PREVENTION OF INFORMATION HARVESTING IN A CLOUD SERVICES ENVIRONMENT

L. M. Batten, J. Abawajy and R. Doss
Deakin University, 221 Burwood Highway, Burwood, Victoria, 3125, Australia

Keywords: Information harvesting, Access, Secret sharing scheme, Cloud computing.

Abstract: We consider a cloud data storage involving three entities, the cloud customer, the cloud business centre which provides services, and the cloud data storage centre. Data stored in the data storage centre comes from a variety of customers and some of these customers may compete with each other in the market place or may own data which comprises confidential information about their own clients. Cloud staff have access to data in the data storage centre which could be used to steal identities or to compromise cloud customers. In this paper, we provide an efficient method of data storage which prevents staff from accessing data which can be abused as described above. We also suggest a method of securing access to data which requires more than one staff member to access it at any given time. This ensures that, in case of a dispute, a staff member always has a witness to the fact that she accessed data.

1 INTRODUCTION

The importance of minimizing information leakage in a cloud computing environment is highlighted by the current use of the cloud infrastructure for applications that require strong confidentiality guarantees. Such applications include e-commerce services, medical records services and back-office business (Ristenpart et al. 2009).

Clouds are sources of large datasets that can be harvested by attackers to obtain private and personal information that can lead to identity compromise and can result in both "true" identity theft, where true information is used to steal the identity of a real person, and "synthetic" identity theft, where true and fake information is used to create a fake identity. Unrestricted and unmonitored access by insiders to diverse datasets can result in both kinds of identity theft – hence there is a need to restrict access by insiders to data stored in cloud data centres.

We note that encryption of data within the cloud will prevent some unauthorized access; but data must be decrypted in order to be processed. There is no current practical method for encryption of data in such a way that the data can be processed in the cloud without decryption. However, there is recent theoretical work in this direction by Gentry (Gentry, 2009), based on homomorphic encryption methods, suggesting that it may be possible. The problem for the foreseeable future is that, using this method, the processing time for even small amounts of data is infeasible (Cattedu, 2009).

1.1 The Threat Model

We consider a cloud data storage involving three entities, the cloud service customer (CSC), the cloud service provider (CSP) which provides services, and the cloud service operator (CSO) (see Figure 1). From time to time, as part of their normal work allocation, staff in the CSP access data in storage. The data stored in the data storage centre comes from a variety of customers and some of these customers may compete with each other in the market place or may own data which comprises confidential information about their own clients.

A large number of staff work in the CSP and job volatility may be high. It is therefore not feasible to perform elaborate security checks on staff, nor to monitor them extensively. The staff potentially have access to data in the data storage centre which could be used to steal identities to sell on the black market, or to blackmail a cloud customer.

The objective of this paper is to establish a cloud architecture which minimizes the opportunity for such information harvesting.

Batten L., Abawajy J. and Doss R..
PREVENTION OF INFORMATION HARVESTING IN A CLOUD SERVICES ENVIRONMENT .
DOI: 10.5220/0003389700660072
In *Proceedings of the 1st International Conference on Cloud Computing and Services Science* (CLOSER-2011), pages 66-72
ISBN: 978-989-8425-52-2

1.2 Related Work

In (Wang et al., 2010) a third party auditor is proposed which employs a series of cryptographic methods to verify that data has been processed according to the agreement between the cloud service and the customer. This is a cumbersome method that does not scale to large clouds. Although it prevents reading of data by the auditors, it does not prevent reading of data by cloud staff.

A completely different approach was taken by (Parakh and Kak, 2009), who focus on methods of storing data within the cloud environment by splitting it into retrievable components before storing it. Thus, a set of medical records might be fragmented in such a way that the viewing of one fragment reveals no usable information to the reader. The roots of a polynomial are used to allocate data components to storage locations. The authors admit that for the management of many large data sets, this method is inefficient for the purposes of data processing. They provide an alternate data security method in this case, whereby a staff member uses a secret sharing scheme to generate different keys for different components of a data set and encrypts each component with a separate key. This protects the data while in storage from being corrupted. It also prevents access to the data by any other staff member. However, it suffers from the drawback that the staff member generating the keys can access the entire data set, and must be trusted not to reveal the keys to others.

