Towards Bidirectional Ratcheted Key Exchange

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Information Security Group

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RUB



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- Alice and Bob communicate
- Active adversary







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- Active adversary







- Alice and Bob communicate
- Active adversary
- Long term communication
 - Local (full) state temporarily exposed







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- Practical protocols w/o precise security definition
 - E.g., Signal 🤇







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- Natural security notion
 - Definition based only on trivial attacks
 - Bellare et al. on unidirectional communication C'17
 - Bob cannot be exposed



Natural Security Notion for Ratcheting?

- Natural security notion
 - Definition based only on trivial attacks
 - Bellare et al. on unidirectional communication C'17
 - Bob cannot be exposed

Our models require and constructions provide *full* security under:

- Asynchronous
 communication
- Exposure of both parties





Agenda

- 1. The Primitive Ratcheted Key Exchange
- 2. General Adversary Model
- 3. Unidirectional Ratcheting \rightarrow Model and Construction
- 4. Sesquidirectional Ratcheting \rightarrow Model and Construction

5. Results



Natural Security Notion for Ratcheting? Modeling RKE **Construction Intuition** Natural security notion Definition based only on trivial attacks • Syntax: Hey Bob! ♡ Hey Bob! ♡ Initialization Love you ♡ Darling? Love you ♡ Darling? 1 year later? later? That's a secret! secret! That's

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• What is Ratcheting?

Results



Natural Security Notion for Ratcheting?

- Natural security notion
 - Definition based only on trivial attacks
- Syntax:
 - Initialization





- Natural security notion
 - Definition based only on trivial attacks
- Syntax:
 - Initialization
 - Sending & receiving





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- Natural security notion
 - Definition based only on trivial attacks
- Syntax:
 - Initialization
 - Sending & receiving
 - Key exchange
 - Consecutive establishment of keys in session
 - *≠ Authenticated key* exchange!





- Natural security notion
 - Definition based only on trivial attacks
- Syntax:
 - Initialization
 - Sending & receiving
 - Key exchange
 - Composition in Bellare et al. C'17





Three Variants of Ratcheting

- Bidirectional ratcheting is complicated
- \rightarrow Understand its components



 k_{A3}



Three Variants of Ratcheting

- Bidirectional ratcheting is complicated
- \rightarrow Understand its components:
 - Unidirectional key establishment



 k_{A3}



Three Variants of Ratcheting

- Bidirectional ratcheting
 is complicated
- → Understand its components:
 - Unidirectional key establishment
 - Alice initiates computation of new key
 - Bob does not respond



rc\



Three Variants of Ratcheting

- Bidirectional ratcheting
 is complicated
- → Understand its components:
 - Unidirectional ratcheted key exchange (RKE)





Three Variants of Ratcheting

- Bidirectional ratcheting is complicated
- → Understand its components:
 - Unidirectional RKE
 - Sesquidirectional RKE
 - Bob contributes (but cannot establish keys)
 - Adds security

(sesqui = 1.5)





Three Variants of Ratcheting

- Bidirectional ratcheting is complicated
- → Understand its components:
 - Unidirectional RKE
 - Sesquidirectional RKE
 - Symmetric roles





Three Variants of Ratcheting

- Bidirectional ratcheting is complicated
- → Understand its components:
 - Unidirectional RKE
 - Sesquidirectional RKE
 - Symmetric roles
 - Bidirectional RKE
 = 2x Sesquid. RKE
 (extended version)





Three Variants of Ratcheting

Unidirectional RKE (+ Exposure of Bob)

from Bob

Sesquidirectional RKE

init

Bidirectional RKE

init

snc

snc

sno

k_{A1}

 k_{A2}

k_{B1} -

 k_{A3}

rcv k_{A1}

rcv k_{A2}

rcv k_{A3}

snd



Bob's responses only help to recover Symmetric roles (extended version)

rcv k_{A1}

snd **k**_{B1}

rcv k_{A2}

rcv k_{A3}



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What is Ratcheting?Modeling RKE Construction Intuition Results

