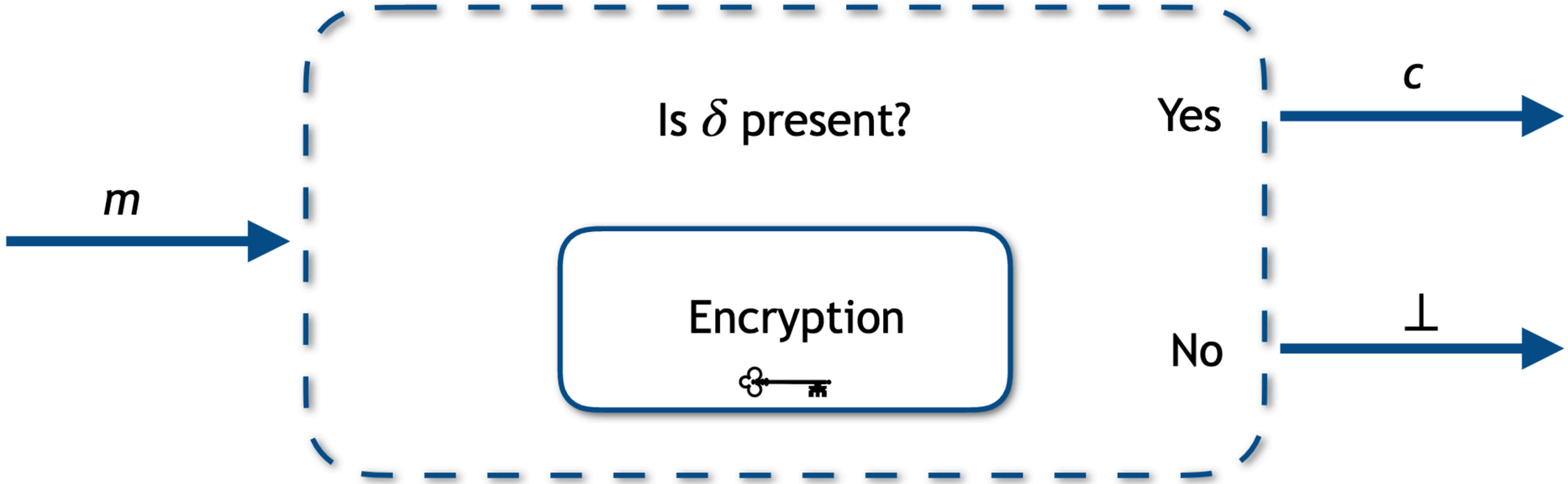
White-box cryptography with global device-binding from message-recoverable signatures and token-based obfuscation

Estuardo Alpirez Bock
Xiphera LTD

Joint work with Shashank Agrawal, Yilei Chen and Gaven Watson while at Visa Research

White-box crypto with device-binding



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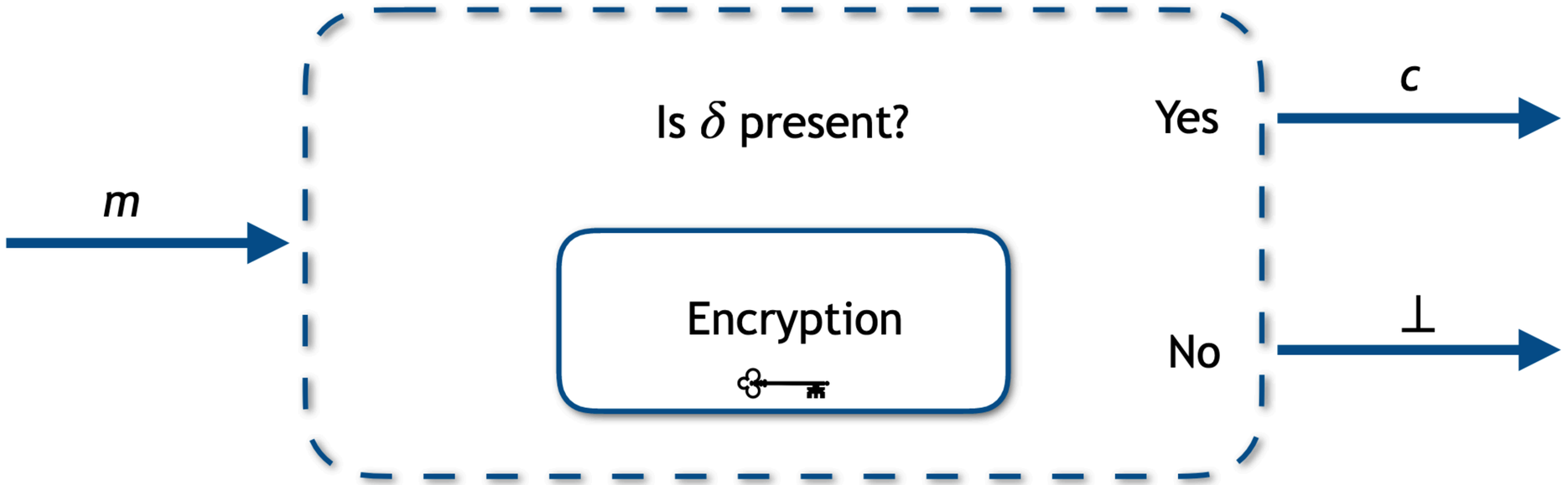

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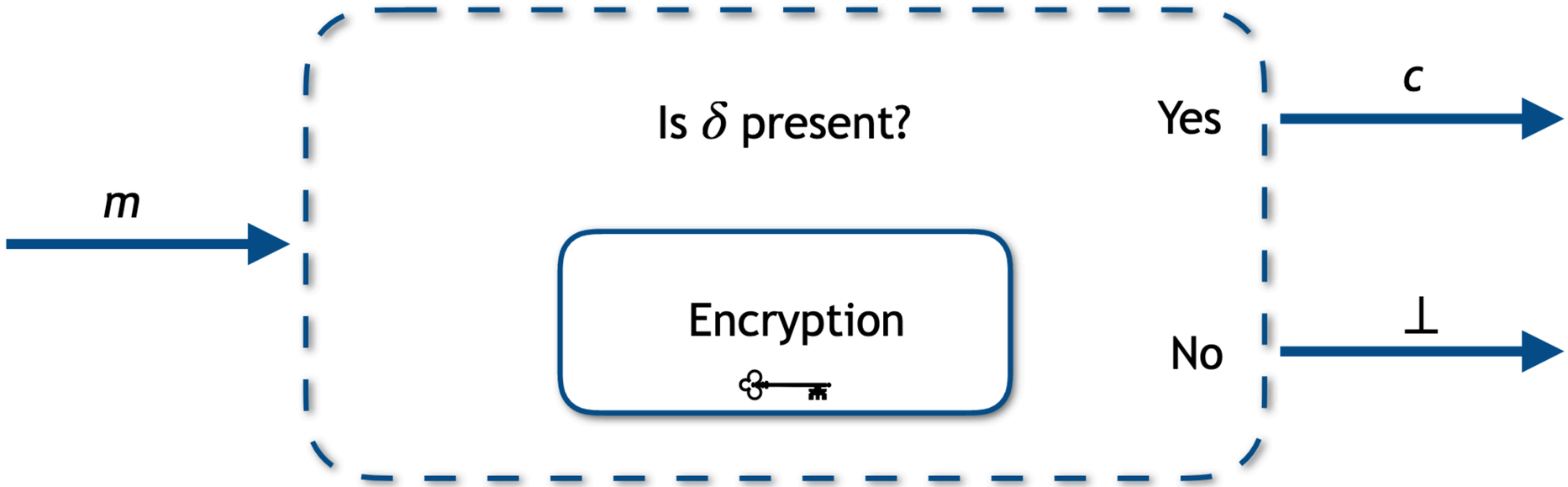

- The white-box program should only run correctly on one specific device (identified by δ)
- Method for mitigating *code-lifting* attacks

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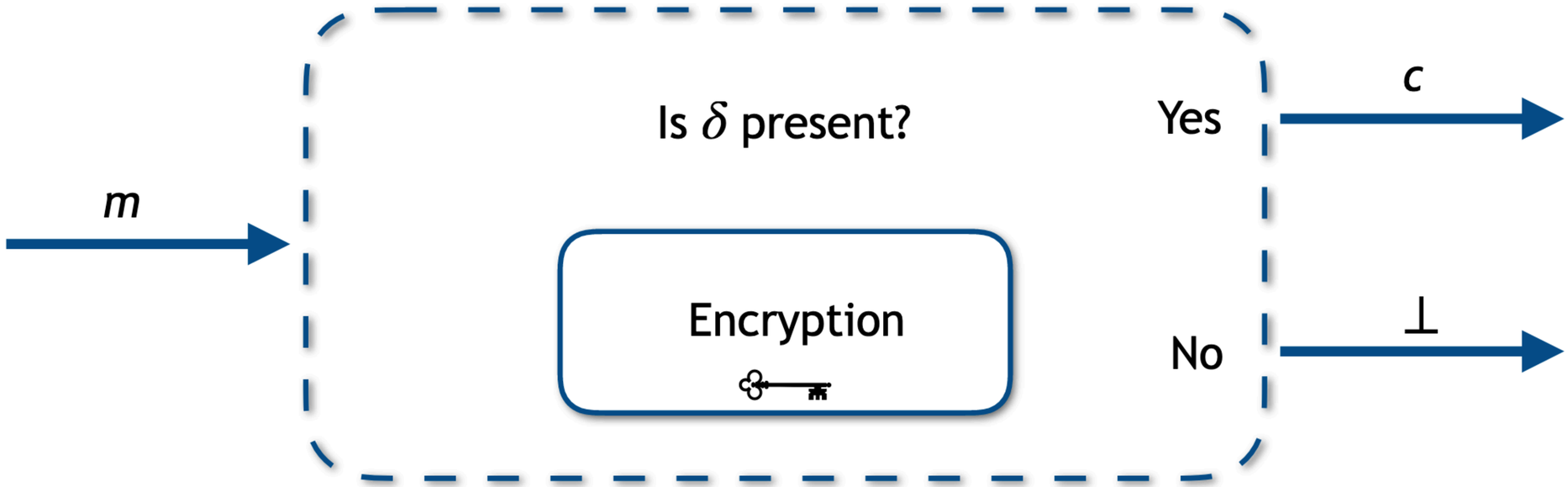

- Definitional studies and feasibility results for white-box crypto
  - Construct white-box programs from established cryptographic primitives —> prove their security in the presence of a white-box adversary

Constructions achieving the property of device-binding

Our results

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- Present feasibility results via token-based obfuscation and message-recoverable signatures
    - Introduce puncturable message-recoverable signatures
    - Show new ways of constructing white-box crypto via token-based obfuscation (which can be constructed from LWE)

Previous work on Device-binding

- The device binding process is *personalised*

[1] Alpirez Bock, Amadori, Brzuska and Michiels: On the security goals of white-box cryptography. CHES 2020

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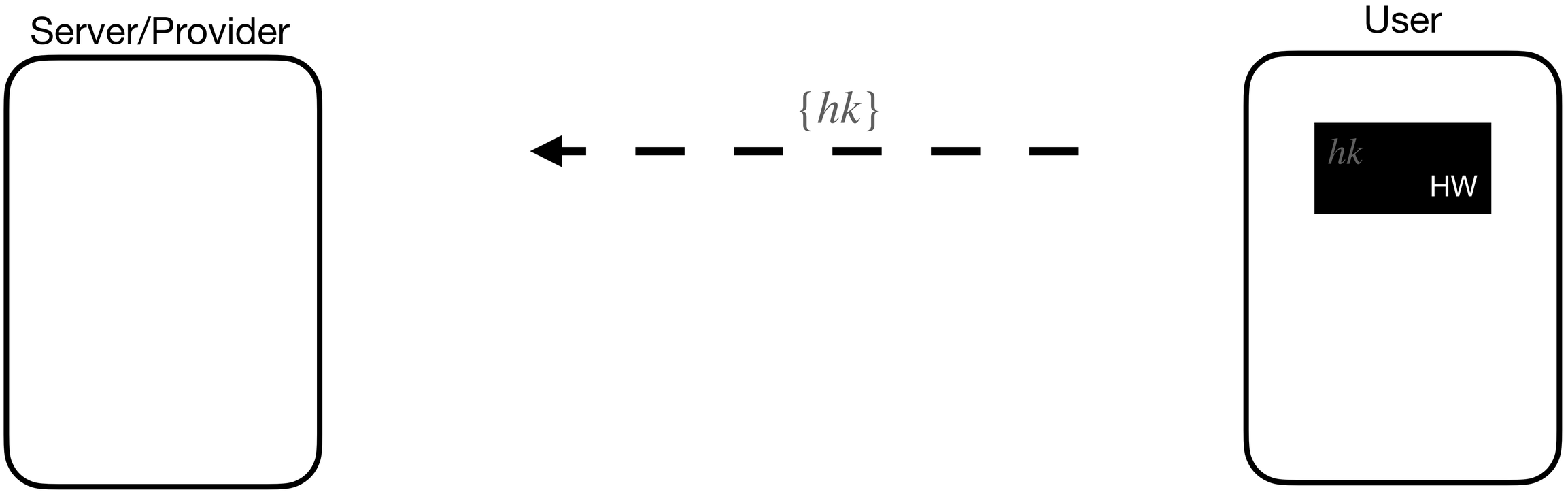

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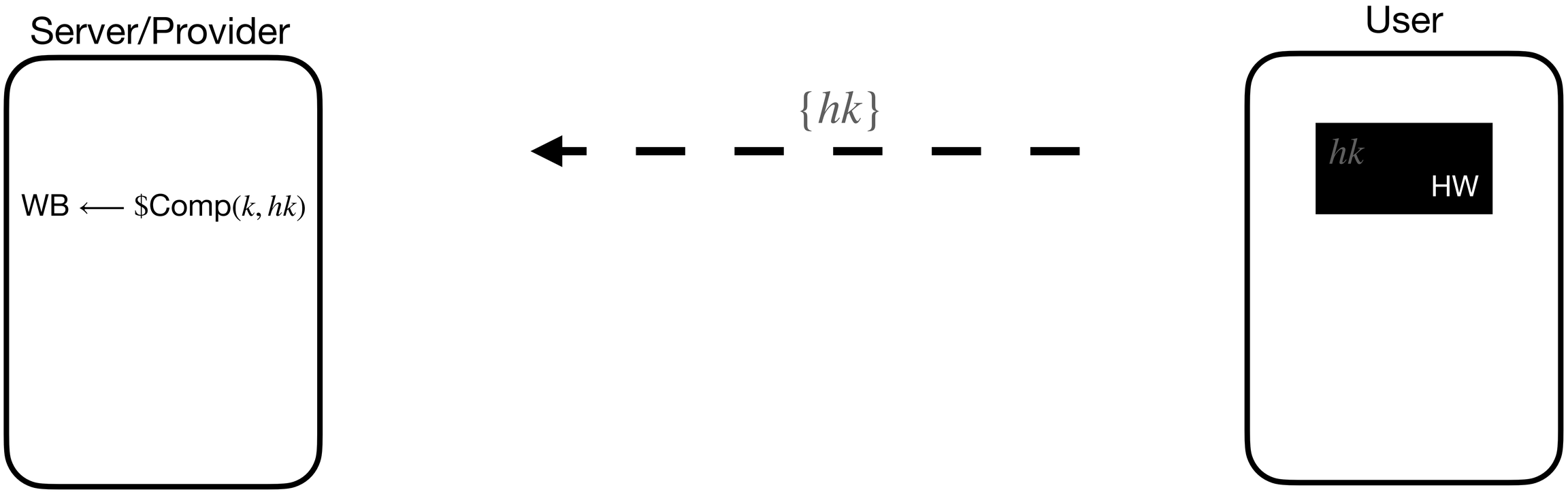

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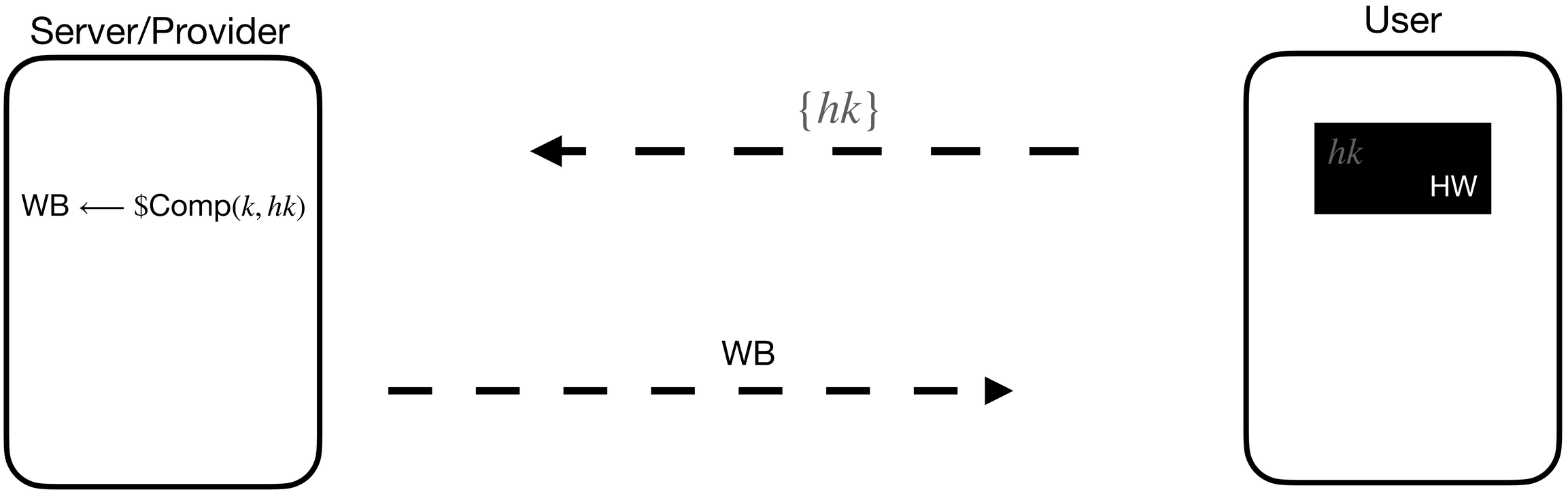

