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Weakness of Shim's New ID-based Tripartite Multiple-key Agreement Protocol

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Abstract - In this article we show that Shim's new ID-based tripartite multiple-key agreement protocol still suffers from the impersonation attack, a malicious user can launch an impersonation attack on their protocol.

Keyword - ID-based, Weil-paring, Impersonation attack, Tripartite authenticated key agreement

1. Introduction

The first one-round tripartite Diffiee-Hellman key agreement protocol [1] was proposed by Joux in 2000. However, Joux's protocol does not authenticate the three communicating entities, and is vulnerable to the man-in-the-middle attack. Recently Liu et al. proposed an ID-based one round authenticated tripartite key agreement protocol with pairing[2,4-12] (LZC protocol) which results in eight session keys in the agreement. However, their scheme could not prevent the "unknown key share" attack proposed by Shim et al. in 2005[3]. In [3], they suggest a method to resist the unknown key share attack. This article will show that their protocol is still vulnerable to the impersonation attack.

2. The Background

In this section, we will first briefly review the basic concept and some properties of bilinear pairing then review the Shim's protocol.

2.1. Bilinear pairing

Let $\mathbb{G}_1$ be a cyclic group generated by P, whose order is a prime q and $\mathbb{G}_2$ be a cyclic multiplicative group of the same order q. We assume that the discrete logarithm problem (DLP) in both $\mathbb{G}_1$ and $\mathbb{G}_1$ are hard. Let $e:\mathbb{G}_1\times\mathbb{G}_1\rightarrow\mathbb{G}_2$ be a pairing which satisfies the following conditions:

(1) Bilinear: $e(aP,bQ)=e(P,Q)^{ab}$, for any $a,b\in\mathbb{Z}$ and $P,Q\in\mathbb{G}_1$.

(2) Non-degenerate: there exists $P\in\mathbb{G}_1$ and

$Q \in \mathbb{G}_1$ such that $e(P,Q) \neq 1$.

(3) Computability: there is an efficient algorithm to compute $e(P,Q)$ for all $P,Q \in \mathbb{G}_1$

2.2 Shim's protocol

(1) Setup: Key generation center (KGC) chooses a random $s \in \mathbb{Z}_q^*$ and set $P_{pub} = sP$. The KGC publishes the system parameters $\langle \mathbb{G}_1, \mathbb{G}_2, q, e, P, P_{pub}, H, H_1 \rangle$ and keep s as a secret master key, which is known only by itself.

(2) Private key extraction: A user submits his identity information ID to KGC. KGC computes the user's public key as $Q_{ID} = H_1(ID)$ and returns $S_{ID} = sQ_{ID}$ to the user as his private key.

(3) Scheme: Assume that there are three entities *A*, *B*, *C*. Each chooses two random numbers then computers their corresponding parameters. For examples, *A* chooses random numbers a and a', and computes $P_A = aP, P_A' = a'P, T_A = S_A + a^2P + a'P_{pub}$. *B* chooses random numbers b and b', and computes $P_B = bP, P_B' = b'P, T_B = S_B + b^2P + b'P_{pub}$. *C* chooses random numbers c and c', and computes $P_C = cP, P_B' = c'P, T_C = S_C + c^2P + c'P_{pub}$. After the computing, they broadcast their values $(P_A, P_A', T_A), (P_B, P_B', T_B)$ and (P_C, P_C', T_C) to all the other parties.

When receiving the other party's communicational parameters, each party performs his/her own verifying equation. For example, *A* checks whether the following equation holds.

$$\begin{aligned} e(T_B + T_C, P) &= e\left(S_B + b^2P + b'P_{pub} + S_C + c^2P + c'P_{pub}, P\right) \\ &= e\left(sP_B + b'sP + sP_C + c'sP, P\right) e\left(b^2, P\right) e\left(c^2, P\right) \\ &\stackrel{?}{=} e\left(Q_B + Q_C + P_B' + P_C', P_{pub}\right) e\left(P_B, P_B\right) e\left(P_C, P_C\right). \end{aligned}$$

B and *C* also do their corresponding verification to check if the equations hold.

If each equation holds, then *A*, *B* and *C* compute the eight session keys respectively, as in the LZC protocol, as follows.

A computes:

$$K_A^{(1)} = e(P_B, P_C)^a, K_A^{(2)} = e(P_B, P_C')^a, K_A^{(3)} = e(P_B', P_C)^a,$$
$$K_A^{(4)} = e(P_B', P_C')^a\ K_A^{(5)} = e(P_B, P_C)^{a'}, K_A^{(6)} = e(P_B, P_C')^{a'},$$
$$K_A^{(7)} = e(P_B', P_C)^{a'}, K_A^{(8)} = e(P_B', P_C')^{a'}$$

B computes:

$$K_B^{(1)} = e(P_A, P_C)^b, K_B^{(2)} = e(P_A, P_C')^b, K_B^{(3)} = e(P_A, P_C)^{b'},$$
$$K_B^{(4)} = e(P_A, P_C')^{b'}\ K_B^{(5)} = e(P_A', P_C)^b, K_B^{(6)} = e(P_A', P_C')^b,$$
$$K_B^{(7)} = e(P_A', P_C)^{b'}, K_B^{(8)} = e(P_A', P_C')^{b'}$$

C computers:

$$K_C^{(1)} = e(P_A, P_B)^c, K_C^{(2)} = e(P_A, P_B)^{c'}, K_C^{(3)} = e(P_A, P_B')^c,$$
$$K_C^{(4)} = e(P_A, P_B')^{c'}\ K_C^{(5)} = e(P_A', P_B)^c, K_C^{(6)} = e(P_A', P_B)^{c'},$$
$$K_C^{(7)} = e(P_A', P_B')^c, K_C^{(8)} = e(P_A', P_B')^{c'}$$

