International Journal of Natural Sciences Research
2016 Vol. 4, No. 4, pp. 68-74
ISSN(e): 2311-4746
ISSN(p): 2311-7435
DOI: 10.18488/journal.63/2016.4.4/63.4.68.74

MULTI-USER SEARCHABLE ENCRYPTION SCHEME WITH USER REVOCATION

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ABSTRACT

We improve the previous method to add the function of user revocation in searchable encryption scheme. When document owner doesn't want to share someone he had shared, he can revoke the user who can't retrieve the specific document. More importantly, the revocation process must not affect other authorized users, the scheme has to keep a low maintenance cost.

Keywords: Access control, Cloud computing, Information security, Multi-user, Searchable encryption, Privacy.

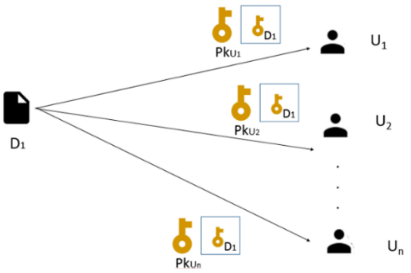
Received: 27 September 2016/ **Revised:** 27 October 2016/ **Accepted:** 2 November 2016/ **Published:** 8 November 2016

Contribution/ Originality

This study contributes in the existing literature are to provide a searchable keyword encryption scheme and the document owner can dynamically authorize a user to retrieve documents or revoke the authorization. The maintenance cost of the revocation process is low.

1. INTRODUCTION

In the most of existing searchable encryption schemes, if the document owner wants to share the document with other users called authorized user, the secret key needed to secure transmit to authorized users. Only the authorized user can retrieve the document .The intuitive way shows as follow [1]:



Document owner encrypts the secret key of the document by user's individual public key. The way increases the document owner's computation overload which needs to encrypt the document N times(If the document shares with N users).The important issue is user revocation in our scheme. When document owner doesn't want to share someone he had shared, he can revoke the user who can't retrieve the specific document. More importantly, the revocation process must not affect other authorized users, the scheme has to keep a low maintenance cost.

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2. RELATED WORK

According to a survey [2] the searchable encryption scheme is classified into four architectures.

The paper focuses on Single owner/Multiple users (S/M). Single owner uses his secret key to create searchable content. A group of owner-defined can generate search token to search and retrieve the document.

The proposed scheme is based on star-based architecture proposed by Lin, et al. [3]. Our scheme uses the concept to let a document can dynamically authorize a user to retrieve document or revoke a user. The document user uses e_0 to encrypt the secret key which encrypted document. As the results, whether the malicious cloud server, any attacker, or other unauthorized user can't retrieve document. Only the authorized users and owner can retrieve and decrypt the document.

3. OUR METHOD

Some searchable encryption schemes have been proposed which can be classified based on secret key cryptography [4]; [5] or based on public key cryptography[6]; [7]. We use the concept of RSA public key cryptosystem [8] was proposed in 1977.

3.1. Key Assignment

The objective of the scheme is to share document to many users, and making users also can execute searchable encryption. Assume that an owner wants to share documents with $U_1, U_2, \dots, U_m$. If the document owners want to share each document for someone among the user group, he needs to assign a secret key $d_1, d_2, \dots, d_m$ to each user. The steps of key assignment show as follows:

1. Document owner randomly chooses two m distinct large primes (p_1, q_1) for U_1, (p_2, q_2) for U_2,….,(p_m, q_m) for U_m. m means the total number of users.

