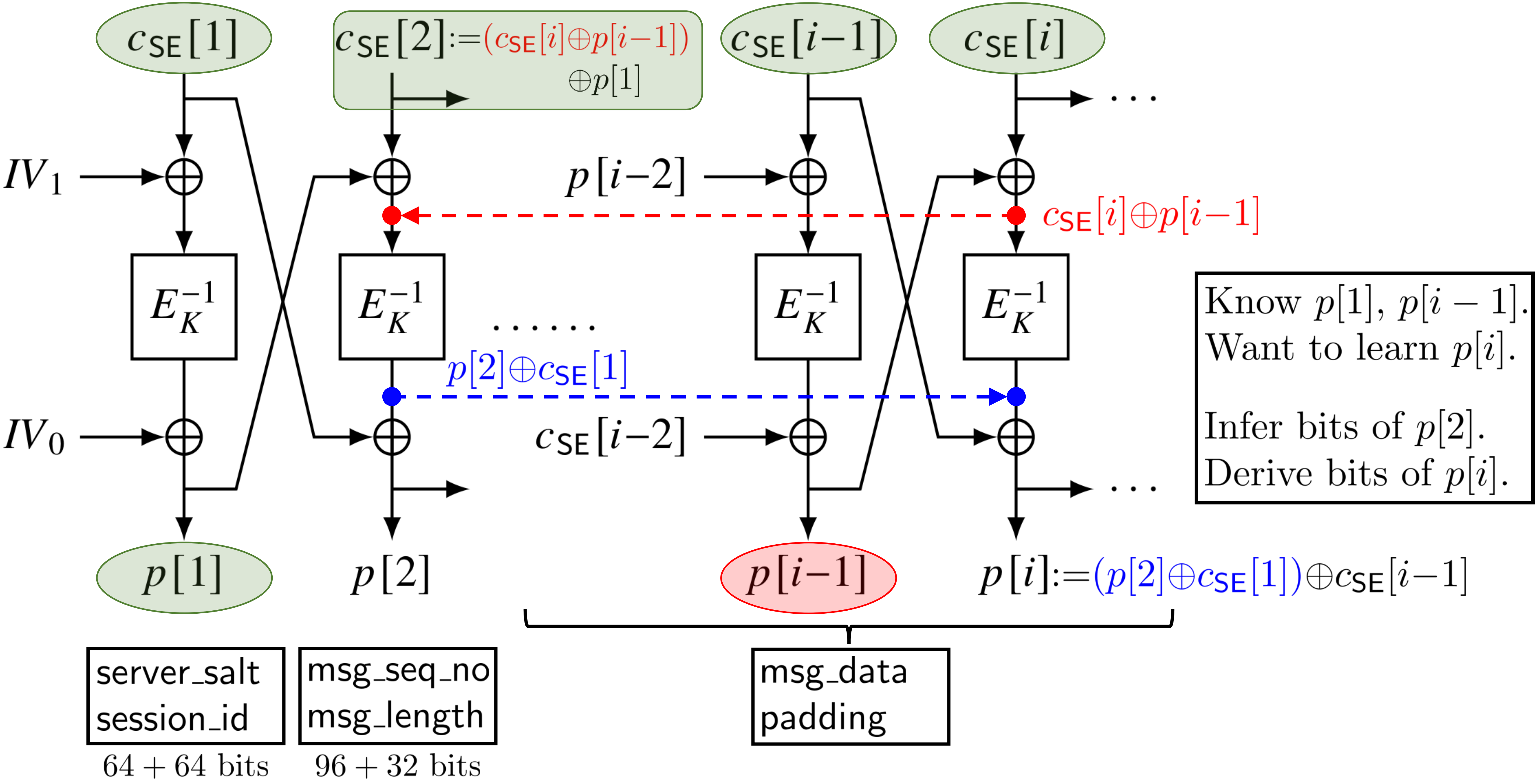

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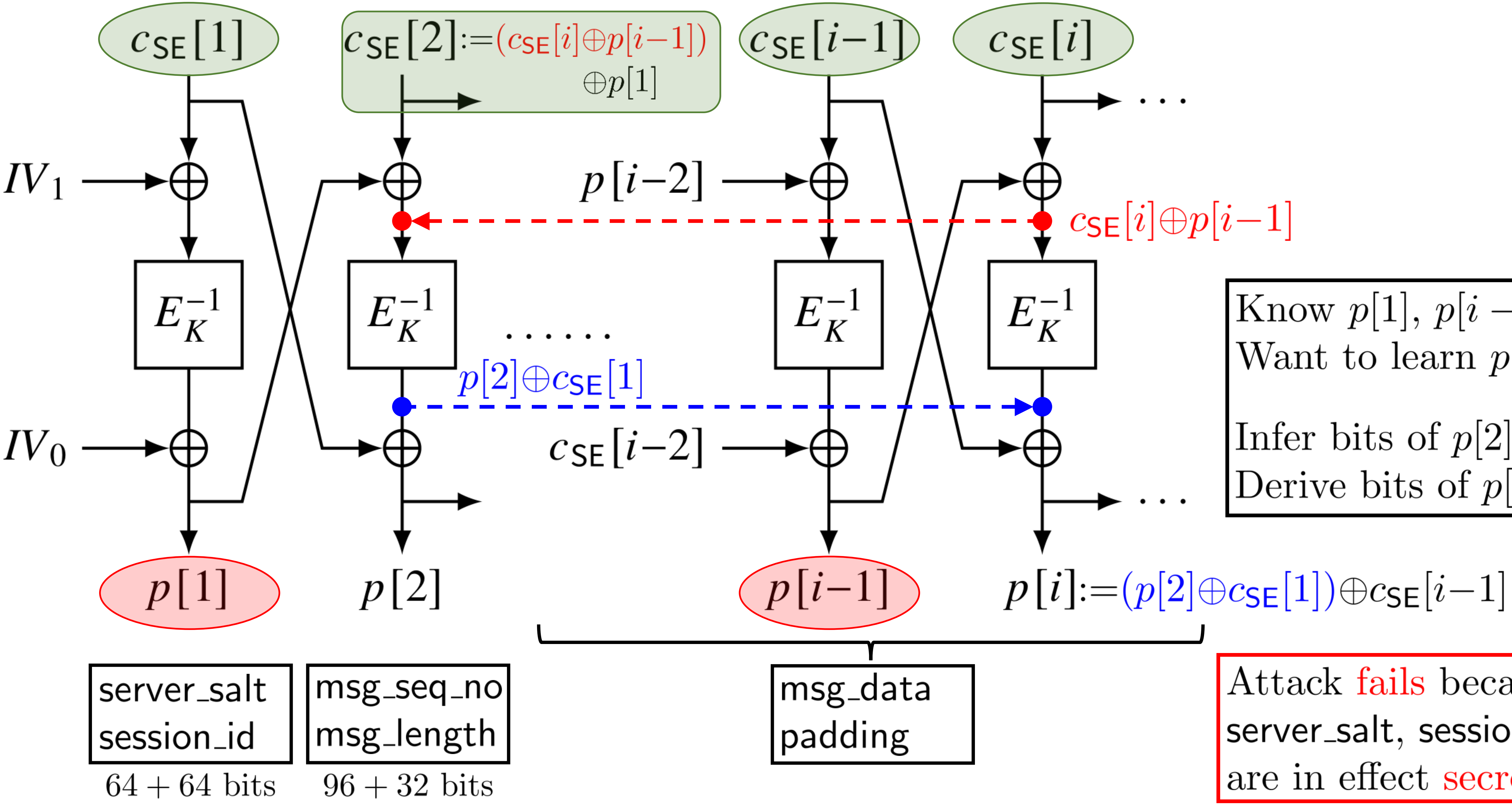

