Attribute-Based Cryptography: Survey and (Inefficient?) Generic Constructions

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Outline

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Traditional Public Key Cryptography

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- Only the user holding the matching sk can decrypt / sign material linked to pk.
- How to know that public key pk really belongs to the intended receiver ?
  Digital certificates, revocation... **inefficiency !!**

IBC → fuzzy IBC → ABC

Identity Based Cryptography (Shamir, 1984)

Only the owner of the identity which **exactly matches** the chosen identity can decrypt / sign the message.

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fuzzy Identity Based Cryptography (Sahai-Waters, 2005)

Identities are now **vectors of attributes**.

Only the owners of identities which **match** the chosen identity in **at least** t **positions** can decrypt / sign the message.

[The threshold t is fixed in Setup.]

IBC → fuzzy IBC → ABC

(Threshold) **Attribute Based Cryptography** (Goyal et al., 2006)

Only the owners of identities which **match** the identity chosen by the sender in **at least** t **positions** can decrypt the message.

[The threshold t is **chosen ad-hoc** by the sender / signer.]

Threshold ABC $\rightarrow$ General ABC

More generally, the sender / signer chooses a set of attributes:

$$S = \{\mathsf{at}_1, \mathsf{at}_2, \ldots, \mathsf{at}_n\}$$

and a **(monotone increasing) family** $\Gamma \subset 2^S$ of subsets of S.

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$$\Gamma_0 = \{\{\mathsf{at}_1\}, \{\mathsf{at}_2, \mathsf{at}_3\}\}, \quad \Gamma = \mathrm{cl}(\Gamma_0)$$

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Considering $\Gamma = \{A \subset S \ : \ |A| \geq t\}$, we recover the **threshold** case.

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- Master entity gives to U the **secret key** $\mathsf{sk}_A \leftarrow \mathsf{ABE.Ext}(\mathsf{params}, A, \mathsf{msk})$.

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- ENCRYPTION: to encrypt a message M, sender chooses a set of attributes $S \subset \mathcal{P}$ and a monotone increasing **decryption policy** $\Gamma \subset 2^S$, and runs $C \leftarrow \text{ABE.Enc}(\text{params}, S, \Gamma, M)$.

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  [For correctness: $\tilde{M} = M \iff A \in \Gamma$.]

ABS: Signature and Verification

- SIGNATURE: to sign a message M for a **signing policy** (S, Γ), where $\Gamma \subset 2^S$, a signer holding attributes $A \subset S$ runs $\sigma \leftarrow \mathrm{ABS.Sign}(\mathrm{params}, S, \Gamma, M, \mathrm{sk}_A)$.

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If $\Pr[\mathcal{A} \text{ wins}] \approx 1/2$, then the ABE scheme is IND-CPA secure.

ABE Security: sIND-CPA

A security game between a challenger and a possible attacker $\mathcal{A}$.

1. The challenger sends a universe of attributes $\mathcal{P}$ to $\mathcal{A}$.
2. $\mathcal{A}$ selects $S \subset \mathcal{P}$ and a decryption policy $\Gamma \subset 2^S$.
3. The challenger runs $(\text{params}, \text{msk}) \leftarrow \text{ABE.Setup}(1^\lambda, \mathcal{P})$ and gives params to $\mathcal{A}$.
4. **Secret key queries:** $\mathcal{A}$ adaptively chooses subsets $B \subset \mathcal{P}$ s.t. $B \cap S \notin \Gamma$, and must receive $\text{sk}_B \leftarrow \text{ABE.Ext}(\text{params}, B, \text{msk})$.
5. $\mathcal{A}$ outputs two messages M_0, M_1 of the same length.
6. **Challenge:** the challenger chooses $b^\star \in_R \{0, 1\}$, computes $C^\star \leftarrow \text{ABE.Enc}(\text{params}, S, \Gamma, M_{b^\star})$ and gives $C^\star$ to $\mathcal{A}$.
7. Step 4 is repeated.
8. $\mathcal{A}$ outputs a bit b, and wins if $b = b^\star$.

If $\Pr[\mathcal{A} \text{ wins}] \approx 1/2$, then the ABE scheme is sIND-CPA secure.

ABS Security: (s)EUF-CMA

A security game between a challenger and a possible attacker $\mathcal{F}$.

