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ORIGINAL ARTICLE

SRFID: A hash-based security scheme for low cost RFID systems

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Abstract Radio Frequency Identification (RFID) technology is a promising technology. It uses radio waves to identify objects. Through automatic and real-time data acquisition, this technology can give a great benefit to various industries by improving the efficiency of their operations. How- ever, this ubiquitous technology has inherited problems in security and privacy, due to the powerful tracking capability of the tags. This paper proposes a new simple, low cost, and scalable security scheme relying on one-way hash functions and synchronized secret information. The proposed scheme provides a two steps mutual authentication between the backend server and the tag which does not require a secure channel between the tag reader and the backend server to complete the authentication process. The proposed scheme meets the requirements for tag delegation and secure tag ownership transfer. The general idea is to change the ID of a tag on every read attempt in a secure and synchronized manner. This means that attempts like eavesdropping, replay attacks, tag cloning, tag tracing, denial of service attack, or man-in-the-middle attacks cannot compromise the scheme. Our analysis results show that the proposed scheme outperforms existing schemes in terms of security and performance.

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1. Introduction

KEYWORDS

RFID;

Auhentication; Hash function; Privacy; Security

Radio Frequency Identification, abbreviated ‘‘RFID,’’ basi- cally provides a means to identify objects having RFID tags

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attached. Fundamentally, RFID tags provide the same func- tionality as barcodes but usually have a globally unique identifier. Using RFID, the identification is performed electromagnetically. Thus, there is, in contrast to barcodes, no line-of-sight necessary, and the identification can also be performed in contactless way. RFID also has the advantage that bulk reading is possible and that it is not susceptible to dust, dirt, or vibration like barcodes. Because of these characteristics, RFID is envisioned to be a convenient replacement for optical barcodes in the future. Unfortunately, RFID also introduces problems respecting data security and privacy arises. RFID systems have three main components [[1]](#_bookmark7):

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*RFID tags:* RFID tags are used as a label for item identi- fication and communicate with a reader [[1]](#_bookmark7). The reader passes tag data to the backend server for further process- ing, including tag identification and information retrieval [[2]](#_bookmark8).

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*RFID readers:* RFID readers send and receive data to and from tags. RFID readers are the connecting element between the RFID tags and the backend systems.

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*Backend server:* Readers are used for querying tags and reading and writing tag data. All the read data need to be processed, and the data to be written need to be avail- able, so that an additional system component is required to form a complete RFID system which is the backend server.

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RFID tags are classified into three types: active, semi- passive, and passive. Active tags contain batteries, so that they can actively communicate with the reader. Semi-passive tags also contain batteries, but they wait for the reader’s query. As for passive tags, the power comes from the reader [[2]](#_bookmark8).

The key challenge in providing security mechanisms to pas- sive RFID tags is that such tags have extremely weak compu- tational power because they are designed to be ubiquitous low cost [[3]](#_bookmark9). This means that heavy duty cryptography is not suit- able for these types of tags. Our proposed scheme requires small amount of computation, since it only needs to have a one-way hash function, which makes the proposed scheme suitable for these types of tags.

* 1. *RFID security problems*

The characteristics of RFID systems can cause several threats which results in serious information leakage. And the adver- sary can engage in various illegal behaviors by using the ac- quired information. These threats are addressed in several studies [[4–7]](#_bookmark10) and summarized in [[2]](#_bookmark8), [[8]](#_bookmark11) and [[9]](#_bookmark13):

*Eavesdropping*: As communication between the tag and the reader is based on radio frequency, anyone can eavesdrop. *Replay attack:* This is an attack in which an adversary retransmits a message obtained by during the authentica- tion process.

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*Cloning*: An adversary can read the tag and then clone the tag by writing all the obtained data into a blank tag.

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*Tag tracing:* Attackers can either identify the same tag from passively logged messages or interact actively with the tag to understand its location.

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*User privacy violation:* The adversary can analyze the output value of a specific RFID tag and acquire the attached object information, which can be used to violate the user’s per- sonal privacy.

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*Data forging:* Attackers can modify information stored on tags like prices which causes great loss.

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*Denial of Service* (DoS) attack: The adversary could block messages transmitted between a server and a tag. Such an attack could cause the server and the tag to lose synchronization.

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*Man-in-the-Middle (MITM) attack:* The adversary could interfere with messages sent between a server and a tag (e.g., by insertion, modification, or deletion).

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* 1. *RFID security requirements*

To solve the security problems above, the following security requirements should be considered. These requirements are mentioned in [[4,7,8,9–11]](#_bookmark10) which are summarized as follows:

*Mutual authentication:* The property permits the reader and the tag in a communication to verify the identity of the other.

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*Confidentiality*: An attacker should be able neither to anal- ogize nor calculate a certain value through all tag messages transmitted through an insecure channel nor infer a tag’s own ID.

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*Indistinguishability*: It is essential that the transmitted tag information should not be the same as, expectable, or dis- tinguishable from the transmission information of another tag.

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*Forward security:* It is essential that the previously transmit- ted information cannot be traced using the present trans- mission tag information.

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*Desynchronization resilience.* An RFID protocol should be resilient to attacks that are targeted toward desynchronizing the tag and the backend server. With the use of shared secrets and information, it is important that the copies of any shared secret or information stored at the tag and the backend server must be consistent.

