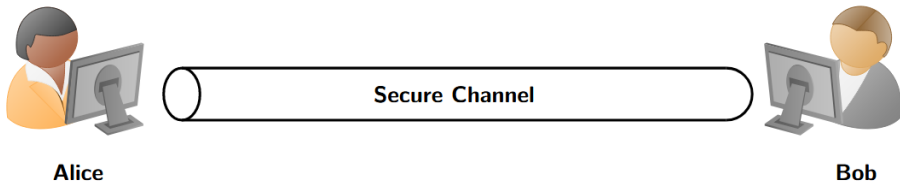




HOW FAST DO YOU HEAL?

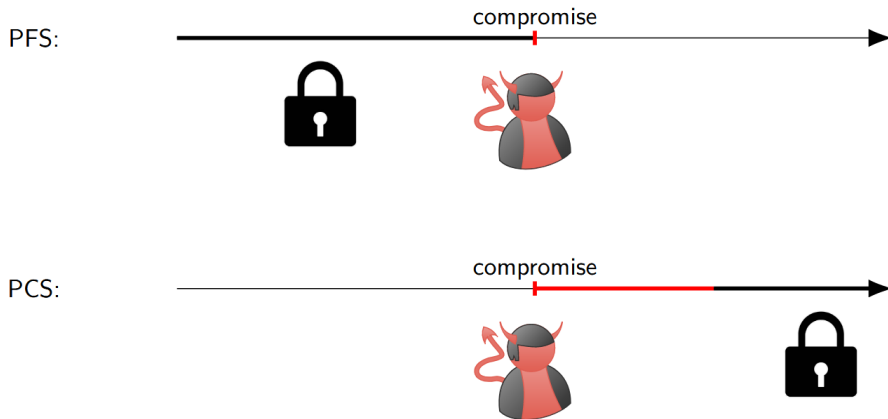
A taxonomy for post-compromise security in secure-channel establishment

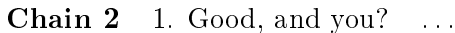
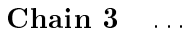
ASYNCHRONOUS MESSAGING PROTOCOLS



- Asynchronicity
- Mutual Authentication
- Perfect Forward Secrecy (PFS)
- **Post-Compromise Security (PCS)**
- ...

PFS (EC'89) AND PCS (CSF'16)