- Active adversary
 - Control whole network traffic





- Active adversary
 - Control whole network traffic
- Analyze key indistinguishability
 - Multi-challenge real or random key
 - \rightarrow Guess bit $b \in \{0,1\}$





- Active adversary
 - Control whole network
 traffic
- Analyze key
 indistinguishability
 - Multi-challenge real or random key
- Model exposures
 of local state





- Active adversary
 - Control whole network
 traffic
- Analyze key indistinguishability
 - Multi-challenge real or random key
- Model exposures of local state
- Single session
- Init abstracted







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5. Results



Modeling Unidirectional RKE





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What is Ratcheting?Modeling RKE Construction Intuition Results

Modeling Unidirectional RKE

Impersonation
 ⇒ No future Challenge
 on Bob





Modeling Unidirectional RKE

- Impersonation \Rightarrow No future Challenge on Bob
- Expose Bob \rightarrow Allowed in our model




Modeling Unidirectional RKE

- Impersonation
 ⇒ No future Challenge
 on Bob
- Expose Bob
 ⇒ No future Challenge





Modeling Unidirectional RKE

- Impersonation
 ⇒ No future Challenge
 on Bob
- Expose Bob

 ⇒ No future Challenge
 if synchronous
 (= if no previous
 active attack)





rcv k_{A1}

rcv k_{A2}

rc\

What is Ratcheting? Modeling RKE **Construction Intuition** Results

Modeling Unidirectional RKE

 k_{A1}

snd

- Impersonation \Rightarrow No future Challenge on Bob
- Expose Bob \Rightarrow No future Challenge if synchronous
- \Rightarrow Exposure of Alice (solely) "okay"



init

Adversary



Modeling Unidirectional RKE

- Impersonation \Rightarrow No future Challenge on Bob
- Expose Bob \Rightarrow No future Challenge if synchronous
- \Rightarrow Exposure of Alice (solely) "okay"





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5. Results







- Expose Alice okay \rightarrow Public key crypto
- Expose Bob \Rightarrow No future Challenge if synchronous









Results





Results

- Expose Alice okay \rightarrow KEM: enc(pk) \rightarrow_s c k dec(sk c) \rightarrow_s k
- Expose Bob
 ⇒ No future Challenge
 if synchronous
 - → Forward secrecy of Bob's state





Results

- Expose Alice okay \rightarrow KEM: enc(pk) \rightarrow_s c k dec(sk c) \rightarrow_s k
- Expose Bob
 ⇒ No future Challenge
 if synchronous
 - → Forward secrecy of Bob's state
 - \rightarrow Divergence of states





Results

Constructing Unidirectional RKE

 k_{A1}

 k_{A2}

 k_{A3}

- Expose Alice okay \rightarrow KEM: enc(pk) \rightarrow_s c k dec(sk c) \rightarrow_s k
- Expose Bob
 ⇒ No future Challenge
 if synchronous
 - → Forward secrecy of Bob's state
 - \rightarrow Divergence of states
 - \rightarrow Random oracle:







Results

Constructing Unidirectional RKE

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- Expose Bob
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Results

Constructing Unidirectional RKE

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 - \rightarrow Model and Construction





5. Results



Modeling Unidirectional RKE

- Impersonation A → B
 ⇒ No future Challenge
 on Bob
- Expose Bob
 ⇒ No future Challenge
 if synchronous





- Impersonation $A \rightarrow B$ \Rightarrow No future Challenge on Bob
- Expose Bob \Rightarrow No future Challenge if synchronous





- Impersonation A → B ⇒ No future Challenge on Bob
- Impersonation B → A
 ⇒ No future Challenge on Alice
- Expose Bob
 ⇒ No future Challenge
 if synchronous





- Impersonation A → B
 ⇒ No future Challenge
 on Bob
- Impersonation B → A
 ⇒ No future Challenge on Alice
- Expose Bob
 ⇒ No future Challenge
 if synchronous
 until Bob recovered