1. The challenger sends a universe of attributes $\mathcal{P}$ to $\mathcal{F}$.
2. (In the selective case), $\mathcal{F}$ selects $S \subset \mathcal{P}$ and a decryption policy $\Gamma \subset 2^S$.
3. The challenger runs $(\text{params}, \text{msk}) \leftarrow \text{ABS.Setup}(1^\lambda, \mathcal{P})$ and gives params to $\mathcal{F}$.
4. **Secret key queries:** $\mathcal{F}$ adaptively chooses subsets $B \subset \mathcal{P}$ s.t. $B \cap S \notin \Gamma$ (selective), and must receive $\text{sk}_B \leftarrow \text{ABS.Ext}(\text{params}, B, \text{msk})$.
5. **Signature queries:** $\mathcal{F}$ adaptively chooses tuples (S', Γ', M') and must receive $\sigma' \leftarrow \text{ABS.Sign}(\text{params}, S', \Gamma', M', \text{sk}_A)$, where $sk_A \leftarrow \text{ABS.Ext}(\text{params}, A, \text{msk})$ and $A \in \Gamma'$.
6. $\mathcal{F}$ outputs a tuple (S, Γ, M, σ).
7. $\mathcal{F}$ wins if (S, Γ, M, σ) has not been obtained in Step 5 and $1 = \text{ABS.Vfy}(\text{params}, S, \Gamma, M, \sigma)$.

If $\Pr[\mathcal{F} \text{ wins}] \approx 0$, then the ABS scheme is sEUF-CMA secure.

ABS Security: Privacy

It can be formalized through an indistinguishability game...

Intuitively: a signature $\sigma \leftarrow \mathsf{ABS.Sign}(\mathsf{params}, S, \Gamma, M, \mathsf{sk}_A)$ must reveal no information about the set of attributes A.

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This property can be achieved **computationally** (relation to a hard problem) or **perfectly**.

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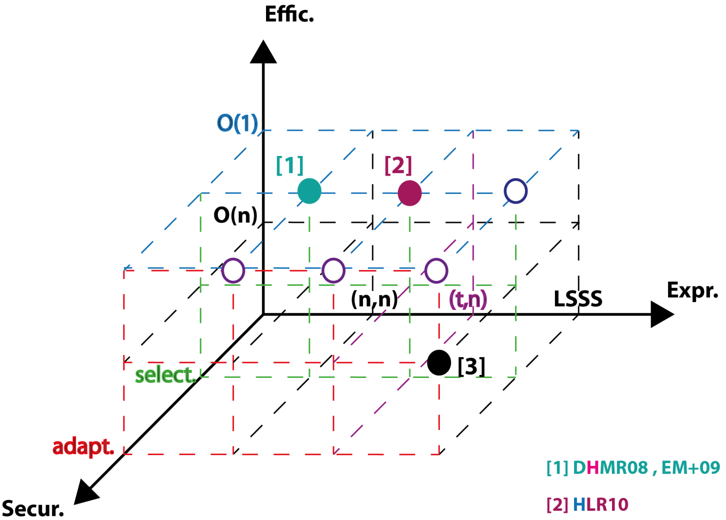
- **Efficiency:** $\left(\ |C| = |\sigma| = \mathcal{O}(n)\ \right) << \left(\ |C| = |\sigma| = \mathcal{O}(1)\ \right)$
- **Security:** $\begin{array}{rcl} \text{selective} & << & \text{adaptive} \\ \text{ROM} & << & \text{standard model} \end{array}$

CP-ABE Panorama

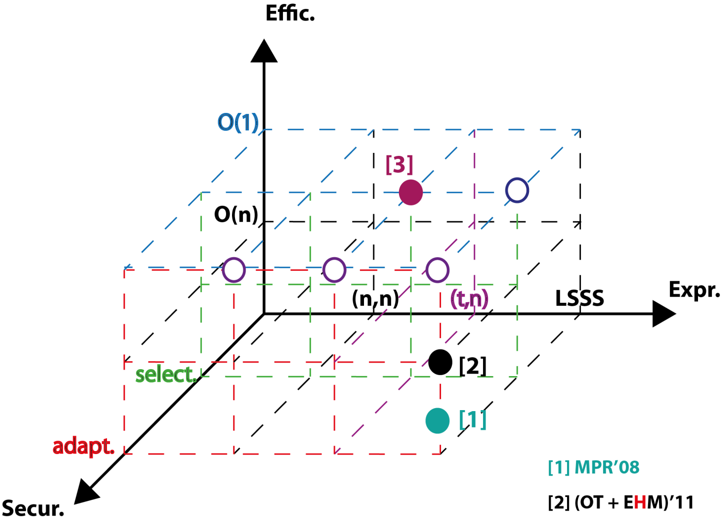


[1] DHMR08 , EM+09

[2] HLR10

[3] (OT + LSW)10

ABS Panorama



[1] MPR'08

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- **All** existing ABE schemes employ bilinear pairings.
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- What about generic constructions of ABE schemes ?

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- ABE.Enc(M, S, Γ): works exactly as $\mathsf{IBDDE.Enc}(M, S, \Gamma)$.
- ABE.Dec$(C, \Gamma, \mathsf{sk}_A)$: works exactly as $\mathsf{IBDDE.Dec}(C, \{\mathsf{sk}_i\}_{\mathsf{at}_i \in A})$.