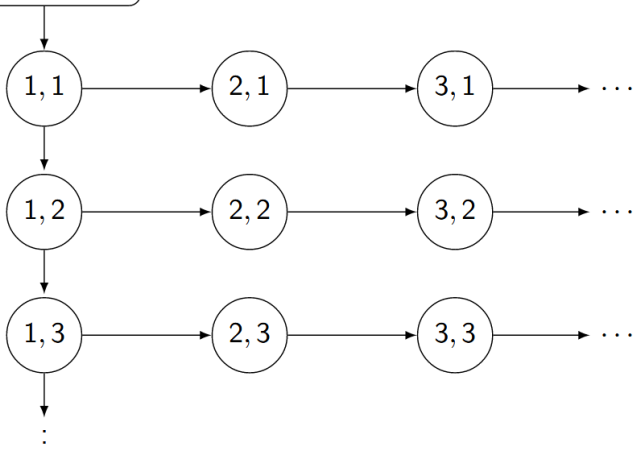


- ÉCOLE POLYTECHNIQUE – Prosecco'23

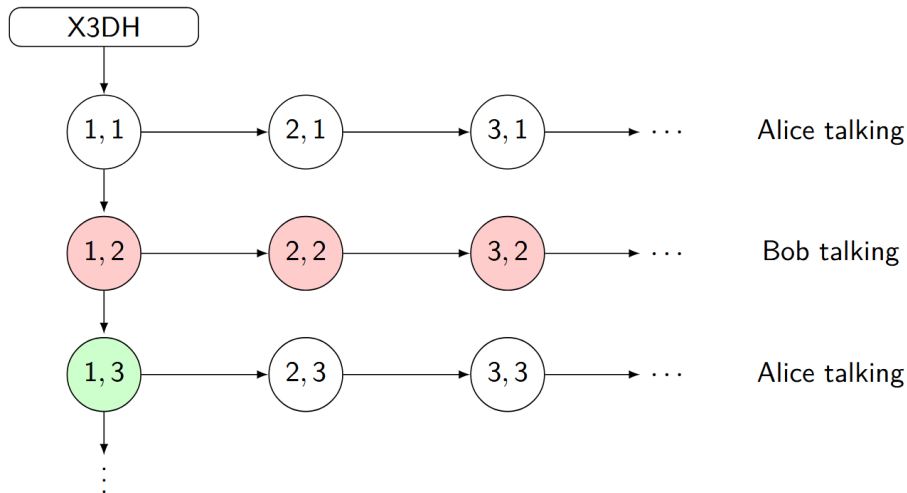
STAGE FLOW OF SIGNAL



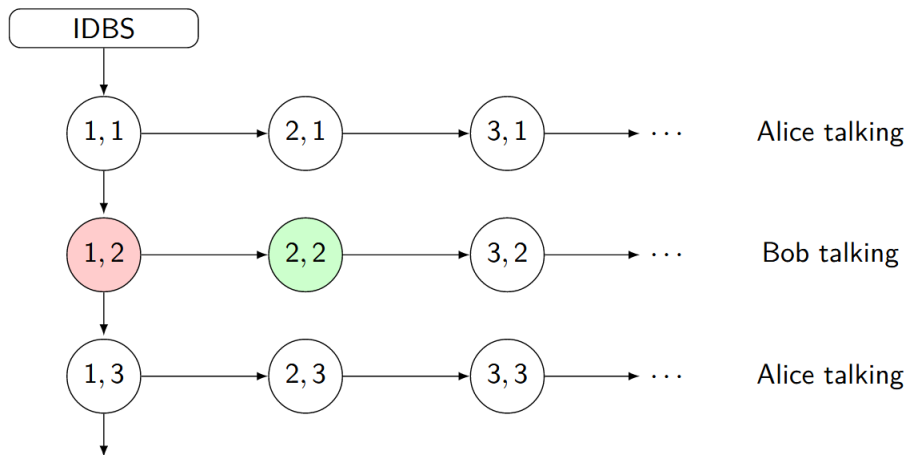
X3DH (AKE)



IN TERM OF PCS



LOOKING AT SAID (EURO S&P'19)



SAID is $(1,0)$ -PCS

SIGNAL VS SAID?



SAID is better than Signal for PCS?

Ok, we cheated a little

- Key hierarchy
- Identity-based
- Key Distribution Authority vs Database

OUR GOAL IN THIS WORK



- Define the adversary/attacker for a better model
- Quantify healing speed
- Compare different protocols through PCS



We will consider the number of stages *lost* after a compromise

OUTLINE



- Description of Signal
- Example of attacks
- Marshal and Samurai protocols
- Our model to quantify healing
- Applying PCS for 5G?

1

DESCRIPTION OF SIGNAL



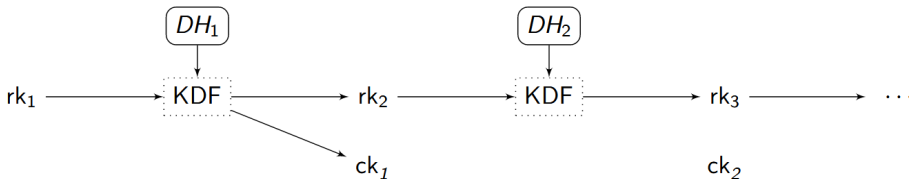
RATCHET ALGORITHMS



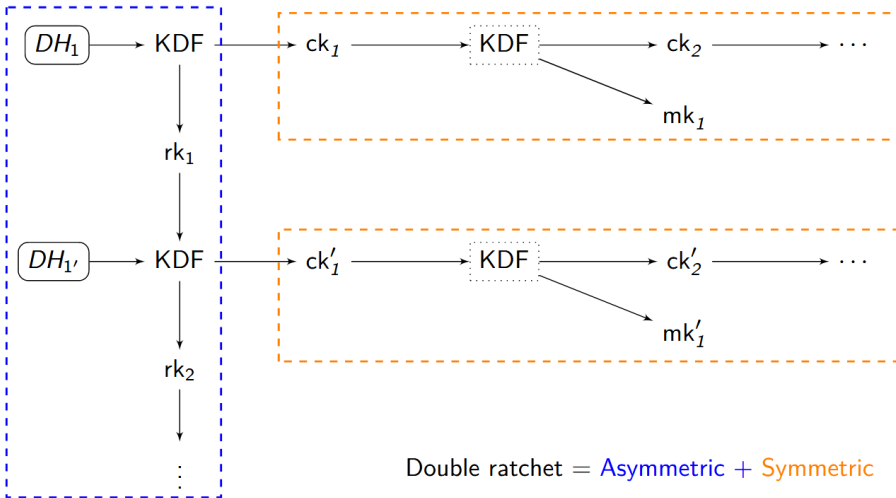
Symmetric Ratchet (PFS)



Asymmetric Ratchet (PCS)



