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Forward-secure 0-RTT Key Exchange from Puncturable Key Wrapping

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based on joint work with Matilda Backendal and Kenny Paterson, in submission

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APPLIED CRYPTO GROUP

The TLS 1.3 Full Handshake

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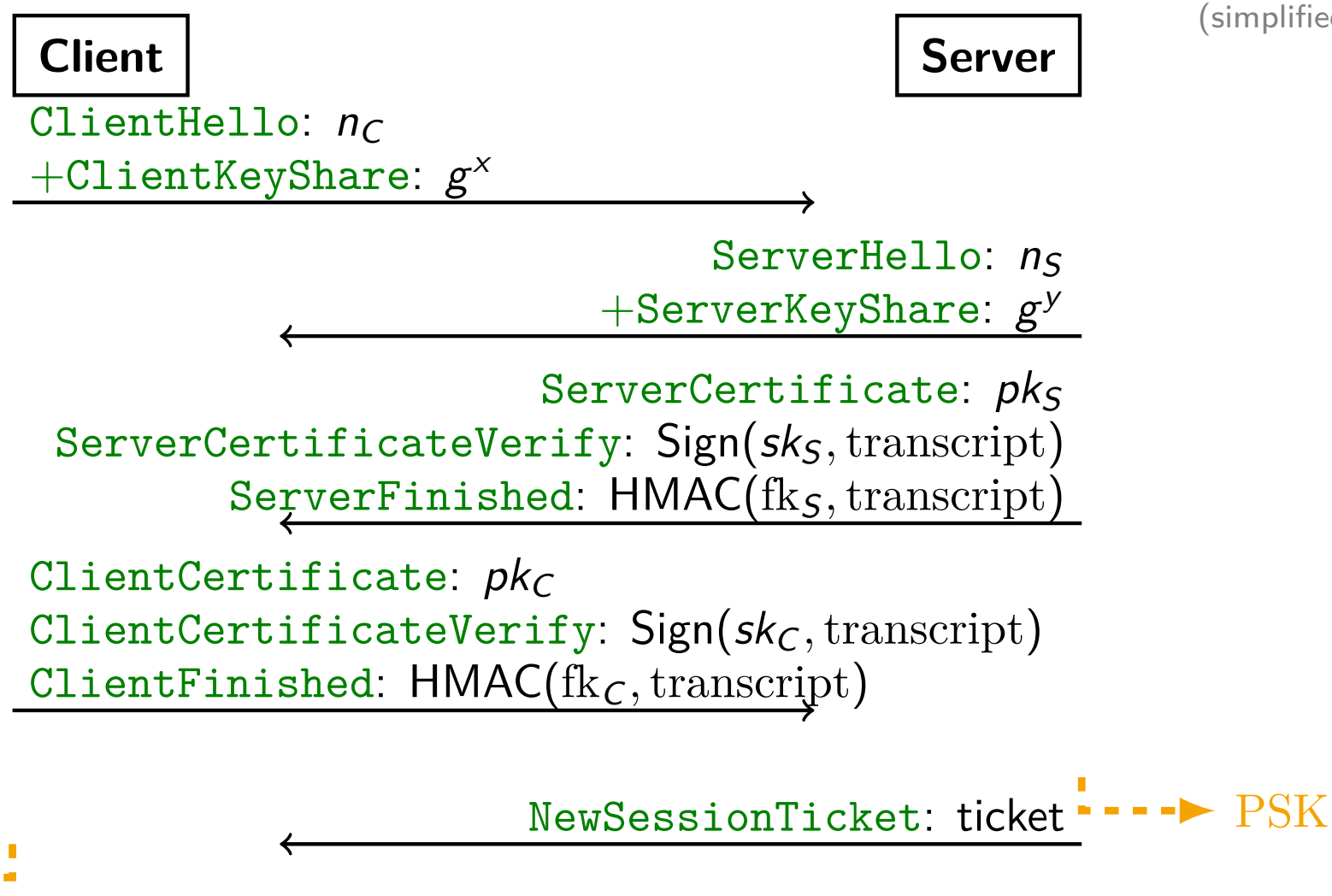
(simplified)



