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                                DASS
                Distributed Authentication Security Service

Status of this Memo

   This memo defines an Experimental Protocol for the Internet
   community. It does not specify an Internet standard. Discussion and
   suggestions for improvement are requested. Please refer to the
   current edition of the "Internet Official Protocol Standards" for the
   standardization state and status of this protocol. Distribution of
   this memo is unlimited.

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1. Introduction

1.1 What is DASS?

   Authentication is a security service. The goal of authentication is
   to reliably learn the name of the originator of a message or request.
   The classic way by which people authenticate to computers (and by
   which computers authenticate to one another) is by supplying a
   password. There are a number of problems with existing password
   based schemes which DASS attempts to solve. The goal of DASS is to
   provide authentication services in a distributed environment which
   are both more secure (more difficult for a bad guy to impersonate a
   good guy) and easier to use than existing mechanisms.

   In a distributed environment, authentication is particularly
   challenging. Users do not simply log on to one machine and use
   resources there. Users start processes on one machine which may
   request services on another. In some cases, the second system must
   request services from a third system on behalf of the user. Further,
   given current network technology, it is fairly easy to eavesdrop on
   conversations between computers and pick up any passwords that might
   be going by.

   DASS uses cryptographic mechanisms to provide "strong, mutual"
   authentication. Mutual authentication means that the two parties
   communicating each reliably learn the name of the other. Strong
   authentication means that in the exchange neither obtains any
   information that it could use to impersonate the other to a third
   party. This can't be done with passwords alone. Mutual
   authentication can be done with passwords by having a "sign" and a
   "counter-sign" which the two parties must utter to assure one another

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of their identities. But whichever party speaks first reveals
information which can be used by the second (unauthenticated) party
to impersonate it. Longer sequences (often seen in spy movies)
cannot solve the problem in general. Further, anyone who can
eavesdrop on the conversation can impersonate either party in a
subsequent conversation (unless passwords are only good once).
Cryptography provides a means whereby one can prove knowledge of a
secret without revealing it. People cannot execute cryptographic
algorithms in their heads, and thus cannot strongly authenticate to
computers directly. DASS lays the groundwork for "smart cards":
microcomputers sealed in credit cards which when activated by a PIN
will strongly authenticate to a computer. Until smart cards are
available, the first link from a user to a DASS node remains
vulnerable to eavesdropping. DASS mechanisms are constructed so that
after the initial authentication, smart card or password based
authentication looks the same.

Today, systems are constructed to think of user identities in terms
of accounts on individual computers. If I have accounts on ten
machines, there is no way a priori to see that those ten accounts all
belong to the same individual. If I want to be able to access a
resource through any of the ten machines, I must tell the resource
about all ten accounts. I must also tell the resource when I get an
eleventh account.

DASS supports the concept of global identity and network login. A
user is assigned a name from a global namespace and that name will be
recognized by any node in the network. (In some cases, a resource
may be configured as accessible only by a particular user acting
through a particular node. That is an access control decision, and
it is supported by DASS, but the user is still known by his global
identity). From a practical point of view, this means that a user
can have a single password (or smart card) which can be used on all
systems which allow him access and access control mechanisms can
conveniently give access to a user through any computer the user
happens to be logged into. Because a single user secret is good on
all systems, it should never be necessary for a user to enter a
password other than at initial login. Because cryptographic
mechanisms are used, the password should never appear on the network
beyond the initial login node.

DASS was designed as a component of the Distributed System Security
Architecture (DSSA) (see "The Digital Distributed System Security
Architecture" by M. Gasser, A. Goldstein, C. Kaufman, and B. Lampson,
1989 National Computer Security Conference). It is a goal of DSSA
that access control on all systems be based on users' global names
and the concept of "accounts" on computers eventually be replaced
with unnamed rights to execute processes on those computers. Until

this happens, computers will continue to support the concept of
"local accounts" and access controls on resources on those systems
will still be based on those accounts. There is today within the
Berkeley rtools running over the Internet Protocol suite the concept
of a ".rhosts database" which gives access to local accounts from
remote accounts. We envision that those databases will be extended
to support granting access to local accounts based on DASS global
names as a bridge between the past and the future. DASS should
greatly simplify the administration of those databases for the
(presumably common) case where a user should be granted access to an
account ignoring his choice of intermediate systems.