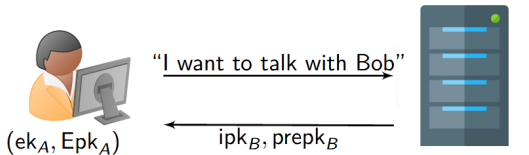
DOUBLE RATCHET ALGORITHM



Double ratchet = Asymmetric + Symmetric

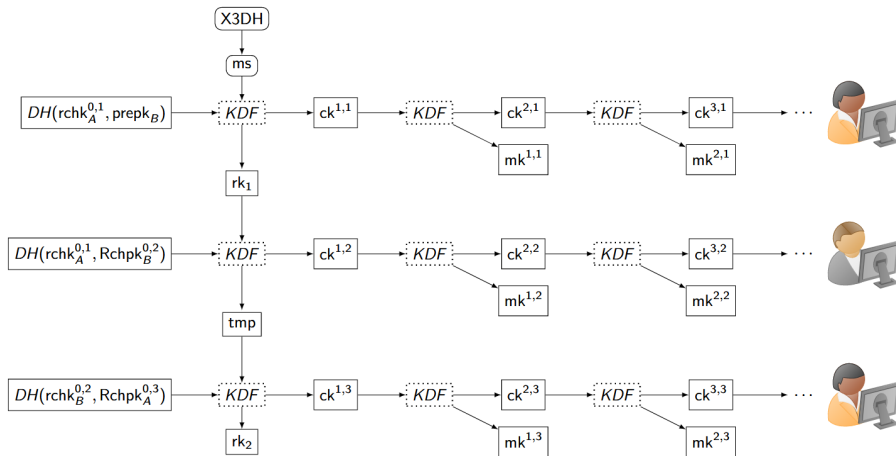
REGISTRATION - SETUP

Description of
Signal



$$\text{X3DH: } ms := (prepk_B)^{ik_A} \parallel (ipk_B)^{ek_A} \parallel (prepk_B)^{ek_A}$$

KEY SCHEDULE OF SIGNAL

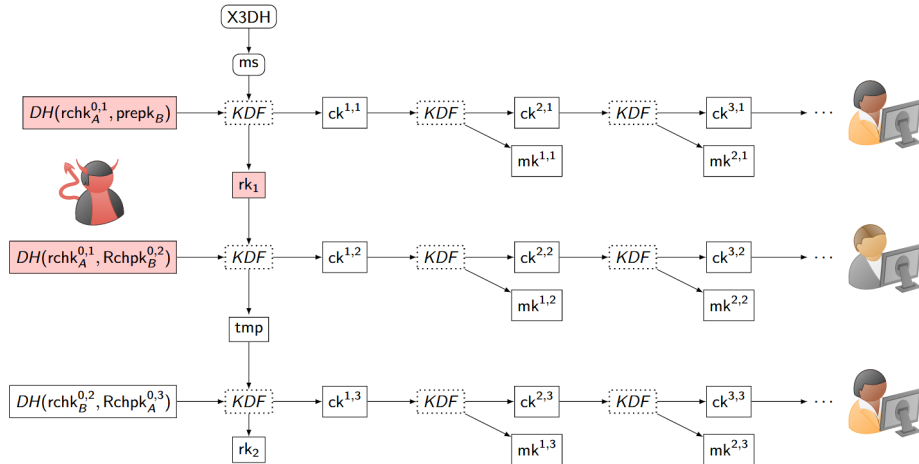


2 EXAMPLE OF ATTACKS



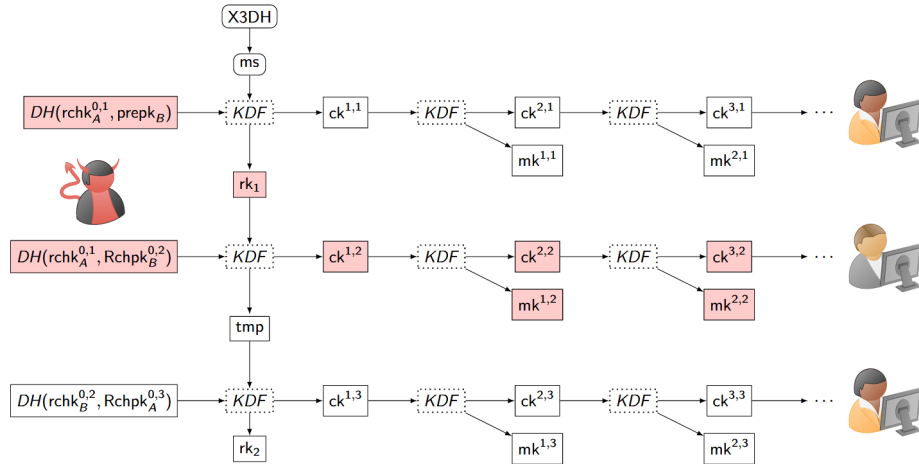
PASSIVE ATTACK ($\text{rchk}_A^{0,1}, \text{rk}_1$)

