Key Confirmation in Key Exchange

A Formal Treatment and Implications for TLS 1.3

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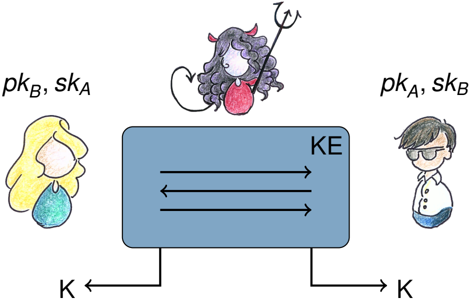
Key Exchange

Security Goals (à la Bellare–Rogaway 1993)



key secrecy

“the key looks random (to Eve)”

(implicit) authentication

“only/at most Bob can hold the key”

drawings by *Giorgia Azzurra Marson*

Key Confirmation

The informal understanding

> ***Key confirmation*** *is the property whereby one party is assured that a second (possibly unidentified) party actually has possession of a particular secret key.*
>
> Handbook of Applied Cryptography, Definition 12.7

- ensuring Bob actually holds the key

- often mentioned in scientific papers on key exchange
- but no formal treatment so far

Key Confirmation Matters

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- crypto: no security problem if no one can decrypt
- seems “clear”: use the key and you get key confirmation

?

- caution: unmitigated use of session key destroys BR’93 key secrecy

!

- folklore transform: derive separate key & send a MAC

- discussions around TLS 1.3: is key confirmation needed?
- specified as goal by NIST standards and for TLS 1.3

?!

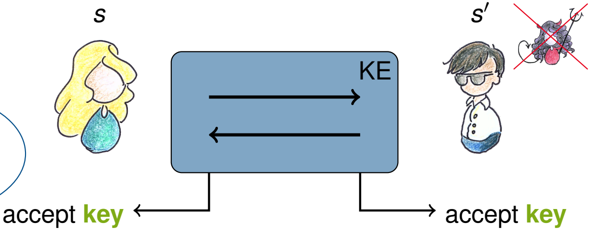
Our Results

- formalize key confirmation to enable a well-founded discussion
- revisit the “refresh-then-MAC” protocol transform
- analyze TLS 1.3 (draft-10) for key confirmation

Formal Model

Full Key Confirmation

- **intuition:** when a session accepts, another session already holds the key



s

s'

KE

accept **key**

accept **key**

e.g.,
$\mathcal{S}$ = clients,
$\mathcal{S}'$ = servers

$$\forall s \in \mathcal{S} :: [s.\text{status} = \texttt{accept} \wedge s.\text{peer} \notin \text{Corr} \cup \{*\}]$$
$$\implies \exists s' \in \mathcal{S}' :: (s'.\text{status} = \texttt{accept} \wedge s.\text{sid} = s'.\text{sid} \wedge s.\textbf{key} = s'.\textbf{key})$$

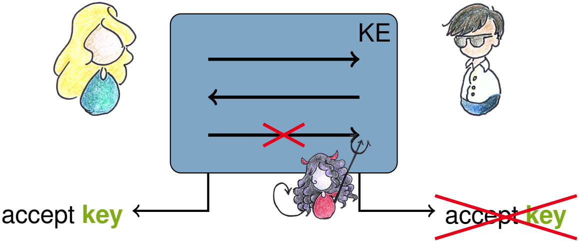
modular

- formalization exposes duality to classical authentication notion:
  - (implicit) authentication: there exists *at most one* session that holds the key
  - (full) key confirmation: there exists *at least one* session that holds the key

Formal Model

Full Key Confirmation

- **note:** cannot have mutual full key confirmation

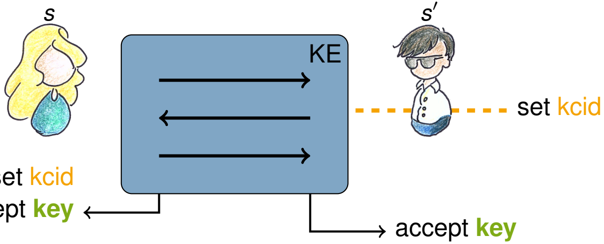


- adversary can always drop the last message
- i.e., sender of last message can only get weaker guarantees

Formal Model

Almost-Full Key Confirmation

- **intuition:** when a session accepts, another session exists that, *if it accepts*, will hold the same key
- introduce **key-confirmation identifier** kcid



set kcid

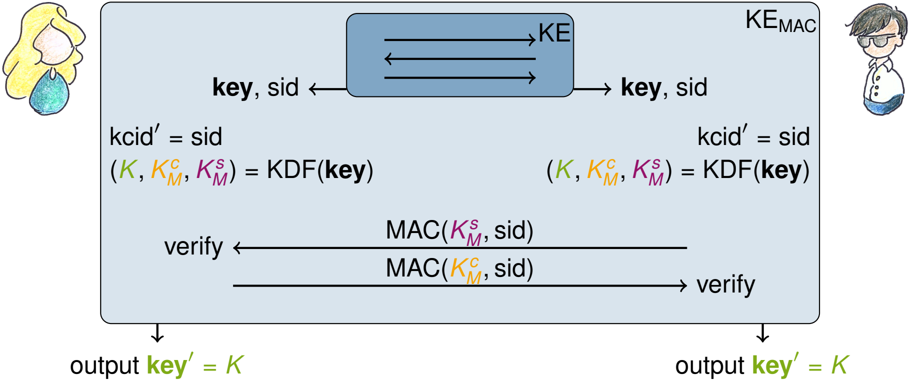
accept **key**

set kcid

accept **key**

$$\forall s \in \mathcal{S} :: [s.\text{status} = \texttt{accept} \wedge s.\text{peer} \notin \text{Corr} \cup \{*\}]$$
$$\implies \exists s' \in \mathcal{S}' :: [s.\text{kcid} = s'.\text{kcid} \wedge (s'.\text{status} = \texttt{accept} \implies s.\textbf{key} = s'.\textbf{key})]$$

