Dynamic Security Authentication Protocol Based on Hash Function for RFID System

Baolong Liu, Bing Yang

Abstract — In order to ensure the information security of the RFID system, this paper proposes a dynamic security authentication protocol based on hash function to prevent asynchronous attack within RFID system. The proposed protocol uses the tag key and the tag ID updating method to ensure the two-way authentication between the tag and the reader to avoid asynchronous attack. The correctness of the protocol is proved by using BAN logic analysis. The experimental results show that the protocol proposed can satisfy the security requirement of RFID system. Compared to existing security protocols, the presented protocol has improved the security level of RFID system. The solution can be implemented in the hardware environment, which provides a reliable approach for RFID system application in practical.

Keywords — RFID systems; authentication; asynchronous attack; hash function; BAN logic.

I. INTRODUCTION

Radio Frequency Identification (RFID) is an automatic recognition technology that utilizes spatial coupling to realize wireless contact of two-way communication. It can automatically identify target objects and transmit information. Compared to the commonly used identification methods (such as bar code, two-dimensional code), RFID tags have advantages of moved recognition, fast read and written. RFID system has high precision [1], adapting to environmental capacity, strong anti-interference, traceability and positioning at any time. Based on the advantages of RFID system, it is widely used in the retail, logistics and other fields.

However, RFID system has information security and privacy issues. Criminals using open wireless environment vulnerabilities carry out illegal attacks, which will cause the system disorders, and even confidential disclosure. There are five major security risks: data privacy, replay attacks, location tracking, forged attacks and asynchronous attack.

Two methods are deployed to solve the security and privacy problems of RFID including: 1) Physical methods of security mechanisms, such as inactivation operation, using Faraday day net to shield the signal, active interference. 2) Logical methods based on information security mechanism, which mainly focuses on authentication technology [2]. Authentication technology can solve some security issues effectively relating to RFID system. Experts and scholars have put forward a lot of RFID security protocols [3]-[4] about the logic of authentication. As the RFID tag for the operation of the memory is very limited, it is necessary the protocol proposed has small space and high security.

In order to improve security, dynamic security authentication protocols and low cost authentication protocol (LCAP) [10] are often adopted in RFID system. The security authentication protocols based on dynamic refresh tag ID are hash-based protocol using varying identifiers. The dynamic refresh tag ID is similar to the hash chain security authentication protocol, but it synchronously updates the relevant authentication data. By adding the random number generator in the system so that the ID exchange information of each response is different. It can resist the retransmission attack. The hash-based protocol also uses varying identifiers, and the tag update ID after only receiving the verification message, so there is a potential security risk of database asynchronous, and the protocol cannot resist the attacker's blocking attack. In addition, the agreement also takes up a lot of storage space. The LCAP protocol is an interrogation-response protocol characterized by using the left and right portions of the hash encrypted value to authenticate. The protocol dynamically refreshes the tag to ensure that the tag responds randomness after each end of the authentication process. It can effectively prevent replay attacks, fake attacks. Similar to the hash-based.ID protocol, the tag also updates the ID after receiving the message and the authentication of the reader, and the database receives the message. Therefore, if the attacker at this time initiates into the camouflage or signal shielding attacks, the authentication data is asynchronous.

In order to overcome problem of authentication information asynchronous, several solutions have been proposed. Huang and Shieh [11] proposed a secret search protocol to solve privacy problems by providing a search mechanism for encrypted data. The protocol directly searches the password which does not need to be decrypted to improve performance. The main drawback of this protocol is that it uses a one-way hash function and therefore it does not conform to the EPC standard. Mtita et al. [12] have developed two mutual authentication and tag searching protocols, which the authors claimed that their agreement requires low computational resources, and readers and tags does not share any secrets.

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However, the server shares the temporary identifier, key and the access rights of the tag with the reader. These protocols are also susceptible to DoS and asynchronous attacks [13] because opponents can block the last messages individually and perform key updates through tags and readers in mutual authentication and tag searching protocols. The tag searching protocols was presented by Zheng and Li using Bloom filter and hash function to identify the “wanted” tags among a set of tags that are in the field of the reader [14]. Chen et al [15] also adopted the Bloom filter, but with an iterative way identifies the desired tag in the field of readers without querying tags. In both solution, the reader and the tag use hash function to determine which bit is checked to select the candidate. Portions of the framework of the slotted Aloha protocol also are adopted in other approaches. For example Shahzad and Liu [16] use a standardized framework to estimate the number size of a given tag group readers in the Aloha protocol. Readers broadcast available numbers of slots, and each tag selects a time slot to respond. When the number of tags is estimated in the reader field, it would begin with initial step rather than searching for a particular tag. Gong et al. [17] used the framework of the Aloha method. The method focuses on the probability, which means a tag participates and generates a hash value during the authentication process, and it determine the number of slots used in response to the reader rather than an index that focuses on time efficiency. However, the research above cannot determine whether the Aloha protocol is valid and safe.

