Grouper: A Framework for Developing C/S Application Using Secret Sharing and Untrusted Servers

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1 Introduction

Conventional client-server mode applications requires central servers for storing shared data. The users of such mobile applications must fully trust the central server and their application providers. If a central server is compromised by hackers, user information may be revealed because data is often stored on the server in cleartext. Users may lose their data when service providers shut down their services.

To solve this problem, Mylar[7], a Web application framework use browser extension to encrypt and decrypt user data only in client. In this paper, we are are implementing a mobile application framework, Grouper, that is not relied on trusted central servers.

A popular approach to address the central server problem is using P2P(Peer to Peer) to transfer user data between devices. However, there is an obvious problem in such a P2P approach. Data transfer can only be finished during two devices are online at the same time. Another problem is that the number of P2P connections becomes large fast as the number of users increases.

Unlike P2P systems, we use multiple untrusted servers for data transfer. Data is divided into several pieces by secret sharing scheme and uploaded to diverse servers. Each server can only keep a piece of data temporarily, we call it share. A share will be deleted after a period of time. These ensure that user data cannot be cracked easily. In addition, all devices of group members keep a complete data set, and data can be recovered even untrusted servers shut down.

2 Design

We design this framework on iOS platform at first. We are aiming at developing applications which is not relying on trusted central server using our Grouper framework.

2.1 Overview

Applications by Grouper can synchronize data between members of a group. In our situation, each group member holds a device. Thus, Grouper should provides main functions.

- Data synchronization: the group member create an object and others synchronize this object.
- Group management: the group owner create a group in his device and invites other members to his group.

2.2 Data Synchronization

In Grouper, a device use Secret Sharing scheme to divide a message into several shares and upload them to multiple untrusted servers. Other devices download shares and recover shares to original message by Secret Sharing scheme.

2.2.1 Shamir's Secret Sharing

Secret sharing plays an indispensable role in protecting user data from getting lost or destroyed. In a secret sharing scheme, a dealer securely shares a secret with a group of members by generating n shares using a cryptographic function[1]. At least k or more shares can reconstruct the secret, but $k-1$ or fewer shares can obtain nothing about the secret[2]. We describe this scheme as a function $f(k, n)$, where n is the number of all shares, and k is the threshold to combine shares. We use Shamir's secret sharing that is a popular technique to implement threshold schemes.

2.2.2 Multiple Untrusted Servers

We design Grouper based on data synchronization through multiple untrusted servers rather than a single server. There are three principles in our proposal.

Firstly, a server transfers data as similar to a router, but does not keep it permanently. Most current popular client-server applications store their user data on several central servers, and the user's data will not be deleted unless the user deletes his account. Grouper uses untrusted servers as a bridge for transferring data. Consider that a group includes three members: Alice, Bob and Carol. Alice creates a new record in her device, this record is uploaded to untrusted

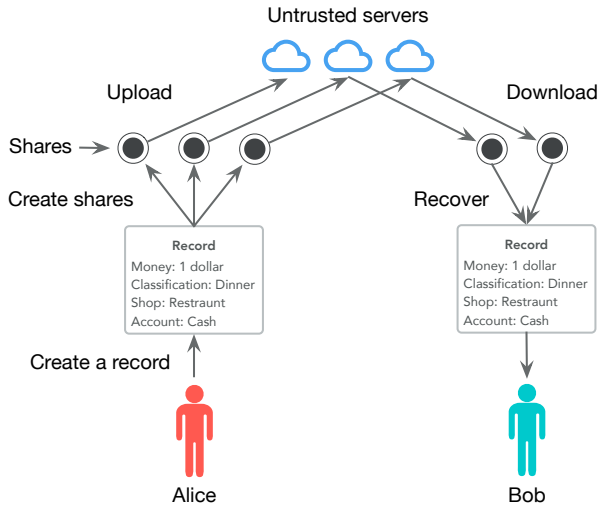

Figure 1: Flow of synchronization.

servers, and the record on servers will be deleted after Bob and Carol download it from servers.

