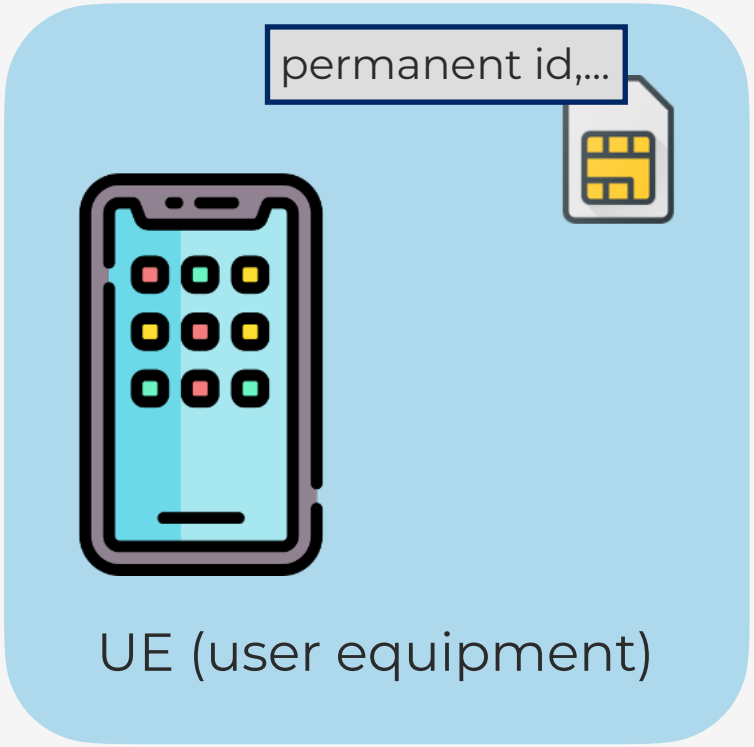
CISPA
HELMHOLTZ CENTER FOR INFORMATION SECURITY

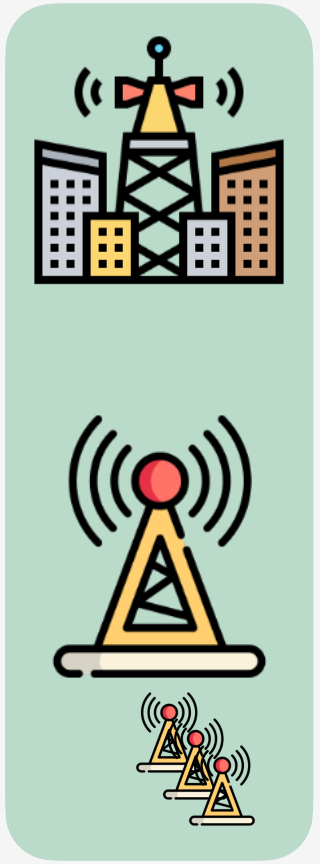
Anonymous Authentication and Key Agreement, Revisited

ACSAC 2025

Yanqi Zhao, **Xiangyu Liu**, Min Xie, Xiaoyi Yang, Jianting Ning, Baodong Qin, Haibin Zhang, Yong Yu
CISPA Helmholtz Center for Information Security

Mobile Systems



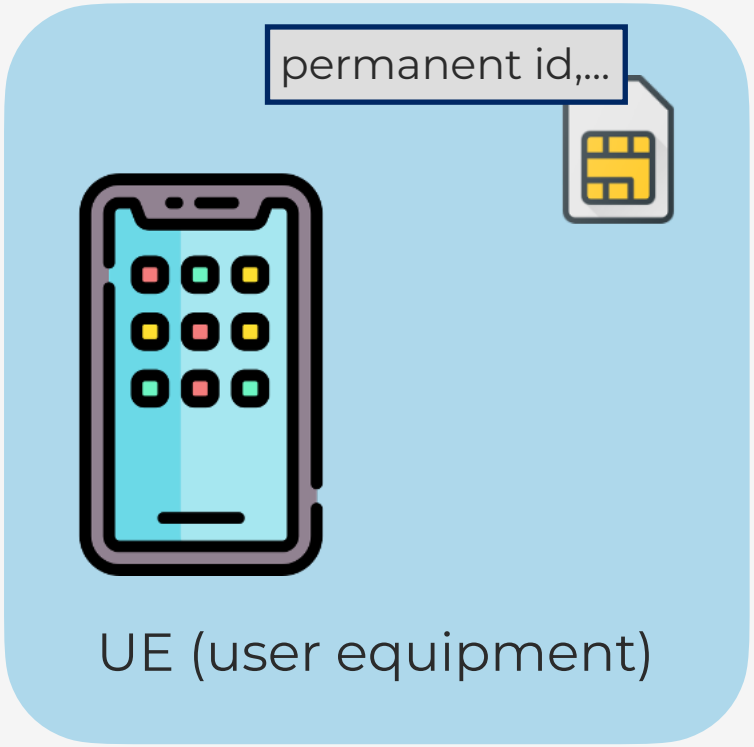


HN (home network)

MNO
(mobile network operators)

SN (serving network)

Mobile Systems



1. payment

HN (home network)

MNO
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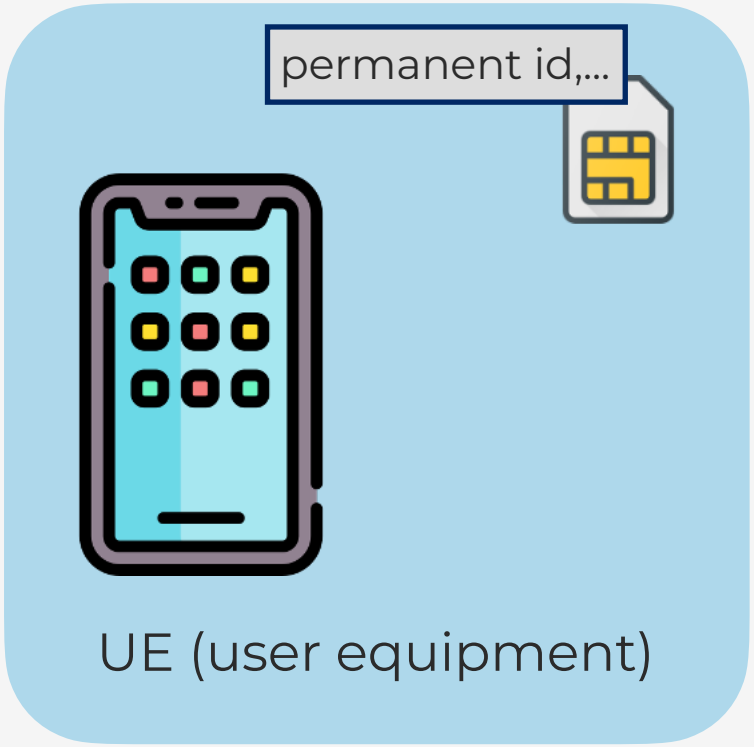

1. payment

2. credential

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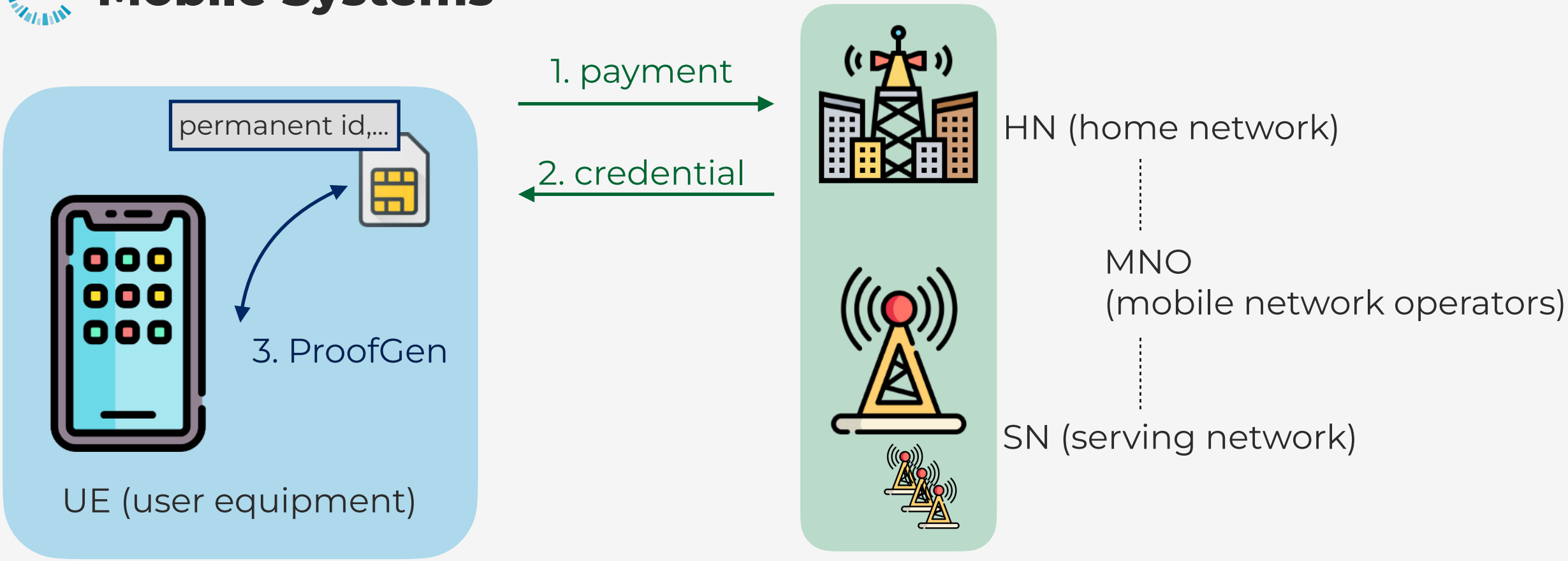

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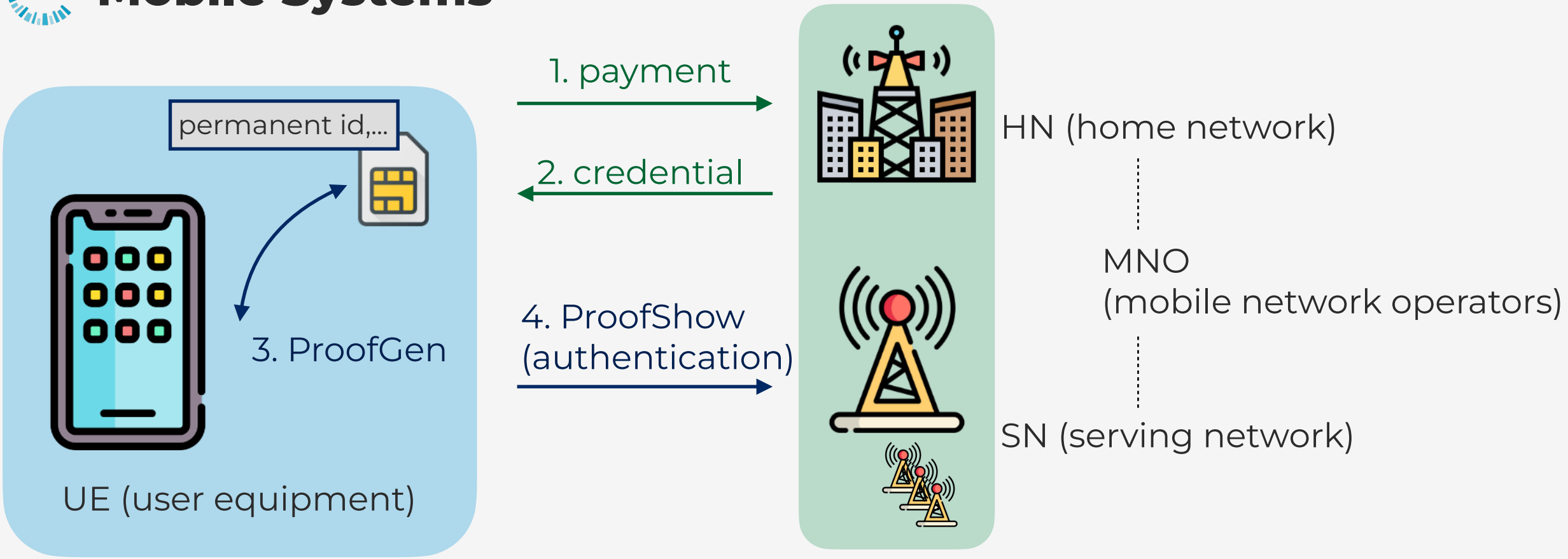

