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BETTER.

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Downgradable Identity-based Encryption and Applications

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- Context
- Model
- Generic Transformations
- Construction

General Context

Identity-Based Encryption

Alice | Bob

$$C = \mathsf{Encrypt}(\text{'Bob'}, M) \longrightarrow$$

M

$$M = \mathsf{Decrypt}(\mathsf{usk}_{\mathsf{Bob}}, C)$$

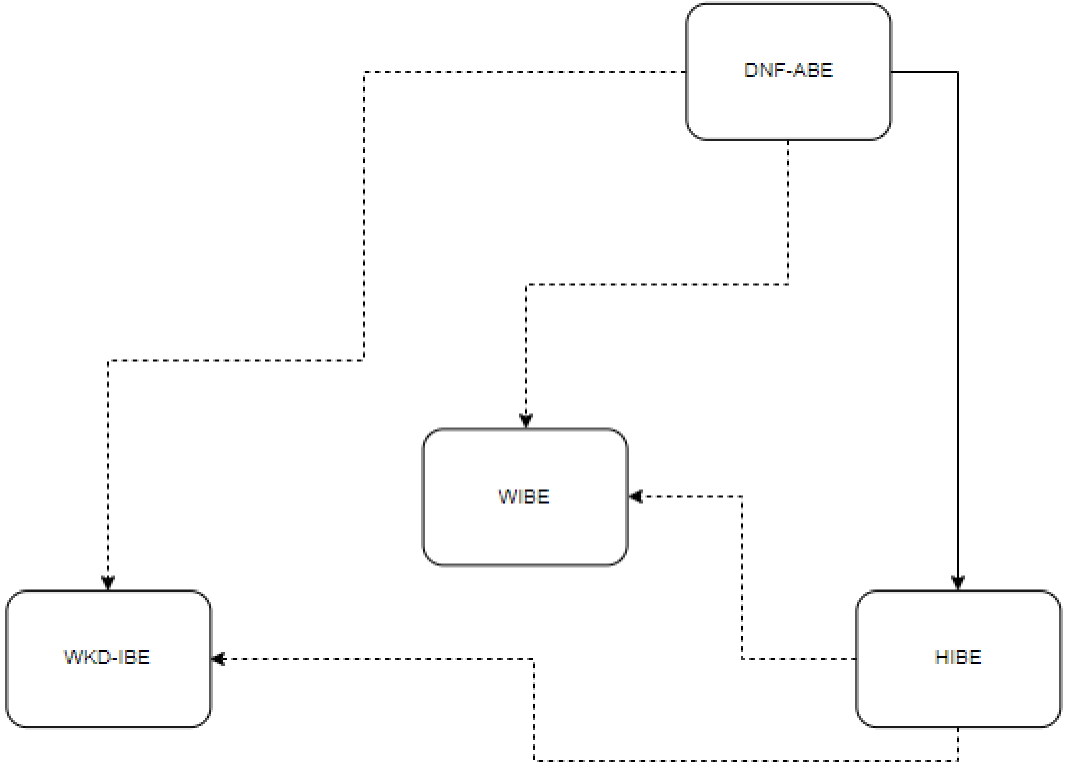
History of IBE

- Shamir ‘84
- Boneh-Franklin, Cocks ‘01
- Boneh-Boyen, Waters ’05
- Waters ’09,
- Chen-Wee, Blazy –Kiltz-Pan