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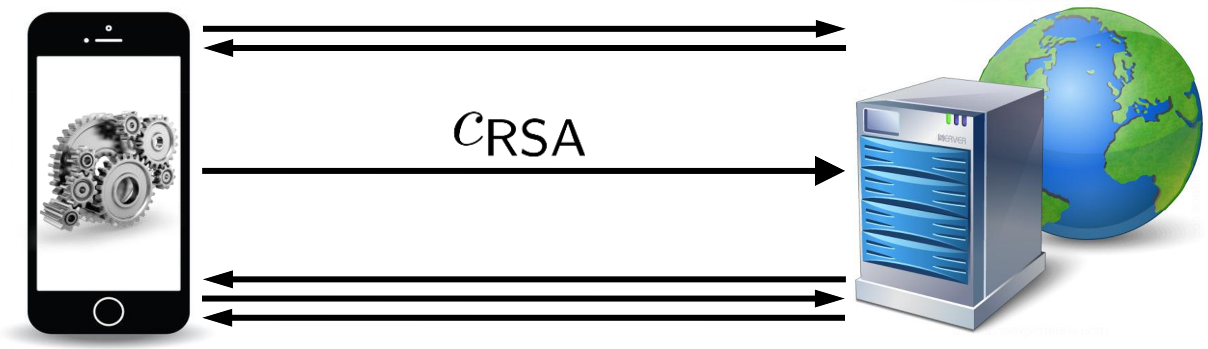
Attack fails because server_salt, session_id are in effect secret.

Timing Side-Channel Attack Against Servers

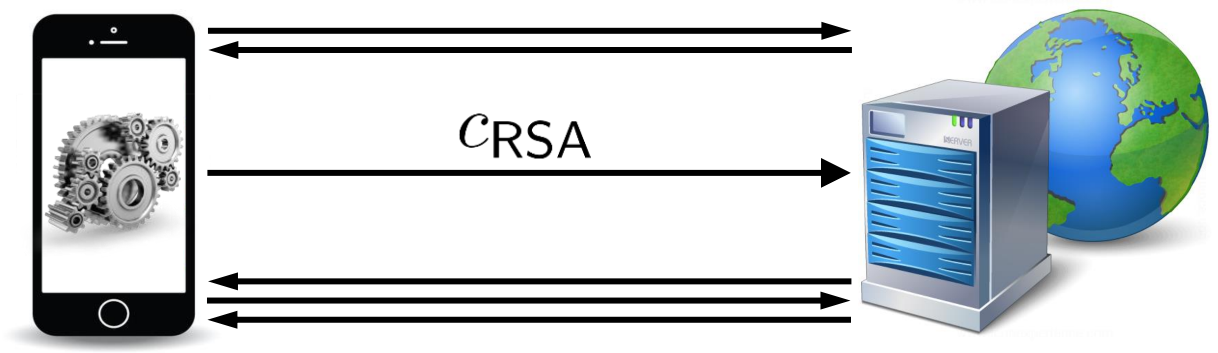
Telegram's key exchange



$$c_{\mathsf{RSA}} \leftarrow \mathsf{RSA.Enc}(pk, n)$$
$$n = \mathsf{SHA\text{-}1(data)} \| \mathsf{data} \| \mathsf{padding}$$

Timing Side-Channel Attack Against Servers

Telegram's key exchange



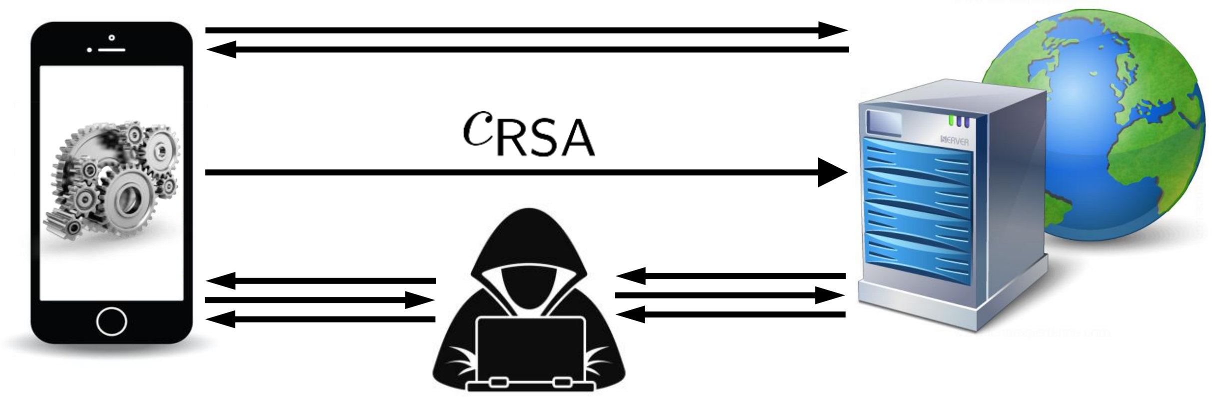
$$c_{\mathsf{RSA}} \leftarrow \mathsf{RSA.Enc}(pk, n)$$
$$n = \mathsf{SHA\text{-}1(data)\|data\|padding}$$

If data can be recovered:

Attacker learns server_salt immediately.
Attacker learns session_id in $\approx 2^{64}$ queries.

The attack against IGE now works!

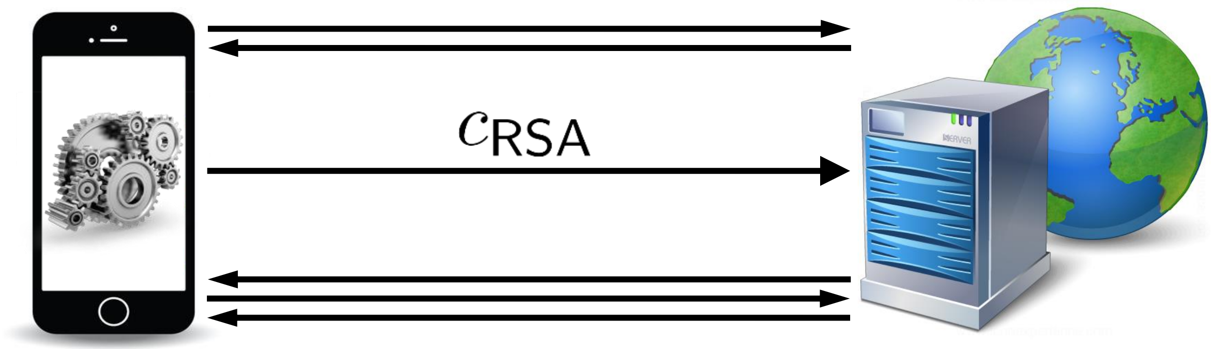
If data can be recovered within 10 min:



Man-in-the-middle attack.

