DigiLock: User-controlled and Server-aware Digital Locker System

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Abstract

The growing popularity of digital systems have paved the way for digital locker that ensures security and safety of the digital documents in store. While facilitating this system to user and availing its services offered by service provider, non-repudiation of service offered and service consumed is an important security requirement in the digital locker system. In this paper, we present a digital locker system that addresses the aspect of confidentiality, integrity, and non-repudiation along with other security properties. The proposed protocol ensures the confirmed participation of the user as well as the service provider while accessing the digital locker. The protocol is analyzed against potential threats in the context of safety and security of the digital locker system.

Keywords: Digital locker; Security; Confidentiality; Authorization; Non-repudiation.

1 Introduction

It has been witnessed that the exponential growth of mobile devices along with the massive power of Internet has eased up the ways of people living. Digital initiatives for facilitating daily needs, whether it is for paying bills, banking, e-learning or e-governance, are encouraging more and more users to come online for saving time as well as money [4]. One of the efficient services of this digital move is to have a digital store in cloud, so that the user can access the service from anywhere and anytime. Digital assets including personal and professional documents are being stored on drive from where it can be accessed in minutes irrespective of time and location. These storage facilities such as Google drive [5], Dropbox [7], OneDrive [6] give us the facility to not only store the documents on the cloud, but also to give different levels of access to different people. This brings the notion of Digital Locker [2], [3] in which storing, accessing and
ensuring the authenticity and accountability of digital assets have become much more efficient and secure.

Digital locker is a digital safe with the objective of keeping important documents safe and secure under a mutually trusted arrangement [1], [8], [9]. The storage and transfer of the documents take place mostly on an online platform, which facilitates anytime-anywhere access to documents. One of the important objectives of the digital locker is to ensure non-repudiation of the parties involved as well as the confidentiality and integrity of the documents [8]. Imagine a scenario wherein documents stored in the locker are manipulated by the user, and then the user can easily blame it on the service provider denying its involvement in the act. Alternatively, the service provider can also alter the documents and put the blame on the user for being involved in the act of misdeed. Ideally, the locker should be opened when both the user as well as the service provider participate in the process, which usually happens in operating of physical locker system [9] used in real-world applications. Therefore, for any transaction with the locker both the service provider and service consumer are equally responsible and answerable for any misconduct intentionally or accidentally. A typical scenario of conventional locker access system is depicted in Figure 1.

![Figure 1: Conventional Locker System](image)

**Our contributions:** In this paper, we present a protocol for securing digital locker system that ensures the locker access is given to the user only on the participation of both the user key and the service provider key. All necessary validations of user and service provider participation takes place inside the locker system, which is managed securely by the service provider’s storage system. A trusted module acts as the safe locker, performs all operations after checking credentials of user’s request and service provider’s consent. The
proposed protocol is analyzed against potential threats in the context of digital locker system and shown secure against repudiation, replay and impersonation attacks.

The organization of the paper: The remaining of the paper is organized as follows. Section 2 presents the protocol for securing digital locker system. Section 3 analyzes the proposed protocol. We conclude the paper in Section 4.

2 Digital Locker System

2.1 System Model and Design Goal

The system consists of three entities – User, Service Provider and the Locker Module. The assumptions and functionalities of these entities are listed below:

User: User is required to register at the service provider for availing the services of the locker system. For this, the user is prompted to submit a secret key $K_i$ and a secret question $m$. The user chooses $m$ to be something that the user can remember at a later time for logging into the system. The secret $m$ is encrypted and the secret key $K_i$ is hashed and stored at the locker system. User secret key $K_i$ is not known to the locker system.

Service Provider: The service provider uses the secret key $R$ to connect to the locker. Without service provider’s involvement the user cannot get access to the locker. All the functions performed and all the information stored within the locker system are assumed to be unavailable to the service provider’s server. The master secret key $R$ of the service provider is not known to the user.

