TOMIN: Trustworthy Mobile Cash with Expiration-date Attached

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Abstract—Online mobile payment systems based on mobile cash provide privacy to customers and are feasible for real point of sale, virtual point of sale, and person-to-person mobile commerce scenarios. The merchant does not perform complex operations and the bank verifies the validity of the mobile cash before the merchant delivers the product. The bank must store the mobile cash spent in a database to prevent a double spending attack. In this paper, we propose an efficient mobile cash scheme in which the customer attaches the expiration date and deposit date. This property reduces the size of the bank’s database and the customer must spend the mobile cash before expiry. Moreover, the customer attaches the merchant’s identity into the mobile cash in the deposit phase. The scheme requires low computational cost and is suitable for mobile devices.

Index Terms—electronic cash, micro-payment, mobile commerce, one-way hash function, secure communication

I. INTRODUCTION

Due to the fast progress of mobile commerce, several mobile payment systems [1], [2], [3], [4], [5], [6], [7], [8], [9], [10] have been proposed. Some of these systems are based on mobile cash (m-cash). The use of m-cash provides privacy to customers and it is suitable for micro-payments.

In classic m-cash and e-cash systems [6], [8], [11], [12] proposed in the literature, the cash is built using hash chains [13]. A hash chain is used to create a chain \( h_i = H(\text{seed}), h_0 \), \( h_1 = H(h_0), h_2 = H(h_1), \ldots, h_i = H(h_{i-1}) \), where \( H(\cdot) \) is a one-way hash function \([14], [15]\), seed is a secret value, \( h_i \) denotes the composition of \( h \) with itself for \( i \) times, and \( h_i = H(\text{seed}) = \text{seed} \). The length of this chain \( l_i \) is defined as the number of function compositions required to obtain the highest value of the m-cash.

A typical online mobile payment system contains three types of participants (a customer, a merchant, and a bank) and four phases (initializing, withdrawing, unblinding, and depositing). In the initialization phase, the bank generates the key pair and publishes the public key \((e, p)\) and a one-way hash function \( H(\cdot) \). In the withdrawal phase, the customer withdraws her m-cash in a blinded version from the bank. Then, she unblinds her blinded m-cash to obtain valid cash. In the deposit phase, the customer sends the m-cash to the merchant and the merchant forwards the m-cash to the bank. The bank verifies whether or not the m-cash is fresh. Finally, the bank deposits the funds in the merchant’s bank account.

In the last few years, new e-cash schemes with date-attached have been introduced in [16], [17], [18]. The use of expiration-date contributes to preventing the bank’s database from growing uncontrollably [16]. Moreover, the use of the date in the m-cash gives the option of calculating the interest on the m-cash [17], [18]. Although the protocol of [17] is more efficient than [18] in storage load and computational cost, the customer and the merchant must perform many asymmetric operations (modular exponentiation computations) to process the electronic cash and to verify the electronic cash, respectively. The use of asymmetric operations (e.g., RSA algorithm) requires high energy- and time-consuming, and therefore these schemes are not efficient or suitable for mobile devices.

In this paper, we propose a new m-cash scheme called TOMIN (Trustworthy Mobile cash with expiration date-attachment). In TOMIN, the customer first attaches the expiration date and then withdraws blind m-cash from the bank. The customer uses a value \( v \) pre-defined by the bank, so that the bank can verify partial information stored in the blinded message and sign it. The scheme provides privacy to customers in the withdrawal step. After the customer obtains her m-cash, she has a short time within which to use it. Moreover, the customer attaches the deposit date and merchant’s identity into the mobile cash using a concatenation operation and a one-way hash function. This characteristic prevents any eavesdropper from trying to deposit the m-cash into her bank account.

The rest of this paper is organized as follows. In Section 2, we review related works. The proposed scheme is described in Section 3. In Section 4, we analyse the performance, security and storage of the proposal, and make comparison with other schemes.

1 Mobile cash is an extension of electronic cash (e-cash) for mobile devices. In this paper we refer to m-cash instead of e-cash.
Finally, concluding remarks of this paper are given in Section 5.