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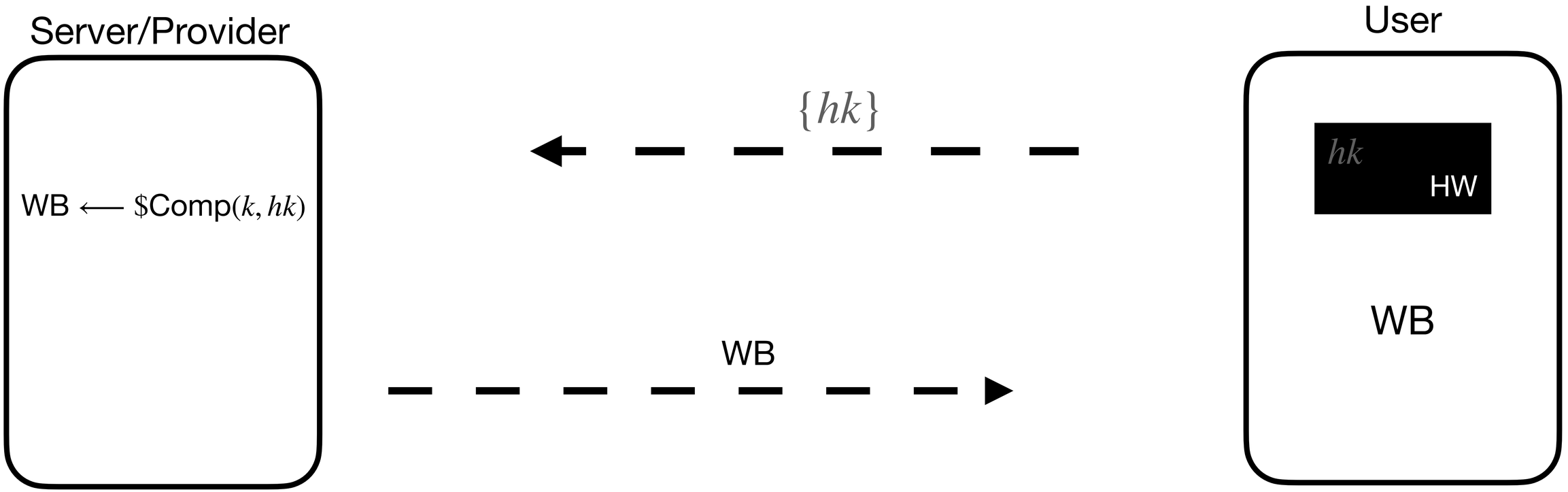

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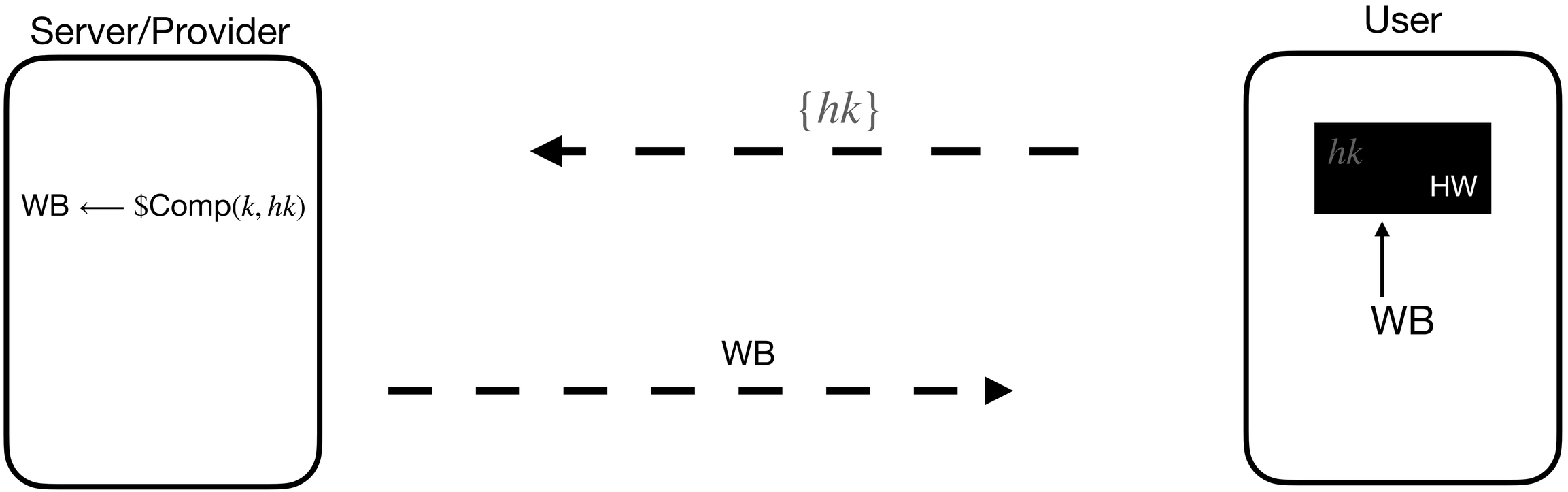

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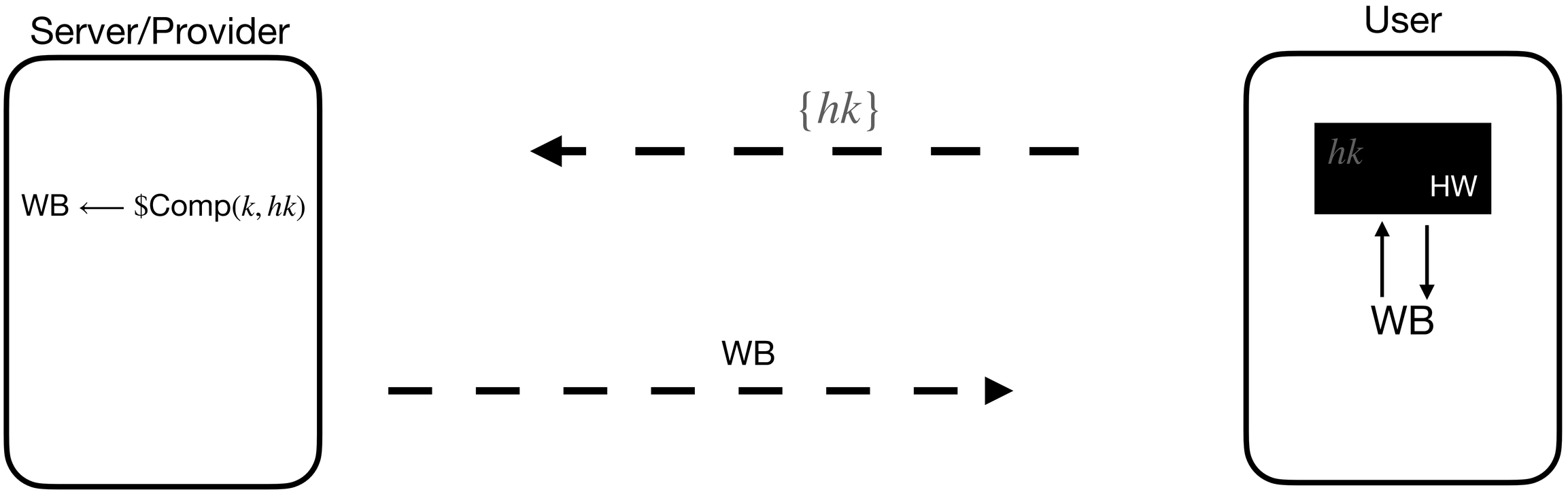

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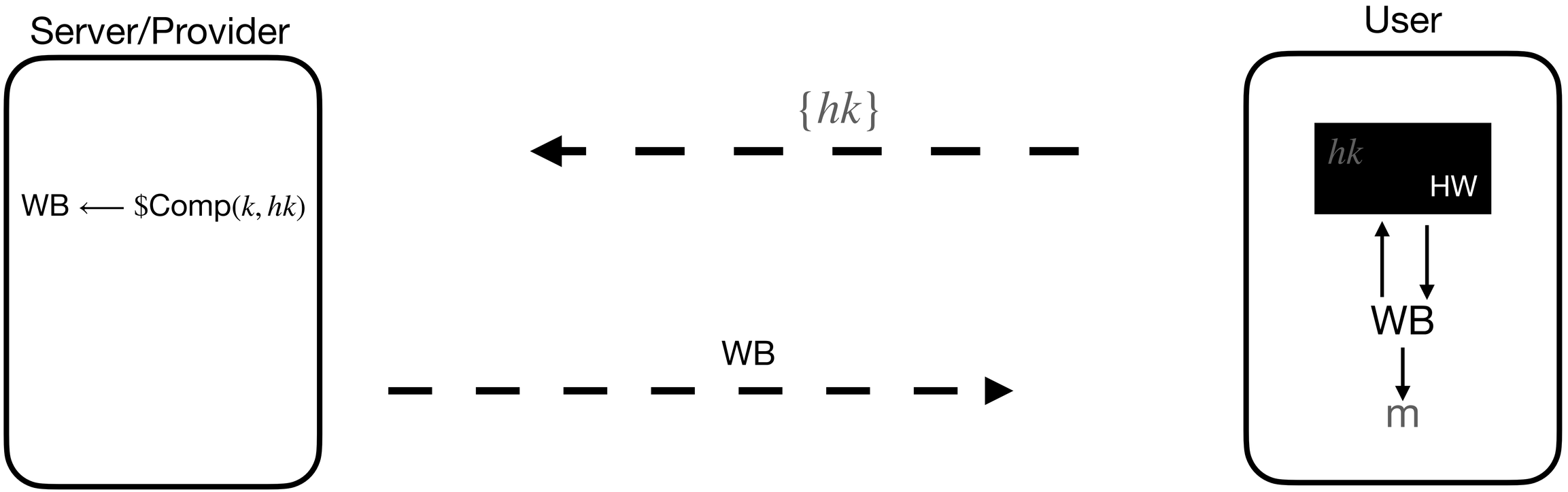

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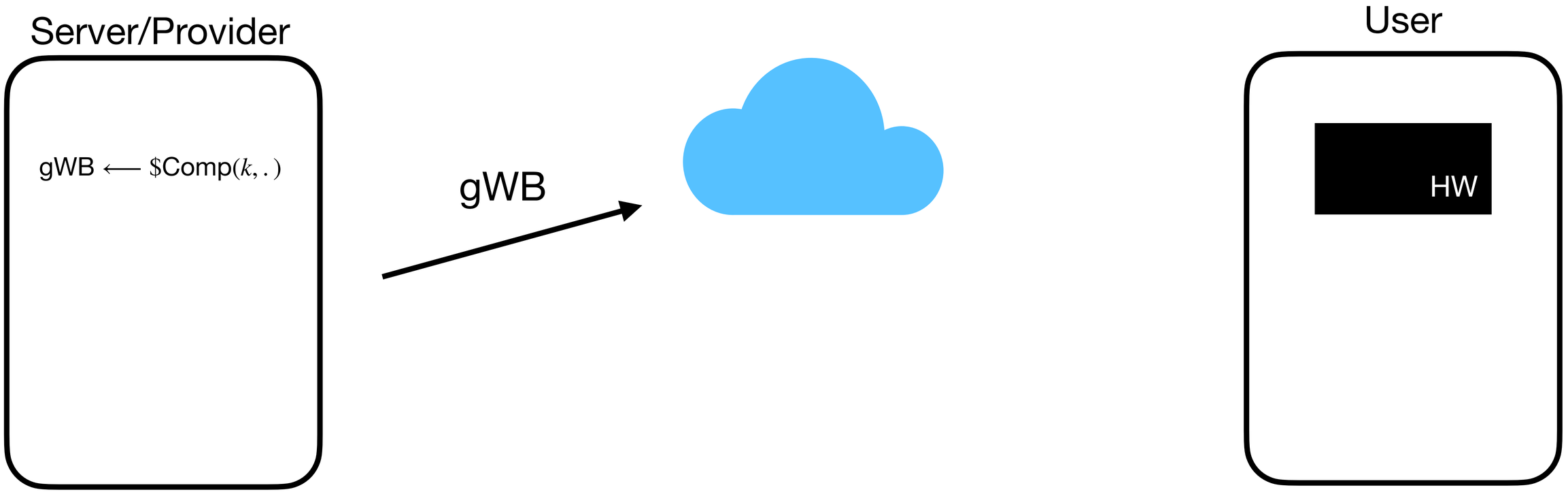

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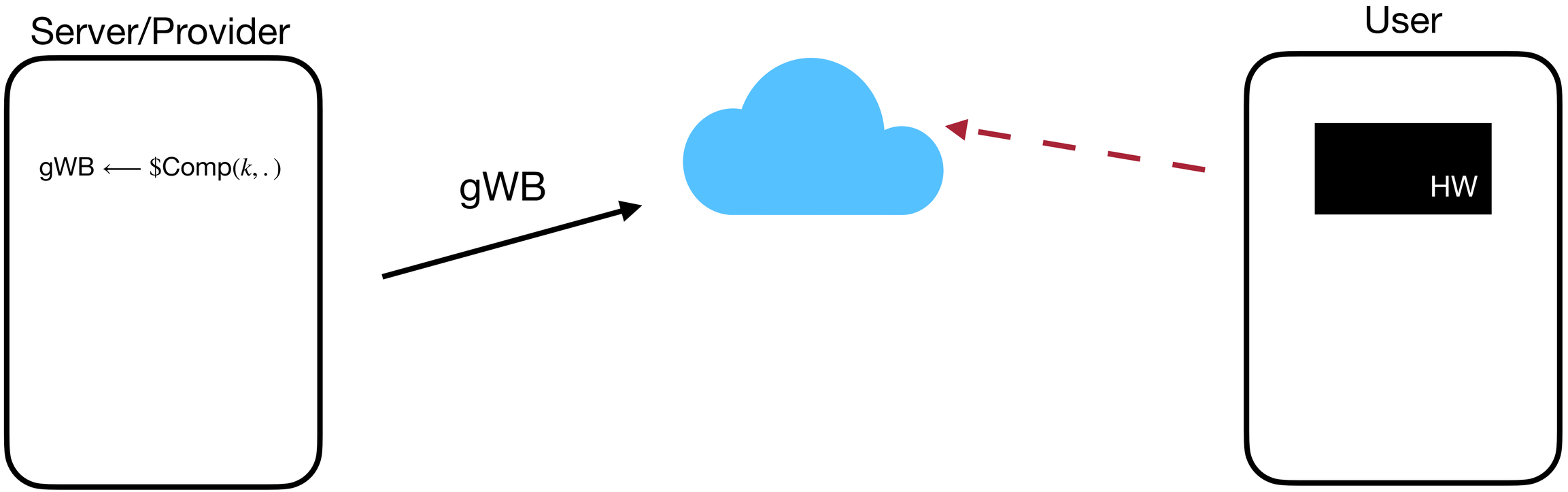

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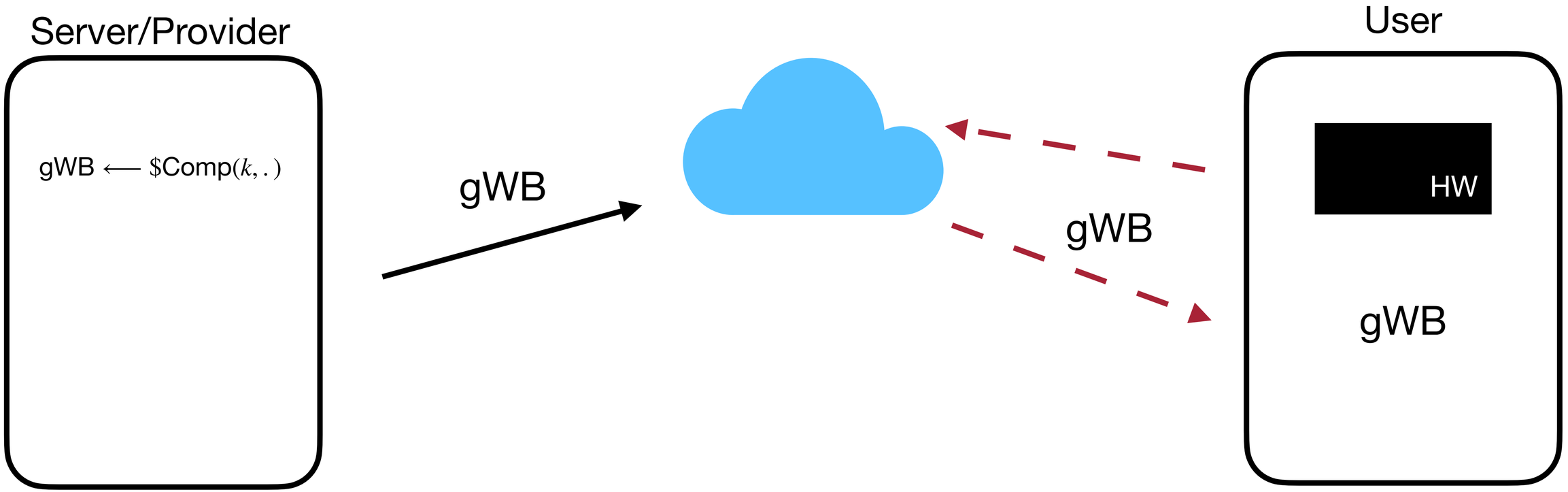

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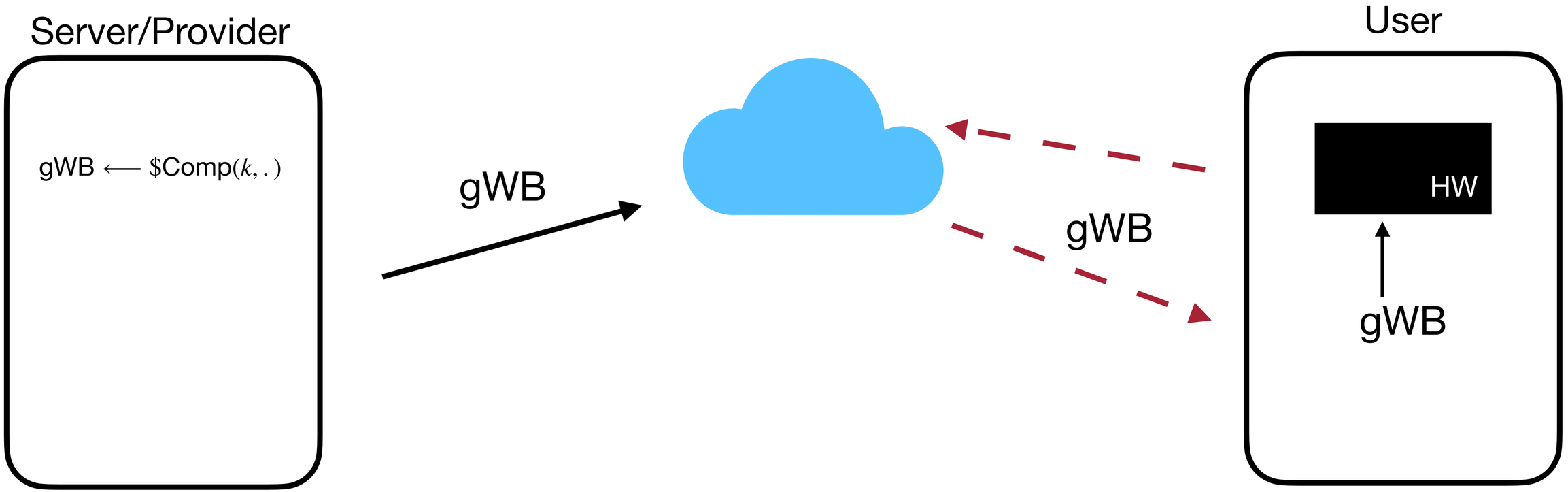

