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# Cryptanalysis of an RFID Tag Search Protocol Preserving Privacy of Mobile Reader

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**Abstract.** RFID tag search system can be used to find a particular tag among numerous tags. In 2011, Chun et al. proposed an RFID tag search protocol preserving privacy of mobile reader holders. Chun et al. claimed that their proposed protocol can withstand five attacks to be considered in serverless search protocols, such as tracking, cloning, eavesdropping, physical, and Denial of Service (DoS) attacks. However, this paper points out that the Chun et al.'s protocol still can be vulnerable to the DoS attack.

**Keywords:** RFID, Privacy, DoS attack, Serverless search, Passive tag.

## 1 Introduction

Recently, Radio frequency identification (RFID) technology has been applied to many real-life applications [1]. Basically, RFID technology is used to identify RFID tags automatically. RFID tag search system can be used to find a particular tag among numerous tags [2,3]. RFID tag search system has many applications such as inventory management, supply chain, and search for books in the library. In 2009, Tan et al. [4] proposed secure serverless search protocols to treat the security and privacy concerns in RFID tag search system. Tan et al.'s protocols enable users with mobile readers to search specific tags even though the mobile readers cannot connect to a backend server. Tan et al.'s protocols also provide the robustness against the losses of mobile readers. Since mobile readers can be easily lost or stolen, the losses of mobile readers lead to leakage of sensitive information such as identifiers or secret keys of tags. Various RFID tag search protocols [5–9] have been proposed to meet security and privacy requirements based on Tan et al.'s protocols.

In 2011, Chun et al.[9] proposed a new RFID tag search protocol which can preserve privacy of mobile reader holders unlike related protocols. In the security analysis, Chun et al. claimed that their proposed protocol can withstand five attacks to be considered in serverless search protocols, such as tracking, cloning, eavesdropping,

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physical, and Denial of Service (DoS) attacks. However, this paper points out that the Chun et al.'s protocol still can be vulnerable to the DoS attack.

The paper is organized as follows. Section 2 reviews the Chun et al.'s RFID tag search protocol and then shows its weakness in Section 3. Finally, Section 4 concludes the paper.

## 2 Review of Chun et al.'s RFID Tag Search Protocol

The Chun et al.'s RFID tag search protocol is composed of two phases, which are an initial setup and a tag search. In the initial setup phase, from a backend server, each reader receives an access list of which each entry is encrypted with the identifiers of the reader and a tag. Then, in the tag search phase, the reader searches a specific tag using this list. Some of the notations used in the Chun et al.'s protocol are defined as follows:

- $R_j, T_i$ : Mobile RFID reader and tag, respectively.
- $RD_j, ID_i$ : Identity of  $R_j$  and  $T_i$ , respectively.
- $SE = (E, D)$ : Efficient symmetric encryption algorithm, e.g. AES-128.
- $t_i$ : Secret encryption key of the RFID tag  $T_i$
- $\lambda$ : Bit length of a plaintext and a ciphertext.
- $x \leftarrow E_t(m)$ : A deterministic polynomial-time algorithm that takes as input a symmetric key  $t \in \kappa_D$  and a message  $m \in \{0,1\}^\lambda$ , outputs a ciphertext  $x \in \{0,1\}^\lambda$ .
- $m \leftarrow D_t(x)$ : A deterministic polynomial-time algorithm that takes as input a private key  $t$  and a ciphertext  $x$ , outputs a plaintext  $m$ .
- $\oplus$ : Bit-wise exclusive-OR (XOR) operation.

### 2.1 Initial Setup Phase

The phase consists of two parts. The first part is performed to generate information for an RFID tag  $T_i$  and the second for a mobile reader  $R_j$ .

S.1 For each RFID tag  $T_i$ , the backend server generates a tag identifier  $ID_i$  and a secret encryption key  $t_i$  and then stores the pair  $(ID_i, t_i)$  with the additional tag information into its own central database. Each tag  $T_i$  stores the pair  $(ID_i, t_i)$ .

S.2 For a mobile reader  $R_j$ , the backend server generates an access list  $L_j$  as follows: If the mobile reader  $R_j$  is assumed to access to the tags  $T_i (1 \leq i \leq n)$ , the

backend server computes each ciphertext  $E_{t_i}(RD_j \oplus ID_i)$  for  $i=1, \dots, n$  by encrypting  $RD_j \oplus ID_i$  with the secret key  $t_i$  under the given encryption algorithm  $E()$ . Then, the backend server adds the pairs  $(ID_i, E_{t_i}(RD_j \oplus ID_i))$  ( $1 \leq i \leq n$ ) in the access list  $L_j$ . The backend server also transmits the access list  $L_j$  to the mobile reader  $R_j$  over a secure channel.