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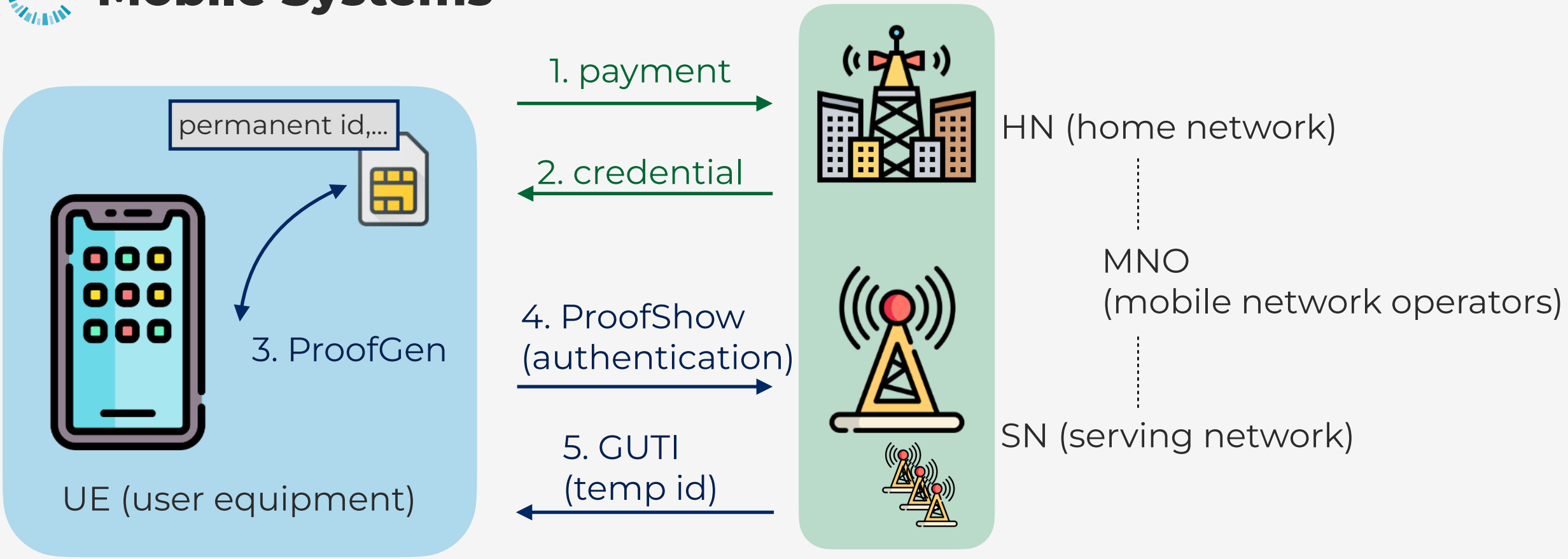
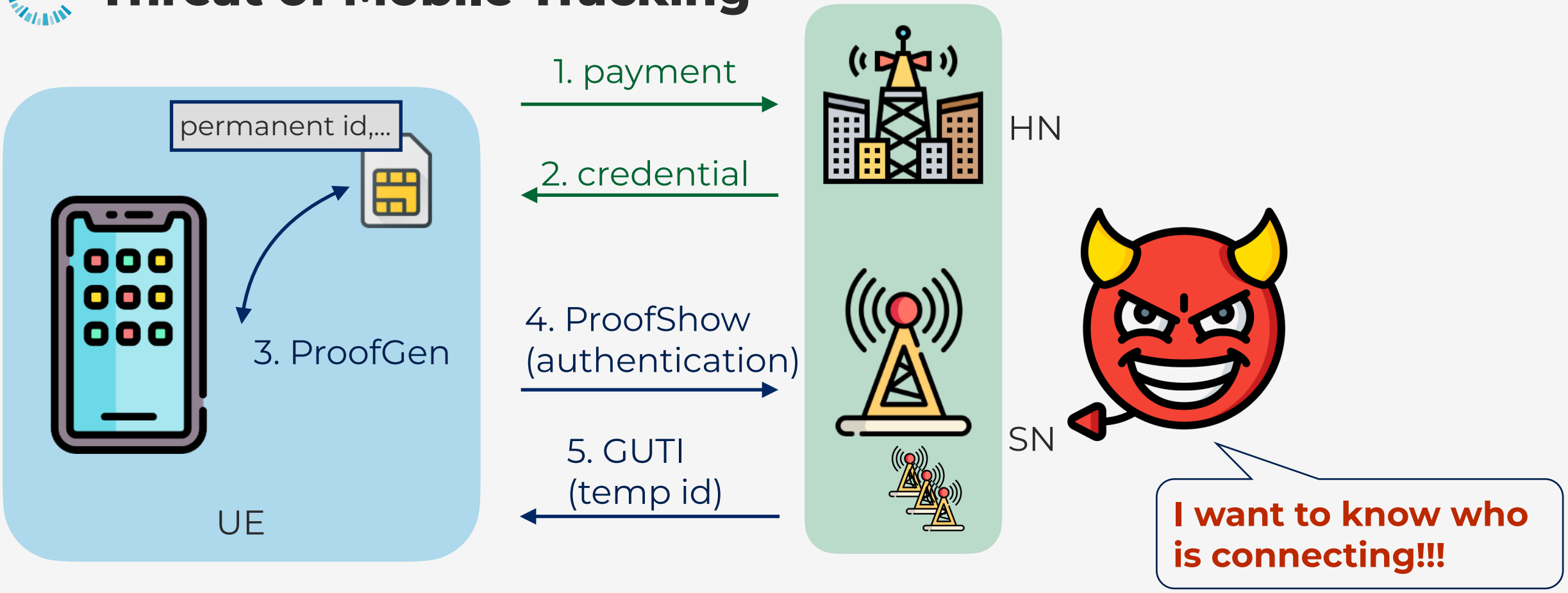
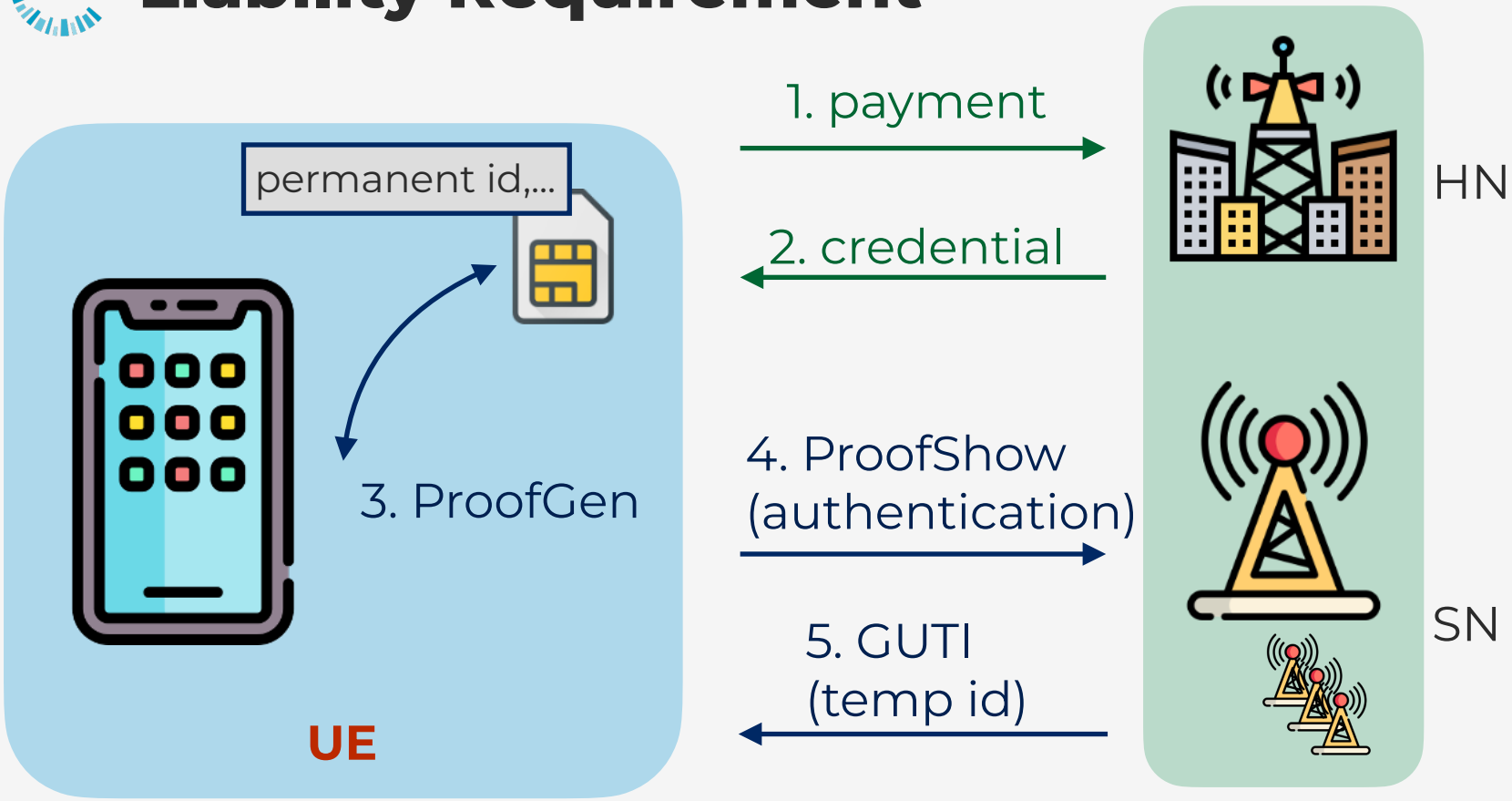


Threat of Mobile Tracking



Mobile carriers may sell users' location history to third parties!

Liability Requirement



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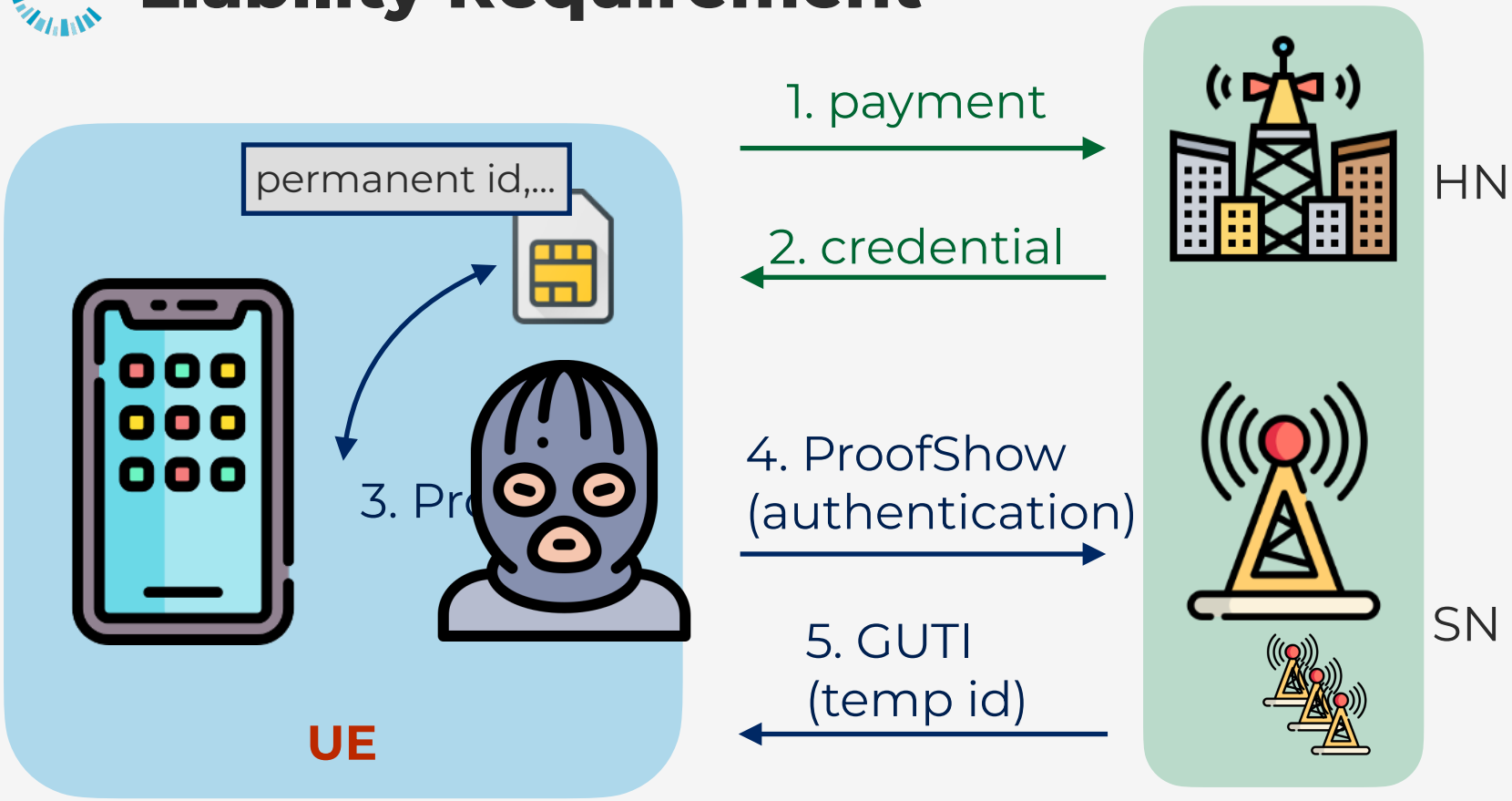

