Crypto-analyses on "user efficient recoverable off-line e-cashs scheme with fast anonymity revoking"

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Abstract

Recently, Fan et al. proposed a user efficient recoverable off-line e-cash scheme with fast anonymity revoking. They claimed that their scheme could achieve security requirements of an e-cash system such as, anonymity, unlinkability, double spending checking, anonymity control, and rapid anonymity revoking on double spending. They further formally prove the unlinkability and the un-forgeability security features. However, after crypto-analysis, we found that the scheme cannot attain the two proven security features, anonymity and unlinkability. We, therefore, modify it to comprise the two desired requirements which are very important in an e-cash system.

1. Introduction

There have been many cryptographic scientists working within the field of e-cash system design [1-21] since Chaum first proposed the concept of e-cash and its paper cash-like properties of anon*ymity*, *verifiability*, and *unforgeability* (Chaum 1982) in 1982 [1]. An e-cash system typically contains three roles: customer, bank, and the merchant, and three protocols: withdrawal protocol, payment protocol, and the deposit protocol. In the protocol design principle, the user's identity cannot be revealed, to assure his purchasing privacy. Conversely, it can be disclosed when double spending or illegal transaction occurs. In an off-line e-cash scheme, the bank cannot prevent the double spending on-line. Therefore, it must have the ability to revoke the anonymity of the user who doubly spent his e-cash. In 2013, Fan et al. [16] proposed an excellent off-line e-cash scheme with fast anonymity revoking. They claimed that each user possessed anonymity and un-linkability, when spending e-cash in their scheme, and the user is allowed to recover his e-cash when lost. Besides, the bank can detect the double spending and efficiently derive the identity of the user, without any help of the TTP. Moreover, TTP can revoke the anonymity of the e-cash owner when illegal transaction occurs. Additionally, their scheme allows the police to trace a specific user. However, after examining their scheme, we found that it does not have anonymity and

un-linkability. We, therefore, for enhancing its security, modify it to comprise these two features which are very important in an e-cash system. We demonstrate it in this article.

2. Review of Fan et al.'s IBS scheme

Fan et al.'s e-cash scheme [16] consists of two main protocols: the withdrawal protocol and the payment (and deposit) protocol, and four entities user, bank, shop and the judge. Meanwhile, they use Chaum's signature and the chameleon hashing functions to design the scheme. The used notations can be referred to the original article. Here, we only list the withdrawal protocol and the payment protocol to illustrate its weakness.

2.1 The withdrawal protocol

The scheme assumes that the bank can authenticate the user through a secure channel. They omit the design relating to this portion. The withdrawal protocol is depicted as follows.

1. User→Bank: $E_{pk\_j}(k, m, r)$.

   The user randomly chooses three strings *(k,m, r)*, where k$\in\{0, 1\}^{lk}$ and m, r$\in z_q^*$.

   Then, he sends $E_{pk\_j}(k, m, r)$ to the bank.

2. Bank→The judge device: ($E_{pk\_j}(k, m, r)$, μ).

   After the bank authenticates the user, it knows the user's identity ID_u. It then sets $\mu = ID_u$, and inputs $E_{pk\_j}(k, m, r)$ and μ into the judge device.

3. The judge device→Bank: (β, $E_k(x, \bar{x}, c, k, \delta)$)).

   After receiving $E_{pk\_j}(k, m, r)$ and μ, the judge device uses *sk_j* to decrypt $E_{pk\_j}(k, m, r)$ and gets *(k,m, r)*. Then, it randomly chooses three strings (r_1, r_2, c), where r_1, $r_2\in$ $\{0, 1\}^{lr}$ and c$\in z_{n_b}^*$ and computes $x=(\mu \parallel r_1)\in z_q^*$, $\bar{x} = x^{-1} \bmod q$, $\delta = E_{pk\_j}(\mu, r_2)$, and $y = g^x \bmod p$. Finally, it computes $\beta = (c^{-1})^{eb} (g^m y^r \bmod p) H(\delta \parallel y) \bmod n_b = (c^{-1})^{e_b} h_{HK}(m, r) H(\delta \parallel y) \bmod n_b$ and outputs

(β , $E_k(x, \bar{x}, c, k, \delta)$) to the bank, where *HK = (p, q, g, y).*

4. Bank→User: ($t, E_k(x, \bar{x}, c, k, \delta)$).

After receiving (β , $E_k(x, \bar{x}, c, k, \delta)$) from the judge device, the bank computes $t = \beta^{d_b} \bmod n_b$ and returns (t, $E_k(x, \bar{x}, c, k, \delta)$) to the user. Then the bank stores (ID_u, $E_{pk\_j}(k, m, r)$, $E_k(x, \bar{x}, c, k, \delta)$) for e-cash tracing and recovery.