The TLS 1.3 PSK/Resumption Handshake

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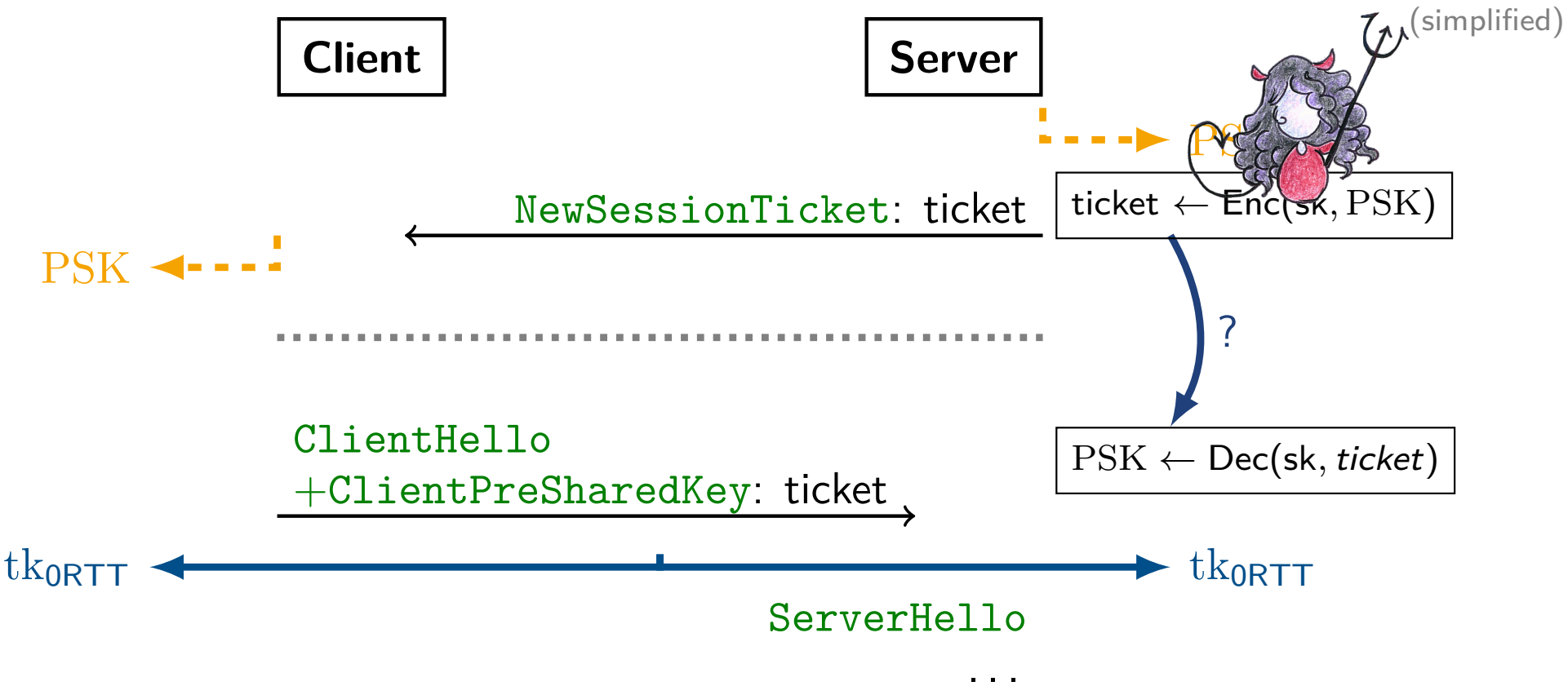

Puncturing to the rescue...

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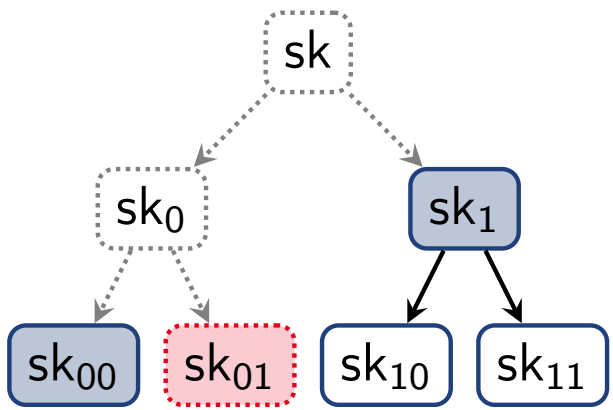
- What if we could "forget" the ability to decrypt a ticket after using it?
- Aviram, Gellert, Jager (2019): "Session resumption protocols & fs TLS 1.3"
  - idea: use *sk* in **Puncturable** PRF + combine with AEAD

Puncturable PRF (PPRF)

- $\text{KeyGen}() \xrightarrow{\$} \text{sk}$
- $\text{Eval}(\text{sk}, x) \rightarrow y/\perp$
- $\text{Punc}(\text{sk}, x) \rightarrow \text{sk}'$