1.2 Central Concepts

1.2.1 Strong Authentication with Public Keys

DASS makes heavy use of the RSA Public Key cryptosystem. The
important properties of the RSA algorithms for purposes of this
discussion are:

  - It supports the creation of a public/private key pair, where
    operations with one key of the pair reverse the operations of
    the other, but it is computationally infeasible to derive the
    private key from the public key.

  - It supports the "signing" of a message with the private key,
    after which anyone knowing the public key can "verify" the
    signature and know that it was constructed with knowledge of
    the private key and that the message was not subsequently
    altered.

  - It supports the "enciphering" of a message by anyone knowing
    the public key such that only someone with knowledge of the
    private key can recover the message.

With access to the RSA algorithms, it is easy to see how one could
construct a "strong" authentication mechanism. Each "principal"
(user or computer) would construct a public/private key pair, publish
the public key, and keep secret the private key. To authenticate to
you, I would write a message, sign it with my private key, and send
it to you. You would verify the message using my public key and know
the message came from me. If mutual authentication were desired, you
could create an acknowledgment and sign it with your private key; I
could verify it with your public key and I would know you received my
message.

The authentication algorithms used by DASS are considerably more
complex than those described in the paragraph above in order to deal

   with a large number of practical concerns including subtle security
   threats. Some of these are discussed below.

1.2.2 Timestamps vs. Challenge/Response

   Cryptosystems give you the ability to sign messages so that the
   receiver has assurance that the signer of the message knew some
   cryptographic secret. Free-standing public key based authentication
   is sufficiently expensive that it is unlikely that anyone would want
   to sign every message of an interactive communication, and even if
   they did they would still face the threat of someone rearranging the
   messages or playing them multiple times. Authentication generally
   takes place in the context of establishing some sort of "connection,"
   where a conversation will ensue under the auspices of the single
   peer-entity authentication. This connection might be
   cryptographically protected against modification or reordering of the
   messages, but any such protection would be largely independent of the
   authentication which occurred at the start of the connection. DASS
   provides as a side effect of authentication the provision of a shared
   key which may be used for this purpose.

   If in our simple minded authentication above, I signed the message
   "It's really me!" with my private key and sent it to you, you could
   verify the signature and know the message came from me and give the
   connection in which this message arrived access to my resources.
   Anyone watching this message over the network, however, could replay
   it to any server (just like a password!) and impersonate me. It is
   important that the message I send you only be accepted by you and
   only once. I can prevent the message from being useful at any other
   server by including your name in the message. You will only accept
   the message if you see your name in it. Keeping you from accepting
   the message twice is harder.

   There are two "standard" ways of providing this replay protection.
   One is called challenge/response and the other is called timestamp-
   based. In a challenge response type scheme, I tell you I want to
   authenticate, you generate a "challenge" (generally a number), and I
   include the challenge in the message I sign. You will only accept a
   message if it contains the recently generated challenge and you will
   make sure you never issue the same challenge to me twice (either by
   using a sequence number, a timestamp, or a random number big enough
   that the probability of a duplicate is negligible). In the
   timestamp-based scheme, I include the current time in my message.
   You have a rule that you will not accept messages more than - say -
   five minutes old and you keep track of all messages you've seen in
   the last five minutes. If someone replays the message within five
   minutes, you will reject it because you will remember you've seen it
   before; if someone replays it after five minutes, you will reject it

   as timed out.

   The disadvantage of the challenge/response based scheme is that it
   requires extra messages. While one-way authentication could
   otherwise be done with a single message and mutual authentication
   with one message in each direction, the challenge/response scheme
   always requires at least three messages.

   The disadvantage of the timestamp-based scheme is that it requires
   secure synchronized time. If our clocks drift apart by more than
   five minutes, you will reject all of my attempts to authenticate. If
   a network time service spoofer can convince you to turn back your
   clock and then subsequently replays an expired message, you will
   accept it again. The multicast nature of existing distributed time
   services and the likelihood of detection make this an unlikely
   threat, but it must be considered in any analysis of the security of
   the scheme. The timestamp scheme also requires the server to keep
   state about all messages seen in the clock skew interval. To be
   secure, this must be kept on stable storage (unless rebooting takes
   longer than the permitted clock skew interval).