We can find that

$K_A^{(1)} = K_B^{(1)} = K_C^{(1)} = e(P,P)^{abc} = K^{(1)}$. Similarly,

we also have

$K_A^{(i)} = K_B^{(i)} = K_C^{(i)} = K^{(i)}$, for $i = 2,3,\ldots,8$. Each entity

then takes the eight computed values $K^{(i)}$

$(i = 1,2,\ldots,8)$ as the final session keys, where

$$K^{(1)} = e(P,P)^{abc}, K^{(2)} = e(P,P)^{abc'}, K^{(3)} = e(P,P)^{ab'c},$$
$$K^{(4)} = e(P,P)^{ab'c'}, K^{(5)} = e(P,P)^{a'bc}, K^{(6)} = e(P,P)^{a'bc'},$$
$$K^{(7)} = e(P,P)^{a'b'c}, K^{(8)} = e(P,P)^{a'b'c'}$$

3. Our Attack

In this section, we show that how the Shim's protocol is insecure against the impersonation attack.

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Assume that there is an adversary X, who wants to impersonate B to communicate with A and C shown as follows:

Step1: X computes $P_X = xP, P'_X = x'P - Q_B, T_X = x'P_{pub} + x^2P$ and broadcast them to A and C. After receiving the broadcast parameters sent by X and C, A verify the equation and we will find that the equation would be hold show below:

$$e(T_X + T_C, P) = e(x'P_{pub} + x^2P + S_C + c^2P + c'P_{pub}, P)$$
$$= e(x'P + Q_C + c'P, P_{pub})e(x^2P + c^2P, P)$$
$$= e(x'P - Q_B + Q_B + Q_C + c'P, P_{pub})e(xP, xP)e(cP, cP)$$
$$= e(P'_X + Q_B + Q_C + c'P, P_{pub})e(xP, xP)e(cP, cP)$$
$$= e(Q_B + Q_C + P'_X + P'_C, P_{pub})e(P_X, P_X)e(P_C, P_C)$$

Step2: C can obtain his parameters sent from other parties and also pass his/her verification by the equation

$$e(T_A + T_X, P) = e(Q_A + Q_B + P'_X + P'_A)e(P_A, P_A)e(P_X, P_X)$$
.

Step3: After that, A can compute the session keys as follows.

$$K_A^{(1)} = e(P_X, P_C)^a, K_A^{(2)} = e(P_X, P'_C)^a, K_A^{(3)} = e(P'_X, P_C)^a,$$
$$K_A^{(4)} = e(P'_X, P'_C)^a\ K_A^{(5)} = e(P_X, P_C)^{a'}, K_A^{(6)} = e(P_X, P'_C)^{a'},$$
$$K_A^{(7)} = e(P'_X, P_C)^{a'}, K_A^{(8)} = e(P'_X, P'_C)^{a'}$$

And C can compute the session keys as follows:

$$K_C^{(1)} = e(P_A, P_X)^c, K_C^{(2)} = e(P_A, P_X)^{c'}, K_C^{(3)} = e(P_A, P'_X)^c,$$
$$K_C^{(4)} = e(P_A, P'_X)^{c'}\ K_C^{(5)} = e(P'_A, P_X)^c, K_C^{(6)} = e(P'_A, P_X)^{c'},$$
$$K_C^{(7)} = e(P'_A, P'_X)^c, K_C^{(8)} = e(P'_A, P'_X)^{c'}$$

Each entity, A and C, then takes the following eight computed values $K^{(i)} = (i = 1,\ldots,8)$ as their final session keys

$$K^{(1)} = e(P,P)^{axc}, K^{(2)} = e(P,P)^{axc'}, K^{(3)} = e(P,P)^{ax'c}e(Q_B,P)^{-ac},$$
$$K^{(4)} = e(P,P)^{ax'c'}e(Q_B,P)^{-ac'}, K^{(5)} = e(P,P)^{a'xc}, K^{(6)} = e(P,P)^{a'xc'},$$
$$K^{(7)} = e(P,P)^{a'x'c}e(Q_B,P)^{-a'c}, K^{(8)} = e(P,P)^{a'x'c'}e(Q_B,P)^{-a'c'}$$

Finally, the adversary X can also get the same session keys $K^{(1)}$, $K^{(2)}$, $K^{(5)}$ and $K^{(6)}$ as A and C by computing:

$$K_X^{(1)} = e(P_A, P_C)^x = e(P, P)^{axc} \equiv K^{(1)},$$
$$K_X^{(2)} = e(P_A, P'_C)^x = e(P, P)^{axc} \equiv K^{(2)},$$
$$K_X^{(5)} = e(P'_A, P_C)^x = e(P, P)^{a'xc} \equiv K^{(5)},$$
$$K_X^{(6)} = e(P'_A, P'_C)^x = e(P, P)^{a'xc'} \equiv K^{(6)}.$$

As a result, X can share these four keys $K^{(1)}$, $K^{(2)}$, $K^{(5)}$, $K^{(6)}$ in the eight session keys. Under this situation, A and C think these four session keys are shared with B, but indeed, they are shared with X. Besides, both A and C come to share the same eight session keys. Thus, the impersonation attack on four of the eight session keys can be successfully mounted. More precisely, the attacker X can use these four session keys to communicate with A and C, and he can have one half of the probability to realize what the communication contents are between A and C.

4. Conclusion

In this article, we show that Shim et al.'s new ID-based tripartite multiple-key agreement protocol in [3] can not resist an impersonation attack. How to design a secure and efficient ID-based authenticated tripartite multiple-key agreement scheme to prevent all kinds of attacks remains an open problem.

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