Using the HashChain to Improve the Security of the Hadoop

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Abstract. For the problem of enforcing mandatory access control on the data nodes in Hadoop, there exists some limitations by analyzing its own the token-based authentication scheme. Therefore, we use the hash chain password method to improve the original authenticationscheme. By analyzing the security, the novel method is effective against the impersonation and replay attacks by increasing the confidentiality of the token compared with the original one. At the same time, it is more efficient in the authentication process for its simplification.

Introduction

Apache Hadoop is an open-source software framework [1,2], which is known for implementing the MapReduce model to support the data-intensive distributed applications. Hadoop Distributed File System (HDFS) is a distributed, extensible, and lightweight file system, which is widely adopted as the cloud storage system [3]. Therefore, a high security authentication system is needed to restrict the access control to confidential data.

The Kerberos authentication scheme came with the release of the Hadoop 1.0.0, which achieve the authentication of nodes in the cluster. It is available only when the nodes pass the authentication, which ensures the security and credibility of the cluster. However, Kerberos does not solve a package for all security issues [4]. Many researchers also have put forward the improvement schemes constantly. For instance, Zhou et al. proposed a data security access scheme based on attribute-group. In the scheme, the data owners do not participate in the specific operation of the property and user rights [5], and Somu et al. proposed a novel authentication model using one-time pad algorithm that removes communication of passwords between the serversto enhance the security in Hadoop environment [6], and Yang et al. achieved a triple encryption scheme for Hadoop-based cloud data to enhance the data security [7].

In this article, the hash chain password method [8] is used to improve the token-based authentication in Hadoop to respond the security authentication problem of the communication between the client in Hadoop and HDFS services, which is effective to implement the authentication between users and HDFS. The scheme has more efficiency, simpler processes, higher security, and nicer compatibility than the original one.

Hash Chain Model and Application

The hash chain is a basic password method to prevent from being stolen. Lamport first proposed the method [8], and the hash chain of length N can be constructed from applying the one-way hash function h(.) to an initial seed value recursively (see Equations 1).

\[ h^N(s) = h\left(h\left(h\ldots h(s)\right)\right) \quad (N \text{ times})\]

If just the \( h^N(s) \) is known and the seed values not, the adversary cannot know the \( h^{N-1}(s) \). However, it is easy to verify the \( h^{N-1}(s) \) through the \( h^N(s) \). The characteristic of hash chain is derived from the nature of one-way hash function [9]. The model can be used to design cryptographic authentication schemes in insecure environments. Even if the adversary can read the system data and even eavesdrop on the communication between users and the system, it also can ensure the password security.
The security password authentication between the user and the system can be achieved by the hash chain perfectly. Here’s as follows:

The user generates a password sequence (e.g., N=1000), let the i-th password is \( x_i = h^{1000-i}(x) \). Thus, the sequence of passwords is:

\[
\begin{align*}
&h^{999}(x), \ldots, h\left(h\left(h(x)\right)\right), h(x), \text{and } x \\
&h^{1000}(x), \ldots, h\left(h\left(h(x)\right)\right), h(x), \text{and } x
\end{align*}
\]  

Thus, the sequence of passwords needed by the system to authenticate the above passwords is:

\[
\begin{align*}
&h^{999}(x), \ldots, h\left(h\left(h(x)\right)\right), h(x), x \\
&h^{1000}(x), \ldots, h\left(h\left(h(x)\right)\right), h(x), x
\end{align*}
\]

According to the above definitions, \( y_1 = x_{i-1} \) each user password is the next password value that the system needs to authenticate. Therefore, the system only needs to initialize the value \( y_1 = h^{1000}(x) \), and then subsequently remember only the last password sent by the user. In this way, the system saves a secret hash value, and the adversary can’t recover the original secret even if the system has been attacked. In the communication between the user and the system, the delivered password is also the secret hash, the hash value of the next password. Based on one-way hash function, the adversary cannot calculate the next password value even if this password is eavesdropped on.