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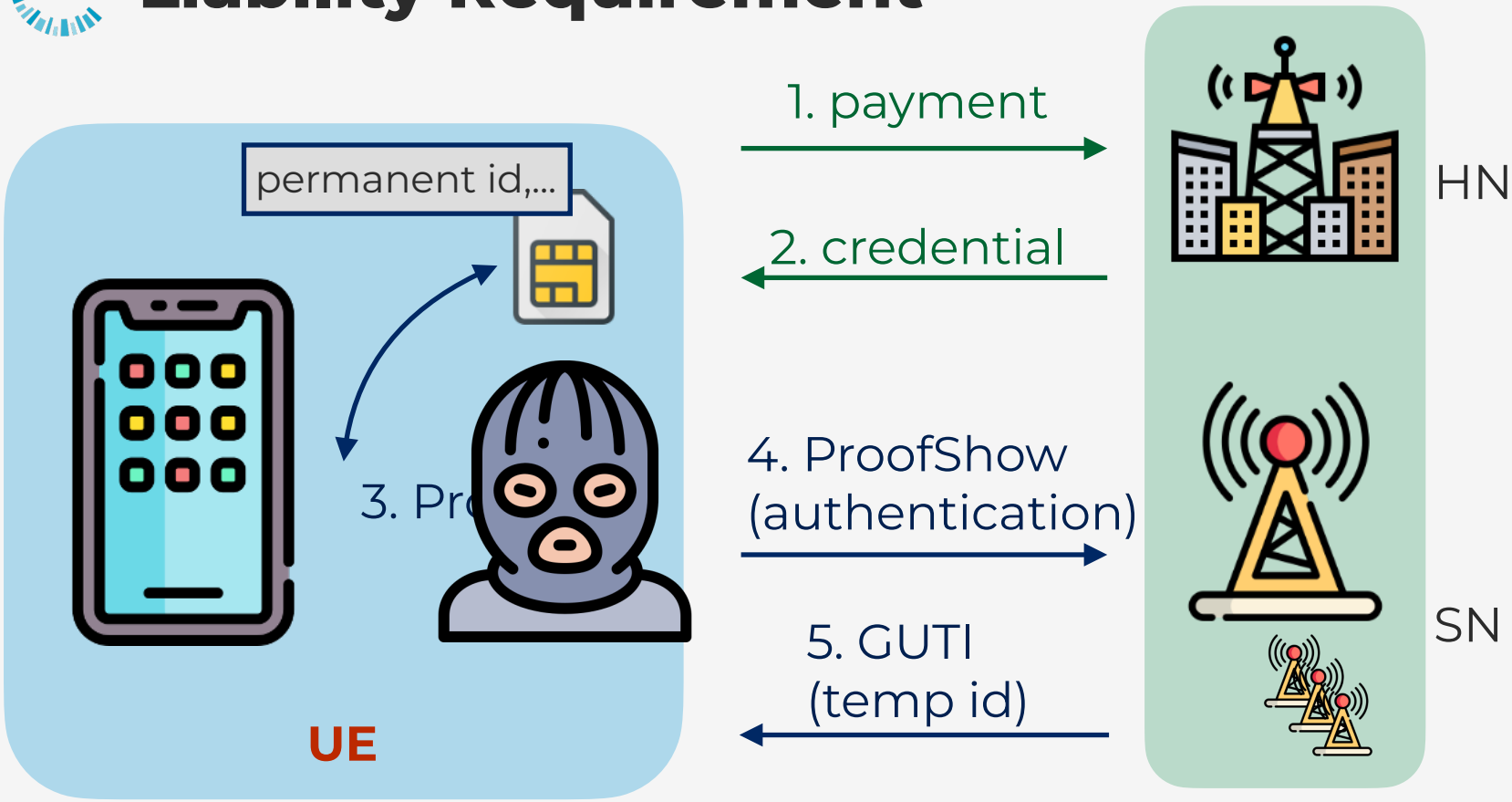

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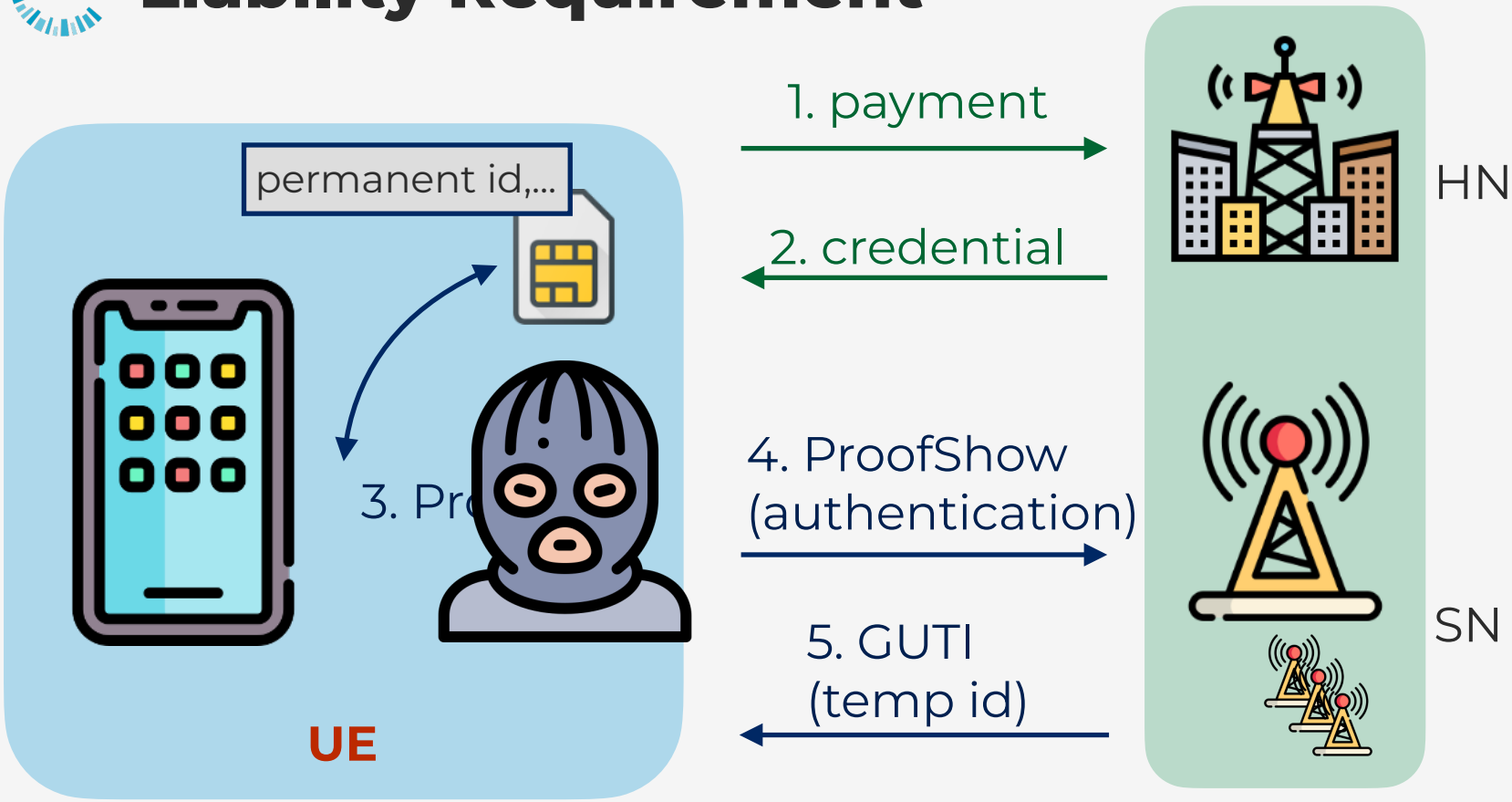

- privacy?
- anti-counterfeiting?
- traceability?
- reliability?

AAKA

AAKA: Anonymous Authentication and Key Agreement [YZZ+24]

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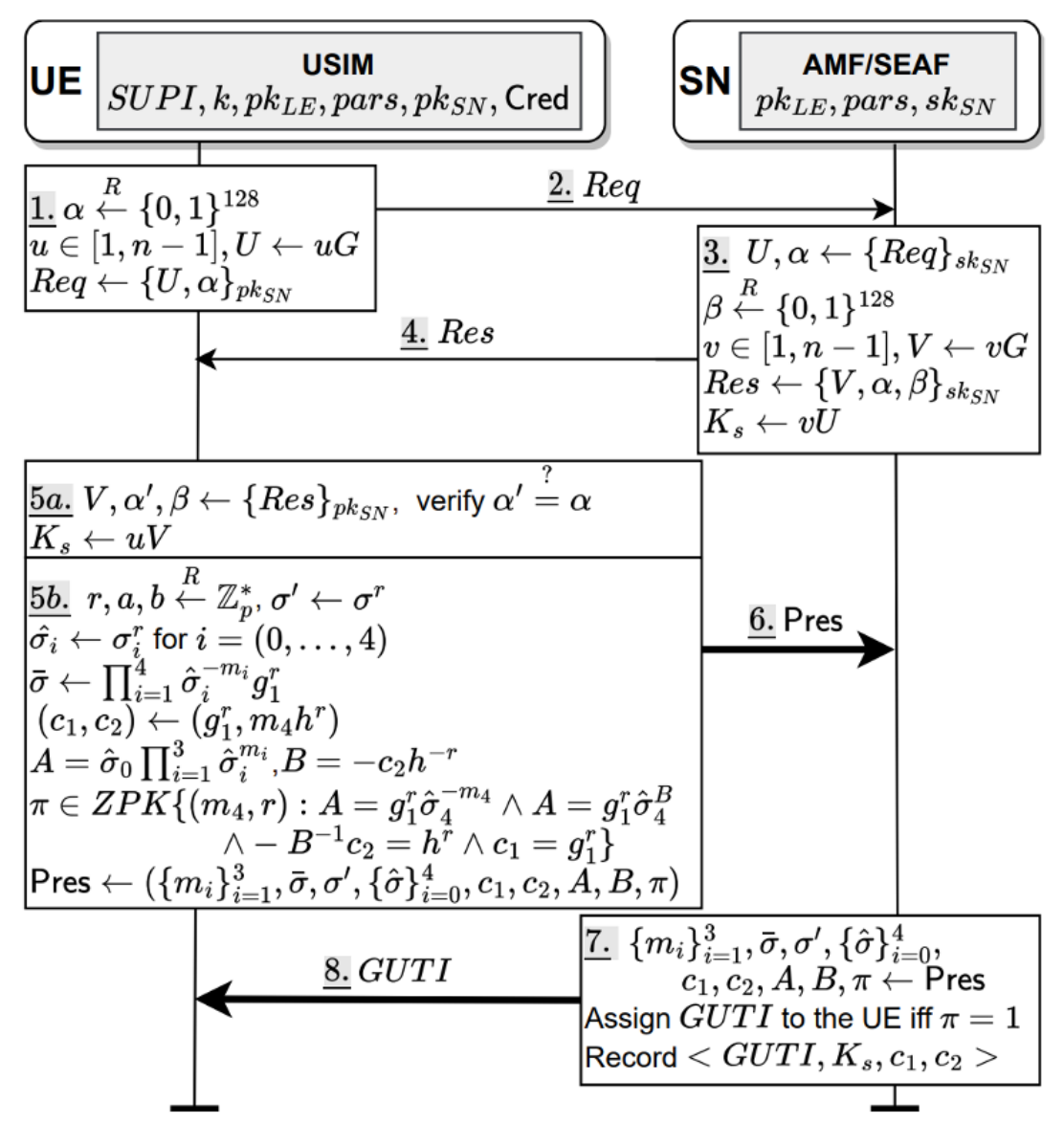
YZZ+ AAKA