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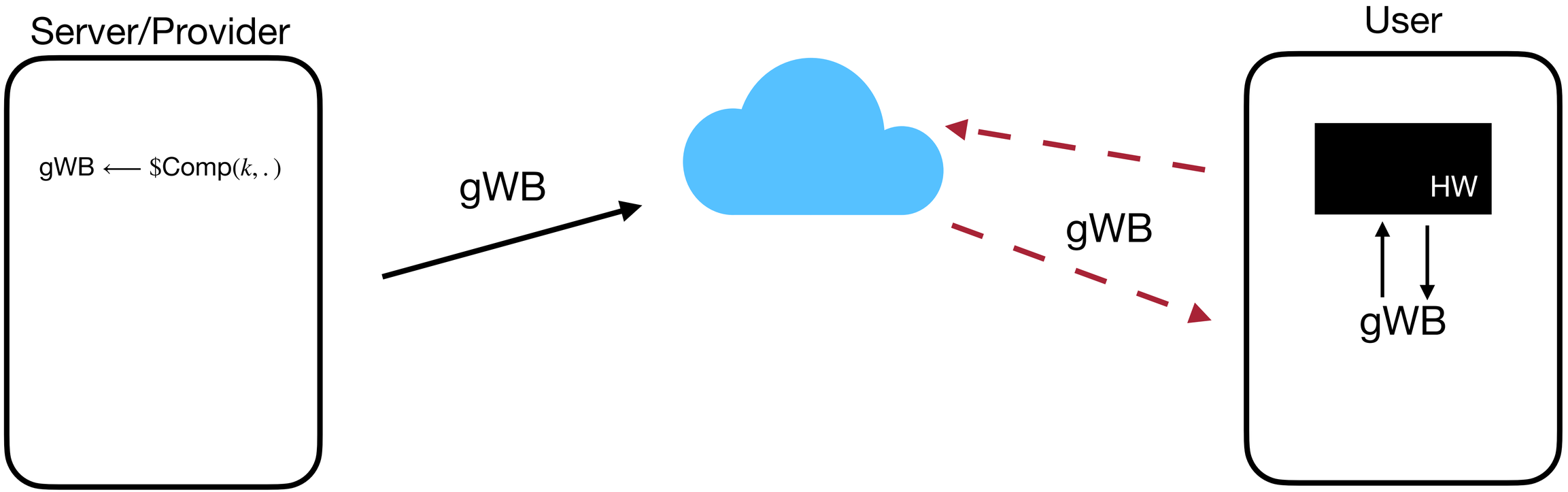

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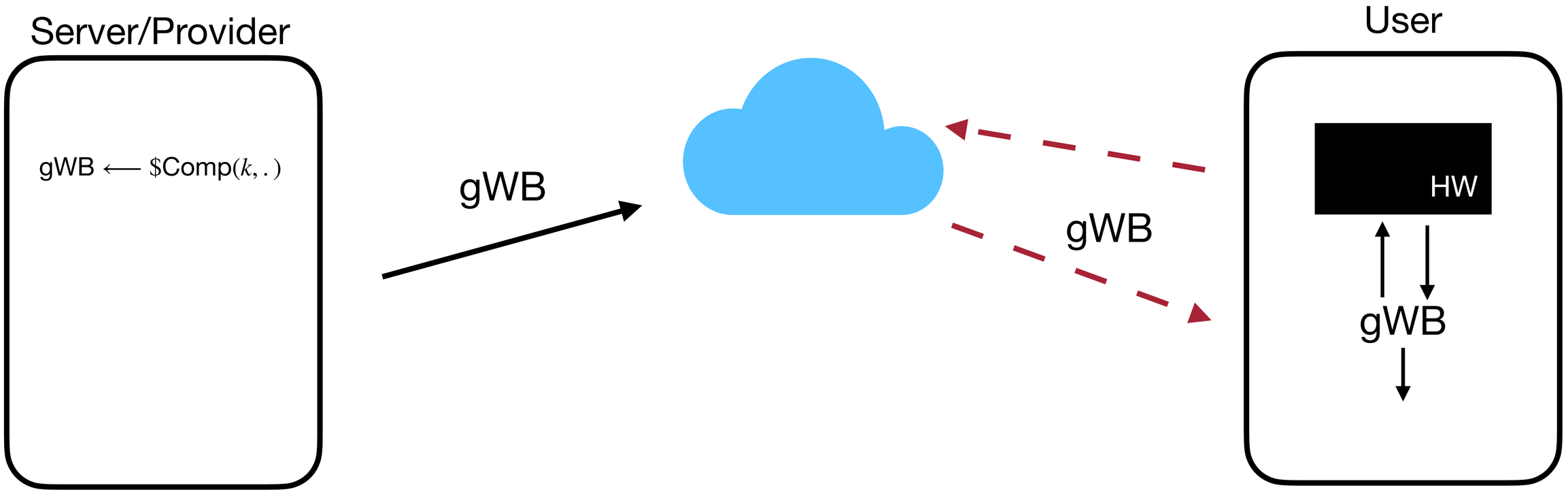

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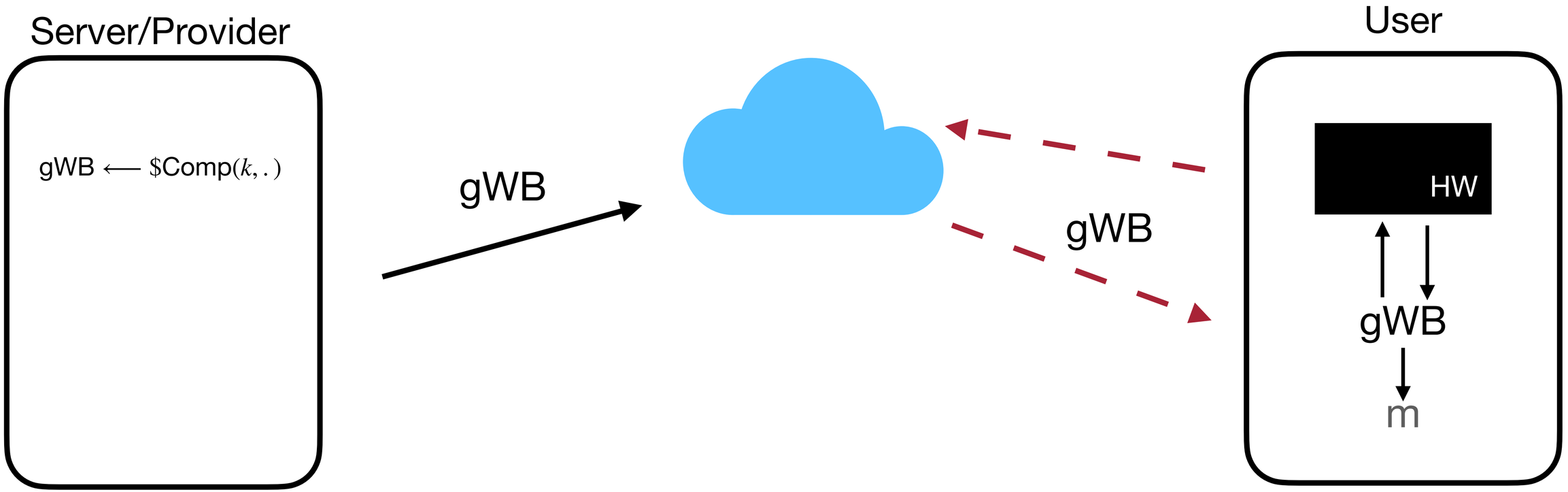

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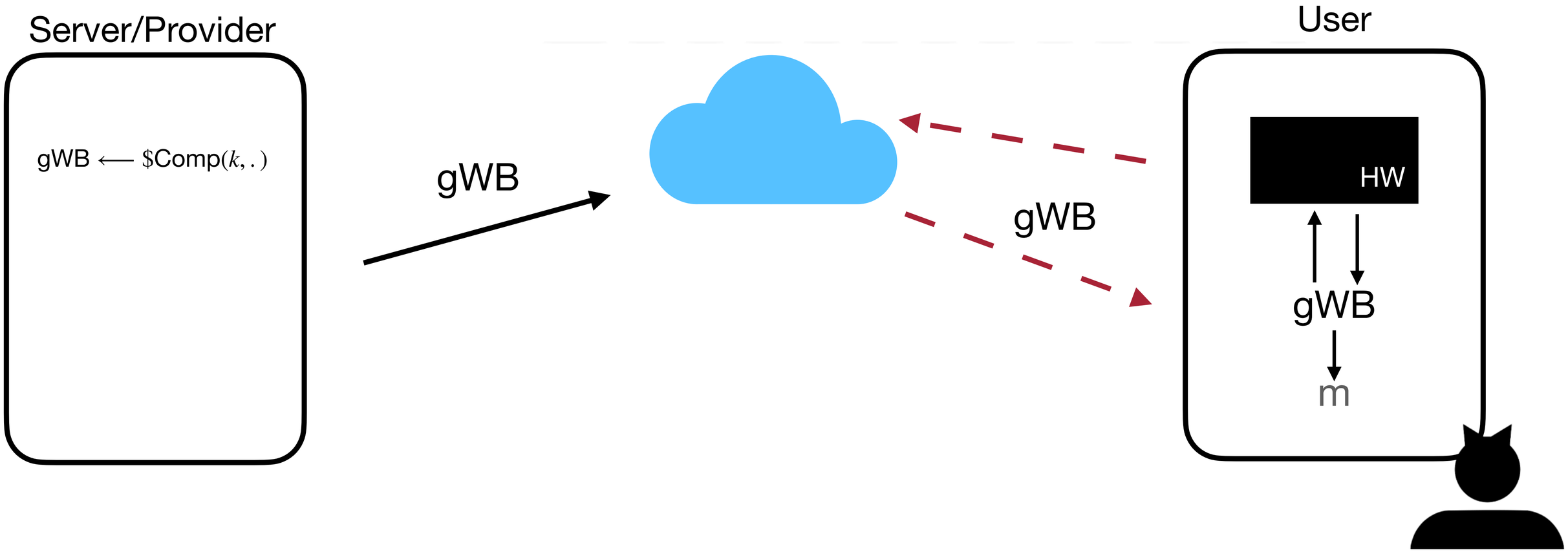

Idea: white-box on encoded inputs

Design the white-box s.t. it always computers on encoded inputs

$\mathsf{HW}(c)$

$\tilde{c} \leftarrow \mathsf{Encode}(e_s, c)$

return $\tilde{c}$

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The encoding function will be available on *certified* devices

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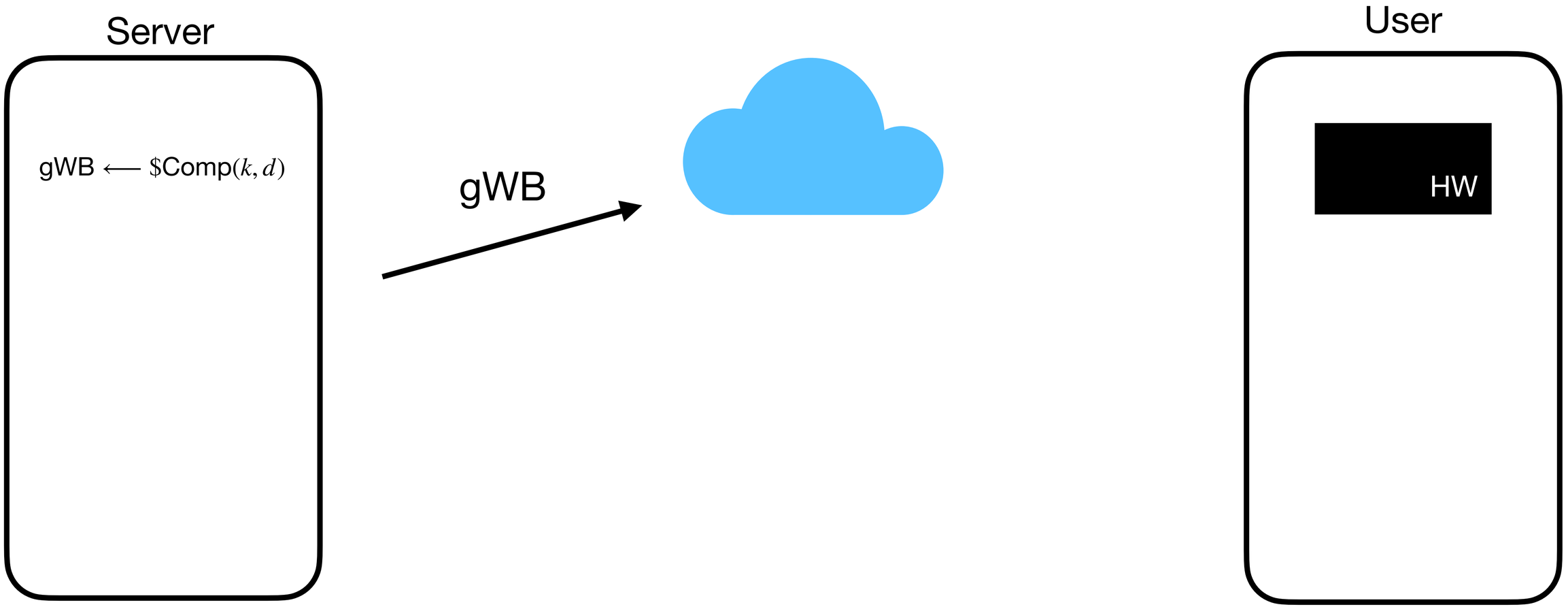

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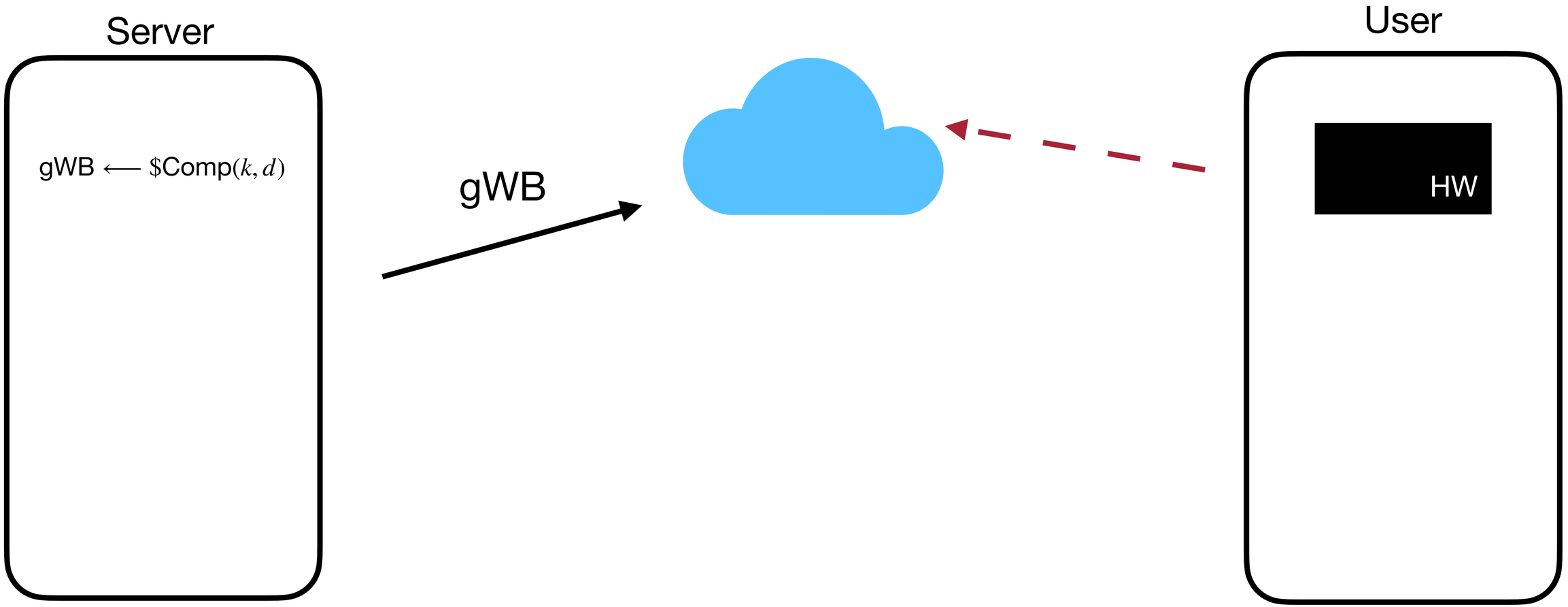

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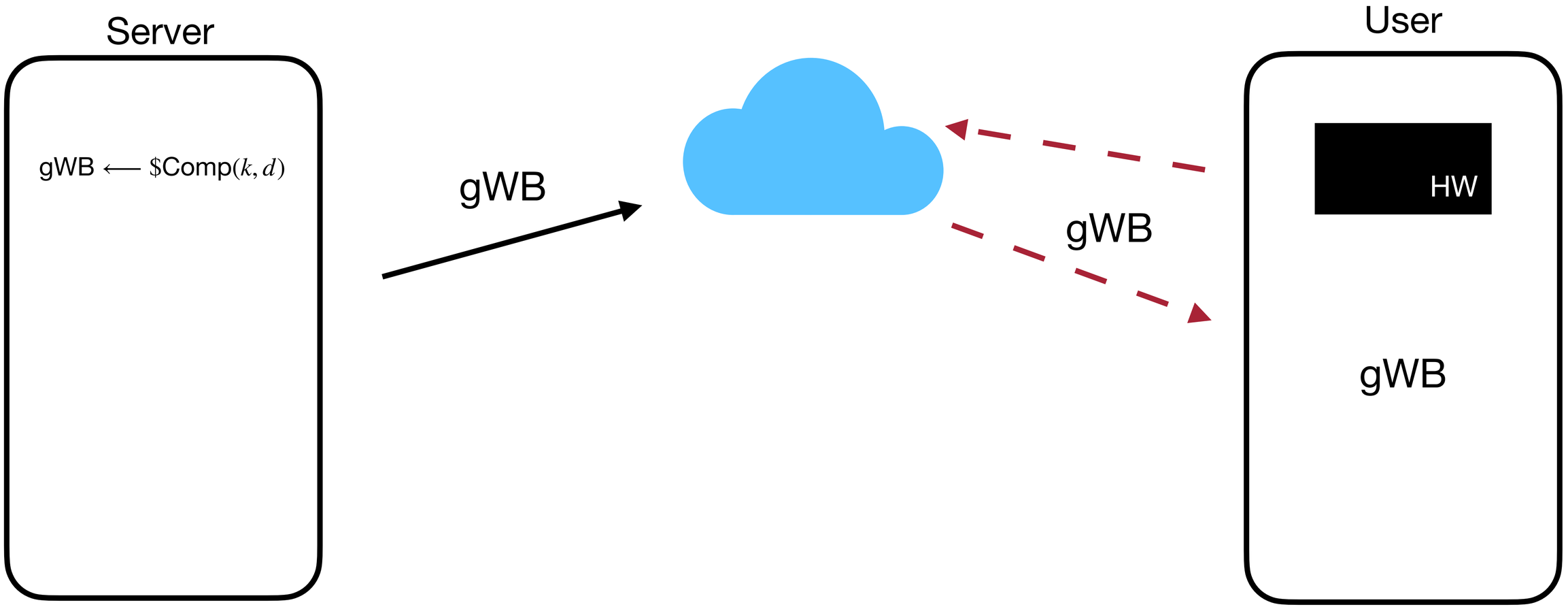