II. PRELIMINARY

A. Untraceable electronic cash based on blind signature scheme

Chaum proposed a blind signature scheme and then applied this scheme to design untraceable electronic cash [19] which provides privacy to customers. There are three participants: a customer, a merchant, and a bank. The scheme consists of the following phases:

Initialization phase. The bank generates its RSA keys. The bank randomly selects two distinct large primes $p$ and $q$, and then computes $n = pq$ and $\varphi = (p - 1)(q - 1)$. The bank chooses a large integer $e$ at random, where $1 < e < \varphi$ and $\text{GCD}(e, \varphi) = 1$, and computes an integer $d$ with $1 < d < \varphi$, such that $ed \equiv 1 \pmod{\varphi}$. Finally, it keeps $(d, p, q)$ secrets and $(e, n)$ public. The bank publishes a one-way hash function $H()$ and $(e, n)$.

Withdrawal phase. The customer defines $v = w \| \delta$, where $\|$ indicates concatenation. Then, the customer randomly selects two integers $m$ and $r$, and computes $\alpha = H(n)\alpha^m (mod n)$. Then, the customer sends $(\alpha, v)$ to the bank. The bank verifies that $v$ is in correct format. If $v$ is correct, the bank computes $\beta = \alpha^d (mod n)$, where $d, e \equiv (ev)^{-1} (mod \varphi)$. The bank deducts $w$ funds (e.g. dinar, euro, etc.) from the customer’s account. Finally, the bank sends $(\beta)$ to the customer.

Unblind phase. After the customer receives $\beta$, she computes $s = \beta r^{-1} \pmod{n}$ to obtain the triple $(\nu, m, s)$, where $(\nu, m, s)$ is the electronic cash for $w$ dinar.

Deposit phase. The customer sends $(m, s)$ to the merchant for a payment of $x$ euros. The merchant verifies the electronic cash computing $s' = H(m)\nu^r (mod n)$. If the verification process is correct, the merchant forwards $(m, s)$ to the bank. The bank verifies if $v$ is in correct format and checks whether or not the electronic cash is fresh. Then, the bank deposits $x$ funds into the merchant’s account and keeps $(m, s)$ in its database.

B. Untraceable electronic cash based on partial blind signature scheme

Abe and Fujisaki introduced the concept of a partial blind signature scheme [16], based on Chaum’s blind signature scheme, in which the bank can verify some term of validity in the signing message. Then, they applied this scheme to date attached electronic cash to prevent the bank’s database from growing uncontrolled.

There are three participants: a customer, a merchant and a bank. The main difference with Chaum’s scheme is that the customer and the bank negotiate and agree the format of constant $v$ which it is used to control the expiration date of the electronic cash. The constant $v$ contains the amount to withdraw $w$ funds (e.g. dinar, euro, etc.) and the expiration date $\delta$. The scheme consists of the following phases:

Initialization phase. The bank generates its RSA keys. The bank randomly selects two distinct large primes $p$ and $q$, and computes $n = pq$ and $\varphi = (p - 1)(q - 1)$. The bank chooses a large integer $e$ at random, where $1 < e < \varphi$ and $\text{GCD}(e, \varphi) = 1$, and computes an integer $d$ with $1 < d < \varphi$, such that $ed \equiv 1 \pmod{\varphi}$. Finally, it keeps $(d, p, q)$ secrets and $(e, n)$ public. The bank publishes a one-way hash function $H()$ and $(e, n)$.

Withdrawal phase. The customer defines $v = w \| \delta$, where $\|$ indicates concatenation. Then, the customer randomly selects two integers $m$ and $r$, and computes $\alpha = H(n)\alpha^m (mod n)$. Then, the customer sends $(\alpha, v)$ to the bank. The bank verifies that $v$ is in correct format. If $v$ is correct, the bank computes $\beta = \alpha^d (mod n)$, where $d, e \equiv (ev)^{-1} (mod \varphi)$. The bank deducts $w$ funds (e.g. dinar, euro, etc.) from the customer’s account. Finally, the bank sends $(\beta)$ to the customer.