2. Document owner computes p_m multiple q_m to N_m. The value of p_m and q_m keeps secret, but N_m makes public.Document owner computes the value of φ(N_m) for each N_m. The formula for φ(N_m) is equal to (p_m-1)(q_m-1). Next, computing the least common multiple L_0 of each φ(N_m) which equals to

$$L_0 = LCM(\varphi(N_1), \varphi(N_2), \dots., \varphi(N_m))$$

3. Document owner chooses a large prime e_0 that must satisfy two requirements as follows:

$$e_0 < \min\{\varphi(N_1), \varphi(N_2), \dots., \varphi(N_m)\}$$

e_0 is relatively prime to L_0

4. Choosing a d_0 using the extended Euclidean algorithm. It also must satisfy two requirements as follows:

$$e_0 \times d_0 = 1(mod\ L_0)$$

$$d_0 > \max\{\varphi(N_1), \varphi(N_2), \dots, \varphi(N_m)\}$$

5. Using d_0 to generate secret key for d_1,d_2,…,d_m for every user U_1,U_2,…,U_m by the following formula:

$$d_m = d_0\ \varphi(N_m)$$

6. Document owner sends secret key$d_1, d_2, \dots, d_m$ to $U_1, U_2, \dots, U_m$ safely.

7. Document owner has a e_0 to encrypted the secret key of document only the authorized user can obtain it. Users own a secret key and N_m is pubic anybody can get it.

3.2. Broadcast Search Key

Assume that the document owner want to authorize some users $AU = \{U_1, U_2, \dots, U_m\}$ can search using keywords. To this purpose, document owner needs to broadcast the search key k_s to them. The expression shows as follows:

$$k_s' = k_s^{e_0}\ mod \prod_{U_m \in AU} N_m$$

Every authorized users can use their d_m to get the search key k. The following expression shows as follows:

$$k_s = (k_s'\ mod\ N_m)^{d_m}\ mod\ N_m$$

Finally, the authorized users can get the search key. The people who is not authorized he don't have the search ability.

3.3. Document Authorize

This step authorizes specific users can retrieve document. If document owner allows U_{m-1}, U_m to retrieve document D_n, encrypting the secret key sk_n using e_0, and attaching it to the document D_n. The following expression shows as follows:

$$sk_n{}' = sk_n{}^{e_0} \; mod \prod_{U_m \in AU} N_m$$

The unauthorized users can't use their secret key d_m to retrieve the secret key sk_n and decrypt the document, even if they can retrieve the encrypted content.

$$sk_n = (sk_n{}' \; mod \; N_m)^{d_m} \; mod \; N_m$$

3.4. Adding User

If the document owner wants to add a user to access D_n, it is easy to do that doesn't bother other original authorized users. Assume the document owner wants to add a user U_{m+1} to retrieve D_n. The following steps will execute:

1. Document owner randomly chooses two *m* distinct large primes (p_{m+1},q_{m+1}) for U_{m+1}.
2. Update the value of L_0 to $L_0{}'$

$$L_0' = LCM(\varphi(N_1), \varphi(N_2), \ldots., \varphi(N_m), \varphi(N_{m+1}))$$

3. Updating $d_0 \; to \; d_0{}'$ that satisfies the two requirements shows as follows:

$$e_0 \times d_0{}' = 1(mod \; L_0{}')$$

$$d_0{}' > \max\{\varphi(N_1), \varphi(N_2), \ldots, \varphi(N_m), \varphi(N_{m+1})\}$$

4. Authorize U_{m+1} to retrieve the secret key sk_n of D_n.

$$sk_n' = sk_n{}^{e_0} \; mod \prod_{U_m \in AU} N_m$$

3.5. Revoking User

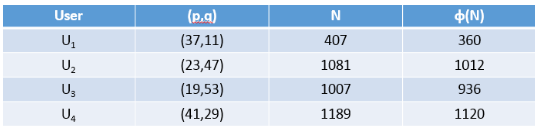
If the document owner wants to revoke some users to access D_n, there assumes that document owner wants to revoke U_{m+1} from D_n. The sk_n need to update to $sk_n{}'$ .The following expression shows as follows:

$$sk_n' = sk_n{}^{e_0{}'} \; mod \prod_{U_m \in AU \cap U_{m+1}} N_m$$

4. EXAMPLE

4.1. Key Assignment

1. Assume the document owner usually share document with U_1, U_2, U_3, U_4. At first, giving every user a pair big distinct prime *p* and *q*. Using the *p* and *q* to compute the value of N_n and φ(N_n). The following table presents the example:



User	(p,q)	N	Φ(N)
U_1	(37,11)	407	360
U_2	(23,47)	1081	1012
U_3	(19,53)	1007	936
U_4	(41,29)	1189	1120

2. Next, computing the least common multiple L_0 of each φ(N_m) which equals to

$$L_0 = LCM\big(\varphi(N_1), \varphi(N_2), \ldots., \varphi(N_m)\big)$$
$$= LCM(360,1012,936,1120)$$

=33153120

3. Document owner chooses a large prime e_0 that must satisfy two requirements as follows:

$$e_0 < \min\{360,1012,936,1120\}$$

e_0 is relatively prime to 33153120

In above requirement, there is choosing $e_0 = 89$.

. 4. Choosing a d_0 using the extended Euclidean algorithm. It also must satisfy two requirements as follows:

$$89 \times d_0 = 1(mod\ 33153120)$$

$$d_0 > \max\{360,1012,936,1120\}$$

In above requirement, there is choosing d_0 **=11175209**.

. 5. Using d_0 to generate secret key and send secure to every users.

$$d_1 = d_0 \text{ mod } \varphi(N_1)$$

=11175209 mod 360 = **89**

$$d_2 = d_0 \text{ mod } \varphi(N_2)$$

=11175209 mod 1012=**705**

$$d_3 = d_0 \text{ mod } \varphi(N_3)$$

=11175209 mod 936 =**305**

$$d_4 = d_0 \text{ mod } \varphi(N_4)$$

=11175209 mod 1120=**969**

4.2. Broadcast Secret Key

Assume document owner usually share document with four users U = $\{U_1, U_2, U_3, U_4\}$ who will get a search key there assume "234" by the following steps:

$$k_s' = (k_s)^{e_0}\ mod\ N_1 \times N_2 \times N_3 \times N_4$$

$$= (234)^{89}\ mod\ 407 \times 1081 \times 1007 \times 1189$$

$$= \mathbf{97319753678}$$

Then document owner broadcasts k_s' to four users.

When U_1 receives k_s':

$$U_1: k_s = (k_s'\ mod\ N_1)^{d_1}\ mod\ N_1$$

$$= (97319753678 \text{ mod } 407)^{89}\ mod\ 407$$

$$= (367)^{89}\ mod\ 407 = \mathbf{234}$$

When U_2 receives k_s':

$$U_2: k_s = (k_s'\ mod\ N_2)^{d_2}\ mod\ N_2$$

$$= (97319753678 \text{ mod } 1081)^{705}\ mod\ 1081$$

$$= (234)^{705}\ mod\ 1081 = \mathbf{234}$$

When U_3 receives k_s':

$$U_3: k_s = (k_s'\ mod\ N_3)^{d_3}\ mod\ N_3$$

$$= (97319753678 \text{ mod } 1007)^{305}\ mod\ 1007$$

$$= (928)^{305}\ mod\ 1007 = \mathbf{234}$$

When U_4 receives k_s':

$$U_4:\ k_s = (k_s'\ mod\ N_4)^{d_4}\ mod\ N_4$$

$$= (97319753678 \text{ mod } 1189)^{969}\ mod\ 1189$$

$$= (235)^{969}\ mod\ 1189 = \mathbf{234}$$

Every authorized user can uses their secret key to get search key k_s'.

4.3. Document Authorize

Document owner wants to share D_1 with *AU*= $\{U_1, U_3, U_4\}$. He doesn't want to share with U_2.There will encrypt the secret key sk_1 of D_1 .

$$sk_1{}' = (sk_1)^{e_0}\, mod\; N_1 \times N_3 \times N_4$$
$$= (123)^{89}\, mod\; 407 \times 1007 \times 1189$$
$$=\mathbf{163652033}$$

Attaching $sk_1{}'$ to the content of D_1.