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*Tag delegation:* Delegation enables a backend server to del- egate the right to identify and authenticate a tag to a spec- ified entity for a limited number of queries.

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*Tag ownership transfer:* Tag ownership means having authorization to identity a tag and control all the related information. Tag ownership transfer implies a shift of such capabilities to a new owner [[12]](#_bookmark14).

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The rest of the paper is organized as follows: Section 2 dis- cusses related works. Section 3 presents the proposed scheme. Security analysis and performance evaluation are conducted in Section 4 and Section 5, respectively. Section 6 concludes the paper.

1. Related work

The authentication protocol proposed in this paper is a hash- based authentication method. Therefore, the related works introduced here focus on the hash-based authentication proto- cols for RFID tags.

The hash-based authentication protocol proposed in [[7]](#_bookmark12) dealt mainly with untraceability as the refreshment of the shared secret between the tag and the reader or the backend server; but this suffers severely from adversarial attacks, including counterfeiting, man-in-the-middle attacks. In other words, it will most likely fail to carry out mutual authentica- tion later on account of desynchronization.

Hash-lock protocol [[13]](#_bookmark14) used *metaID* = *H*(*K*) to hide the tag’s real ID, where *K* is the shared secret between the tag and the backend server and *H* is a one-way hash function. Although this scheme offers certain level of reliability at low cost, an adversary can easily track the tag via its *metaID,* and thus, the transaction secret or privacy would be at risk. Furthermore, since the key shared between the tag and the

backend server is sent in plaintext, even an inactive adversary can easily sniff the channel to spoof the tag later [[14]](#_bookmark14). The pro- tocol also requires a secure channel between the reader and the backend server during the authentication process to transfer the tag *ID* form the backend server to the reader.

Gervasi [[15]](#_bookmark14) proposed a mutual authentication protocol for RFID tags. The RFID reader and tag will carry out the authentication based on their synchronized secret information. The synchronized secret information will be monitored by a component of the database server. However, the protocol is subject to denial of service, and tag impersonation attacks as proved by Piramuthu [[16]](#_bookmark14), and backend server takes need work of *O*(*n*) to identify a tag. The protocol also requires a secure channel between the reader and the backend server to complete the authentication process.

The following protocol is offered by [[17]](#_bookmark15). This protocol al- lows for mutual authentication in two message exchanges and at the same time prevents the tag ID to be compromised during the authentication process. However, the protocol is not scal- able; the backend server is not able to handle a large tag pop- ulation. It is not able to identify multiple tags using the same radio channel. The server requires an exhaustive search to identify individual tags. The protocol also requires a secure channel between the reader and the backend server during the authentication process to transfer the tag *ID* between the backend server and the reader and suffers from desynchroniza- tion attack.

Shen [[18]](#_bookmark15) proposed a novel anonymous RFID authentica- tion protocol, termed ARAP, which can accomplish the authentication without disclosing real IDs of the participating tags, and it offers the anonymity of tags in addition to tag unlocatability and untrackability. It assumes that each tag should use and store dynamic pseudonyms IDs. This could not be applicable to the limited memory RFID tags. The pro- tocol is also subject to denial of service attack; an attacker can continuously query the same tag until the tag exhausts all the pseudonyms. Further, the protocol cannot satisfy the forward security since knowledge of the stored tag’s pseudonyms can help to identify tag previous interactions.

Boyeon [[19]](#_bookmark15) proposed a protocol for low cost tags using the hash function, the keyed hash function, the pseudo-random number generator, and the XOR operator to guarantee the security and privacy of the RFID system. The protocol is found to be under an elaborate replay attack which can make the attacker get authenticated by the tag unlawfully and is also prone to denial of service attacks [[12,14]](#_bookmark14).

Lim et al. proposed a new protocol [[4]](#_bookmark10) to solve almost all of the existing RFID security problems. However, Zhou [[14]](#_bookmark14) showed that information in this protocol can be exposed via the brute-force attack. It is also found that this protocol is sub- ject to denial of service attack, since the tag stores the received random number *NR* until it received the last message from the reader to authenticate the backend server. An adversary can query the tag many times with different random numbers *NR* each time. When the tag receives the query with *NR* from the adversary, it will store it as a pseudo-random number to identify the session which consume the tag’s user memory, so that it can no longer respond to the reader.

Zhou [[14]](#_bookmark14) proposed a lightweight anti-desynchronization privacy preserving RFID authentication protocol. In this pro- tocol, the backend server keeps the history of the random key update to prevent the active attackers from desynchronizing

the shared secret between the tag and the backend server. Although this technique prevents the replay attack, it is found that there exists a serious problem; an adversary can launch a denial of service attack. An adversary can query the tag *n* times with different random numbers *r* each time. When the tag re- ceives the query with *r* from the adversary, it will calculate and store *H*(*Ti* ¯ *r*) as a pseudo-random number to identify the ses- sion which consume the tag’s user memory, so that it can no longer respond to the reader.

