Proxy Certificate Trust List for Grid Computing

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Abstract. This paper proposes Proxy Certificate Trust List (PCTL) to efficiently record trusted delegation trace for grid computing. Our solution based on PCTL provides functions as follows: (1) On-demand inquiry service for real time delegation information of grid computing underway; (2) Lightweight mutual authentication that is beneficial for proxy nodes with short life span or limited computation power as wireless devices in mobile computing; (3) A kind of revocation mechanism for proxy certificates to improve the security and availability of grid computing.

Keywords: Grid Computing, Proxy Certificate, Mutual Authentication

1 Introduction

Proxy certificate (PC) is used in grid computing for securing private keys, dynamic grid service initialization, delegation and single-sign-on[1] [2]. PC is issued by either grid users or other grid proxys with short life span. PC's private key is stored on grid nodes without encryption. Therefore grid users no longer need to input passphrase to access private keys again and again. However there are some open problems for PC management of grid computing. First, since there is no certificate revocation mechanism for PC, grid Security Infrastructure (GSI) provides weak control on agents. For instance, a PC may become invalid while computing is still underway due to network latency, underestimate, etc. Next, proxy certificate path verification is mechanically repeated in each mutual authentication, placing a heavy burden on agents to keep and exchange a long proxy certificate chain. Last but not least, grid participants often need to know the current delegation information, but GSI provides no means to do this.

In this paper, Proxy Certificate Trust List (PCTL) is proposed to partially solve these problems by providing on-demand delegation information inquiries, lightweight mutual authentication, and a kind of proxy certificate revocation mechanism.

2 Core Strategy for System Based on PCTL

2.1 Certificate Register Authority (CRA)

Our solution is based on the existing Public Key infrastructure (PKI)[3]. The additional and independent module is a trusted third party named the Certificate

Register Authority (CRA). The main functions of the CRA are: (1) Maintain delegation relations of PCs for each end entity involved in a grid computing underway. (2) Respond to on-demand inquiries for detailed information about PCs and the delegation information. (3) Generate PCTL. (4) Revoke compromised or expired PCs.

The data structure PNode is defined to record PC information in CRA, as shown in Table 1. The information of End Entity Certificate (EEC), a standard X.509 certificate, is supplied directly from CA/LDAP servers. Since PCs with the same relative distinguished name (RDN) and different certificate serial numbers may be issued for separate use as signing and encryption, the uniqueness of the RDN is assured by including the hash code of its public key. The reason why certificate serial number is still considered in "Index" here is that a PC's key pair is suggested to keep unchanged for update in case that this PC expires during the computing. The availability and efficiency of grid computing will be greatly improved in this way.

Table 1. Data Structure PNode for Proxy Certificate in CRA

Entry	Value
Index	Relative Distinguished Name + Certificate Serial Number
Delegation Depth	Permitted length of the delegation trace
Certificate Identifier_1	Hash code of proxy certificate
Certificate Identifier_2	Hash code of public key
Certificate Status	"Valid","Wait for Update","Invalid"
Validity	Life span of proxy certificate
Public Key	Public key of proxy certificate
Parent Pointer	Pointers to the issuer
Child Pointer	Pointers to all the issued grid proxys

2.2 Definition of PCTL

PCTL is designed to record trusted delegation traces for grid computing. An n-ary dual-linked tree, called TrustLogicTree, is constructed based on PNode to maintain delegation relations, as in Figure 1. PCTL records PC information on some trusted delegation trace with short life span, issuer information, security context, etc and is signed by CRA. The format for each entry in PCTL differs at various security levels and is defined in the following. An example of PCTL with a high security level is shown in Figure 2.

- High Security Level: An entry is a triplet (Index, Issuer, Certificate Identifier_1), each item of which corresponds to the definition in PNode. The hash of PC ensures the integrity of the whole certificate information.
- Middle Security Level: An entry is a triplet (Index, Issuer, Certificate Identifier_2). The hash of the PC's public key ensures the binding of the proxy

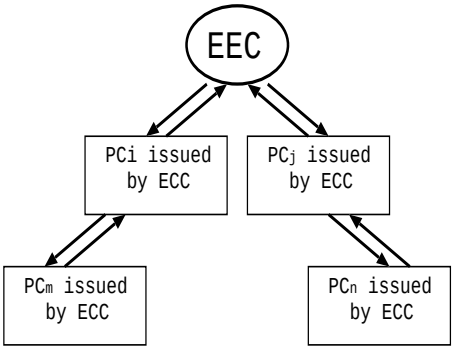

Fig. 1. N-ary dual-linked tree TrustLogic

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Proxy Certificate Trust List (PCTL):
Signature Algorithm: md5WithRSAEncryption
Issuer: /C=Japan/ST=Ishikawa/O=Jaist/OU=School
        of Informaion Science/CN=CRA
Last Update: June 1 16:20:30  2004 GMT
Next Update: June 2 00:20:30  2004 GMT