Example of attacks



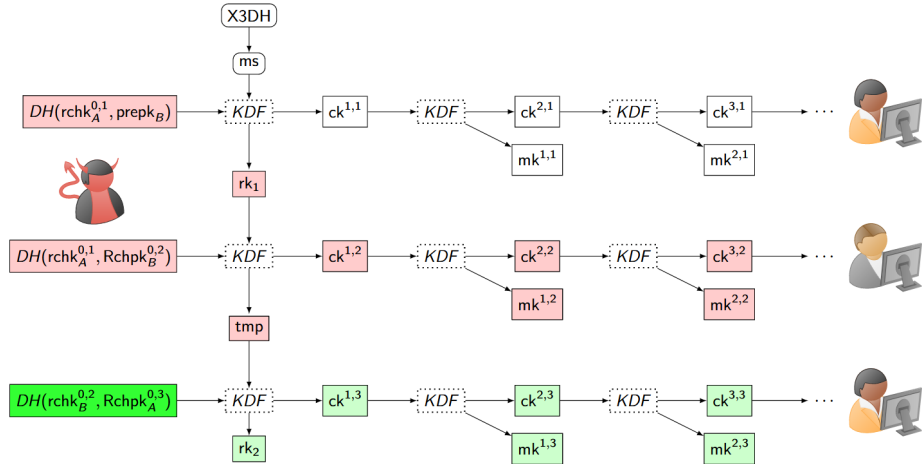
PASSIVE ATTACK ($\text{rchk}_A^{0,1}, \text{rk}_1$)

Example of attacks



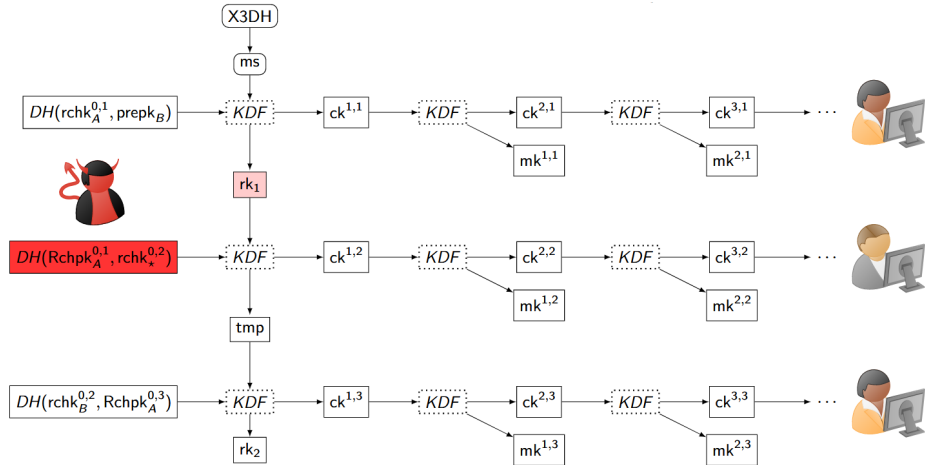
PASSIVE ATTACK ($\text{rchk}_A^{0,1}, \text{rk}_1$)

Example of attacks



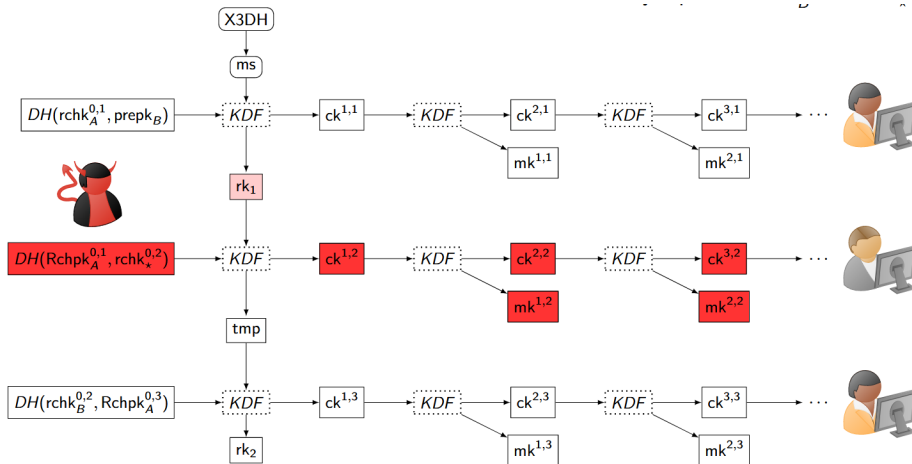
ACTIVE ATTACK (rk_1), NEW $rchk_*^{0,2}$