Locker Module: This functionality ensures the participation of the parties, both user and the service provider. The system has $h(K_i)$ and $h(R)$ stored in it for verification of the secret keys of user and service provider, respectively. It also stores the user secret $m$ appended with user secret key $K_i$ encrypted as $E_L(m||K_i)$, where $L$ is a computed symmetric key.

Design Goal. There are two main design objectives of the proposed protocol. Firstly, there should be participation of both the entities for accessing the locker just like that in a physical locker system. For example, a physical locker in a bank requires user to insert the user’s key as well as the bank’s key. Later, in case of any theft or misconduct, the bank cannot back out denying its participation nor can the user put false allegations on the bank. Thus, ensuring non-repudiation of both parties in the digital locker system is an integral requirement. Secondly, the user can verify the computation results and can send an acknowledgement message to the locker module. If the acknowledgement is correct, then only the locker opens and the user is allowed access. In other words, the locker module ensures the usage of user’s key and service provider’s key before opening the digital lock for accessing user’s digital assets.

The symbols and notations used in the protocol are described in Table 1.

We note that $m$ is a secret question that must be remembered by the user without storing it. Upon successful validation of the user into the locker system,
Table 1: Symbols and Notations used in the Protocol

| Notation | Description |
|----------|-------------|
| $R$      | the master secret key of the bank which will be needed to ensure the participation of the bank. |
| $K_i$    | the key of $i^{th}$ user. |
| $N_a$    | the random number generated by the user for each session. |
| $m$      | the secret question chosen by the user during the time of registration. |
| $N_r$    | the random number generated by the locker facility for each session. |
| $K_s$    | the shared symmetric key between user and the locker system. |
| $L$      | the symmetric key with which locker encrypts the correct version of user key and the secret message. |
| $E_x(message)$ | the message is encrypted with $x$. |
| $D_x(message)$ | the message in decrypted with $x$. |

the user can see this $m$ on the screen.

2.2 The Proposed Protocol

The protocol consists of a one-time Setup phase, and Locker Access phase as when user wants to access the locker system.
2.2.1 Setup phase

The user requests to connect to the service provider server. The connection to the service provider server is done through a secure TLS connection over HTTPS [11], [10]. Once secure session is established between user and service provider, the user requests access to the locker facility of the service provider. All the messages between the user and the locker system are sent through the service provider server (e.g. like bank acts the service provider between the user and the physical locker in conventional locker system). Each user, say \( U_i \), selects a different secret key \( K_i \) for accessing the locker system. The service provider has a master key \( R \) known to service provider server only. It is assumed that the secret keys of the users and the master key of the service provider remain uncompromised. The locker system stores the hash of the \( <\text{user id}, \text{user key}> \), that is \( h(U_i \parallel K_i) \) as well as the hash of the server key \( h(R) \). Each user submits a secret question \( m \) to the server at the time of registration. The secret \( m \) is a word or a phrase that is easy for the user to remember and verify. The locker system computes a symmetric key \( L \) as \( h(U_i \parallel K_i) \oplus h(R) \). The user secret message \( m \), and \( K_i \) are stored in the locker system encrypted with this symmetric key \( L \) as \( E_L(m \parallel K_i \parallel U_i) \). All other message exchanges are encrypted with the help of the shared secret key \( K_s \) as computed in the Verification and Access of Locker phase explained below.

2.2.2 Locker Access phase

This phase is comprised of User-Locker Authentication and Locker Access sub-phases.