Subject: /C=Japan/ST=Ishikawa/O=Jaist/OU=School
        of Informaion Science/CN=Lab51/CN=Proxy
Serial Number: 1
Issuer: /C=Japan/ST=Ishikawa/O=Jaist/OU=School
        of Informaion Science/CN=Lab51

Certificate Identifier(sha-1):
5D 4D 82 86 E1 02 AC CB 4F 07 8B 4D B3 3A BC 05 98 6D B4 04

Subject: /C=Japan/ST=Ishikawa/O=Jaist/OU=School
        of Informaion Science/CN=Lab51/CN=Proxy/CN=PrxoyDB
Serial Number: 1
Issuer: /C=Japan/ST=Ishikawa/O=Jaist/OU=School
        of Informaion Science/CN=Lab51/CN=Proxy

Revocation Time: June 1 19:13:25  2004 GMT

Certificate Identifier(sha-1):
AD 47 19 A4 0D 7C BB 2D 93 33 64 B0 46 AF 69 22 6A 30 FB 85
......
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Fig. 2. Example for PCTL in High Level

name and its public key. Thus none can pretend to be another proxy by issuing PC with the same RDN.

– Low Security Level: An entry is a pair (Index, Issuer). It runs with the highest efficiency and benefits mobile computing with limited computation power.

2.3 Basic Algorithms

Register Whenever the delegation is needed, the issuer is required to register the new PC to the CRA after signing. The CRA will find the entry for the issuer by Index and verify the PC to be issued. If verification succeeds, CRA will create a corresponding PNode for the new PC and add it into the TrustLogicTree.

PCTL Acquisition Figure 3 shows a synchronous manner to get a PCTL when delegation and register are bounded together and the sequence order is preserved. Sequence (1)-(3) in Figure 4 shows an asynchronous manner where delegation and register are independent. It is a more lightweight handshake, but may require a timeout and retry if mutual authentication proceeds right after the delegation, that is, if an update of TrustLogicTree is later than a correlative PCTL use. Sequence (4)-(5) shows an on-demand inquiry for PCTL.

PCTL Generation The algorithm to generate PCTL is governed by "Flags" (Figures 3 and 4). If the concerned PC exists and is valid, CRA will generate PCTL for it as described in the following. To improve availability, PCs with status "Wait for update" are also recorded in PCTL with revocation times, as in Figure 2.

– Flags=0 (Only the concerned PC is known): Find PNode for the concerned PC in CRA, and record all nodes whose status is "Valid" or "Wait for update" on the path between EEC and the concerned PC into PCTL.
– Flags=1 (Only the trusted ancestor of some concerned PC is known): Traverse the subtree rooted with the trusted ancestor by Depth-First-Search,

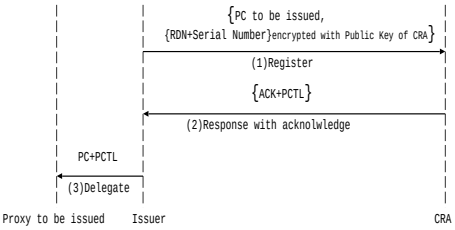

Fig. 3. Synchronous Message Sequence

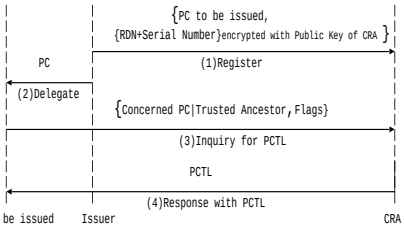

Fig. 4. Asynchronous Message Sequence

and ignore the subtree rooted with PNode whose status is "Invalid". Then record all the satisfied nodes in terms of path that starts with this trusted ancestor into the PCTL.

– Flags=2 (Both the concerned PC and its trusted ancestor are known): Starting with the concerned PC, backward search the subtree along the parent pointer until trusted ancestor is reached or some node with status be "Invalid", then record all the visited nodes whose status is "Valid" or "Wait for update" on the path into PCTL.

Proxy Certificate Revocation (1) When some private key leaks, CRA will be notified to disable all the sub-trees rooted with the attacked PC by resetting all nodes' status from "Valid" to "Invalid". (2)When some PC expires, CRA does similarly to (1). The difference is only the expired PC will be disabled by resetting the status to "Wait for update" to improve availability.

Free Once an end entity finishes its task, CRA will release the subtree rooted with its EEC.

