

## INTRUSION-TOLERANT SECURITY SERVERS FOR DELTA-4

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### **Abstract**

This paper describes a new approach for security in open distributed systems. This approach is currently developed in the framework of the Delta-4 project. After a few reminders about two existing distributed security architectures, the proposed "intrusion-tolerant" approach is specified. It is based on a fragmentation-scattering technique applied to a security server running on several security sites. These sites are such that intrusions into a number of sites less than a given threshold have no consequence on the global security. The different security services provided are then presented.

### **Introduction: Security for an Open Distributed System**

The security approach presented here is developed within the framework of the ESPRIT Delta-4 project. Delta-4 means Definition and Design of an **open** Dependable **Distributed** architecture. Notice the two important characteristics: openness and distribution.

Openness means that security can be implemented on any machines. The security part of an open system must not add "too much" specific hardware and software. Furthermore, security must not be so much of a constraint such that it becomes difficult to add new hosts to the system. These two considerations involve important differences with approaches such as the Red Book criteria [NCSC 87a] which impose rigid uses of software and hardware.

Distribution involves the choice of a distributed model for the security architecture. A classical one is the client-server model. An application running on one or several hosts provides services to clients on the same or other hosts. The client (the server) does not need to know on which host the server (the client) resides. This corresponds to transparent distribution. Security can follow the same model.

These two characteristics (openness and distribution) led us to give a particular approach in order to apply our security techniques.

Firstly, to keep the openness and the flexibility of the system, the intrusion-tolerant security techniques will not be integrated into the basic system design, but will be provided only as tools and applications.

Secondly, each host is considered to be under the local control of either the local administrator (time-sharing system) or the user (workstation). Local security is ensured by these persons and only global security for remote access can be ensured by specific security components. No additional security components need to be added to every new host. If and only if this host needs to do remote protected accesses or needs to be protected from remote accesses, new software and hardware components will be incorporated.

Thirdly, the client-server model must be applied to security too. The objects to be protected are servers and so the requests/accesses from clients to server must be verified. Two solutions can be adopted in order to secure the servers. The first one is to provide tools permitting construction of a secured server with authentication, authorization, audit.... The problem of this solution is that of the cost of building a new protection system for each server and all the interfaces with clients. The second solution is to provide a set of security services available for all servers which need security and which become clients of these security servers. These services are also available for clients which want to access secured servers. The advantage of this solution is that the part which is implemented on the secured servers is relatively small. The major part of security is ensured by the security servers. This is equivalent to the Kerberos approach [MILL 87]. Kerberos provides only identification, authentication and audit, whereas our approach includes sensitive data management and recovery.

The security services which are presented concern only distributed applications for which the location of application entities is transparent. In this sense, the security services can be viewed as complementary to network security services [ISO 7498-2] which are focused on communication confidentiality and integrity, rather than authorization to access application servers.

## 1. Distributed Security Architectures

Our intrusion tolerant security service is a new concept with regard to existing architectures such as those implied by Orange Book [DoD 85], Red Book [NCSC 87a] and Kerberos [MILL 87, STEIN 88].

### 1.1. THE ORANGE BOOK AND RED BOOK ARCHITECTURES

The Trusted Computer System Evaluation Criteria (TCSEC), often called Orange Book, describes a multilevel mandatory policy and Bell-LaPadula model [BELL 74] and their implementation requirements. This architecture is based on two components: the **Trusted Computing Base (TCB)** and the **Security Kernel**.

- The TCB consists of all the of protection mechanisms within a computer system -- including hardware, firmware and software -- the combination of which is responsible for enforcing an authorization policy. The ability of a TCB to correctly enforce a authorization policy depends solely on the mechanisms within the TCB and on the correct input by system administrative personnel of parameters related to the authorization policy.

