Unbounded HIBE with Tight Security

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Outline

Unbounded HIBE

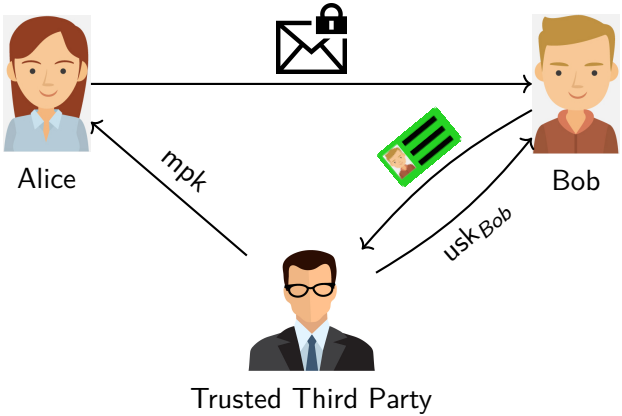
Tight security

Related works

Technical overview

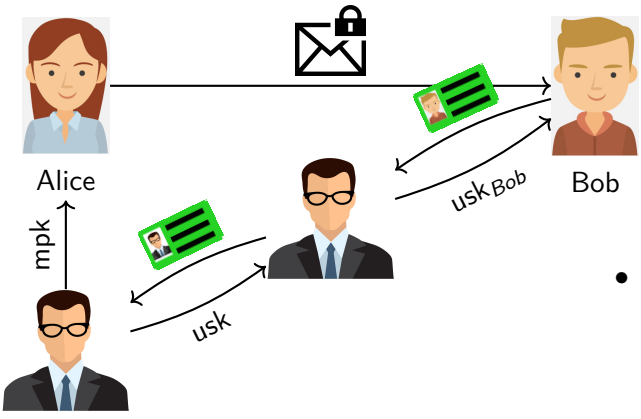
Future work

Identity-based encryption



- Alice needs to obtain only the master public key
- Encryption with identities (e.g. e-mail address)

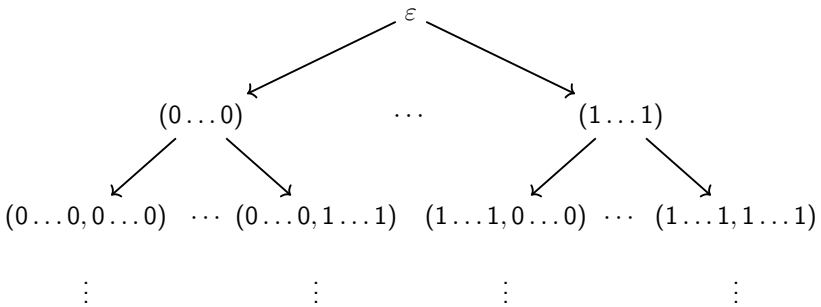
Hierarchical Identity-based encryption



- Hierarchy of key generators

Key delegation

Identities have the form $(\mathsf{id}_1, \ldots, \mathsf{id}_p)$.



- Each user can generate keys for its children

(Un)bounded HIBE

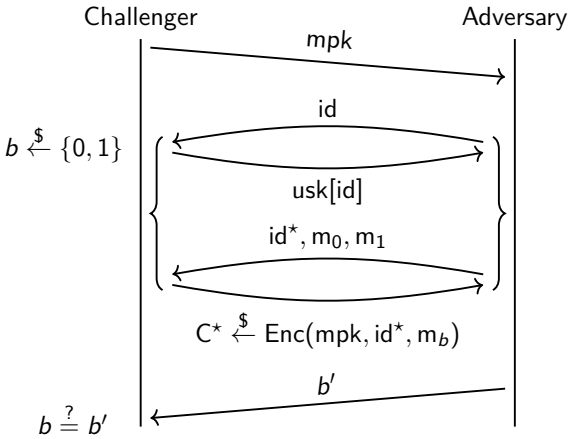
(Bounded) HIBE: Hierarchy depth L is fixed in advance

- mpk grows with L
- usks have a delegation term

Unbounded HIBE: No limit on the hierarchy depth

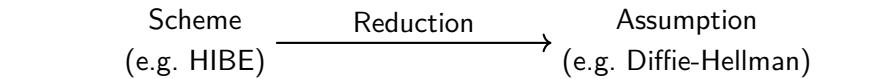
- More flexibility
- Better scalability

Security game (IND-HID-CPA)



- The adversary must not ask user secret keys for prefixes of challenge identities ($\mathsf{id}^\star$).
- IND-HID-CCA is easy once you have IND-HID-CPA.
- Master-key KDM-security can be achieved with [GGH20].