In this paper, we provide an efficient method of data storage which prevents staff accessing data and which can be used in the threat model described above. We also suggest a method of securing access to data which requires more than one staff member to access it at any given time. This ensures that, in case of a dispute, a staff member always has a witness to the fact that she accessed data.

In the next section, we motivate the work with a detailed scenario based on medical data. In Section 3, we describe the basic cloud storage model and our approach in separating data within the storage centre area. Section 4 describes a secret sharing scheme method for ensuring that no single person may access a data storage area alone. In Section 5, we consider how to adapt this scheme to the situation of staff joining or departing the cloud business centre. Finally, in Section 6, we draw conclusions and propose some areas for future work.

2 MOTIVATING SCENARIO

Assume that Jo is an individual whose data is stored in the databases of a number of organizations; this includes an automobile registration organization, a government health plan, a pharmacy and an insurance company. All four organizations employ Cloud X to store and process their data. Thus, in Cloud X, the complete identity information relating to Jo can be represented as a 4-tuple <C1, C2, C3, C4>, where Ci, $1 \leq i \leq 4$, refers to the data of each of the organizations. If data relating to the different categories of Jo's personal identity information is stored in the same location in a cloud data area, then it is clear that an insider can easily capture the identity information required to impersonate her. Further, having captured the identity information, the attacker will be able to harvest different types of information relating to the stolen identity leading to privacy disclosure. For instance, if C2 was the individual's, Medicare number, the insider can execute a combined query using C3 and C4 on the medical records database stored in the cloud infrastructure to synthesize the medical history of a given individual. This can be attractive especially for say, medical insurance providers who can then unfairly take into account the person's detailed medical history while assessing their application for medical insurance cover. By periodic information harvesting over the datasets in the cloud, expensive claims can be predicted leading to unfair termination of insurance policies.

Equally important is the fact that information such as medical history, medical conditions and related drug usage is evolving information that can be exploited by insider abuse (Cavoukian, 2008). For instance, trends in the medical conditions of "at risk", individuals such as the elderly or people with pre-conditions can be monitored – frequent visits to the GP may be used as an indicator of a recurring or on-going medical condition that might result in hospitalization and possibly an expensive claim or the prescription of pregnancy-related drugs may be perceived as indicating the medium to short-term plans of an individual to start a family.

Hence, while it is important that data be stored in the cloud in a distributed manner to ensure that insider compromise is minimized, it is equally critical that data access is tightly controlled to ensure that information leakage leading to identity theft and privacy disclosure can be prevented.

3 THE CLOUD STORAGE REFERENCE MODEL

We refer again to Figure 1. A CSC rents storage from a CSP and pays for the amount of storage their data is actually consuming or for what the CSCs have allocated. CSCs range from individuals, small businesses and financial institutions to Fortune 500 firms to governments. The management of the storage is done solely by the CSOs, and thus CSCs are relieved of the burden of maintaining storage infrastructure. The CSOs migrate data between storage tiers, set up connections, maintain disk drives, manage firmware upgrades, establish virtual machine replication timetables, take snapshots as well as scheduled data backups and are responsible for safe storage of the backup media (Abawajy, 2009).

The CSPs own the cloud resources and expertise in building and managing cloud storage servers. They provide data storage as a service, which is virtualised storage on demand over a network to CSCs based on a request for a given, agreed quality of service. The use of virtualisation allows CSPs to maximise storage resource utilisation by multiplexing data storage of many cloud customers across a shared physical infrastructure. The term multi-tenancy is commonly used to describe sharing of cloud storage among multiple customers who could be separate companies, or departments within a company, or even just different applications.

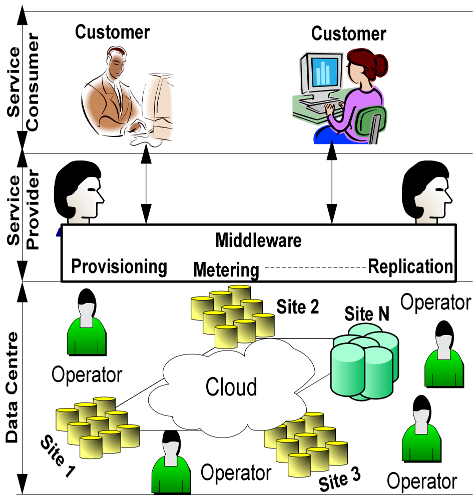


Figure 1: The Cloud Storage Reference Model.