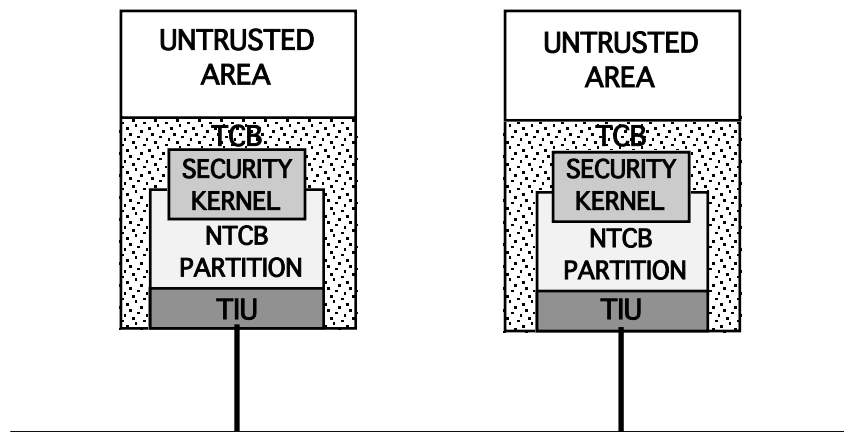
- The Security Kernel is the set of hardware, firmware and software elements of the TCB that implement the reference monitor concept. It is *trusted, tamperproof, always invoked and verifiable as correct*.

The Orange Book provides only for a centralized system. The National Computer Security Centre also provided a Trusted Network Interpretation (Red book) of the TCSEC; the same requirements are then applied in the context of distributed system. The Red Book extends the TCB and Security Kernel concepts to distributed configurations. The idea is to connect distributed components together so as to form a global secure network. The security functionalities may be distributed.

There exists a **Network Trusted Computing Base (NTCB)** for the network. The NTCB is partitioned in such a way that the set of the partitions constitutes a global TCB. But all local accesses must be mediated locally by local mechanisms. For components which are not hosts, functionalities can be reduced since such components are not concerned by all the rules of the network security policy. This is not so for a host. The local security mechanisms must perform local security policy, because there exist subjects and objects within the host.

Thus each host possesses (Fig 1.1):

- subjects and objects which are local on the host (i.e. not distributed),
- a TCB as defined above,
- a NTCB partition which is the local part of the global TCB and which mediates all accesses from remote subjects to local objects or from local subjects to remote objects (the NTCB partition and the TCB are thus often merged),
- certain functionalities of the NTCB partition which can be used by other hosts,
- a Security Kernel which mediates *all* accesses, be they remote or local,
- a **Trusted Interface Unit (TIU)** managing communication security between hosts.



**Fig. 1.1. TNI Architecture.**

This approach requires large trusted parts on all computers on the network. It is not a very open approach since it is difficult to add new computers to an existing network. The computer has to be evaluated in stand-alone mode and then in the network. Moreover, "trusted" is a very subjective property that is hard to verify and implies important software and hardware protections.

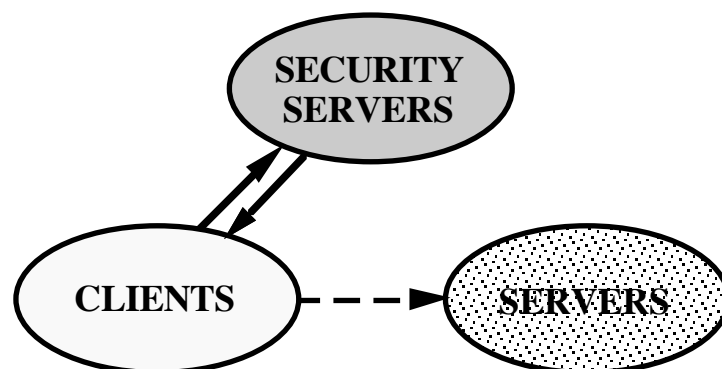
## 1.2. THE KERBEROS ARCHITECTURE

Kerberos was developed at MIT [STEIN 88, MILL 87] within the framework of the Athena project. The architecture of the Kerberos is based on the Client-Server model. Kerberos provides authentication and authorization services. In the Athena project, there exist different kinds of sites: unprotected Public workstations, private workstations, protected servers... Kerberos must authenticate legitimate users who want to use remote secured services. The workstations are not considered like time-sharing systems. They are totally under the control of the user, and local security services can be easily by-passed by the local user. Consequently, the network administration cannot trust any authentication carried out on a workstation. While a user accesses only local services, such local authentication is sufficient. But when the user wants to access remote services, the authentication must be carried out by a trusted service. This is the role of the Kerberos service, split in several security servers.

The network is seen as in Fig. 1.2. Servers are trusted and so they are physically protected. Clients are not trusted. However anything occurring on the client host is under the responsibility of the user. And the server is under the responsibility of its administrator.

When a client logs in and wants to access a protected server:

- He asks the Key Distribution Server (KDS) for a session key.
- The KDS authenticates the client and gives him the session key.
- The client now asks the Ticket-Granting Server (TGS) for a ticket to access the protected server.
- The TGS provides a ticket to communicate with the server.
- The client uses this ticket to open a session with the server.
- It is the server itself which finally authorizes access.



