Tightly-Secure Group Key Exchange with Perfect Forward Secrecy

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Introduction

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P_i $(\mathsf{pk}_i, \mathsf{sk}_i)$		$\mathcal{P}_i$
$(m_i, \mathsf{st}) \leftarrow \mathsf{Begin}(\mathsf{sk}_i, \{\mathsf{pk}_j\}_{j \in \mathcal{P}_i})$	$\xrightarrow{(i, m_i)}$	
	$\xleftarrow{\mathcal{M}_i = \{(j, m_j)\}_{j \in \mathcal{P}_i}}$	
$(\hat{m}_i, \mathsf{st}) \leftarrow \mathsf{Respond}(\mathsf{sk}_i, \mathsf{st}, \mathcal{M})$	$\xrightarrow{(i, \hat{m}_i)}$	
	$\xleftarrow{\hat{\mathcal{M}}_i = \{(j, \hat{m}_j)\}_{j \in \mathcal{P}_i}}$	
$(\bar{m}_i, \mathsf{st}) \leftarrow \mathsf{Final}(\mathsf{sk}_i, \mathsf{st}, \hat{\mathcal{M}})$	$\xrightarrow{(i, \bar{m}_i)}$	
	$\xleftarrow{\bar{\mathcal{M}}_i = \{(j, \bar{m}_j)\}_{j \in \mathcal{P}_i}}$	
$K := \mathsf{Derive}(\mathsf{sk}_i, \mathsf{st}, \bar{\mathcal{M}})$		

Challenges in GAKE

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Non-Tight Security Proofs:

- Inefficient parameter settings due to loose reductions.

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Let p be a prime number and g an element of a group G. Let n be the number of parties.

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- Each P_i broadcasts $c_i = (k_{i+1}/k_{i-1})^{x_i} \mod p$.
- Each P_i computes the key $K = k_{i-1}^{nx} \cdot c_i^{n-1} \cdot c_{i+1}^{n-2} \cdots c_{i-2} \mod p$ $= g^{x_1 x_2 + x_2 x_3 + \cdots + x_n x_1} \mod p$.

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Using digital signatures over all messages sent, this protocol can be made actively secure.

Fresh Perspective on BD Protocol

A ring structure for the parties.

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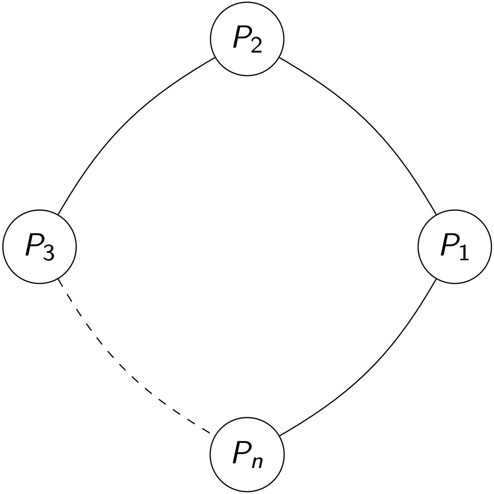

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- $K_{i,i+1}$ is only given to P_{i-1} and $K_{i-1,i}$ is only given to P_{i+1}, then publish $K_{i,i+1}/K_{i-1,i} = (k_{i+1}/k_{i-1})^{x_i} = c_i$.

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- P_i can compute $K = g^{x_1x_2+x_2x_3+\ldots+x_nx_1} = K_{1,2}K_{2,3}\cdots K_{n,1}$.

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- P_i can compute $K = g^{x_1x_2+x_2x_3+\ldots+x_nx_1} = K_{1,2}K_{2,3}\cdots K_{n,1}$. It can step-wisely compute the value
  $K_{i,i+1} = K_{i-1,i} \cdot c_i \iff K_{i,i+1}/c_i = K_{i-1,i}$.

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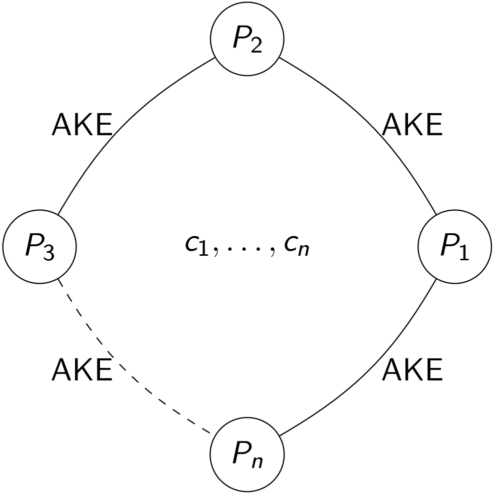

$$c_i = K_{i,i+1}/K_{i-1,i} = SymEnc(K_{i,i+1}, K_{i-1,i}) = SymEnc'(K_{i-1,i}, K_{i,i+1}).$$

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- Use Unilateral Authenticated Key Exchange (UAKE) instead of AKE.
- In the second phase, P_i distributes the symmetric key shared with P_{i+1} to P_{i-1} (and not vice versa).
- A random oracle-based symmetric encryption system is used, where the sharing of key $K_{i,i+1}$ to P_{i-1} now proceeds as $c_i = h(K_{i-1,i}) \oplus K_{i,i+1}$.

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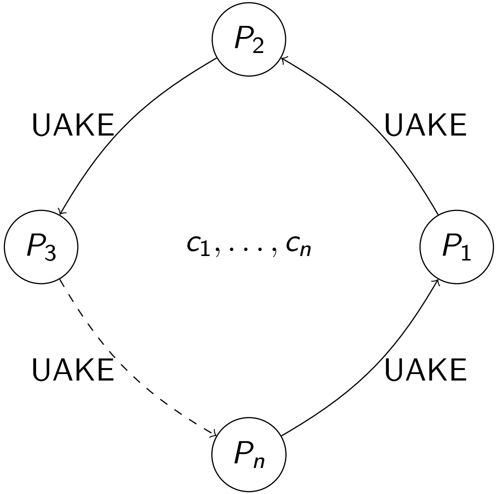

$$c_i = h(K_{i-1,i}) \oplus K_{i,i+1} = SymEnc(K_{i,i+1}, K_{i-1,i})$$

Design Choices

One-way Authentication:

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Random Oracle Model (ROM):

- Utilized for tight security guarantees.

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KEM to UAKE$_{\mathsf{WFS}}$:

- Utilize an ephemeral public key and key encapsulation to derive a fresh session key, ensuring authenticated encryption tied to the long-term key.

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- Introduce key confirmation since it is unilaterally authenticated, and it does not increase number of moves.

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\mathsf{LWE} \arrow[ur, "\text{[PWZ23]}"'] & & & &
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Post-Quantum Readiness:

- Lattice-based constructions secure against quantum adversaries.

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- Post-quantum tight security proof in a security model where reveal state queries are allowed.
- Perfect Forward Secrecy is guaranteed.

Questions?

Thanks for your attention!