Cryptanalysis of AFMAP

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Abstract: Radio frequency identification systems which use radio frequency for object identification are widely developed nowadays. Security problems such as privacy and untraceability had lead to propose numerous protocols for RFID systems. However most of these attempts have not been successful.

In this paper we present a desynchronization attack against a recently proposed RFID protocol called Anonymous Forward-Secure Mutual Authentication or in short AFMAP. The complexity of attack is a few runs of the protocol and the success probability is 1. To the best of our knowledge, this is the first attack on AFMAP.

Keywords: RFID, Anonymous Forward-Secure Mutual Authentication Protocol, AFMAP, desynchronization

Classification: Science and engineering for electronics

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1 Introduction

One of automatic objects, people and animals identification technologies is Radio Frequency Identification (RFID) that widely developed nowadays. Three entities of an RFID system are tag, reader and back-end database. Tag is a microchip with constraint computational capabilities and storage resources which communicates with reader by an antenna. The reader is the unit which can achieve the saved information in the tags by radio frequency. Back-end database stores tag's identifiers, pseudonyms and keys that the reader uses through the tag authentication process.

One of the most concerns in RFID applications is security. Privacy, mutual authentication and untraceability are such problems that aroused researchers' interest on RFID security. For addressing theses problems a lot of protocols have been proposed [8, 4, 7]. However, most of these attempts [6, 5, 1, 2, 3, 9] have failed to achieve their desired security goals.

Recently, Sadighian and Jalili [10] have proposed a new protocol called Anonymous Forward-security Mutual Authentication Protocol or in short AFMAP for RFID systems. Among other security properties, they have claimed that AFMAP has sufficient resistance against desynchronization attack. However, in this paper, we show that the AFMAP protocol is vulnerable to the desynchronization attack.

The reminder of this paper is organized as follows: section 2 describes AFMAP. Our desynchronization attack is presented in section 3. Section 4 concludes the paper.

2 Description of the AFMAP protocol

It is an accepted assumption to consider the communication channel between reader and back-end database secure. Hence, throughout this paper we do not distinguish between back-end database and reader and just call them reader.

The AFMAP protocol is a mutual authentication protocol based on a secure hash function denoted by h . Tag and reader in the AFMAP have only one shared value which is denoted by k and updated after each successful run

of protocol. In round i this secret key denoted by k_i . To resist desynchronization attack both tag and reader keep two records of key, i.e. k_{ilast} and k_i , where k_{ilast} denotes the previous value of k_i . Several time related parameters are used in the AFMAP protocol. These parameters are denoted by t_{sys} , t_{tag} , t_{max} and t_0 and defined as follows:

t_{sys} : The system's time is a parameter that reader indicates the system time by it.

t_{tag} : The tag's time is a parameter that is initiated by t_0 and updates after each successful run of protocol.

t_{max} : The maximum time is a predefined constant parameter that tag considers it as the upper bound of system's time.

t_0 : It is a parameter that initiates t_{tag} .

The details of AFMAP protocol is depicted in Algorithm 1. We have used the following assumptions and notations in the description of algorithm:

- All parameters in the protocol are of length t -bit.
- The expression $A \rightarrow B$ refers to assigning A to B .
- For a finite set $\mathcal{X}$, $x \xleftarrow{\$} \mathcal{X}$ is the experiment of uniformly choosing a random element from $\mathcal{X}$ and assigning it to x .

In the next section we analyze the security of AFMAP.

3 Desynchronization Attack against AFMAP

Our desynchronization attack is based on this observation that an attacker can modify both t_{sys} and n_1 such that the tag authenticates the reader. On the other hand, if $t_{sys} \leq t_{tag}$ or $t_{sys} \geq t_{max}$ the tag does not authenticate the reader. So, if the attacker can force the tag to set t_{tag} to a value almost equal to t_{max} , tag does not authenticate the reader any more, because $t_{sys} \leq t_{tag}$. So, the attacker needs to determine an upper bound for t_{max} . Hence, at the first step we explain how the attacker can extract the value of t_{max} . Algorithm 2 presents an approach to determine the accurate value of t_{max} in AFMAP. In this algorithm the following notations are used:

- Given finite set $\mathcal{X}$, $|\mathcal{X}|$ denotes the cardinality of $\mathcal{X}$.
- A^i denotes the i^{th} bit of A . More precisely A^0 and $A^{|A|-1}$ denote the least significant bit and most significant bit of A respectively.

Line 3 of Algorithm 2 guarantee that $t'_{sys} > t_{tag}$. On the other hand, $X' = h(k_i \oplus (n_1 \oplus t'_{sys} \oplus t_{sys}) \oplus t'_{sys}) = h(k_i \oplus n_1 \oplus t_{sys}) = X$. Hence, the tag authenticates the reader if and only if $t'_{sys} = t'_{max} < t_{max}$. Otherwise the tag sends two pseudo random numbers. In this case the reader does not authenticate the tag and the attacker, through the condition of line 11, will find out that $t_{max} < t'_{max}$ and in the next attempt it selects a smaller value for t'_{max} , line 13. Otherwise, in the next attempt the attacker selects a bigger value for t'_{max} . The attacker repeats this game at most $|t_{max}|$ -time to achieve

Algorithm 1: The AFMAP protocol

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input :  $k_{ilast}, k_i, t_{tag}, t_{max}$ 

1 The reader;
2  $\{0, 1\}^t \xrightarrow{\$} n_1$ ;
3  $h(k_i \oplus n_1 \oplus t_{sys}) \rightarrow X$ ;
4 Pass  $(t_{sys}, n_1, X)$  to the tag;