This paper presents RFID security authentication protocol based on dynamic ID [18] and index value updating. Compared to other protocols, the proposed protocol uses the ID information and index value updated simultaneously [19]. All the tag’s related key information is not directly exposed as well as the index value in the entire process of identification. The protocol can ensure the reliability of identity authentication to a certain extent. The tag only needs to generate once a random number, reducing the computational redundancy of the tag. The protocol proposed can not only effectively protect the security of RFID systems but also reduce storage capacity, communication and the computational load between the two sides. The correctness and security of presented method is proved by using BAN logic. The experimental results show that the protocol proposed can satisfy the security requirement of RFID system.

II. THE PROPOSED SECURITY PROTOCOL

The assumptions of this protocol are as follows.

1. The server and the reader is a wired transmission, which means they are connected physically [20]. It can be seen as a secure channel. The reader and the tag is a wireless transmission channel. Because of non-physical connected, it can be seen as an unsecure channel, which means that the attacker can intercept and control the channel data.

2. The tags referred to the protocol are low-cost passive tags, and the resources of each tag are strictly limited. Each tag in the protocol needs to have the capabilities of unidirectional hash function operation, random number generation, XOR operation and connection operation.

3. The tag will not be easily cracked by the attacker [21], which means the attacker cannot obtain the internal information of the tag, and one-way hash function is safe enough for violent crack from the attacker.

A. Initial conditions and related instruction

For the security authentication protocol with dynamic ID, the random number generators are the same to ensure mutual authentication for the tag, the reader and the server. The backend database stores the data pair (RID, θ) of the legal reader and the data of the legal tag (Iold, Inew, IDold, IDnew, Kj, Sj) and data table to store the random number of the reader. The database needs to read the current time and has the capabilities of hash function operation, random number generation, XOR operation and connection operations. An index value is used to verify the identity of the tag in the first step, which consist of 8-bit binary numbers such as ‘11111110’. The ID information is used to verify the identity of tag again to ensure its freshness, which consists of 16-bit numbers.

The reader stores data pair (RID, θ) and the tag also stores data tuple (Ij, ID, Kj, Sj), and its data is always fresh in the authentication process. Kj and Sj also consist of 16-bit number to make the calculation complex. The attacker is not easy to eavesdrop the key data of the tag. For the initial state, there are two conditions as follows: Ijnew = Ijold and IDRnew = IDRold

The symbols adopted in the protocol are described in Table 1.

Table 1. The description of symbols adopted in protocol

<table>
<thead>
<tr>
<th>Signs</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rj</td>
<td>Random number generated by reader</td>
</tr>
<tr>
<td>Ijold</td>
<td>The old index value of the jth tag</td>
</tr>
<tr>
<td>Ijnew</td>
<td>The new index value of the jth tag</td>
</tr>
<tr>
<td>IDold</td>
<td>The old ID information of the tag</td>
</tr>
<tr>
<td>IDnew</td>
<td>The new ID information of the tag</td>
</tr>
<tr>
<td>Kj</td>
<td>Secret value shared by the tag and the database</td>
</tr>
<tr>
<td>Sj</td>
<td>The secret value of the tag</td>
</tr>
<tr>
<td>H(·)</td>
<td>Hash function</td>
</tr>
<tr>
<td>⊕</td>
<td>XOR operator</td>
</tr>
<tr>
<td>[</td>
<td>Connection operator</td>
</tr>
<tr>
<td>θ</td>
<td>Excepted communication delay</td>
</tr>
<tr>
<td>PRNG(·)</td>
<td>Random number operator</td>
</tr>
<tr>
<td>RID</td>
<td>The ID information of the reader</td>
</tr>
</tbody>
</table>
B. Authentication process

The statement of authentication protocol is divided into eight steps. The implementation of the authentication process is shown in Figure 1.

1. The reader generates a random number $R_t$ and sends query and $R_t$ to the tag as an authentication request, and record the current time $t$ and $R_t$.

2. After receiving the reader request, the tag generates a random number $R_t$ and records the random number into its memory area. Using $ID$, $K_t$ and $S_t$ calculates the following operation as: $y = S_t \oplus R_t$, $\alpha = h(ID \oplus R_t \oplus K_t) \oplus R_t$.