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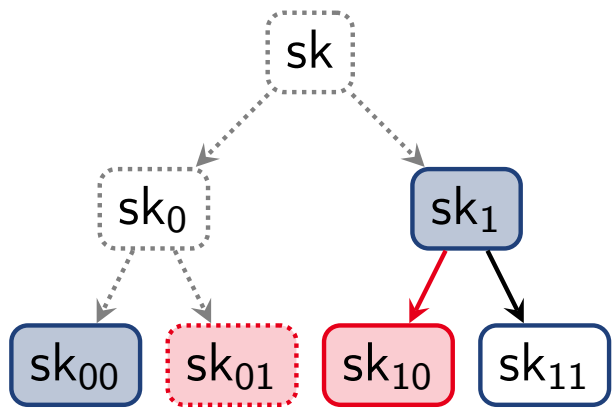

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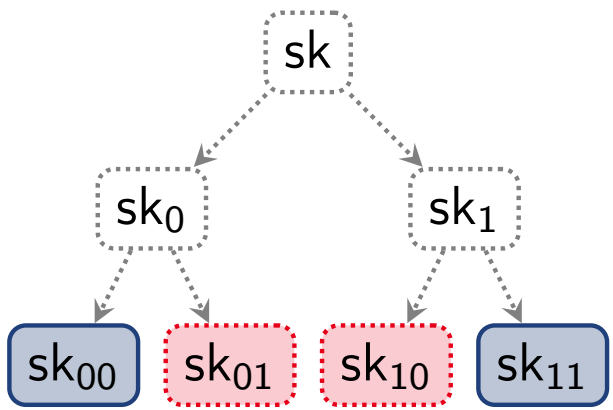

Forward-secure Resumption from PPRF+AEAD [AGJ]

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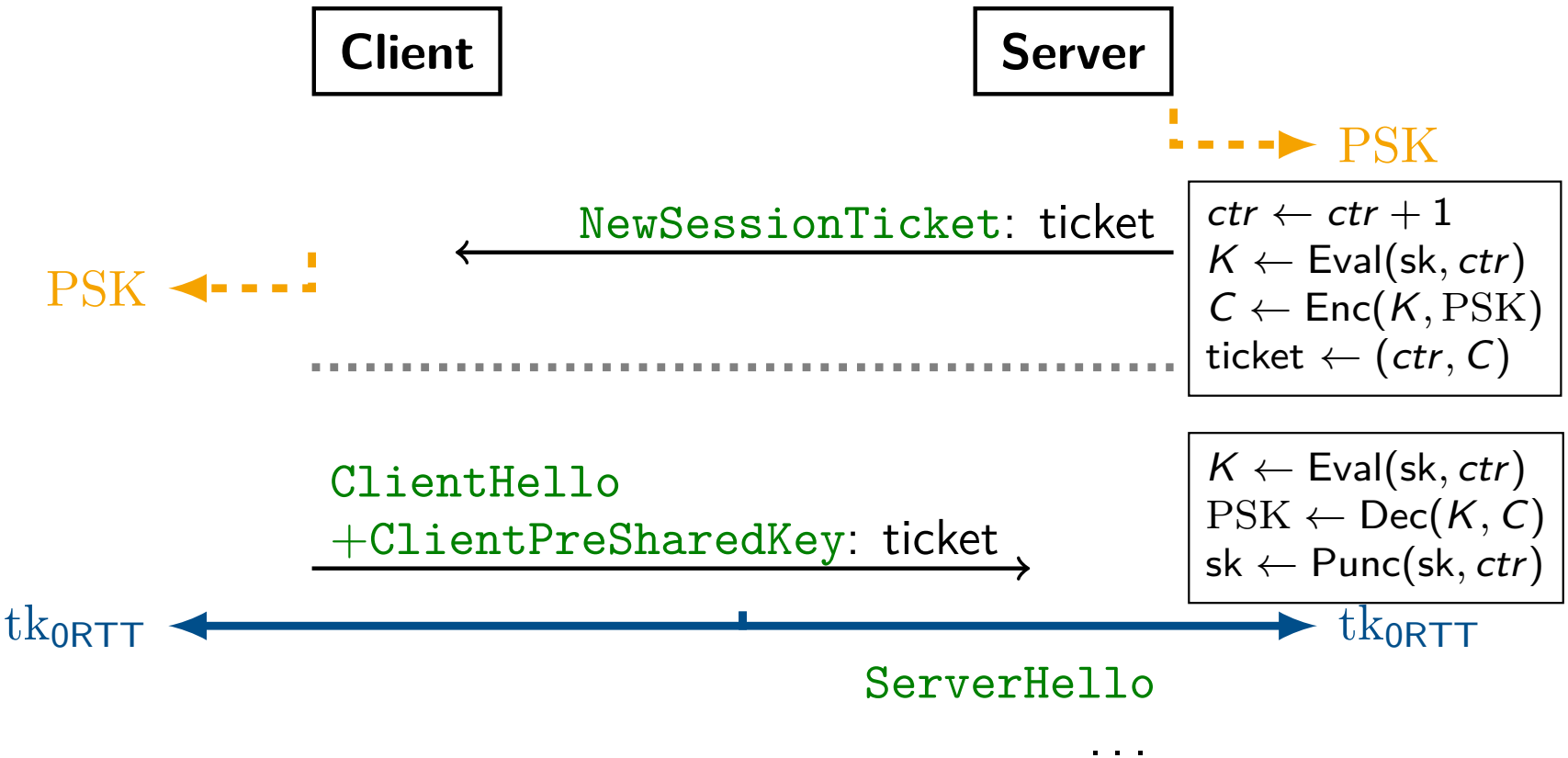
(simplified)