2.4 A Lightweight Mutual Authentication with PCTL

Let Proxy A and Proxy B be under a mutual authentication. Let PC_B be the PC of Proxy B. Let $PCTL\_B$=(Index, Issuer, CI) be the PCTL of Proxy B. Certificate verification with PCTL for Proxy A is shown briefly as follows: First, A decrypts $PCTL\_B$ with CRA's public key and check its validity. If it expired, A updates $PCTL\_B$ from CRA or asks B to provide a fresh one. After that,

– High Level: Proxy A finds the entry for B by Index in $PCTL\_B$, and then computes the hash of PC_B and compares it with CI.
– Middle Level: Proxy A finds the entry for B by Index in $PCTL\_B$, and then computes the hash of B's public key and compares it with CI.
– Low Level: If there is an entry for Proxy B in $PCTL\_B$, Proxy B can be trusted without any computation.

3 Compatibility with GSI

There are two ways to implement CRA based on the existing PKI. Certificate Authority (CA) can serve as CRA or sign another trusted third party to act as

CRA. Figure 5 shows how to deploy CRA into the existing PKI with more details. Usually, CA and RA are deployed on different sites with secure interaction. "CRA Agent" is an additional module to be added into the existing PKI to provide the functions of CRA. It is deployed on a secure site B that can be the same site for CA. "CRA Agent" acts as a server when handling requests from grid proxys and acts as a client when interacting with the LDAP server. To support PCTL, the required modification can be kept to a minimum: (1) Additional negotiation is needed for SSL/TLS protocol when PCTL is enabled. In SSL/TLS Handshake, peers will authenticate each other and establish a secure communication with public key encryption technique. In this procedure, they need to negotiate upon many points as compression method, data encryption algorithm, etc. Probably when peers exchange hello messages to negotiate some parameters, whether or not use PCTL in this session need to be agreed on. (2) A new Object Class pkiProxyLDAP is needed for LDAP Schema [4] [5] (Figure 6).

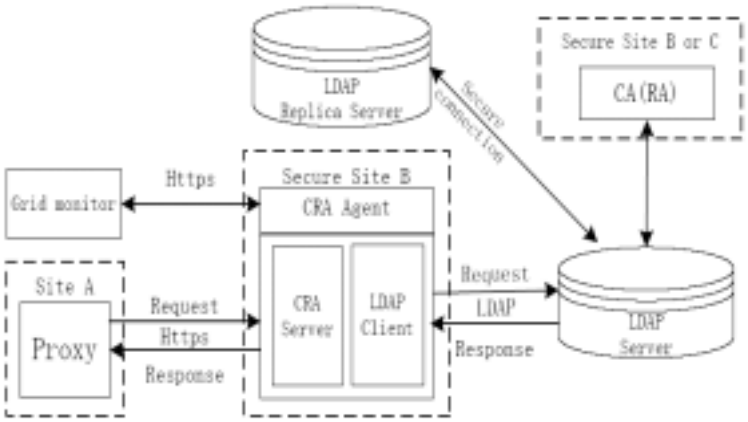

Fig. 5. CRA implementation based on PKI

4 Conclusions and Future Work

Our solution provides a "One-Time-Verification" on behalf of grid agents. A delegation tracing method was proposed in [6] by suggesting use of a ProxyCertInfo extension field. However this method can not reflet dynamic delegation changes. With the introduction of CRA, bottle-neck and single-point failure problems need to be considered. Fortunately, fault-tolerant techniques similar to those applied to CA can be used in a real implementation. Since in the current system grid agents might access CA for a Certificate Revocation List (CRL) during the

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pkiProxy OBJECT-CLASS ::={
SUBCLASS OF   {top}
KIND          auxiliary
MAY CONTAIN   {proxyIndex|proxyIdentifier_1|
              proxyIdentifier_2|proxyStatus|
              proxyValidy|proxyIssuer|
              proxyParent|proxyChildren}
ID joint-iso-ccitt(2)ds(5)attributeType(4)pkiProxy(...)}

ProxyIndex        ATTRIBUTE ::={...}
proxyIdentifier_1 ATTRIBUTE ::={...}
proxyIdentifier_2 ATTRIBUTE ::={...}
proxyStatus       ATTRIBUTE ::={...}
proxyValidy       ATTRIBTUE ::={...}
......
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Fig. 6. LDAP schema to support PC

mutual authentication, the only additional overhead of the PCTL-based solution is the handshake between the issuer and CRA in the register phrase. However, this handshake doesn't take the time of grid computing in asynchronous manner. In our solution, certificate chain exchange in the mutual authentication can be avoided by exchanging a much smaller PCTL or by getting the PCTL itself. Certificate chain verification can also be avoided by simple hash manipulation. Assume L be the delegation depth and W the delegation width, the rough time cost of mutual authentication for the current system is $O(LW)$. So the advantages of our solution loom large when delegation is deep and frequent.

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