Timing Side-Channel Attack Against Servers

Telegram's key exchange



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We recover data by solving noisy linear equations via lattice reduction.

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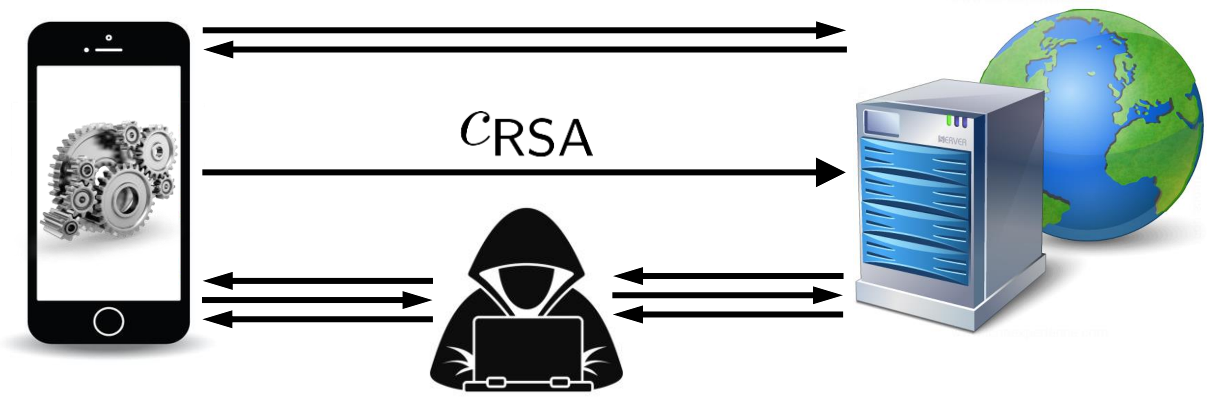

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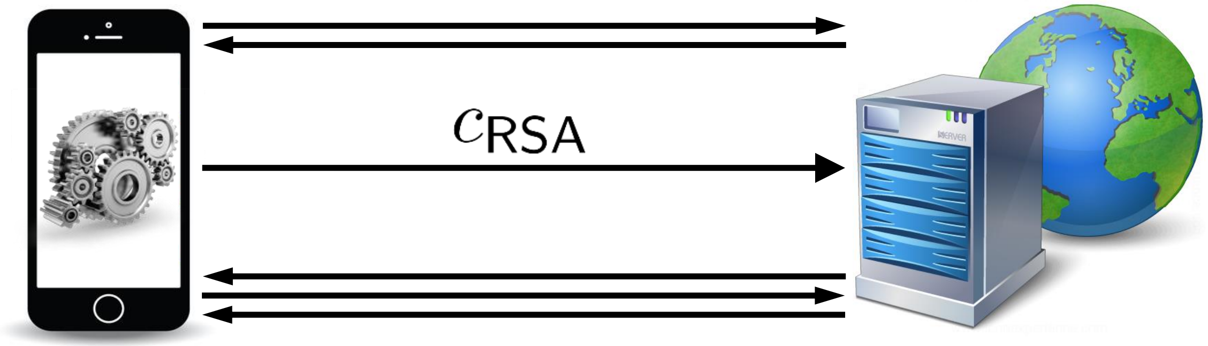

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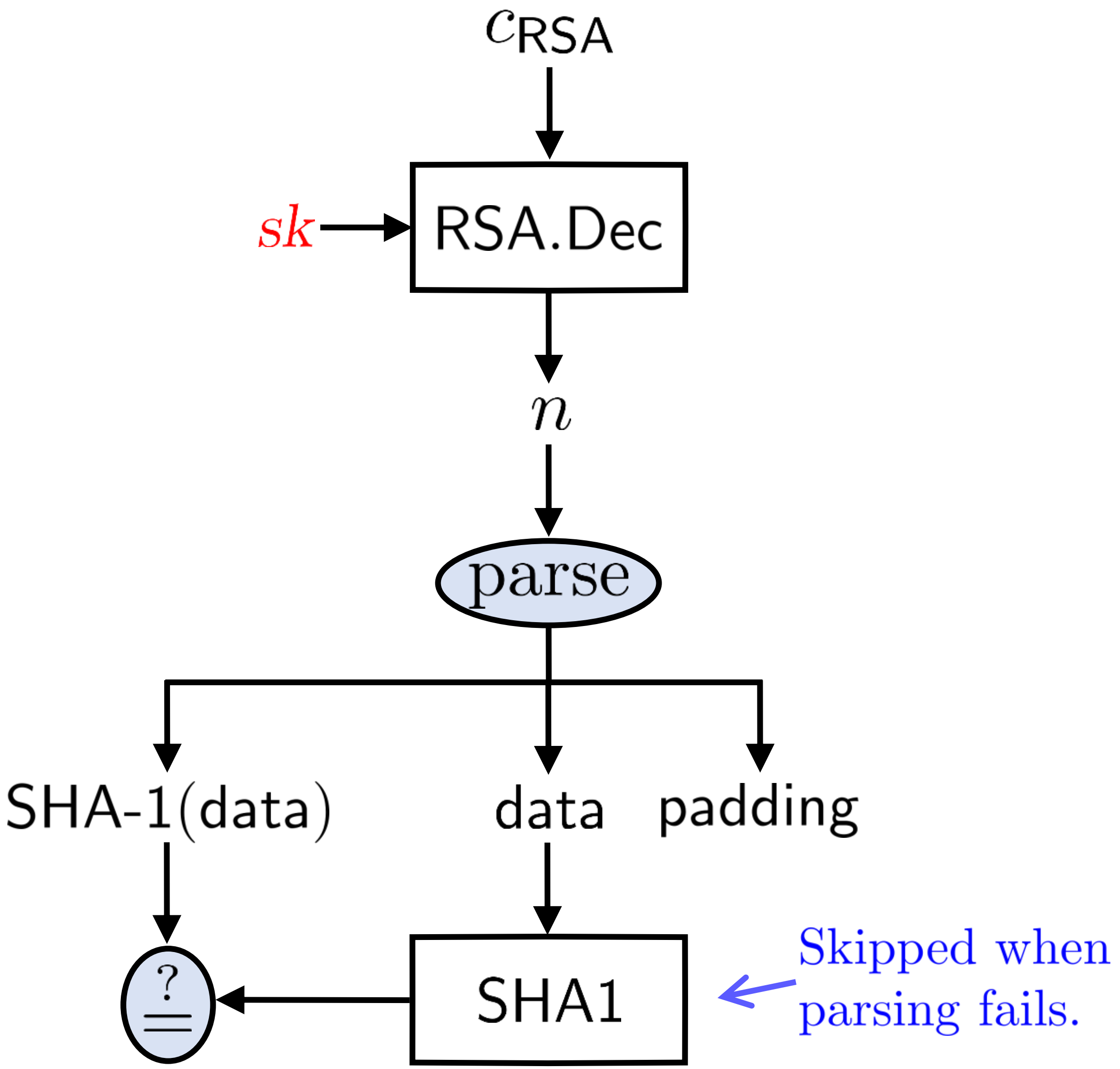
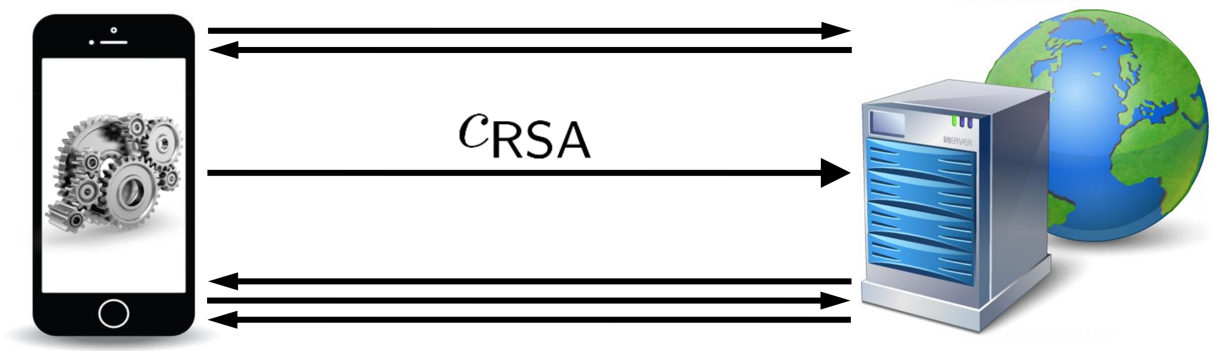