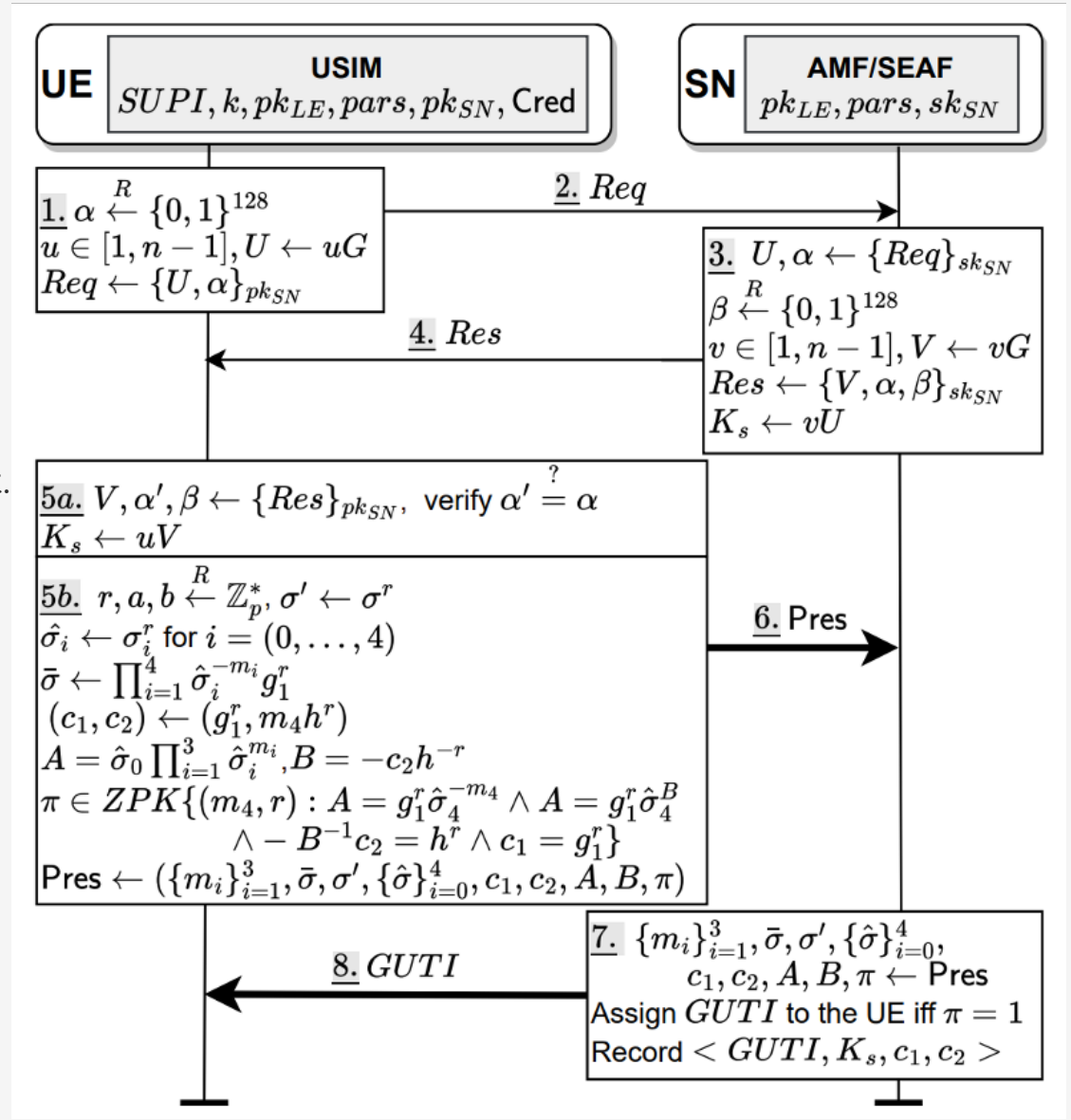


the Presentation and Verification protocol in YZZ+ AAKA

YZZ+ AAKA

m_1, m_2, m_3: public info (subscription)
m_4: private info (permanent id)

$X_0, \ldots, X_4$: public key of HN
h: public key of LEA
(c_1, c_2): ElGamal encryption of m_4
π: zero-knowledge proof for (m_4, r) s.t.
$\ldots, -B^{-1}c_2 = h^r, \ldots$



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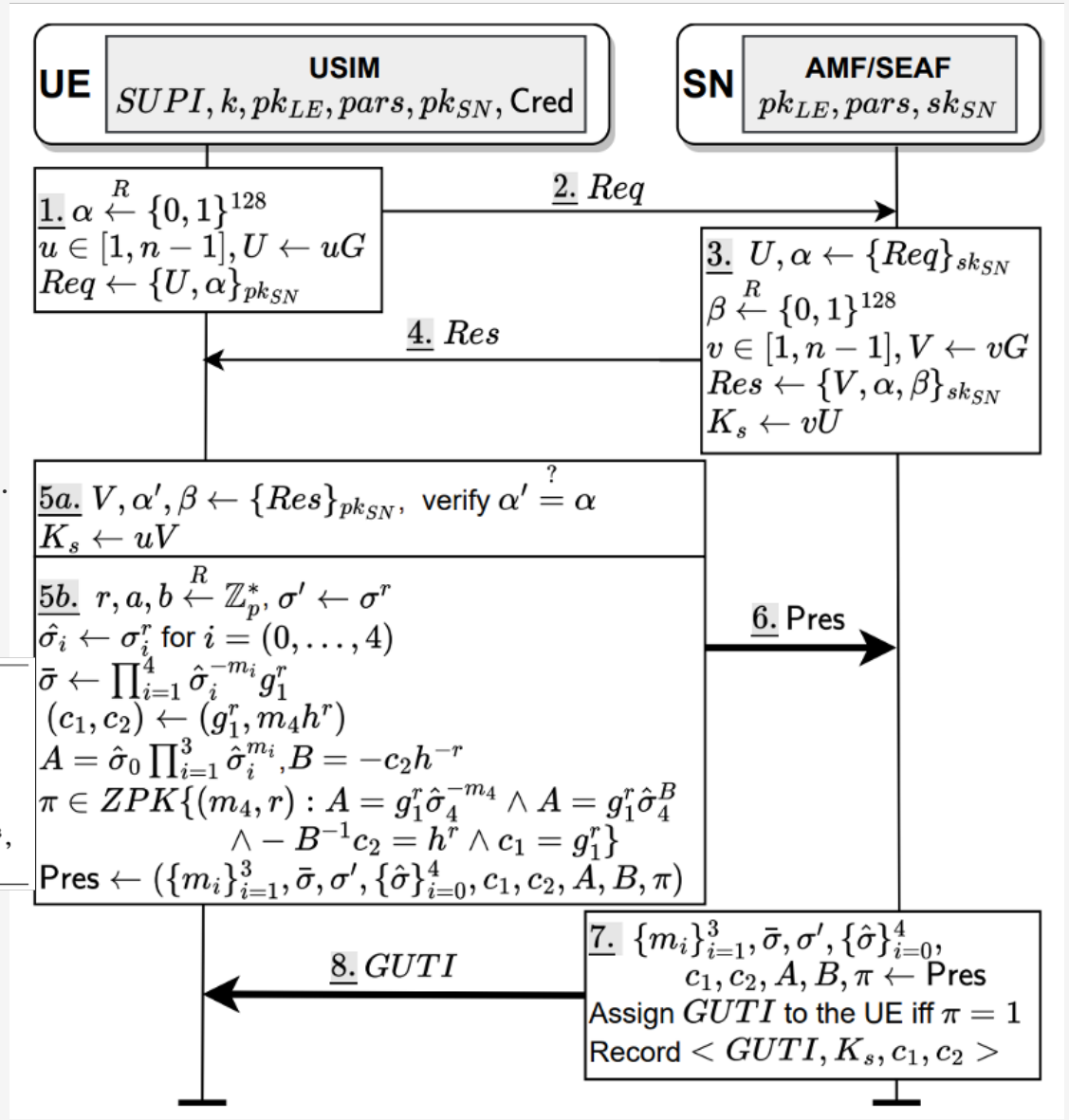
Let $y_3 = -B^{-1}c_2$. UE executes the following steps:
1) Randomly takes $a_3 \in Z_p^*$
2) Choose challenge $C_3 = H(\bar{y_3})$
3) Compute $\bar{a_3} = a_3 + C_3 r$
4) Sends $(y_3, C_3, \bar{a_3})$ to the SN

SN then computes $\bar{y_3} = h^{\bar{a_3}} y_3^{-C_3} = h^{a_3 + C_3 r} h^{-C_3 r} = h^{a_3}$, and check if $C_3 = H(\bar{y_3})$



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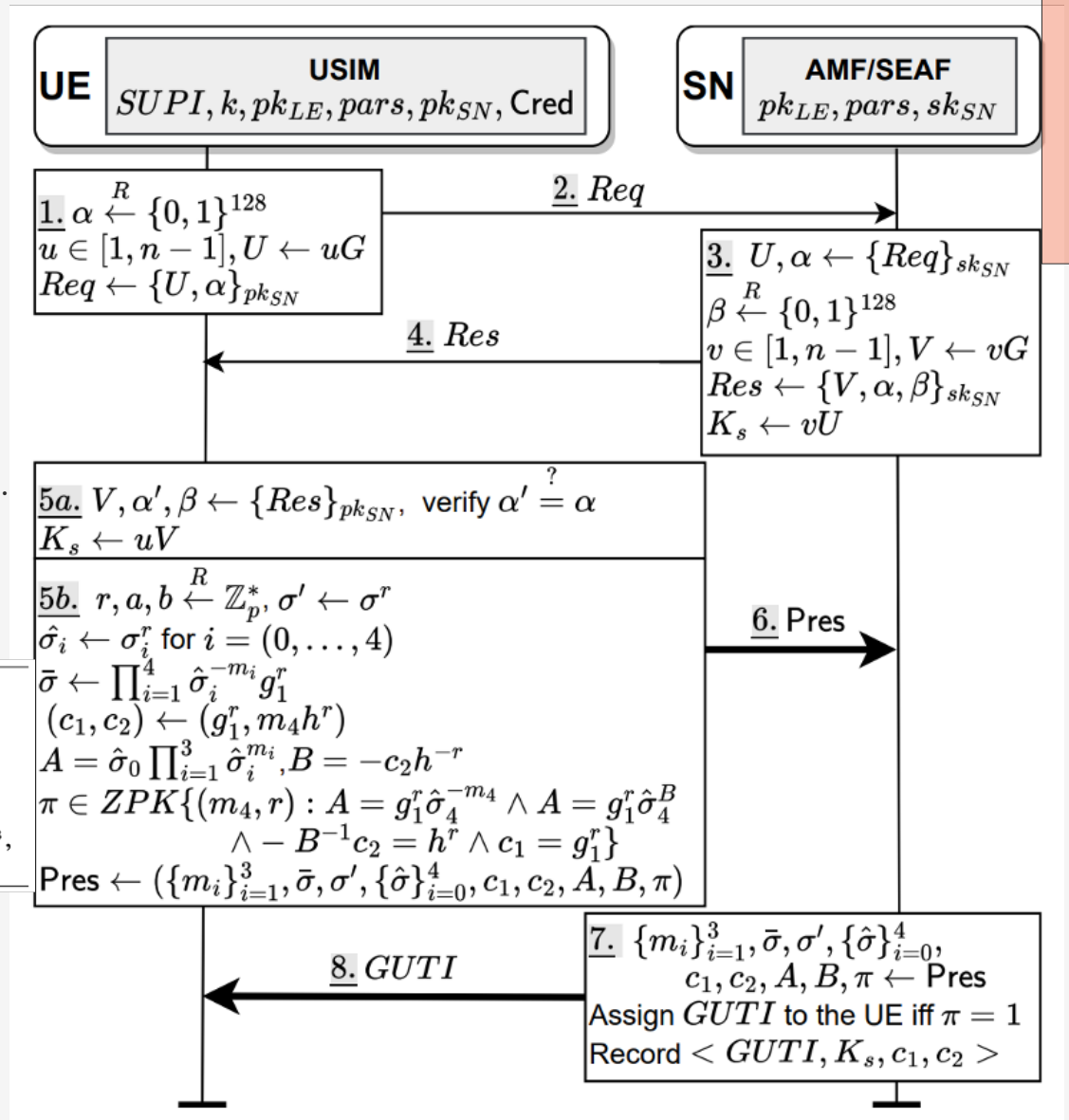