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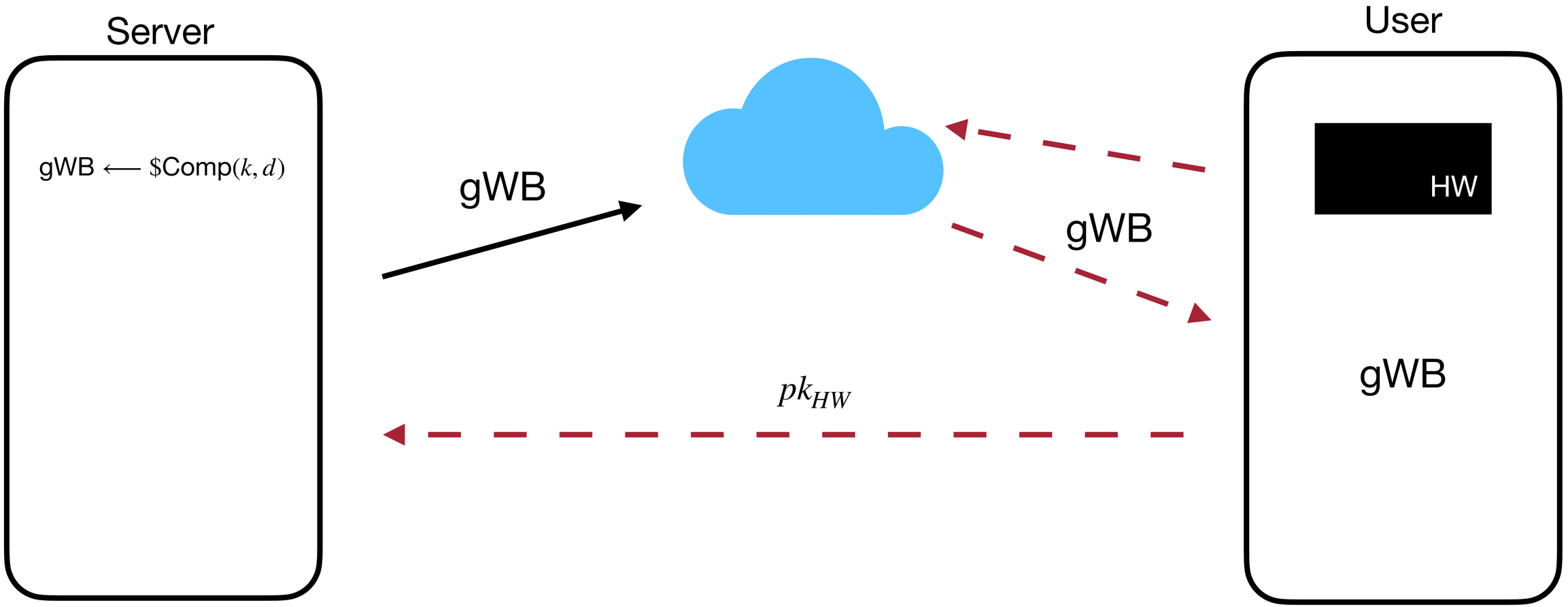

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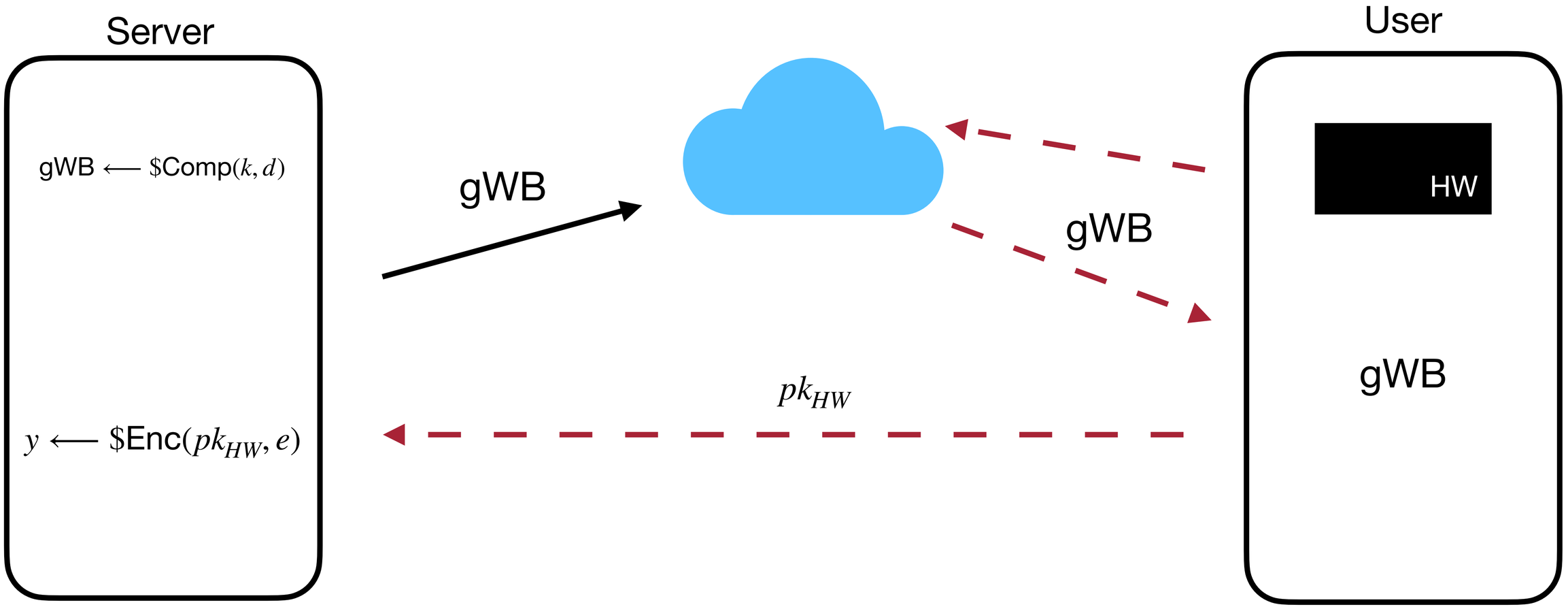

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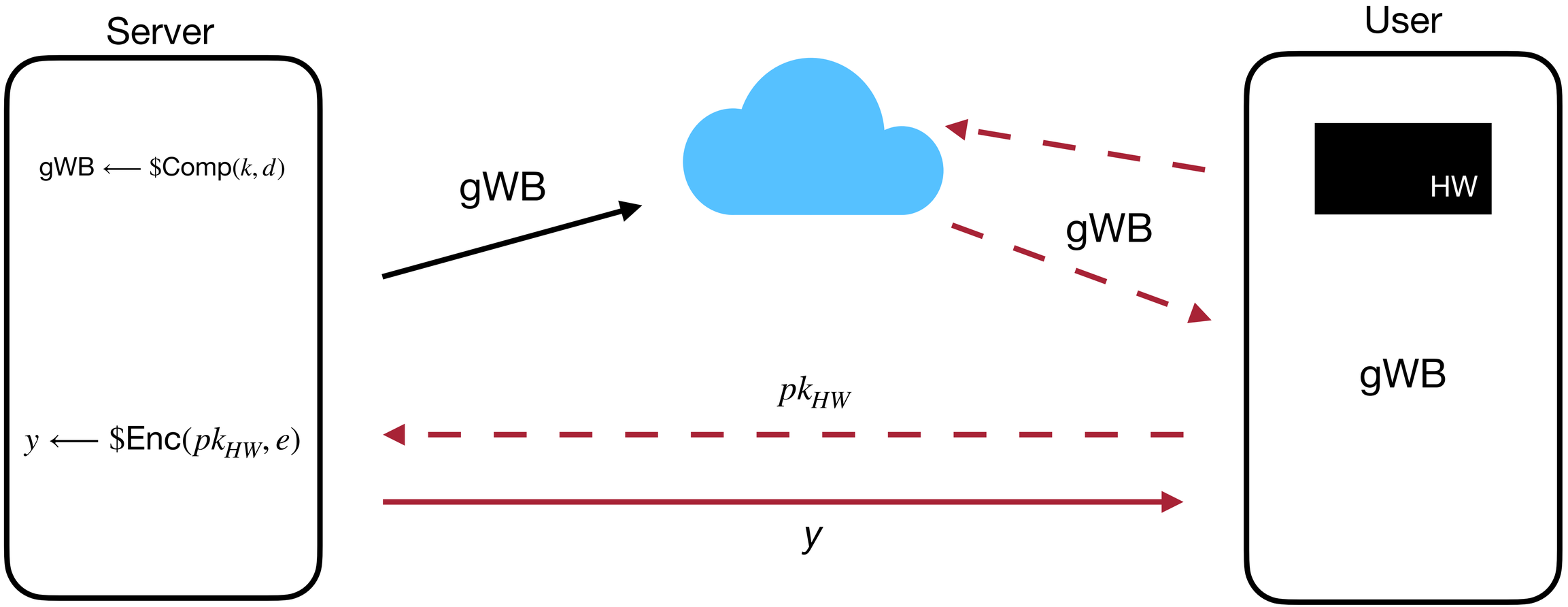

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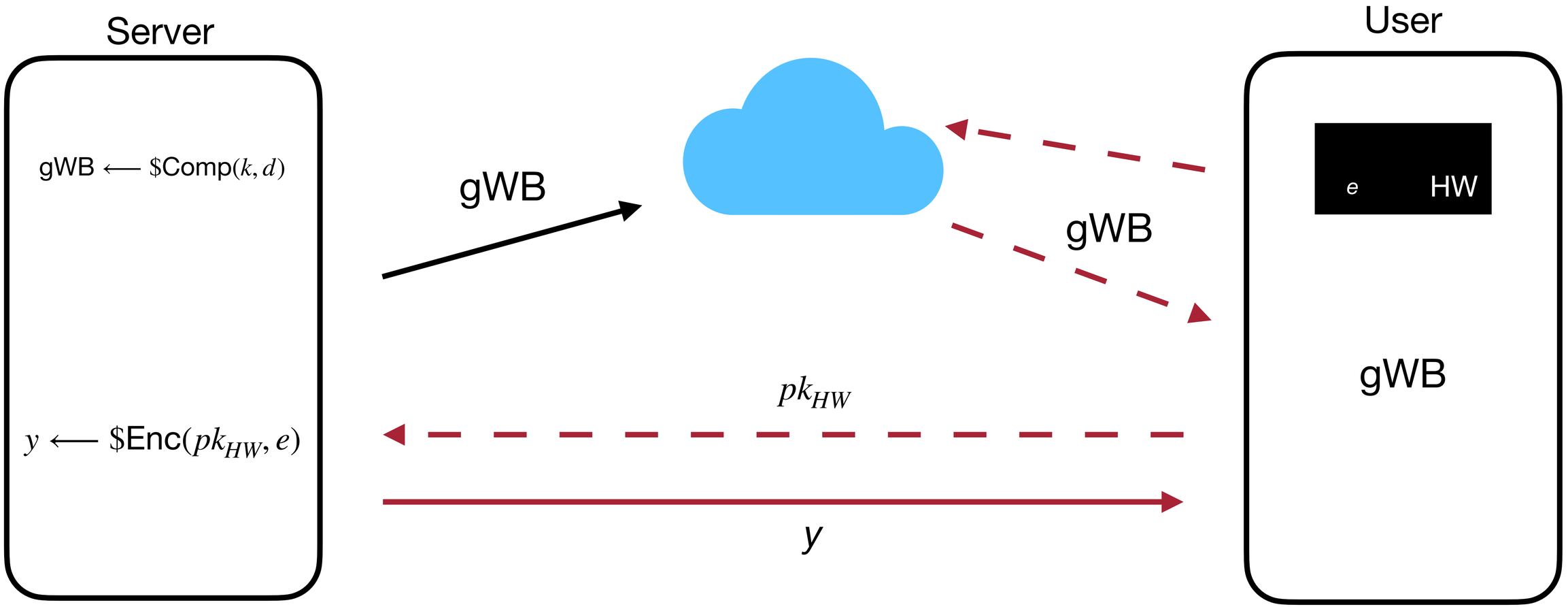

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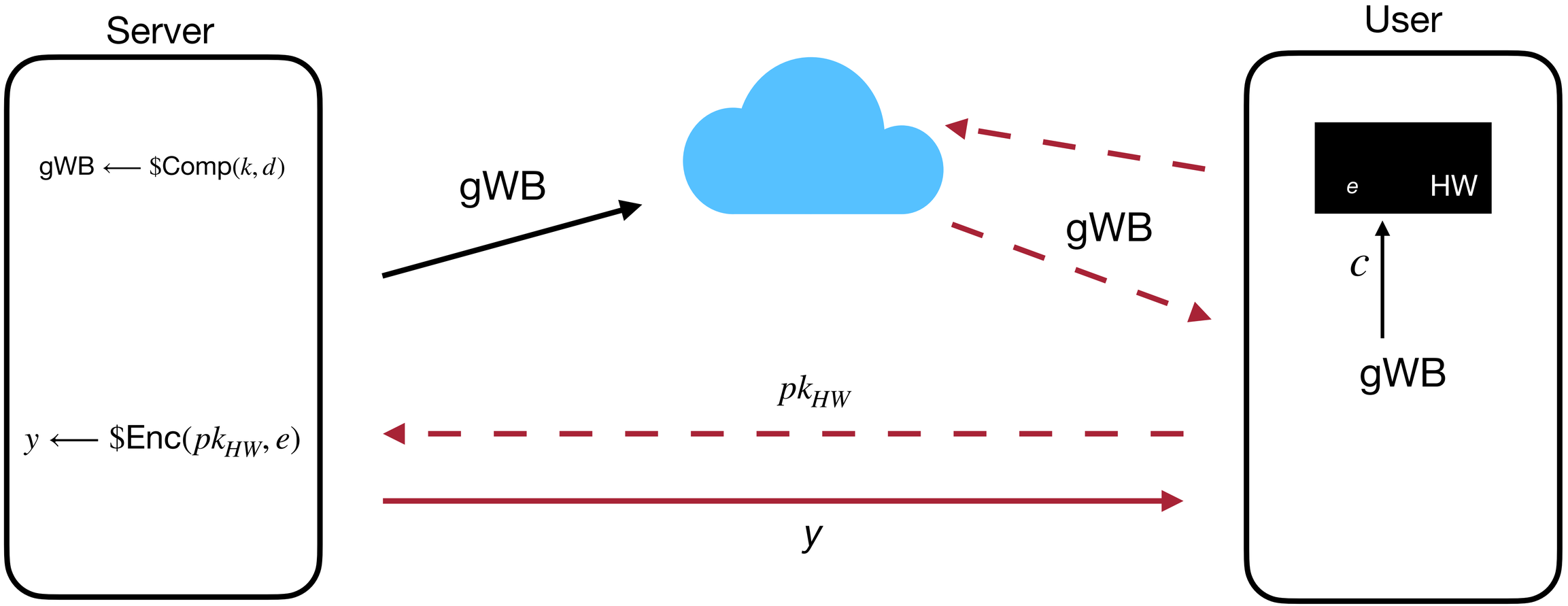

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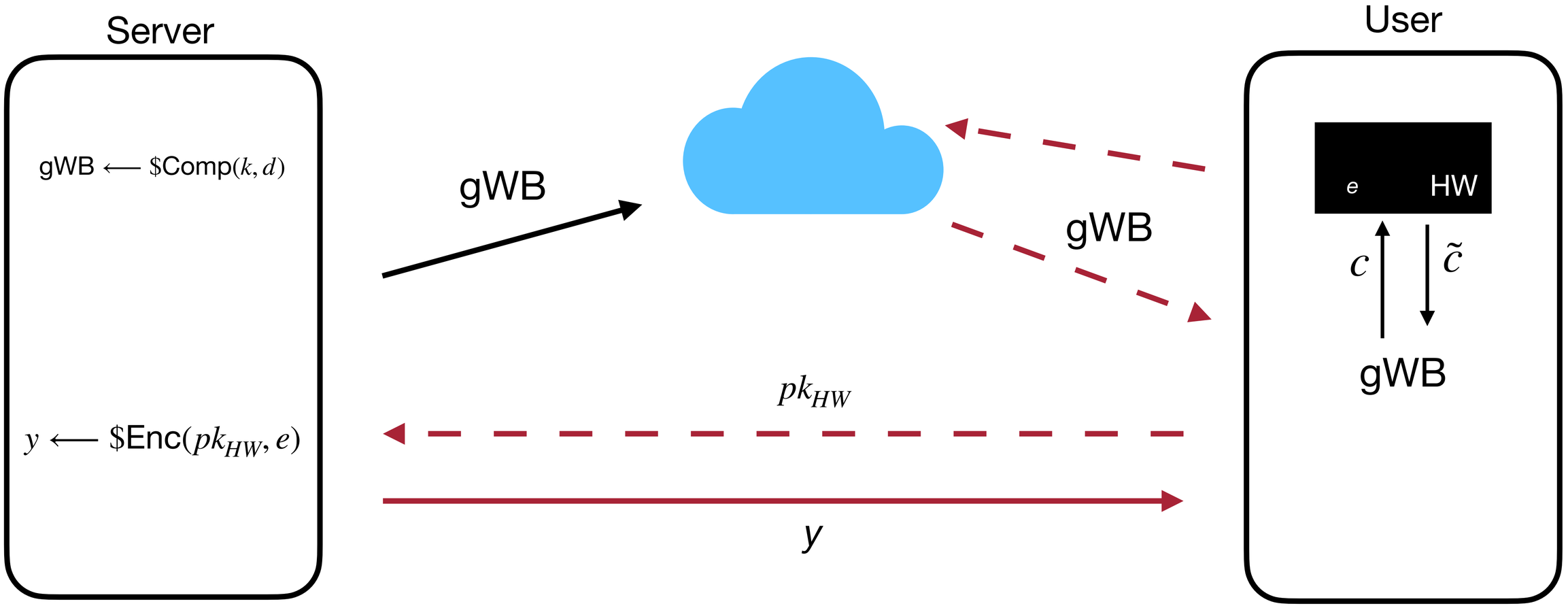