Timing Side-Channel Attack Against Servers

Telegram's key exchange



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We recover data by solving noisy linear equations via lattice reduction.

Telegram uses textbook RSA scheme.

Why textbook RSA?

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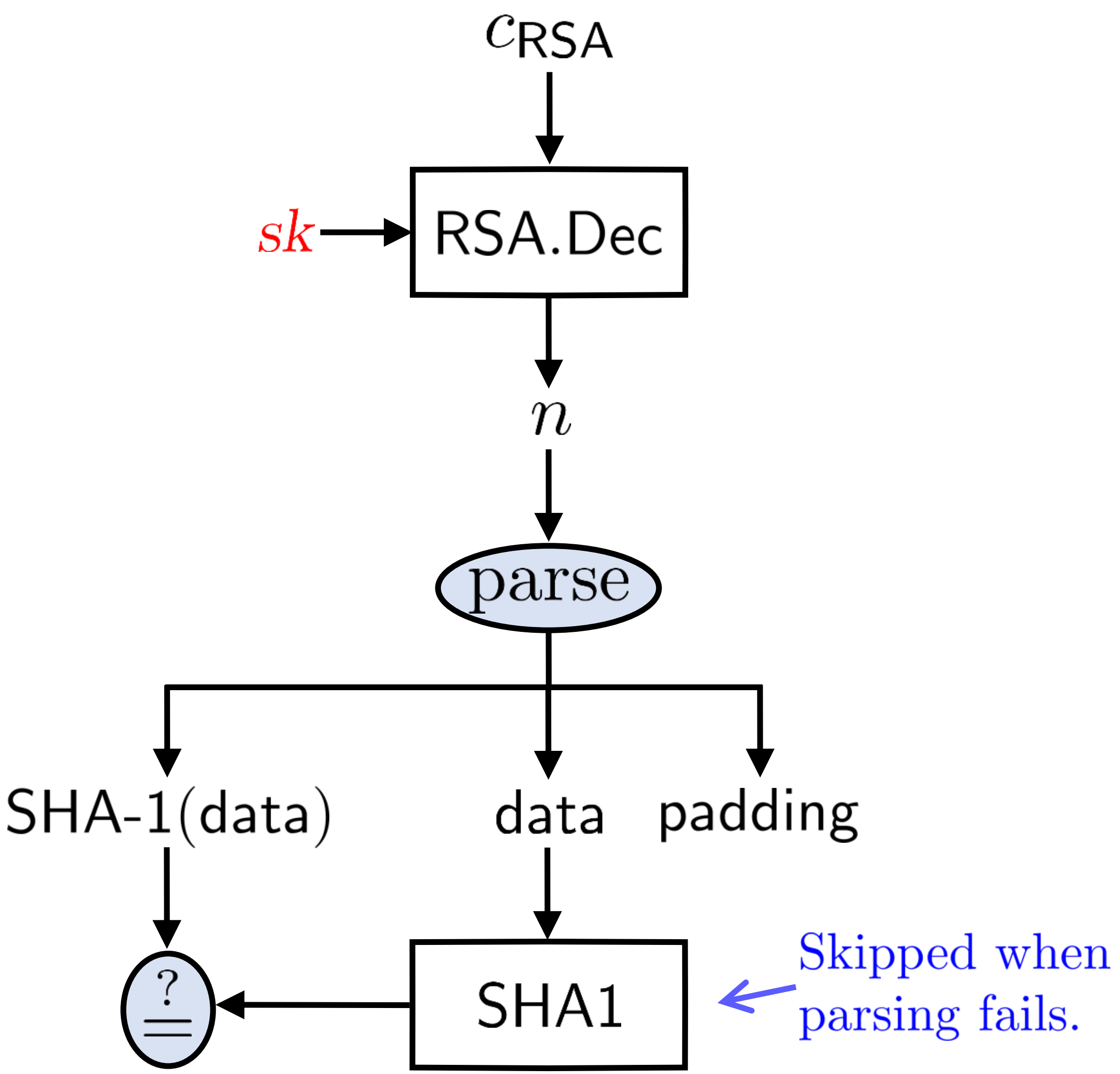

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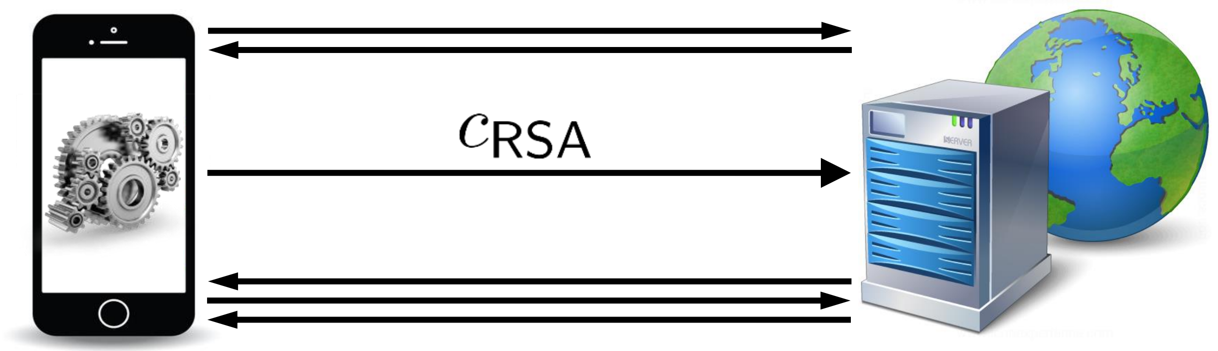