**Table 1.** Access list  $L_j$  for a mobile reader  $R_j$ .

$ID$	$PW$
$ID_1$	$E_{t_1}(RD_j \oplus ID_1)$
$ID_2$	$E_{t_2}(RD_j \oplus ID_2)$
$\dots$	$\dots$
$ID_n$	$E_{t_n}(RD_j \oplus ID_n)$

## 2.2 Tag Search Phase

The Chun et al.'s tag search protocol is illustrated in Fig. 1 and is performed as follows:

T.1  $R_j \rightarrow T_i$ :  $\alpha \parallel n_r$

When  $R_j$  wants to search  $T_i$ ,  $R_j$  first chooses a  $\lambda$ -bit random number  $n_r$  and computes  $\alpha = E_{ID_i}(RD_j \oplus n_r)$ , then broadcasts  $\alpha \parallel n_r$  to  $T_i$ .

T.2  $T_i \rightarrow R_j$ :  $\beta \parallel n_t$

Each tag  $T_i$  who receives a message  $\alpha \parallel n_r$  obtains  $RD_j$  by computing  $D_{ID_i}(\alpha) \oplus n_r = D_{ID_i}(E_{ID_i}(RD_j \oplus n_r)) \oplus n_r$  using its own identifier  $ID_i$  and  $n_r$ . Then, each tag  $T_i$  computes  $K_i = E_{t_i}(RD_j \oplus ID_i) \oplus n_r$  with its own secret key  $t_i$ . Finally, each tag  $T_i$  chooses a  $\lambda$ -bit random number  $n_t$  and computes  $\beta = E_{K_i}(ID_i \oplus n_t)$ , then sends  $\beta \parallel n_t$  to  $R_j$ .

T.3  $R_j$  computes  $K_i = E_{t_i}(RD_j \oplus ID_i) \oplus n_r$  using the random number  $n_r$  chosen before and the stored value  $E_{t_i}(RD_j \oplus ID_i)$  in the access list  $L_j$ . Then,  $R_j$  obtains  $ID_i'$  by computing  $D_{K_i}(\beta) \oplus n_t = D_{K_i}(E_{K_i}(ID_i \oplus n_t)) \oplus n_t$  using  $K_i$

and  $n_t$ . Finally,  $R_j$  checks whether  $ID_i' \stackrel{?}{=} ID_i$  or not. If  $ID_i' = ID_i$  then  $R_j$  knows that  $T_i$  exists nearby  $R_j$ .

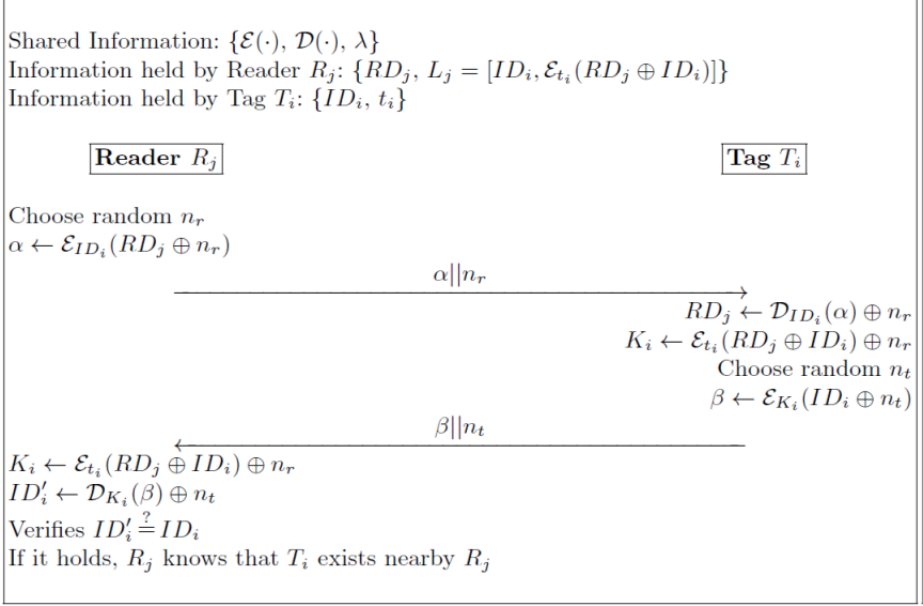


Fig. 1. Chun et al.'s RFID tag search protocol

### 3 Denial of Service Attack against Chun et al.'s Protocol

The Chun et al.'s RFID tag search protocol is vulnerable to Denial of Service (DoS) attack. DoS attack is one category of attacks on RFID systems. An adversary tries to find ways to fail target tag from receiving services. Almost all resources in an RFID system can become target of the DoS attack, including tag, reader, or backend server. Attacks on the air interface include shielding tags, flooding the reader field with a multitude of tags or selectively jamming the reader field. The goal is usually to sabotage specific resources of an RFID system, such a digital supply chain, effectively making the system unavailable to its intended users.