The deployment of data storage as a service is powered by data centres at different geographical sites (site 1, site 2, … , site n in Figure 1) over the Internet running in a simultaneous, cooperative and distributed manner. Most service providers allow CSCs to store unstructured database blocks, which are then mirrored in partial segments over multiple storage sites. Once the data is stored on the cloud, CSCs do not control and may not even know the exact location of their data and copies may be hosted in the cloud. Thus, a cloud environment can result in a loss of transparency about where client data is stored and this can have legal implications.

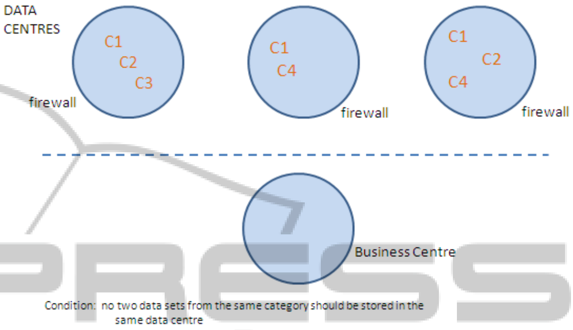
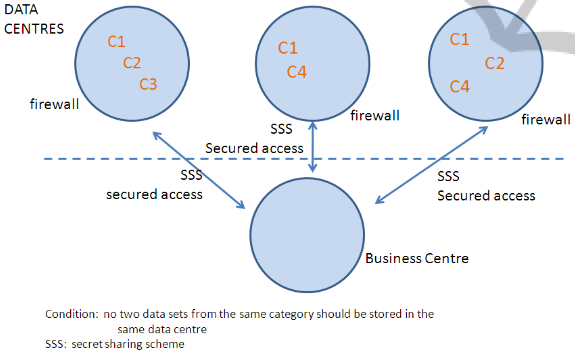

DATA CENTRES
C1
C2
C3
firewall
C1
C4
firewall
C1
C2
C4
firewall
Business Centre
Condition: no two data sets from the same category should be stored in the same data centre

Figure 2: Secure data storage.

A service consumer is able to perform a variety of actions on her data including the ability to create, update, append, reorder and delete their stored data. The CSCs interact with the cloud servers via the cloud middleware. The middleware incorporates components such as different storage protocols including file-based options and block-based options, advanced data replication techniques, access control mechanisms, storage provisioning and storage metering (Buyya et. al., 2010; Yildiz, et. al., 2009). CSCs need to allocate storage before they can use it. Also, the storage usage metering component provides CSCs with information on how much storage their data consumed so that they know what their bill will be at the end of the billing cycle.

The cloud creates unique requirements for data in terms of security and manageability. Once the data is stored, it is completely under the control of the cloud service provider. As users no longer possess their data locally, it is of critical importance to assure users that their data are being correctly stored and maintained (Wang et al., 2010). An obvious threat to the customer data sets is from malicious insider abuse. Thus, one of the key issues in data storage for clouds is to effectively detect any unauthorized data modification and corruption, possibly due to server compromise or attacks that rely upon subverting a cloud's administrative functions via malicious insider abuse.

Our aim is to ensure that no employee working in the cloud can access separate data sets which, combined, might yield information which is considered to be private or confidential. In order to ensure this, we propose pre-classification of data by the customer itself according to a cloud service determination in order to be able to store data in separate fire-walled and access protected data centre areas. The customer will be asked to classify its data into one of several categories. A single category might be health data such as medical insurance, hospital and pharmaceutical information. Those data sets belonging to the same category would be separated in storage. Figure 2 describes how this would be done. In the health data example, all three data sets would be classified as being in the same category C1 and therefore stored in three separate areas. Other data not in the same category can be stored with C1 data as shown in the Figure. The condition is that no two data sets in the same category should be stored in the same data centre. This requires enough data storage centres to store all data in any one category at any given time. In a virtual machine environment, however, it is a trivial, and normal, task to establish additional data centres as needed.