**Fig. 1.2. Kerberos Architecture.**

The NTCB is in part on the Kerberos server (authentication) and in part on the secured server (authorization).

An essential characteristic of the Kerberos architecture is the centralization of servers. Indeed, the security services are not distributed. The Kerberos master server is replicated on passive

slaves, which can replace the master when it fails. This replication is carried out by dumping the master Kerberos database every hour. This architecture has several potential weaknesses.

- The security administrator who manages the master server can misuse his privileges to perform unauthorized actions. The security administrator must be trusted. Furthermore, if an intruder succeeds in penetrating the master server, global security is no longer ensured.
- The slaves can also give enough information to intruders who can read them to use it later in order to act as authorized users. Each slave must be very well protected.
- If Kerberos server fails, the last database changes are lost.

There exists a single point of failure, from the viewpoint of both accidental faults and intrusions.

The openness of the Kerberos architecture induces another drawback with respect to the Red Book proposals; it is not possible to enforce a mandatory access control policy by the Kerberos servers; nothing is provided to prevent "covert" channels which can be easily implemented by communications between workstations or by a memory channel within a workstation.

## **2. The Delta-4 Intrusion Tolerant Approach**

An **intrusion** can be defined as a *deliberate interaction fault*. The definition of fault is given by [LAP 90]. Intrusions can be treated with the same means as for other faults (fault-avoidance and fault-tolerance). The means used to provide security in architectures described above is *intrusion-avoidance*. On the contrary, the means used in our approach is *intrusion-tolerance*. It is based on the fragmentation-scattering technique [FRAG 85, FRAY 86] in order to implement an intrusion-tolerant archive server and an intrusion-tolerant security server.

### **2.1. THE FRAGMENTED-SCATTERED ARCHIVE SERVICE**

In Delta-4, fragmentation-scattering was first used to implement a secure distributed archive service [RAN 88]. Data security is provided by intrusion-tolerance and more precisely by geographical fragmentation-scattering. The basis of the fragmentation and scattering technique in this case is to cut every sensitive file into several fragments in such a way that one or more fragments (but not all) are insufficient to reconstitute the file. These fragments are then stored in geographically distributed archive sites. An intruder who could access some sites cannot obtain all the fragments of the same file unless he has almost overall control of the complete distributed system. On the other hand, in order to ensure availability, several copies of each fragment are stored on different archive sites. This service thus answers all three security requirements: confidentiality, integrity and availability. Confidentiality and integrity are directly provided by fragmentation-scattering while availability is obtained by replication of fragmented data.

The archiving steps can be described as follows:

- Enciphering of the file with the fragmentation key (private to file's owner).
- Splitting of the file into fixed-length pages.
- Fragmentation of these pages, and fragment naming using the fragmentation key.
- Fragment replication.

- Transmission of fragment replicates to the archive sites.
- Agreement between sites according random parameters in order to decide where fragment replicates will be stored.

The intrusion-tolerant security server described in this paper provides the services that are needed to complete this secure file archive service; namely, user authentication, access-rights verification, protection of fragmentation keys, etc. The same basic services can of course be used in a more general context.

## 2.2. REQUIREMENTS AND ASSUMPTIONS FOR AN INTRUSION-TOLERANT SECURITY SERVER

The objectives of the intrusion tolerant approach are:

- openness and compatibility (for Delta-4 requirements), no specific hardware.
- reduction of TCB (by intrusion tolerance).
- modular security requirements.

The Security view of a Delta-4 network defines three kinds of sites (Fig. 2.1):

- **User sites** are untrusted computers where users can log in. The local security is ensured by users.
- **Security sites** are computers providing security services: registration, identification-authentication, authorization, sensitive information management, audit and recovery service. Each security site is managed by a different security administrator.
- **Particular servers** whose access needs to be secured. In the current system, this is the case of the Archive service located on Archive sites.