Attack on Privacy:
SN obtains
$y_3 = -B^{-1}c_2 = h^r$
$c_2 = m_4 / h^r$
so, $m_4 = c_2 / y_3$

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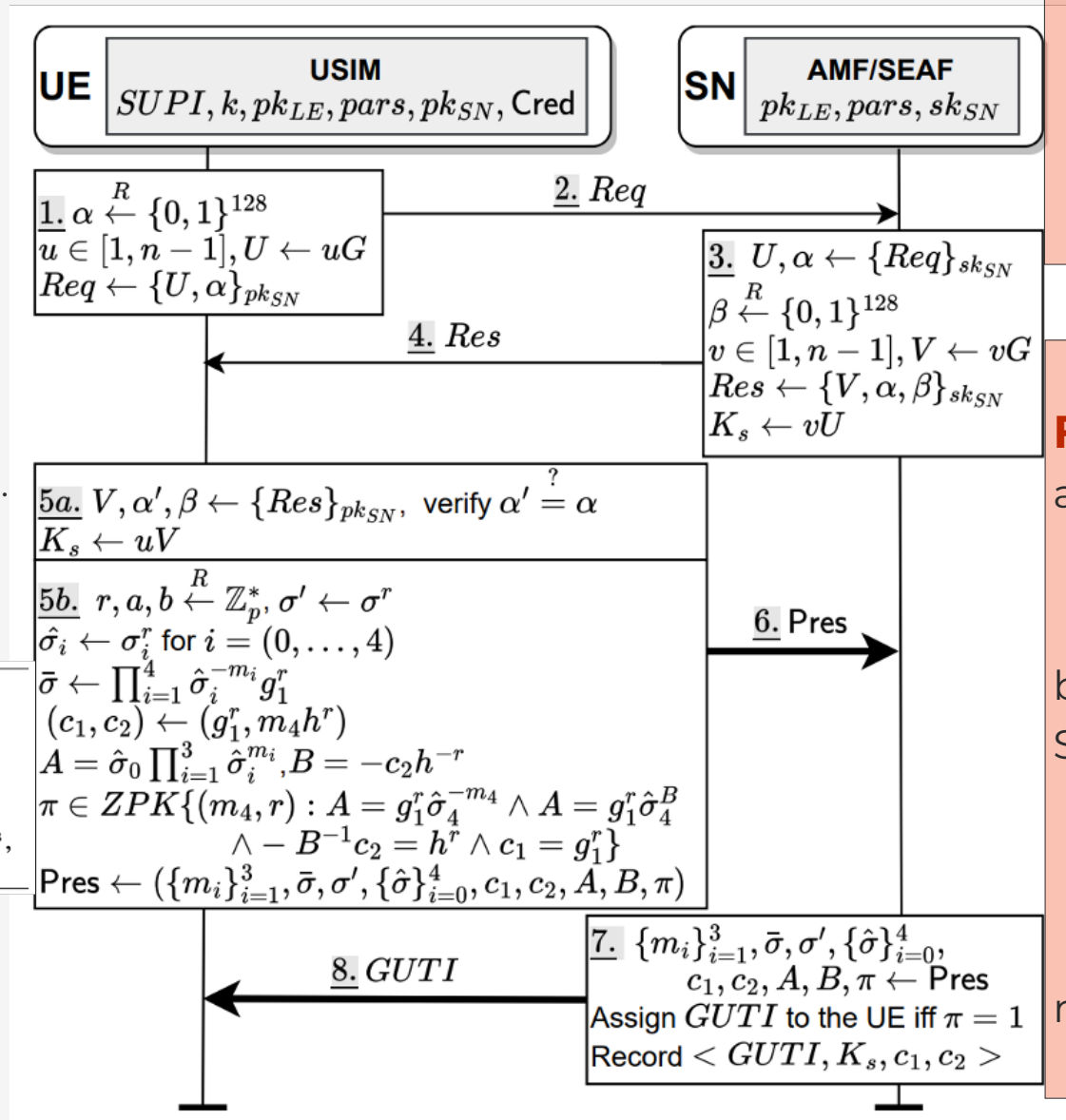

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$c_2 = m_4 / h^r$
so, $m_4 = c_2 / y_3$

Flaw in Correctness:
a credential is a BB signature σ s.t.
$$e(\sigma, X_0 \prod_{i=1}^4 X_i) = e(g_1, g_2)$$
but in Verification,
SN checks $(\hat{\sigma}_0, \ldots, \hat{\sigma}_4, \hat{\sigma}, \sigma', \pi')$ s.t.
$$e(\hat{\sigma}, g_2) = e(\sigma', X_0)$$
$$\pi' : \ \hat{\sigma}_0 \prod_{1}^{3} \hat{\sigma}_i^{m_i} = g_1^r \hat{\sigma}_4^{-m_4}$$
no use of public keys $X_1, \ldots, X_4$

the Presentation and Verification protocol in YZZ+ AAKA

Revisiting AAKA

BB: the Boneh-Boyen signature scheme
PS: the Pointcheval-Sanders signature scheme

Revisiting AAKA

- Identify the insecurity of YZZ+ AAKA

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- Formalize the model and redesign AAKA

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- AAKA+: verifier-local revocation

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- Identify the insecurity of YZZ+ AAKA
- Formalize the model and redesign AAKA
- AAKA+: verifier-local revocation
- Two schemes AAKA+BB and AAKA+PS

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Revisiting AAKA

- Identify the insecurity of YZZ+ AAKA
- Formalize the model and redesign AAKA
- AAKA+: verifier-local revocation
- Two schemes AAKA+BB and AAKA+PS
- Practice evaluation

BB: the Boneh-Boyen signature scheme
PS: the Pointcheval-Sanders signature scheme

Boneh-Boyen Signatures

[BB04] D. Boneh and X. Boyen, “Short signatures without random oracles,” in EUROCRYPT 2004.

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- signing on multiple messages $m_1, \cdots, m_i, \cdots$

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Boneh-Boyen Signatures

- signing on multiple messages $m_1, \cdots, m_i, \cdots$

- public key $X_0 = g_2^{x_0}, X_1 = g_2^{x_1}, \cdots$
- secret key $x_0, x_1, \ldots$
- signature on $m_1, \cdots, m_i, \cdots$
- $\sigma = g_1^{\frac{1}{x_0 + \sum_i x_i m_i}}$
- verification checks if

$$e(\sigma, X_0 \prod_i X_i^{m_i}) = e(g_1, g_2)$$

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Anonymous Credentials

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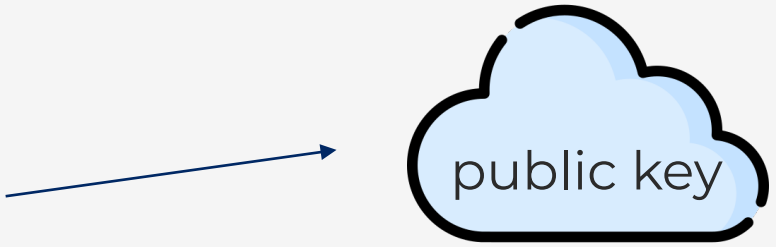
Authority

User

Verifier

Anonymous Credentials

Authority



User

Verifier

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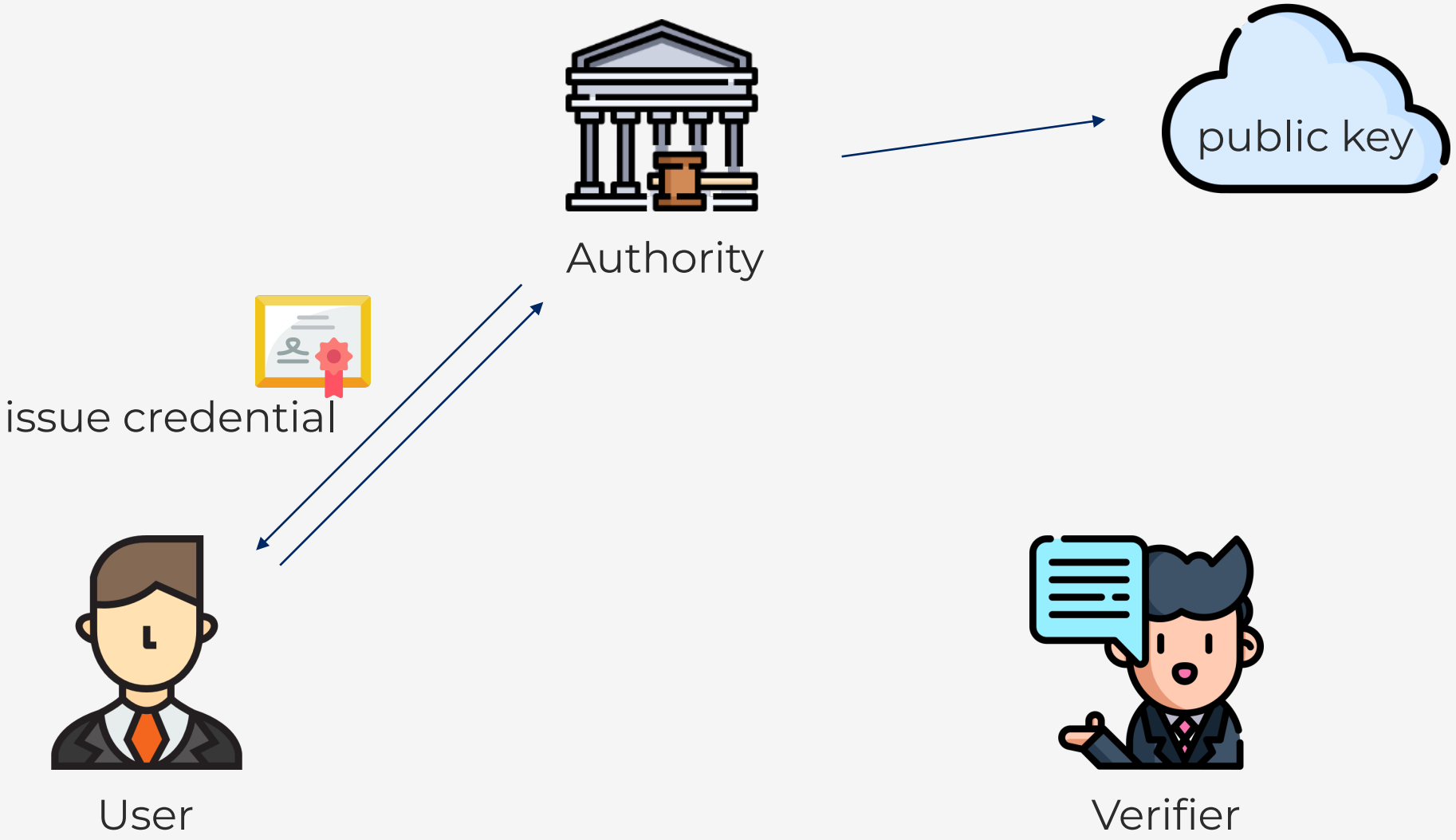