Condition: no two data sets from the same category should be stored in the same data centre
SSS: secret sharing scheme

Figure 3: A secret sharing scheme used in securing access to data.

4 ACCOUNTABILITY – THE USE OF SECRET SHARING SCHEMES

Secret sharing schemes have been used by (Upmanyu, 2010) in designing a provably-secure privacy-preserving protocol to limit access to related data sets stored in the cloud. Their method is substantially more efficient than previous known methods, but still adds noticeable cost to the cloud service. We approach the goal of securing access in two ways. One is by means of the cloud architecture itself, compartmentalizing and separating the storage spaces, as described in the previous section; the other is by means of cryptographic access and authentication procedures. These access and authentication procedures need to be mapped across the compartmentalized cloud structure.

Since our aim is to ensure that no employee working in the cloud can access separate data sets which, combined, might yield information which is considered to be private or confidential, a secret sharing scheme will be used to ensure that no set of less than *t*, for some fixed value *t*, people can collaborate to gain access to enough data sets from the same category to be able to deduce information which is confidential.

DEFINITION: Let *t* and *w* be positive integers, $t \leq w$. A *(t,w)-threshold secret sharing scheme* is a method of sharing a message M among a set of w participants in such a way that any t participants can reconstruct the message M, but no subset of smaller size can reconstruct M.

Adi Shamir invented the first such scheme in 1997 (Menezes et al.,1997) and it is based on the idea of Lagrange interpolation, or, equivalently, the fact that knowing n+1 points of a degree n polynomial determines the whole polynomial.

Here, we shall set up a secret sharing scheme in a finite field over a prime, GF(*p*), where a secret *M* is represented as a number modulo the prime *p*, and we want to split *M* among *w* people in such a way that any *t* can reconstruct the message, but no fewer than *t* people can do so.

We randomly choose *t*-1 coefficients s_i (mod *p)* and define the polynomial

$$s(x) = M+s_1x+\ldots+s_{t-1}x^{t-1} (\text{mod } p) \qquad (1)$$

Any of *p* possible choices for *x* will result in a value for *s(x)*. These values need not all be distinct. We can thus distribute up to *p* 'shares' in the secret to participants, of the form (*x*, *s*(*x*)). Note that *s(0)* = *M*, so this share will not be used. As long as $w \leq p-1$, we have a *(t,w)*-threshold secret sharing scheme as any *t* participants can combine their shares and solve a system of equations which will determine *M*. No fewer than *t* people can do this.

In a cloud services situation, some staff may have seniority which permits them to hold more than one share of a secret which allows access to a data centre; this will be determined in-house. However, no matter how many shares of a secret a person holds, they should never have enough shares to determine the secret alone. This ensures that each employee can be held accountable for accessing a data centre based on the evidence of a third party; it also provides a witness to the fact that an employee acted appropriately in accessing data.

In addition, the same set of people should never be able to access two data centres holding information which cannot be shared. Thus, conditions on distribution of any secret sharing scheme apply as below.

CONDITIONS:

(i) Any data centre needs at least two people to be able to access it,

(ii) The same set of people should never hold shares to a key accessing different data centres holding data of the same category.

Figure 3 describes the data and business centres with access based on secret sharing schemes.

Example: Here, we give an example of a secret sharing scheme which satisfies the two conditions above. Let $M = 190503180520$ be the secret message and let $p = 1234567890133$. (Note that p is greater than M.). We construct a (3,6)-threshold scheme as follows. We choose

$s(x) = M + 482943028839x + 1206749628665x^2$ modulo p

where $s_1 = 482943028839$ and $s_2 = 1206749628665$. And now we distribute shares of the secret to 8 participants, using values of x from 1 to 8. The shares are:

- (1, 645627947891)
- (2, 1045116192326)
- (3, 154400023692)
- (4, 442615222255)
- (5, 675193897882)
- (6, 852136050573)
- (7, 973441680328)
- (8, 1039110787147)

The first four people are each given one share, person i receiving share *(i, s(i))* above.