“Refresh-then-MAC” Protocol Transform



$\mathsf{KE}_{\mathsf{MAC}}$

KE

key, sid ← → **key**, sid

$\mathrm{kcid}' = \mathrm{sid}$ $\qquad$ $\mathrm{kcid}' = \mathrm{sid}$

$(K, K_M^c, K_M^s) = \mathrm{KDF}(\mathbf{key})$ $\qquad$ $(K, K_M^c, K_M^s) = \mathrm{KDF}(\mathbf{key})$

verify $\xleftarrow{\mathrm{MAC}(K_M^s, \mathrm{sid})}$

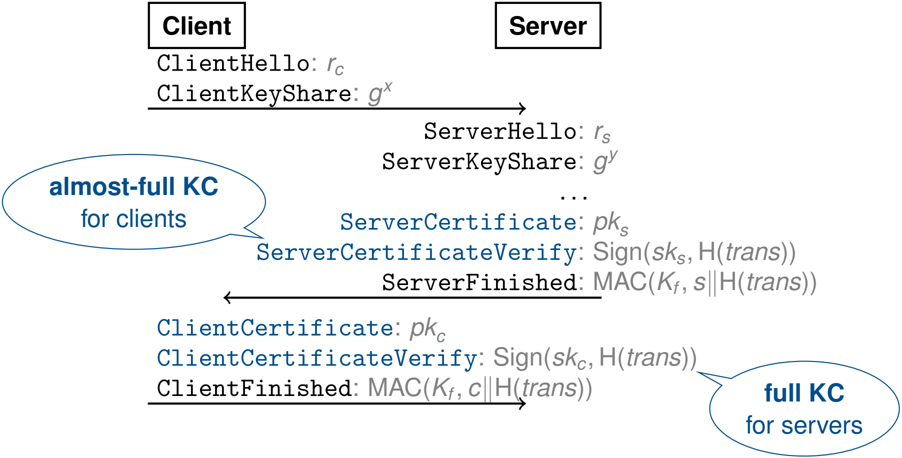
$\xrightarrow{\mathrm{MAC}(K_M^c, \mathrm{sid})}$ verify

output $\mathbf{key}' = K$ $\qquad$ output $\mathbf{key}' = K$

- key secrecy and authentication is preserved
- full KC for receiver, almost-full KC for sender of final message

Key Confirmation in TLS 1.3

draft-10 Full (EC)DHE Handshake



Client

Server

`ClientHello`: r_c

`ClientKeyShare`: g^x

`ServerHello`: r_s

`ServerKeyShare`: g^y

...

`ServerCertificate`: pk_s

`ServerCertificateVerify`: $\mathsf{Sign}(sk_s, \mathsf{H}(trans))$

`ServerFinished`: $\mathsf{MAC}(K_f, s \| \mathsf{H}(trans))$

`ClientCertificate`: pk_c

`ClientCertificateVerify`: $\mathsf{Sign}(sk_c, \mathsf{H}(trans))$

`ClientFinished`: $\mathsf{MAC}(K_f, c \| \mathsf{H}(trans))$

almost-full KC
for clients

full KC
for servers

Key Confirmation in TLS 1.3

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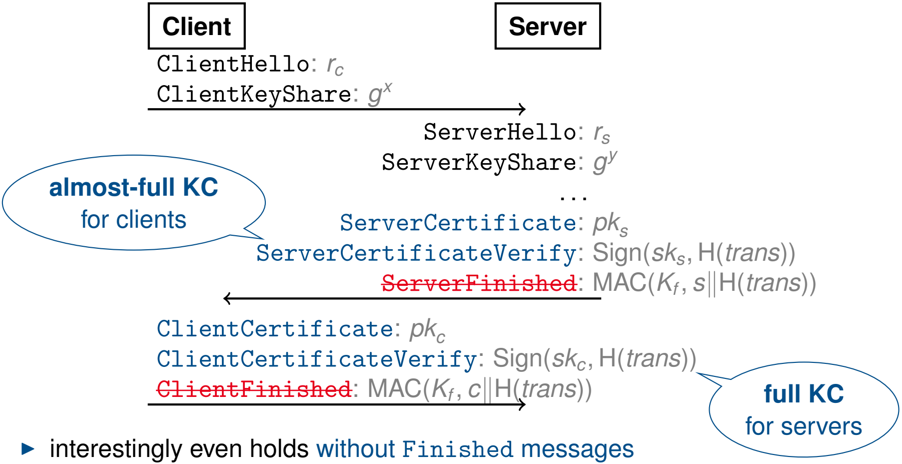

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almost-full KC
for clients

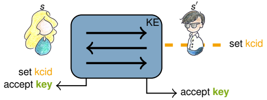
full KC
for servers

- interestingly even holds without `Finished` messages
- in the paper: (similar) results on unilateral authentication case

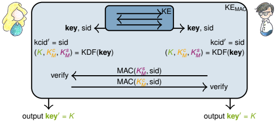
Summary

We

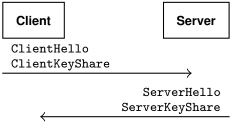
- formalize key confirmation
  in a game-based model
  - full key confirmation for receiver,
  - almost-full key confirmation for sender of last message



- confirm that the “refresh-then-MAC” transform generically adds key confirmation



- show that TLS 1.3 provides key confirmation
  (even without `Finished` messages)



Thank You!