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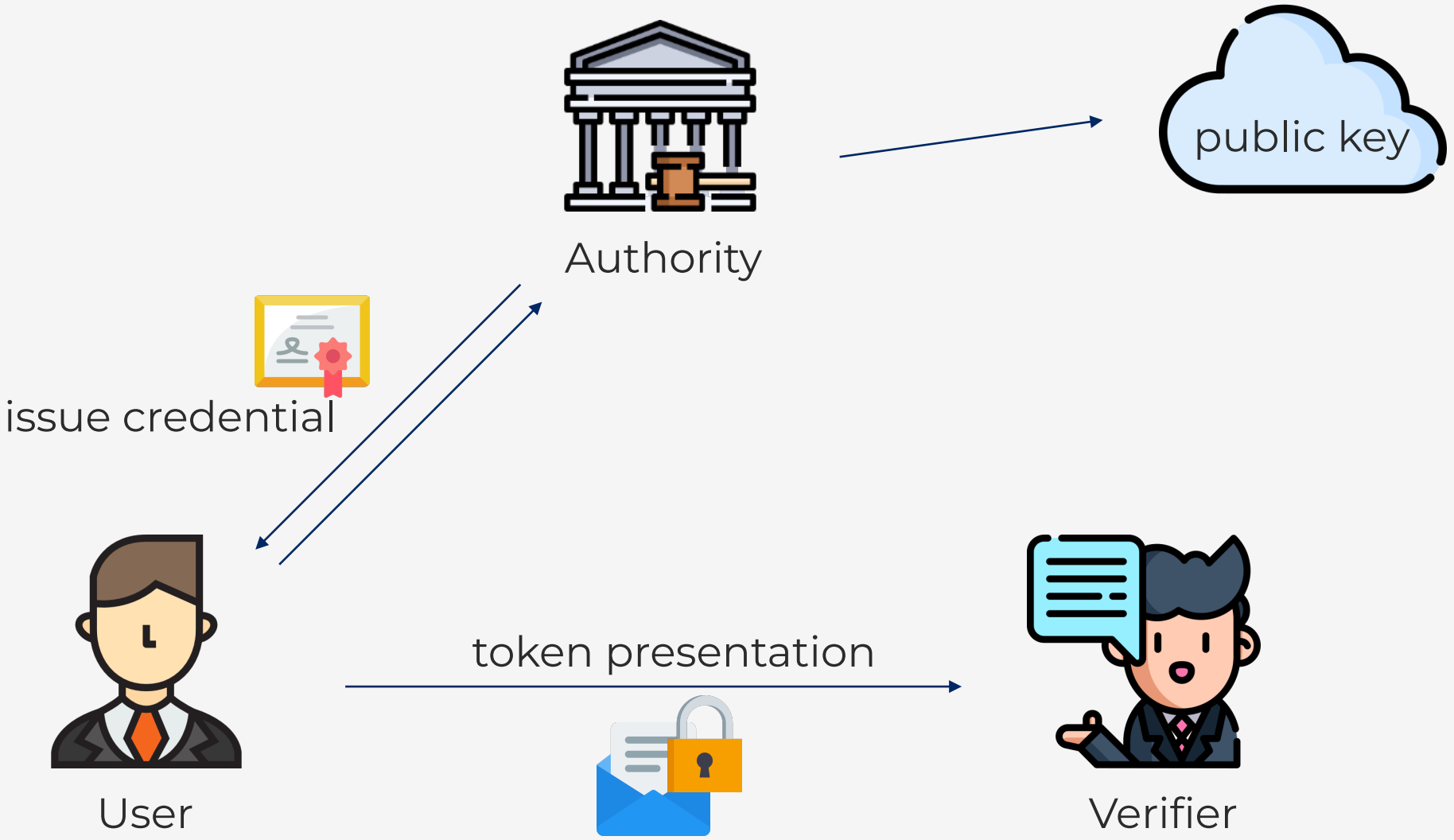

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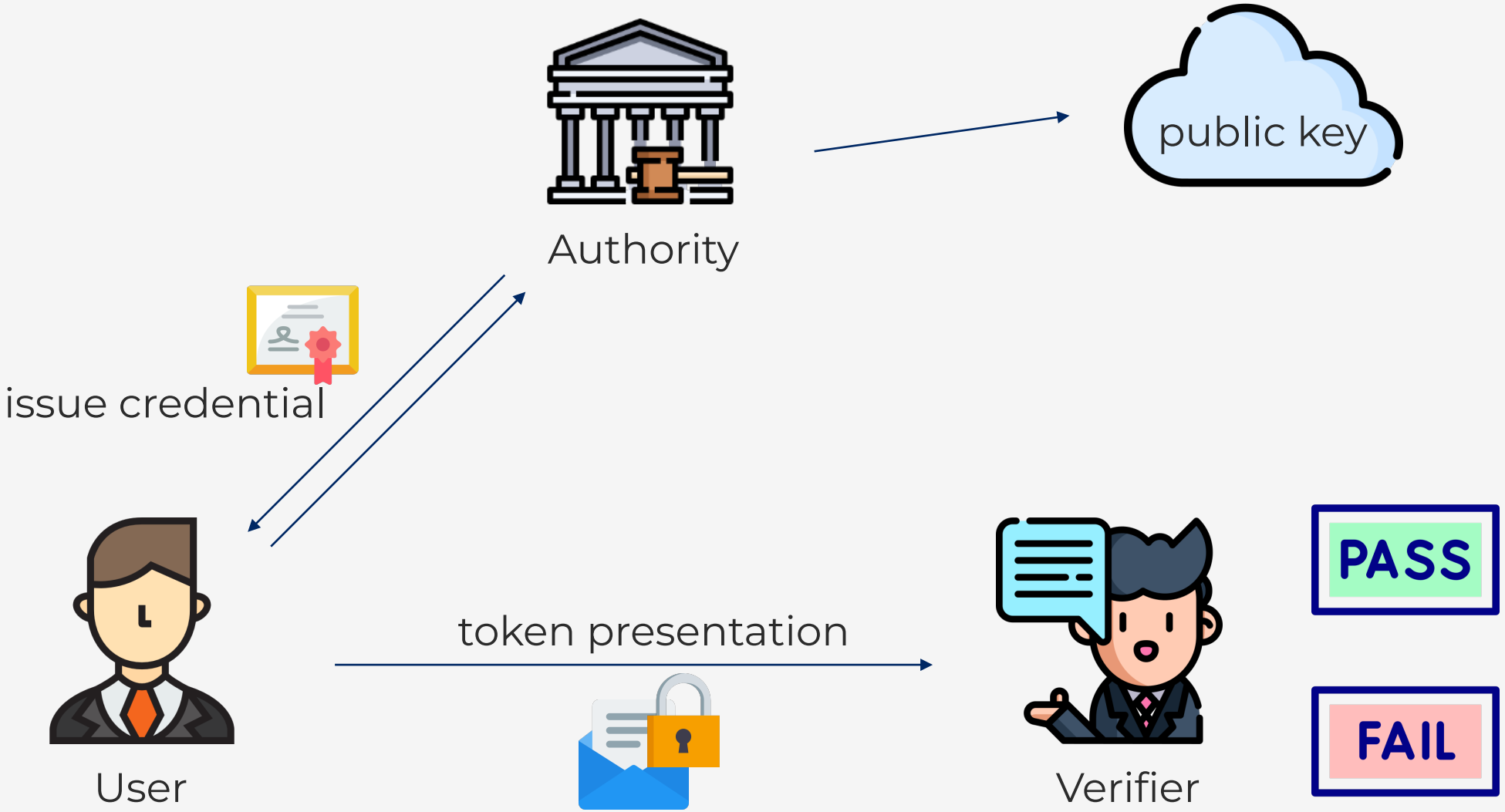

Anonymous Credential for BB Signatures

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Anonymous Credential for BB Signatures

- public key $X_0 = g_2^{x_0}, X_1 = g_2^{x_1}, X_2 = g_2^{x_2}$
- m: public message
- pm: private message
- $\sigma = g_1^{\frac{1}{x_0 + x_1 m_1 + x_2 pm}}$
- verification: $e(\sigma, X_0 X_1^m X_2^{pm}) = e(g_1, g_2)$

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- $\hat{\sigma} = \sigma^r, C_1 = X_0 X_1^m X_2^{pm} g^t, C_2 = g_1^r \hat{\sigma}^t$
- π: zero-knowledge for the witness (pm, r, t)
- Verify $e(\hat{\sigma}, C_1) = e(C_2, g_2)$ and π

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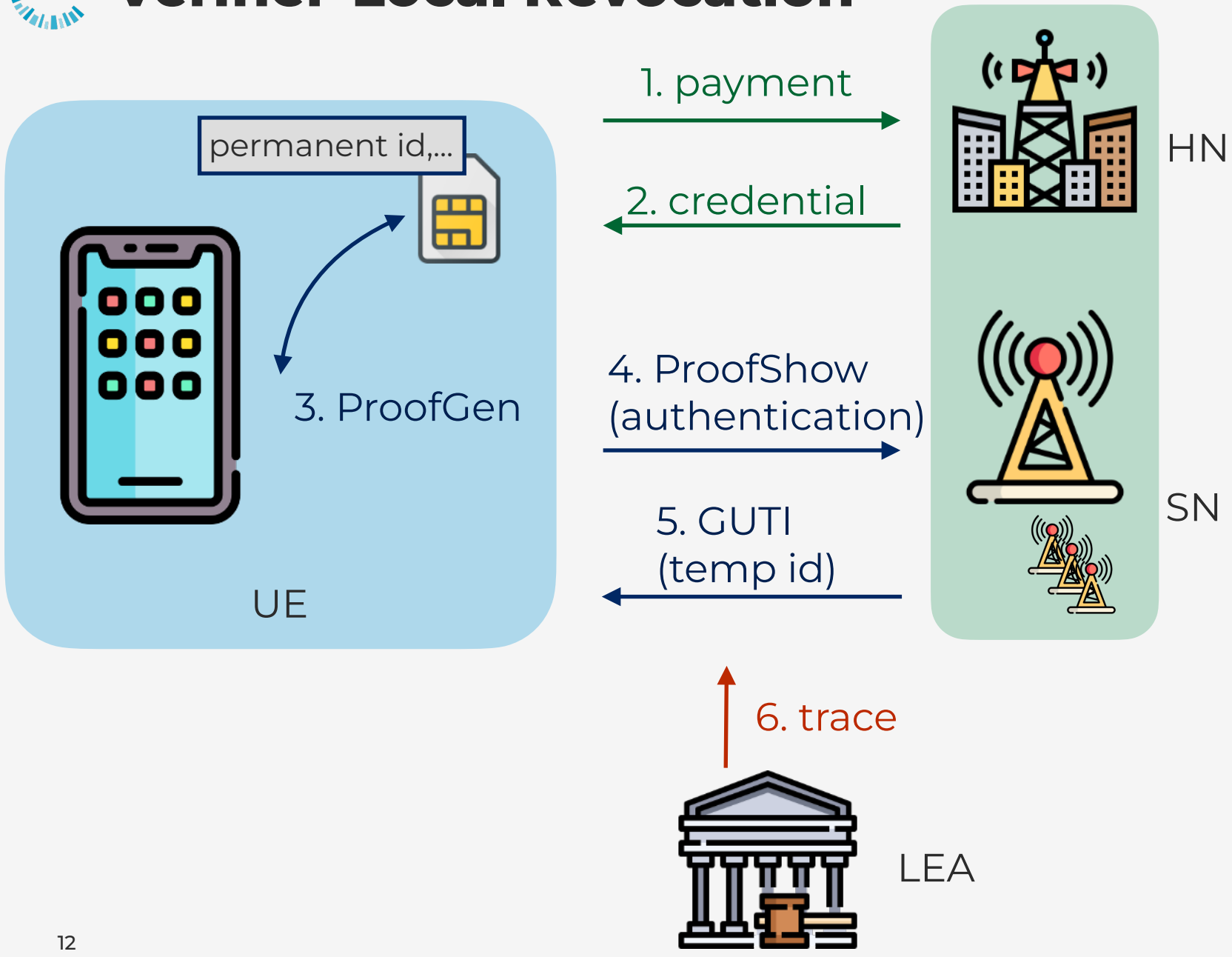
Verifier-Local Revocation



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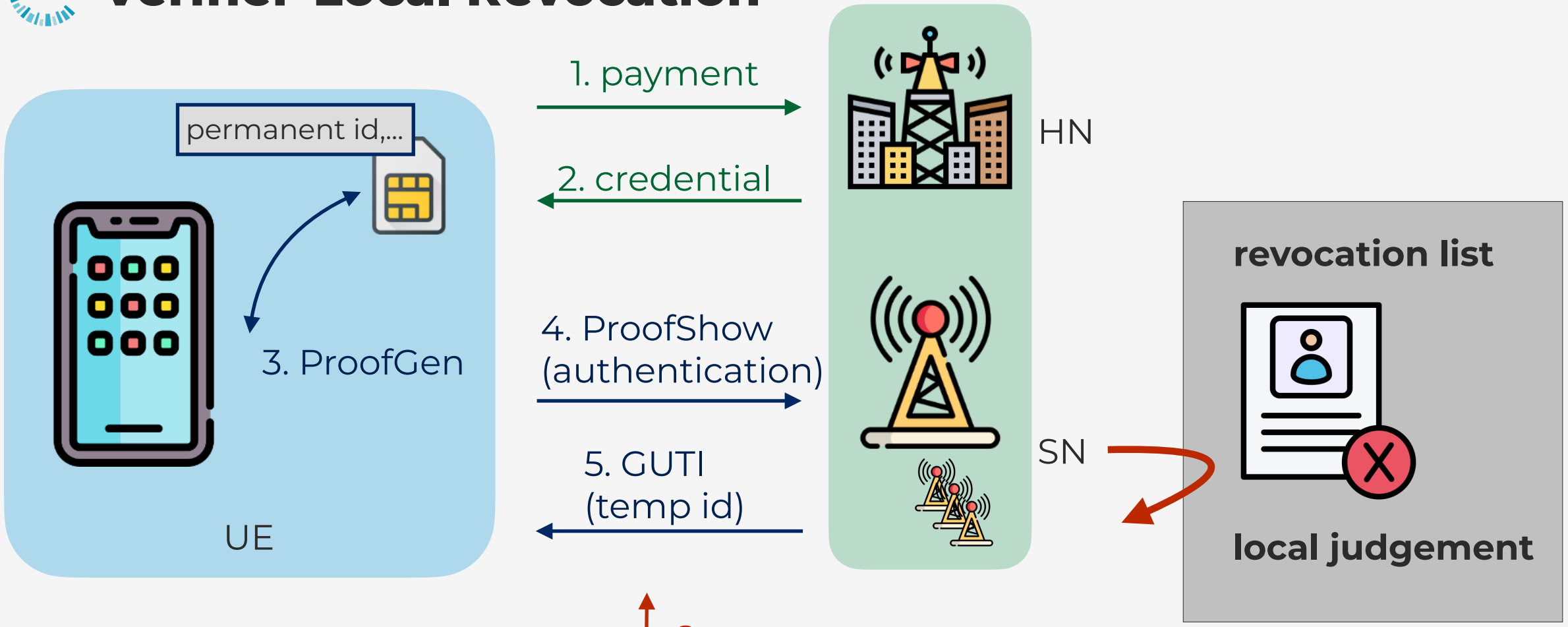