Tight security



Larger security loss requires larger security parameter.
Security loss ℓ can depend on:

- scheme parameters
- λ: the security parameter
- the attacker's resources (e.g. # user secret key queries Q_k or # challenge ciphertext queries Q_c, hierarchy depth L)

Tight security:

} allowed

} not allowed

History: Unbounded HIBE

Unbounded HIBEs:

[LW11]	CPG	$\mathcal{O}(Q_k L)$ (single-challenge)
[Lew12], [GCTC16]	PPG	$\mathcal{O}(Q_k L)$ (single-challenge)
[OT12] (weakly unbounded)	PPG	$\mathcal{O}(Q_k L^2)$ (single-challenge)
This work	PPG	$\mathcal{O}(\gamma)$ (multi-challenge)

- Q_k: # user secret key queries
- L: maximum hierarchy depth
- γ: Output bit length of a CRHF

History: Tight (H)IBE

Tight IBEs in prime-order pairing groups:

[CW13], [BKP14]	$\mathcal{O}(n)$ (single-challenge)
[AHY15], [GCD+16], [GDCC16], [HJP18]	$\mathcal{O}(n)$ (multi-challenge)

- n: Bit-length of the identities

Tight HIBEs in prime-order pairing groups:

[LP19]	$\mathcal{O}(\gamma)$ (single-challenge)
[LP20]	$\mathcal{O}(\gamma L)$ (multi-challenge)

- γ: Output bit length of a CRHF

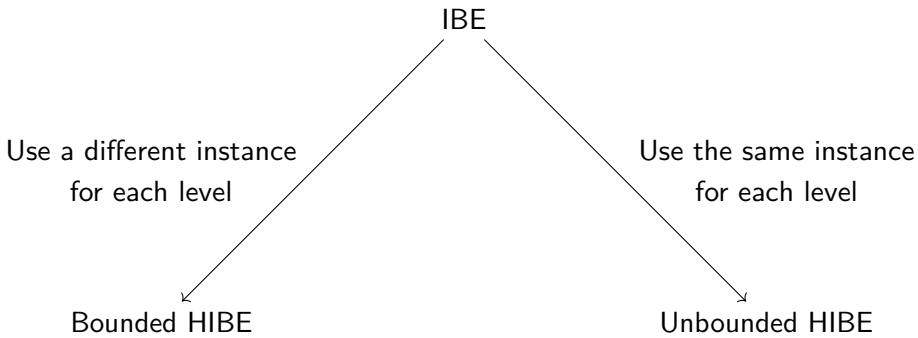
The gap

Scheme	|mpk|	|usk|	|C|	Loss	MC	Assumption
[LP20]	$\mathcal{O}(\gamma L L)$	$\mathcal{O}(p)$	$\mathcal{O}(p)$	$\mathcal{O}(\gamma L L)$	✓	SXDH

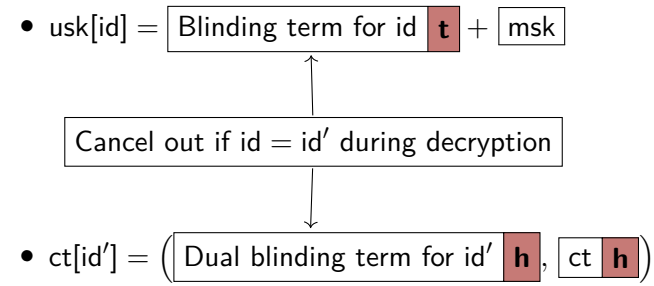
- L: maximum hierarchy depth
- p: actual hierarchy depth
- γ: bit-length of hashes

- We need to get rid of the factor L in $|\mathsf{mpk}|$ and in the security loss.