Person 5 is given shares 5 and 6 and person 6 is given shares 7 and 8. Since 3 shares are needed to determine the secret, condition (i) automatically applies.

Suppose shares 1, 2 and 7 are allocated to access the first data centre in Figure 3. Then shares 1, 2 and 8 cannot be allocated to access the second or the third data centres; this is because the same person holds shares 7 and 8 and can use either, together with share-holders 1 and 2 to breach condition (ii).

A cloud service business is dynamic; staff come and go, as do data and files. If an additional data centre must be set up, then the existing secret sharing scheme must be adapted to cope without a complete re-distribution of secret shares. Similarly, if a staff member arrives or departs, shares need to be allocated or deleted from the existing scheme. In this paper, we discuss only this latter case of a dynamic staffing situation. We leave a dynamic data situation for future work as it requires a different approach.

5 A DYNAMIC STAFFING SITUATION AND DYNAMIC SECRET SHARING SCHEMES

Each data centre is accessed by means of a secret M from a secret sharing scheme as in equation (1). In order that condition (ii) be maintained, it is necessary to use different equations for different data centres. Nevertheless, different equations with the same secret for different data centres is permissible as different sets of shares need to be used to compute the secret.

5.1 Extending Secret Sharing Schemes in Order to Add Staff

The lemmas in this section describe how to adjust secret sharing schemes to accommodate staff who leave or join the service provider. Lemma 1 shows that as long as the parameters are within prescribed bounds, an additional staff member can easily be accommodated.

LEMMA 1: *Let t and w be positive integers, $2 \leq t \leq w \leq p-1$, p a prime. Any (t,w)-threshold secret sharing scheme over GF(p) based on (1) with $w+1 \leq p-1$ can be extended to a (t,w+1)-threshold secret sharing scheme over GF(p) also based on (1).*

PROOF. Suppose we have a (t,w)-threshold secret sharing scheme over GF(p) based on (1) with $w+1 \leq p-1$. Since $w < p-1$, we can distribute an additional share based on (1), thus resulting in a (t,w+1)-threshold secret sharing scheme over GF(p). QED.

The above lemma and its proof describe how a staff member can be added to a scheme which continues to need t members to access a secret. As long as the bounds are met, members can continue to be added. We thus have the following.

COROLLARY: *Let t, w and r be positive integers, $2 \leq t \leq w \leq w+r \leq p-1$, p a prime. Any (t,w)-threshold secret sharing scheme over GF(p) based on (1) with $w+1 \leq p-1$ can be extended to a (t,w+r)-threshold secret sharing scheme over GF(p) also based on (1).*

In order to allow flexibility in adding many staff, the prime p is normally chosen to be much larger than the potential number of staff. The situation of staff departing is somewhat more difficult. The shares of departing staff must be revoked and we deal with this in the next two sub-sections.

5.2 Revocation Lists

As staff leave, each data centre stores revoked shares. To prevent a set of t shares, at least one of which is revoked, from accessing a secret M associated with a data centre, the polynomial (1) is adjusted to the following:

$$s(x) = (M*\Pi(x - r_i))/\Pi(x - r_i) + s_1x + \ldots + s_{t-1}x^{t-1} \pmod p \qquad (2)$$

where the product is taken over the abscissa of each revoked share. When a non-revoked value for x is substituted, the coefficient of M is 1, and (2) reduces to (1). However, when a revoked value for x is used, the coefficient of M is not computable, M is not revealed and access is denied.

Revocation can continue to the point where precisely t associated shares are available to access a data centre, but not beyond. The service provider must ensure that enough shares are available at any time in order to access the data centre. Thus, we have the following lemma.

LEMMA 2: *Any (t,w)-threshold secret sharing scheme over GF(p) based on (2) with* $2 \leq t \leq w \leq p-1$*, p a prime, permits revocation of up to w-t shares while still operating as a (t,r)-threshold secret sharing scheme over GF(p) based on (2) with* $2 \leq t \leq r \leq w \leq p-1$.