In the tag search phase, all tags  $T_i$  nearby a mobile reader  $R_j$  must respond to the request of  $R_j$ . Especially, in Step T.2 of the Chun et al.'s RFID tag search phase, all tags  $T_i$  always must compute 3 times symmetric encryption operations to respond the request of  $R_j$ . These computations can be vulnerable to the following an adversary  $Adv$ 's DoS attack which is illustrated in Fig. 2.

A.1  $Adv \rightarrow T_i: \alpha \| n_r$ .

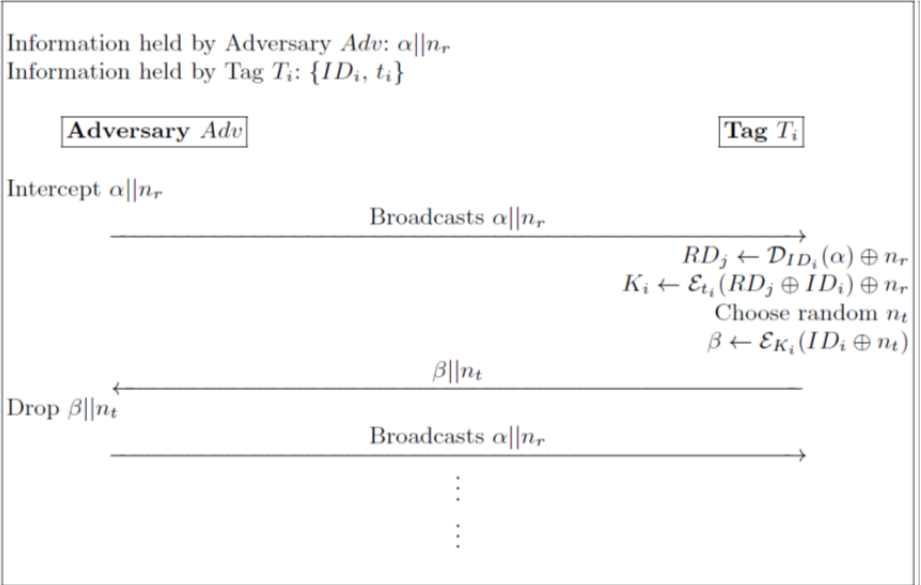
Suppose that an adversary  $Adv$  intercepts  $\alpha \| n_r$  from Step T.1.  $Adv$  broadcasts  $\alpha \| n_r$  to  $T_i$ .

A.2  $T_i \rightarrow Adv: \beta \| n_t$

All tags  $T_i$  nearby  $Adv$  will respond to the request of  $Adv$  as follows:

Each tag  $T_i$  who receives a message  $\alpha \| n_r$  will obtain  $RD_j$  by computing  $D_{ID_i}(\alpha) \oplus n_r = D_{ID_i}(E_{ID_i}(RD_j \oplus n_r)) \oplus n_r$  using its own identifier  $ID_i$  and  $n_r$ . Then, each tag  $T_i$  will compute  $K_i = E_{t_i}(RD_j \oplus ID_i) \oplus n_r$  with its own secret key  $t_i$ . Finally, each tag  $T_i$  will choose a  $\lambda$ -bit random number  $n_t$  and compute  $\beta = E_{K_i}(ID_i \oplus n_t)$ , then send  $\beta \| n_t$  to  $Adv$ .

A.3  $Adv$  drops  $\beta \| n_t$  and then broadcasts  $\alpha \| n_r$  to  $T_i$  continuously until success DoS attack.



**Fig. 2.** DoS Attack against Chun et al.'s Protocol

From the computation results of above Step A.2, we can see that all tags  $T_i$  automatically must compute 3 times symmetric encryption operations to respond the request of  $Adv$ . These 3 times symmetric encryption operations of the RFID passive

tag  $T_i$  can be quite expensive operations because  $T_i$  uses a low-power microcontroller for sensing and communication with the RFID reader  $R_j$ .

Therefore, if  $Adv$  broadcasts the intercepted  $\alpha \parallel n_r$ , continuously, all tags  $T_i$  cannot respond to the request of the legitimate leaders. Moreover,  $Adv$  can simply perform the above described DoS attack by choosing a random  $\alpha^* \parallel n_r^*$  without intercepting the  $R_j$ 's sending message  $\alpha \parallel n_r$ .

As a result, the Chun et al.'s RFID tag search protocol is vulnerable to the above described DoS attacks.

## 4 Conclusions

This paper analyzed the security of Chun et al.'s RFID tag search protocol preserving privacy of mobile reader holders. We presented a denial of service (DoS) attack against this protocol. Further works will be focused on improving the protocol which can not only withstand the DoS attack but also provide more computational efficiency.

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