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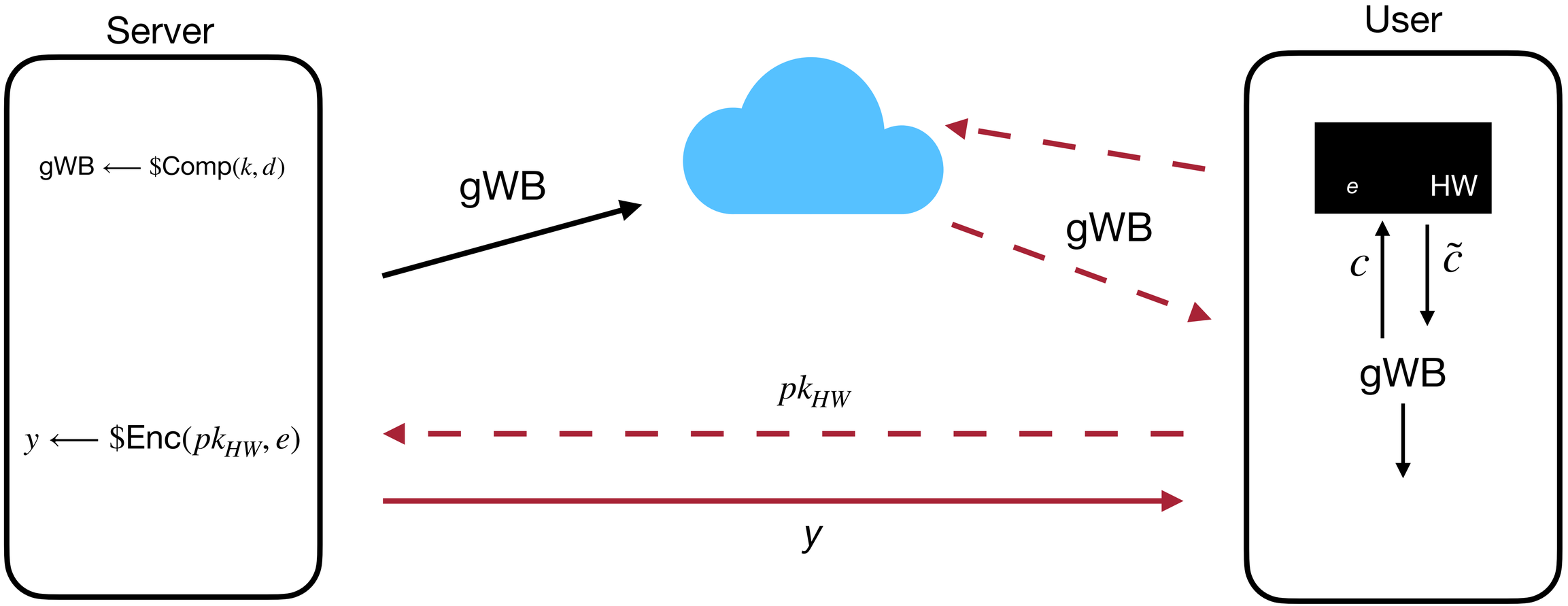

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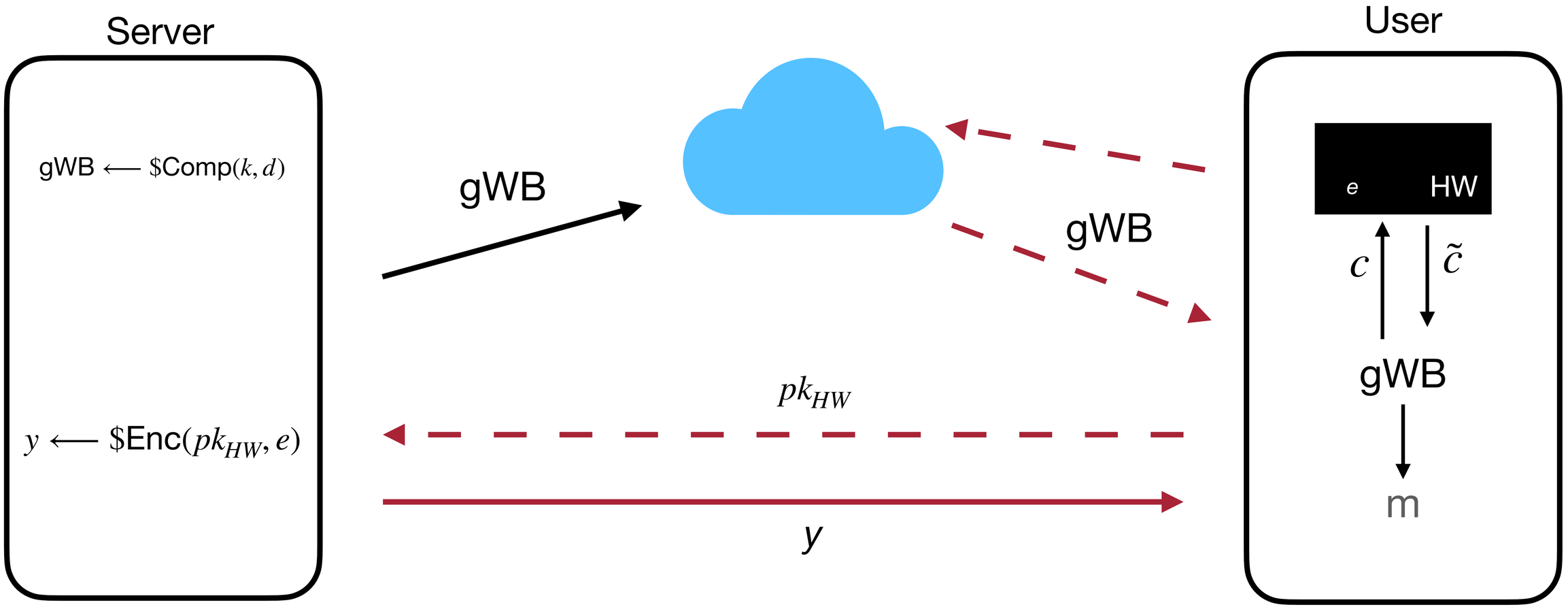

Global white-boxes via TBO

We can directly build such gWB via Token-based obfuscation [3]

$$\text{TBO.Obf}(C)\$ \longrightarrow \text{MSK}, O[C]$$

$$\text{TBO.InpGen}(\text{MSK}, x)\$ \longrightarrow \tilde{x}$$

$$O[C]\ (\text{InpGen}(\text{MSK}, m)) \ = \ C(m)$$

$$O[C]\ (\tilde{m}) \ = \ C(m)$$

—> Just place the token-generation algorithm in the secure hardware

[3] Goldwasser et al.: Reusable garbled circuits and succinct functional encryption. STOC 2013

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Can we provide an alternative?

Strong global white-boxes via message-recoverable signatures [4]

[4] Bellare and Rogaway: The exact security of digital signatures - how to sign with RSA and Rabin. Eurocrypt 96

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Use secret key for encoding and pk for decoding

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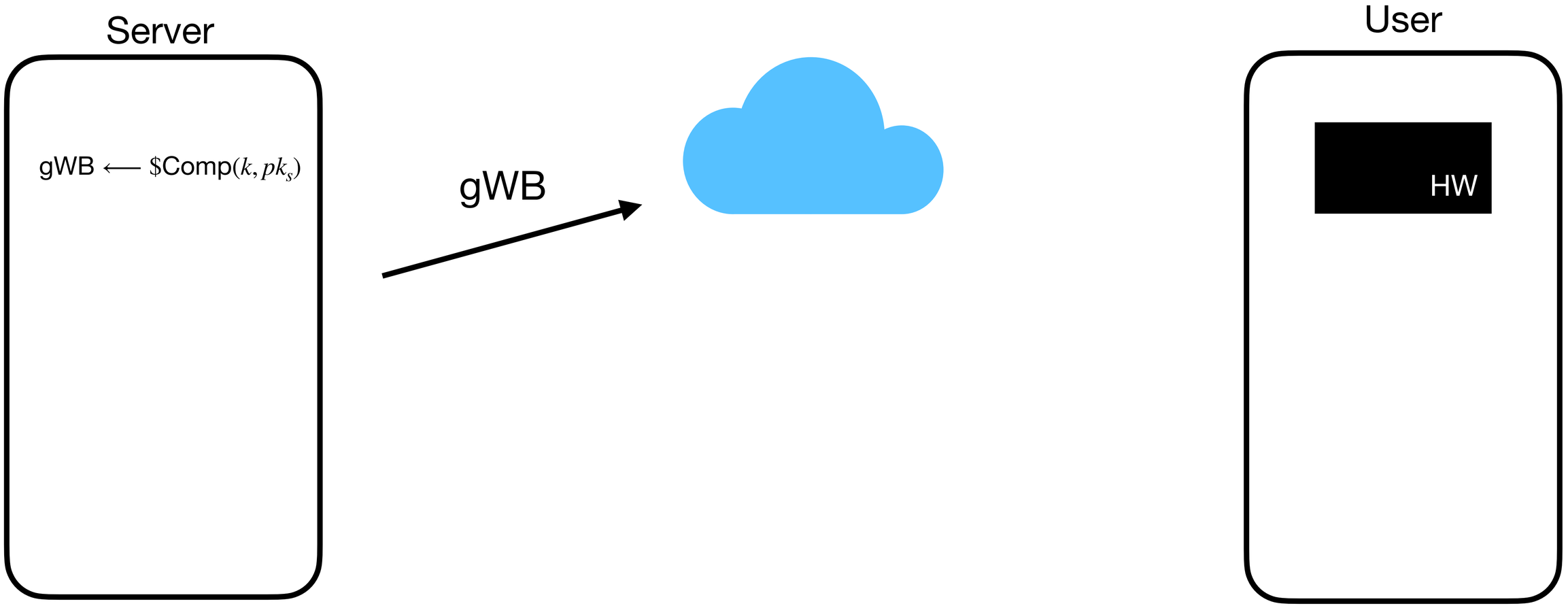

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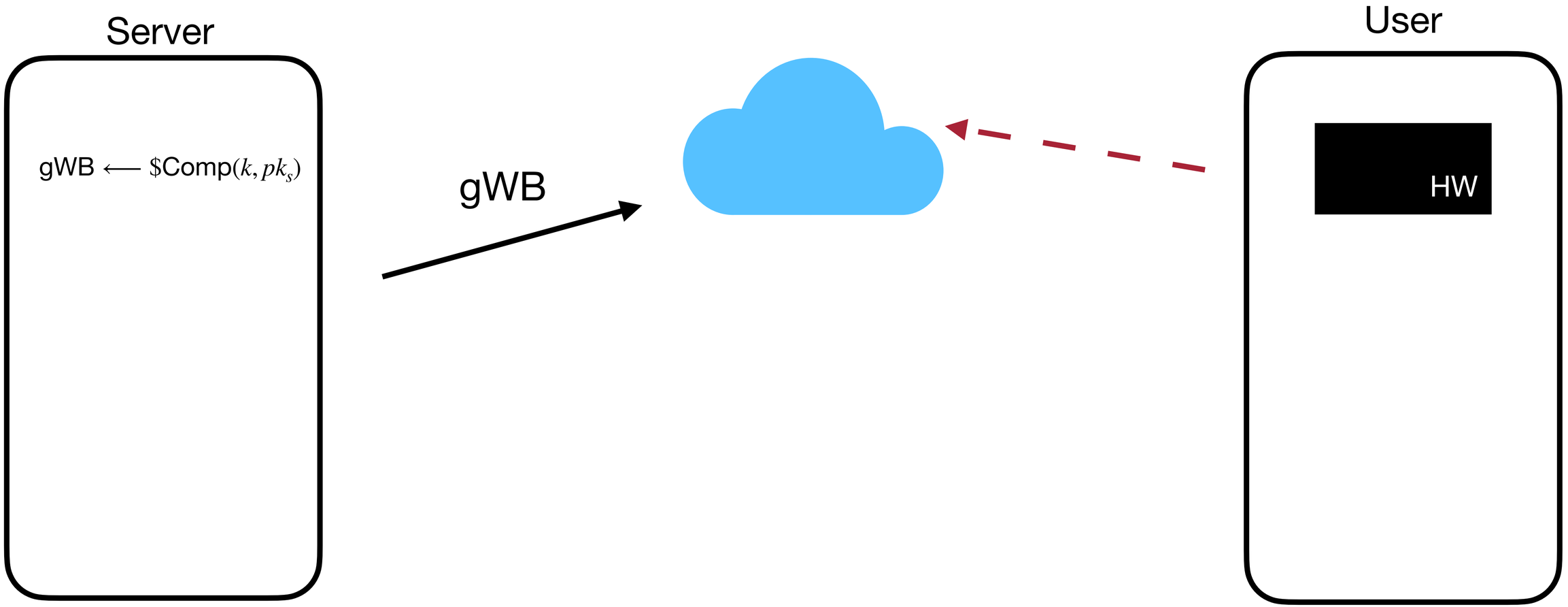

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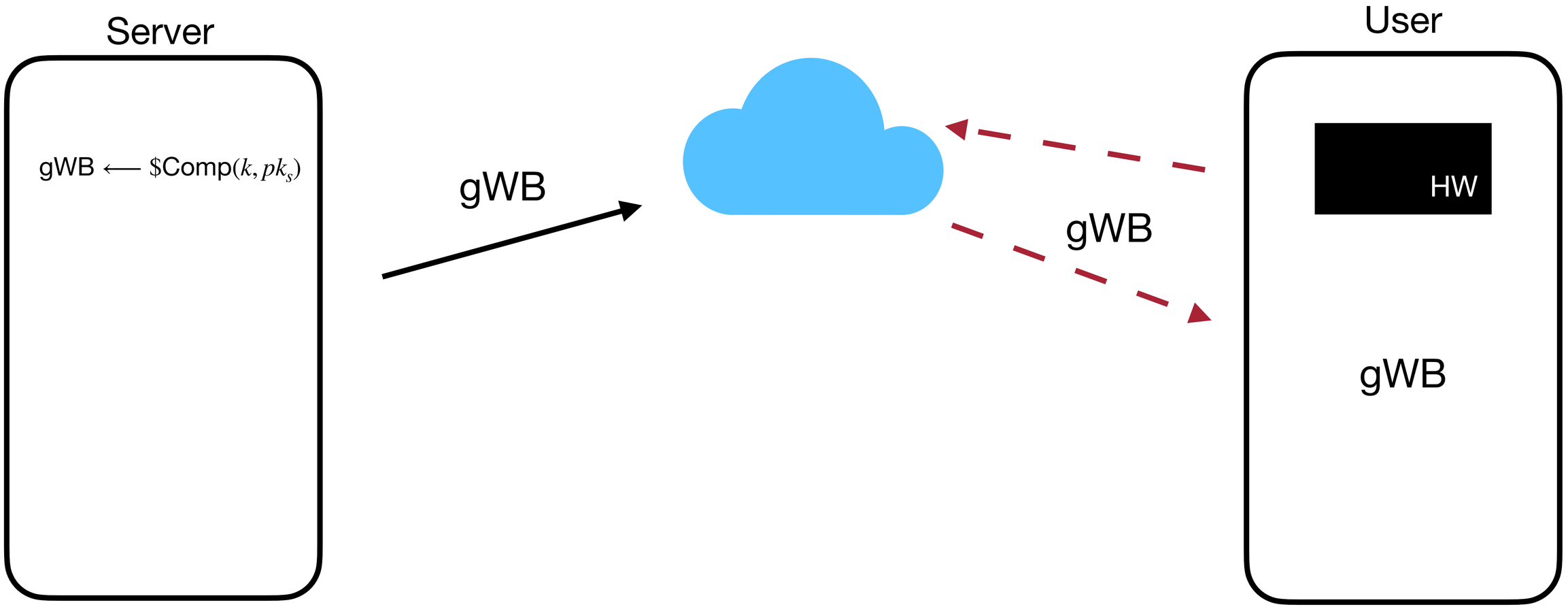

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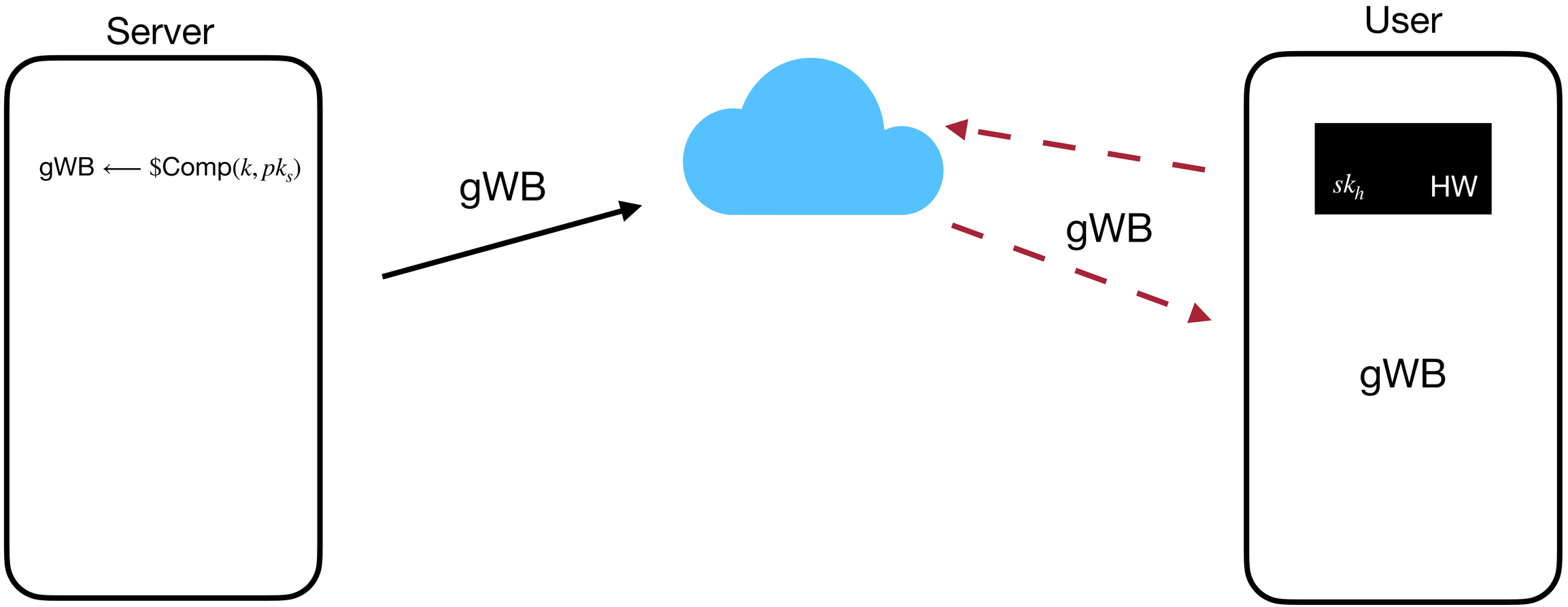

