A Note on “A Secure Anonymous D2D Mutual Authentication and Key Agreement Protocol for IoT”

Zhengjun Cao\(^1\), Lihua Liu\(^2\)

Abstract. We show that the key agreement scheme [Internet of Things, 2022(18): 100493] is flawed. (1) It neglects the structure of an elliptic curve and presents some false computations. (2) The scheme is insecure against key compromise impersonation attack.

Keywords: Device to Device communication, Key agreement, Elliptic curve, Internet of Things, Key compromise impersonation attack

1 Introduction

Recently, Hajian, Haghighat, and Erfani [1] have presented an anonymous Device-to-Device mutual authentication and key agreement protocol for IoT, in which there are two entities: IoT devices and trusted authority (TA). These devices include embedded sensors in smart vehicles, intelligent health systems, and other single-hop or hierarchical networks. They communicate with their peers or remote servers without human involvement. TA provides offline information for IoT devices. In the considered scenario, IoT devices communicate through a public channel. An adversary can eavesdrop, modify, remove, and duplicate messages transmitted in the public channel. The adversary can act as an insider to obtain secret parameters of other members to implement attacks. Though the proposed scenario and scheme are interesting, we find the scheme is flawed because of some false computations. We also find it is vulnerable to key compromise impersonation attack.

2 Review of the scheme

Let \( p \) be a large prime number, \( F_p \) be a prime finite field, \( E/F_p \) be an elliptic curve over field \( F_p \), \( Z_p^* \) be the set of numbers \( \{1, \cdots, p - 1\} \), \( G \) be a base point over \( E/F_p \). \( h(\cdot) \) is a one-way hash function defined by: \( \{0, 1\}^* \rightarrow \{0, 1\}^l \) with arbitrary length inputs and fixed-length outputs. \( \triangle T \) is the maximum allowable transmission delay.

The scheme [1] consists of four phases: initial system configuration, registration and key generation, authentication and key agreement, public and private keys update. For conveniences, we now describe the related phases as follows (see Table 1).

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Table 1: The Hajian-Haghighat-Erfani key agreement scheme

<table>
<thead>
<tr>
<th>User $U_i$</th>
<th>Initial System Configuration</th>
<th>TA</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>request</td>
<td></td>
</tr>
<tr>
<td></td>
<td>$\leftarrow device D_i$</td>
<td></td>
</tr>
<tr>
<td></td>
<td>[secure channel]</td>
<td></td>
</tr>
</tbody>
</table>

Pick $s, K_{pri} \in \mathbb{Z}_p^*$ and set $K_{pub} = K_{pri}G$. Assign a unique ID to the IoT device. Compute $HID_x = h(ID_x || s || K_{pri})$. Store $\{HID_x, sG\}$ in the device. Publish $\{E/F_p, h(\cdot), G, K_{pub}\}$.

<table>
<thead>
<tr>
<th>Device $D_i : {HID_i, sG}$</th>
<th>Registration &amp; Key Generation</th>
<th>TA: ${K_{pri}, s}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pick $r_i \in \mathbb{Z}_p^*$, compute $R_i = r_i G$, $MID_i = ID_i \oplus h(r_i sG)$, $MAC_i = h(ID_i</td>
<td></td>
<td>HID_i</td>
</tr>
<tr>
<td>Compute $f_i = F_i \oplus h(ID_i</td>
<td></td>
<td>R_i)$, $d_i = f_i + r_i$, $M_i = N_i - h(ID_i</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>$D_i$</th>
<th>Authentication &amp; Key Agreement</th>
<th>$D_j$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pick $x \in \mathbb{Z}_p^*$, the timestamp $t_1$, compute $TID_i = h(ID_i</td>
<td></td>
<td>x)$, $\alpha_i = xQ_j, \tau_i = xG$, $AID_i = h(\alpha_i) \oplus TID_i$, $Z_i = h(TID_i</td>
</tr>
<tr>
<td>Check if $</td>
<td>t'_j - t_2</td>
<td>&lt; \Delta T$. If true, compute $\beta_j = d_j \tau_j$, $TID_j = h(\beta_j) \oplus AID_j$, $K_j = h(\alpha_i</td>
</tr>
</tbody>
</table>
3 Some false computations and corrections