Unblind phase. After the customer receives $\beta$, she computes $s = \beta r^{-1} \pmod{n}$ to obtain the triple $(\nu, m, s)$, where $(\nu, m, s)$ is the electronic cash for $w$ euros.

Deposit phase. The customer sends $(m, s)$ to the merchant for a payment of $x$ euros. The merchant verifies the electronic cash computing $s' = H(m)\nu^r (mod n)$. If the verification process is correct, the merchant forwards $(m, s)$ to the bank. The bank verifies if $v$ is in correct format and checks whether or not the electronic cash is fresh. Then, the bank deposits $x$ funds into the merchant’s account and keeps $(m, s)$ in its database.

C. Date attachable electronic cash

Fan et al. [17] introduced the concepts of withdrawal date and effective date in the electronic cash. The scheme contains three participants (a customer, a merchant, and a bank) and consists of the following phases:

Initialization phase. The bank randomly selects two distinct primes $p$ and $q$. Then, it computes $n = pq$ and $\varphi = (p - 1)(q - 1)$. The bank chooses a large integer $e$ at random, where $1 < d < \varphi$ such that $ed \equiv 1 \pmod{\varphi}$. The bank keeps secret $(d, p, q)$, and publishes $(e, n)$ as a public.

Withdrawal phase. The customer randomly chooses an integer $r$ and six numbers $x_1, x_2, x_3, x_4, x_5, x_6$. Then, she computes $\alpha = H(m)\nu^r (mod n)$, where $m = H^{100}(x_1) || H^{101}(x_2) || H^{102}(x_3) || H^{103}(x_4) || H^{104}(x_5) || H^{105}(x_6)$. The customer sends $(\alpha)$ to the bank. The bank computes $\beta = \alpha^d (mod n)$ and sends it to the customer. The bank deducts $w$ funds (e.g. dinar, euro, etc.) from the customer’s bank account.

Unblind phase. The customer computes $s = \beta r^{-1} \pmod{n}$ and obtains her electronic cash $(m, s)$.

Deposit phase. The merchant chooses a large integer $\delta$ and computes $\kappa = \delta^d (mod n)$, where $d, e \equiv (ev)^{-1} (mod \varphi)$. The bank deducts $w$ funds (e.g. dinar, euro, etc.) from the customer’s account. Finally, the bank deposits $x$ funds into the merchant’s bank account.
D. Flexible date-attachment electronic cash

In this scheme [18], there are three participants (a customer, a merchant and a bank). The customer withdraws the m-cash from the bank and pays it to merchant. This scheme consists of five steps: 1) initializing; 2) withdrawing; 3) unblinding; 4) date-attaching; 5) depositing. The customer attaches the effective date in a phase called date-attaching.

Initialization phase. The bank generates two key pairs. The bank keeps secret \((d, p, q)\) and \((q_1, p_1, q_1)\), and publishes \((e, n), (e_1, n_1)\), and a one-way hash function \(H(.)\).

Withdrawal phase. The customer randomly chooses an integer \(r\) and computes \(\alpha = H(m)^r (mod \ n)\), where \(m\) is a random number in each withdrawal. Then, the customer sends \((\alpha)\) to the bank. The bank computes \(\beta = \alpha^e (mod \ n)\) and sends it to the customer. The bank deducts \(w\) (e.g. dinar, euro, etc.) from the customer’s bank account.

Unblind phase. The customer computes \(s = \beta r^e (mod \ n)\) and obtains her electronic cash \((m, s)\).