Example of attacks



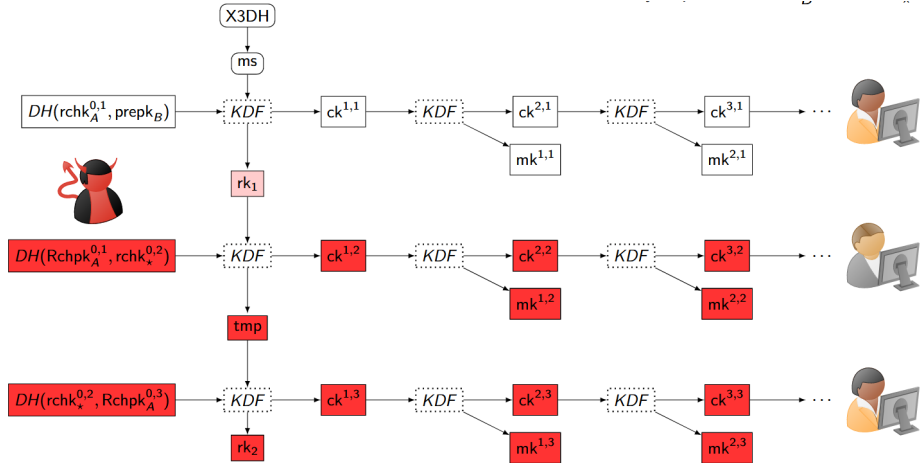
ACTIVE ATTACK (rk_1), NEW $rchk_*^{0,2}$