High-Level approach



IBE structure



Blinding terms

- Blinding term for x **t** $\cdot$ Dual blinding term for x **h** $= 0$
- Blinding term for x **t** is pseudorandom
  - If no dual blinding term for x is known
- Blinding terms are publicly sample
  - Dual blinding terms are not publicly sample
- Tight realization: Abstraction of [LP20]

Generalisation to Bounded HIBE

- $\mathsf{usk}[\mathsf{id}_1, \ldots, \mathsf{id}_p] = \sum_{i=1}^{p} \boxed{\text{Level } i \text{ blinding term for } H(\mathsf{id}_1 || \cdots || \mathsf{id}_i) \; \mathbf{t}_i} + \boxed{\mathsf{msk}}$
- Delegation: Blinding terms are publicly sampable
- $\mathsf{ct}[\mathsf{id}'_1, \ldots, \mathsf{id}'_{p'}] = \left(\left(\boxed{\text{Dual level } i \text{ blinding term for } H(\mathsf{id}'_1 || \cdots || \mathsf{id}'_i) \; \mathbf{h}} \right)_{1 \le i \le p'}, \boxed{\mathsf{ct} \; \mathbf{h}} \right)$

  Obstacles for Unbounded HIBE:

- mpk has size $\mathcal{O}(nL^2)$
  (n: bit-length of the identities)
  - Use a collision-resistant hash function H
- mpk has size $\mathcal{O}(\gamma L)$
  - Can we use the same blinding terms for all levels?

    $\Rightarrow$ We need individual randomness on the dual blinding terms

Unbounded HIBE

- $\mathsf{usk}[\mathsf{id}_1, \ldots, \mathsf{id}_p] = \Bigg(\sum_{i=1}^{p} \boxed{\text{Blinding term for “2”}\ \tilde{\mathbf{t}}_i} + \boxed{\mathsf{msk}},$

  $\Big(\boxed{\text{Blinding term for } H(\mathsf{id}_1 || \cdots || \mathsf{id}_i)\ \mathbf{t}_i} + \boxed{\text{Blinding term for “1”}\ \tilde{\mathbf{t}}_i} \Big)_{1 \le i \le p} \Bigg)$

- $\mathsf{ct}[\mathsf{id}'_1, \ldots, \mathsf{id}'_{p'}] = \Bigg(\Big(\boxed{\text{Dual blinding term for } H(\mathsf{id}'_1 || \cdots || \mathsf{id}'_i)\ \mathbf{h}_i},$

  $\boxed{\text{Dual blinding term for “1”}\ \mathbf{h}_i} + \boxed{\text{Dual blinding term for “2”}\ \tilde{\mathbf{h}}} \Big)_{1 \le i \le p'}, \boxed{\mathsf{ct}\ \tilde{\mathbf{h}}} \Bigg)$

Comparison of unbounded HIBEs (in prime-order pairing groups)

Scheme	|mpk|	|usk|	|C|	Loss	MC	Assumption
[Lew12]	$\mathcal{O}(1)$	$\mathcal{O}(p)$	$\mathcal{O}(p)$	$\mathcal{O}(Q_k)$	✗	2-LIN
[OT12]	$\mathcal{O}(1)$	$\mathcal{O}(p^2 L)$	$\mathcal{O}(p)$	$\mathcal{O}(Q_k L^2)$	✗	2-LIN
[GCTC16]	$\mathcal{O}(1)$	$\mathcal{O}(p)$	$\mathcal{O}(p)$	$\mathcal{O}(Q_k)$	✗	SXDH
Ours	$\mathcal{O}(\gamma)$	$\mathcal{O}(p)$	$\mathcal{O}(p)$	$\mathcal{O}(\gamma)$	✓	SXDH

- L: maximum hierarchy depth
- p: actual hierarchy depth
- γ: bit-length of hashes
- Q_k: # user secret key queries

[GGH20] Tight MC secure (IBE) $\Longrightarrow$ master-key KDM-secure (IBE)

- Same idea applies here $\Longrightarrow$ First unbounded HIBE with master-key KDM security

Future work

- Does the "inject-and-pack" strategy work in a more general setting, like predicate encryption?
- Can we have Unbounded HIBE with constant usk/ct size?

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Pictures

Alice, Bob, Trusted Party: freepik.com

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