On the claimed privacy of EC-RAC III

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Abstract. In this paper we show how to break the most recent version of EC-RAC with respect to privacy. We show that both the ID-Transfer and ID&PWD-Transfer schemes from EC-RAC do not provide the claimed privacy levels by using a man-in-the-middle attack. The existence of these attacks voids the presented privacy proofs for EC-RAC.

Keywords: RFID, Protocols, EC-RAC, Privacy

1 Introduction

In [2] Lee, Batina, Singelée and Verbauwhede presented an improved version of EC-RAC, after the previous versions [3, 4] were broken.

The first version of the EC-RAC protocol [3] was broken in [5] and [1], which show that a tag could be traced by an attacker using a quality-time attack [5]. The attacker can generate a *unique attribute* of a tag by sending the same challenge twice, and the *unique attribute* can then be used to identify the tag.

The subsequent version of EC-RAC [4] introduced three different sub-protocols: ID-transfer, Pwd-Transfer and server authentication. These sub-protocols were combined into several protocols. One of the fundamental problems is that protocols, which in isolation are secure and/or untraceable, are not necessarily secure and/or privacy preserving when combined. The second version of EC-RAC was broken in [6]. The ID-transfer scheme was broken with respect to untraceability using a man-in-the-middle attack, in which the attacker uses a previous, valid, execution of the protocol to modify the communication. If the reader accepts the modified values, the attacker can identify the previously eavesdropped tag. The ID&Pwd-Transfer protocols were broken with respect to tag-to-server authentication, allowing the attacker to impersonate a tag. The main cause of this attack is the reuse of the same keys for both the ID- and Pwd-Transfer sub-protocol.

To resolve this issue a non-linearity was introduced in the ID-Transfer protocol and the ID&Pwd-Transfer protocol was modified to exclude the usage of the same key and to ensure that different randomness was used. The paper [2] claims that the ID-transfer protocol (protocol 1 from [2]) and the ID&Pwd-Transfer protocol (protocol 3 from [2]) provide *wide-strong* privacy (see [7] for definition).

Throughout this paper, we also use the privacy notions from Vaudenay [7]. A *wide* attacker has access to the result of the verificication by the server while a *narrow* attacker does not. A *strong* attacker can extract the secrets from a tag and can keep reusing the tag, while a *weak* attacker cannot.

We show in this paper that the new EC-RAC protocols [2], including the ID&Pwd-Transfer protocols (protocol 2,3) and the ID-Transfer protocol (protocol 1), do not provide the claimed privacy properties. The ID&Pwd-Transfer protocols are broken by a (wide) man-in-the-middle attack, and a tag can be traced by the attacker. The introduction of the non-linearity was ineffective. Since our attacks on the ID&Pwd-Transfer scheme do not require access to the tag's secrets, not even *wide-weak* privacy is provided by the protocols. $Narrow$*-weak* privacy might be provided by these protocols, but no formal proof for this is included. Also the ID-transfer protocol does not provide the claimed *wide-strong* privacy. An attacker that knows the identity of a certain tag, can always identify this tag using a man-in-the-middle attack. The highest privacy levels that could be provided by the ID-Transfer scheme are *narrow-strong* privacy or *wide-destructive*, although no formal proof for this exists.

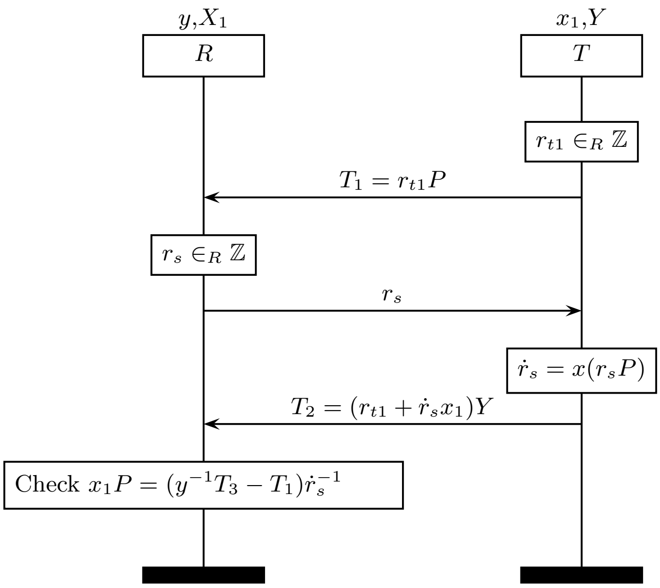
2 Untraceable authentication protocols for RFID

The EC-RAC protocols are all based upon elliptic curve cryptography. Let P be a generator of the elliptic curve group. Every tag has two private-public key pairs $x_1, X_1 = x_1P$ and $x_2, X_2 = x_2P$. In this case x_1 serves as the identity of the tag and is also known by the reader. The reader has a private-public key pair $y, Y = yP$.