User and Locker Authentication: User \( U_i \) generates a random number \( N_a \). The value of a pseudo-random function \( PRF_{h(U_i \parallel K_i)}(N_a) \) is calculated with \( h(U_i \parallel K_i) \) as the key. The user sends \( PRF_{h(U_i \parallel K_i)}(N_a) \) and \( N_a \) to the locker system. When \( PRF_{h(U_i \parallel K_i)}(N_a) \) and \( N_a \) are sent through the service provider server, the locker system verifies \( h(U_i \parallel K_i) \) by computing \( PRF_{h(U_i \parallel K_i)}(N_a) \) with its pre-stored value of \( h(U_i \parallel K_i) \). If the computed value does not match with the received one, then the user is notified with an error message stating that the key submitted was incorrect. If the values match, then the process is carried forward. If the user is verified, the locker system requests for the service provider master key \( R \). On getting the service provider master key, the locker system calculates \( h(R) \) and matches it with the pre-stored value. In case of mismatch of this verification, the authentication of service provider cannot be established, and as a result, the user’s request gets denied. The instruction-flow of the locker access system is shown in Figure 3.

Locker Access: Following operations are performed to ensure that both user and the service provider participate in accessing the locker system.

Step-1. The user symmetric key \( L \) is calculated as \( L = h(U_i \parallel K_i) \oplus h(R) \), which is used to decrypt the pre-stored encrypted message \( E_L(m \parallel K_i \parallel U_i) \). On decrypting the message, \( K_i \) is extracted from \( m \parallel K_i \parallel U_i \).
Step-2. Locker system then computes the shared secret key $K_s$ as $K_s = h(U_i || K_i || N_a)$ using the user secret key $K_i$ and the random number $N_a$ sent by the user.

Step-3. The Locker generates a random number $N_r$.

Step-4. The secret message $m$ and $N_r$ have to protected while transmitting them to the user. The locker system encrypts the user secret message $m$ and $N_r$ with $K_s$ and sends it to the user.

Once the user receives the message from the locker, it also computes the symmetric key $K_s$. It uses the freshly computed $K_s$ to decrypt the received message and gets the secret message $m$. This secret message is verified by the user. If the secret message $m$ is displayed correctly it ensures correctness of the protocol as follows: (i) the server master key $R$ was submitted correctly by the service provider server and hence also ensuring its participation, and (ii) since the $K_s$ is computed using the random number $N_a$ given by the user, it ensures the freshness property. After confirming the correctness of the secret message $m$, the user sends an acknowledgement to the locker system. It computes a digest $h(N_a || N_r)$ with $N_r$ and $N_a$ as inputs and transmits it to the locker system. The locker already has $N_a$ and $N_r$ and thus it verifies this digest by recomputing $h(N_a || N_r)$. This is done to ensure the user’s agreement to access the locker services. Once the verification is succeeded, the locker services are made available to the user. If the secret message $m$ is not decrypted properly, that is, if not confirmed by the user then one of the above statements is invalid and hence user does not send back the acknowledgement. If the locker does not receive the confirmation within certain time period it ends the current session without opening the locker to the user. After the successful authentication of the user-locker system, the Locker Access works with Algorithm 1.
Algorithm 1 Locker Access

1: Locker computes user’s key $L$ as $L = h(U_i || K_i) \oplus h(R)$.
2: Locker decrypts $E_L(m || K_i || U_i)$ using the key $L$ and obtains $m$ and $K_i$ for the user.
3: Locker computes the shared secret key $K_s = h(U_i || K_i || N_a)$, where $N_a$ is provided by the user.
4: Locker generates a random number $N_r$.
5: Locker encrypts $E_{K_s}(m || N_r)$ and sends it to the user.
6: User decrypts $E_{K_s}(m || N_r)$ and gets the secret message $m$.
7: User sends an acknowledgement $h(N_a || N_r)$ to the Locker.
8: Upon receiving user’s acknowledgement the locker verifies it and allows the user to access the Locker space allocated for the user.

The DigiLock protocol is shown in Figure 4.

Figure 4: DigiLock: The proposed protocol
3 Security Analysis

We note that the proposed protocol for locker system is run under the protection of TLS protocol. In other words, the message exchange between the participating entities in the proposed locker system is done through a secure channel. On top of the TLS protection, we show that the proposed locker system is secure against repudiation, replay and impersonation attacks.