When U_1 receives $sk_1{}'$:

$$U_1\!: sk_1 = (sk_1{}'\; mod\; N_1)^{d_1}\, mod\; N_1$$
$$= (163652033\; mod\; 407)^{89}\, mod\; 407$$
$$= (182)^{89}\, mod\; 407 = \mathbf{123}$$

When U_3 receives $sk_1{}'$:

$$U_3\!: sk_1 = (sk_1{}'\; mod\; N_3)^{d_3}\, mod\; N_3$$
$$= (163652033\; mod\; 1007)^{305}\, mod\; 1007$$
$$= (435)^{305}\, mod\; 1007 = \mathbf{123}$$

When U_4 receives $sk_1{}'$:

$$U_4\!: sk_1 = (sk_1{}'\; mod\; N_4)^{d_4}\, mod\; N_4$$
$$= (163652033\; mod\; 1189)^{969}\, mod\; 1189$$
$$= (206)^{969}\, mod\; 1189 = \mathbf{123}$$

U_1, U_3, U_4 successfully get sk_1 to decrypt document.

When U_2 receives $sk_1{}'$:

$$U_2\!: sk_1 = (sk_1{}'\; mod\; N_2)^{d_2}\, mod\; N_2$$
$$= (163652033\; mod\; 1081)^{705}\, mod\; 1081$$
$$= (182)^{705}\, mod\;\; 1081 = \mathbf{708}$$

Unfortunately, U_2 can't recover sk_1. He can't decrypt D_1 using 708.

4.4. Adding User

Assume that U_5 joining to the search group, the steps of the adding user process are as follows.

1. Document owner randomly chooses two *m* distinct large primes (p_5,q_5) for U_5.
   Computing N_5 and $\varphi(N_5)$ shows as follow:

User	(p,q)	N	ϕ(N)
U₅	(71,43)	3053	2940

2. Update the value of L_0 to $L_0{}'$

$$L_0{}' = LCM(\varphi(N_1), \varphi(N_2), \varphi(N_3), \varphi(N_4), \varphi(N_5))$$
$$= LCM(360,1012,936,1120,2940) = \mathbf{232071840}$$

3. Update d_0 *to* $d_0{}'$ that satisfies the two requirements shows as follows:

$$e_0 \times d_0{}' = 1(mod\; 232071840)$$
$$d_0{}' > \max\{360,1012,936,1120,2940\}$$

   There chooses $d_0{}'$ = 4925449

4. Using $d_0{}'$ to generate secret key $d_5$and secure sent to U_5 , the other original authorized user don't be bothered.

$$d_5 = d_0\; mod\; \varphi(N_5)$$

= 4925449 mod 2940 = **949**

4.5. Revoking User

Assume that the document owner revokes U_4 to access D_1, so the value of sk_1 changes to 99.

$$sk_1' = (sk_1)^{e_0}\ mod\ N_1 \times N_3 \times \cancel{N_4}$$

$$= (99)^{89}\ mod\ 407 \times 1007 = \mathbf{4147}$$

When U_1 receives sk_1':

$$sk_1 = (sk_1'\ mod\ N_1)^{d_1}\ mod\ N_1$$

$$= (4147\ mod\ \ 407)^{89}\ mod\ 407$$

$$= \mathbf{99}$$

When U_3 receives sk_1':

$$sk_1 = \ (sk_1'\ mod\ N_3)^{d_3}\ mod\ N_3$$

$$= (4147\ mod\ 1007)^{305}\ mod\ 100$$

$$= \mathbf{99}$$

U_1 and U_3 can retrieve the new key sk_1' of D_1.

Suppose the revoke user U_4 wants to get sk_1 using d_4

$$sk_1 = (sk_1'\ mod\ N_4)^{d_4}\ mod\ N_4$$

$$= (4147\ mod\ 1189)^{969}\ mod\ 1189$$

$$= \mathbf{1044}$$

Obviously, U_4 can't recover sk_1 to decrypt D_1 from now on.