**Hadoop Clients and HDFS Authentication and Improvement**

**Token Scheme in Hadoop**

The communication between Hadoop client and HDFS consists of two processes: (1) the RPC connection from client to NameNode; (2) the block transport from client to DataNode. The RPC connection can pass the Kerberos or the delegation token authentication. The delegation token is the shared secret between the client and the NameNode, which can be used for the subsequent access authentication without using the Kerberos key server. To obtain a delegation token, the client must use a Kerberos authentication connection. The Block transport uses block access token authentication, and each block access token is specific to a concrete block generated by the NameNode. Although you can achieve the target authentication by only using Kerberos on the NameNode RPC, the delegation token has some critical advantages [10, 11].

However, the file access permissions are set on the NameNode. The DataNode needs to obtain the information whether the client is authorized to access these blocks from the NameNode. This can achieve via a block access token. When a client visits the NameNode to access a file, the NameNode will check the file permissions, and generate a block access token for each block based on the permissions, and return the block access token as well as the position of each piece to the client. When the client visits the DataNode to access data block, the block access token is passed to the DataNode to authenticate. Only the NameNode can issue a block access token to verify [12] by the DataNode.

**The Improved Authentication Scheme**

The token scheme does improve the efficiency of authentication in Hadoop, and reduce the dependency on KDC. However, fundamentally, the token is the shared secret by both sidesand only two sides know. The loss of the secret by either side will lead to the collapse of the authentication. So the secret is better not to transmit on an insecure network environment, and at least to reduce the frequency of transmission on its network. Neither the delegation token nor the data access token should not transfer its shared secret directly. Thus, we put forward an improved token scheme. The scheme uses hash chain method to realize the authentication between the users, the NameNode and DataNode (the data flow of authentication is shown in Fig. 1), and ensure that the secret do not transmit on the network repeatedly, which improve the efficiency and security of the authentication. Specifically, the authentication process is as follows:
(1) After the user completes the initial authentication through the Kerberos certification and the NameNode, the delegation token is obtained that can be used to authenticate the subsequent user’s work to the NameNode. The user randomly generates a secret $x$, assuming that the secret is used for subsequent 1,000 authentications, and then applies for a new token through the Kerberos certification to the NameNode. The user save the secret $x$, and send the secret hash value $y_1 = h^{1000}(x)$ (see section 1, Equations 3) to the NameNode as a shared secret of both for subsequent validation of the user’s delegation token. The NameNode keeps the user ID and $y_1$ in the database. The user delegation token is generated by its own hashchain $h^{999}(x), \ldots, h(h(h(h(x)))), h(h(x)), x$. Each time the token is authenticated to the NameNode, a value is extracted from the hash chain to send the NameNode. Because each authentication uses a different token, there is no token update and tokens transmit repeatedly on the Network.

The structure of the delegation token is as follows:

Delegation Token = \{ownerID, $x_1$\}

The user delegation token is a hash chain generated based on the secret $x$ that shared with the NameNode, and the next value is extracted from the hash chain and passed to the NameNode when each access request.

(2) When the user applies for data access to the NameNode, the access request is generated to obtain the data access token. The request contains user ID, delegation token, and access files and operations. After the NameNode receives the user requests, the delegation token is first extracted and carried out a hash, and then compared with the user corresponding value that extracted from the database. If it matches, then it passes the authentication. Once each certification is completed, the old $y$ value is replaced with a secret hash from the user. Then the NameNode checks the permissions of application. If satisfied, it generates the data access token, the corresponding data block, and the permissions of operation to send to the user together.