3. Tag sends $y$, $\alpha$ and $I_j$ to the reader.

4. The reader using current time $t_1$ checks whether the inequality $t_1-t \leq \theta$ is satisfied. If the inequality is satisfied, the formula $\beta = h(RID \| R_t)$ is computed, and the results of $\alpha$, $\beta$, $y$, $R_t$, $I_j$, $t_1$ are sent to the backend database, otherwise the authentication is ended up.

5. After receiving the message from the reader, the backend server performs the following operations.
   - The server returns current time $t_2$ and checks whether the inequality $t_2-t_1 \leq \theta$ is satisfied. If it is satisfied then continue with the next step, otherwise authentication process is stopped.
   - The server queries random number table $T$. If $R_t$ is found, the database may be attacked by default or a system error occurred, otherwise, the process continues next step and stores this random number into the table for the next authentication.
   - In order to authenticate the reader, the server calculates $\beta' = h(RID \| R_t)$. If $\beta = \beta'$, the identity of the reader is authenticated successfully, otherwise, the process is terminated.
   - In order to authenticate the tag, the server queries the tag index value $I_j$ in the list. If matched item is found, the process continues to next step, otherwise, the authentication process is stopped.
   - The generated random number $R_t$ by tag can be calculated using the secret value $S_t$ and $y$ in tag’s list. With the tag’s data $ID_{new}$, the server calculates $\alpha' = h(ID_{new} \oplus R_t \oplus K_t) \oplus R_t$. If $\alpha = \alpha'$, the server updates the tag’s ID value and does following operations: $ID_{new} = ID \oplus h(ID \| R_t)$. If $\alpha \neq \alpha'$, the server computes the value $\alpha' = h(ID_{old} \oplus R_t \oplus K_t) \oplus R_t$. If $\alpha = \alpha'$, the tag’s ID keeps unchanged, otherwise, the authentication process stopped.

6. The server returns $\lambda$, $\phi$ to the reader side.

7. The reader obtains the ID value of the tag according to its own RID and the random number $R_t$ by the exclusive OR operation with $\lambda$, and sends the value $\phi$ to the tag.

8. The tag authenticates identity of the backend server and updates the key of the tag itself. The tag calculates the formula $\phi = h(ID \| R_t)$. If $\phi = \phi'$, the tag updates the value of ID and the index value of itself: $I_{new} = PRNG(I_j \oplus K_t)$ and $ID_{new} = ID \oplus h(ID \| R_t)$, otherwise, the authentication process is terminated.

III. SECURITY ANALYSIS

The presented protocol can resist most of attacks for RFID system. The detailed analysis is as follows.

- Data privacy. The messages sent in the solution are encrypted using the hash function and the XOR operation. Because the hash function is the one-way, the attacker is difficult to obtain $ID$, $RID$ and other confidential information.

- For the next round authentication process, the data updated are as follows: $I_{new} = PRNG(I_j \oplus K_t)$, $I_{old} = I_{new}$.

- Finally, the server calculates the data for the reader and the tag to authenticate the identity of the backend server in the next step: $\lambda = RID \oplus ID \oplus R_t$, $\phi = h(ID \| R_t)$.

- The server returns $\lambda$, $\phi$ to the reader side.
also possible to determine whether the communication delay is satisfied at the reader side. With solution above, the replay attack is avoided totally.

- Fake attack. If the attacker intercepts the reader's requested information and impersonates the reader to send message, the tag responds the attacker to send the message. Since the reader and the backend server are physically connected, the attacker cannot obtain the message transferred between reader and backend server. When the attacker counterfeits reader, with the identifier of the \( R_{ID} \), the identity authentication will be failed. If the attacker intercepts the tag's responded message and sends the counterfeit tag to the reader, the first time each authentication process, the reader and the tag will generate a random number, which means that each of the authentication responses of the tag is not the same, and the attack can be prevented. In addition, the backend server and the reader must determine whether the expected communication delay is satisfied once received the response message. The fake attack cannot be established.

- Position tracking. Theoretically, an attacker can attack [22] the tag by intercepting the status information. Since the information in this protocol is encrypted using hash function and the XOR operation, and the ID of each communication tag is dynamically updated. In this way, the information for each response is different, so the attacker is difficult to intercept the information with a particular tag, and cannot track the tag location [23].

- Asynchronous attack. The tag and the backend server only update the corresponding index value and the tag identifier after the mutual authentication is finished successfully. Assuming the tag does not update the message in the current round due to some reasons, it cannot affect the next step of authentication because the server store two pairs of necessary data. In the next round authentication process, if the server side cannot obtain the corresponding message \( I_{new} \) and \( ID_{new} \) in the list, the server queries the list for \( I_{old} \) and \( ID_{old} \), and the corresponding index value and ID value are temporarily not updated. By this method, the generation of the asynchronous attack is prevented effectively.