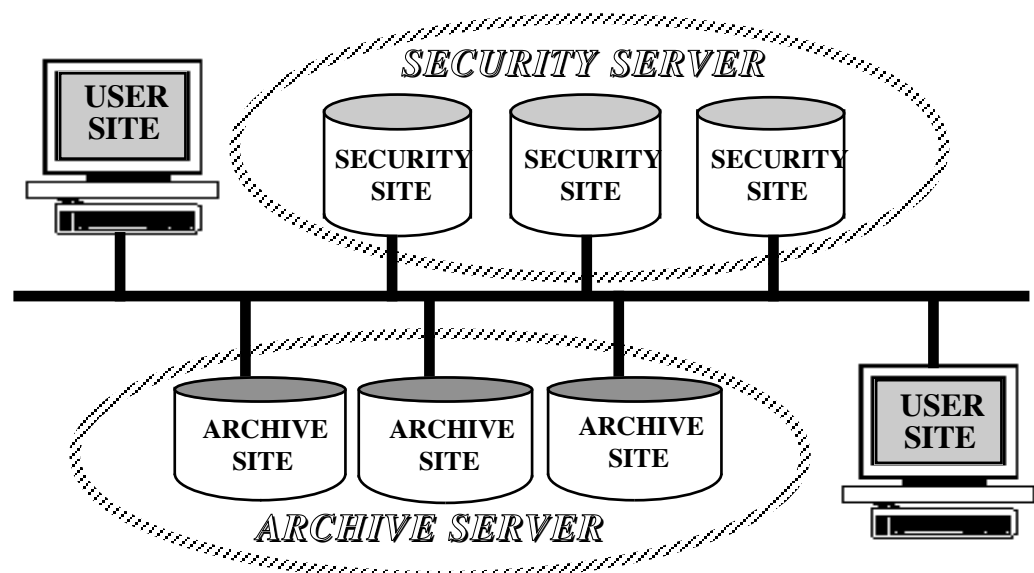


Fig. 2.1. The different types of sites of the network.

The fault assumptions for security sites are:

- The probability of more than one intrusion before detection and recovery is small.
- The probability of an intrusion into a site is independent of the previous intrusion(s) in other site(s).

The characteristics of the intrusion-tolerant security approach are:

- An intrusion or a misuse on one security site is immediately masked and has no consequence on the service and on its properties.
- If errors occur on some security sites before recovery, the number which will be masked depends on the services and their properties (confidentiality, integrity, availability). The service performances can be degraded.

### 2.3. INTRUSION TOLERANCE FOR A SECURITY SERVER

The different types of intrusion depend on who makes an intrusion.

- It can be somebody outside the system who tries to access it. This is the most well known kind of intruder, but not the most important. In this case the intruder has to *by-pass* physical, procedural and logical protections.
- The second kind of intruder is a user of the system who tries to access information or services without access rights. The intruder tries to *extend his privileges*. This the most common intrusion. The intruder has "only" to by-pass the logical protection.
- The third - and the most dangerous - type of intruder is a security administrator who *uses his rights* to perform illegitimate actions. In this later case, the administrator has enough access-rights to do these actions but, according to the security policy, is not supposed to do them.

The architectures described in section I are intrusion avoidance architectures. A user/intruder **is trusted not to misuse his rights**. All the protection mechanisms must prevent the unauthorized actions. If an intruder succeeds in by-passing these protections, the security of the system is no longer ensured. If a security administrator decides to carry out illegal actions, there is no logical protection to prevent him from so doing. He could only be detected by using an intrusion-detection model [DENN 86] which is able to detect intrusions by monitoring system's audit records for abnormal patterns of system usage.

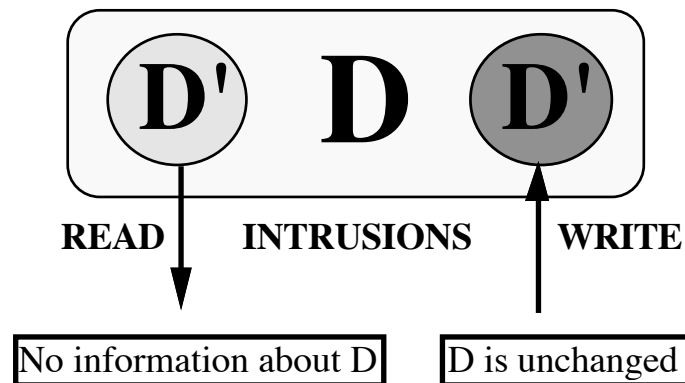
The principles of the intrusion tolerance are different. The system tolerates a bounded number of misuses. If one or more intruders by-pass the protection mechanisms and if the number of misuses they do is less than a given threshold, the security properties of the system (confidentiality, integrity and availability) are always ensured.