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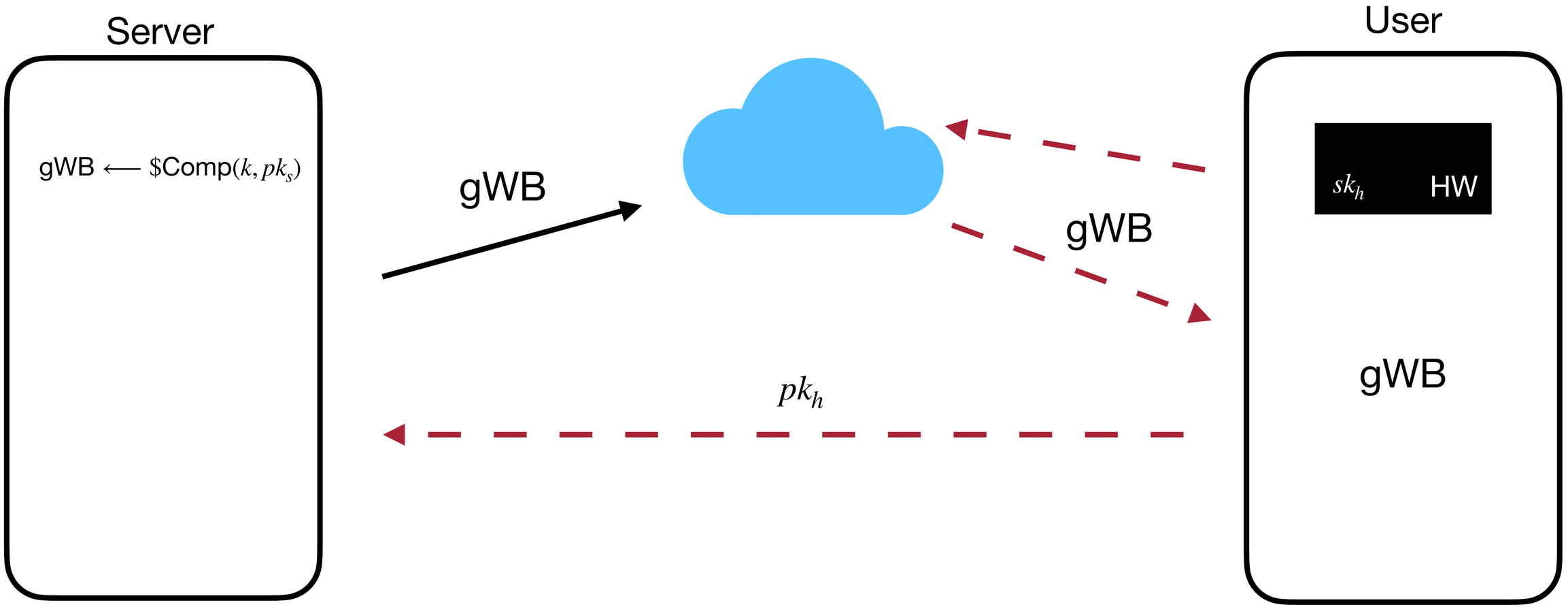

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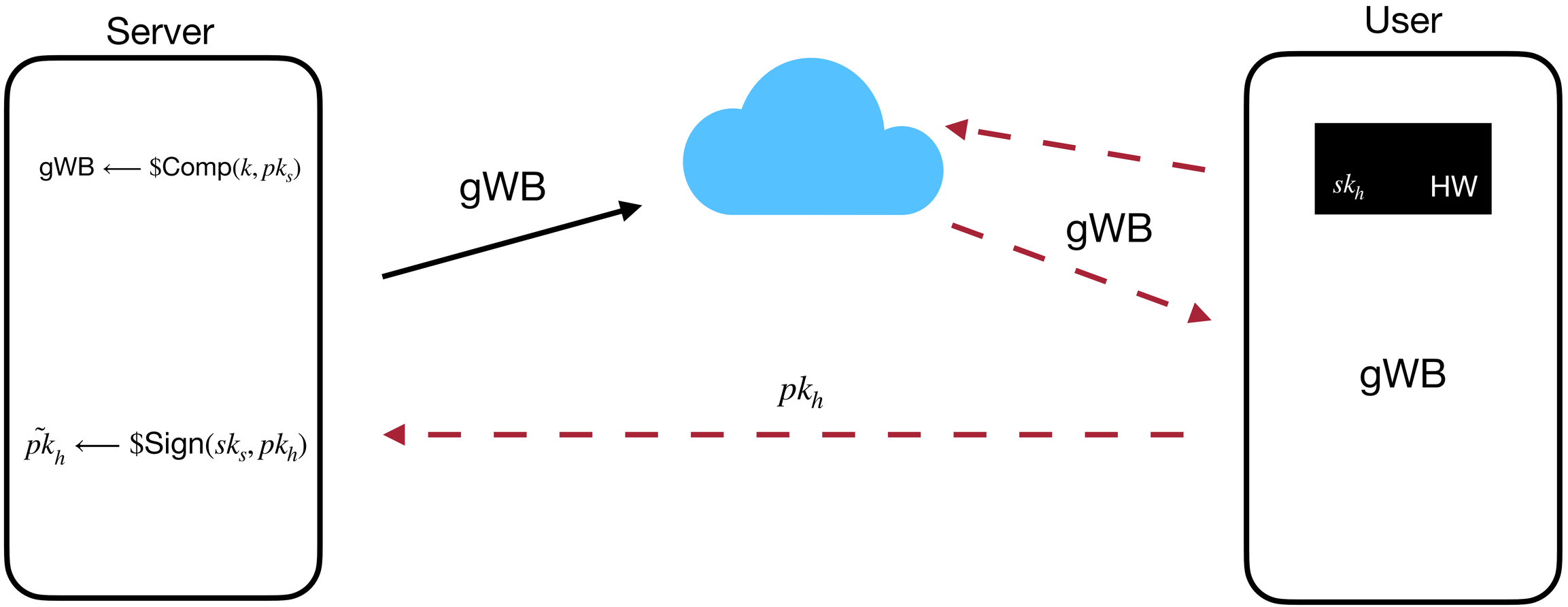

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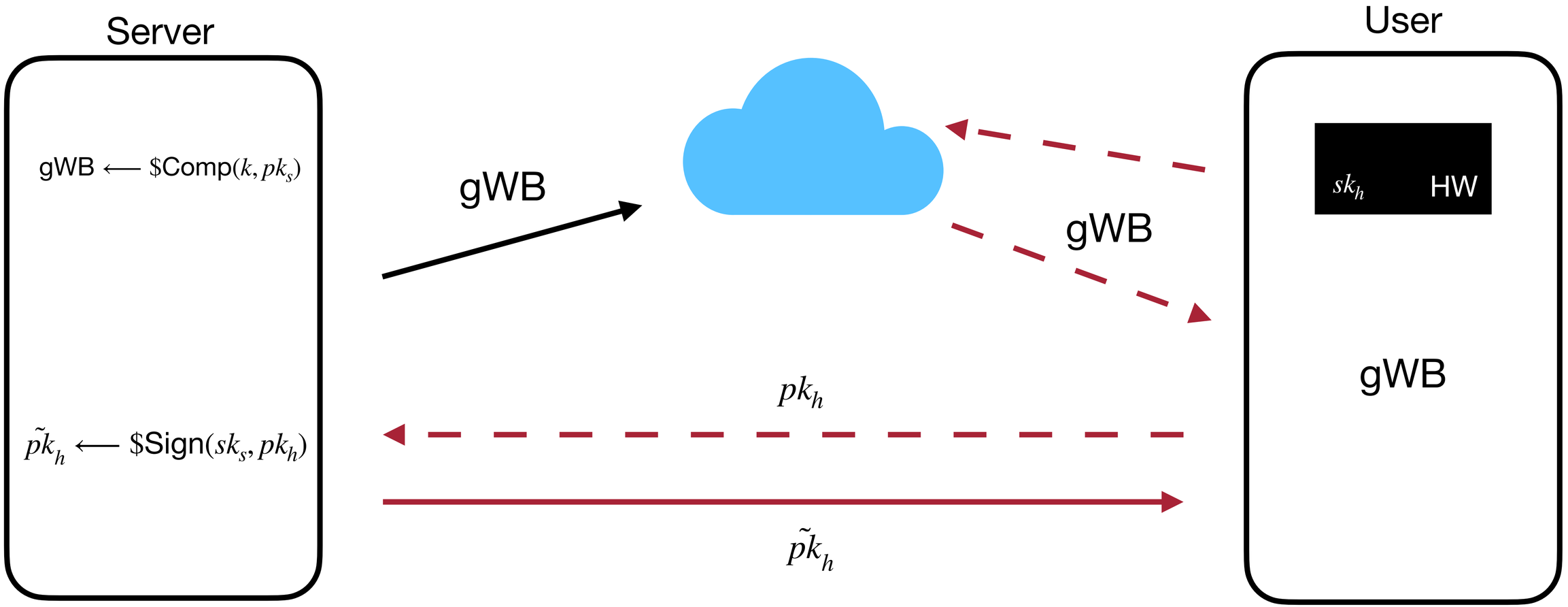

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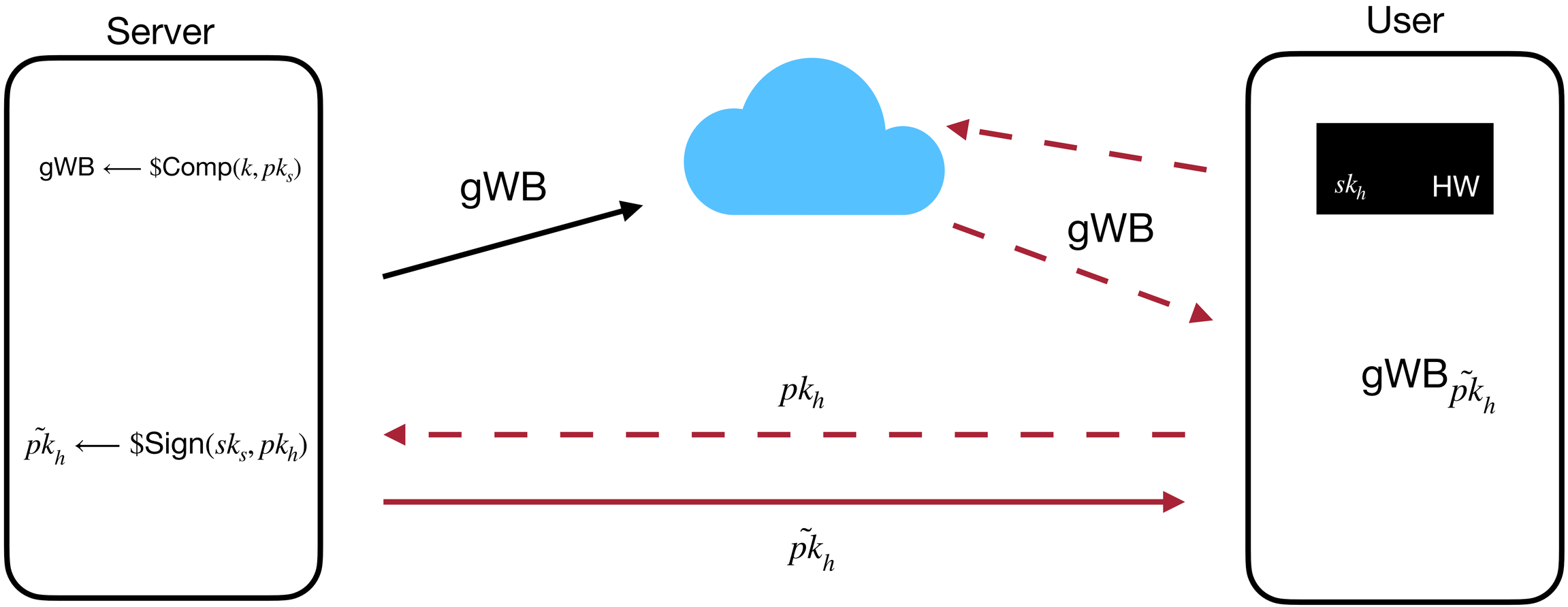

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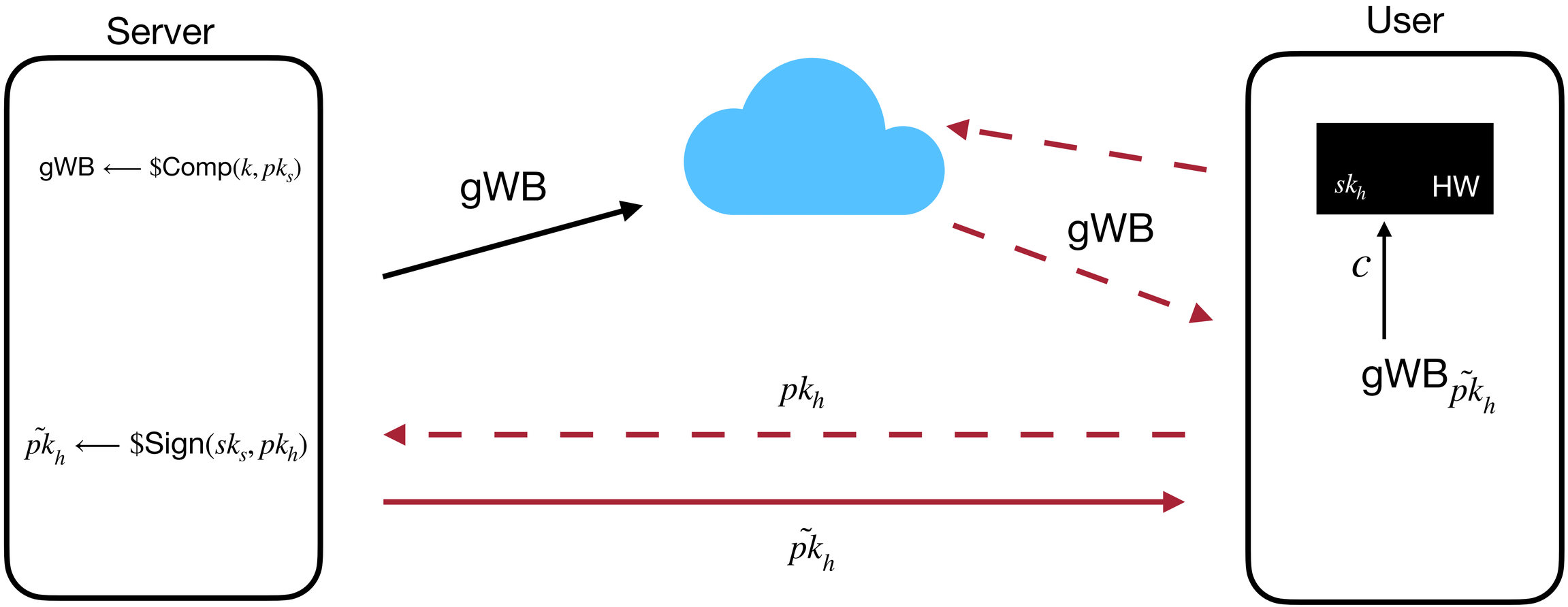

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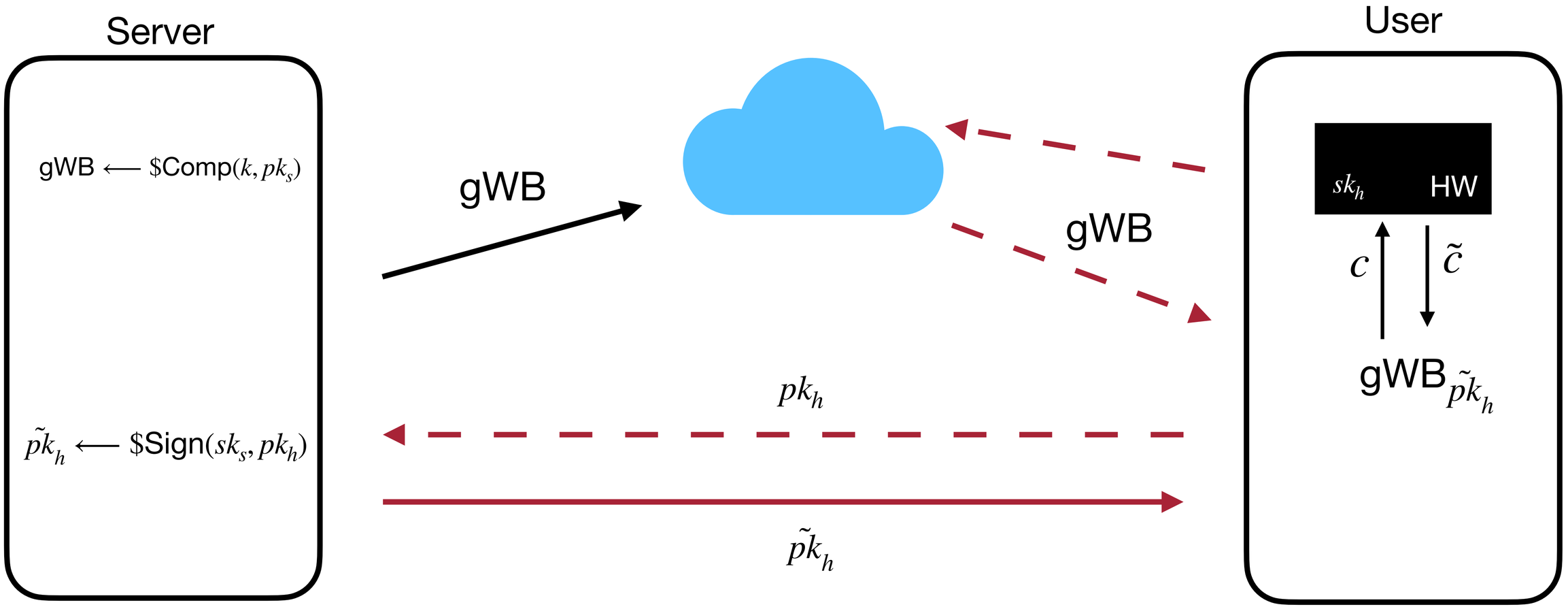