5. Unblinding: After receiving (t, $E_k(x, \bar{x}, c, k, \delta)$), the user decrypts $E_k(x, \bar{x}, c, k, \delta)$ and parses the 4th parameter in the decryption result as k' . Then he checks whether $k' = k$. If it's true, he computes $\sum = ct \bmod n_b$. At last, the user obtains an e-cash $(\sum, y, m, r, \delta)$.

2.2 The off-line payment protocol

The off-line payment protocol is described as follows.

1. Shop→User: (m').

When a user makes a payment to a shop, the shop will randomly choose a string r_s and compute $m' = (ID_s \,||\, r_s)$, such that $m' \in z_q^*$, where ID_s is the shop's identity. Then the shop sends m' to the user.

2. User→Shop: $(\sum, y, r', \delta)$.

After receiving m', the user computes $r' = \bar{x}(m + xr - m') \bmod q$. (1)

Then, he sends $(\sum, y, r', \delta)$ to the shop.

3. Shop→Bank: $(\sum, y, m', r', \delta)$.

After receiving $(\sum, y, r', \delta)$, the shop verifies if $\sum^{e_b} = h_{HK}(m', r')H(\delta \| y) \bmod n_b$, where *HK = (p, q, g, y).* If it's true, shop accepts the e-cash and stores $(\sum, y, m', r', \delta)$. Later, the shop will send the bank the received e-cash.

4. Bank: acceptance or rejection.

The shop deposits e-cash $(\sum, y, m', r', \delta)$ to the bank. The bank first verifies it by checking if $\sum^{e_b} = h_{HK}(m', r')H(\delta \| y) \bmod n_b$ and $(\sum, y, \delta)$ has not existed in the

database. If both are true, the bank stores e-cash $(\sum, y, m', r', \delta)$ in the database and deposits tit into the shop's account.

3. The weakness

An attacker can collect the transmitted message on the Internet, and obtain some information as follows:

(1) From message 2, 3, and 4 in the withdrawal protocol, the attacker can know the values, μ, β , and *t.*

(2) From message 3 in the off-line payment protocol, the attacker can know the values, $(\sum', y', m', r', \delta')$.

He then can launch an offline attack by the following ways.

(1) Computes $c' = \sum' t^{-1} \bmod n_b$

(2) Computes to see if $\beta ? = [(c')^{-1}]^{e_b} h_{HK}(m', r') H(\delta' \| y')$.

If the equation in (2) he knows that the e-cash $(\sum, y, m', r', \delta)$ owner is μ *(= IDc).* Thus, the features of anonymity and un-linkability are broken.

4. Modification

From the weakness found in section 3, we see that the key point is that μ and *t* in messages 2 and 4 of the withdrawal protocol were not hidden from the attacker. This makes it suffer from the above attack. To enhance, we hide the two parameters into $E_{pk\_j}(k, m, r)$ and $E_k(x, \bar{x}, c, k, \delta)$ to become $E_{pk\_j}(k, m, r, \mu)$ and $E_k(x, \bar{x}, c, k, \delta, t)$, respectively.

Accordingly, if an attacker launches the above attack on our modification; although, he knows β , without the value of *t*, he cannot break the un-linkability; and without the value of μ , the anonymity is assured.

5. Conclusion

In this paper, we showed that Fan et al.'s recoverable off-line e-cash's scheme is flawed. It suffers from linkability and identity leakage. We, therefore, for enhancing its security, modified it to avoid these two weaknesses. From the analysis shown in section 5, we see that we have reached the goal of the security promotion.

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