Example of attacks



ACTIVE ATTACK (rk_1), NEW $rchk_*^{0,2}$

Example of attacks

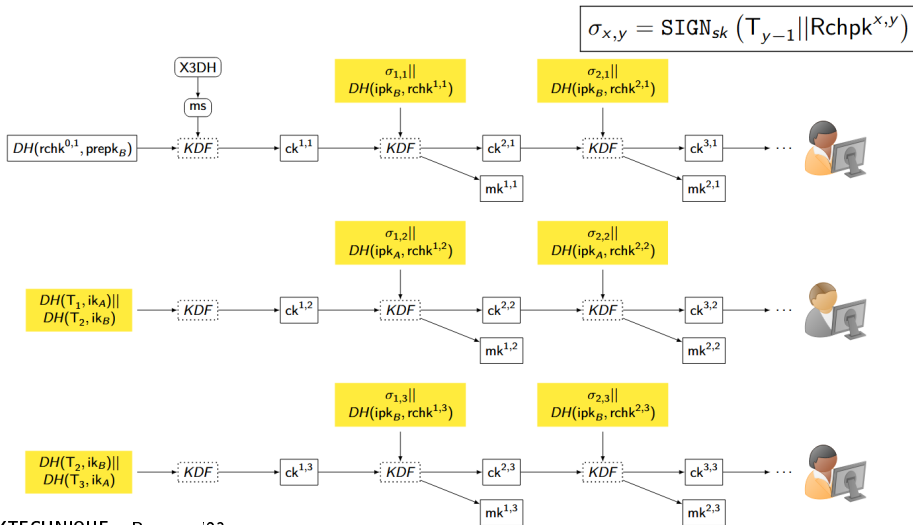


3

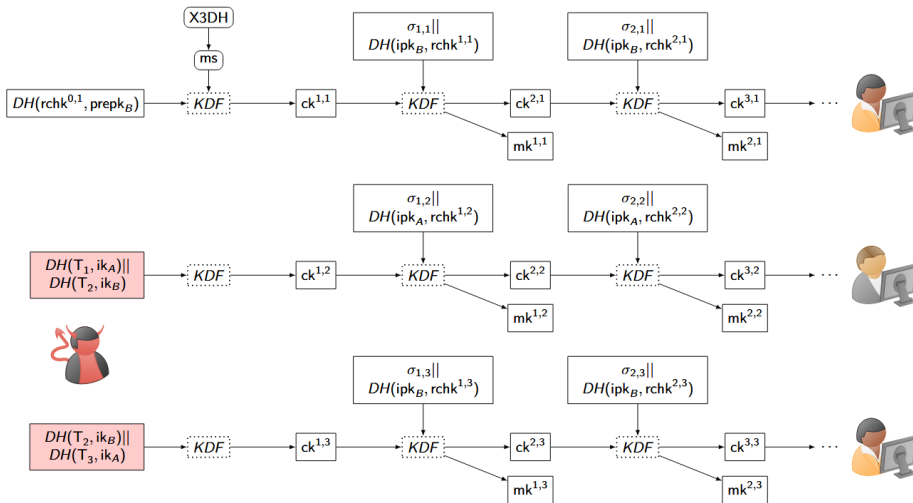
MARSHAL AND SAMURAI



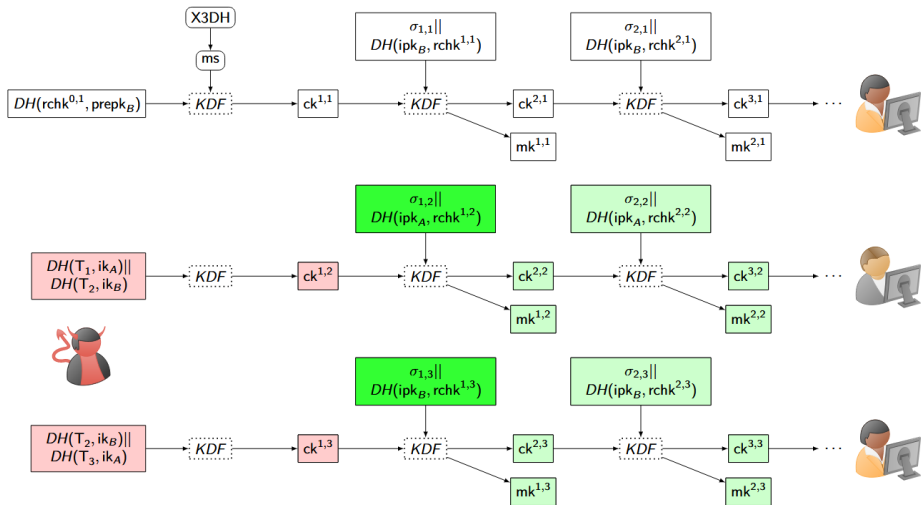
MARSHAL KEY SCHEDULE



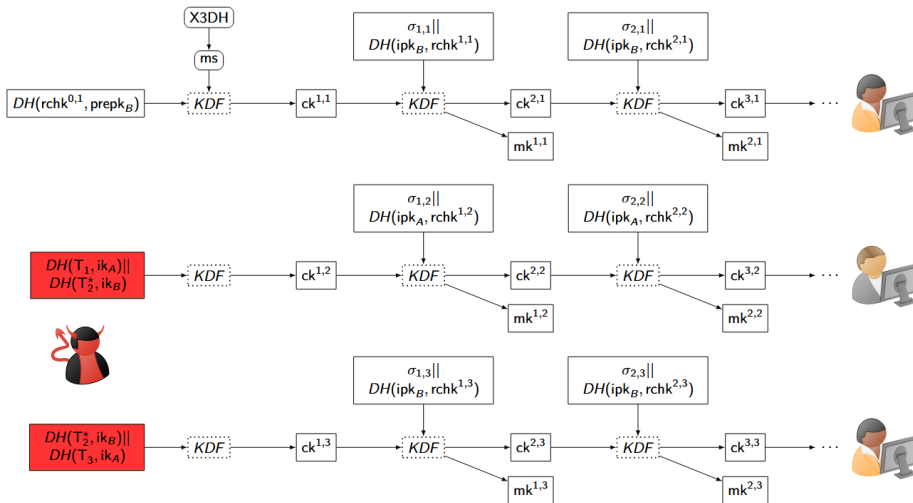
PASSIVE ATTACK (T_2)



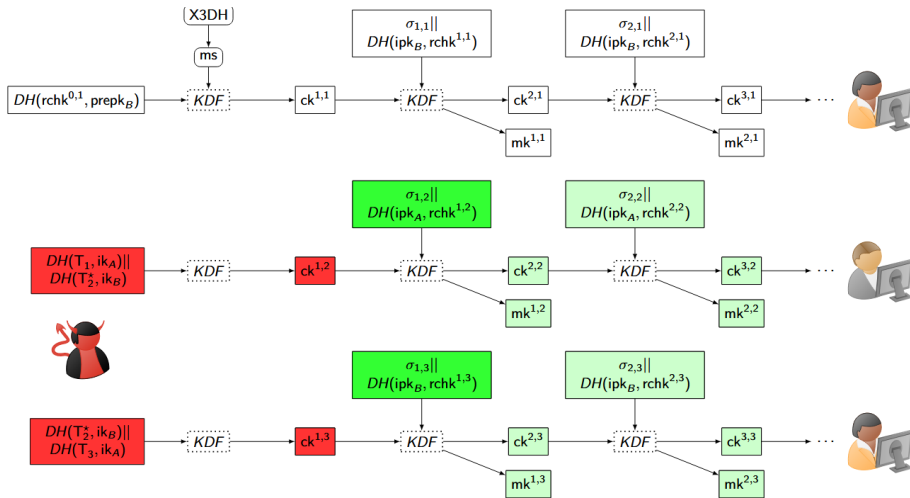
PASSIVE ATTACK (T_2)

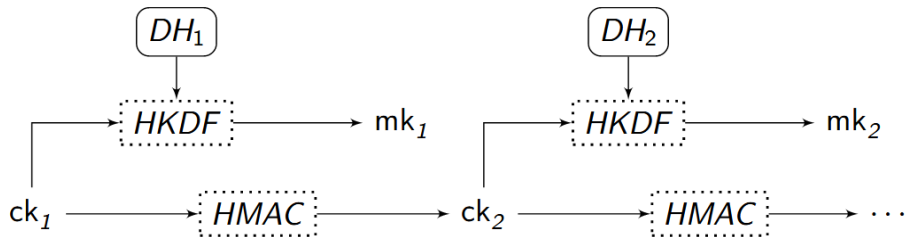


ACTIVE ATTACK (T_2^*)



ACTIVE ATTACK (T_2^*)





Supersedes the signature, by a MAC.