Three types of intrusion tolerance can be formulated:

- for **confidentiality**: read access to a subset of confidential data gives no information about the data.
- for **integrity**: the change of a subset of data does not change the data perceived by legitimate users.

- for **availability**: the change or deletion of a subset of data or of a server does not produce a denial of service to legitimate users.

For each property, a tolerance threshold is defined. If the reading, modification or destruction is done on a part  $D'$  of data/server  $D$  such that  $|D'|$  (size of  $D'$ ) is less than the threshold, the properties are always verified (Fig. 2.2).



**Fig. 2.2. Intrusion tolerance.**

This concept is implemented on the security sites. The security sites are particular sites in that they collectively offer security services in a way such that security is always ensured in spite of intrusions on a bounded number of sites. The security sites also tolerate intrusions of malicious security administrators intrusions as they are described above. A security administrator manages only one security site. The security can thus be ensured in spite of a collusion between a minority of security administrators.

The security services are *distributed* and *intrusion tolerant*. The implementation has the essential property of requiring no local TCB.

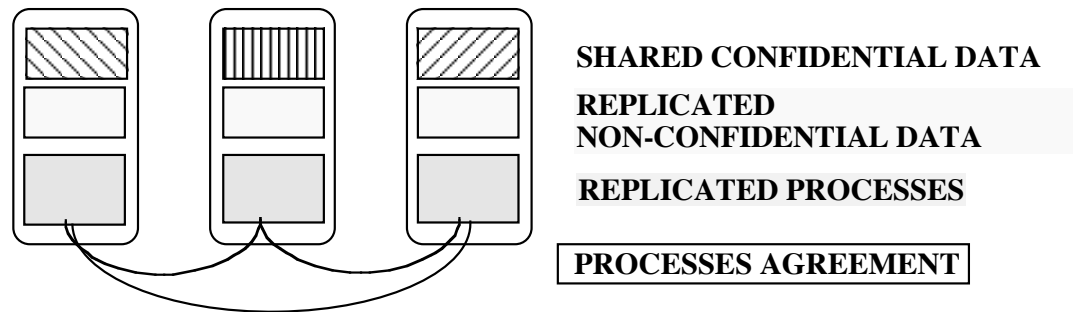
### 2.3.1. Intrusion Tolerance by Distribution

Intrusion tolerance for data is relatively easy to implement. Data intrusion-tolerance techniques have existed for a long time. Confidentiality can be ensured by cryptographic tools like threshold scheme [SHA 79, BLAK 79]. The data is shared in "shadows", each shadow being stored on one security site. To build the data you only need a sufficient number of shadows called the threshold. If you do not have enough shadows, you cannot build the initial data. The same scheme can ensure availability and integrity.

Some data is not confidential, so it is also possible to replicate such data on each security site. Data is *shared* or *replicated* according to its confidentiality.

The most important point and the hardest one is the prevention of denial of service. In this case, it is not just data but a service that has to be protected. The server thus has to be replicated on each site in order to prevent denial of service in case of a security site unavailability. However the different sites cannot take certain decisions independently. They must agree by communicating data and local decisions. To ensure the last property, the servers must obey to two implementation principles: *replication* and *agreement* (Fig. 2.3).

The distribution of the security service permits a geographic distribution of the security sites. This makes the intruder's task more difficult since even if he succeeds in accessing one site, it will be more difficult for him to access other sites if they are not in the same place. It would indeed be a pity to distribute programs and data to perform logical intrusion tolerance and to not provide geographic distribution to assist physical intrusion tolerance.



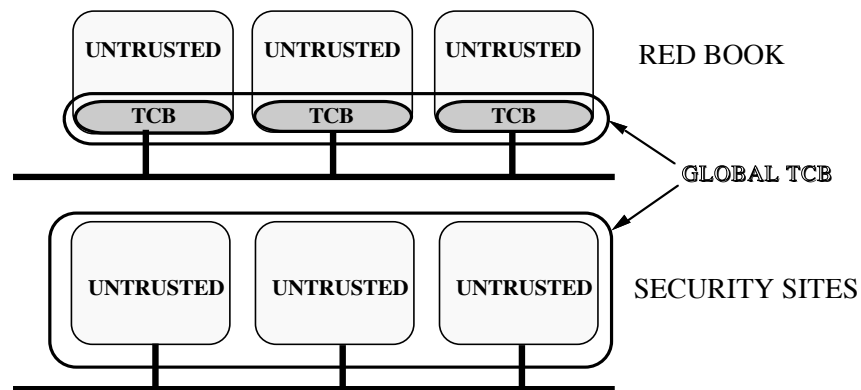
**Fig. 2.3. Distributed Security Services on three security sites.**