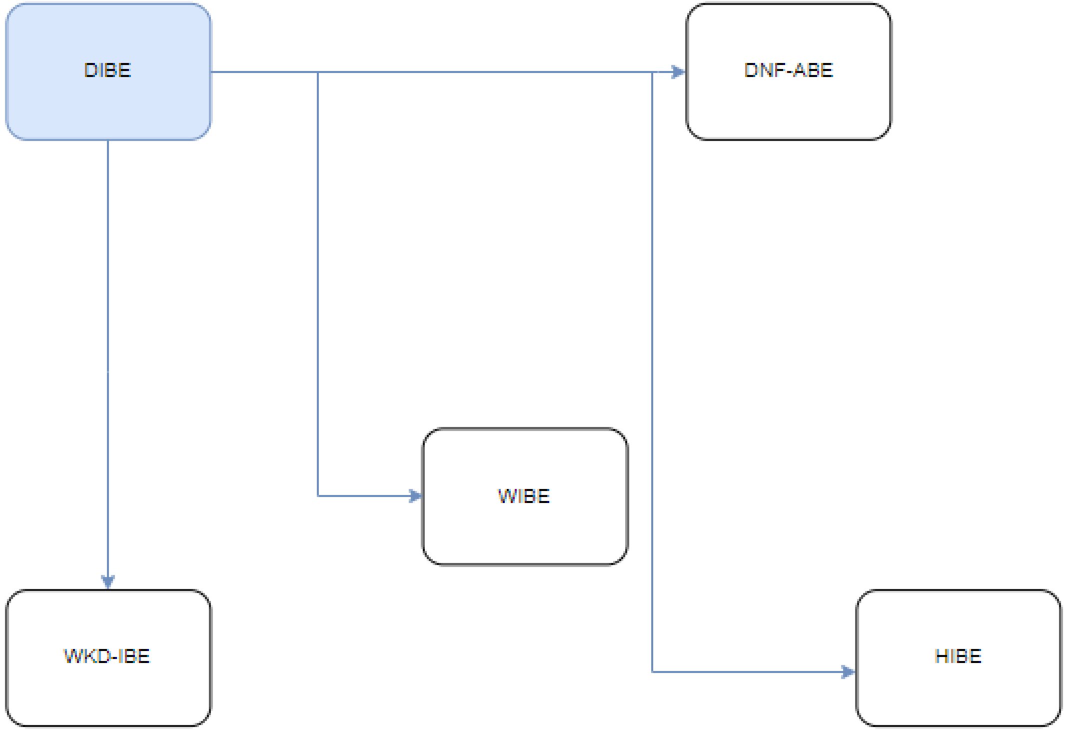
So Many Variants

- Hierarchical IBE
- Wildcarded IBE
- Wicked IBE
- …

Relations ?



Relations ?



Model

Identity-Based Encryption

- 4 algorithms:
  - Keygen: Generates mpk, msk
  - USKGen(id, msk): Generates usk[id]
  - Enc(mpk,id): Generates a capsule C leading to a key K for id
  - Dec(C,usk[id]): Recovers K' from C

<u>Procedure Initialize:</u>
$(\mathsf{mpk}, \mathsf{msk}) \xleftarrow{\$} \mathsf{Gen}(\mathfrak{K})$
Return mpk

<u>Procedure USKGen(id):</u>
$\mathcal{Q}_{\mathsf{ID}} = \mathcal{Q}_{\mathsf{ID}} \cup \{\mathsf{id}\}$
Return $\mathsf{usk}[\mathsf{id}] \xleftarrow{\$} \mathsf{USKGen}(\mathsf{msk}, \mathsf{id})$

<u>Procedure Enc(id*):</u> //one query
$(\mathsf{sk}^*, \mathsf{C}^*) \xleftarrow{\$} \mathsf{Enc}(\mathsf{mpk}, \mathsf{id}^*)$
$\boxed{\mathsf{sk}^* \xleftarrow{\$} \mathcal{K}; \mathsf{C}^* \xleftarrow{\$} \mathsf{CS}}$
Return $(\mathsf{sk}^*, \mathsf{C}^*)$

<u>Procedure Finalize(β):</u>
Return $(\mathsf{id}^* \notin \mathcal{Q}_{\mathsf{ID}}) \wedge \beta$

IDfix

Downgradable Identity-Based Encryption

- *5* algorithms:
  - Keygen: Generates mpk, msk
  - USKGen(id, msk): Generates usk[id]
  - Enc(mpk,id): Generates a capsule C leading to a key K for id
  - Dec(C,usk[id]): Recovers K’ from C
  - USKDown(usk[id],id’): Return usk[id’] if id’ << id

  - Given a key for an id, one can deduce a key for id’ if id’ can be obtained by replacing some 1 in id by 0. (101 << 111)

Downgradable Identity-Based Encryption

Procedure $\mathsf{Initialize}$:

$(\mathsf{mpk}, \mathsf{msk}) \xleftarrow{\$} \mathsf{Gen}(\mathfrak{K})$

Return mpk

Procedure $\mathsf{USKGen}(\mathsf{id})$:

$\mathcal{Q}_{\mathsf{ID}} = \mathcal{Q}_{\mathsf{ID}} \cup \{\mathsf{id}\}$

Return $\mathsf{usk}[\mathsf{id}] \xleftarrow{\$} \mathsf{USKGen}(\mathsf{msk}, \mathsf{id})$

Procedure $\mathsf{Enc}(\mathsf{id}^*)$: //one query

$(\mathsf{sk}^*, \mathsf{C}^*) \xleftarrow{\$} \mathsf{Enc}(\mathsf{mpk}, \mathsf{id}^*)$