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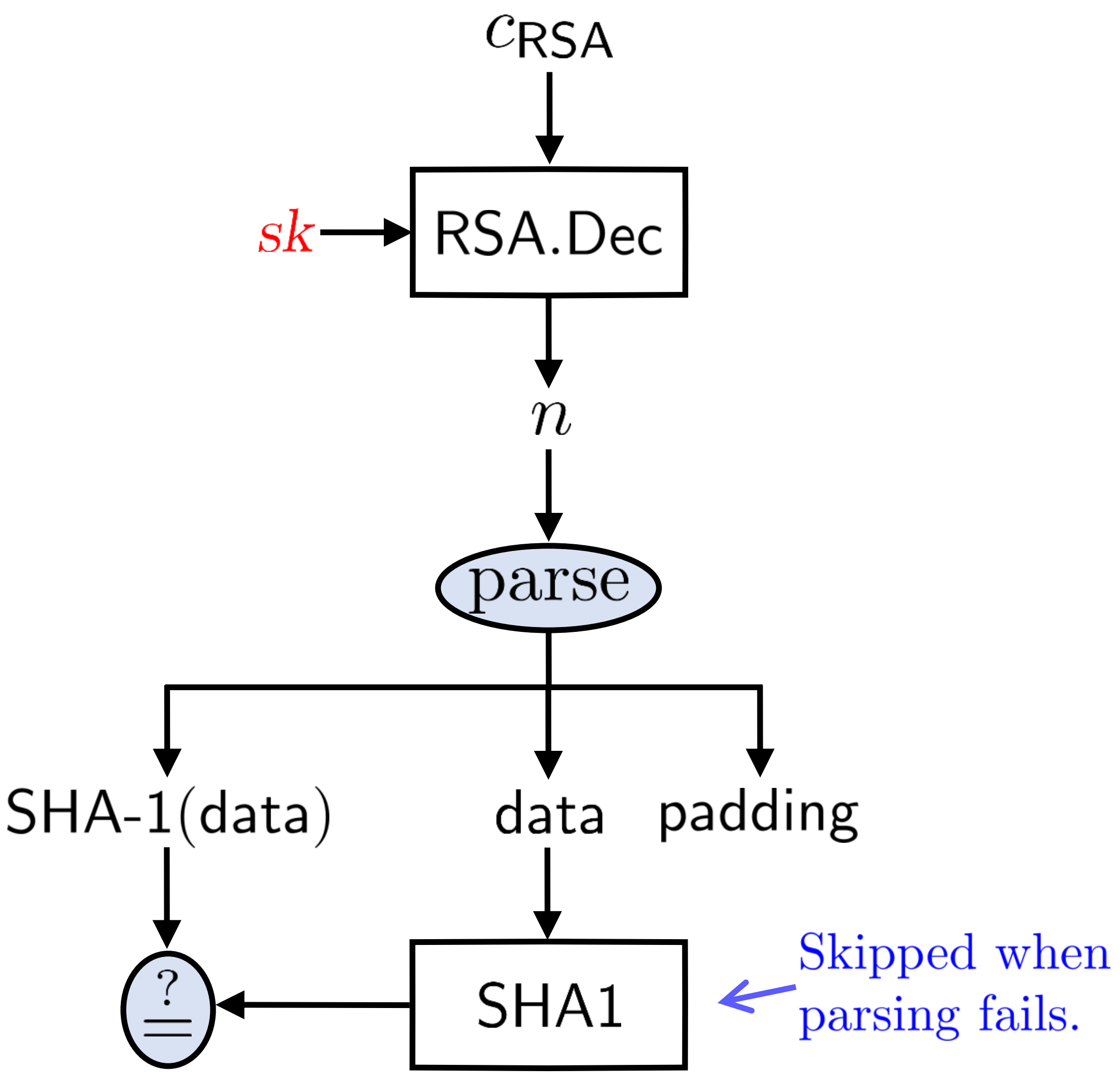
We recover data by solving noisy linear equations via lattice reduction.

Telegram uses textbook RSA scheme.

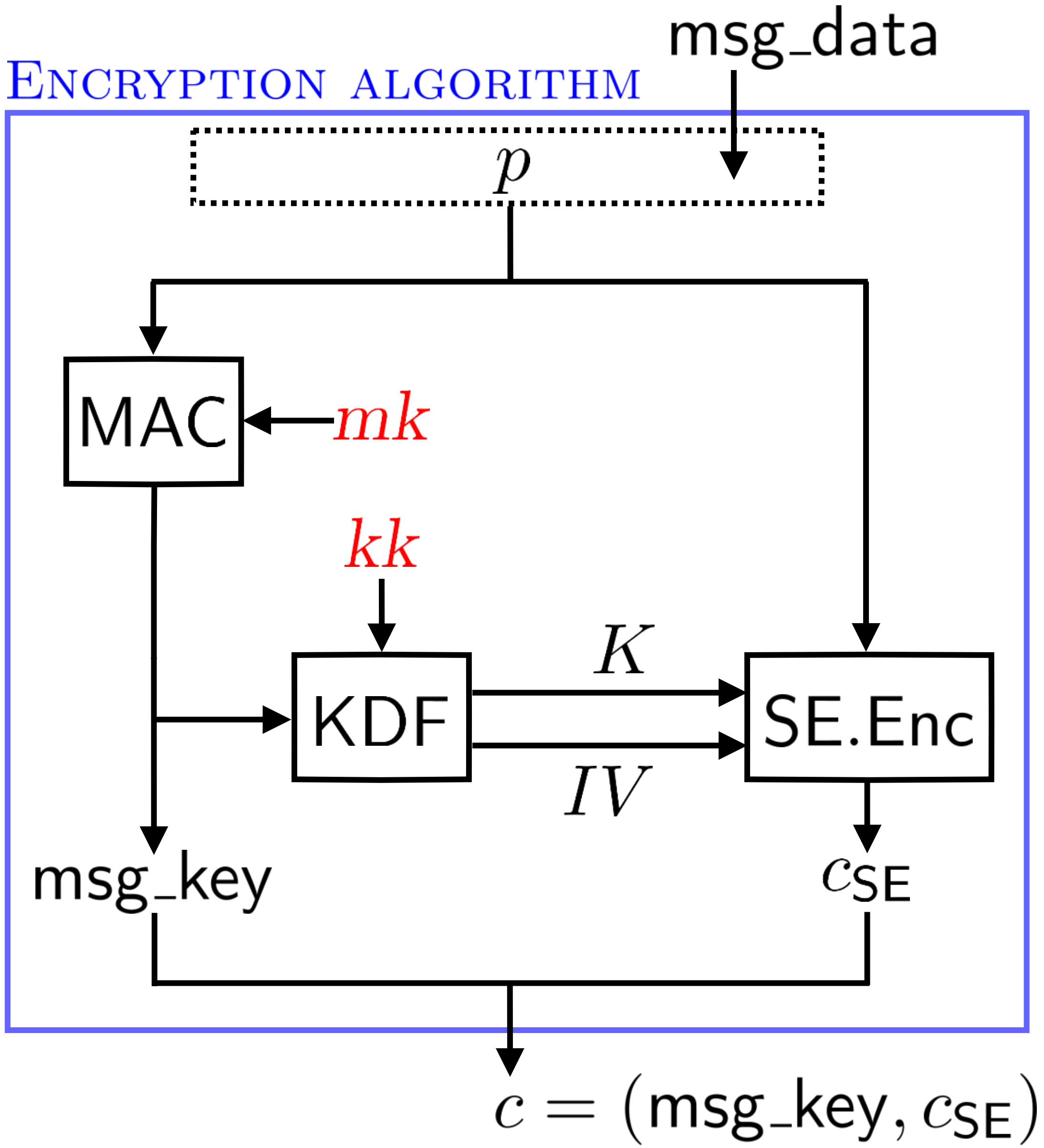
Why textbook RSA?