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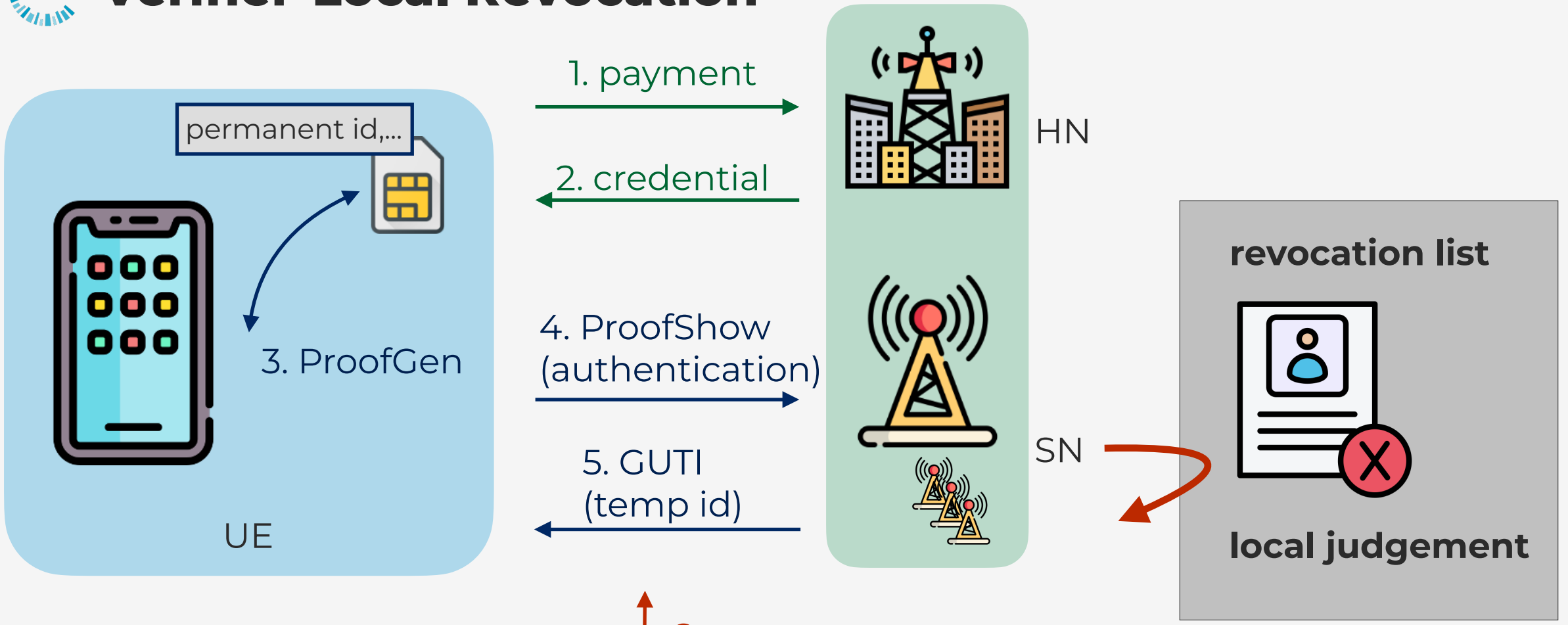

Determine if UE has been revoked immediately (without querying HN)

All Together, AAKA+BB

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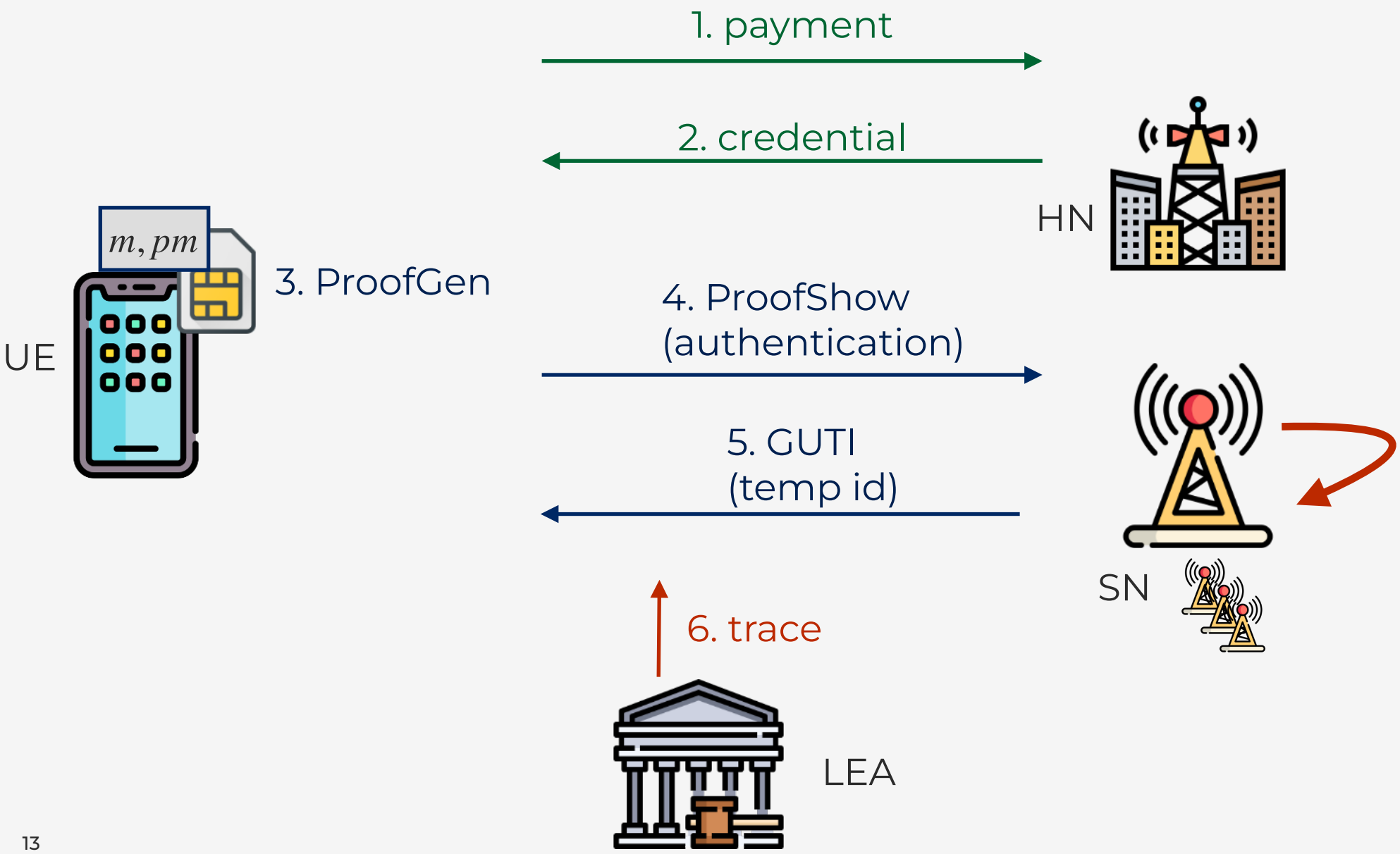
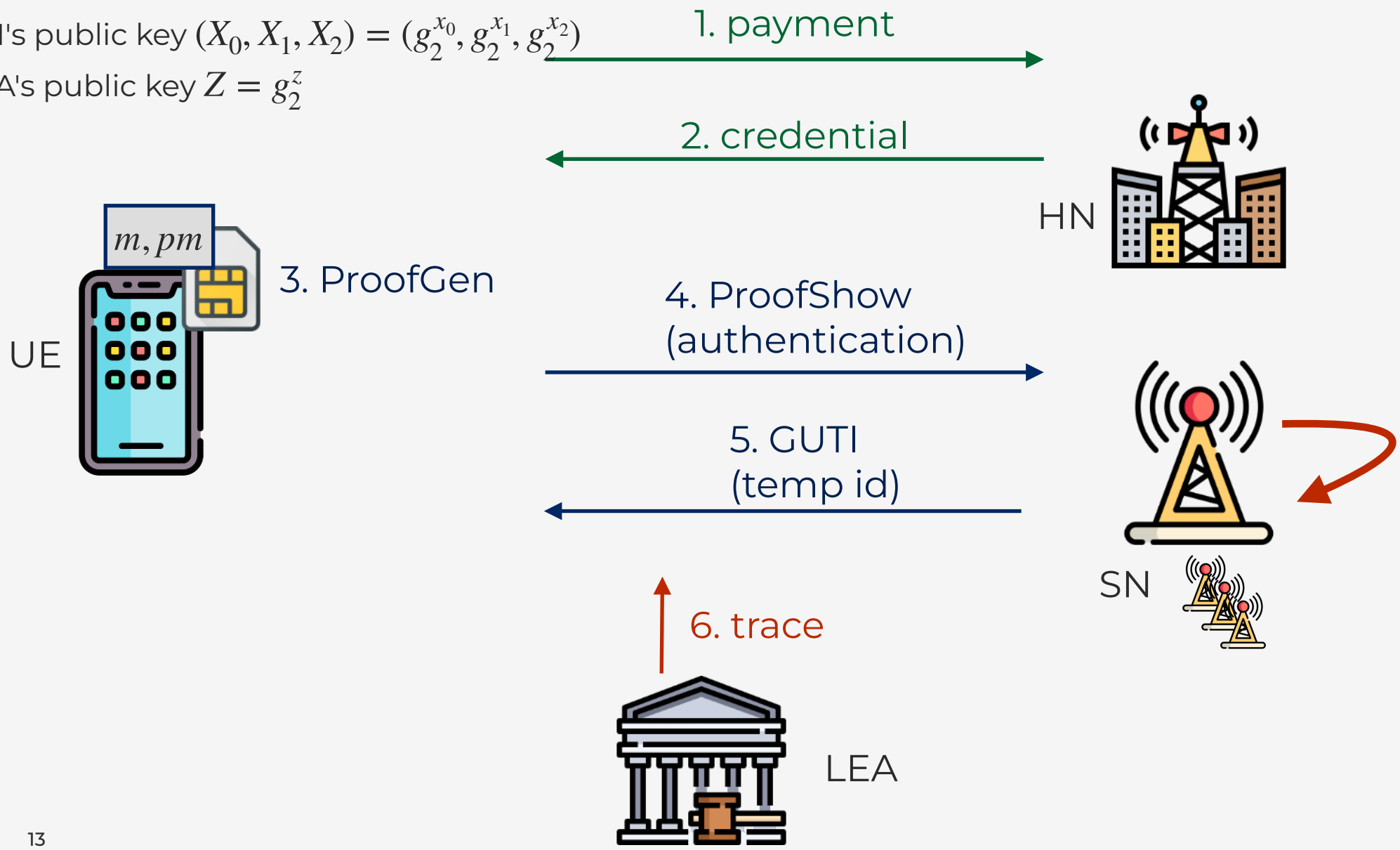


All Together, AAKA+BB

- HN's public key $(X_0, X_1, X_2) = (g_2^{x_0}, g_2^{x_1}, g_2^{x_2})$
- LEA's public key $Z = g_2^z$