$\boxed{\mathsf{sk}^* \xleftarrow{\$} \mathcal{K}; \mathsf{C}^* \xleftarrow{\$} \mathsf{CS}}$

Return $(\mathsf{sk}^*, \mathsf{C}^*)$

Procedure $\mathsf{Finalize}(\beta)$:

Return $(\neg(\mathsf{id}^* \preceq \mathcal{Q}_{\mathsf{ID}})) \wedge \beta$

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Transformations

Wildcard Identity-Based Encryption

- Allows * in targeted identities

$$\mathsf{id}[2i, 2i+1] = \begin{cases} 01 & \text{if } \mathsf{wid}[i] = 0 \\ 10 & \text{if } \mathsf{wid}[i] = 1 \\ 00 & \text{otherwise.} \end{cases}$$

Wildcard Identity-Based Encryption

$\mathsf{WIBE.Gen}(\mathfrak{K})$: $\mathsf{Gen}(\mathfrak{K})$, except that instead of defining ID as strings of size 2ℓ, we suppose the public key define WID of enriched identities of size ℓ.
$\mathsf{WIBE.USKGen}(\mathsf{sk}, \mathsf{id}) = \mathsf{USKGen}(\mathsf{sk}, \phi(\mathsf{id}))$.
$\mathsf{WIBE.Enc}(\mathsf{mpk}, \mathsf{id}) = \mathsf{Enc}(\mathsf{mpk}, \phi(\mathsf{id}))$.
$\mathsf{WIBE.Dec}(\mathsf{usk}[\mathsf{id}], \hat{\mathsf{id}}, \mathsf{C})$ checks if $\hat{\mathsf{id}} \preceq \mathsf{id}$, then computes $\mathsf{usk}[\phi(\hat{\mathsf{id}})] = \mathsf{USKDown}(\mathsf{usk}[\phi(\mathsf{id})])$.
Returns $\mathsf{Dec}(\mathsf{usk}[\phi(\hat{\mathsf{id}})], \hat{\mathsf{id}}, \mathsf{C})$ or rejects with $\perp$.

Hierarchical Identity-Based Encryption

- Allows to derive keys for lower level
  - This means * at the end of original identities

$$\mathsf{id}[2i, 2i+1] = \begin{cases} 01 & \text{if } \mathsf{hid}[i] = 0 \\ 10 & \text{if } \mathsf{hid}[i] = 1 \\ 11 & \text{otherwise}(\mathsf{hid}[\mathrm{i}] = \perp). \end{cases}$$

Hierarchical Identity-Based Encryption

$\mathsf{HIB.Gen}(\mathfrak{K})$: $\mathsf{Gen}(\mathfrak{K})$, except instead of defining ID as strings of size 2ℓ, we suppose the public key define HID of enriched identities of size ℓ.
$\mathsf{HIB.USKGen}(\mathsf{sk}, \mathsf{id}) = \mathsf{USKGen}(\mathsf{sk}, \phi(\mathsf{id}))$. It should be noted that in case of an DIBKEM, some identities are never to be queried to the downgradable IBKEM: those with 00 is $2i, 2i+1$, or those with 11 at $2i, 2i+1$ and then a 0 (this would correspond to *punctured* identities).
$\mathsf{HIB.USKDel}(\mathsf{usk}[\mathsf{id}], \mathsf{id} \in \mathcal{BS}^p, \mathsf{id}_{p+1}) = \mathsf{USKDown}(\mathsf{usk}[\phi(\mathsf{id})], \phi(\mathsf{id}||\mathsf{id}_{p+1}))$. By construction we have $\phi(\mathsf{id}||\mathsf{id}_{p+1}) \preceq \phi(\mathsf{id})$.
$\mathsf{HIB.Enc}(\mathsf{mpk}, \mathsf{id}) = \mathsf{Enc}(\mathsf{mpk}, \phi(\mathsf{id}))$.
$\mathsf{HIB.Dec}(\mathsf{usk}[\mathsf{id}], \mathsf{id}, \mathsf{C})$ returns $\mathsf{Dec}(\mathsf{usk}[\phi(\mathsf{id})], \phi(\mathsf{id}), \mathsf{C})$ or the reject symbol $\perp$.