The scheme confuses the underlying elliptic curve group operation, which results in some false computations. In the registration and key generation phase, it specifies that

\[ f_i = (e_i + P_i)K_{pri} \]  

(1)

where \( e_i \in \mathbb{Z}_p^* \) is picked by the TA, \( K_{pri} \in \mathbb{Z}_p^* \) is the TA’s private key. But

\[ P_i = e_iK_{pub} + R_i = (e_iK_{pri} + r_i)G \in E/F_p \]  

(2)

is a point over the elliptic curve. So, the notation \( e_i + P_i \) makes no sense because it tries to add two different objects. The following computation

\[ Q_i = P_i + P_iK_{pub} \]  

(3)

is false, too. In fact,

\[ P_i \in E/F_p, \ K_{pub} = K_{pri}G \in E/F_p \]  

(4)

The notation \( P_iK_{pub} \) is not well-defined [2]. To revise, one can specify that

\[ f_i = (e_i + \hat{h}(P_i))K_{pri} \]  

(1’)

\[ Q_i = P_i + \hat{h}(P_i)K_{pub} \]  

(3’)

where \( \hat{h} : \{0, 1\}^* \rightarrow \mathbb{Z}_p^* \) is a hash function.

Correctness. We have

\[ Q_i = P_i + \hat{h}(P_i)K_{pub} = (e_iK_{pub} + R_i) + \hat{h}(P_i)K_{pub} \]
\[ = (e_i + \hat{h}(P_i))K_{pub} + R_i = (e_i + \hat{h}(P_i))K_{pri}G + r_iG = (f_i + r_i)G = d_iG \]

In the authentication and key agreement phase, it specifies that

\[ Z_i = h(TID_i || \tau_i || M_iQ_j || t_1) \]  

(5)

Note that

\[ M_i = K_{pri}Q_i = K_{pri}d_iG \in E/F_p, \ Q_j = d_jG \in E/F_p \]  

(6)

So, both are two points over the elliptic curve and the notation \( M_iQ_j \) makes no sense. Likewise, the notation \( M_jQ_i \) is false, too. To revise, it needs to replace them as follows

\[ M_iQ_j \leftarrow d_iQ_j, \ M_jQ_i \leftarrow d_jQ_i \]  

(7)

In this case, \( d_iQ_j = d_id_jG = d_jd_iG \in E/F_p \). Unfortunately, this replacement results in other security problems because the secret parameters \( M_i, M_j \) will be never invoked in the whole process.
4 Insecure against key compromise impersonation attack

In the considered model, it assumes that the adversary can compromise all network entities and obtain all temporary as well as permanent credentials (see §3.2, on page 5, [1]). As for the security against key compromise impersonation attack, it argues that (see page 18, [1]):

\[ SK_i = SK_j \text{ because the hidden parameters } M_i/M_j \text{ are stored in devices as } M_i = K_{pri}Q_i, \]
\[ \text{which are extracted only when the Elliptic Curve Diffie-Hellman Problem (ECDHP) is solved}. \]

This is a clear self-contradiction. In fact,

\[ M_i = K_{pri}Q_i = K_{pri}d_iG = d_iK_{pri}G = d_iK_{pub} \quad (8) \]

Since \( K_{pub} \) is a system public key, it is certainly available to the adversary. Therefore, the adversary can retrieve the hidden parameter \( M_i \) once \( d_i \) is compromised.

5 Conclusion

In this note, we show that the Hajian-Haghighat-Erfani key agreement scheme has some flaws. The findings could be helpful for the future works on designing such schemes.

References