Finally, Cho [[8]](#_bookmark11) proposed a hash-based mutual authentica- tion protocol as a solution to the privacy and forgery prob- lems. The protocol is designed to send a random number generated by a tag to a backend server without disclosure. However, the backend server takes *O*(*n*) to identify a tag. Also, an adversary can perform a desynchronization attack by inter- cepting the message in Step 5 [[8]](#_bookmark11) and replacing *Rt* ¯ *sj*+1 by a random value *v*. According to the protocol, the tag will try to extract *sj*+1 from *v* using *Rt*. In this case, *Rt* ¯ *v* „ *sj*+1, this can bring system to a mess. Further, the protocol cannot satisfy the forward security since knowledge of the stored tag’s secret can help to identify tag previous interactions with complexity *O*(248).

1. Proposed SRFID scheme

A security scheme to solve the RFID security and privacy issues is proposed in this section. The scheme provides mutual authentication and tag *ID* updating, which can resists most at- tacks between backend server and tag including tracing, clon- ing, eavesdropping, and other attacks described in Section

1.1. The proposed scheme also satisfies the security require- ments described in Section 1.2. The proposed scheme is based on the challenge––response mechanism. The backend server stores all the relevant information of the tags. The content of tags is indexed by a unique *ID*. Therefore, the searching is effi- cient, and the system is scalable. A tag transmits its current tag *ID* to the reader which forwards it to the backend server as in- dex in the database. In order to cope with the counterfeiting at- tack issues discussed in Section 1.1, the proposed scheme is based on the mutual authentication between the tag and the backend server. The mutual authentication is based on the sharing of two secret values between the tag and the backend server.

After a successful mutual authentication, the tag *ID* is up- dated by both the tag and the backend server, which provides the forward security for the system. These secret update mech- anisms may results in desynchronization attack. To prevent this attack, the backend server keeps the current records and the previous records of the update process. While the server fails to authenticate a tag because of the desynchronization at- tack, it recovers the old *ID* from the previous secrete values up- date record to complete the authentication. A secret update protocol is also proposed for tag delegation and tag ownership transfer.

* 1. *Notation*

The following table lists the notations used in the proposed scheme protocol.

[Table 1](#_bookmark1)

* + - *ID* is the tag’s current *ID*. Its initial value is

Table 1 Notation.

Symbol Meaning

*ID* The current tag’s ID stored in the server

*IDT* The current tag’s ID stored in the tag

*IDold* The previous tag’s ID

*IDH* The current tag’s hidden ID: Mutually shared secret between backend server and tag

*IDH\_old* The previous tag’s hidden ID

*h*() One hash function available to all parties

*R* Random number generated by the reader

*SQN* A sequence number: Mutually shared secret between backend server and tag.

*INC*() SQN increment function

*DEC*() SQN decrement function

*h*(*IDH* ||*SQN* ).

* + - *IDold* is the last session tag’s *ID*.
    - *IDH\_old* is the last session tag’s hidden *ID*.

*3.3. Authentication process*

To carry out the tag identification by the authorized devices, tag, reader, and server conduct the following steps which are visualized in [Fig. 1](#_bookmark2):

* 1. *Assumptions*

In the proposed scheme, the following assumptions are defined:

1. Tags have limited processing power.
2. Server has significantly greater computational ability than a tag.
3. The channel between the server and the reader is assumed to be secure if detailed tag information is going to be trans- ferred from the server to the reader after the authentication process. Otherwise, the proposed scheme does not require a secure channel between the server and the tag during the mutual authentication process.
4. The reader and tags communicate over an insecure channel
5. Tags are passively powered and only need to have a one- way hash function *h*(), which makes the proposed proto- col suitable for low cost RFID-based. Lightweight cryp- tographic hash functions for implementing RFID protocols have been recently proposed, for example, Kec- cak and Quark lightweight hash functions [[20,21]](#_bookmark15). The RFID tag does not need a pseudo-random number gen- erator PRNG. This will further reduce the cost of the RFID tags.
6. The tag and the backend server share two secrete values: *IDH* is a hidden tag identification number which is only known to the tag and the backend server and is updated each authentication session.

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*SQN* is a sequence number which is known only to the tag and the backend server and is updated after each authentication session. The initial value of *SQN* is *n*0. The sequence number *SQN* prevents third parties from using intercepted authentication messages for fake aut- hentications later on. It also proves to both the server and the tag that the authentication messages have not been used before.

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These two values are generated by the backend server and are written in a secure manner into the tag’s user-bank memory before deployment

1. The backend server database stores three more values for each tag: *ID*, *IDold,* and *IDH\_old*, where:

Step 1. A reader transmits a query and a random challenge number *R* to the tag.

Step 2. Upon receiving *R*, the tag computes its current *IDT* = *h*(*IDH*||*SQN*) and the message *M*1 = *h*(*IDH*||*R*) then transmits them to the reader which forwards them along with *R* to the server. The backend server uses *IDT* to locate the tag in the database and uses *M1* to authenticate the tag Step 3. When the backend server receives *IDT* and *M*1, it searches its database for *ID* to find the corresponding tag record.

Step 4. The backend server computers *M* '1 = *h*(*IDH* ||*R*) and compares it to the received *M*1 if they do not match, the connection is terminated. If, *M* '1 *M* 1, the tag is authenti- cated, Step 5 is performed.

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Step 5. The backend server authenticate itself to the tag by:

* + Incrementing *SQN*: *SQN* = *INC*(*SQN*)

Saving the current value of *IDH*: *IDHold IDH* to prevent the abnormal operation problem described later.

