The Pre-Shared Key Modes of HPKE

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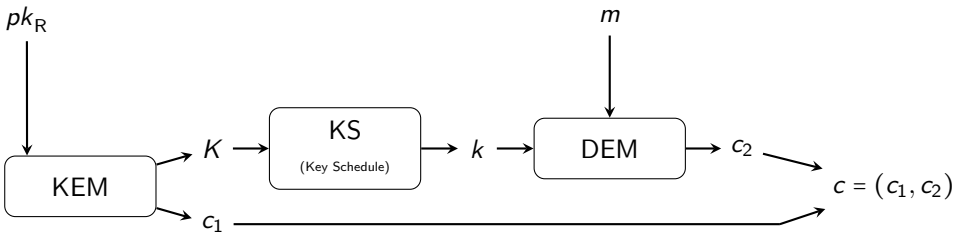
Overview

1. Hybrid Public Key Encryption (HPKE)
2. Modeling Pre-Shared Key (PSK) Modes of HPKE
3. Security
4. Post-Quantum Security

Overview

Hybrid Public Key Encryption (HPKE)



- Follows KEM/DEM paradigm

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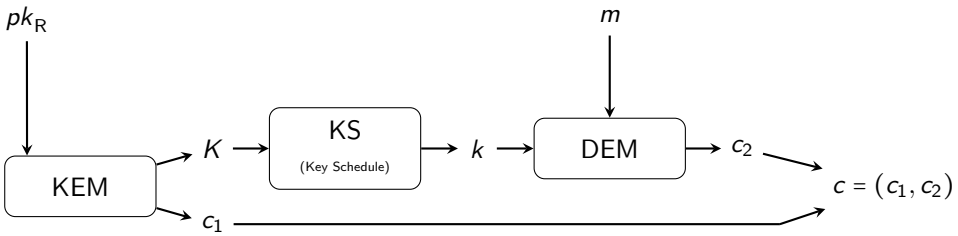
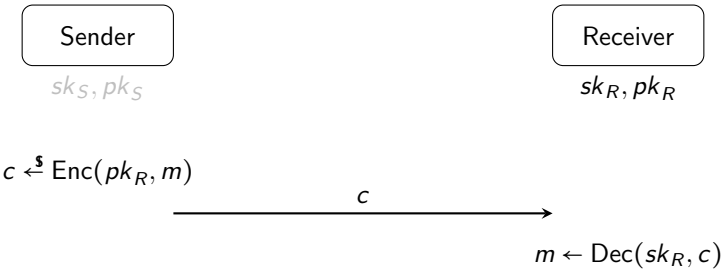


- Follows KEM/DEM paradigm
- Published as RFC 9180 by the Internet Research Task Force [BBLW22]
- Used in TLS 1.3 Encrypted Client Hello Extension, Message Layer Security (MLS), Oblivious DNS over HTTPS, ...

HPKE – Base Mode



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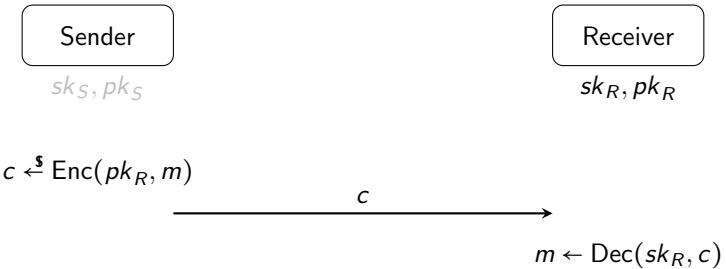
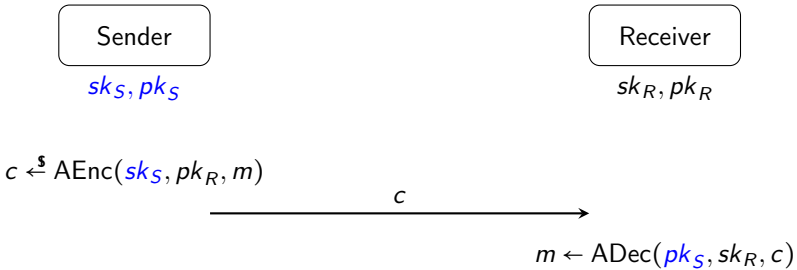


Mode	Sender Key	PSK	Primitive	Security	Source
$\mathrm{HPKE}_{\mathrm{Base}}$	–	–	PKE	CCA	folklore