Timings very small. Infeasible in practice.
Caveat: **Telegram**'s server code is secret.

Timing side-channel:



Attack Against IND-CPA Security



Theoretical attack.

MTProto requires message acknowledgements.
If no acknowledgement, then payload is resent.
Acknowledgements are encrypted.

Our attack subverts this.

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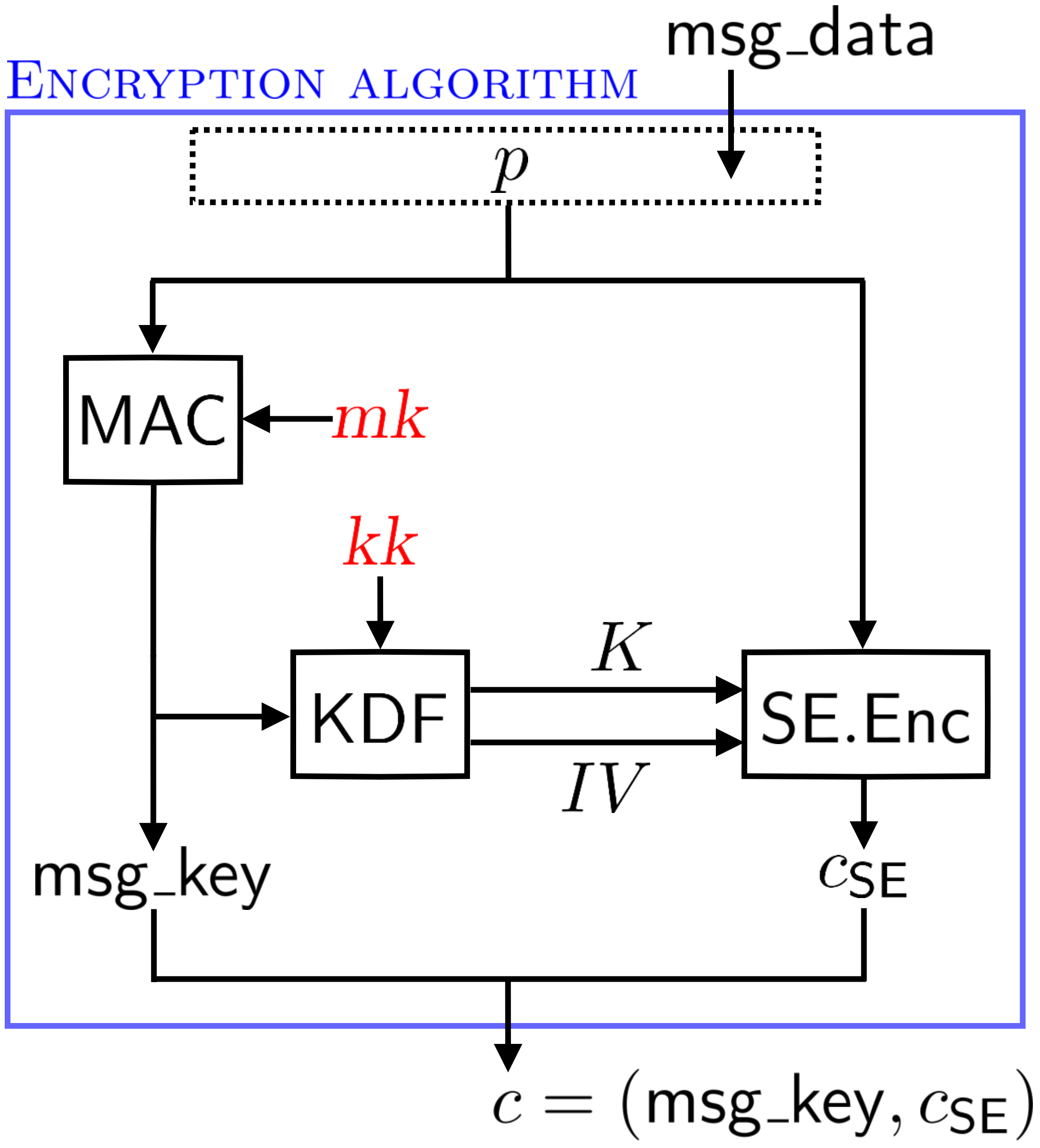

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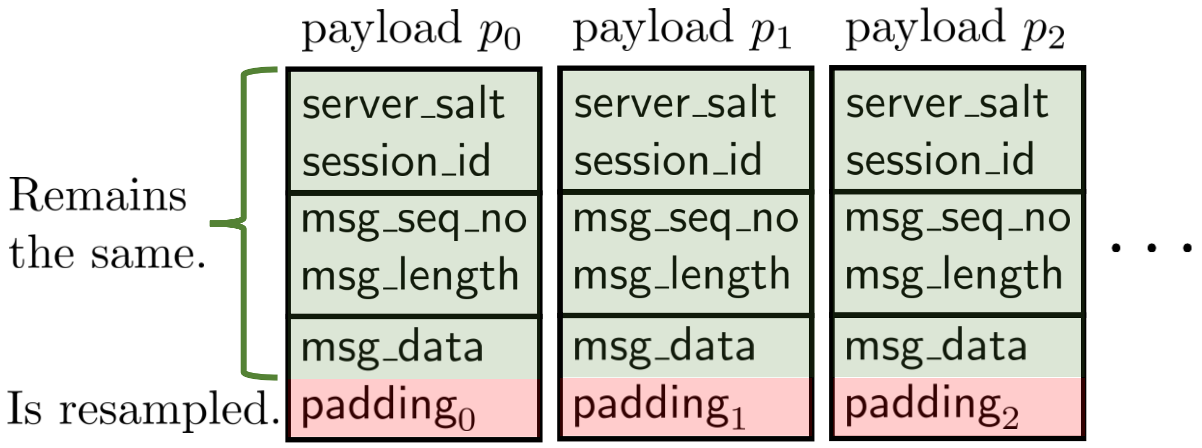