● =

* + Update *IDH*: *IDH* = *h*(*SQN*||*IDH*)

Compute *M*2 = *h*(*IDH*||*SQN*||*R*) which is used by the tag to authenticate the reader and the server.

●

Step 6. The backend server sends *IDT*, *M*2, and *R* to the reader which forwards them to the tag.

Step 7. The backend server updates the current tag *ID* for the next authentication process by:

* + Incrementing *SQN* one more time: *SQN* = *INC*(*SQN*). Saving the current value of *IDold*: *IDold* = *ID* to prevent the abnormal operation problem described later.

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* + Computing the next *ID* of the tag: *ID* = *h*(*IDH*, *SQN*)

Step 8. When the tag receives *M*2 and *R*, it authenticates the reader and the backend server as follows:

Incrementing its *SQN*: *SQN* = *INC*(*SQN*). This should match the value of SQN computed by the server in Step 5.

●

* + Computing *IDtmp* = *h*(*SQN*||*IDH*). This should match the value of *IDH* computed by the server in Step 5.
  + Computing *M* '2 = *h*(*IDtmp*||*SQN* ||*R*) and comparing it to the received *M*2:
    - If they do not match, the tag restores its last state by decrementing *SQN*: *SQN* = *DEC*(*SQN*) and deleting *IDtmp*. The connection is then terminated.
    - If they match (i.e., the backend server is authenti- cated), Step 9 is performed.

Step 9. The tag updates *SQN*: *SQN* = *INC*(*SQN*) and *IDH: IDH* = *IDtmp* to be able to compute *ID* = *h*(*IDH*||*SQN*) for the next authentication process.

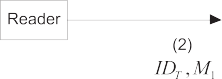
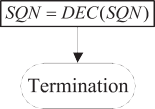
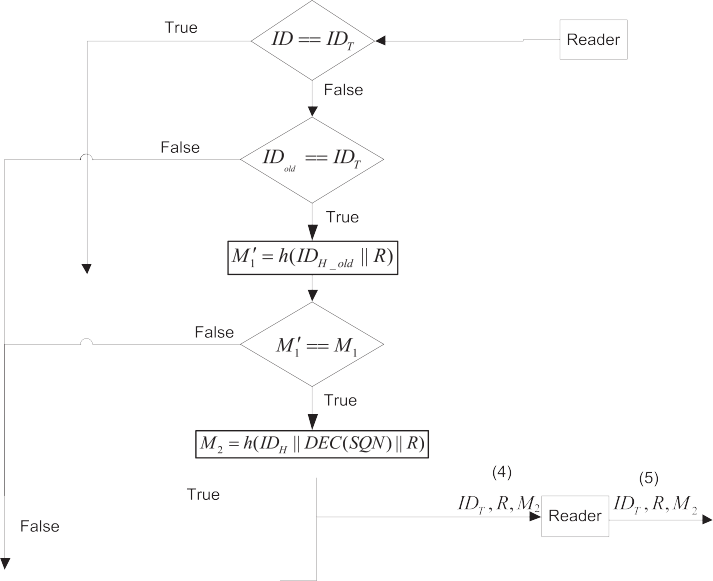
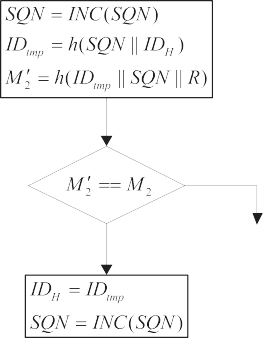
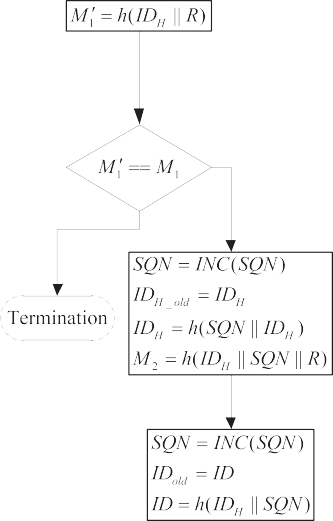
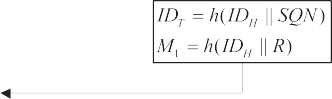


Figure 1 The proposed SRFID scheme.

This should match the value of *ID* and *IDH* computed by the server in Step 6.

*3.3.1. Abnormal operation of authentication process*

Loss, interception, or blocking of messages exchanged between the tag and the reader results in abnormal operation of the proposed scheme. There are three cases:

1. Loss, interception, or blocking of *R* in Step 1 has no impli- cations and will not result in any synchronization problem. The reader will resend *R* after a predefined time *t*.
2. Loss, interception, or blocking of *ID* and *M*1 in Step 2 has no implications and will not result in any synchronization problem; since both *IDH* and *SQN* have the same values in both the tag and the backend server. The reader will resend *R* after a predefined time *t*.
3. Loss, interception, or blocking of *R* and *M*2 in Step 5 results in synchronization problem, since the backend ser- ver’s *SQN* is greater than the tag’s *SQN* by two incre- ments, and both the backend server’s *IDH* and the tag’s *IDH* are different; because the tag’s *IDH* equal to *IDH\_old* stored in the server.