HPKE – Auth Mode



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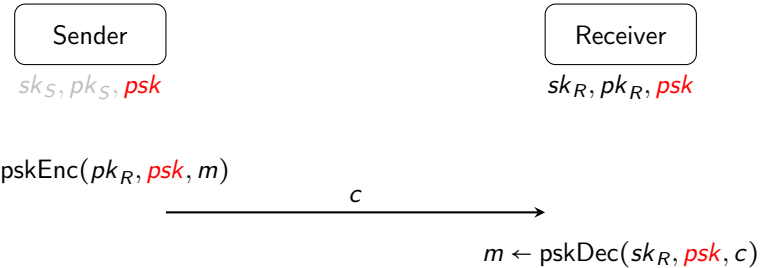
HPKE – PSK Mode



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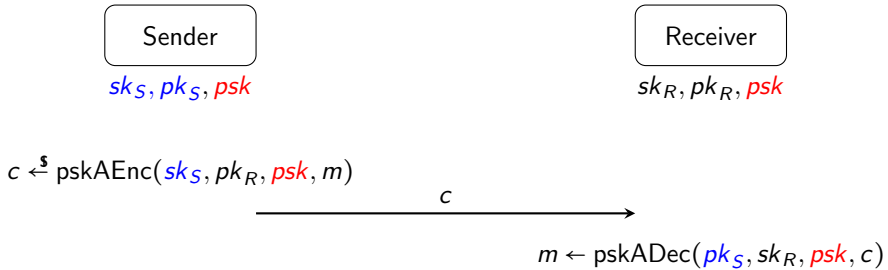
$\mathsf{HPKE}_{\mathsf{PSK}}$	–	$\surd$	?	?	

HPKE – AuthPSK Mode



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HPKE_{PSK}	–	$\surd$	?	?	
$\text{HPKE}_{\text{AuthPSK}}$	$\surd$	$\surd$	?	?	

Filling the Gaps

1. Modeling syntax and security of PSK modes
2. Proving security (confidentiality and authenticity)

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$\mathsf{HPKE}_{\mathsf{PSK}}$	–	$\surd$	pskPKE	CCA & Auth	This work
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Overview

Syntax

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$\mathsf{pskPKE} \coloneqq (\mathsf{GenSK}, \mathsf{GenPSK}, \mathsf{pskEnc}, \mathsf{pskDec})$

- $(sk, pk) \xleftarrow{\$} \mathsf{GenSK}$
- $psk \xleftarrow{\$} \mathsf{GenPSK}$
- $c \xleftarrow{\$} \mathsf{pskEnc}(pk_R, psk, m)$
- $m \leftarrow \mathsf{pskDec}(sk_R, psk, c)$

Syntax

Mode	Sender Key	PSK	Primitive	Security	Source
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$\mathsf{pskAPKE} \coloneqq (\mathsf{GenSK}, \mathsf{GenPSK}, \mathsf{pskAEnc}, \mathsf{pskADec})$

- $(sk, pk) \xleftarrow{\$} \mathsf{GenSK}$
- $psk \xleftarrow{\$} \mathsf{GenPSK}$
- $c \xleftarrow{\$} \mathsf{pskAEnc}(sk_S, pk_R, psk, m)$
- $m \leftarrow \mathsf{pskADec}(pk_S, sk_R, psk, c)$

Outsider-Auth for APKE [ABH+21]

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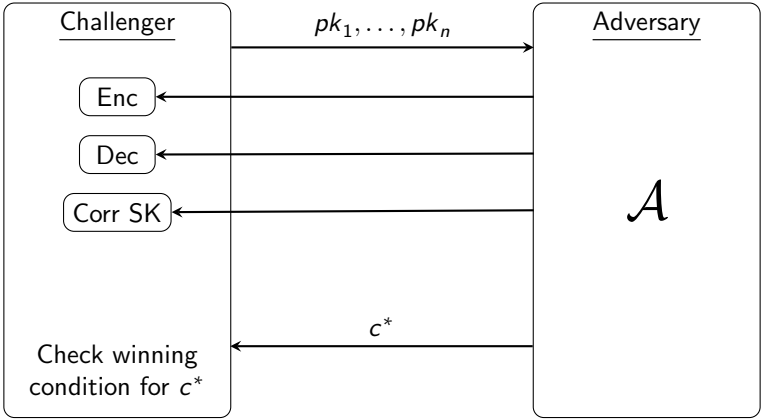