Secondly, a server keeps data temporarily. We define a period of time in which data can be kept in a server, we call it interval time. In this paper, we set this period to 1 hour for our example situations. The record Alice uploaded to untrusted servers can exist for 1 hour. After 1 hour since uploaded, this record will be deleted. Alice requires to upload this record again to serves until all of other members have downloaded successfully. The longer keeping period means the higher risk of data reveal. We will find suitable periods as the number of group members, security requirement and others.

Thirdly, servers do not know the cleartext of data. Keeping data temporarily cannot ensure data security, because servers know the cleartext of data in this temporary period. For this problem, developers often encrypt data before uploading to servers, and this needs a decryption key to decrypt data in other devices. In order to distribute the decryption key, users should share it by themselves. In Grouper, we do not encrypt data but we use a secret sharing scheme as described in Section 2.2. Servers do not know the cleartext of a share generated by a secret sharing scheme.

Figure 1 describes our synchronization flow based on these three principles. At first, Alice adds a record and Grouper creates three shares by a secret sharing scheme where n is three and k is two. Next, Grouper uploads those shares to three untrusted servers. When Bob is online, Grouper in Bob's device downloads two shares from servers and recovers the new record created by Alice. In this situation, Grouper can recover the record after getting two or more shares. In this process, each server is separated from other servers, and cannot access to other servers. This means these servers cannot recover user data because they do not have permission to access other untrusted servers. In our proposal, only group members have permission to access these untrusted servers.

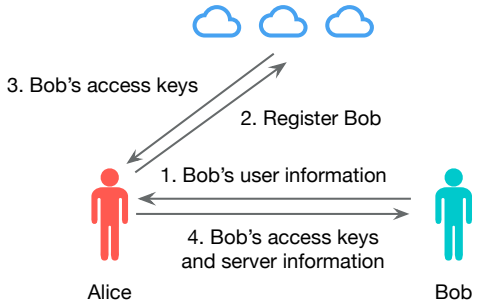

Figure 2: Adding a new member.

2.3 Group Management

2.3.1 Creating Group

A group is created by its owner. For example, Alice is a group owner. Alice should prepare her own user information including email and name at first. Then, she should add multiple untrusted servers by submitting group ID and group name. Here, the group ID and group name are assigned by Alice and they should be same in all untrusted servers of this group.

At last, Alice should initialize this group on all untrusted server by submitting her node identifier. The node identifier which can represent Alice's device, is generated by Group randomly when the app is launched at first time. In each untrusted server, its Web service initializes this new group and returns a master key including the highest privilege to Alice. Alice can add other members to an untrusted server by the master key.

2.3.2 Inviting Member

After creating a group, Alice can invite her friends to her group. As a friend of Alice, Bob should also prepare his user information at first. Figure 3 shows the procedure to add a new member to a group. Alice can only invite Bob by a face-to-face way rather than connection via Internet using central server. Before inviting, Grouper use Multipeer Connectivity, a framework on iOS to exchange data by peer-to-peer Wi-Fi and Bluetooth, to establish connection between Alice's and Bob's devices. Firstly, Bob's device sends his user information and node identifier to Alice's device. Alice saves Bobs's user information and node identifier to her device. Secondly, Alice register Bob on multiple untrusted server by submitting Bob's node identifier. Thirdly, untrusted servers returns Bob' access key to Alice. Lastly, Alice send Bob's access key, server related information and all users' information she has to Bob.

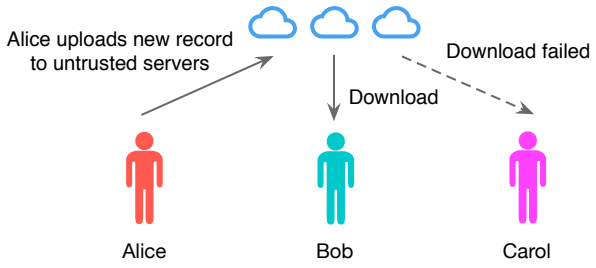

Figure 3: Unreliable synchronization.