### 2.3.2. Distributed TCB

In the Red Book architecture, there exists on each computer a part called the Trusted Computing Base including the NTCB partition (cf. 1.1.). The TIU assumes only communications security whereas the NTCB partition implements the local part of the network authorization policy. This NTCB partition must have a very high physical and logical protection. Moreover all sites have to trust one another. On each computer, accesses are mediated by the local TCB which is firstly the implementation of the **local** authorization policy. The **global** authorization policy is implemented in the set of NTCB partitions. When all computers are connected by a network and a subject wants to access a remote object, the NTCB partitions communicate with each other. In this case, a subject on a given site must trust all sites he wants to access. If one site has been penetrated by an intruder, the security of the network cannot be ensured.

In the Kerberos architecture, the most important part of the TCB is within the security server. There also exists on each server an important TCB which has to carry out authorization operations. However if an intruder succeeds in penetrating a server, he cannot access the other ones. The consequences of an intrusion are then limited. The only site you really have to trust to ensure global security is the security server site. However, in this case there exists a single point of failure.

In the intrusion tolerant approach, there is no local "Trusted" Computing Base on the security sites. Only the set of security sites is globally trusted (Fig. 2.4). There is also a small local TCB on the user sites and the secured servers. The servers themselves, for instance the Archive Service, can have a distributed TCB. In this case, the only single point of failure is on the user site. This can be minimized if the user site is considered as a one-user computer when a user accesses a secured service. If this were not so, there would always exist trapdoors on the local protections between users.



**Fig. 2.4. Red Book versus Security Sites TCB.**

The security server is trusted, but not the different computers. The security service is considered as one global server. If an intrusion in one computer is successful in a classical architecture with a local TCB, the security of the full system is no longer verified. On the contrary, if protections of one security site in the intrusion tolerant approach are by-passed, the security of the global system is maintained. These differences come from three different points of view about security and networks:

- In the Red Book, a network is seen as only a communication channel (low layers) between centralized systems. A subject, or an object, is located on one site and cannot be shared between several sites. In our architecture, the network is a support for distributed applications. A subject or an object can be shared on several sites.
- In the Red Book, sites are time-sharing systems with several users working on the same host. These computers are controlled by a system administrator. In Kerberos, sites are workstations under the control of one local user. In our system, whenever possible, the use of one host by several users during access to a secured service will be prohibited.
- The Red Book architecture is a support for DoD policy, a multilevel mandatory policy where confidentiality is the most important property to be ensured. All sites thus need to have an important trusted part. It is not possible to implement this policy in our system. Trusted paths between all user sites would be needed.

## 2.4. THE PROVIDED SERVICES

The different services which must be provided by the security sites are registration, authentication, authorization, sensitive data management, audit and recovery service.

### 2.4.1. The Registration Service

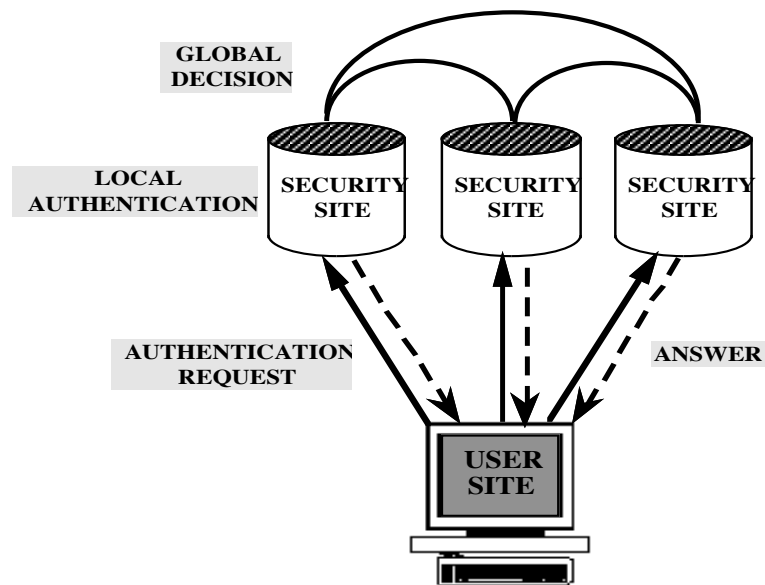
The registration service permits a user to be registered by the system for future access to secured services. This operation must be carried out independently on each security site to prevent a single site from using information to impersonate the user. The operation is done under control of the security administrator of each site.

