An Authentication Protocol with Encrypted Biometric Data
AFRICACRYPT 2008

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Work partially supported by french ANR RNRT project BACH

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2008, June 11th

Biometrics: the 3rd factor. Who I am

- allows authentication of one person and identification among a large set of persons;
- is unique, permanent, easy to use, non-transferable;

but. . .

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- cannot be chosen;
- cannot be modified if compromised;
- is public;

- is a personal data;
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How to manage *fuzzy* biometric authentication with privacy protection?

Model for a biometric system with a database

Entities:

- human user U_i who wants to authenticate himself with his biometric;
- sensor client $\mathcal{C}$ which measures biometric templates and checks their liveness;
- service provider $\mathcal{SP}$ possibly with an access to a *HSM* which manages the secret keys;
- database $\mathcal{DB}$ which stores enrolled biometric information.

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We assume $\mathcal{SP}$ and $\mathcal{DB}$ do not collude. $\mathcal{C}$ is always considered as honest.

Private biometric authentication

- $\mathcal{DB}$ stores information related to couples (ID_i, b_i),
- U_i presents its ID_i and a new measure b',
- $\mathcal{SP}$ wants to check whether b_i matches with b'.

To respect privacy, stored data and transactions must be secured.

Secure Sketches [Dodis-Reyzin-Smith'04]

Let $(\mathcal{H}, \mathrm{d})$ be a metric space. A secure sketch is a pair (SS, Rec) where

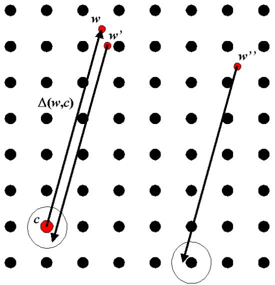
- $\mathsf{SS}(w)$, with $\mathsf{SS} : \mathcal{H} \rightarrow \{0,1\}^*$, does not leak too much about w,
- $\mathsf{Rec}(w', \mathsf{SS}(w)) = w$ if $d(w, w')$ small enough.

Allows to correct differences between measures but security should be improved by other means.

Code-offset construction [Juels-Wattenberg'98]

Given C a binary linear code, $(\mathrm{SS}_\mathrm{C}, \mathrm{Rec}_\mathrm{C})$ are defined by

- $\mathrm{SS}_\mathrm{C}(w)$ outputs $P = c \oplus w$, where $c \in_R C$;
- $\mathrm{Rec}_\mathrm{C}(w', P)$ decodes $w' \oplus P$ into a codeword c', and then outputs $c' \oplus P$.



An authentication protocol is achieved by storing $(P, H(c))$.

Goldwasser-Micali Scheme '82

Parameters

- p and q large primes, $n = pq$
- a non-residue x for which the Jacobi symbol is 1

Scheme

- $pk = (x, n)$ and $sk = (p, q)$
- $\text{Enc}(m, pk) = y^2 x^m$ for $m \in \{0, 1\}$ and $y \in_R \mathbb{Z}_n^*$
- $\text{Dec}(c, sk) = 0$ if $c = \square$, 1 otherwise.

Goldwasser-Micali Scheme '82

Properties

- IND-CPA under Quadratic Residuosity (QR) assumption
- homomorphic: $\mathrm{Dec}(\mathrm{Enc}(m, pk) \times \mathrm{Enc}(m', pk), sk) = m \oplus m'$

Generalization:
$\sqsubset m \sqsupset = (\mathrm{Enc}(m_0, pk), \ldots, \mathrm{Enc}(m_{l-1}, pk))$ for $m \in \{0, 1\}^l$

Authentication with encrypted sketches

1. Enrollment of the user U_i with b_i.
   - $\sqsubset P \sqsupset$ is stored in $\mathcal{DB}$ with $P = \mathsf{SS}_{\mathrm{C}}(b_i) = c \oplus b_i$
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2. Authentication of U_i with b'
   - $\sqsubset b' \sqsupset$ is sent to $\mathcal{DB}$
   - $\mathcal{DB}$ computes $\sqsubset P \sqsupset \times \sqsubset b' \sqsupset = \sqsubset c \oplus b_i \oplus b' \sqsupset = Z$ and sends it to $\mathcal{SP}$
   - $\mathcal{SP}$ decrypts Z, decodes $c \oplus b_i \oplus b'$ into a codeword c' and checks if $H(c') = H(c)$.