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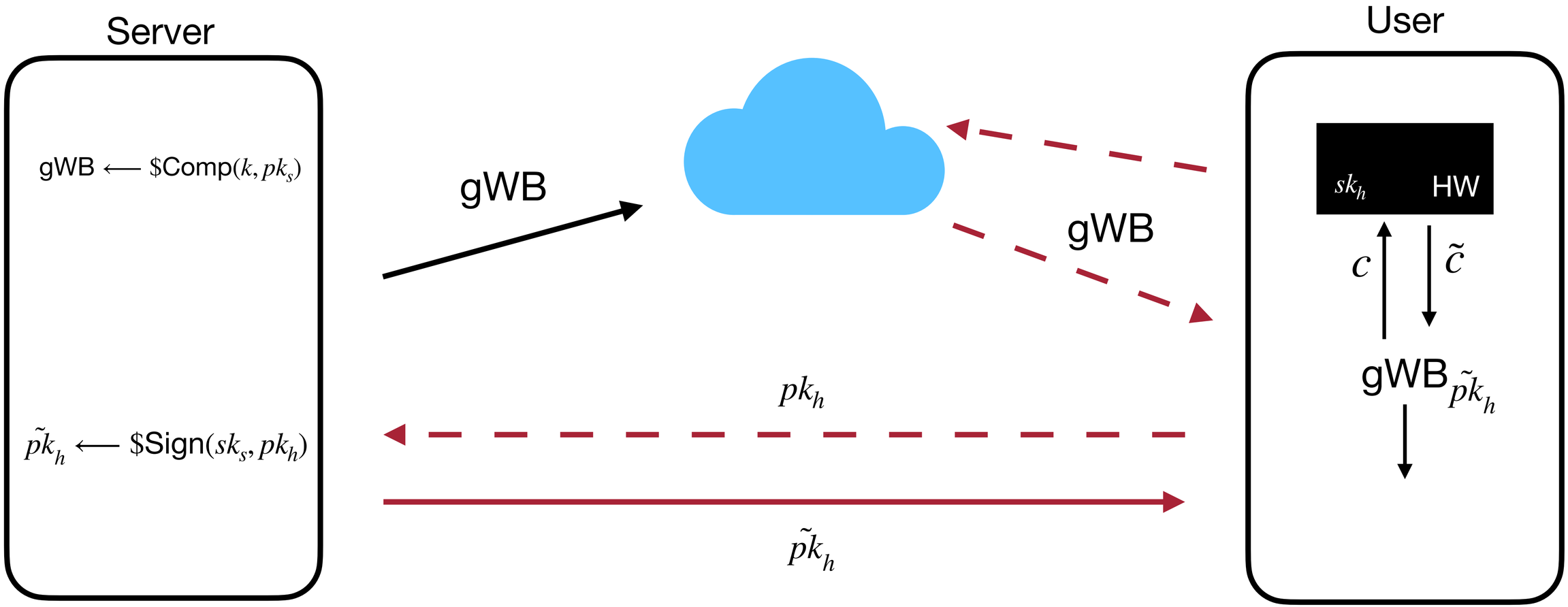

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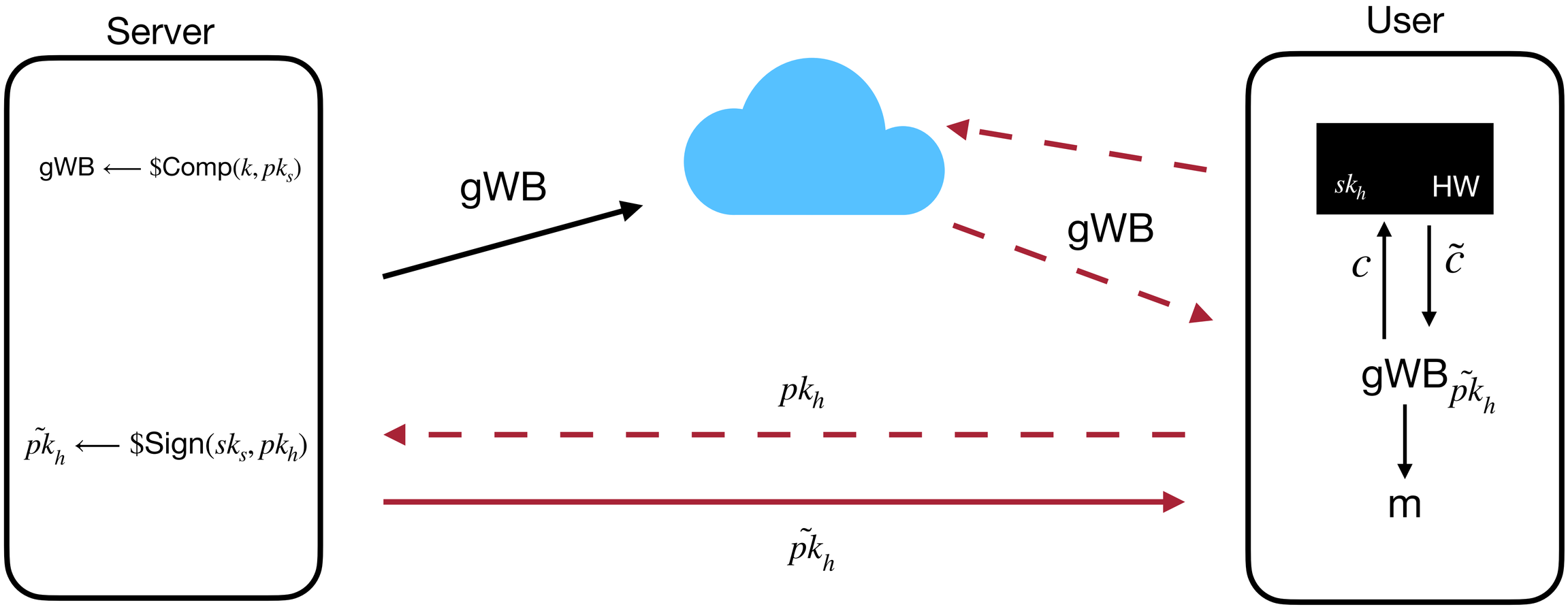

Strong global white-boxes

Design the white-box s.t. it always computers on encoded inputs

But additionally —> require the decoding key to be an *input* to the white-box

$\underline{\mathsf{Server}(d_h)}$

$\tilde{d_h} \leftarrow \mathsf{Encode}(e_s, d_h)$

return $\tilde{d_h}$

$\underline{\mathsf{HW}(c)}$

$\tilde{c} \leftarrow \mathsf{Encode}(e_h, c)$

return $\tilde{c}$

$\underline{\mathsf{WB}(\tilde{d_h}, \tilde{c})}$

$d_h \leftarrow \mathsf{Decode}(d_s, \tilde{d_h})$

$c \leftarrow \mathsf{Decode}(d_h, \tilde{c})$

$m \leftarrow \mathsf{Dec}(k, c)$

return m

The server encodes the personal encoding key

The white-box embeds a key for decoding the personal key

Each user can use their own key for encoding

Strong global white-boxes via message-recoverable signatures

Construct via puncturable primitives and indistinguishability obfuscation

—> construct *puncturable* MRS

—> obfuscate the circuit via iO

—> prove security via Sahai-Waters [5]

[5] Sahai and Waters: How to use indistinguishability obfuscation. STOC 2014

Strong global white-boxes vs *standard* ones

Positives for constructions of strong global white-boxes

Positives for constructions of standard global white-boxes

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Positives for constructions of standard global white-boxes

- Allows us to obfuscate any program, including AES
- TBO can be achieved from more accepted assumptions than iO (LWE, garbled circuits)
- Faster, smaller white-boxes due to obfuscation means

Danke!

eprint: https://eprint.iacr.org/2021/767

Provider

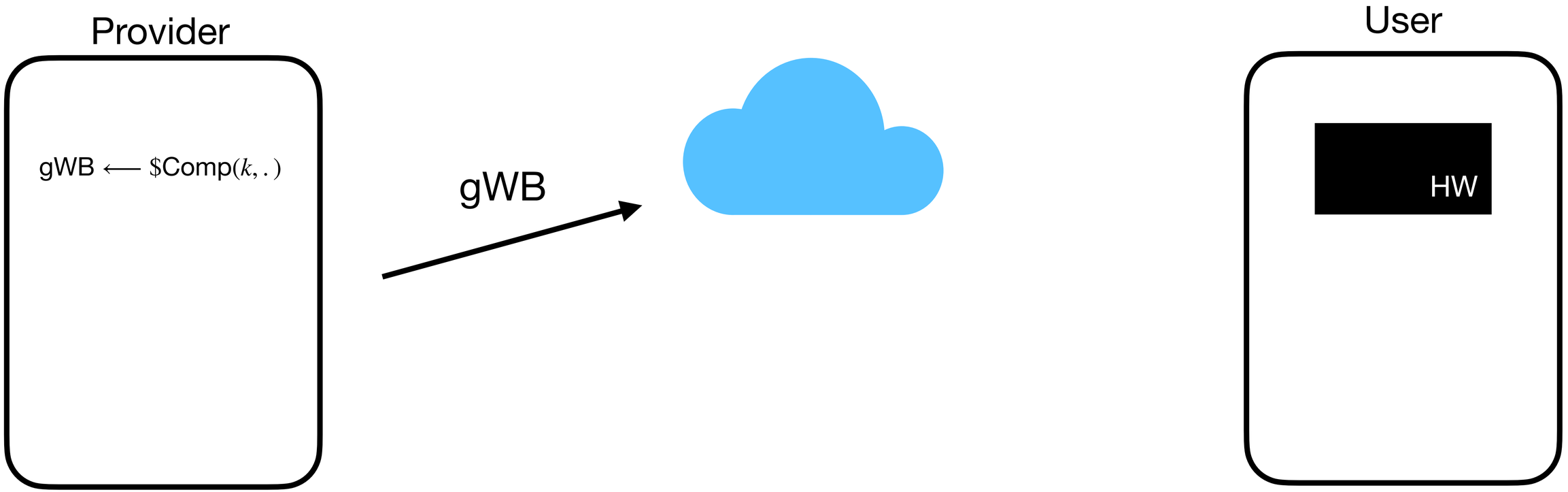
gWB ⟵ $Comp($k$, .)

User

HW

Danke!

eprint: https://eprint.iacr.org/2021/767



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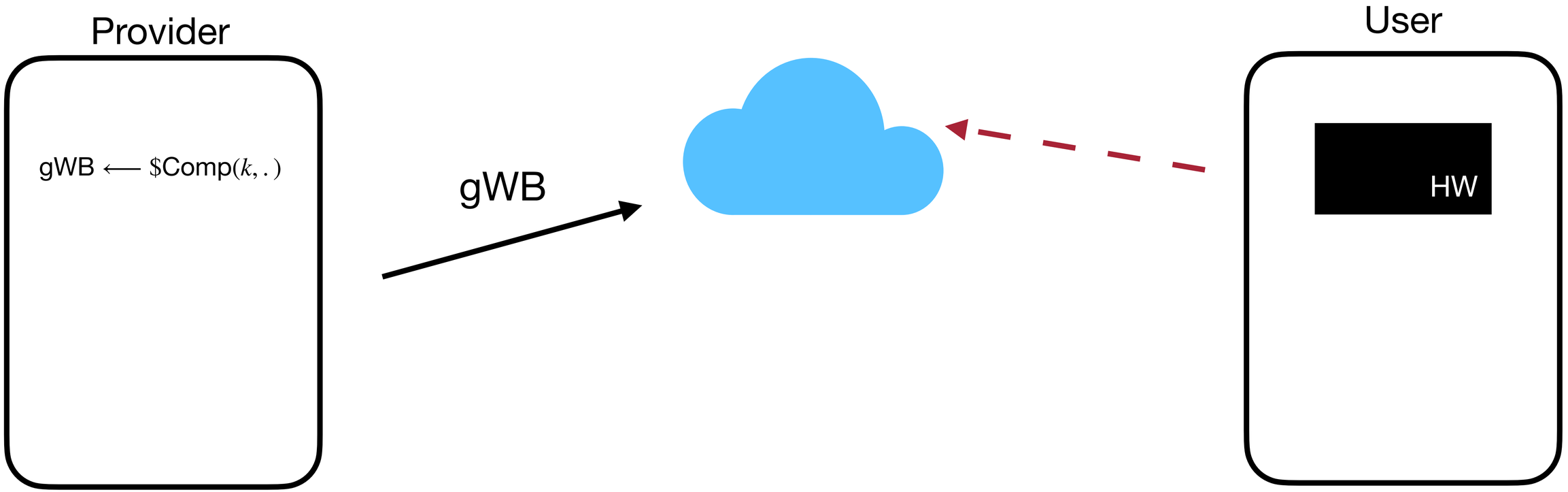

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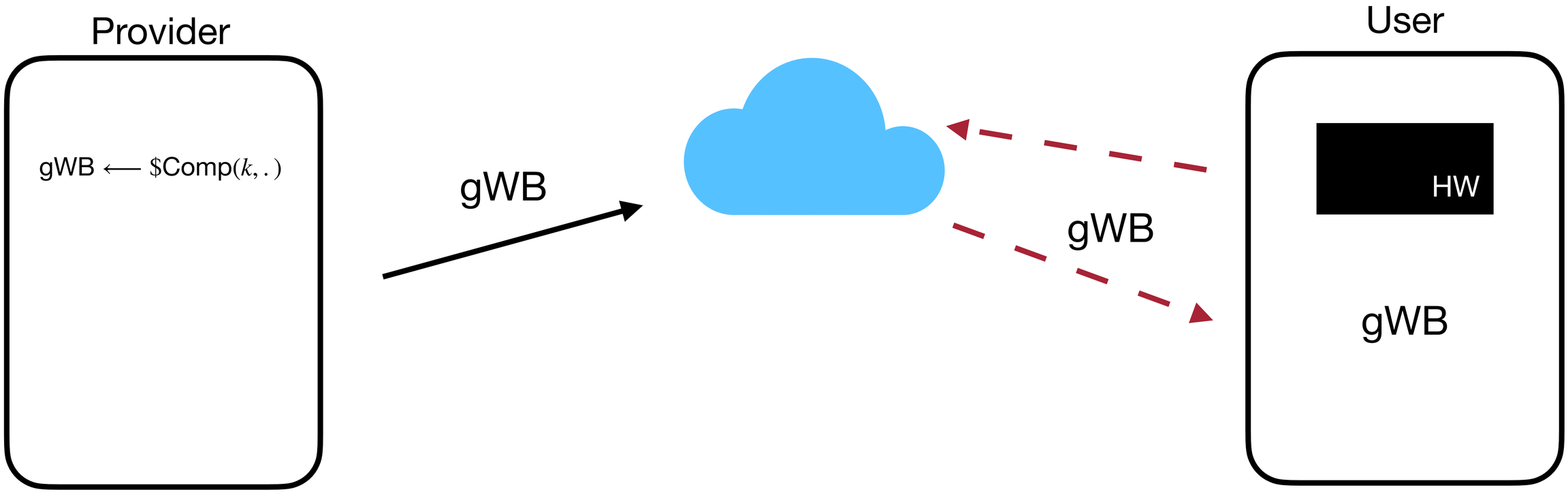

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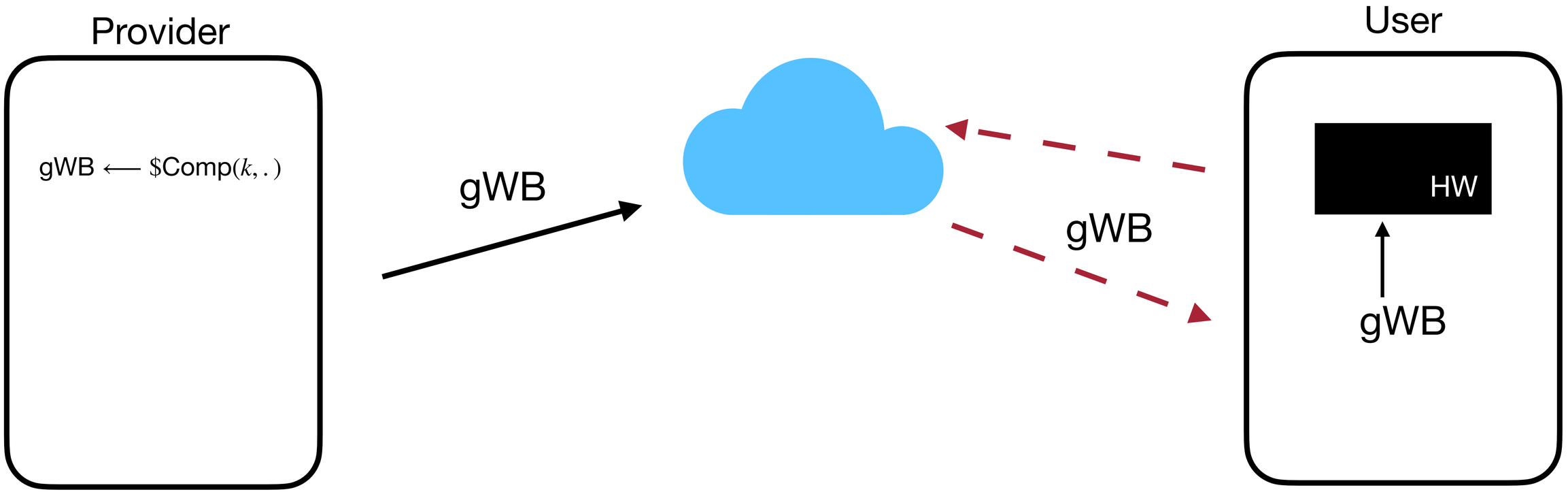

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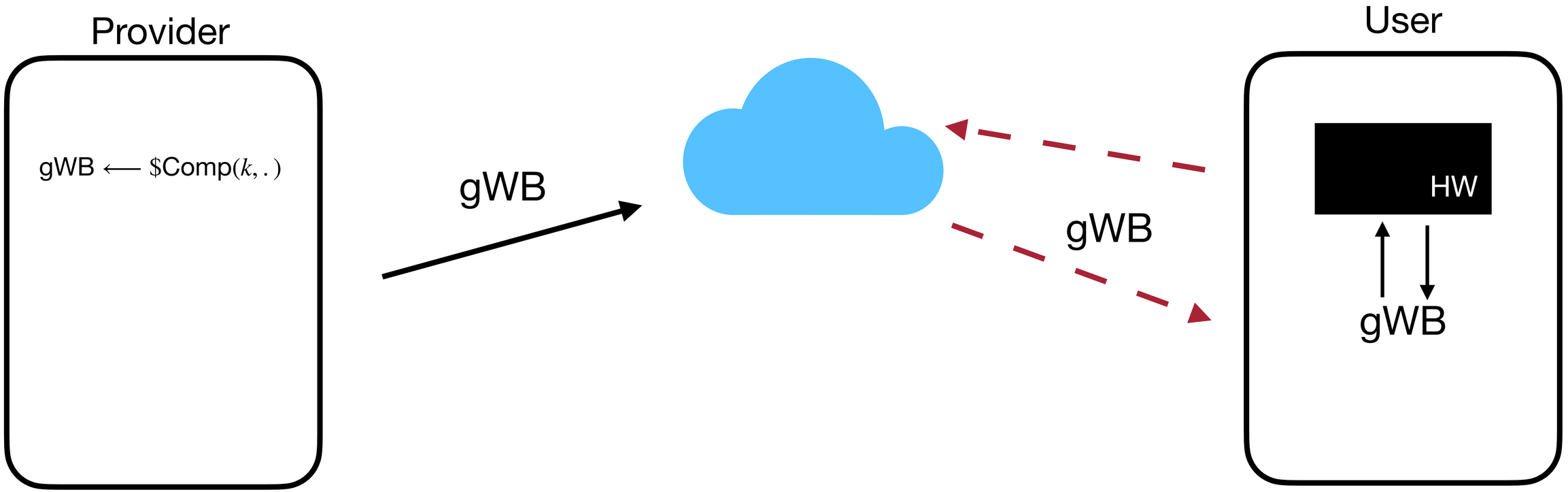