Assume k_s change from 234 to 345.

$$k_s' = (k_s)^{e^0}\ mod\ N_1\ \times N_2 \times N_3$$

$$= (345)^{89}\ mod\ 407\ \ \times 1081 \times 1007$$

= 56346964

When U_4 receives k_s':

$$U_4\colon k_s = (k_s'\ mod\ N_4)^{d_4}\ mod\ N_4$$

$$= (56346964\ \mathrm{mod}\ 1189)^{969}\ mod\ 1189$$

$$= (254)^{969}\ mod\ 1189 = 5$$

U_4 doesn't have the ability to search documents.

5. SECURITY ANALYSIS

5.1. Document Confidentiality

If U_m isn't be authorized to access D_m, he can't receive document. As above example in document authorize section. U_2 can't obtain the secret key of D_1 123($708 \neq 123$).

$$U_2\colon sk_1 = (C\ mod\ N_2)^{d_2}\ mod\ N_2$$

$$= (163652033\ mod\ 1081)^{705}\ mod\ 1081$$

$$= (182)^{705}\ mod\ \ 1081$$

$$= \mathbf{708}$$

5.2. Revoking User

Continuing the previous example. If the document owner revokes U_4 to access D_1. U_4 can't access it, and other authorized users don't need to re-key.

$$sk_1' = (C\ mod\ N_4)^{d_4}\ mod\ N_4$$

$$= (4147\ mod\ 1189)^{969}\ mod\ 1189$$

$$= 1044$$

Revoked users also lose their search ability.

When U_4 receives k_s':

$$U_4\colon k_s = (k_s'\ mod\ N_4)^{d_4}\ mod\ N_4$$

$$= (56346964\ \mathrm{mod}\ 1189)^{969}\ mod\ 1189$$

$$= (254)^{969}\ mod\ 1189 = 5(5 \neq 345).$$

6. CONCLUSION

Cloud server only acts as a storage space and knows nothing expect for search pattern in our scheme. The multi-user searchable encryption scheme is easy for the document owner adds or revokes a user from user group that don't bother other authorized users. Document can't recover expect for the authorized users.

Funding: This study received no specific financial support.

Competing Interests: The authors declare that they have no competing interests.

Contributors/Acknowledgement: All authors contributed equally to the conception and design of the study.

REFERENCES

[1] I. C. Lin and Y. H. Liu, "Searchable encryption for text document with ranked results," presented at the International Conference on Advanced Information Technologies, 2016.

[2] C. Bosch, P. Hartel, W. Jonker, and A. Peter, "A survey of provably secure searchable encryption," *ACM Computing Surveys (CSUR)*, vol. 47, pp. 18:1-18:51, 2015.

[3] I. C. Lin, S. S. Tang, and C. M. Wang, "Multicast key management without rekeying processes," *Computer Journal*, vol. 53, pp. 939-950, 2010.

[4] D. Song, D. Wagner, and A. Perrig, "Practical techniques for searches on encrypted data," presented at the IEEE Symposium on Security and Privacy, 2000.

[5] E.-J. Goh, "Secure indexes," Technical Report 2003/216, IACR ePrint Cryptography Archive, 2003.

[6] Y. C. Chang and M. Mitzenmacher, "Privacy preserving keyword searches on remote encrypted data," *Applied Cryptography and Network Security*, vol. 3531, pp. 442–455, 2005.

[7] D. Boneh, G. di Crescenzo, R. Ostrovsky, and G. Persiano, "Public key encryption with keyword search," presented at the Annual International Conference on the Theory and Applications of Cryptographic Techniques, 2004.

[8] R. L. Rivest, A. Shamir, and L. Adleman, "A method for obtaining digital signatures and public-key cryptosystems," *Communications of the ACM*, vol. 21, pp. 120-126, 1978.

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