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- Suppose a message is encrypted for $S = \{\mathrm{at}_1, \ldots, \mathrm{at}_4\}$ with a **threshold** decryption policy, $t = 3$.
- With the construction based on IB-DDE, a **coalition** of a user holding $\{\mathrm{at}_1, \mathrm{at}_2\}$ and a user holding $\{\mathrm{at}_3\}$ will be **able to decrypt**.

  [This contradicts the security requirements for ABE.]

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To achieve **coalition-resistance**, one can *try* to modify ABE.Ext: linking the values $\{\mathsf{sk}_{\mathsf{at}_i}\}_{\mathsf{at}_i \in A}$ with some additional value, **different** for each user.

From IB-DDE to ABE: Precedents

1. IB-DDE scheme in [DHMR,ProvSec'07] $\longrightarrow$ ABE scheme in [DHMR,AAECC'10] (available at ePrint 2008/502 since 2008).

   Schemes work for LSSS monotone policies, have selective security, and $|C| = 2(n - t) + \mathcal{O}(1)$.

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2. IB-DDE scheme in [DelPoi,Crypto'08] $\longrightarrow$ ABE scheme in [HLR,PKC'10].

   Schemes work for threshold policies, have selective security, and $|C| = \mathcal{O}(1)$.

But ... is there a **generic** way to achieve **'coalition-resistance'** ?

Outline

1. Attribute-Based Cryptography
2. ABC: State of the Art
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The Simple Idea

ABE = IBE + ‘secret sharing’ + ‘coalition-resistance’

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ABE $=$ IBE $+$ 'brute force approach'

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Consider **all** the subsets of A for sk_A, and **all** the subsets in Γ_0 for C.

The Scheme: Setup and Key Extraction

Let $\mathsf{IBE} = (\mathsf{IBE.Setup}, \mathsf{IBE.Ext}, \mathsf{IBE.Enc}, \mathsf{IBE.Dec})$ be an IBE scheme.

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ABE.Setup$(1^\lambda, \mathcal{P})$:

1. Run $(\mathsf{params}_{\mathsf{IBE}}, \mathsf{msk}_{\mathsf{IBE}}) \leftarrow \mathsf{IBE.Setup}(1^\lambda)$.
2. Let ID be the identity space of IBE, included in $\mathsf{params}_{\mathsf{IBE}}$. Choose a hash function $H : \{0,1\}^* \rightarrow \mathsf{ID}$.
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$\mathsf{ABE.Ext}(\mathsf{params}, A, \mathsf{msk})$:

1. For every subset $A' \subseteq A$, $A' \neq \emptyset$, run $\mathsf{sk}_{A'} \leftarrow \mathsf{IBE.Ext}(\mathsf{params}_{\mathsf{IBE}}, H(A'), \mathsf{msk})$.
2. Define $\mathsf{sk}_A = \{\mathsf{sk}_{A'}\}_{A' \subseteq A}$.

The Scheme: Encryption and Decryption

$\mathsf{ABE.Enc}(\mathsf{params}, S, \Gamma, M)$:

1. Find the basis Γ_0 of minimal subsets of Γ.
2. For each $B \in \Gamma_0$, compute $c_B \leftarrow \mathsf{IBE.Enc}(\mathsf{params}_{\mathsf{IBE}}, H(B), M)$.
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$\mathsf{ABE.Dec}(\mathsf{params}, C, \Gamma, \mathsf{sk}_A)$:

1. Find a subset $A' \subseteq A$ such that $A' \in \Gamma_0$.
2. Extract $c_{A'}$ from C, and extract $\mathsf{sk}_{A'}$ from sk_A.
3. Output $M \leftarrow \mathsf{IBE.Dec}(\mathsf{params}_{\mathsf{IBE}}, c_{A'}, H(A'), \mathsf{sk}_{A'})$.

The Scheme: (Bad) Efficiency, and "Improvements"

- Let $n = |\mathcal{P}|$ be the number of attributes.
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What about AB Signatures ? Same ideas, using **IB ring signatures** instead of IBE.

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- If the answer is **YES**, what are the typical values for $n, |A|, |\Gamma_0|$?

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AB Crypto: Theory and Practice

Theory

Practice

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- Designing new AB cryptosystems is challenging (strong security requirements).
- Many open problems $\rightarrow$ possible theoretical crypto **papers** !
- In particular, is there any **efficient and generic** way to achieve **'coalition-resistance'**, when IB-DDE $\rightarrow$ ABE ?

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Practice

- Theoretical research should be complemented with practical issues.
- Real **needs of the market** in terms of AB crypto ?
- Maybe for a small company which implements access control for its workers, IBE $\rightarrow$ ABE suffices...

Attribute-Based Cryptography: Survey and (Inefficient?) Generic Constructions

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