On Post-Quantum 5G

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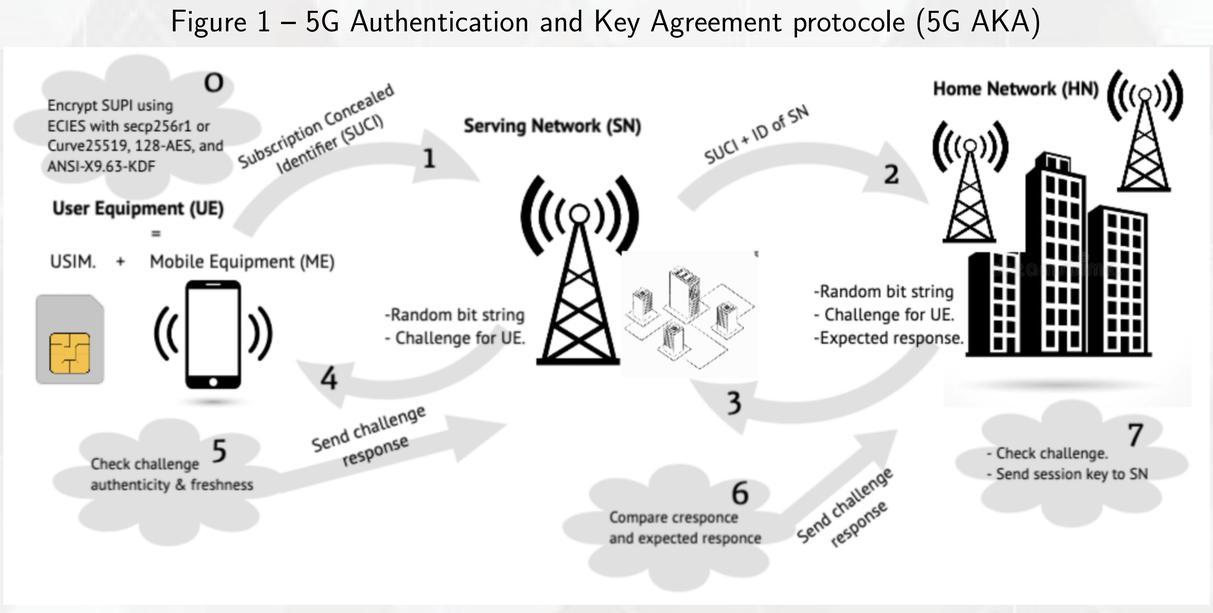
INTRODUCTION

In 5G networks, security issues are mainly handled using symmetric key cryptography, i.e, AES, SNOW 5G...etc. However, public key cryptography is still a crucial ingredient in the authentication process in 5G technology. In fact, the current Authentication and Key Agreement protocol in 5G (5G AKA) is based on an Elliptic Curve Integrated Scheme (ECIES) [3GPP TS 33.501], hence the interest in studying the possibility of extending 5G AKA to a quantum resistance protocol by replacing ECIES by Post-Quantum Cryptography (PQC). Unfortunately, quantum attacks are not the only issue facing 5G AKA. Indeed, further privacy and security threats were discovered shortly after adopting 5G AKA by 3GPP, to name a few we mention, linkability attacks and the lake of forward/backward security; thus, it is natural to consider such issues while implementing PQC in 5G AKA. In the present work, we first study the extension of the 5G AKA protocol to a quantum resistant framework, that is by investigating NIST round 3 finalist *Key Encapsulation Mechanisms* (KEMs). Then we will use our understanding of post-quantum KEMs to propose an upgrade to 5G AKA that we call 5G $\mathrm{AKA}^{\oplus}$, which is a standard compatible post-quantum authentication and key agreement protocol offering both forward and backward security at the user side and resistance to known linkability attacks.

Post-Quantum Identification in 5G

Figure 1 – 5G Authentication and Key Agreement protocole (5G AKA)



We investigate the communication and computational costs of NIST round 3 finalist KEMs in the 5G identification. We recall that pk_{HN} and sk_{HN} are stored at the UE and HN respectively, while the ciphertext c is sent over the radio channel.