Table 2 shows the security comparison of protocol proposed with existing solutions. It can be seen clearly that the proposed protocol has the best security performance compared to existing protocols, and it can resist the asynchronous attack.

<table>
<thead>
<tr>
<th>Attacks</th>
<th>[11]</th>
<th>[14]</th>
<th>[15]</th>
<th>[16]</th>
<th>[17]</th>
<th>ours</th>
</tr>
</thead>
<tbody>
<tr>
<td>Data privacy</td>
<td>√</td>
<td>√</td>
<td>√</td>
<td>√</td>
<td>√</td>
<td>x</td>
</tr>
<tr>
<td>Replay attack</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Fake attack</td>
<td>√</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Position tracking</td>
<td>√</td>
<td>√</td>
<td>√</td>
<td>√</td>
<td>√</td>
<td>√</td>
</tr>
<tr>
<td>Asynchronous attack</td>
<td>√</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
</tbody>
</table>

Note: ‘√’ indicates that the solution can prevent attack, and ‘x’ indicates that the solution cannot resistant attack.

IV. BAN LOGICAL ANALYSIS AND PROOF OF SECURITY
The BAN logic provides an effective way for the formal analysis of the protocol. Logic only discusses the security of the authentication protocol at the abstraction level. It does not take into account the security flaws caused by the concrete implementation of the protocol and the flaws caused by the shortcomings of the encryption system. In general BAN logic reasoning is about to infer the specified protocol whether achieve the desired effect using the relevant rules in the BAN logic and the idealized protocol assumptions to.

Before using the BAN logic proves the protocol, the authentication body is usually represented by a concise reasoning symbol. The tag is denoted by \( T \), the reader is denoted by \( R \), and the ID of the tag is represented by \( IDT \).

A. Establish and idealized protocol model

\[
M_1: R \rightarrow T : Query, R_r
\]
\[
M_2: T \rightarrow R : \alpha = h(ID \oplus R_i \oplus K_i) \oplus R_r
\]
\[
y = S_t \oplus R_t \oplus I_j
\]

\[
M_3: R \rightarrow T : \phi = h(ID || R_i)
\]

where, \( M_1 \), \( y \) and \( I_j \) are expressly transmitted, and they have no effect on the logical attributes of the analysis protocol. Above model can be converted to the following BAN logical language.

\[
M_2: R \triangleleft h(IDT, R_i, K_i) > R_r
\]
\[
M_3: T \triangleleft h(IDT, R_i)
\]

B. Protocol initialization hypothesis

\[
P_1: R \equiv R \leftrightarrow R \rightarrow T
\]
\[
P_2: T \equiv T \leftrightarrow R
\]
\[
P_3: R \equiv R \leftrightarrow IDT \rightarrow T
\]
\[
P_4: T \equiv T \leftrightarrow IDT \rightarrow R
\]

The above four initial assumptions are obvious. For assumption P1, because \( R_i \) (random number generated by the reader) is always fresh, it is believed that it sent \( R_i \) is fresh. \( IDT \) is the tag itself identifier, and it is certainly believed that \( IDT \) is fresh.

C. The expectations of the protocol

The expected objective of this protocol is to achieve:

1. \( R \equiv T \sim IDT \)
2. \( T \equiv R \sim IDT \)

D. Proof of the authentication process

The proving process is as follows.
(1) Proof evidence for objective: $R \vdash T \not\vdash IDT$

With M2:
$$R \not\vdash h(IDT,R_i,K_i) >_{R_i}$$
and the initial hypothesis P1:
$$R \vdash R \leftarrow_{R_i} T$$

Using the message meaning rule
$$P \vdash P \leftarrow (X,Y) \quad P \vdash \neg \neg X$$

We can obtain result:
$$R \vdash T \not\vdash h(IDT,R_i,K_i)$$

With M2:
$$R \not\vdash h(IDT,R_i,K_i) >_{R_i}$$

Using the receive message rule
$$P \vdash (X,Y) \quad P \vdash \neg \neg X$$

We can obtain result:
$$R \vdash h(IDT,R_i,K_i)$$

It indicates that
$$R \vdash h(IDT,R_i,K_i)$$

From the message
$$R \vdash T \not\vdash h(IDT,R_i,K_i)$$

and
$$R \vdash h(IDT,R_i,K_i)$$

Using logical community rule
$$P \vdash \neg \neg X \vdash H(X_1,X_2,\ldots,X_n) \vdash P \not\vdash X_1,X_2,\ldots,X_n$$

We can learn that
$$R \vdash T \not\vdash h(IDT,R_i,K_i)$$.  