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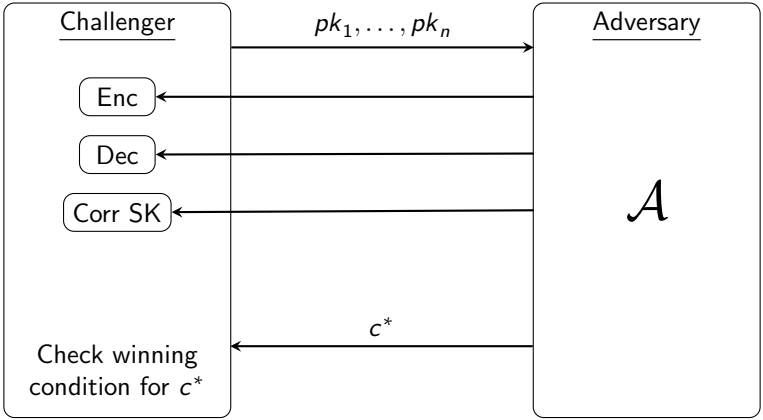
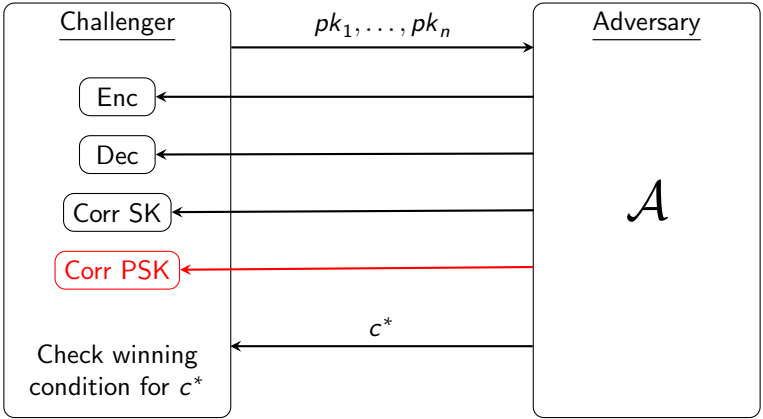


Winning condition:

- Fresh and valid ciphertext
- Sender secret key corresponding to c^* is not corrupted

Outsider-Auth for pskAPKE



Winning condition:

- Fresh and valid ciphertext
- Sender secret key and pre-shared key corresponding to c^* are not both corrupted

Overview

Security – Overview

Four generic composition theorems for hybrid constructions

Primitive	Confidentiality	Authenticity
pskPKE		
pskAPKE		

Security – Overview

Four generic composition theorems for hybrid constructions

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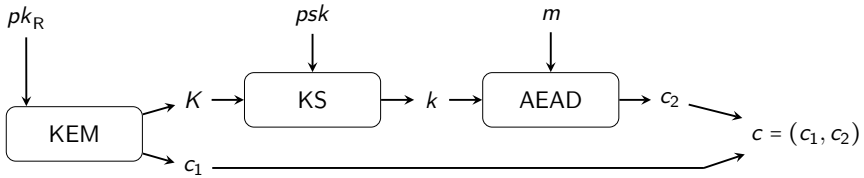
Security – Overview

Four generic composition theorems for hybrid constructions

Primitive	Confidentiality	Authenticity
pskPKE	Thm. 1 **CCA**	Thm. 2 **Auth**
pskAPKE	Thm. 3 **Insider** – **CCA** (implies Outsider-CCA)	Thm. 4 **Outsider** – **Auth**

Security – pskPKE

Mode $\mathsf{HPKE}_{\mathsf{PSK}}$:



Security – pskPKE

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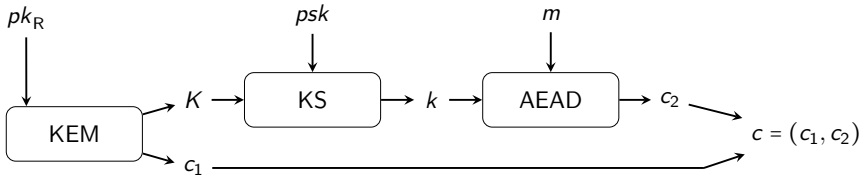
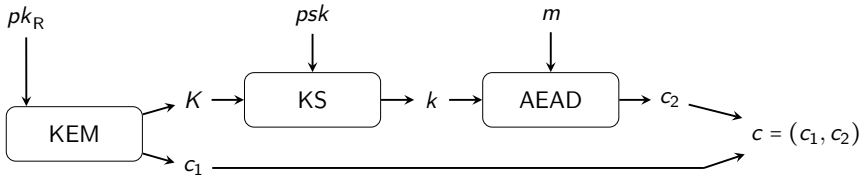