To solve this problem, the backend server stores *IDH\_old* which is equal to the tag’s current *IDH* and stores *IDold* which equal to the tag’s current *ID*. This problem is fixed as follows:

Step 1. The backend server sends a random number R to the tag as specified by Step 1 of the authentication process. Step 2. When the tag receives *R,* it computes *IDT* = *h*(*IDH*||*SQN*) which is equal to *IDold* stored in the server, and computes *M*1 = *h*(*IDH*, *R*) which is equal to *h IDHold* ; *R* and sends them to the reader which forwards

( )

them to the backend server.

Step 3. When the backend server receives *IDT* and *M*1, it searches its database for *IDT* to find the corresponding tag record. In this case, a match is not fond. So, it searches the database for *IDold*. If a match is found, the server com- putes *M* '1 *h IDHold R* and compares it to the received *M*1

= ( || )

if they do not match, the connection is terminated. If

*M* '1 *M* 1, the backend server recomputes *M*2 which is sent before in Step 6 of the authentication process: *M*2 = *h*(*IDH*||*DEC*(*SQN*)||*R*). Note that we used

=

*DEC*(*SQN*) instead of *SQN* in the calculation of the message *M*2 since *SQN* is incremented in Step 7 of the

authentication process after sending *M*2 in Step 6 of the authentication process. Also note that using *DEC*(*SQN*) instead of *SQN* in the calculation of the message *M*2 does not implies the changing of *SQN* value calculated in Step 7 of the authentication process. This step is shown in the gray area of [Fig. 1](#_bookmark2).

* 1. *Tag delegation and ownership transfer*

The proposed scheme is scalable. It provides tag delegation and ownership transfer in an effective way. To prove the sca- lability of our scheme, we follow the approach and assump- tions used in [[9]](#_bookmark13).

* + 1. *Tag delegation*

Tag delegation enables a server to delegate the right to iden- tify and authenticate a tag to a specified entity for a given

* + - * *M*2 = *IDH*/*new* ¯ *h*(*R*'||*IDH*), this securely transfer the new *IDH* to the tag.

*M*3 = *SQNnew* ¯ *h*(*R*'||*SQN*), this securely transfer the new *SQN* to the tag.

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* + - * *M*4 = *h*(*IDH*/*new*||*SQNnew*||*R*')
      * *IDH* = *IDH*/*new*, this updates the new owner *IDH* value. *SQN* = *SQNnew*, this updates the new owner *SQN* value.

●

Step 4. The backend server sends *IDT*, *R*', *M*2, *M*3, and *M*4

to the reader which forwards them to the tag.

Step 5. When the tag receives *R*', *M*2, *M*3, and *M*4 it per- forms the following computations:

* + - * *IDtmp = M2* ¯ *h(R*'*||IDH)*
      * *SQNtmp* = *M*3 ¯ *h*(*R*'||*SQN*).
      * *M* '4 = *h*(*IDtmp*||*SQNtmp* ||*R*').

Step 6. Compares *M* ' to the received *M* . If they match, the

number of times [[9]](#_bookmark13), as described in Section 1.2. Such a pro- 4 4

cedure could be used to reduce the computational load on a server [[9]](#_bookmark13).

In the proposed scheme, tag delegation is straightforward. When a server *S* wants to delegate tag *T* to an entity, that is, allows an entity to query tag *m* times, it generates the following

tag lets *IDH* = *IDtmp* and *SQN* = *SQNtmp*. If they do not

match, the connection is terminated.

1. Security analysis

values for tag *T*: *IDi*; *IDi* ; *Mi* ; *Mi* ; *Ri*, where *i* = 1, .. ., *m*.

*old* 1 2

These values can be easily generated by the server, since the server does need to interact with the tag or the reader to gen- erate these values. These values are transferred to the entity via a secure channel. As a result, the entity can authenticate *T* a maximum of *m* times. However, the entity receiving the delega- tion right cannot update the tag secrets, as it does not know *IDH* or *SQN*.

* + 1. *Tag ownership transfer*

In order to achieve ownership transfer of a tag *T*, *S* must transfer the secrets *IDH* and *SQN* to the new owner via a se- cure channel. This transfer should only take place after the old owner has updated the secrets and identifiers for *T*, in or- der to protect the privacy of previously conducted transac- tions against possible tracking by the new owner [[9]](#_bookmark13). The server of the new owner should also update the tag secrets after receiving them from the old owner, in order to protect the privacy of future transactions against possible tracking by the old owner [[9]](#_bookmark13). This latter update needs to take place in an environment where there is no possibility of eavesdrop- ping by the old owner [[9]](#_bookmark13). Once this is complete, only the ser- ver of the new owner will be able to authenticate *T* and update the secrets for *T* [[9]](#_bookmark13). A protocol to update tag secrets for secure tag ownership transfer is introduced and visualized in [Fig. 2](#_bookmark3):

Step 1. The server transmits an update message and a ran- dom number *R* through the reader to the tag.