   DASS uses the timestamp-based scheme. The primary motivations behind
   this decision were so that authentication messages could be
   "piggybacked" on existing connection establishment messages and so
   that DASS would fit within the same "form factor" (number and
   direction of messages) as Kerberos.

1.2.3 Delegation

   In a distributed environment, authentication alone is not enough.
   When I log onto a computer, not only do I want to prove my identity
   to that computer, I want to use that computer to access network
   resources (e.g., file systems, database systems) on my behalf. My
   files should (normally) be protected so that I can access them
   through any node I log in through. DASS allows them to be so
   protected without allowing all of the systems that I might ever use
   to access those files in my absence. In the process of logging in,
   my password gives my login node access to my RSA secret. It can use
   that secret to "impersonate" me on any requests it makes on my
   behalf. It should forget all secrets associated with me when I log
   off. This limits the trust placed in computer systems. If someone
   takes control of a computer, they can impersonate all people who use
   that computer after it is taken over but no others.

   Normally when I access a network service, I want to strongly
   authenticate to it. That is, I want to prove my identity to that
   service, but I don't want to allow that service to learn anything
   that would allow it to impersonate me. This allows me to use a

service without trusting it for more than the service it is
delivering. When using some services, for example remote login
services, I may want that service to act on my behalf in calling
additional services. DASS provides a mechanism whereby I can pass
secrets to such services that allow them to impersonate me.

Future versions of this architecture may allow "limited delegation"
so that a user may delegate to a server only those rights the server
needs to carry out the user's wishes. This version can limit
delegation only in terms of time. The information a user gives a
server (other than the initial login node) can be used to impersonate
the user but only for a limited period of time. Smart cards will
permit that time limitation to apply to the initial login node as
well.

1.2.4 Certification Authorities

A flaw in the strong authentication mechanism described above is that
it assumes that every "principal" (user and node) knows the public
key of every other principal it wants to authenticate. If I can fool
a server into thinking my public key is actually your public key, I
can impersonate you by signing a message, saying it is from you, and
having the server verify the message with what it thinks is your
public key.

To avoid the need to securely install the public key of every
principal in the database of every other principal, the concept of a
"Certification Authority" was invented. A certification authority is
a principal trusted to act as an introduction service. Each
principal goes to the certification authority, presents its public
key, and proves it has a particular name (the exact mechanisms for
this vary with the type of principal and the level of security to be
provided). The CA then creates a "certificate" which is a message
containing the name and public key of the principal, an expiration
date, and bookkeeping information signed by the CA's private key.
All "subscribers" to a particular CA can then be authenticated to one
another by presenting their certificates and proving knowledge of the
corresponding secret. CAs need only act when new principals are
being named and new private keys created, so that can be maintained
under tight physical security.

The two problems with the scheme as described so far are "revocation"
and "scaleability".

1.2.4.1 Certificate Revocation

Revocation is the process of announcing that a key has (or may have)
fallen into the wrong hands and should no longer be accepted as proof

of some particular identity. With certificates as described above,
someone who learns your secret and your certificate can impersonate
you indefinitely – even after you have learned of the compromise. It
lacks the ability corresponding to changing your password. DASS
supports two independent mechanisms for revoking certificates. In the
future, a third may be added.

One method for revocation is using timeouts and renewals of
certificates. Part of the signed message which is a certificate may
be a time after which the certificate should not be believed.
Periodically, the CA would renew certificates by signing one with a
later timeout. If a key were compromised, a new key would be
generated and a new certificate signed. The old certificate would
only be valid until its timeout. Timeouts are not perfect revocation
mechanisms because they provide only slow revocation (timeouts are
typically measured in months for the load on the CA and communication
with users to be kept manageable) and they depend on servers having
an accurate source of the current time. Someone who can trick a
server into turning back its clock can use expired certificates.

The second method is by listing all non-revoked certificates in the
naming service and believing only certificates found there. The
advantage of this method is that it is almost immediate (the only
delay is for name service "skulking" and caching delays). The
disadvantages are: (1) the availability of authentication is only as
good as the availability of the naming service and (2) the security
of revocation is only as good as the security of the naming service.

A third method for revocation – not currently supported by DASS – is
for certification authorities to periodically issue "revocation
lists" which list certificates which should no longer be accepted.