### 2.4.2. The Identification-Authentication Service

The role of this service is to verify the claimed identity of a subject. When a user, or a process acting for a user wants to access a secured service, he must first be authenticated. The authentication service verifies that the subject is really who he claims to be. To do this, both logical or physical techniques are available. These can be based on passwords, zero-knowledge authentication [FIAT 86, GUIL 88], smartcards or chip-cards. All these techniques use the same protocol principle: the subject must prove its identity to the authentication server by showing that he possesses a secret information, its authenticator.

In a distributed system with several authentication servers, each server must independently authenticate the subject (Fig. 2.5). Indeed, the security sites are untrusted and one site could try to use authentication information given by the user and the data stored on the site to impersonate him in another authentication phase. The independence of the authentications on each site must be complete (different authentication objects for each site or zero-knowledge authentication). The second phase of the protocol is the agreement. The servers communicate their decision to each other and they take a global decision. If a majority of servers succeed in authenticating the subject, the subject can be considered as authenticated by all the servers.

The servers will send some specific data to the subject (session key, identifier, ...) with a time-out. If the time-out expires, the subject must repeat the authentication phase.



**Fig.2.5. The Authentication protocol.**

### 2.4.3. The Authorization Service

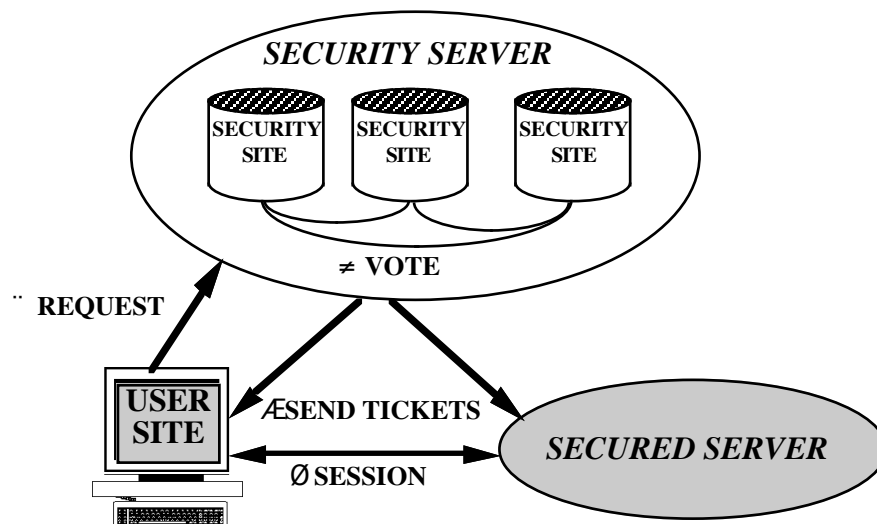
The role of this service is to check that the access to a secured service by a subject is authorized according to its access-rights. In Kerberos, this service is provided by the servers themselves because of the large size of the managed database and of the difficulty of modelling different access-rights for different services. However, these two problems can be solved.

It is possible to implement access-rights for different services using standard UNIX rights. In UNIX, all objects are viewed as files. The read, write and execute rights are thus applied to all objects of the system. The accesses to the services can be authorized using the same access-rights model. In this case, access-rights can be implemented for all kinds of services thus leading to a reduction in the cost of the access-rights database management.

The authorization service is made intrusion tolerant when it is implemented on security servers. The rights must be changed by all security administrators. One of them cannot access service if he is not authorized by others. An intruder cannot modify access rights as easily as he could do if they were located on the server. But it is obvious that if an intruder controls the service, he can do what he wants. The only solution is to build an intrusion tolerant service such as the archive service, but this is not always possible ( e.g. consider a printer service).

The different phases of authorization are (Fig. 2.6):

- The subject asks the security servers for permissions to access a secured service by sending its identifier (received in the authentication phase) (1).
- The access-rights stored on the security sites enable the latter to verify that the subject is authorized to access the requested service.
- The security sites vote to decide if the access is authorized using the same protocol as that defined for authentication (2).
- If the sites agree to permit access, they send a ticket to the subject and another ticket to the secured server (3).
- With the ticket, the subject can open a session with the server (4).