5 The tag;
6 if  $(t_{tag} < t_{sys} < t_{max}) \ \& \ (h(k_i \oplus n_1 \oplus t_{sys}) == X)$  then
7   The tag authenticates the reader;
8    $\{0, 1\}^t \xrightarrow{\$} n_2$ ;
9    $h(X \oplus k_i \oplus n_2) \rightarrow Y$ ;
10  Pass  $(n_2, Y)$  to the reader;
11   $k_i \rightarrow k_{ilast}$ ; //  $k_{ilast}$  updating;
12   $h(Y \oplus k_i) \rightarrow k_i$ ; //  $k_i$  updating;
13   $t_{sys} \rightarrow t_{tag}$ ; //  $t_{tag}$  updating;
14 else
15   The tag does not authenticate the reader;
16    $\{0, 1\}^t \xrightarrow{\$} n_2$ ;
17    $\{0, 1\}^t \xrightarrow{\$} Y$ ;
18   Pass  $(n_2, Y)$  to the reader;
19 end

20 The reader;
21 if  $h(X \oplus k_i \oplus n_2) == Y$  then
22   The reader authenticates the tag;
23    $k_i \rightarrow k_{ilast}$ ; //  $k_{ilast}$  updating;
24    $h(Y \oplus k_i) \rightarrow k_i$ ; //  $k_i$  updating;
25 else
26   The reader does not authenticate the tag;
27 end

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the accurate value of t_{max} . Hence, the attacker can retrieve the tag's t_{max} of AFMAP, line 18.

However, when Algorithm 2 is terminated, the tag has assigned $t_{max} - 1$ to t_{tag} . It means that for the later runs of protocol and for any t_{sys} that the reader passes to the tag, the condition $t_{sys} < t_{tag}$, line 6 of Algorithm 1, would not be satisfied. Hence, the tag never authenticates the reader any more and we can claim that the tag and the reader were desynchronized. The expected complexity of attack is $|t_{max}|$ and the success probability is 1.

remark 1 . One may argues that any value which is returned by the tag is meaningless for the attacker, because it does not know the secret key k_i and therefore the expected value for Y . However, if the tag returns random values, happens if $t'_{max} > t_{max}$, then the reader does not authenticate the tag and it

Algorithm 2: An algorithm to find the value of t_{max} in AFMAP

input : The initial guess of t_{max} such that $t'_{max} = 2^{\lfloor t_{max} \rfloor - 1}$
output: The accurate value of t_{max}

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1 for ( $i = \lfloor t_{max} \rfloor; i > 0; i - -$ ) do
2   Eavesdrop the  $i^{th}$  round of protocol and achieve  $t_{sys}$ ,  $n_1$  and  $X$ ;
3   while  $t'_{max} < t_{sys}$  do
4     flip the  $(i - 2)^{th}$ -bit of  $t'_{max}$ ; //  $(t'_{max})^{i-2} = (t'_{max})^{i-2} \oplus 1$ ;
5      $i - -$ ;
6   end
7    $t'_{max} \rightarrow t'_{sys}$ ;
8    $(n_1 \oplus t'_{sys} \oplus t_{sys}) \rightarrow n'_1$ ;
9   Send the  $(t'_{sys}, n'_1, X)$  triplet to the tag;
10  Pass the tag's outputs to the reader;
11  if the reader does not authenticate the tag then
12    flip the  $(i - 1)^{th}$ -bit of  $t'_{max}$ ; //  $(t'_{max})^{i-1} = (t'_{max})^{i-1} \oplus 1$ ;
13  end
14  if  $i > 1$  then
15    flip the  $(i - 2)^{th}$ -bit of  $t'_{max}$ ; //  $(t'_{max})^{i-2} = (t'_{max})^{i-2} \oplus 1$ ;
16  end
17 end
18 return  $t'_{max} + 1$ ;

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is expected to restart the game. It can be evidence that the attacker uses to validate its guesses. On the other hand, if the tag authenticates the reader, which is equivalent to the case $t'_{max} < t_{max}$, the attacker must wait for another game running by the reader. By the way, we put this assumption on the protocol that the attacker has the capability to find out whether the reader has authenticated the tag. This is not an unrealistic assumption. Recall that, in practical for many applications, we expect a physical observation after the tag authentication process, e.g. a door would be opened, we receive some information related to object, and so on.

remark 2 . To overcome this attack, both reader and tag should consider t_{sys} in their calculation such that they are not authenticate each other if the attacker changes t_{sys} . A potential solution is to change the calculation of X and Y as follows:

$$X = h(h(k_i \oplus n_1) \oplus t_{sys})$$

$$Y = h(X \oplus h(k_i \oplus t_{sys}) \oplus n_2)$$

Since, the attacker has no knowledge about k_i and it can not determine $h(k_i \oplus t_{sys})$ or $h(k_i \oplus n_1)$ any change in t_{sys} leads to a situation that protocol does not run properly and tag does not authenticate the reader or vice versa. However, the cost of this security strengthening is two extra calls to the hash function for both tag and reader.

4 Conclusion

In this paper we analyzed the security of Anonymous Forward-Secure Mutual Authentication Protocol (AFMAP). We presented a desynchronization attack against this protocol with small complexity and the success probability of 1. In addition, we proposed a modification to the protocol which prevents the presented attack. However, it costs two extra calls to the hash function. It would be interesting to study the security of the modified protocol.

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