Date-attachment phase. The customer randomly chooses an integer \(r_1\) and computes \(\alpha_1 = H(s)v_{r_1}^{ed} (mod \ n)\). The customer sends \((\alpha_1)\) to the bank. The bank computes \(\beta_1 = \alpha_1^{e_1} (mod \ n)\) and sends it to the customer. The customer computes \(\delta = \beta_1 r_1^e (mod \ n)\) and obtains the date slip \((s, \delta)\) of her electronic cash. Then, the customer sends \((s, \delta, yy, mm, dd)\) to the bank, where \(yy, mm, dd\) corresponds to the year, month, and the date for the effective date. The bank verifies if the date slip is valid computing \(\delta' = H(s) (mod \ n)\). If the verification process is correct, the bank computes \(\beta_2 = H(s || yy || mm || dd)^{e_1} (mod \ n)\) and sends it to the customer. The customer computes \(s_1 = \beta_2 r_1^{e_1} (mod \ n)\) and obtains the effective date of her electronic cash \((m, s, s_1, yy, mm, dd)\).

Deposit phase. When a customer wants to pay for a product, she sends \((m, s, s_1, yy, mm, dd)\) to the merchant. The merchant verifies the electronic cash computing \(\delta' = H(s) (mod \ n)\). Then, the merchant forwards the electronic cash to the bank. The bank verifies the electronic cash and check whether or not it is fresh. Finally, the bank deposits \(x\) funds in to the merchant’s bank account.

III. TOMIN SCHEME

In this section, we propose an efficient m-cash scheme with expiration-date attached to control the bank’s database and memory of the customer’s mobile device. The date is attached using a string concatenation and a one-way hash function. The proposal does not require several hundred hashes or complex mathematical operations. The m-cash maintains the privacy of the customers. Moreover, the scheme contemplates the deposit date for financial purposes. The proposed scheme includes the following participants.

- A bank is the entity that issues and manages m-cash.
- A customer is a person who uses a mobile device and m-cash to pay for products.
- A merchant is a person or vending machine that accepts m-cash.

The scheme consists of four phases: initializing, withdrawing, unblinding, and depositing. Figure 1 shows the proposed scheme.

- In the initialization step, the bank generates its private/public keys, and publishes the public key and one-way hash function \(H(.)\).
- In the withdrawal step, the customer attaches the expiration date to the m-cash and withdraws her m-cash from the bank.
- In the unblinding step, the customer recovers her m-cash signed by the bank.
- In the depositing step, the customer pays \(w\) m-cash to a merchant and the bank deposits the funds in the merchant’s account.

The notation used in the description of the proposed protocol is given in Table 1.

<table>
<thead>
<tr>
<th>Notation</th>
<th>Meaning</th>
</tr>
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<tbody>
<tr>
<td>(p)</td>
<td>Bank</td>
</tr>
<tr>
<td>(C_i)</td>
<td>ith customer</td>
</tr>
<tr>
<td>(M_i)</td>
<td>ith merchant</td>
</tr>
<tr>
<td>(ID_m)</td>
<td>Merchant’s identity</td>
</tr>
<tr>
<td>(\delta)</td>
<td>Expiration date</td>
</tr>
<tr>
<td>(\delta_1)</td>
<td>Deposit date</td>
</tr>
<tr>
<td>(w)</td>
<td>The amount to withdraw</td>
</tr>
<tr>
<td>(x)</td>
<td>The amount to pay and to deposit</td>
</tr>
<tr>
<td>(r, seed)</td>
<td>Random numbers</td>
</tr>
<tr>
<td>(h_i = H^r(seed))</td>
<td>Perform (r) times one-way hash function</td>
</tr>
<tr>
<td>(l)</td>
<td>The length of the hash chain</td>
</tr>
<tr>
<td>(|)</td>
<td>The concatenation operation</td>
</tr>
</tbody>
</table>

The details of the scheme are as follows:

A. Initialization phase

The bank randomly selects two distinct primes \(p\) and \(q\). Then, it computes \(n = pq\) and \(\varphi = (p-1)(q-1)\). The bank chooses a large integer \(e\) at random, where \(1 < d < \varphi\) such that \(ed = 1 (mod \ \varphi)\). The bank keeps secret \((d, p, q)\), and publishes \((e, n)\) and a one-way hash function \(H(.)\).