1.2.4.2 Certification Authority Hierarchy

While using a certification authority as an introduction service
scales much better than having every principal learn the public key
of every other principal by some out of band means, it has the
problem that it creates a central point of trust. The certification
authority can impersonate any principal by inventing a new key and
creating a certificate stating that the new key represents the
principal. In a large organization, there may be no individual who
is sufficiently trusted to operate the CA. Even if there were, in a
large organization it would be impractical to have every individual
authenticate to that single person. Replicating the CA solves the
availability problem but makes the trust problem worse. When
authentication is to be used in a global context – between companies
– the concept of a single CA is untenable.

DASS addresses this problem by creating a hierarchy of CAs. The CA
hierarchy is tied to the naming hierarchy. For each directory in the
namespace, there is a single CA responsible for certifying the public
keys of its members. That CA will also certify the public keys of
the CAs of all child directories and of the CA of the parent
directory. With this cross-certification, it is possible knowing the
public key of any CA to verify the public keys of a series of
intermediate CAs and finally to verify the public key of any
principal.

Because the CA hierarchy is tied to the naming hierarchy, the trust
placed in any individual CA is limited. If a CA is compromised, it
can impersonate any of the principals listed in its directory, but it
cannot impersonate arbitrary principals.

DASS provides mechanisms for every principal to know the public key
of its "parent" CA – the CA controlling the directory in which it is
named. The result is the following rules for the implications of a
compromised CA:

 a) A CA can impersonate any principal named in its directory.

 b) A CA can impersonate any principal to a server named in its
    directory.

 c) A CA can impersonate any principal named in a subdirectory to
    any server not named in the same subdirectory.

 d) A CA can impersonate to any server in a subdirectory any
    principal not named in the same subdirectory.

The implication is that a compromise low in the naming tree will
compromise all principals below that directory while a compromise
high in the naming tree will compromise only the authentication of
principals far apart in the naming hierarchy. In particular, when
multiple organizations share a namespace (as they do in the case of
X.500), the compromise of a CA in one organization can not result in
false authentication within another organization.

DASS uses the X.500 directory hierarchy for principal naming. At the
top of the hierarchy are names of countries. National authorities
are not expected to establish certification authorities (at least
initially), so an alternative mechanism must be used to authenticate
entities "distant" in the naming hierarchy. The mechanism for this
in DASS is the "cross-certificate" where a CA certifies the public
key for some CA or principal not its parent or child. By limiting
the chains of certificates they will use to parent certificates
followed by a single "cross certificate" followed by child

certificates, a DASS implementation can avoid the need to have CAs
near the root of the tree or can avoid the requirement to trust them
even if they do exist. A special case can also be supported whereby
a global authority whose name is not the root can certify the local
roots of independent "islands".

1.2.5 User vs. Node Authentication

In concept, DASS mechanisms support the mutual authentication of two
principals regardless of whether those principals are people,
computers, or applications. Those mechanisms have been extended,
however, to deal with a common case of a pair of principals acting
together (a user and a node) authenticating to a single principal (a
remote server). This is done by having optionally in each
credentials structure two sets of secrets – one for the user and one
for the node. When authentication is done using such credentials,
both secrets sign the request so the receiving party can verify that
both principals are present.

This setup has a number of advantages. It permits access controls to
be enforced based on both the identity of the user and the identity
of the originating node. It also makes it possible to define users
of systems who have no network wide identities who can access network
resources on the basis of node credentials alone. The security of
such a setup is less because a node can impersonate all of its users
even when they are not logged in, but it offers an easier transition
from existing global identities for all users.

1.2.6 Protection of User Keys

DASS mechanisms generally deal with authentication between principals
each knowing a private key. For principals who are people, special
mechanisms are provided for maintaining that private key. In
particular, it many cases it will be most convenient to keep
passwords as secrets rather than private keys. This architecture
specifies a means of storing private keys encrypted under passwords.
This would provide security as good as hiding a private key were it
not that people tend to choose passwords from a small space (like
words in a dictionary) such that a password can be more easily
guessed than a private key. To address this potential weakness, DASS
specifies a protocol between a login node and a login agent whereby
the login agent can audit and limit the rate of password guesses.
Use of these features is optional. A user with a smart card could
store a private key directly and bypass all of these mechanisms. If
users can be forced to choose "good" passwords, the login agent could
be eliminated and encrypted credentials could be stored directly in
the naming service.