Theorem 1 (CCA security)

KEM **CCA** + KS **dual-PRF** + AEAD **CCA** ⇒ pskPKE **CCA**

Security – pskPKE

Mode $\mathsf{HPKE}_{\mathsf{PSK}}$:



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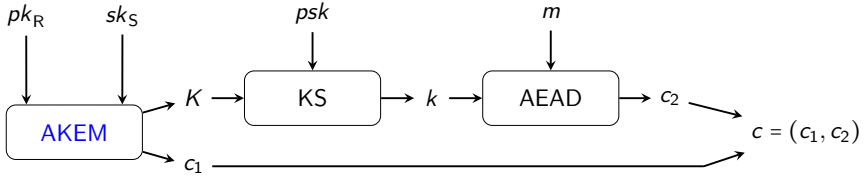
KEM **CCA** + KS **dual-PRF** + AEAD **CCA** ⇒ pskPKE **CCA**

Theorem 2 (Auth security)

KEM **CCA** + KS **dual-PRF** + AEAD **INT-CTXT** ⇒ pskPKE **Auth**

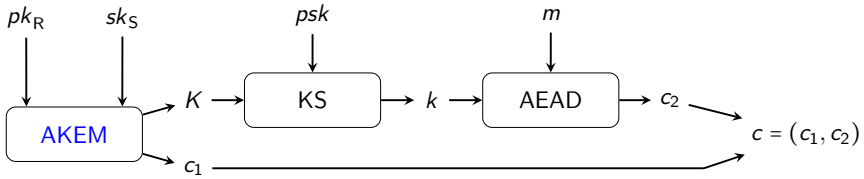
Security – pskAPKE

Mode $\mathsf{HPKE}_{\mathsf{AuthPSK}}$:



Security – pskAPKE

Mode $\mathsf{HPKE}_{\mathsf{AuthPSK}}$:

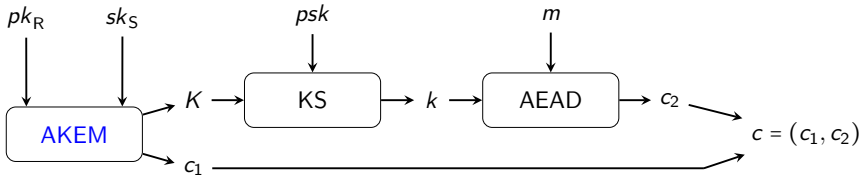


Theorem 3 (Insider-CCA security)

AKEM **Insider-CCA** + KS **dual-PRF** + AEAD **CCA** ⇒ pskAPKE **Insider-CCA**

Security – pskAPKE

Mode $\mathsf{HPKE}_{\mathsf{AuthPSK}}$:



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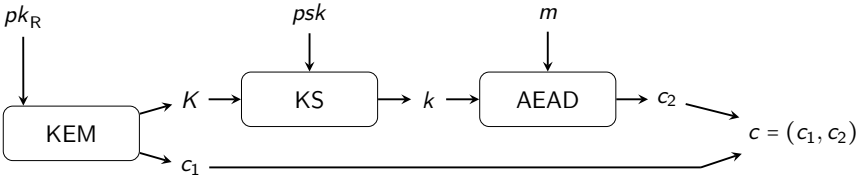
Theorem 4 (Outsider-Auth security)

AKEM **Outsider-CCA** + AKEM **Outsider-Auth** + KS **dual-PRF** + AEAD **INT-CTXT** ⇒ pskAPKE **Outsider-Auth**