B. Withdrawal phase

We assume that the customer \(C_i\) wants to withdraw \(w\) units of m-cash. The customer \(C_i\) should perform the following steps:

- She randomly chooses two integers \(r\) and \(seed\), and defines \(v = w || \delta\), where \(\delta\) represents a short time pre-defined by the bank (e.g. 30 days).
- She computes \(h_i = H^r(seed)\) and \(\alpha = H(m)^r (mod \ n)\), where \(m = h_i || l || v\).
- She sends \((\alpha, v)\) to the bank \(B\) through a secure channel.
Upon receiving the message from the customer $C_i$, the bank $B$ performs the following steps:

- It verifies the correct format of $v$.
- It computes $\beta = d^\beta \pmod{n}$.
- It sends $\beta$ to the customer $C_i$ through a secure channel.

Finally, the bank deducts $w$ funds (e.g., dinar, euro, etc.) from the customer’s account. The transmitted messages of this phase are showed in Figure 1.

C. Unblind phase

The customer $C_i$ computes $s = \beta r^j \pmod{n}$ and obtains her electronic cash $(m, s)$.

D. Deposit phase

We assume that the customer $C_i$ buys a product and must pay $x$ units of m-cash. The customer $C_i$ performs the following steps:

- It computes $h_{i,x} = H^*(m)$ such that $H^*(h_{i,x}) = h_i$.
- It computes $F = H(x \parallel h_{i,x} \parallel ID_M \parallel \delta_i)$ and $G = H(m \parallel s \parallel F)$.
- It sends $(m, s, x, h_{i,x}, ID_M, \delta_i, G)$ to the merchant $M_i$ through a secure channel.

After the merchant $M_i$ receives the message, she performs the following steps:

- It verifies whether or not $\delta_i$ is correct.
- It computes $F^* = H(x \parallel h_{i,x} \parallel ID_M \parallel \delta_i)$ and $G^* = H(m \parallel s \parallel F)$.
- It compares $F^*$ with $F$ and $G^*$ with $G$.
- It sends $(m, s, x, h_{i,x}, ID_M, \delta_i, G)$ to the bank $B$ through a secure channel.

Upon receiving the message from the $M_i$, the bank $B$ performs the following steps:

- It verifies whether or not $\delta_i$ is correct.
- If computes $F = H(x \parallel h_{i,x} \parallel ID_M \parallel \delta_i)$ and $G = H(m \parallel s \parallel F)$.
- It checks whether or not $h_i$ is fresh.
- It computes $s' = H(m) \pmod{n}$ and $h_i = H'(h_{i,x})$.
- It deposits $w$ funds into the merchant’s account.
- It computes $s' = H(m \parallel v) \pmod{n}$, where $m = h_{i,x} \parallel \delta_i \parallel v$.
- It sends $(m', s')$ to the merchant $M_i$ through a secure channel.

Finally, the bank stores $(m, s)$ in a database to prevent a double-spending attack and to delete the m-cash expire.

Then, the merchant $M_i$ forwards the m-cash to the customer $C_i$.

Figure 2 shows the transmitted messages among the customer $C_i$, merchant $M_i$, and bank $B$.

IV. ANALYSIS AND COMPARISONS

In this section, we examine the security, performance and storage of the proposed scheme.

A. Security Analysis

In this sub-section, we analyse the security of the proposed scheme.

In the $i$-th withdrawal step, the bank cannot link $s$ to $\beta$ because it does not have the blinding factor $r$. Moreover, the merchant cannot obtain information about the customer from the payment information $(m, s, x, h_{i,x}, ID_M, \delta_i, G)$. The customer’s privacy from the bank and the merchant is guaranteed in the withdrawing and depositing steps.

In the $i$-th withdrawal step, the bank verifies the correct format of $v$.

In the $i$-th unblind step, the customer cannot forge another m-cash $(m, s)$ without the bank’s secret key $d$. Factoring $n$ is intractable, so that it is computationally infeasible for an attacker forging a valid m-cash $(m, s)$, such that $s H(m) m' = 1 \pmod{n}$.

In the $i$-th deposit step, the customer cannot use her m-cash after the expiration date $\delta_i$. If the customer tries to pay using expired m-cash, the bank will reject the transaction.