EFFICIENCY



	Signal	Marshal / Samurai
Session Setup	3.856ms	6.924ms
Message $(1, y)$	1.284ms	5.082ms
Message $(100, y)$	0.06ms	1.512ms

4

OUR MODEL TO QUANTIFY HEALING



GENERIC APPROACH

Our model to
quantify
healing



Security Properties

- Post Compromise Security
- Authentication
- ...

Protocols

- Signal
- Said
- Marshal

Adversaries

- Power
- Behavior
- ...

THREE CATEGORIES OF KEYS

Cross-session keys (long-term)

Keys that repeat in at least two sessions

Cross-stage keys (medium-term)

Keys that repeat in at least two stages of the same session, but do not repeat in two distinct sessions

Single-stage keys (ephemeral)

These are keys that only occur in one stage of one protocol instance

Our model to
quantify
healing



ADVERSARIES

Reach

- **Local adversaries:** can reveal single-stage keys
- **Medium adversaries:** can reveal single and cross-stage keys
- **Global adversaries:** can reveal all keys

Power

- **Active adversaries:** can send/receive messages → session hijacking
- **Passive adversaries:** try to learn as much as possible about future keys without actually interfering in the session too much

Access

- **Insider adversaries:** these attackers are the super-user (server)
- **Outsider adversaries:** these attackers cannot corrupt the server



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POST COMPROMISE SECURITY QUANTIFICATION

Our model to
quantify
healing



Outsider	Reach	Signal	SAID	Marshal
Passive	Global	$(\infty, 2)$	$(\infty, 2)$	$(1, 0)$
	Medium	$(\infty, 2)$	$(\infty, 2)$	$(1, 0)$
	Local	$(\infty, 1)$	$(1, 0)$	$(1, 0)$
Active	Global	(∞, ∞)	(∞, ∞)	(∞, ∞)
	Medium	(∞, ∞)	(∞, ∞)	$(1, 0)$
	Local	$(\infty, 1)$	$(1, 0)$	$(1, 0)$

POST COMPROMISE SECURITY QUANTIFICATION

Our model to
quantify
healing



Insider	Reach	Signal	SAID	Marshal
Passive	Global	$(\infty, 2)$	$(\infty, 2)$	$(1, 0)$
	Medium	$(\infty, 2)$	$(\infty, 2)$	$(1, 0)$
	Local	$(\infty, 1)$	$(\infty, 1)$	$(1, 0)$
Active	Global	(∞, ∞)	(∞, ∞)	(∞, ∞)
	Medium	(∞, ∞)	(∞, ∞)	(∞, ∞)
	Local	(∞, ∞)	(∞, ∞)	(∞, ∞)