Step 2. Upon receiving *R*, the tag computes *IDT* = *h*(*IDH*||*SQN*) and *M*1 = *h*(*IDH*||*R*) then transmits them to the reader which forwards them along with *R* to the server. Step 3. When the backend server receives *IDT* and *M*1, it compares them with the stored *ID* and *M*1. If they do not match, the connection is terminated. If they match, the backend server generates a random number *R*' and per- forms the following computations:

In this section, the security of the proposed scheme with re-

spect to the aforementioned types of attacks, Section 1.1, is analyzed. Finally, a proof that the proposed protocol satisfies the security requirements presented in Section 1.2 is presented.

* 1. *Attack analysis*
     + *Eavesdropping*: Throughout the SRFID protocol, the values the adversary can acquire via eavesdropping are *R*, *ID*, *M*1, and *M*2. Also, throughout the tag secret update protocol, the values the adversary can acquire via eavesdropping are *R*', *R*, *ID*, *M*1, *M*2, *M*3, and *M*4. The adversary tries to use this information to determine *IDH* and *SQN*. As these values are protected by the hash function and XOR operation, they cannot be exposed by simple eavesdrop- ping. Therefore, the proposed scheme is secure against eavesdropping.

*Replay attack:* An adversary cannot reuse messages used in previous sessions because each response is a crypto- graphic function of a fresh random number. More specif- ically, *M*1, *M*2, *M*3, and *M*4 depend on *R*. Also, *ID* depends on *SQN* which is shared secrete between the tag and the backend server and updated each authentication session.

●

*Tag cloning:* If an adversary wants to clone a genuine tag by creating a fake tag with the eavesdropping information, he needs to first query the tag and obtains a response which is *ID* and *M*1. Then, the adversary places *ID* on a counterfeit- ing tag. The adversary will succeed if the RFID reader believes that the fake tag is a real one. However, in the pro- posed scheme, the real tag returns a different hashed value *M*1 based on the random number *R* generated by the reader. Because the adversary cannot predict the random number *R*, the hashed value that the adversary obtains from the real tag (*M*1) is not the same as the hashed value that the reader obtains. Thus, the adversary cannot clone a tag to fool the reader.

●

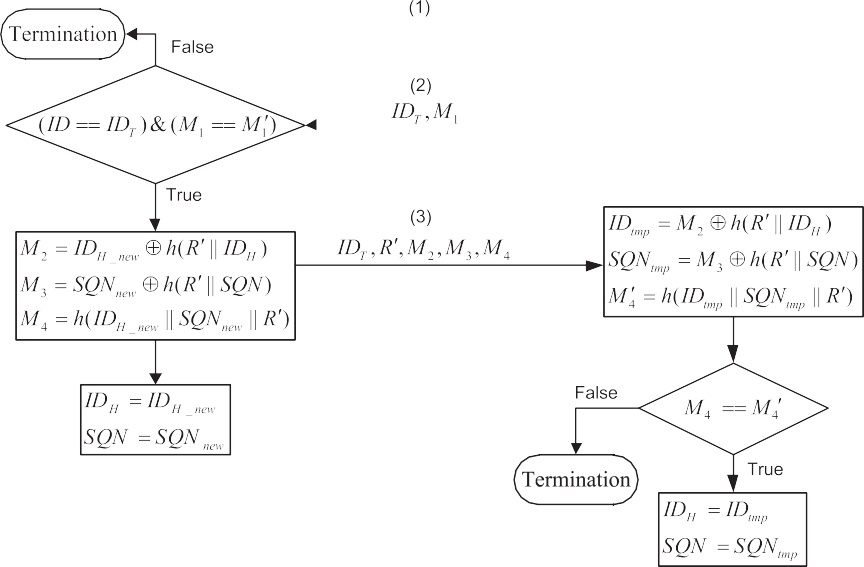
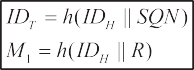
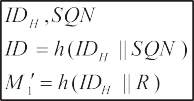


Figure 2 Tag secrets update protocol.

Table 2 Attacks resistance comparison against other schemes.

Replay attack

Tag cloning Tag tracing Data forging DoS attack MITM attack

p: Resists such an attack.

-

-

p

p p

p

-

-

p

p p

p

p

p

p

p

p

p

p

p

\*

\*

\*

-

p

p

-

p

p

-

p

p

\*

p

p p

\: Partially resists such an attack.

–: Does not protect against such an attack.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Attacks | Protocol |  | | | | |
|  | Shen [[18]](#_bookmark15) | Boyeon [[19]](#_bookmark15) | Chen [[4]](#_bookmark10) | Zhou [[14]](#_bookmark14) | Cho [[8]](#_bookmark11) | SRFID |
| Eavesdropping | p | p | p | p | p | p |

*Tag tracing and user privacy violation:* In the proposed pro- tocol, tags responses are random in each session. More spe- cifically, *ID* is a hash of *SQN* which is secret number and is updated each authentication session. The identifier *ID* is also a hash of *IDH* which is secret and is updated each authentication session using *SQN*. Thus, the adversary does not know which tag the response belongs to. Therefore, the location privacy is guaranteed. However, the scheme still allows a degree of tag tracking, because a tag always replies with the same hashed *ID* before the next successful authen- tication. An authorized reader can query the tag every time period *t* to reduce this type of tag tracing attack.