Another way in which user keys are protected is that the architecture
does not require that they be available except briefly at login.
This reduces the threat of a user walking away from a logged on
workstation and having someone take over the workstation and extract
his key. It also makes the use of RSA based smart cards practical;
the card could keep the user's private key and execute one signature
operation at login time to authenticate an entire session.

1.3 What This Document Won't Tell You

Architecture documents are by their nature difficult to read. This
one is no exception. The reason is that an architecture document
contains the details sufficient to build interoperable
implementations, but it is not a design specification. It goes out of
its way to leave out any details which an implementation could choose
without affecting interoperability. It also does not specify all the
uses of the services provided because these services are properly
regarded as general purpose tools.

The remainder of this section includes information which is not
properly part of the authentication architecture, but which may be
useful in understanding why the architecture is the way it is.

1.3.1 How DASS is Embedded in an Operating System

While architecturally DASS does not require any operating system
support in order to be used by an application (other than the
services listed in Section 2), it is expected that actual
implementations of DASS will be closely tied to the operating systems
of host computers. This is done both for security and for
convenience.

In particular, it is expected that when a user logs into a node, a
set of credentials will be created for that user and then associated
by the operating system with all processes initiated by or on behalf
of the user. When a user delegates to a service, the remote
operating system is expected to accept the delegation and start up
the remote process with the delegated credentials. Most nodes are
expected to have credentials of their own and support the concept of
user accounts. When user credentials are created, the node is
expected to verify them in its own context, determine the appropriate
user account, and add node credentials to the created credentials
set.

1.3.2 Forms of Credentials

In the DASS architecture, there is a single data structure called
"Credentials" with a large number of optional parts. In an

implementation, it is possible that not all of the architecturally
allowed subsets will be supported and credentials structures with
different subsets of the data may be implemented quite differently.

The major categories of credentials likely to be supported in an
implementation are:

- Claimant credentials – these are the credentials which would
  normally be associated with a user process in order that it be
  able to create authentication tokens. It would contain the
  user's name, login ticket, session private key, and (at least
  logically) local node credentials and cached outgoing
  contexts.

- Verifier credentials – these are the credentials which would
  normally be associated with a server which must verify tokens
  and produce mutual authentication response tokens. Since
  servers may be started by a node on demand, some
  representation of verifier credentials must exist independent
  of a process. If an operating system wishes to authenticate a
  request before starting a server process, the credentials must
  exist in usable form. An implementation may choose to have
  all services on a "node" share a verifier credentials
  structure, or it may choose to have each service have its own.

- Combined credentials – architecturally, a server may have a
  structure which is both claimant credentials and verifier
  credentials combined so that the server may act in either role
  using a single structure. There is some overlap in the
  contents. There is no requirement, however, that an
  implementation support such a structure.

- Stub credentials – In the architecture, a credentials
  structure is created whenever a token is accepted. If delegation
  took place, these are claimant credentials usable by their
  possessor to create additional tokens. If no delegation took
  place, this structure exists as an architectural place holder
  against which an implementation may attempt to authenticate
  user and node names. An implementation might choose to
  implement stub credentials with a different mechanism than
  claimant or verifier credentials. In particular, it might do
  whatever user and node authentication is useful itself and not
  support this structure at all.

1.3.3 Support for Alternative Certification Authority
      Implementations

   A motivating factor in much of the design of DASS is the need to
   protect certification authorities from compromise. CAs are only used
   to create certificates for new principals and to renew them on
   expiration (expiration intervals are likely to be measured in
   months). They therefore do not need to be highly available. For
   maximum security, CAs could be implemented on standalone PCs where
   the hardware, software, and keys can be locked in a safe when the CA
   is not in use. The certificates the CA generates must be delivered to
   the naming service to be registered, and a possible mechanism for
   this is for the CA to have an RS232 line to an on-line component
   which can pass certificates and related information but not login
   sessions. The intent would be to make it implausible to mount a
   network attack against the CA. Alternatively, certificates could be
   carried to the network on a floppy disk.