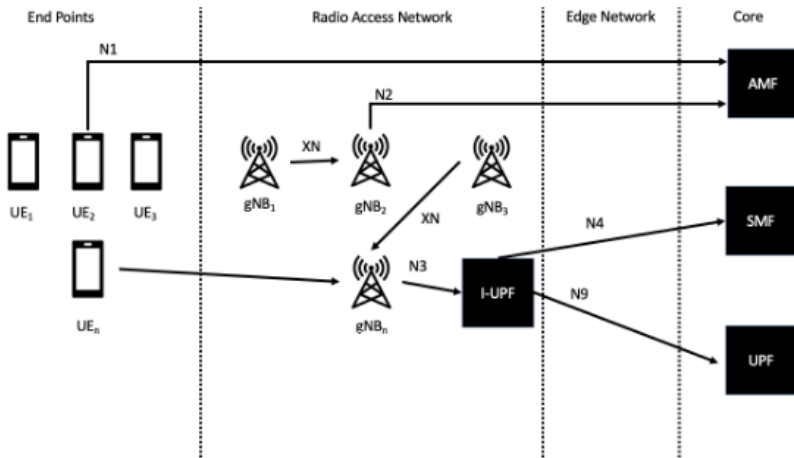
5

APPLICATION TO 5G



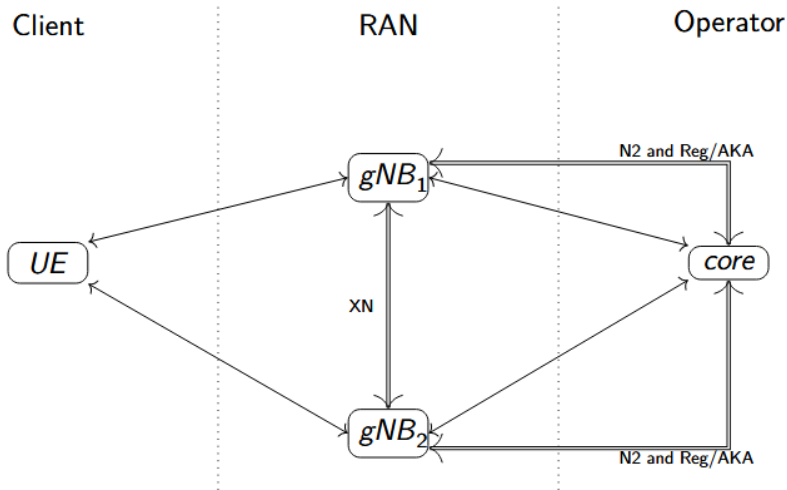
HANDOVER PROCEDURES IN 5G NETWORKS

Application to
5G



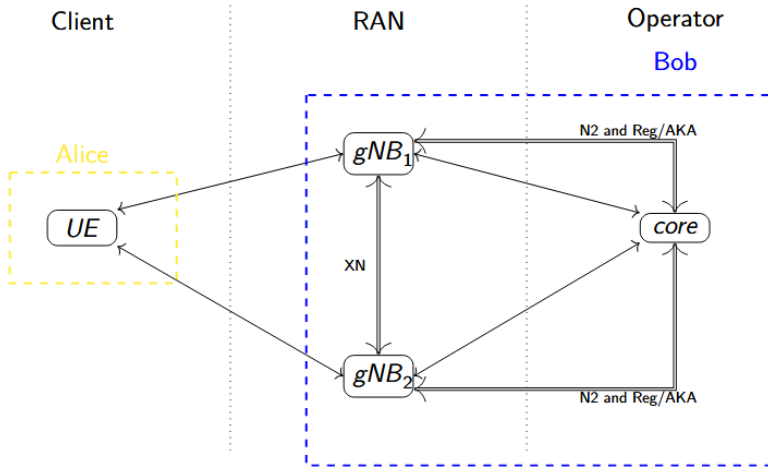
A FOCUS ON XN AND N2 (SCEKE)

Application to
5G



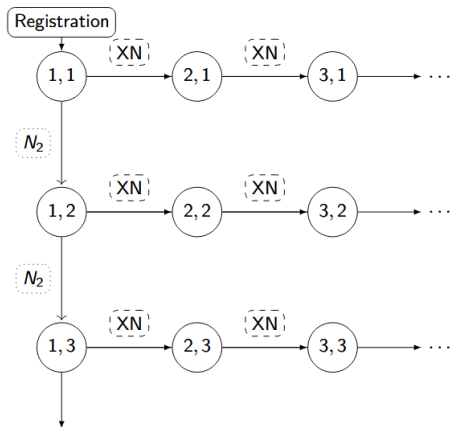
A FOCUS ON XN AND N2 (SCEKE)

Application to
5G

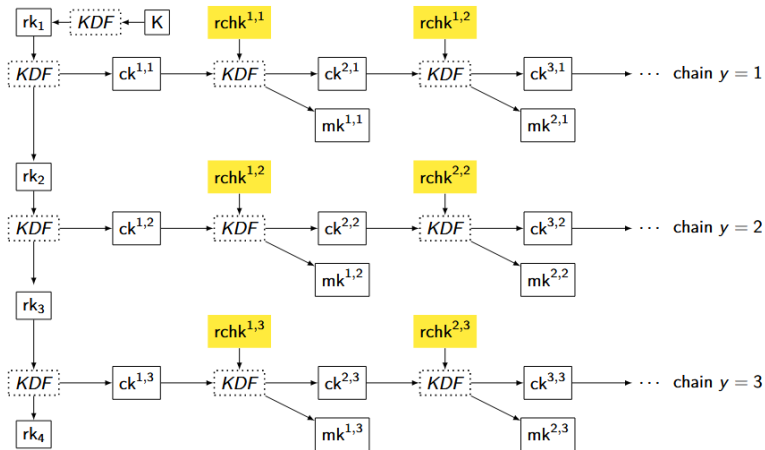


COMING BACK TO OUR MODEL...

Application to
5G



REVISITING THE KEY SCHEDULE



POST COMPROMISE SECURITY QUANTIFICATION

Application to
5G



Outsider	Reach	5G	Improved 5G
Passive	Global	(∞, ∞)	$(1, 0)$
	Medium	(∞, ∞)	$(1, 0)$
	Local	$(\infty, 1)$	$(1, 0)$
Active	Global	(∞, ∞)	(∞, ∞)
	Medium	(∞, ∞)	(∞, ∞)
	Local	$(\infty, 1)$	$(\infty, 1)$

POST COMPROMISE SECURITY QUANTIFICATION

Application to
5G



Insider	Reach	5G	Improved 5G
Passive	Global	(∞, ∞)	$(1, 0)$
	Medium	(∞, ∞)	$(1, 0)$
	Local	(∞, ∞)	$(1, 0)$
Active	Global	(∞, ∞)	(∞, ∞)
	Medium	(∞, ∞)	(∞, ∞)
	Local	(∞, ∞)	(∞, ∞)

WRAPPING UP

New Framework

- Taxonomy on adversaries/keys
- Healing speed
- Comparison between different protocols

Future Work

- Consider all features (out-of-order messages)
- Other protocols TLS, Matrix, Olvid, Wire
- Multi-party protocols / Groups (dynamic)
- Automated verification