Figure 1 shows the ID-transfer protocol from [2]. This protocol should identify the tag as x_1 in a secure and *wide-strong* privacy preserving way. The main difference with the previous versions of the protocol is the introduction of the non-linearity $\dot{r}_s = x(r_sP)$, with $x(\cdot)$ the x-coordinate function for an elliptic curve point.

Figure 2 shows the ID&Pwd-Transfer protocol from [2]. In addition to the reader identifying the tag correctly as x_1, it also authenticates

Fig. 1. Protocol 1 from [2]



the tag using the public-private key pair $x_2, X_2 = x_2P$. (Note that the secret x_1 is known to both the tag and the reader and cannot be used for authentication.)

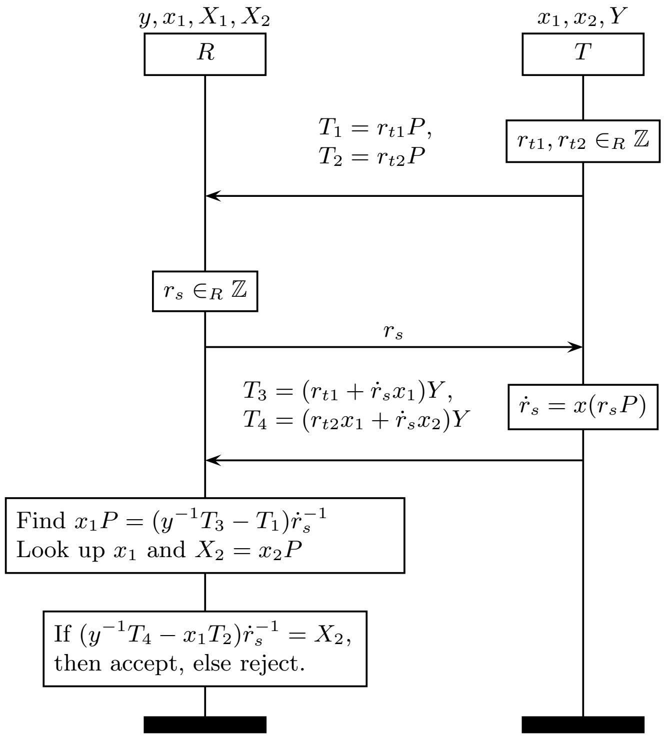
3 Attacks on the protocols

The main flaw in the ID&Pwd-Transfer scheme is the fact that the "hash" of the challenge, i.e. $\dot{r}_s$ does not mask all of the secret keys x_1 and x_2. Indeed, in the response T_4, the x_1 part is only masked by the randomness r_{t2}.

3.1 First attack

The first attack exploits the fact that it is possible to force $\dot{r}_s$ to become 0. Indeed, note that the protocol does not verify whether r_s is a multiple of the order of P. As such, it is possible for an attacker impersonating