**Fig.2.6. The Authorization protocol.**

A subject may also want to access secured data stored on security sites, like access-rights or authentication keys. In this case, the access control protocol is the same as the one described above for the phases 1 and 2 and then, if and, when the security sites accept the access, they perform it on each site and send the information or the affirmative response to the user site.

#### 2.4.4. The Sensitive Data Management Service

The role of this service is to store, manage and retrieve the sensitive information on the security servers so that their protection verifies the hypothesis made in §2.2. This information consists of short data items needed to achieve security services.

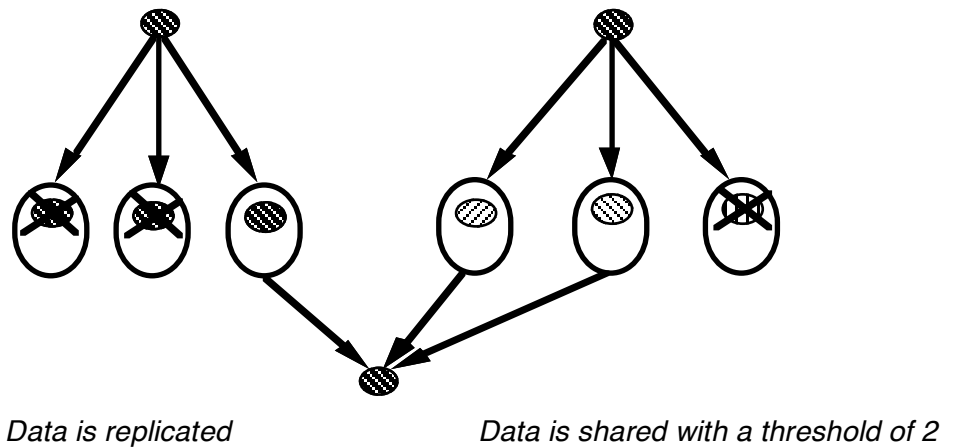
The data management service must enforce the three main security properties (confidentiality, integrity and availability). The integrity property is provided by modification detection mechanism such as cryptographic signatures. According to the sensitivity of the security data, it can be important to preserve both the confidentiality and availability of this data, or only the availability. For this, two storage techniques can be applied: replication (for availability) or threshold schemes (for confidentiality and availability). In function of this, the security administrators (data for a service access) or a subject (data for authentication) will store data with one of the two algorithms (Fig. 2.7).

If a data item is replicated on  $N$  security sites, it is assumed:

- with respect to availability, that  $N-1$  replicates can be lost (modified or destroyed),
- with respect to confidentiality, that one replicate is sufficient to observe data.

If one data is shared on  $N$  security sites (in this case we speak of shadows) using a threshold  $T$ , it is assumed:

- with respect to availability, that  $N-T$  shadows can be lost,
- with respect to confidentiality, that  $T$  shadows are necessary and sufficient to observe data (less than  $T$  shadows gives **no information** about the data).



**Fig.2.7. Replication and Threshold Scheme.**

#### 2.4.5. The Audit Service

The role of this service is to record all information related to security. Such information is sent by the services defined above. There exists two kinds of information, authorized operations performed by authorized users (registration, access, rights change, ...) and attempted or successful intrusions or misuses. It is not the role of the services to determine what is an intrusion or misuse by an authorized user. This is the function of an audit trail analysis.

The audit information is sent not only by security sites but also by secured servers and user sites. For the former, it will be access-requests, and for the latter it will be, for instance, information about correct or incorrect shared data sent by security sites (bad shadows received from certain security sites).

The audit trails are stored on each security site. The information received on one site is not sufficient to compromise the security of the system.

The analysis of this audit information will be done off-line by security administrators. As one intrusion is masked, it is not necessary to detect intrusion on-line.

#### *2.4.6. The Recovery Service*

It acts as an error recovery mechanism to correct certain modified data (e.g. shadows of the threshold scheme). Other recovery functions can be performed manually by security administrators using audit trails.

### **3. Conclusion**

In this paper, a new approach for security in an open distributed system has been described. It is based on a client-server model. Several security services are provided in order to secure the access to remote servers. These services are intrusion tolerant and reside on several security sites.

The intrusion tolerant technique is based on fragmentation-scattering to ensure confidentiality and integrity of data and availability of services. The security site architecture uses replication of data and processes, threshold schemes for confidential data and agreement protocols between processes. The different services built on this architecture are registration, identification, authentication, authorization, management of sensitive data, audit and recovery.

### **Acknowledgements**

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