The following conclusion can be achieved.
$$R \vdash T \not\vdash (IDT,R_i,K_i)$$

With the belief rule
$$P \vdash \neg \neg X \vdash (X,Y)$$

We can get
$$R \vdash T \not\vdash (IDT,R_i,K_i)$$

And objective (1) is derived as
$$R \vdash T \not\vdash IDT$$.

(2) Proof evidence for objective: $T \vdash R \not\vdash IDT$

With M3:
$$T \not\vdash h(IDT,R_i)$$

and the initial hypothesis P2:
$$T \vdash T \leftarrow_{R_i} R$$

Using the message meaning rule
$$P \vdash P \leftarrow (X,Y) \quad P \vdash \neg \neg X$$

We can get
$$T \vdash T \leftarrow_{R_i} h(IDT,R_i)$$

And the result can be obtained.
$$T \vdash R \not\vdash h(IDT,R_i)$$

With the message M3:
$$T \vdash h(IDT,R_i)$$

Using receive message rule
$$P \vdash (X,Y) \quad P \vdash \neg \neg X$$

We can obtain
$$T \vdash h(IDT,R_i)$$

and that is to say
$$T \vdash h(IDT,R_i)$$

With the message
$$T \vdash R \not\vdash h(IDT,R_i)$$

and
$$T \vdash h(IDT,R_i)$$

Using logical community rule
$$P \vdash \neg \neg X \vdash H(X_1,X_2,\ldots,X_n) \vdash P \not\vdash X_1,X_2,\ldots,X_n$$

We can deduce the result
$$T \vdash R \not\vdash h(IDT,R_i)$$

This means that
$$T \vdash R \not\vdash (IDT,R_i)$$

From the belief rule
$$P \vdash \neg \neg X \vdash (X,Y)$$

we can obtain
$$T \vdash R \not\vdash (IDT,R_i)$$

Finally, the objective (2) can be derived as
$$T \vdash R \not\vdash IDT$$.

The protocol proposed in the paper can be deduced by the formal analysis of the BAN logic, so the protocol can effectively achieve the security objectives of the two-way legal authentication of tags and readers in the RFID sensor network.
V. EXPERIMENTAL RESULTS

A. Experimental environment

All the experimental is performed on a PC with a 3.3GHz, 2GB of RAM, and the Windows 7 32 bits operating system. The algorithms are coded in Java, and the backend database is deployed with MySQL. Readers are wired connect to backend server, and communication of readers and tags are wireless. In simulation process, all calculation, verification and updated operations in the backend server are completed by the computer, and the read/write device for tags is accomplished using MCU-51 and RF module. The tag uses the passive MIFARE Plus IC card. The hardware for simulation is shown in Figure 2.

B. Experimental flowchart

According to authentication process, the flowchart used to simulate the experimental is shown in Figure 3.

C. Experimental results

Figure 4 is the main interface for system testing. As shown in Figure 4, the menu “Reader” is used to complete the process of authentication between readers and tags. The menu “Database” is used to store information exchanged within the whole authentication process.

When click the menu “Reader”, the detailed items to complete authentication is shown in Figure 5.

In order to authenticate the reader identity, user input reader’s identifier used in simulation as shown in Figure 7.
After obtained reader’s identifier, user click button “Reader authentication”, and the results of $\beta = h(RID||R_\text{r})$ is shown.

![Figure 7. Reader authentication](image1)

The backend server should also authenticate whether the tag is legitimate. When the button “Tag authentication” is clicked, the system returns the result of tag authentication as shown in Figure 8. To this stage, one round authentication is completed. Because the protocol proposed is a dynamic authentication process, the tag’s ID and Key are changed after one round authentication. If previous tag’s ID input, it will obtain a negative authentication results.

![Figure 8. Tag authentication](image2)

Through a large number of testing, the experimental results indicate that the solution proposed can correctly distinguish legitimate and illegal tags, and it can prevent attacks mentioned above. The solution can be implemented in the hardware environment, which provides a reliable approach for RFID system application in practical.

VI. CONCLUSIONS

This paper introduces a dynamic RFID security protocol based on hash function in RFID sensor networks. A new scheme has been proposed to solve the shortcomings existing protocols. The protocol proposed can effectively solve various security and privacy problems faced in readers and tags in RFID sensor network. Finally, through establishment of the idealized model of the protocol, the BAN logic is used to prove correctness of the protocol. The security has been proved in theory. The experimental results show that the solution proposed can correctly distinguish legitimate and illegal tags, and it can prevent various attacks within RFID system.

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