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$\Rightarrow$ encrypted data in $\mathcal{DB}$; $\mathcal{SP}$ obtains no information on biometric data

Private Information Retrieval

[Chor-Kushilevitz-Goldreich-Sudan'98]

A PIR protocol enables a user to retrieve a bit from a database.
When user asks for bit i,

- Soundness: the user retrieves the bit i
- User-Privacy: the database learns nothing about i

Symmetric PIR:

- Database-Privacy: the user learns nothing about other bits in the database

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Private Block Retrieval

A PBR protocol enables a user to retrieve a block from a block-database.

Allows to reduce communication cost to poly-log complexity [Lipmaa'05,Gentry-Ramzan'05]

Paillier Cryptosystem '99

Parameters

- $n = pq$ an RSA integer, g of order n modulo n^2

Scheme

- $pk = (n, g)$ and $sk = \lambda(n)$ (λ Carmichael function)
- $\mathrm{Enc}(m, pk) = g^m r^n \mod n^2$ for $m \in \mathbb{Z}_n$ and $r \in_R \mathbb{Z}_n^*$
- $\mathrm{Dec}(c, sk) = \frac{L(c^{\lambda(n)} \mod n^2)}{L(g^{\lambda(n)} \mod n^2)} \mod n$ with $L(u) = \frac{u-1}{n}$

Properties

- IND-CPA under degree n decisional Composite Residue problem
- $\mathrm{Dec}(\mathrm{Enc}(m, pk) \times \mathrm{Enc}(m', pk) \mod n^2, sk) = m + m' \mod n$
- $\mathrm{Dec}(\mathrm{Enc}(m, pk)^k \mod n^2, sk) = km \mod n$

Generalization [Damgård-Jurik'01-03]

Length flexible encryption

For $m \in \mathbb{Z}_{n^s}^*$, $[\![m]\!]_s = (1+n)^m r^{n^s} \mod n^{s+1}$ with $r \in \mathbb{Z}_n^*$

Allows re-encryption of encrypted messages.

Used in Lipmaa's PIR to reduce the communication cost by working on a multidimensional $\mathcal{DB}$.

Successive re-encryptions lead to reduce progressively the size of the processed database and to obtain only the requested data at the end (after successive decryptions).

Identity Privacy

The adversary $\mathcal{A}$ plays the role of $\mathcal{DB}$ or $\mathcal{SP}$, and tries to learn some information from the enrolled data.

1. $\mathcal{A}_1$ generates a set $(i, ID_i, b_i^{(0)}, b_i^{(1)}, (ID_j, b_j)(j \neq i))$
2. The challenger randomly chooses a template $b_i^{(e)}$ for ID_i and simulates the enrollment phase for $(ID_i, b_i^{(e)})$ and all the (ID_j, b_j)
3. $\mathcal{A}_2$ lets the challenger to issue Verification queries on the sensor side
4. $\mathcal{A}_2$ outputs a guess e'

Transaction Anonymity

The adversary $\mathcal{A}$ plays the role of $\mathcal{DB}$, and tries to learn some information from the user.

1. $\mathcal{A}_1$ generates a set $\{(ID_j, b_j)\}$
2. The challenger simulates the enrollment phase for all the (ID_j, b_j)
3. $\mathcal{A}_2$ lets the challenger to issue Verification queries on the sensor side and outputs (i_0, i_1)
4. The challenger randomly chooses $e \in_R \{0, 1\}$ and issues a Verification query with input i_e
5. $\mathcal{A}_3$ lets the challenger to issue Verification queries on the sensor side and outputs a guess e'

Adaptation of the PIR User-Privacy property. The same is possible for Data-Privacy vs $\mathcal{SP}$.

Secure Biometric Authentication

A biometric authentication scheme must satisfy

- Soundness: $\mathcal{SP}$ will accept an authentication request of (ID_i, b') from $\mathcal{C}$ side iff b' and b are matching (biometric) data, except for a small probability
- Identity Privacy vs $\mathcal{DB}$ or $\mathcal{SP}$
- Transaction Anonymity vs $\mathcal{DB}$

Soundness: in practice, probability of failure depends of biometrics performances (FRR/FAR)

Overview

We want to combine encrypted secure sketches with PIR in an efficient and quite transparent way.