Algorithm	sk_{HN}	pk_{HN}	Ciphertext c	Shared secret
Classic-McEliece-348864	6452	261120	128	32
Kyber 512	1632	800	768	32
NTRU-HPS-2048-509	935	699	699	32
LightSaber-KEM	1568	672	736	32

Table 1 – Round 3 finalists (communication cost in bytes)

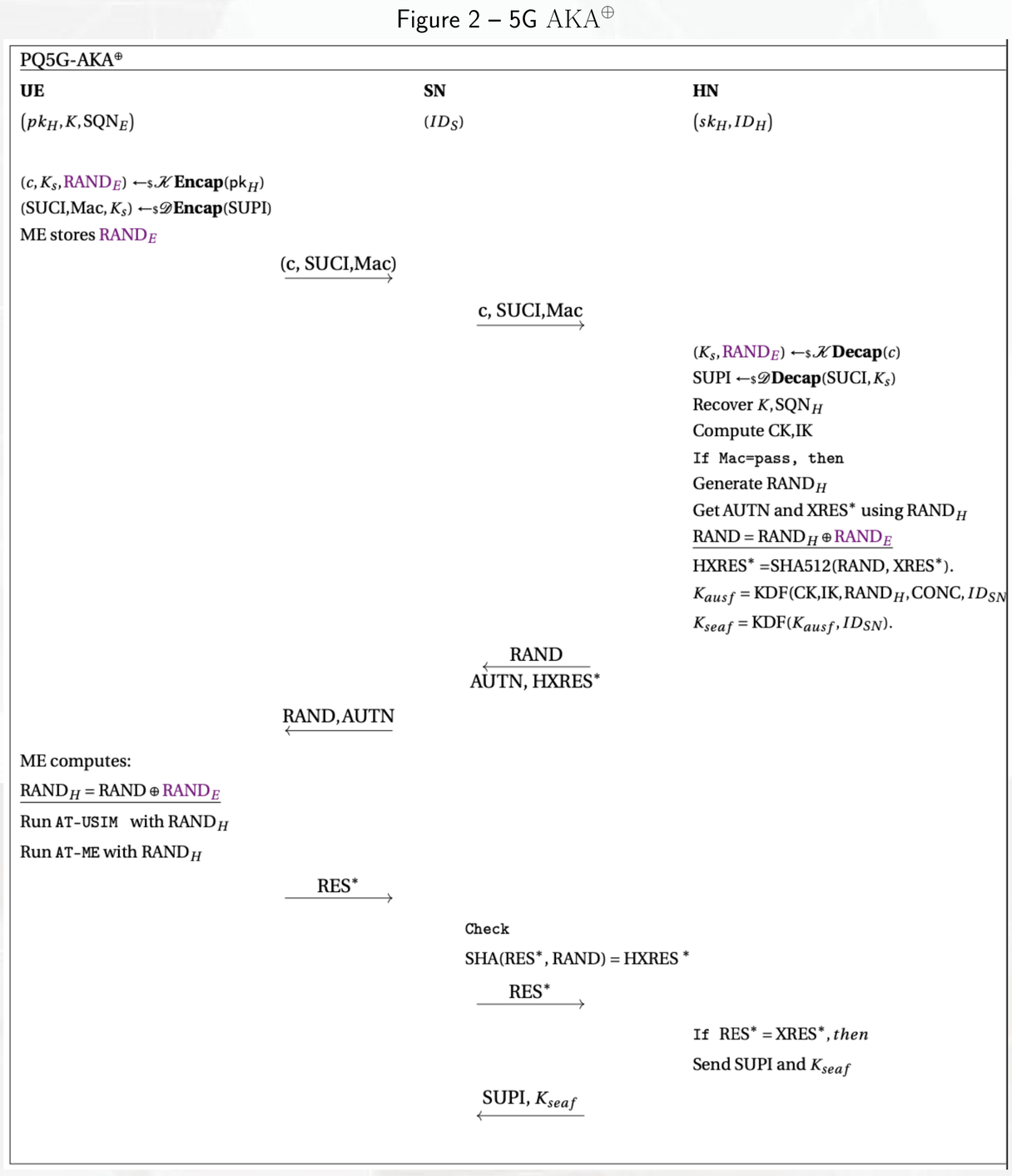
We led a comparative study of the running time of the the operations at the UE and the HN, where we implemented the current standardized ECIES profiles, namely, Curve 25519 and Secp256r1, and NIST round 3 finalist KEMs. Our implementation uses Liboqs and OpenSSL on a 3.5 GHz Core i7 workstation.