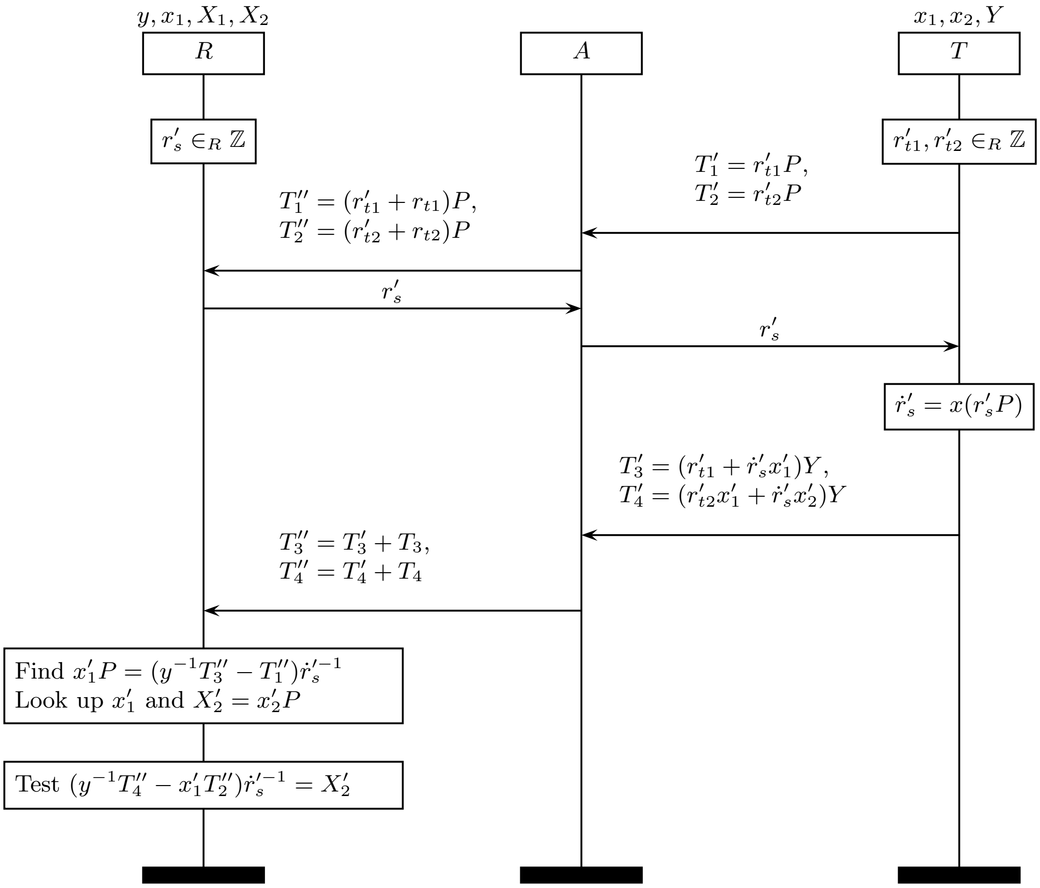
Fig. 2. Protocol 3 from [2]



a reader to send $r_s = k \cdot \text{ord}(P)$ to the tag, who will then compute $\dot{r}_s = x(r_sP) = 0$ and therefore return $T_3 = r_{t1}Y$ and $T_4 = r_{t2}x_1Y$. Using the messages ($T_1 = r_{t1}P$, $T_2 = r_{t2}P$, $T_3 = r_{t1}Y$, $T_4 = r_{t2}x_1Y$), it is then possible to mount a man-in-the-middle attack on a second communication to test whether the same tag from the first run is present or not. This attack is described in Figure 3 where the tag's secret keys are now denoted by x_1' and x_2'.

The adversary adds T_1 and T_2 to the messages T_1' and T_2' obtained from the unknown tag and forwards these to the reader. The reader responds with a nonce r_s', which the attacker simply forwards to the tag. The tag responds with valid messages T_3' and T_4' which the attacker uses to obtain $T_3'' = T_3' + T_3$ and $T_4'' = T_4' + T_4$ and sends these to the reader. The reader

Fig. 3. Man-in-the-middle attack on protocols 2 and 3



then computes

$$(y^{-1}T''_3 - T''_1)\dot{r}'^{-1}_s = (r_{t1} + r'_{t1} + \dot{r}'_s x'_1 - r_{t1} - r'_{t1})\dot{r}'^{-1}_s P = x'_1 P\,,$$

and looks up x'_1 and $X'_2 = x'_2 P$. Note that this step always verifies. The reader then tests whether $(y^{-1}T''_4 - x'_1 T''_2)\dot{r}'^{-1}_s = X'_2$, which is equivalent with

$$(r'_{t2}x'_1 + \dot{r}'_s x'_2 + r_{t2}x_1 - x'_1(r'_{t2} + r_{t2}))\dot{r}'^{-1}_s P = x'_2 P\,.$$

The test will succeed if and only if $x_1 = x'_1$, i.e. if the tag is the same as the one from the first run.