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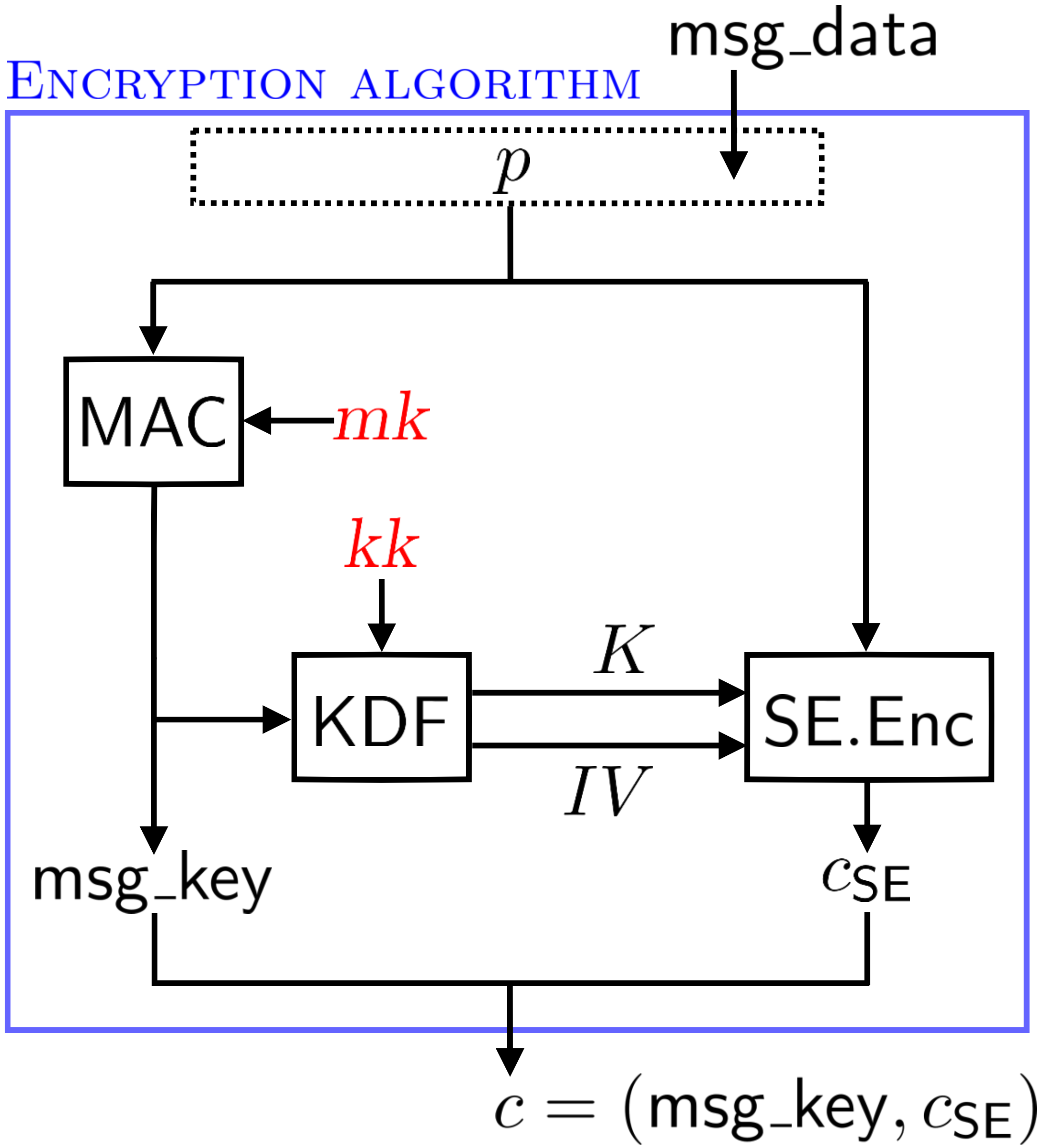

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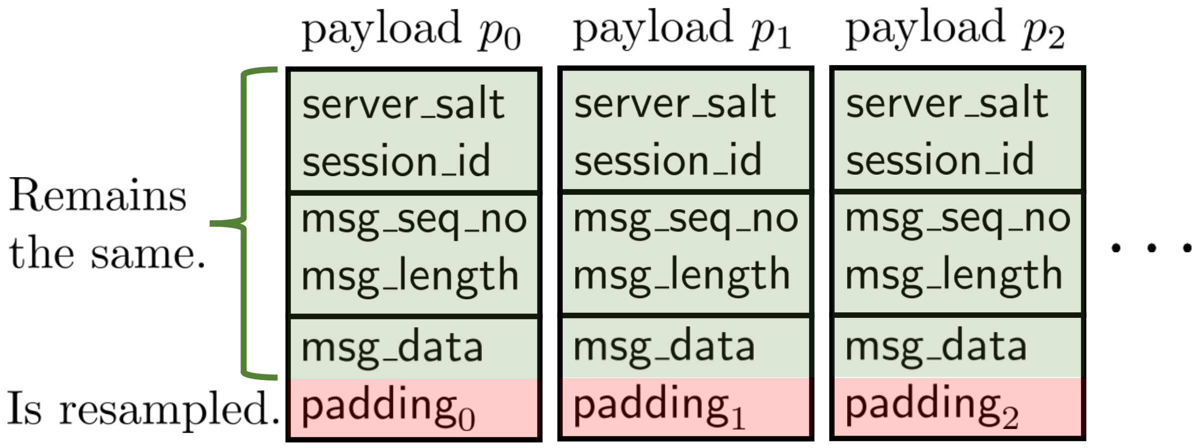
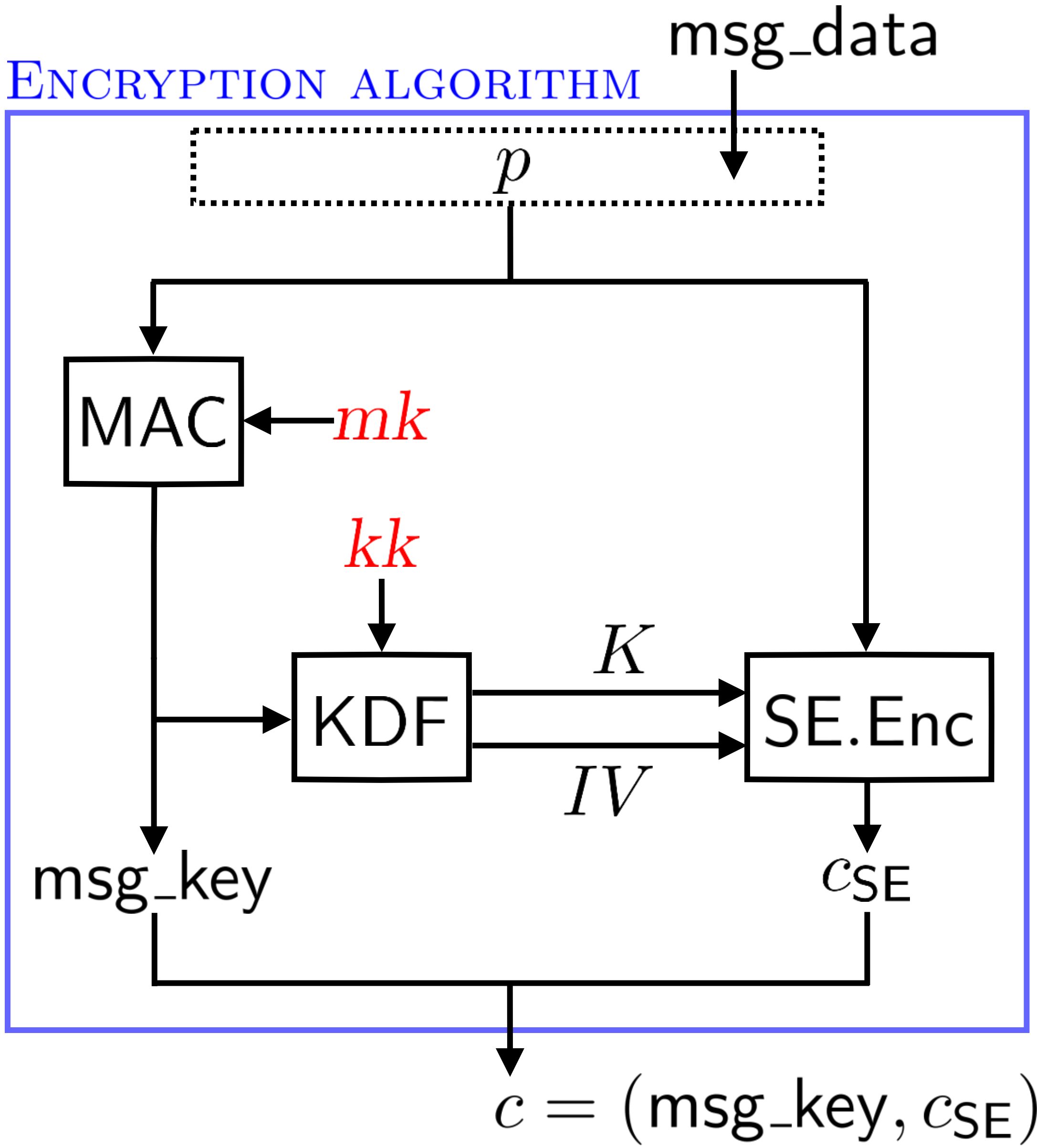