Algorithm	At UE (μs)	At HN (μs)
ECIES Curve25519	49.221	48.110
ECIES Secp256r1	131.201	131.001
Classic-McEliece-348864	16.167	49.319
LightSaber-KEM	17.039	16.563
NTRU-HPS-2048-509	14.722	20.015
Kyber512	14.351	10.101

Table 2 – Running time of the operations at the UE/HN

5G $\mathrm{AKA}^{\oplus}$

Figure 2 – 5G $\mathrm{AKA}^{\oplus}$



Advantages of 5G $\mathrm{AKA}^{\oplus}$

- Quantum secure (used quantum resistant algorithms).
- Resistance to linkability attacks (ability to detect replied messages).
- Forward and Backward secrecy at the UE (the session key depends on the freshly generated randomness).
- Backward compatibility features:
  - No changes at the USIM (we can keep the old SIM card).
  - Requires the ME to perform one extra XOR operation.
  - No changes at the SN in the case of SUPI.

Note that the temporary identifier called *Globally Unique Temporary User Equipment Identity* (GUTI) is favoured over the use of SUPI, clearly because the use of GUTI does not require extra asymmetric encryption, thus, in theory, no need to consider PQC in the GUTI case. However, our protocol covers such case by requiring the SN to generate a random bit string RAND_S which will play the roll of RAND_E in the case of SUPI and it will be sent to the UE by the SN during *the GUTI assignment phase:*

- The SN generates a GUTI and RAND_S then sends $c = \mathrm{Enc}_{K_{session}}(\mathrm{GUTI}, \mathrm{RAND}_S)$
- The UE decrypts c and stores GUTI and RAND_S

Operations at the HN, ME and USIM in 5G $\mathrm{AKA}^{\oplus}$

Figure 3 – Authentication Vector generation at the HN

AV(RAND, K, SQN_H, ID_{SN}, AMF):

1. Compute $Mac = f_1(K, RAND, \mathrm{SQN}_H, \mathrm{AMF})$.
2. XRES=$f_2(K, RAND)$, $CONC = f_5(K, RAND) \oplus \mathrm{SQN}_H$.
3. AUTN=$\{CONC, \mathrm{AMF}, \mathrm{MAC}\}$.
4. CK=$f_3(K, \mathrm{RAND})$, IK=$f_4(K, \mathrm{RAND})$.
5. XRES*=KDF(CK,IK,RAND,XRES, ID_{SN}).
6. HXRES*=$SHA256(RAND, \mathrm{XRES}^*)$
7. K_{ausf} = KDF(CK,IK,RAND,$CONC$, ID_{SN}).
8. K_{seaf} = KDF(K_{ausf}, ID_{SN}).
9. **Return** (RAND, AUTN, HXRES*, K_{ausf}, K_{seaf}).

Figure 4 – Operations at the Mobile Equipment

AT-ME(RAND, CK, IK, AUTN, ID_{SN}, RES):

1. RES* = KDF(CK,IK,RAND,RES, ID_{SN}).
2. Get $CONC$ from AUTN.
3. K_{ausf} = KDF(CK,IK,RAND,$CONC$, ID_{SN}).
4. K_{seaf} = KDF(K_{ausf}, ID_{SN}).
5. **Return** (K_{seaf}, RES*)

Figure 5 – Operations at the USIM

AT-USIM(RAND, AUTN, K, AMF):

1. $AK = f_5(K, RAND)$.
2. Parse AUTN as $AK \oplus \mathrm{SQN}_H, AMF, MAC$.
3. Check $f_1(K, RAND, \mathrm{SQN}_H, \mathrm{AMF}) = MAC$ If this check does not pass, **Return** $\perp$.
4. Check $\mathrm{SQN}_U < \mathrm{SQN}_H < \mathrm{SQN}_U + \Delta$, where Δ is a constant chosen by HN.
   - If this check does not pass:
     - $MAC^* = f_1^*(K, RAND, \mathrm{SQN}_U)$,
     - **Return**: AUTS := $\{f_5^*(K, RAND) \oplus \mathrm{SQN}_U, \mathrm{MAC}^*\}$
   - Else:
     (a) $\mathrm{SQN}_U \leftarrow \mathrm{SQN}_H$
     (b) RES = $f_2(K, RAND)$.
     (c) CK=$f_3(K, \mathrm{RAND})$, IK=$f_4(K, \mathrm{RAND})$.
     (d) **Return** (RES, CK, IK)