- ✓ forward security: through PPRF puncturing
- ▶ meta data: tickets now possibly linkable, via counters
- ▶ is there a more general perspective?

Puncturable Key Wrapping

Syntax

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- idea: merge classical **key wrapping** (Rogaway-Shrimpton, 2006) with **puncturable encryption** (Green-Miers, 2015)

Puncturable Key Wrapping (PKW)

- KeyGen() $\xrightarrow{\$}$ sk
- Wrap(sk, T, H, K) $\rightarrow C/\perp$
- Unwrap(sk, T, H, C) $\rightarrow K/\perp$
- Punc(sk, T) $\rightarrow$ sk$'$

Remarks:

- puncturing on tags T, for now: think nonce
  but may subsume multiple ciphertexts/keys

PKW[PPRF,AEAD]

KeyGen():

1 Return PPRF.KeyGen()

Wrap(sk_{pprf}, T, H, K):

2 $sk_{aead} \leftarrow$ PPRF.Eval(sk_{pprf}, T)
3 $C \leftarrow$ AEAD.Enc(sk_{aead}, T, H, K)
4 Return C

Punc(sk_{pprf}, T):

8 $sk'_{pprf} \leftarrow$ PPRF.Punc(sk_{pprf}, T)
9 Return sk'_{pprf}

Puncturable Key Wrapping

Security

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- ex.: **confidentiality**
- we also define integrity and some further properties

Game $\mathbf{G}^{\text{find\$-cpa}}_{\text{PKW}}(\mathcal{A})$, $\boxed{\mathbf{G}^{\text{find\$-rcpa}}_{\text{PKW}}(\mathcal{A})}$:

1 $b \leftarrow\$ \{0,1\}$; $u \leftarrow 0$
2 $b^* \leftarrow\$ \mathcal{A}()$
3 Return $b^* = b$

NEW():

4 $u{+}{+}$
5 $sk_u \leftarrow\$ \mathsf{KeyGen}()$
6 $\mathcal{S}_{PT,u}, \mathcal{S}_{\$T,u}, \mathcal{S}_{T,u} \leftarrow \emptyset$
7 $\mathsf{corr}_u \leftarrow \text{false}$

WRAP(i, T, H, K):

8 If $T \in \mathcal{S}_{T,i}$ then return $\perp$
9 $C \leftarrow \mathsf{Wrap}(sk_i, T, H, K)$
10 $\mathcal{S}_{T,i} \xleftarrow{\cup} \{T\}$
11 Return C

RO\$-WRAP(i, T, H, K):

12 If $T \in \mathcal{S}_{T,i}$ or corr_i:
13 Return $\perp$
14 $C_1 \leftarrow \mathsf{Wrap}(sk_i, T, H, K)$
15 If $C_1 = \perp$ then return $\perp$
16 $C_0 \leftarrow\$ \{0,1\}^{\mathsf{cl}(|K|)}$
17 $\mathcal{S}_{\$T,i} \xleftarrow{\cup} \{T\}$; $\mathcal{S}_{T,i} \xleftarrow{\cup} \{T\}$
18 Return C_b

CORR(i):