Wicked Identity-Based Encryption

- Allows to derive keys for lower level
  - This means * in the original identities

$$\mathsf{id}[2i, 2i+1] = \begin{cases} 01 & \text{if } \mathsf{wkdid}[i] = 0 \\ 10 & \text{if } \mathsf{wkdid}[i] = 1 \\ 11 & \text{if } \mathsf{wkdid}[i] = * \end{cases}$$

Wicked Identity-Based Encryption

$\mathsf{WKDIB.Gen}(\mathfrak{K})$: $\mathsf{Gen}(\mathfrak{K})$, except instead of defining ID as strings of size 2ℓ, we suppose the public key define WKDID of enriched identities of size ℓ.
$\mathsf{WKDIB.USKGen}(\mathsf{msk}, \mathsf{id}) = \mathsf{USKGen}(\mathsf{msk}, \phi(\mathsf{id}))$. It should be noted that in case of an WKD-DIBE, some identities are never to be queried to the downgradable IBE: those with 00.
$\mathsf{WKDIB.USKDel}(\mathsf{usk}[\mathsf{id}], \mathsf{id}, \mathsf{id}') = \mathsf{USKDown}(\mathsf{usk}[\phi(\mathsf{id})], \phi(\mathsf{id}), \phi(\mathsf{id}'))$.
$\mathsf{WKDIB.Enc}(\mathsf{mpk}, \mathsf{id}) = \mathsf{Enc}(\mathsf{mpk}, \phi(\mathsf{id}))$.
$\mathsf{WKDIB.Dec}(\mathsf{usk}[\mathsf{id}], \mathsf{id}, \mathsf{C})$ returns $\mathsf{Dec}(\mathsf{usk}[\phi(\mathsf{id})], \phi(\mathsf{id}), \mathsf{C})$ or the reject symbol $\perp$.

Transformations

- All those transformations are tight
- However they use a space of size 4 for a ternary alphabet.
  - It could be improve, but would not drastically improve the tightness

Attribute-Based Encryption

- User keys have 1 where they have the attribute
- Ciphertext have a 0 where an attribute is not mandatory
- If the policy < attributes, a user can properly downgrade his key

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Construction

Downgradable Identity-Based Encryption

- Can be constructed by adapting BKP'14
  - Can be instantiated under any k-MDDH assumption (SXDH, Dlin,…)

  - Depending on the use case, it is possible to ensure that the downgraded key is indistinguishable from a fresh one.

  - Encapsulation is only k+1 elements (k=1 for SXDH)
  - Same goes for user keys

Wicked / Wildcard Identity-Based Encryption

Name	$\lvert pk \rvert$	$\lvert usk \rvert$	$\lvert C \rvert$	assump.	Sec	Loss
WKD [AKN07]	$n+4$	$n+2$	2	BDDH	Sel. standard	$O(nq_k)$
WKD [AKN07]	$(n+1)n+3$	$n+2$	2	BDDH	Full standard	$O(q_k^n)$
WKD-DIBE	$4n+2$	$3n+5$	5	DLin (any $k-$MDDH)	Full standard	$O(q_k)$
SWIBE [KLLO18]	$n+4$	$2n+3$	4	ROM	Full	$O((n+1)(q_k+1)^n)$
WIBE [BDNS07]	$(n+1)n+3$	$n+1$	$(n+1)n+2$	BDDH	Full standard	$O(n^2q_k^n)$
Wild-DIBE	$4n+2$	$3n+5$	5	DLin (any $k-$MDDH)	Full standard	$O(q_k)$

Attribute-Based Encryption

Name	$\|pk\|$	$\|sk\|$	$\|C\|$	pairing	exp $\mathbb{G}$	exp $\mathbb{G}_t$	Reduction Loss
[OT10]	$4U+2$	$3U+3$	$7m+5$	$7m+5$	0	m	$O(q_k)$
[LW12]	$24U+12$	$6U+6$	$6m+6$	$6m+9$	0	m	$O(q_k)$
[CGW15]	$6UR+12$	$3UR+3$	$3m+3$	6	$6m$	0	$O(q_k)$
[Att16] scheme 10	$6UR+12$	$3UR+6$	$3m+6$	9	$6m$	0	$O(q_k)$
[Att16] scheme 13	$96(M+TR)^2+log(UR)$	$3UR+6$	$3m+6$	9	$6m$	0	$O(q_k)$
Our DNF-ABE	$4U+2$	$3U+3$	$3k+2$	13	0	0	$O(q_k)$

Conclusion

- Another IBE related primitive
  - However it can be tightly linked to the others
  - So any progress on DIBE should lead to progress to the other primitive

- Can DIBE be achiever in a Post Quantum world?
- How to avoid the DNF limitation for ABE

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Thank you

Any questions?