●

*Data forging:* To modify the tag data, an adversary needs to authenticate himself to the tag. This is not possible, since the attacker needs to know *IDH* and *SQN* to

●

construct the message *M*2 which is not possible. The attacker who wants to modify *IDH* and *SQN* of a valid tag, using the tag secrets update protocol, needs to know both the current *IDH* and *SQN*. The two secrets are hid- den by the hash function and the XOR operations. In addition, the secret information stored on each tag is per- tinent to itself. Unless the adversary broke the tag via physical method, he cannot know the secret information of the tag.

*Denial of Service* (DoS) attack: The active attacker can intercept the fifth message, shown in [Fig. 1](#_bookmark2), from the reader to the tag. Therefore, the backend server has refreshed the key, while the tag will not do it. Thus, the shared key between the backend server and the tag may not be the same. After a successful DoS attack which is caused by

●

desynchronization attack, the tag can never be legally authenticated. The desynchronization resistant mechanism discussed in Section 3.3.1 makes the protocol resistant to DoS attacks.

*Man-in-the-Middle (MITM) attack:* An adversary cannot interfere with the exchanged messages by inserting or mod- ifying messages, because of the use of the random number *R* and the secrets *IDH* and *SQN*, which are only known to the backend server and the tag.

●

A simple comparison of several attacks resistance among the proposed SRFID protocol and five of the most recent pro- tocols [[4,8,14,18,19]](#_bookmark10) is shown in [Table 2](#_bookmark4).

* 1. *Security requirements analysis*

*Mutualauthentication:* In the proposed scheme, the backend server can authenticate a tag through a synchronized *ID* value, which is updated at every session and created by the secret values *IDH* and *SQN* shared by both the backend server and the tag. The backend server also authenticates a tag through a synchronized *M1* value in the third message of [Fig. 1](#_bookmark2), which is created by *IDH* and a random fresh num- ber *R*. Thus, an attacker without knowing *IDH* and *SQN* cannot calculate it. The tag authenticates the backend ser-

●

ver by computing *M* '2 = *h*(*IDtmp*||*SQN* ||*R*) and comparing it to the received *M*2 value in the fifth message of [Fig. 1](#_bookmark2) as described in Step 8 in Section 3.3.

*Confidentiality*: The proposed protocol protects the infor- mation necessary for tag authentication by using the hash function, and guarantees that only the authenticated object knowing the tag *IDH* and *SQN* pair can verify the informa- tion. Furthermore, as mentioned earlier, the proposed pro- tocol is secure against eavesdropping by an adversary, and guarantees confidentiality by demanding that the complex- ity of a brute-force attack is high through the use of hash functions.

●

*Indistinguishability*: The proposed scheme uses *ID* to iden- tify tags. This *ID* is a hash of *SQN* which is secret number and is updated each authentication session. The identifier *ID* is also a hash of *IDH* which is secret and updated each authentication session using *SQN*. So, it is impossible to anticipate the response message of the tag each session which guarantees indistinguishability.

●

* + - *Forward security:* The proposed protocol updates *ID* and *IDH* every session using a one-way hash function. Even when an attacker has obtained the last *IDH* and *SQN* values of a tag through capturing a tag in a physical way, he can- not calculate *IDH* values of previous sessions due to the one-way property of hash functions (*IDH* = *h*(*SQN*||*IDH*)) and therefore cannot restore a message of a previous session (*ID* and *M*1) to know or trace a user’s past behaviors. Note that the tag stores only the last *IDH* and *SQN* values. *Desynchronization resilience.* The desynchronization resis- tant mechanism discussed previously in Section 3.3.1 and Section 4.1 makes the protocol meet this requirement.

*Tag delegation:* The tag delegation mechanism discussed in Section 3.4.1 makes the protocol meet this requirement. However, the entity receiving the delegation right cannot update the tag secrets, as it does not know *IDH* or *SQN*. It also cannot calculate *IDH* values of previous sessions due to the one-way property of hash functions.

●

●

*Tag ownership transfer:* The tag ownership transfer mecha- nism discussed in Section 3.4.2 makes the protocol meet this requirement. In order to achieve ownership transfer of a tag *T*, server *S* must transfer the secrets *IDH* and *SQN* to the new owner via a secure channel. Then, the new owner gen- erates the new values *IDH\_new* and *SQNnew* and transfers them to the tag after encrypting them:

●

*M*2 = *IDH new* ⊕ *h*(*R*'||*IDH*)

*M*3 = *SQNnew* ⊕ *h*(*R*'||*SQN*)

This transfer needs to take place in an environment where there is no possibility of eavesdropping by the old owner [[9]](#_bookmark13). The message *M*4 in [Fig. 2](#_bookmark3) proves to the tag that *M*2 and *M*3 are generated by the new owner, since only the tag owner and the tag can generate *h*(*R*'||*IDH*) and *h*(*R*'||*SQN*).

A comparison of the security level among the proposed SRFID protocol and five of the most recent protocols [[4,8,14,18,19]](#_bookmark10) is shown in [Table 3](#_bookmark5).

1. Performance evaluation

This section evaluates the performance of the proposed scheme in terms of computational cost, communication cost, and storage requirement. First, the computational cost for the

Table 3 Security level comparison against other schemes.

Security requirements

Mutual authentication Confidentiality Indistinguishability Forward security

Anti-desynchronization Tag delegation

Tag ownership transfer

p: Satisfies the requirement.