19 If $\mathcal{S}_{\$T,i} \not\subseteq \mathcal{S}_{PT,i}$:
20 Return $\perp$
21 $\mathsf{corr}_i \leftarrow \text{true}$
22 Return sk_i

PUNC(i, T):

23 $sk_i \leftarrow \mathsf{Punc}(sk_i, T)$
24 $\mathcal{S}_{PT,i} \xleftarrow{\cup} \{T\}$

Forward-secure Resumption from PKW

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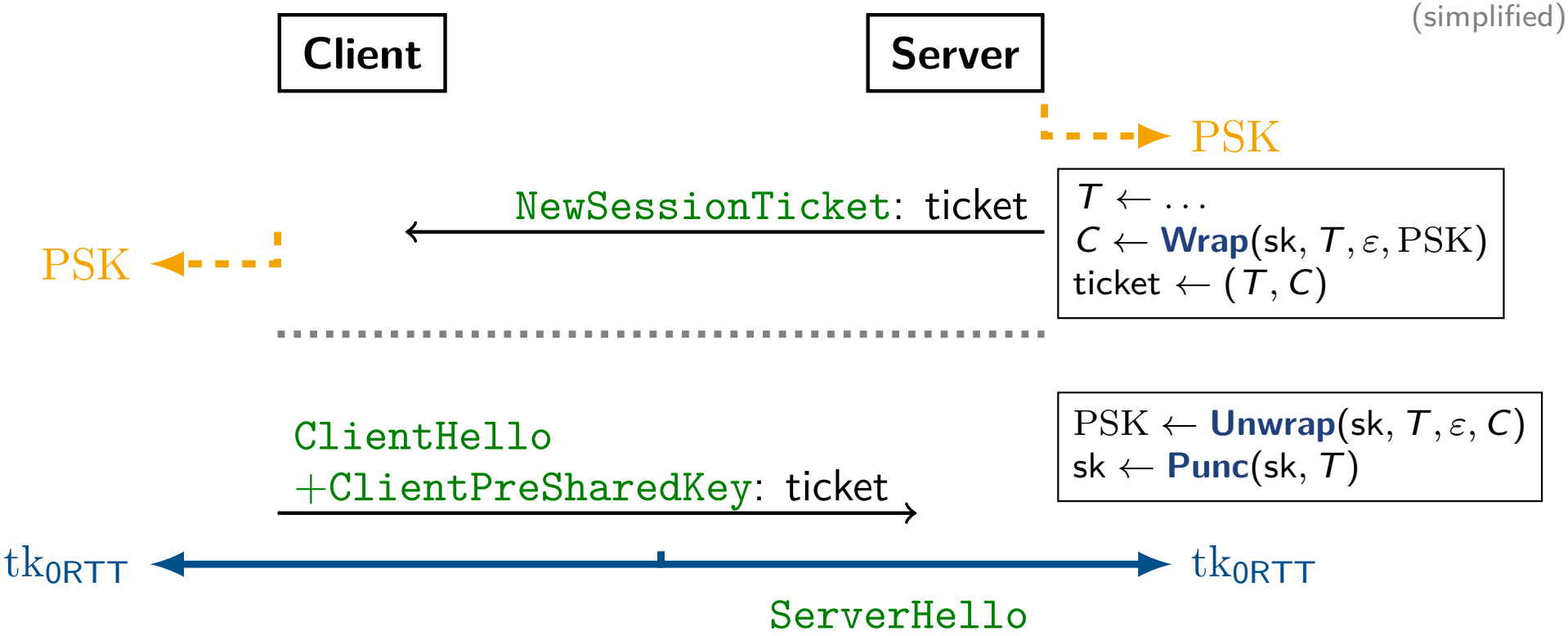
(simplified)



- generic, natural instantiation
- ✓ recast **[AGJ]**: take T to be a counter *ctr* ($\rightarrow$ identified gaps)
- ✓ meta-data **privacy**? sample T at random (req. larger space)
- more **coarse-grained** forward security? reuse T across tickets (req. MRAE)

Concluding Thoughts

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- **Puncturable Key Wrapping** as a conceptual abstraction for fine-grained forward security in symmetric key hierarchies
- **Constructions**:
  - generic PPRF+AEAD (w/ or w/o MR), others?
    - unified PPRF notions along the way
  - tag-based syntax allows for
    - ctr — possibly efficient puncturing
    - $ — enhanced privacy
    - middle ground(s)?
- **Applications:**
  - forward-secure resumption, rephrasing [AGJ]
  - cloud storage w/ fine-grained forward security
  - ...

Thank You!

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