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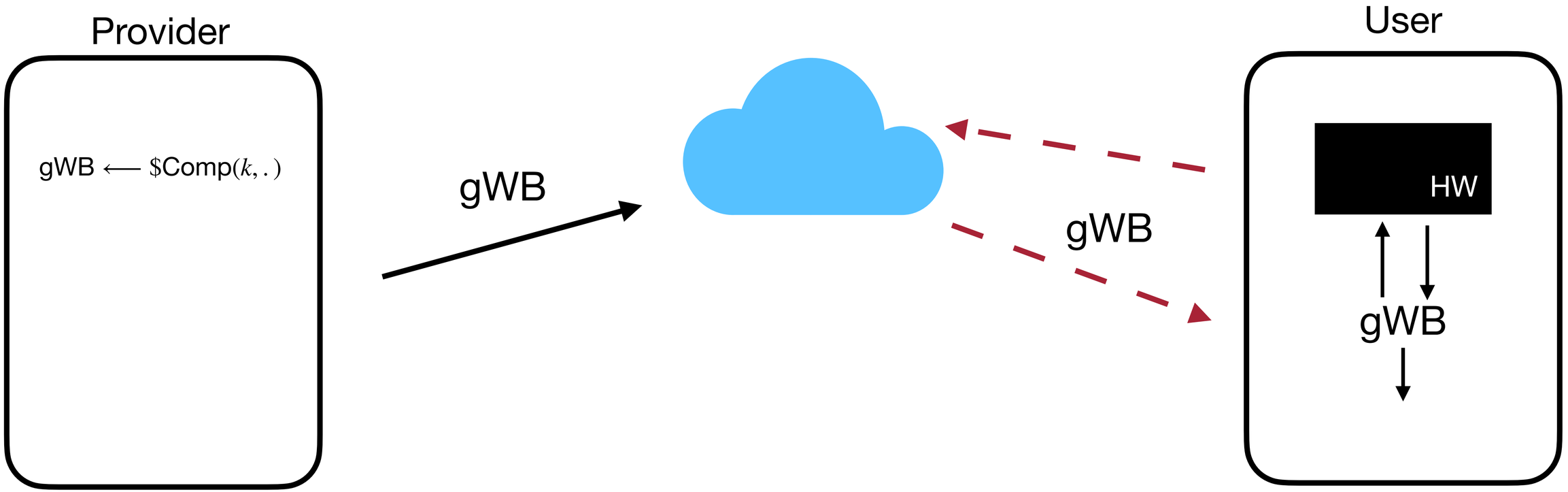

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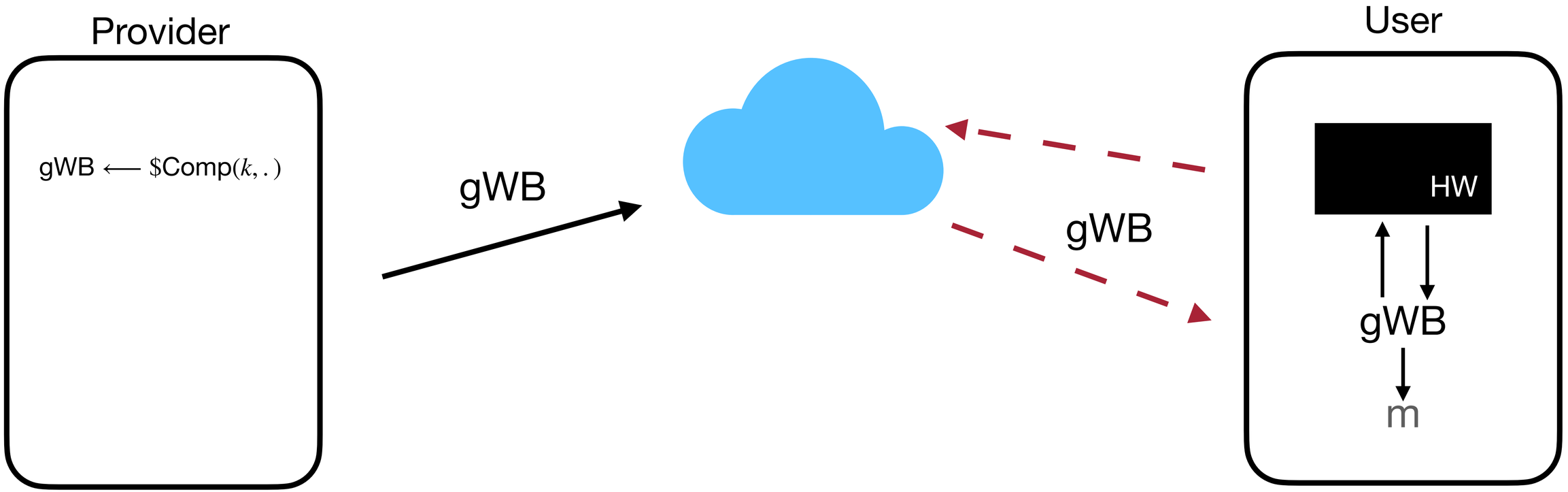

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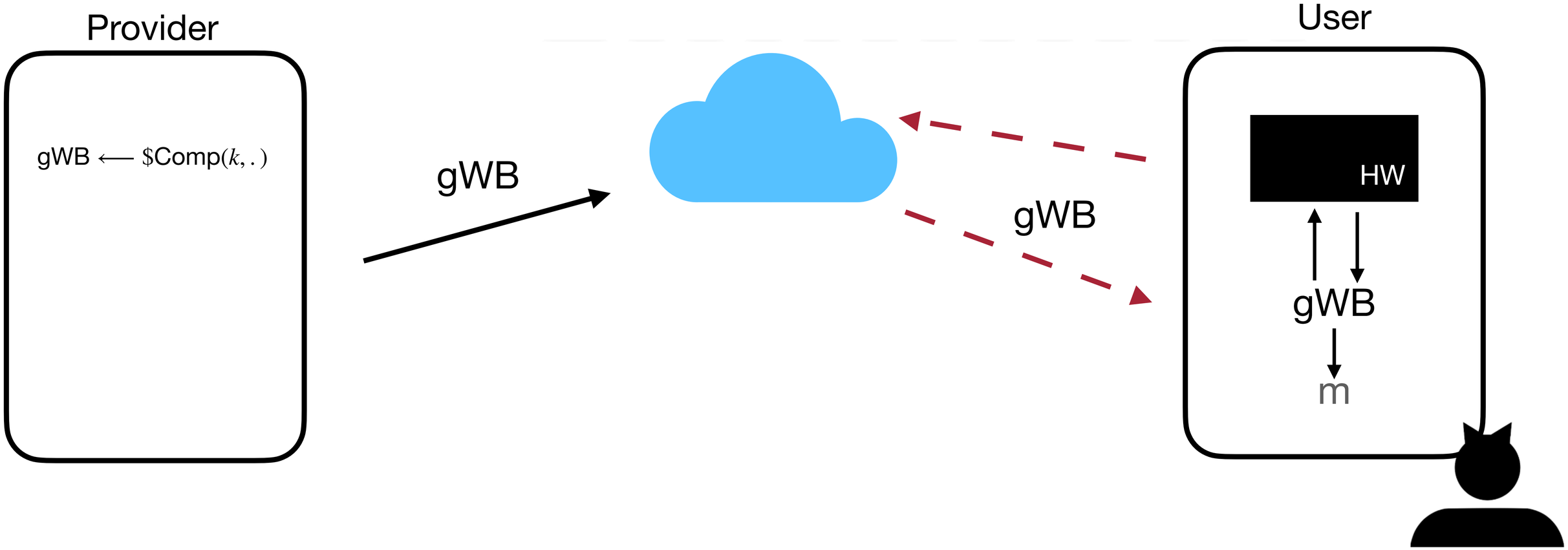

Summary

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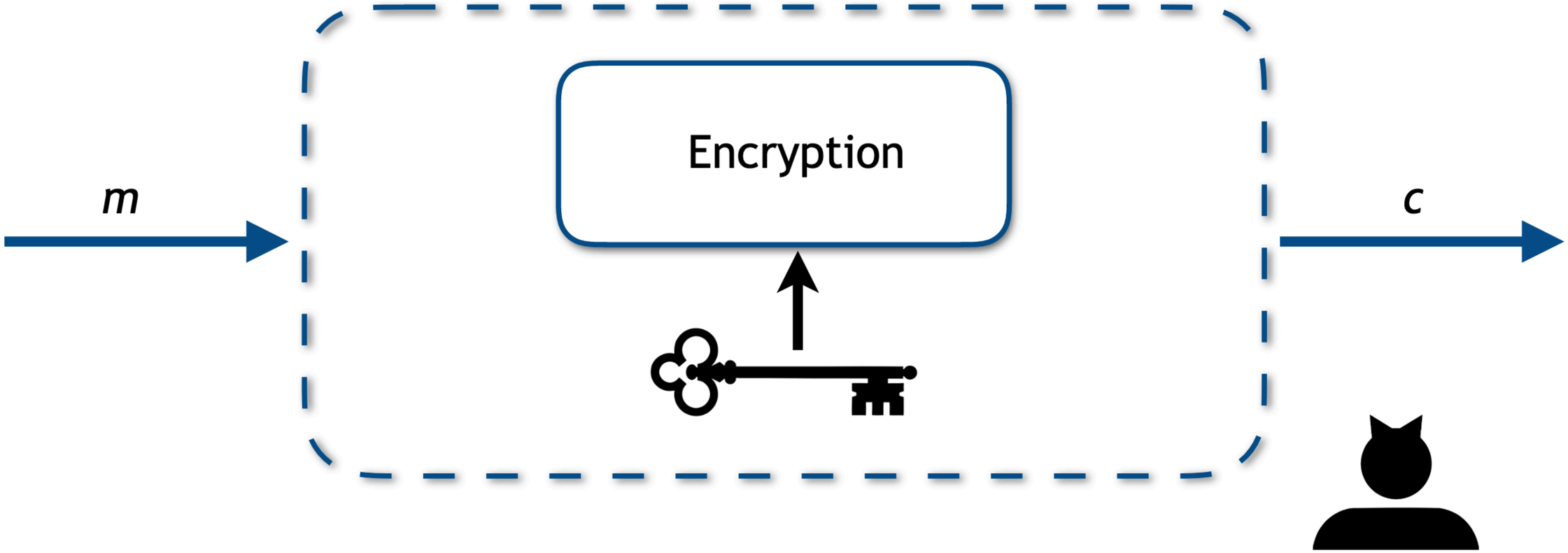
- More details and further results on the extended version of our paper: eprint/2021



- Definitional studies and feasibility results for white-box cryptography
  - Construct white-box programs from established cryptographic primitives —> prove their security in the presence of a white-box adversary

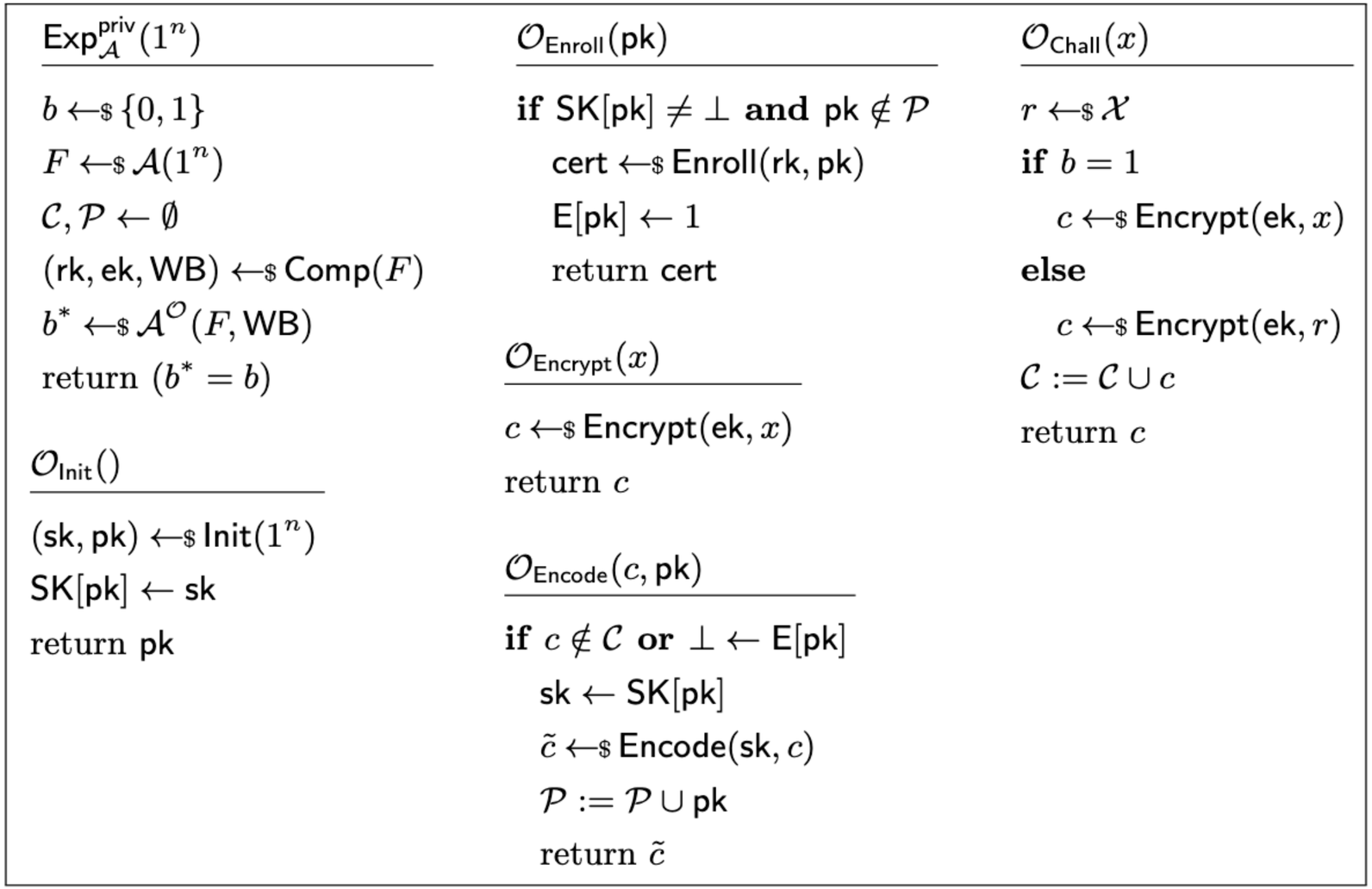


Fig. 2: Privacy $\mathsf{Exp}^{\mathsf{priv}}_{\mathcal{A}}(1^n)$ security game.

$\Gamma[\mathsf{pk}_2, \mathsf{ek}, F](\mathsf{cert}, \tilde{c}, y)$

$\mathsf{cert}||\mathsf{pk}_1 \leftarrow \mathsf{cert}$
$\tilde{c}||c \leftarrow \tilde{c}$
if $G(\mathsf{pk}_1) \neq G(\mathsf{Rcvr}(\mathsf{pk}_2, \mathsf{cert}))$
  return $\perp$
else if $G(c) \neq G(\mathsf{Rcvr}(\mathsf{pk}_1, \tilde{c}))$
  return $\perp$
else
  $t, r \leftarrow c$
  $v \leftarrow \mathtt{PPRF}(\mathsf{ek}, r)$
  $x \leftarrow t \oplus v$
  return $F(x, y)$
else *return* $\perp$

$\mathsf{Comp}(F)$

1 : $\mathsf{sk}_2, \mathsf{pk}_2 \leftarrow\!\!\$\ \mathsf{MRS.KGen}(1^\lambda)$
2 : $\mathsf{rk} \leftarrow \mathsf{sk}_2$
3 : $\mathsf{ek} \leftarrow\!\!\$\ \{0,1\}^\lambda$
4 : $\mathsf{WB} \leftarrow\!\!\$\ \mathtt{iO}(\Gamma[\mathsf{pk}_2, \mathsf{ek}, F])$
5 : *return* $\mathsf{rk}, \mathsf{ek}, \mathsf{WB}$

$\mathsf{Encrypt}(\mathsf{ek}, (x))$

1 : $r \leftarrow\!\!\$\ \{0,1\}^n$
2 : $v \leftarrow \mathtt{PPRF}(\mathsf{ek}, r)$
3 : $t \leftarrow x \oplus v$
4 : $c \leftarrow (t, r)$
5 : *return* c

$\mathsf{Enroll}(\mathsf{rk}, (\mathsf{pk}_1))$

1 : $\mathsf{cert} \leftarrow\!\!\$\ \mathsf{MRS.Sig}(\mathsf{rk}, \mathsf{pk}_1)$
2 : $\mathsf{cert} \leftarrow \mathsf{cert}||\mathsf{pk}_1$
3 : *return* cert

$\mathsf{Encode}(\mathsf{sk}_1, c))$

1 : $\tilde{c} \leftarrow\!\!\$\ \mathsf{MRS.Sig}(\mathsf{sk}_1, c)$
2 : $\tilde{c} \leftarrow \tilde{c}||c$
3 : *return* $\tilde{c}$

$\mathsf{Init}(1^\lambda)$

1 : $\mathsf{sk}, \mathsf{pk} \leftarrow\!\!\$\ \mathsf{MRS.KGen}(1^\lambda)$
2 : *return* $(\mathsf{sk}_1, \mathsf{pk}_1)$

Theorem 2. *Let* iO *be a an indistinguishability obfuscator and let* MRS *be a puncturable MRS scheme. Let PRG be a pseudorandom generator, and* PPRF *a secure puncturable pseudorandom function. Then Construction 5 is a privacy-secure* sGW *scheme.*