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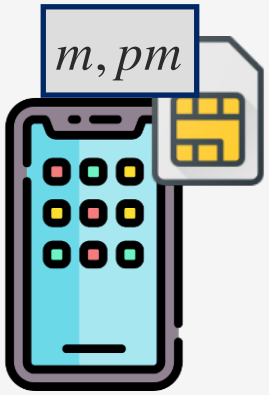
BB signature $\sigma = g_2^{\frac{1}{x_0 + x_1 m + x_2 pm}}$

1. payment

2. credential

HN

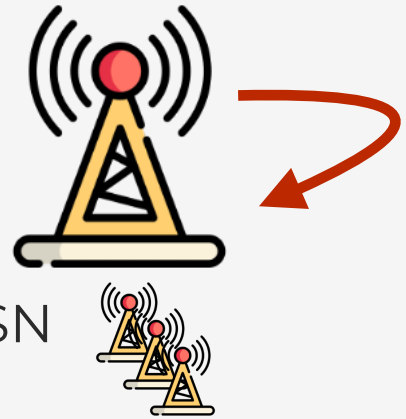


UE

3. ProofGen

4. ProofShow
(authentication)

5. GUTI
(temp id)



SN

6. trace

LEA

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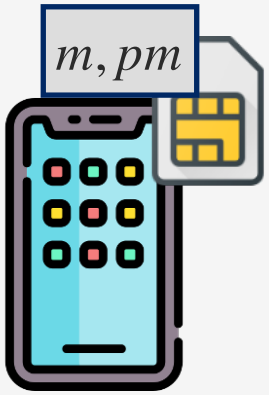
- LEA's public key $Z = g_2^z$

BB signature $\sigma = g_2^{\frac{1}{x_0 + x_1 m + x_2 pm}}$

1. payment

2. credential

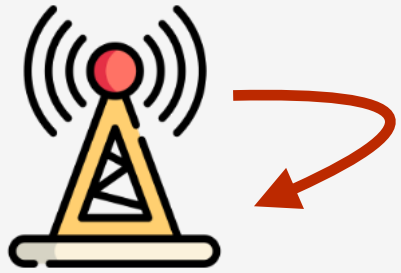
HN



UE

3. ProofGen

4. ProofShow
(authentication)



SN

5. GUTI
(temp id)

$\hat{\sigma} = \sigma^r,$
$C_1 = X_0 X_1^m X_2^{pm} g_2^t, C_2 = g_1^r \hat{\sigma}^t$
$C_3 = g_2^u, C_4 = Z^u \cdot g_2^{pm};$
$C_5 = h^{pm}$ s.t. $h = \text{Hash(context)}$
π : proof of well-formedness

6. trace

LEA

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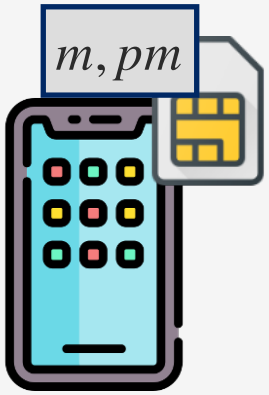
HN



UE

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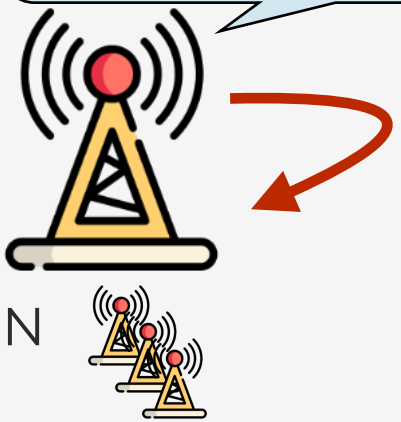
4. ProofShow
(authentication)

verify $e(\hat{\sigma}, C_1) = e(C_2, g_2)$ and π



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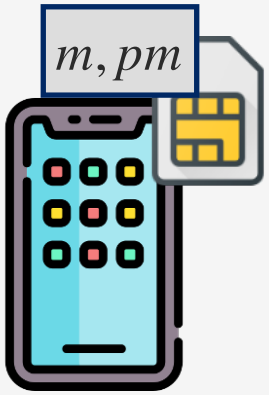
← 2. credential

HN 



UE

3. ProofGen

4. ProofShow (authentication) →

verify $e(\hat{\sigma}, C_1) = e(C_2, g_2)$ and π

SN 

local judgement checks if $e(h, W) = e(C_5, g_2)$ for $W = g_2^{pm'}$ in revocation list

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↑ 6. trace

LEA

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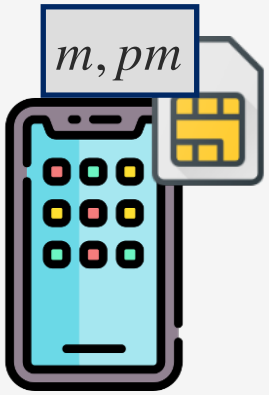
HN 



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π : proof of well-formedness

6. trace ↑

LEA

trace $C_4 / C_3^z = g_2^{pm}$

Pointcheval-Sanders Signatures

- public key $X_0 = g_2^{x_0}, X_1 = g_2^{x_1}, \ldots$
- secret key $x_0, x_1, \cdots$
- signature on $m_1, \cdots, m_i, \cdots$
- $\sigma_1 \leftarrow \mathbb{G}_1^*, \sigma_2 = \sigma_1^{x_0 + \sum_i x_i m_i}$
- verification checks if

$$e(\sigma_1, X_0 \prod_i X_i^{m_i}) = e(\sigma_2, g_2)$$

D. Pointcheval and O. Sanders, “Short randomizable signatures,” in Topics in Cryptology - CT-RSA 2016.

AAKA+PS

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- LEA's public key $Z = g_2^z$

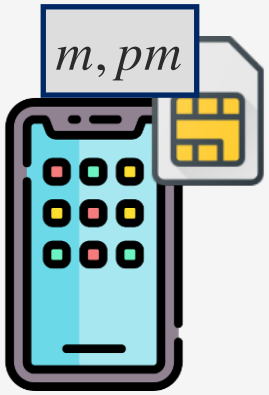
1. payment

PS signature $(\sigma_1, \sigma_2 = \sigma_1^{x_0+x_1 m+x_2 pm})$

2. credential

HN

UE



3. ProofGen

4. ProofShow
(authentication)

verify $e(\hat{\sigma}_1, C_1) = e(\hat{\sigma}_2, g_2)$ and π

SN

local judgement checks if
$e(h, W) = e(C_4, g_2)$
for $W = g_2^{pm'}$ in revocation list

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$\hat{\sigma}_1 = \sigma_1^r, \hat{\sigma}_2 = \sigma_2^r \cdot \hat{\sigma}_1^t$
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π : proof of well-formedness

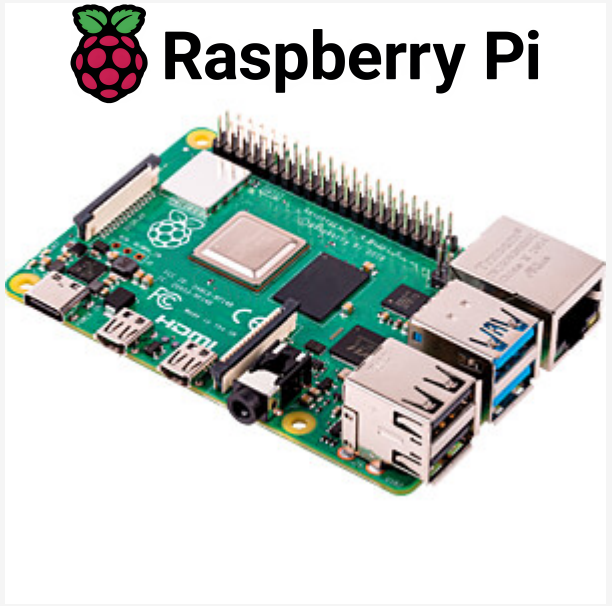
6. trace

LEA

trace $C_3 / C_2^z = g_2^{pm}$

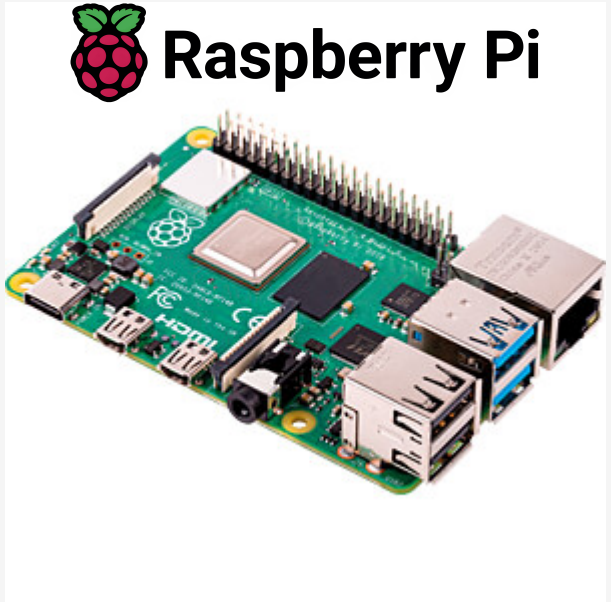
Evaluation

Evaluation



Raspberry Pi 4

Evaluation

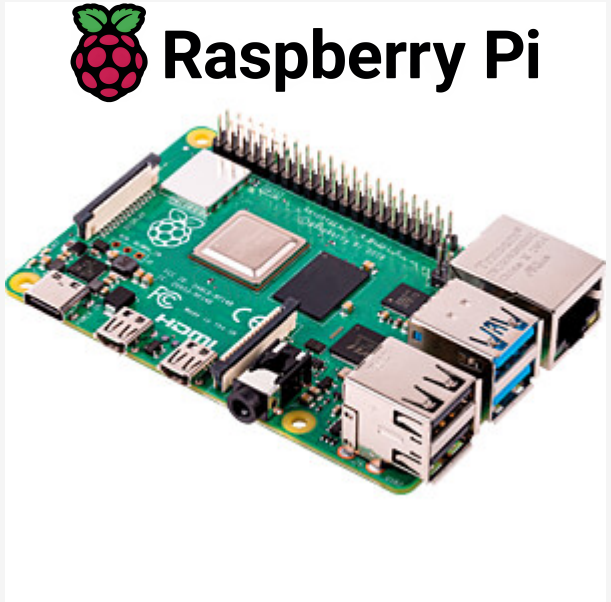


Raspberry Pi 4

Communication Complexity

Components	Size	
	AAKA+BB	AAKA+PS
CredIssue	$4([\mathbb{G}_1] + [\mathbb{Z}_q])$	$2[\mathbb{G}_1] + 4[\mathbb{Z}_q]$
Key Agreement (UE)	$1[\mathbb{G}_1]$	$1[\mathbb{G}_1]$
Key Agreement (SN/HN)	$1[\mathbb{G}_1] + \lambda$	$1[\mathbb{G}_1] + \lambda$
ProofShow	$3([\mathbb{G}_1] + [\mathbb{G}_2]) + 5[\mathbb{Z}_q]$	$3([\mathbb{G}_1] + [\mathbb{G}_2]) + 4[\mathbb{Z}_q]$
Trace	$1[\mathbb{G}_2]$	$1[\mathbb{G}_2]$

Evaluation



Raspberry Pi 4

Time Cost (ms)

Different stages	Entity	AAKA+BB	AAKA+PS
CredIssue	HN	6.82	3.98
CredVer	UE	38.82	12.17
Key Agreement	UE	∼4.30	∼4.30
Key Agreement	SN/HN	∼0.89	∼0.89
ProofShow	UE	18.40 (+29.45)	18.09(+26.10)
ProofVer	SN/HN	19.93	18.87
Trace	LEA	∼0.96	∼0.96

Communication Complexity

Components	Size	
	AAKA+BB	AAKA+PS
CredIssue	$4([\mathbb{G}_1] + [\mathbb{Z}_q])$	$2[\mathbb{G}_1] + 4[\mathbb{Z}_q]$
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ProofShow	$3([\mathbb{G}_1] + [\mathbb{G}_2]) + 5[\mathbb{Z}_q]$	$3([\mathbb{G}_1] + [\mathbb{G}_2]) + 4[\mathbb{Z}_q]$
Trace	$1[\mathbb{G}_2]$	$1[\mathbb{G}_2]$

Summary

- Identify the insecurity of YZZ+ AAKA
- Formalize the model and redesign AAKA
- AAKA+: verifier-local revocation
- Two schemes AAKA+BB and AAKA+PS
- Practice evaluation
- full paper: eprint.iacr.org/2025/1986

Summary

- Identify the insecurity of YZZ+ AAKA
- Formalize the model and redesign AAKA
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Questions?