Post-quantum Plaintext-awareness

Ehsan Ebrahimi and Jeroen Van Wier
University of Luxembourg

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- It has been formalized in the standard model as well [Bellare-Palacio, ASIACRYPT 2004]

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Adversary's goal: Generating a valid ciphertexts for which its corresponding plaintext is unknown

- PA0: Adversary can make one decryption query
- PA1: Adversary can make many decryption queries
- PA2: Adversary can make many decryption queries and eavesdrop some ciphertexts

More Formal Definition: PA0, PA1

- For ∀ PT adversary A , ∃ a PT plaintext extractor A^* such that for ∀ PT distinguisher D the following two games are indistinguishable where R is the random tape of A:

Real-world Game:

$x \leftarrow A^{Dec_{sk}}(pk)$

$b \leftarrow D(x)$

Fake Game:

$x \leftarrow A^{A^*(R,pk)}(pk)$

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More Formal Definition: PA2

- For ∀ PT adversary A , ∃ a PT plaintext extractor A^* such that for ∀ PT plaintext-creator P and for ∀ PT distinguisher D the following two games are indistinguishable where R is the random tape of A:

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$$\sum \frac{1}{\sqrt{|M|}} |m\rangle \longrightarrow \boxed{Enc_{pk}} \longrightarrow \sum \frac{1}{\sqrt{|M|}} |Enc_{pk}(m;r)\rangle$$

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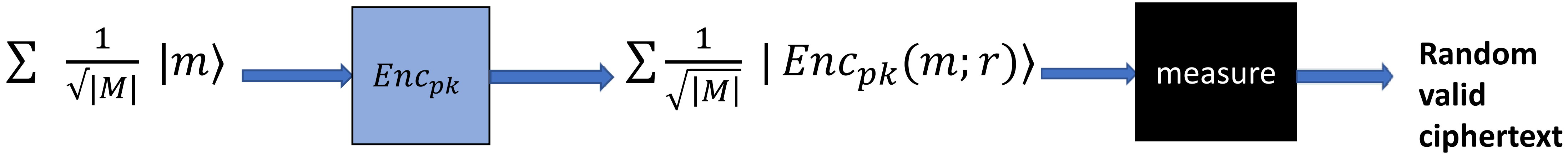

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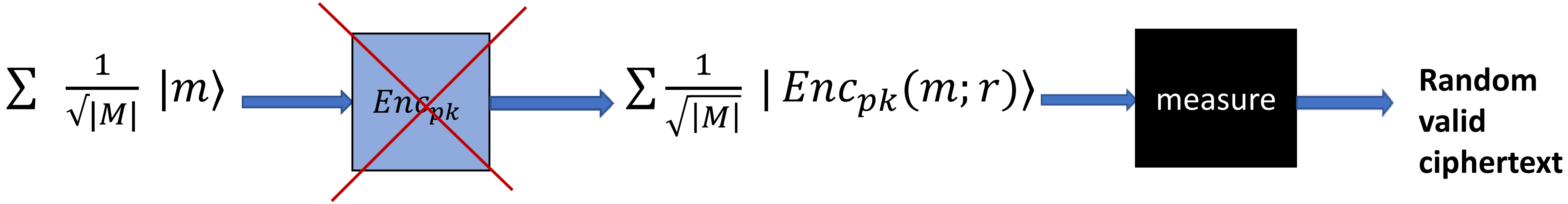

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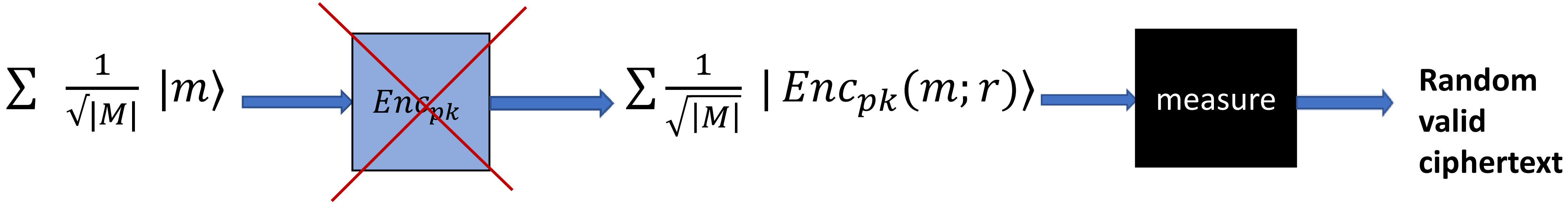

- We consider standard implementation: $|\mathrm{m}, \mathrm{y}\rangle \rightarrow |m, y \oplus Enc_{pk}(m;r)\rangle$

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3. PA2 + IND-CPA $\Longrightarrow$ IND-CCA but PA2 + IND-qCPA $\nRightarrow$ IND-qCCA [Boneh-Zhandry's Definition, Crypto 2013]

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Six Security notions

pqPA0-C_{Dec}, pqPA1-C_{Dec}

- For ∀ QPT adversary A , ∃ a QPT plaintext extractor A^* such that for ∀ QPT distinguisher D the following two games are indistinguishable where Q_{int} is the internal quantum register of A:

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Table of Implications and non-implications

	pqPA2-Q_{dec}	pqPA2-C_{dec}	pqPA1-Q_{dec}	pqPA1-C_{dec}	pqPA0-Q_{dec}	pqPA0-C_{dec}
pqPA2-Q_{dec}		$\Rightarrow$ Theorem 1	$\Rightarrow$ Theorem 2	$\Rightarrow$	$\Rightarrow$	$\Rightarrow$
pqPA2-C_{dec}	$\nRightarrow$ Theorem 4		$\Rightarrow$	$\Rightarrow$ Theorem 1	$\nRightarrow$ Corollary 2	$\Rightarrow$
pqPA1-Q_{dec}	$\nRightarrow$	$\nRightarrow$ Theorem 5		$\Rightarrow$ Theorem 1	$\Rightarrow$ Theorem 3	$\Rightarrow$
pqPA1-C_{dec}	$\nRightarrow$	$\nRightarrow$	$\nRightarrow$ Theorem 4		$\nRightarrow$	$\Rightarrow$ Theorem 3
pqPA0-Q_{dec}	$\nRightarrow$	$\nRightarrow$	$\nRightarrow$	$\nRightarrow$ Theorem 6		$\Rightarrow$ Theorem 1
pqPA0-C_{dec}	$\nRightarrow$	$\nRightarrow$	$\nRightarrow$	$\nRightarrow$	$\nRightarrow$ Corollary 1	

pqPAi-C_{Dec} $\not\Rightarrow$ pqPAi-Q_{Dec}

pqPAi-C_{Dec} $\nRightarrow$ pqPAi-Q_{Dec}

- Take a $PKE = (Gen, Enc, Dec)$ that is one-way and pq$PAi - C_{Dec}$. Commit to a valid ciphertext $c_v = Enc(m; r)$: $Com(c_v) = (c_{com}, r_{open})$

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- Change Dec to Dec':
  - A periodic function f on c_v is embedded in Dec'
  - A query to Dec' on $(\perp, c_v)$ reveals r and r_{open}

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- Distinguisher checks if $c_v := Enc(m; r)$ and $verif\left(c_{com}, c_v, r_{open}\right) = 1$

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- Change Dec to Dec':
  - A periodic function f on c_v is embedded in Dec'
    - Simon's algorithm can output c_v using quantum queries
  - A query to Dec' on $(\perp, c_v)$ reveals r and r_{open}

- Distinguisher checks if $c_v := Enc(m; r)$ and $verif(c_{com}, c_v, r_{open}) = 1$

pqPA1-Q_{Dec} $\nRightarrow$ pqPA2-C_{Dec}

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- Make it malleable by defining: $Enc'(m) = Enc(m)||0\ and\ Dec'(c||b) = Dec(c)$

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- Show that PKE'=(Gen, Enc', Dec') is $pqPA1 - Q_{Dec}$

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- Adversary A sends two messages $0^n, 1^n$ to P and gets a ciphertext $c||0$, queries $c||1$ as a decryption query

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- Take a $pqPA1 - Q_{Dec}$ $PKE = (Gen, Enc, Dec)$ that is IND-qCPA secure
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- Adversary A sends two messages $0^n, 1^n$ to P and gets a ciphertext $c||0$, queries $c||1$ as a decryption query
- Show that if PKE=(Gen, Enc', Dec') is $pqPA2 - C_{Dec}$, then it is not IND-qCPA secure

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- Write $c_v = c_v^1 \oplus c_v^2$ and $r_{open} = r_{open}^1 \oplus r_{open}^2$. Change Dec to Dec' that reveals one of c_v^1, c_v^2 and r_{open}^1, r_{open}^2 randomly in each query. It reveals r as well.

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- Show that PKE remains $\text{p}qPA0 - Q_{Dec}$ with this new Dec'

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- Take a $PKE = (Gen, Enc, Dec)$ that is one-way and pq$PA0 - Q_{Dec}$. Commit to a valid ciphertext $c_v := Enc(m; r)$: $Com(c_v) = (c_{com}, r_{open})$

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- Show that PKE remains pq$PA0 - Q_{Dec}$ with this new Dec'

- Adversary with many decryption queries can get c_v and checks if $c_v := Enc(m; r)$ and $verif\left(c_{com}, c_v, r_{open}\right) = 1$

Relation with IND-qCCA

- Any public-key encryption scheme Enc that is $pqPA2 - Q_{Dec}$ plaintext-aware and IND-qCPA secure is IND-qCCA secure.

Achievability

- We lift a $pqPA2 - C_{Dec}$ plaintext-aware encryption scheme to a $pqPA2 - Q_{Dec}$ plaintext-aware encryption scheme using a quantum secure PRP

Conclusion

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- We studied the relations between these six security notions
- We show the relation with IND-qCCA notion
- We lift a post-quantum PA2 encryption scheme to a $pqPA2 - Q_{Dec}$ plaintext-aware encryption scheme using a quantum-secure PRP

Thank you for listening