2.4 Reliable Synchronization

Grouper should provide a reliable synchronization service. For example, Alice is a user in a group and creates a new record in her device. All of other members in a group should synchronize this record, even if this record may be deleted by untrusted servers after a period of time. We call this problem *reliable synchronization*.

Figure 2 describes an unreliable situation that data cannot be synchronized. Alice sends a new record to untrusted servers and Bob downloads it successfully within the interval time. Carol becomes online after the interval time and fails to download shares of this record because they have been deleted by servers. To solve this problem, Alice should upload her new record again until Carol downloads it successfully.

To solve this problem, we reference the basic reliable multicasting scheme in distribute systems. Messages in this scheme should have sequence number which is added one by one, to indicate the sending order of those messages. For example, the sender of a group send a message No.25 and all of the receivers receive the message No.25 successfully. When the receivers receive new message No.25, they will compare No.25 with the newest sequence number in their persistent store. One of the receivers finds that his newest sequence number is No.23, that means he missed the message No.24. Thus, when they send feedback to the receiver, he will report that he missed the message No.24. At last, the sender will send the missed message to him.

3 Implementation

Grouper consists of clients that run an iOS application and multiple untrusted servers that run a Web service. In Section 2, we have introduced how to share strings with other deices via multiple untrusted servers. In this section, we describe persistent store and data synchronization. Grouper stores all data on mobile devices with an object-oriented way.

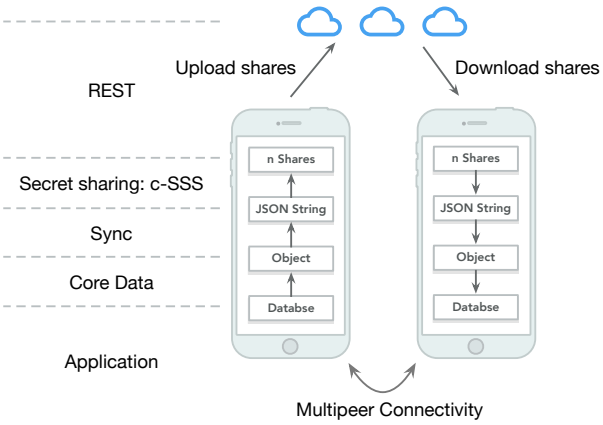

Figure 4: Architecture of the iOS application.

3.1 iOS Application

Grouper uses Core Data[3], a native iOS framework to manage the model layer objects. Core Data provides generalized and automated solutions to common tasks associated with object life cycle and object graph management, including persistence. Sync[4] is a modern JSON synchronization framework for Core Data, and performs data synchronization by generating and parsing JSON strings. With Sync based on Core Data, we can concentrate on sharing with untrusted servers rather than data storage and synchronization.

In this paper, we use c-SSS[5], an implementation of Shamir's secret sharing in the C language. This implementation supports the UTF-8 character set without limitation of length. It provides two main functions: *generate*, which generates n shares by a string text with the threshold k, and *extract*, which recreates the text string from more than k shares.

c-SSS generates shares from a JSON string. There shares are stored as an entity in Core Data. Grouper generates shares and upload them by a REST API to servers.

Figure 4 describes the architecture of the iOS application running on clients. Grouper stores all data on mobile devices in an object-oriented way. Grouper uses Core Data to store and operate data as objects. *NSManagedObject+HYPPropertyMapper* is a part of the Sync framework and creates JSON string from objects. The REST API provided by the Web service in untrusted servers uploads and downloads shares between clients and servers. User information and server information are transferred between clients using the Multipeer Connectivity framework.

Figure 5 is a screen shoot of the view *Add Record*. In this view, users add a new record including amount of money, classification, account, a shop, time and remark in this view.