If a revoked share is used in attempting to gain access to a data centre, the authentication centre can determine which share it was and hence also to whom it belongs. While equation (2) does not reveal this, the following does. Once a set of t shares fails to produce the secret, the authentication centre compares each submitted share with each entry in the list of revoked shares to find a match and thus also identifies the owner.

5.3 Managing Revocation Lists

Since *p-1* shares can be distributed, up to *p-1-t* shares can be revoked with a usable secret sharing scheme remaining. Once *p-1-t+1 = p-t* shares are revoked, the scheme is no longer usable and a new threshold secret sharing scheme must be deployed.

The current share holders may retain their existing shares if a new polynomial is designed in the following way: retain the *t-1* or fewer existing valid shares. Choose additional pairs randomly, but excluding all revoked shares from the first scheme, so that a total of *t'* pairs is available where *t'* is to be the threshold of the new scheme. Use these *t'* pairs to determine uniquely a polynomial of the form (1) over some (large) prime *p'*. This new polynomial can now be used to formulate *p'* shares, such that the holders of old shares retain these.

6 CONCLUSIONS AND FUTURE WORK

We have presented two approaches, which can be combined, to protection of data inside a cloud service centre. One, expressed in Figure 2, stores the data in such a way as to separate data of similar ‘types’. The second deals with allocating shares to cloud staff in such a way that access to more than one data set of the same type is prevented. Thus, in allocating shares, conditions (i) and (ii) must not be violated; refer to Figure 2.

We showed that in such a setting revocation of up to a certain number of shares distributed to staff can be easily managed.

We leave for future work the following problem: automate an efficient scheme for allocation of shares in a dynamic environment (staff leaving and joining) such that conditions (i) and (ii) are always valid. Extend this scheme so that it includes the addition and removal of data centres.

REFERENCES

Abawajy, J. 2009. Determining Service Trustworthiness. In Intercloud Computing Environments, Proc. of the *10th IEEE International Symposium on the Pervasive Systems, Algorithms and Networks (ISPAN 2009)*, pp: 784-788, 2009.

Buyya, R., Beloglazov, A. and Abawajy, J. 2010. Energy-Efficient Management of Data Center Resources for Cloud Computing: A Vision, Architectural Elements, and Open Challenges. In *Proc. of PDPTA 2010, pp: 6-20*, July 12 - 15, Las Vegas, Nevada.

Cattedu, D. and Hogben, G., editors. ‘Cloud computingsecurity benefits, risks and recommendations’, Nov. 2009 – *Report by the European Network andInformation Security Agency.*

Cavoukian, A., 2008. Privacy in the Clouds. In *Indentity inthe Information Society* (pp. 89-108). Springer.

Gentry, C. (2009) ‘Fully homomorphic encryption usingideal lattices’. *Proceedings of the 41st annualACM symposium on Theory of computing, ACM*, New York, pp. 169-178.

Menezes, A., van Oorschot, P. and Vanstone, S. 1997. Handbook of Applied Cryptography. *CRC PressBoca*

Raton, USA.

Parakh, A. and Kak, S. 2009. Online data storage using implicit security. *Information Sciences 179* (2009)3323-3331.

Ristenpart, T., Tromer, E., Shacham, H., & Savage, S. (2009). Hey, You, Get off of my Cloud: Exploring Information Leakage in *Third Party Compute Clouds. CCS'09, (pp. 199 - 210)*. Chicago, Illinois, USA.

Upmanyu, M., Namboodiri, A., Srinathan, K. and Jawahar, C. V. 2010. 'Efficient Privacy Preserving K-Means Clustering' *PAISI 2010, LNCS 6122*, pp. 154–166.

Wang, C., Wang, Q., Ren K. and Lou, W. 2010 "Privacy-Preserving Public Auditing for Storage Security in Cloud Computing," *Proc. IEEE INFOCOM '10*, Mar. 2010.

Yildiz, M., Abawajy, J., Ercan, T. and Bernoth, A., 2009. A Layered Security Approach for Cloud Computing Infrastructure. In *Proc. of the 10th IEEE International Symposium on Pervasive Systems, Algorithms and Networks (ISPAN 2009)*, pp. 763-767, 2009.