Observe $c = (\mathsf{msg\_key}, c_{SE})$, $c^* = (\mathsf{msg\_key}^*, c^*_{SE})$ **with** $\mathsf{msg\_key} = \mathsf{msg\_key}^*$, $c_{SE}[2] = c^*_{SE}[2]$ **?**

Attack Against IND-CPA Security



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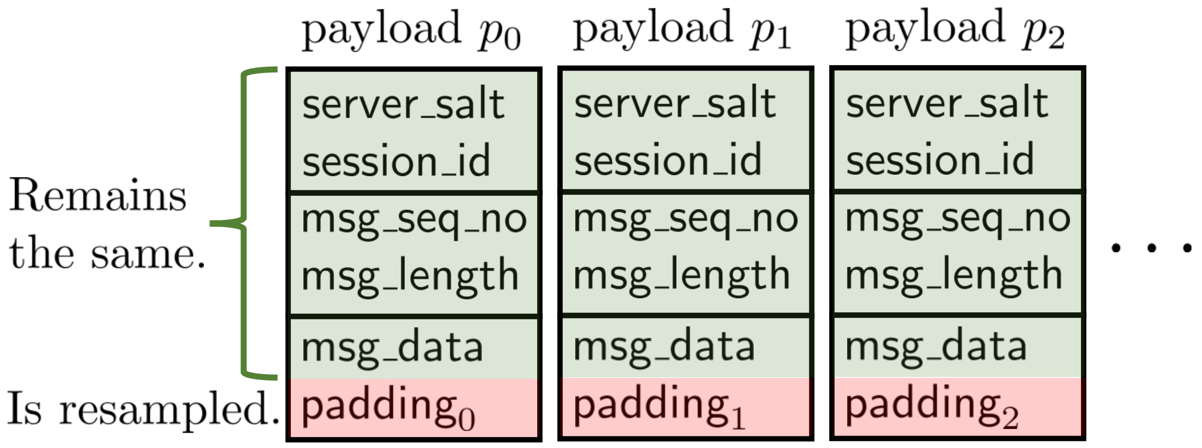

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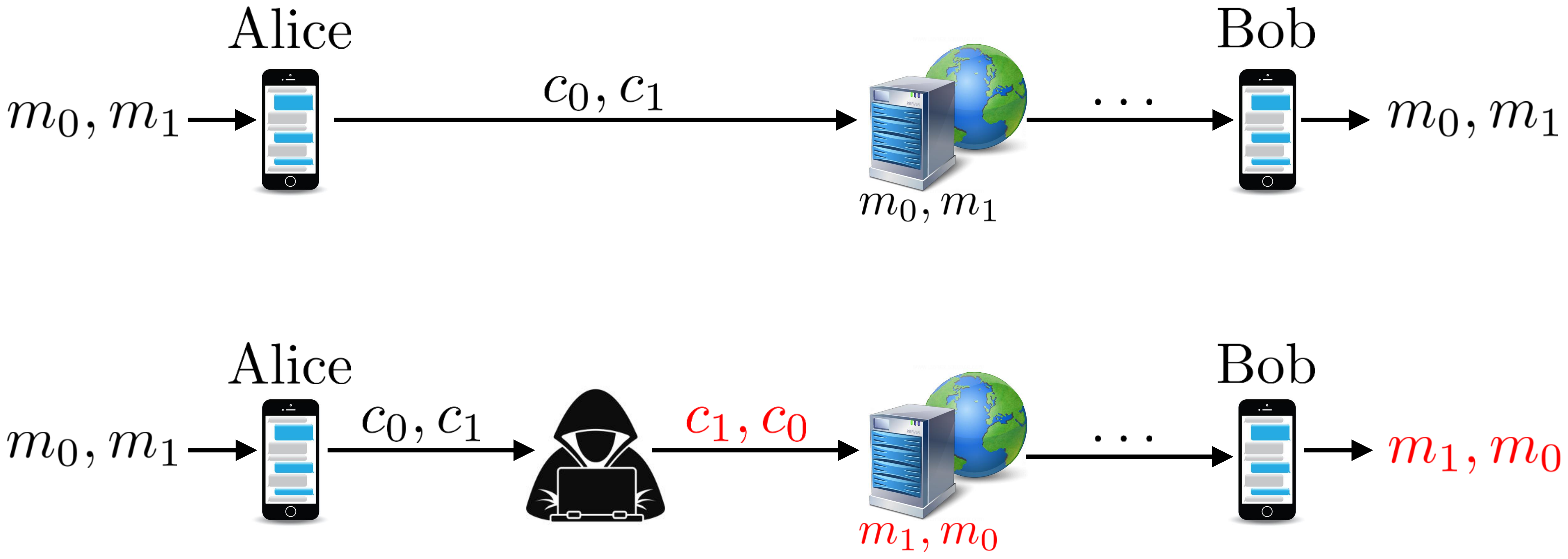
Then c, c^* encrypt the same message!

No acknowledgement received between sending c, c^*.

Message Reordering Attack



Technically trivial. Easy to exploit.

Future Work

Large parts of **Telegram** unstudied:

SECRET CHATS
KEY EXCHANGE

…, multi-user security, forward secrecy, Telegram Passport, bot APIs, higher-level message processing, control messages, encrypted CDNs, cloud storage, …

Thank you!

More information at
https://mtpsym.github.io/