   For CAs to be secure, a whole host of design details must be done
   right. The most important of these is the design of user and system
   manager interfaces that make it difficult to "trick" a user or system
   manager into doing the wrong thing and certifying an impostor or
   revealing a key. Mechanisms for generating keys must also be
   carefully protected to assure that the generated key cannot be
   guessed (because of lack of randomness) and is not recorded where a
   penetrator can get it. Because a certificate contains relatively
   little human intelligible information (its most important components
   are UIDs and public keys), it will be a challenge to design a user
   interface that assures the human operator only authorizes the signing
   of intended certificates. Such considerations are beyond the scope of
   the architecture (since they do not affect interoperability), but
   they did affect the design in subtle ways. In particular, it does
   not assume uniform security throughout the CA hierarchy and is
   designed to assure that the compromise of a CA in one part of the
   hierarchy does not have global implications.

   The architecture does not require that CAs be off-line. The CA could
   be software that can run on any node when the proper secret is
   installed. Administrative convenience can be gained by integrating
   the CA with account registration utilities and naming service
   maintenance. As such, the CA would have to be on-line when in use in
   order to register certificates in the naming service. The CA key
   could be unlocked with a password and the password could be entered
   on each use both to authenticate the CA operator and to assure that
   compromise of the host node while the CA is not in use will not
   compromise the CA. This design would be subject to attacks based on
   planting Trojan horses in the CA software, but is entirely
   interoperable with a more secure implementation. Realistic tradeoffs

     must be made between security, cost, and administrative convenience
     bearing in mind that a system is only as secure as its weakest link
     and that there is no benefit in making the CA substantially more
     secure than the other components of the system.

1.3.4 Services Provided vs. Application Program Interface

     Section 3 of this document specifies "abstract interfaces" to the
     services provided by DASS. This means it tells what services are
     provided, what parameters are supplied by the caller, and what data
     is returned. It does not specify the calling interfaces. Calling
     interfaces may be platform, operating system, and language dependent.
     They do not affect interoperability; different implementations which
     implement completely different calling interfaces can still
     interoperate over a network. They do, however, affect portability. A
     program which runs on one platform can only run on another which
     implements an identical API.

     In order to support portability of applications – not just between
     implementations of DASS but between implementations of DASS and
     implementations of Kerberos – a "Generic Security Service API" has
     been designed and is outlined in Annex B. This API could be the only
     "published" interface to DASS services. This interface does not,
     however, give access to all the functions provided by DASS and it
     provides some non–DASS services. It does not give access to the
     "login" service, for example, so the login function cannot be
     implemented in a portable way. Clearly an implementation must provide
     some implementation of the login function, though perhaps only to one
     system program and the implementation need not be portable.
     Similarly, the Generic API provides no access to node authentication
     information, so applications which use these services may not be
     portable.

     The Generic API provides services for encryption of user data for
     integrity and possibly privacy. These services are not specified as a
     part of the DASS architecture. This is because we envisioned that
     such services would be provided by the communications network and not
     in applications. These services are provided by the Generic API
     because these services are provided by Kerberos, there exist
     applications which use these services, and they are desired in the
     context of the IETF–CAT work. The DASS architecture includes a Key
     Distribution service so that the encryption functions of the Generic
     API can be supported and integrated. Annex B specifies how those
     services can be implemented using DASS services.

     The Services Provided also differ from the GSSAPI because there are
     important extensions envisioned to the API for future applications
     and it was important to assure that architecturally those services

were available. In particular, DASS provides the ability for a
principal to have multiple aliases and for the receiver of an
authentication token to verify any one of them. We want DASS to
support the case where a server only learns the name it is trying to
validate in the course of evaluating an ACL. This may be long after
a connection is accepted. The Services Provided section therefore
separates the Accept_token function from the Verify Principal Name.
The other motivation behind a different interface is that DASS
provides node authentication – the ability to authenticate the node
from which a request originates as well as the user. Because
Kerberos provides no such mechanism, the capability is missing from
the GSSAPI, but we expect some applications will want to make use of
it.

1.3.5 Use of a Naming Service

With the exception of the syntactical representation of names, which
is tied to X.500, the DASS architecture is designed to be independent
of the particular underlying naming service. While the intention is
that certificates be stored in an X.500 naming service in the fields
architecturally reserved for this purpose in the standard, this
specification allows for the possibility of different forms of
certificate stores. The SPX implementation of DASS implements its
own certificate distribution service because we did not want to
introduce a dependency on an X.500 naming service.