RFC Specification: $\mathsf{HPKE}_{\mathsf{PSK}}$



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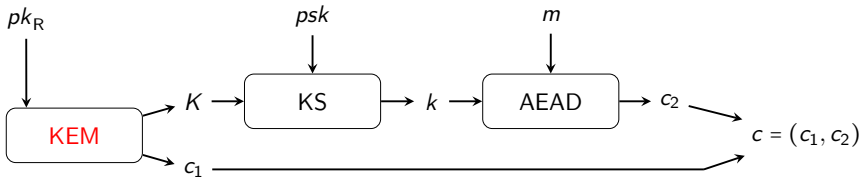
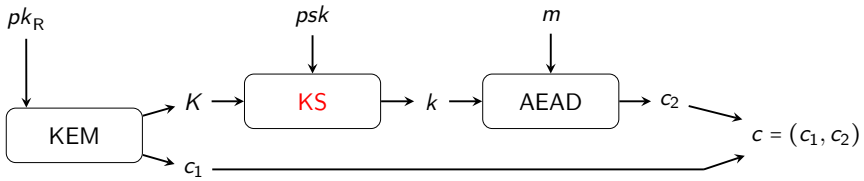


- (1) KEM: basic Diffie-Hellman KEM fulfilling CCA security

RFC Specification: HPKE_{PSK}



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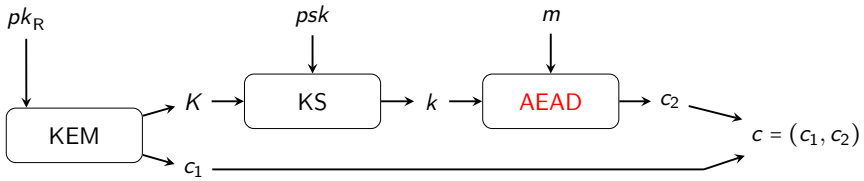

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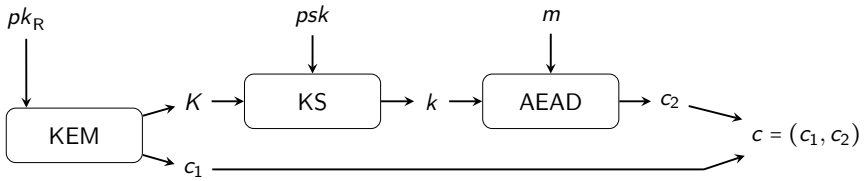

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$$(\mathbf{1}) + (\mathbf{2}) + (\mathbf{3}) \overset{\text{Thm.1+2}}{\Rightarrow} \textbf{CCA and Auth}$$

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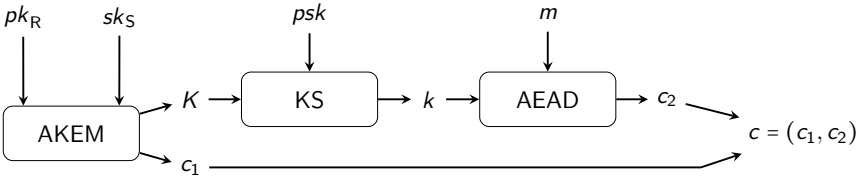

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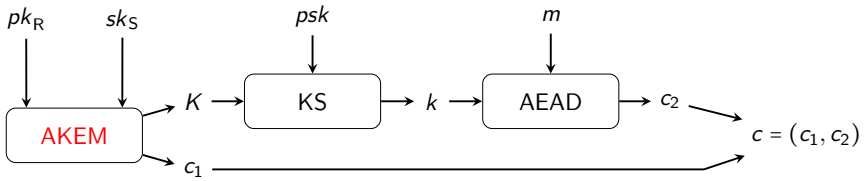

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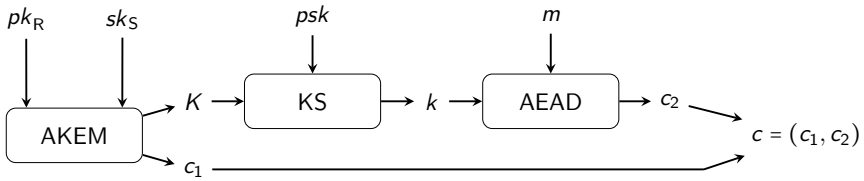

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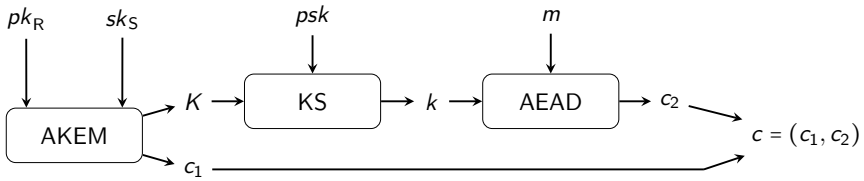

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$$(\mathbf{1}) + (\mathbf{2}) + (\mathbf{3}) \overset{\text{Thm.3+4}}{\Rightarrow} \textbf{Insider-CCA and Outsider-Auth}$$

Overview

Post-Quantum HPKE

- We need the underlying primitives to be post-quantum secure
  - KEM ✓
  - AKEM ?