3.2 Second attack

The second attack even works when the tag adds an extra verification that $\dot{r}_s \neq 0$. Note that the first attack worked because the attacker obtained $(T_1 = r_{t1}P, T_2 = r_{t2}P, T_3 = r_{t1}Y, T_4 = r_{t2}x_1Y)$, so it suffices to explain how such a tuple can be obtained when the tag verifies whether $\dot{r}_s \neq 0$. In fact, obtaining such a tuple is trivial by querying the tag twice with the same r_s and subtracting the results, since the parts involving $\dot{r}_s$ will cancel out. As such we obtain a valid tuple $(T_1^* = r_{t1}^*P, T_2^* = r_{t2}^*P, T_3^* = r_{t1}^*Y, T_4^* = r_{t2}^*x_1Y)$, which can then be used in the first attack.

3.3 Third attack

The third attack shows that the ID-transfer scheme (protocol 1 from [2]) is not wide-strong. A *strong* attacker is able to read a tag's ID x_1 without destroying the tag. We will now show how a *strong* attacker can then be used to track a particular tag using a man-in-the-middle attack.

This attack is described in Figure 4. By definition of *strong*, the attacker knows x_1 of a certain tag. In order to test if a random tag is the corrupted one, she plays a man-in-the-middle attack as follows. The attacker replaces the value r_s with another random value r'_s and replaces $T_2 = (r_{t1} + \dot{r}'_s x'_1)Y$ by

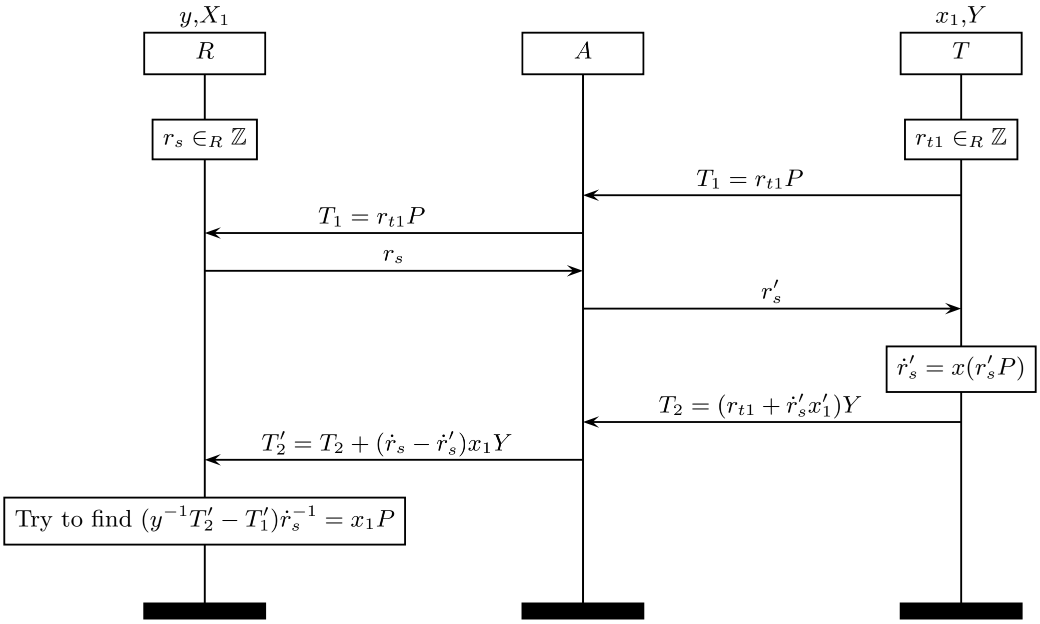
$$T'_2 = T_2 + (\dot{r}_s - \dot{r}'_s)x_1Y = (r_{t1} + \dot{r}'_s(x'_1 - x_1) + \dot{r}_s x_1)Y$$

The reader will accept this only if $x_1 = x'_1$ (provided $\dot{r}'_s \neq 0$, which the attacker can assure). This allows the attacker to identify the tag x_1 upon acceptance by the reader. The ID-transfer protocol is thus not *wide-strong* private. Since our attacker is both *wide* and *strong*, the ID-transfer might be *narrow-strong* private or *wide-destructive* private, although no proof for this is given in the original paper.

4 Conclusions

In this paper we have shown three successful attacks on the latest version of EC-RAC [2]. We prove that the ID&PWD-Transfer scheme is not *wide-strong* private and is not even *wide-weak* private. The highest possible

Fig. 4. Man-in-the-middle attack on protocol 1



privacy level that might be achieved by the ID&PWD-Transfer scheme is *narrow-weak* privacy.

We also prove that the ID-transfer scheme is not *wide-strong* private as claimed and can be at most *wide-destructive* or *narrow-strong* private.

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