**Security against repudiation.** Non-repudiation being a major issue in digital locker system, is addressed in our protocol as it ensures the participation of both the entities the user and the service provider, so that at a later time none of them can back out from their participation in the accessing of the locker. The encryption key $L$ is computed using both $K_i$ (key of the user) and $R$ (key of the service provider). Assume that the user is sending incorrect $K'_i$. Then the computation of encryption key will be as follows.

$$L' = h(U_i || K'_i) \oplus h(R)$$
$$D'_L(E_L(m || K_i || U_i))$$

Since the encryption is done with the key that involved the true $K_i$, the message will not be decrypted properly. As a result, the message $m$ will not be displayed on the screen and thereby, locker will not open. Same is the case if the service provider enters an incorrect $R$. If either of them do not participate or provide a faulty input, then the message $m$ is not decrypted properly and the locker will not open. Therefore, for availing the locker services, the message $m$ has to be displayed correctly for which the participation of both user and the service provider is essential.

**Security against replay attack.** If an attacker tries to replay messages intercepted from previous run of the protocol to make locker system believe that its a genuine user, then the attacker will not succeed because the locker system always calculates $K_s$ with the fresh nonce $N_a$ generated by the user.

Suppose the attacker $A$ intercepts a message from an older session and uses it in the current session to manipulate the user $U$ and the locker server $L$, i.e., replays an older message to manipulate the user or locker server into believing that they are communicating with the each other.

$$U \rightarrow A : PRF_{h(U_i || K_i)}(N_a), N_a$$
$$A \rightarrow L : PRF_{h(U_i || K_i)}(N'_a), N'_a$$

As the $N_a$ inside the function matches with the external one, locker thinks that it has got message from right user and authenticates the sender. It then does the computations as follows.

$$K'_s = h(U_i || K'_i || N'_a)$$
$$L \rightarrow A : \{m, N_r\} K'_s$$
$$A \rightarrow U : \{m, N_r\} K'_s$$
$$U$$

computes the key $K_s = h(U_i || K_i || N_a)$

The secret message $m$ does not get decrypted properly as $K'_s \neq K_s$ and hence the decrypted message $m' \neq m$. Therefore, the user does not send the acknowledgement message to the locker, thereby, mitigating the replay attack.
Security against impersonation attack. The user key $K_i$ is kept confidential and uncompromised, which prevents any adversary to impersonate the user. Suppose that the server $S$ tries to impersonate the user, i.e., tries to imitate the behaviour of the user without hinting the locker system about it by computing the following:

$$U \rightarrow S : PRF_{h(U_i||K_i)}(N_a), N_a$$
$$S \rightarrow L : PRF_{h(U_i||K_i)}(N_a), N_a$$

Now since the $N_a$ inside the function matches with the external one, locker thinks that it has got message from right user and authenticates the sender. It then computes

$$L \rightarrow S : \{m, N_r\}_{K_s}$$

Now, $S$ that is for example, the service provider cannot decrypt the message as it cannot compute $K_s$ because it does not have $K_i$. No acknowledgement message will be sent to the locker. As a result, locker impersonation by the server is prevented in our protocol. Furthermore, suppose that the service provider tries to imitate the locker system. As we have stated above, we assume that all the information stored in the locker is concealed from the service provider server. Thus, the service provider will not have access to the encrypted message. Therefore, it cannot send the message back to the user for further verification.

4 Conclusion
Digital lockers are becoming popular in modern digital space because of its ease of use from anywhere and at anytime. We have proposed a locker system that ensures the participation of both the user and the server so as to ensure non-repudiation of participatory role of availing as well as facilitating this service. In addition, the proposed protocol ensures the data confidentiality and integrity during the message exchange of the protocol. The proposed protocol mitigates impersonation, replay attacks, and ensures that any illegitimate party is not able to breach the security of the locker system.

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