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  - KEM ✓
  - AKEM ?
- We introduce two AKEM constructions:
  - KEM + Signature + Hash (PRF)
  - NIKE + Hash (PRF)

Classical/Post-Quantum Hybrid

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- Relies on classical (C) and post-quantum (PQ) assumptions

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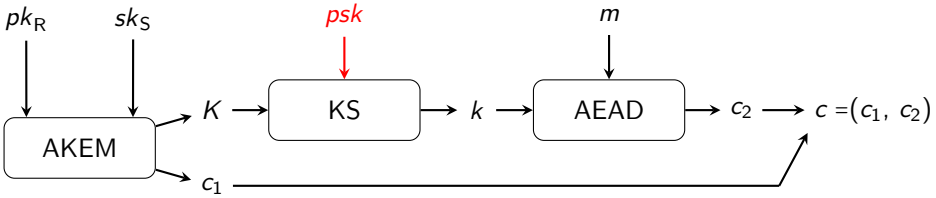
- Relies on classical (C) and post-quantum (PQ) assumptions
- Direct plug-in construction from HPKE PSK modes::

$$\text{PQ KEM} + \text{pskPKE} \Rightarrow \text{C/PQ PKE}$$
$$\text{PQ AKEM} + \text{pskAPKE} \Rightarrow \text{C/PQ APKE}$$

Hybrid From HPKE PSK Modes



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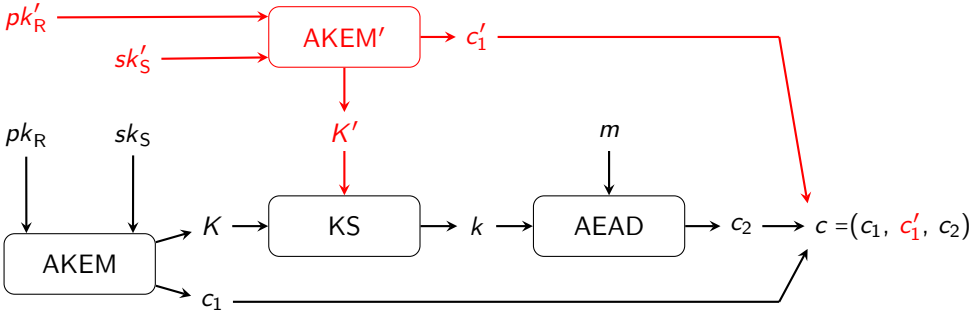

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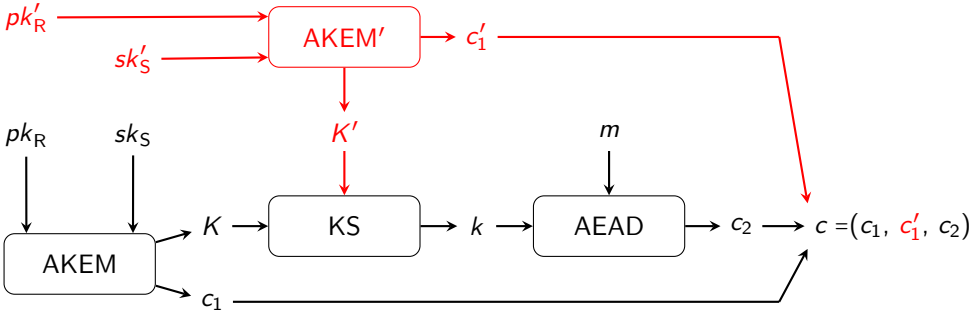

Theorem 5

If KS, AEAD, *and (*AKEM *or* AKEM′*) are secure, then* APKE *is secure.*

Summary

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Credit: [Mas09]

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- Security model for pskPKE and pskAPKE
- Security proofs of pre-shared key modes of HPKE
- Two post-quantum AKEM constructions
- Post-quantum security and plug-in hybrid construction

ia.cr/2023/1480

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Credit: [Mas09]

References I


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