In the $i$-th deposit step, the merchant can deposit the m-cash $(m, s)$ just on the indicated date by the customer. If the merchant wants to deposit the m-cash after the deposit date $\delta_i$, the bank will reject the transaction.

If the merchant tries to deposit the m-cash more than one time, the bank will detect the attack when it checks the validity of $h_i$.

If an attacker intercepts the payment information, she cannot deposit the m-cash $(m, s)$ in her bank account because the m-cash is linked together with the merchant’s identity $ID_M$ via $F = H(x \parallel h_{i,x} \parallel ID_M \parallel \delta_i)$. The difficulty of deriving $F^* = H(x \parallel h_{i,x} \parallel ID_M \parallel \delta_i)$ and $G = H(m \parallel s \parallel F^*)$ with other merchant’s identity $ID_M^*$ relies on the strength of the one-way hash function.
In the i-th deposit step, the bank verifies whether or not $h_i$ is fresh.

In the i-th deposit step, the bank verifies whether or not $\delta$ and $\delta_i$ are correct.

In the i-th deposit step, the merchant cannot use the m-cash $(m', s')$ to carry out a payment because she do not know the seed of the hash chain.

Given the payment information $(m, s, x, h_{i+1}, ID_M, \delta, G)$, the bank cannot find the instance of the withdrawing step that produced the m-cash.

B. Performance Analysis

Due to the resources constraints of mobile devices, the m-cash scheme must take efficiency evaluation into consideration. In this sub-section, we evaluate our scheme and compare with related schemes in Table 2. The notation $T_R$ and $T_{exp}$ are defined as the execution times for hash functions and exponential operations, respectively. The execution time of exponential operations, under a modulus $n$, is about $O[|n|]$ time, where $|n|$ denotes the bit length of $n$. On the other hand, the execution time of a hash function does not take longer than the exponential operations. The time complexity associated with the different operations can be expressed as $T_R < T_{exp}$.

The computational cost is defined as the total time of various operations executed in each step. According to the above definition, the computation cost in the withdrawal phase is time $(w + 1)T_R + 2T_{exp}$. The consumer requires $T_{exp}$ time in the unblinding phase. The times required by the customer, merchant and bank in the depositing phase are $(w + x + 2)T_R$, $2T_R$, and $(x + 4)T_R + 2T_{exp}$, respectively.

C. Storage Analysis

In this sub-section, we compare our scheme with the related schemes in terms of storage capacity. We use the following assumptions to evaluate the storage capacity of our scheme and related works. Assume the $ID_M$, $l$, $r$, seed, $x$ and $w$ are 40-bit length, and $\delta$ and $\delta_i$ are 64-bit length; the large prime in modular operation is 1024-bit length. We also assume that the output size of a one-way hash function is 128-bit length. In our scheme, the customer stores the following parameters in her mobile device: $m$, $s$, $r$, and seed, so the memory needed in the customer’s mobile device is 1376$(4*40) + 64 + 128$ bits. The comparison of our scheme and related schemes are shown in Table 3.

Moreover, we summarize the functionality of the proposed scheme and make comparison with related schemes in Table 4. It demonstrates the advantage of our scheme.

V. CONCLUSIONS

In this paper, we have proposed TOMIN, an efficient, practical, and trustworthy m-cash with expiration-date attached. In this scheme, the expiration date is important to control the bank’s database and the customer’s mobile device memory. The scheme uses a concatenation operation and a one-way hash function to attach the expiration date to m-cash. We demonstrate that our scheme satisfies the basic security requirements and prevents forgery and double-spending attacks. It is well suited to mobile devices.
In addition, the proposed scheme has the following merits: 1) the storage capacity and computational cost are more efficient than those of previous works; 2) our scheme can resist several attacks; 3) the deposit date is attached by the customer; and 4) the customer attaches the merchant’s identity into the m-cash.

ACKNOWLEDGMENT

This work has been partially supported by the Spanish public funded projects ARES (CONSOLIDERINGENIO-2010 CSD2007-00004) and ITACA (TSI2006-13409-C02-02), and graduate scholarship from CONACYT (Mexico).

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