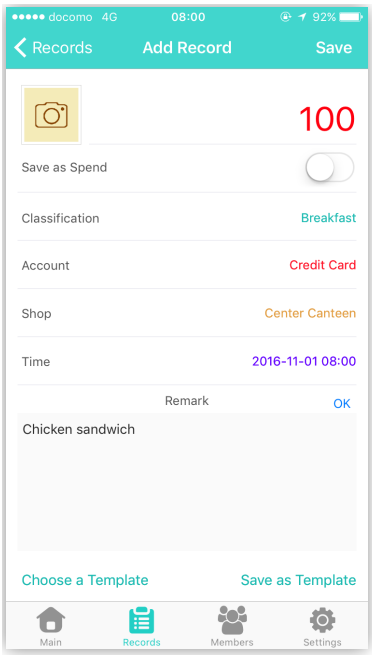

Figure 5: A screen shoot of adding a record.

3.2 Web Service

Grouper needs its own Web service rather than using commercial general cloud services like Amazon S3, Google Cloud for following reasons:

- The Web service supports reliable synchronization.
- The Web service ensures that shares are deleted after a prescriptive time.
- The Web service allows only group members who have access keys to download shares.

Our Web service runs on the Tomcat server that is an open source implementation of the Java Servlet, JavaServer Pages, Java Expression Language and Java WebSocket technologies. We use the Spring Web model-view-controller (MVC) framework to create our REST API. Like in the iOS application, we use Hibernate, an open source Java persistence framework, to save and operate object in the Web service. Hibernate enables developers to easily write applications whose data outlives the processes of the applications.

There are three entities including *Group*, *User* and *Transfer* in our Web service. Figure 6 describes the attributes of these entities and relationship between them. The relationship between *Transfer* and *User* and the relationship between *User* and *Group* are *many-to-one*. The *Group* entity has the unique identifier, group name and its owner. The *User* entity has basic information of a user, access key for this user, and group of this user. The *Transfer* entity has a share generated with a secret sharing scheme, the time when the user uploads it and its creator. For each user, there is a unique access key for him in an

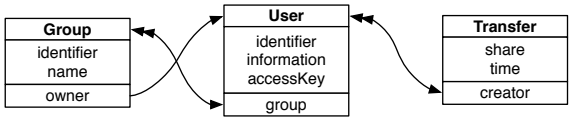

Figure 6: Entities in the Web service.

untrusted server. Thus, only this user can modify or remove what he uploaded to this server. For a group, one of a user is its owner who has the highest privilege of this group.

4 Related Work

DepSky[6] is a system that stores encrypted data on servers and runs application logic. DepSky provides a storage service that improves the availability and confidentiality by using commercial storage services. *Cloud-of-Clouds* is the core concept in DepSky. It represents that DepSky is a virtual storage, and its users invoke operations in several individual severs. DepSky keeps encrypted data in commercial storage services and do application logic in individual servers. In Grouper, untrusted servers undertake responsibility of temporarily data storage and message delivery with server-side computation.

Mylar[7] stores encrypted and sensitive data on a server, and decrypts this data only in users browsers. Developers of Mylar use its API to encrypt a regular(non-encrypted) Web application, and users decrypt data by a browser extension. Like in Grouper, applications in Mylar can control how user data is shared. Mylar builds its system on a browser with extension while Grouper uses mobile devices.

There are many applications and frameworks that use untrusted networks and servers. Compared to them, Grouper uses secret sharing and temporary data storage with untrusted servers to protect user data. Using secret sharing is more convenient and faster than using data encryption because clients need not to distribute decryption keys and perform heavy encryption computation.

5 Conclusion

This paper introduces Grouper, a group finance manager that synchronizes data among mobile devices with multiple untrusted servers. Grouper uses secret sharing and temporary data storage services. Grouper consists of clients that run an iOS application and multiple untrusted servers that run a Web service. Each server of Grouper does not know the others and keeps one piece of the shares generated by secret sharing temporarily to protect user data. We connect clients and multiple untrusted servers by a REST API.

We are developing a robust protocol of reliable synchronization using multiple untrusted servers.

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