Protocol

Shen [[18]](#_bookmark15)

p p p

p

-

-

-

Boyeon [[19]](#_bookmark15)

p p p p

-

-

-

Chen [[4]](#_bookmark10)

p p p

-

-

-

-

Zhou [[14]](#_bookmark14)

p p p p

-

-

-

Cho [[8]](#_bookmark11)

p p p

-

-

-

-

SRFID

p p p p p p p

-: Does not satisfy the requirement.

Table 4 Overhead comparison against other schemes.

Protocol

Computation cost

*T*

3*H* + *RNG*

Communication

*R*

*S*

Boyeon protocol [[19]](#_bookmark15) 3*H* + *RNG*

Chen protocol [[4]](#_bookmark10)

Zhou protocol [[14]](#_bookmark14)

Cho protocol [[8]](#_bookmark11) SRFID protocol

4*H*

5*H*

*R* → *T*

*lR* + *lH lR* + *lH lR* + *lH*/2

*T* → *R*

Storage

*T*

*R S*

Shen protocol [[18]](#_bookmark15)

*RNG O*( log *m* log *n*)+ 3*H*

*RNG O*(*n*) + (*n* + 1)*H RNG O*(*n*) + (*n* + 3)*H*

2*lH* + *lR* (*m* + 1) *lS* + *lH lR n*((*m* + 1) *lS* + *lH*)

2*lH*

5*lH*/2

*RNG O*( log *n*)+ 3*H* + *RNG* 2*lR* + *lH*/2 5*lH*/2

2*H* + 2*MOD* + *RNG RNG O*(*n*) + 2*n*(*H* + *MOD*) 2*lR* + *lH*

4*H RNG O*(1) + 4*H* 2*lR* + *lH*

*lH*

3*lH*

*lS* + 2*lH lH* + *lR lR* + 2*lS* 2*lH lS* + *lH*

*lR* 2*n*(*lS* + *lH*)

*lR* 3*nlH*

*lR n*(2*lS* + 2*lH*)

*lR* 2*nlS*

*lR n*(*lS* + 3*lH*)

*H*: hash operation: *RNG:* random number generator operation: *MOD*: modular operation: *lH*: length of the hash function output: *lR*: length of

*RNG* output: *lS*: length of any stored value.

proposed scheme is examined. The tag *T* performs only four hash operations. These operations are low cost and can be effectively implemented on low cost RFIDs; lightweight cryp- tographic hash functions for implementing RFID protocols have been recently proposed, for example, Keccak and Quark lightweight hash functions [[20,21]](#_bookmark15).The server *S* requires *O*(1) work to identify a tag in addition to four hash operation for mutual authentication. The reader *R* performs one random number generation operation.

Regarding the communication cost, only communication between the reader and the tag is considered. [Table 4](#_bookmark6) shows the size of messages exchanged between the tag and the reader, which in total demands 2*lR* + 3*lH*. See [Table 4](#_bookmark6) for the meaning of *lR* and *lH*.

Regarding the storage requirement, each tag stores *lS* + *lH* bits, the backend server stores *n*(*lS* + 3*lH*) bits, where *n* is the number of tags and the reader stores *lR* bits.

To analyze efficiency of the proposed *scheme*, the proposed scheme is compared with five of the most recent protocols [[4,8,14,18,19]](#_bookmark10) in [Table 4](#_bookmark6). The comparison shows that the per- formance of the proposed protocol compares favorably with existing schemes.

1. Conclusion

In this paper, a hash-based security scheme for low cost RFID systems (SRFID) is propose. The proposed scheme seeks to mitigate the performance and security weaknesses of previous schemes. A security analysis of the proposed schemes is per- formed by comparing its ability to meet security requirements against several attacks and find that the schemes perform well against other previously proposed schemes in term of forward security, desynchronization resilience, secure tag delegation, and secure tag ownership transfer as shown in [Tables 2 and](#_bookmark4)

[3](#_bookmark4). While the added security comes with some costs, it is found that the costs are reasonable and can be comparable or even lower than previously proposed schemes. The computation cost of the proposed scheme outperforms that of other schemes. A tag T requires only four hash operations. Light- weight cryptographic hash functions for implementing RFID protocols have been recently proposed [[20,21]](#_bookmark15). The server S requires *O*(1) work to identify a tag in addition to four hash operation for mutual authentication. The reader R performs one random number generation operation. The total size of messages exchanged between the tag and the reader in the pro- posed scheme (2*lR* + 3*lH*) which is the same or less than those

of the schemes proposed in [[4,8,14,18]](#_bookmark10). However, the total size of messages of the proposed scheme is less than that of [[19]](#_bookmark15) which is *lR* + 3*lH,* that is, the difference is just 32-bits, which is the size of the random number. The storage cost of the pro- posed scheme is *lS* + *lH* bits for the tag, *n*(*lS* + 3*lH*) bits for the backend server, and *lR* bits for the reader. This outperforms the other schemes except the scheme presented in [[19]](#_bookmark15) in which the tag stores only *lS,* that is, the difference is just the size of the digest.

The proposed scheme has two unique features supporting scalability; a backend server takes only *O*(1) work for tag iden- tification, and tag delegation and ownership transfer is straightforward. A protocol to update tag secrets for secure tag ownership transfer is also introduced.

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