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The idea is to combine two "compatible" encryption schemes to benefit from both homomorphic properties

$$[\![\sqsubset c \sqsupset]\!]_s^{\sqsubset w \sqsupset} = [\![\sqsubset c \sqsupset \times \sqsubset w \sqsupset]\!]_s = [\![\sqsubset c \oplus w \sqsupset]\!]_s$$

where $\sqsubset . \sqsupset$ stands for Golwasser-Micali encryption and $[\![.]\!]_s$ for Damgård-Jurik of length n^s

It allows us to embed information in a classical PIR request.

Parameters

- $\mathcal{SP}$ is associated to (pk_{GM}, sk_{GM}) and (pk_{DJ}, sk_{DJ}); secret keys are stored inside a *HSM*
- M users $U_1, \ldots, U_M$
- $\mathcal{DB}$ contains $a_i = (a_{i,0}, \ldots, a_{i,l-1}) = \sqsubset \mathrm{SS}_{\mathrm{C}}(b_i) \sqsupset$, for $i = 1, \ldots, M$, with $\mathrm{SS}_{\mathrm{C}}(b_i) = b_i \oplus c_i$ and b_i l-bits biometric template.
- $\mathcal{DB}$ stores also $a_{i,l} = H(c_i)$.

To simplify, we explain now the verification phase for $s = 1$, i.e. with Paillier and only one iteration in Lipmaa's PIR.

Verification Phase

Authentication of user U_i

1. $\mathcal{C}$ measures b', computes $\sqsubset b' \sqsupset$ and sends to $\mathcal{DB}$, $[\![\delta_k^u]\!]$, $k = 1, \ldots, M$, $u = 0, \ldots, l$ where $(\delta_k^0, \ldots, \delta_k^{l-1}, \delta_k^l) = (\sqsubset b' \sqsupset, 1)$ if $k = i$ and $(0, \ldots, 0)$ otherwise

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2. $\mathcal{DB}$ computes for $u = 0, \ldots, l-1$

$$[\![\sqsubset (\mathrm{SS}_{\mathrm{C}}(b_i) \oplus b')_u \sqsupset]\!] = [\![a_{i,u} \times \sqsubset (b')_u \sqsupset]\!] = \prod_{k=1}^{M} [\![\delta_k^u]\!]^{a_{k,u}}$$

and $[\![H(c_i)]\!] = [\![a_{i,l}]\!] = \prod_{k=1}^{M} [\![\delta_k^l]\!]^{a_{k,l}}$. Then sends everything to $\mathcal{SP}$

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   and $[\![H(c_i)]\!] = [\![a_{i,l}]\!] = \prod_{k=1}^{M} [\![\delta_k^l]\!]^{a_{k,l}}$. Then sends everything to $\mathcal{SP}$
3. HSM decrypts with sk_{GM}, sk_P to recover $\mathrm{SS_C}(b_i) \oplus b'$ and $H(c_i)$, decodes into c', checks if $H(c') = H(c_i)$ and forwards the result to $\mathcal{SP}$

PIR Performances

- With Paillier, communication cost linear in M
- Expandable to Lipmaa's protocol for a dimension λ with λ Damgård-Jurik encryption scheme $[\![.]\!]_s, \ldots, [\![.]\!]_{s+\lambda-1}$
  Communication cost in $O(\log^2 M)$

This combination is valid with all PIR based on a homomorphic scheme with a compatible group law (e.g. [Chang'04]).

Security / Privacy

- Soundness: if the PIR and $(\mathrm{SS}_{\mathrm{C}}, \mathrm{Rec}_{\mathrm{C}})$ are sound
- Identity Privacy: under QR assumption
- Transaction Anonymity vs $\mathcal{DB}$: if the PIR achieves User-Privacy

Transaction Anonymity vs $\mathcal{SP}$?

Needs to renew c_i after each Verification query
(or regularly to avoid long-term tracking)

Conclusion

We have described a new Biometric Authentication Scheme

- Improvement of a previous scheme presented at ACISP'07 [Bringer-Chabanne-Izabachène-Pointcheval-Tang-Zimmer]
- Preserves privacy of users
- Deals only with encrypted biometric data
  a new way to manage secure sketches with homomorphic encryption to enable a strict separation between biometric data and temporary data
- Uses a communication efficient PIR

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Research issues

- Improve information rates (encryption)
- Improve computational cost

Thanks! Any question?