- Impersonation A → B
 ⇒ No future Challenge
 on Bob
- Impersonation B → A
 ⇒ No future Challenge on Alice
- Expose Bob
 ⇒ No future Challenge
 if synchronous
 until Bob recovered





- Impersonation A → B
 ⇒ No future Challenge
 on Bob
- Impersonation B → A
 ⇒ No future Challenge on Alice
- Expose Bob
 ⇒ No future Challenge
 if synchronous
 until Bob recovered





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5. Results



Constructing Sesquidirectional RKE

Expose Bob
 ⇒ No future Challenge
 if synchronous
 until Bob recovered





Results

- Expose Bob
 ⇒ No future Challenge
 if synchronous
 until Bob recovered
 - → Forward secrecy and recovery of Bob's state





Results

- Expose Bob
 ⇒ No future Challenge
 if synchronous
 until Bob recovered
 - → Forward secrecy and recovery of Bob's state
 → Send new pk





Results

- Expose Bob
 ⇒ No future Challenge
 if synchronous
 until Bob recovered
 - → Forward secrecy and recovery of Bob's state
 - \rightarrow Send new pk \rightarrow Divergence of states





Results

- Expose Bob
 ⇒ No future Challenge
 if synchronous
 until Bob recovered
 - → Forward secrecy and recovery of Bob's state
 - \rightarrow Send new pk \rightarrow Divergence of states





Results

- Expose Bob
 ⇒ No future Challenge
 if synchronous
 until Bob recovered
 - → Forward secrecy and recovery of Bob's state
 → Send new pk
 - \rightarrow Divergence of states \rightarrow Update key pair





Results

Constructing Sesquidirectional RKE

snd

- Expose Bob \Rightarrow No future Challenge if synchronous until Bob recovered
 - \rightarrow Forward secrecy and recovery of Bob's state
 - \rightarrow Send new pk
 - \rightarrow Divergence of states \rightarrow Update key pair



 k_{A1}

 k_{A2}

 k_{A3}





Results

- Expose Bob
 ⇒ No future Challenge
 if synchronous
 until Bob recovered
 - → Forward secrecy and recovery of Bob's state
 - \rightarrow Send new pk
 - \rightarrow Divergence of states \rightarrow Update key pair







Results

Constructing Sesquidirectional RKE

- Expose Bob
 ⇒ No future Challenge
 if synchronous
 until Bob recovered
 - → Forward secrecy and recovery of Bob's state
 - \rightarrow Send new pk \rightarrow Divergence of states
 - \rightarrow Update key pair



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- Unidirectional RKE
 - KEM + ROM (+ MAC)

ia.cr/2018/296 (ext. version)



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- Unidirectional RKE
 - KEM + ROM (+ MAC)
- Sesquidirectional RKE
 - Key updatable KEM (+ signatures)
 - # up (sk T) = #crossing ciphertexts
 - \rightarrow Depth of HIBE practically bounded



@roeslpa

ia.cr/2018/296 (ext. version)





- Unidirectional RKE
 - KEM + ROM (+ MAC)
- Sesquidirectional RKE
 - Key updatable KEM (+ signatures)
 - # up (sk T) = #crossing ciphertexts
 → Depth of HIBE practically bounded
 - Multi encapsulation
 - \rightarrow Bounded in ping-pong pattern
 - \rightarrow Alternative: key updatable signatures



@roeslpa

ia.cr/2018/296 (ext. version)





- Unidirectional RKE
 - KEM + ROM (+ MAC)
- Sesquidirectional RKE
 - Key updatable KEM (+ signatures)
 - # up (sk T) = #crossing ciphertexts
 → Depth of HIBE practically bounded
 - Multi encapsulation
 - \rightarrow Bounded in ping-pong pattern
 - \rightarrow Alternative: key updatable signatures
- BRKE = 2x SRKE + OT signatures
 → Build SRKE, BRKE too complex!

ia.cr/2018/296 (ext. version)



@roeslpa

rcv kas