(3) After the user has obtained the data access token, the related data operation can be carried out. The data access token is a secret shared by the NameNode and all DataNode, which is used to pass the user access rights granted by the NameNode to the DataNode. That is, each DataNode keeps this secret. The adversary can attack any node to get the secret to generate a valid token. Therefore, the data access token is better not transferable, and only its owner can use it without worry about the steal of the token. In order to achieve this goal, we adopt the method of hash chain. When using Kerberos authentication to register on the NameNode, the NameNode checks its validity. After passing the validation, the NameNode randomly choose a secret $z$ and generate the hash chain sequence (e.g., the Equations 2 of section 1, assumes that the length of sequence is 1000), and the $h^{1000}(z)$ is sent to the DataNode, which can be used to validate the subsequent data access token. The structure of the data access token is as follows:

TokenID = \{ownerID, blockID, accessModes\}

Block Access Token = \{TokenID, TokenAuthenticator\}

Where the ownerID represents the user identity of requesting data access, the blockID represents the block number needed to access, and the accessModes represents the authorized operation...
privileges that can be a combination of the following set \{READ, WRITE, COPY, REPLACE\}, and the TokenAuthenticator is a hash value that NameNode extract from the hash chain, which shared with the DataNode to verify the authenticity of the token. After receiving the data access token, the DataNode carries out a hash operation for TokenAuthenticator, and compare it with the value extracted from the database, which is a shared secret with the NameNode. If it matches, then it passes the authentication, and uses the TokenAuthenticator to replace the original value in the database in order to verify the next data access token and allows users to perform the corresponding data operations.

The Security Analysis
In the improved scheme we propose, the method of the hash chain is adopted. According to the definition, each user password is that the confirmer needs to use to authenticate the next password value. Thus, the confirmer just needs to remember orderly the last password that the user sends. By the application of hash chain, The HDFS authentication of the user in Hadoop has the following security features:

(1) Anti-counterfeiting
This method can be used to against the tampering with or eavesdropping on the authentication password during the communication process safely. It is supposed that an adversary knows the previous 987 passwords sequence \( (h^{999}(x), ..., h^{13}(x)) \), he can find the next password \( h^{12}(x) \). Then \( y' = h^{13}(x) \) is given, the \( h^{14}(x), ..., h^{999}(x) \) can be calculated, thus you can calculate the \( x' = h^{12}(x) \) to make \( y' = h(x') \). It conflicts the one-way hash function, and so the assumption fails. And the hash sequence of password local generate by the user in advance without the network interactive communication, so the intruder cannot through the tampering with or eavesdropping on the communication between the two sides for the secret and further impersonate as a legitimate user.

(2) Prevent replay attacks
In our hash chain approach, it may lose synchronization between the system and the user because of a system crash. For instance, the user sends \( x_1 \) to the system, while the authentication code of the system still kept in \( y_{1-3} \). That is, the user may send two data access tokens during the system crash, which happens to be record by a malicious user. When the system restores to its origin, the malicious user can take his record of token to impersonate as its corresponding user. We can solve this problem by the jump forward ways, and assumes that the system restore to its origin \( y_{374} = h^{626}(x) \), and send the password to the user will not be more than two during the collapse, and the system may require the user to provide \( x_{376} \) as a password to validate. Because only the user can provide \( x_{376} \), so it can effectively prevent the intruder from utilizing the failure loopholes that the system restore to for the system collapse and impersonating as a legitimate user by the eavesdropped key. It also prevent the malicious users from implementing replay attacks effectively.

(3) Confidentiality
The hash chain method is used in the process of authentication, whether the delegation token or data access token will not transfer twice on the network. According to the one-way hash function, the adversary cannot infer the subsequent password from the previous passwords. The basic process of authentication is similar to the one time pad methods, which greatly improve the security of the password. The method simplifies the authentication process, applies a password to each task individually, without the need for updating token regularly, effectively reduces the traffics of communication, and improves efficiency of the authentication.

Summary
The communication between Hadoop client and HDFS needs a trusted client to authenticate, in order to ensure that the legitimate users perform related operations and prevent the malicious users to impersonate as other users to invade the HDFS cluster. At the same time, the DataNode also authenticate the access rights of the users to realize the access control of data in HDFS. We propose
a solution to use the hash chain password method to improve the delegation token and the data access token scheme, which effectively improve the efficiency and security of the authentication process. Using public key scheme to identify authentication is also a possible method. Although it is expensive to calculate, it is still a direction worth studying.

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