1.3.6 Key Hiding – Credentials

The abstract interfaces described in section 3 specify that
"credentials" and "keys" are the inputs and outputs of various
routines. Credentials structures in particular contain secret
information which should not be made available to the calling
application. In most cases, keeping this information from
applications is simply a matter of prudence – a misbehaving
application can do nearly as much damage using the credentials as it
can by using the secrets directly. Having access to the keys
themselves may allow an application to bypass auditing or leak a key
to an accomplice who can use it on another node where a large amount
of activity is less likely to be noticed. In some cases, most
dramatically where a "node key" is present in user credentials, it is
vital that the contents of the credentials be kept out of the hands
of applications.

To accomplish this, a concrete interface is expected to create
"credentials handles" that are passed in and out of DASS routines.
The credentials themselves would be kept in some portion of memory
where unprivileged code can't get at them.

There is another aspect of the way credentials are used which is
important to the design of real implementations. In normal use, a
user will create a set of credentials in the process of logging on to
a system and then use them from many processes or jobs. When many
processes share a set of credentials, it is important for the sake of
performance that they share one set of credentials rather than having
a copy of the credentials made for each. This is because information
is cached in credentials as a side effect of some requests and for
good performance those caches should be shared.

As an example, consider a system executing a series of copy commands
moving files from one system to another. The credentials of the user
will have been established when the user logged on. The first time a
copy is requested, a new process will start up, open a connection to
the destination system, and create a token to authenticate itself.
Creating that token will be an expensive operation, but information
will be computed and "cached" in the credentials structure which will
allow any subsequent tokens on behalf of that user to that server to
be computed cheaply. After the copy completes, the connection is
closed and the process terminates. In response to a second copy
request, another new process will be created and a new token
computed. For this operation to get a performance benefit from the
caching, the information computed by the first process must somehow
make it to the second.

A model for how this caching might work can be seen in the way
Kerberos caches credentials. Kerberos keeps credentials in a file
whose name can be computed from the name of the local user. This
file is initialized as part of the login process and its protection
is set so that only processes running under the UID of the user may
read and write the file. Processes cache information there; all
processes running on behalf of the user share the file.

There are two problems with this scheme: first, on a diskless node
putting information in a file exposes it to eavesdroppers on the
network; second, it does not accomplish the "key hiding" function
described earlier in this section. In a more secure implementation,
the kernel or a privileged process would manage some "pool" of
credentials for all processes on a node and would grant access to
them only through the DASS calls. Credentials structures are complex
and varying length; DASS may organize them as a set of pools rather
than as contiguous blocks of data. All such design issues are
"beyond the scope of the architecture". Implementations must decide
how to control access to credentials. They could copy the Kerberos
scheme of having credentials available to processes with the UID of
the login session which created them and to privileged processes or
there may be a more elaborate mechanism for "passing" credentials
handles from process to process. This design should probably follow

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the operating system mechanisms for passing around local privileges.

1.3.7 Key Hiding – Contexts

The "GSSAPI" has a concept of a security context which has some of
the same key hiding problems as a credentials structure. Security
contexts are used in calls to cryptographically protect user data
(from modification or from disclosure and modification) using keys
established during authentication. The "services provided"
specification says that create_ and accept_token return a "shared
key" and "instance identifier". The GSSAPI says that a context
handle is returned which is an integer. A secure implementation
would keep the key and instance identifier in protected memory and
only allow access to them through provided interfaces.

Unlike credentials, there is probably no need to provide mechanisms
for contexts to be shared between processes. Contexts will normally
be associated with some notion of a communications "connection" and
ends of a connection are not normally shared. If an implementation
chooses to provide additional services to applications like message
sequencing or duplicate detection, contexts will have to contain
additional fields. These can be created and maintained without any
additional authentication services.

1.4 The Relationship between DASS and ISO Standards

This section provides an introduction to DASS authentication in terms
of the ISO Authentication Framework (DP10181-2).   The purpose of
this introduction is to give the reader an intuitive understanding of
the way DASS works and how its mechanisms and terminology relate to
standards. Important details have been omitted here but are spelled
out in section 3.

1.4.1 Concepts

The primary goal of authentication is to prevent impersonation, that
is, the pretense to a false identity. Authentication always involves
identification in some form. Without authentication, anyone could
claim to be whomever they wished and get away with it.

If it didn't matter with whom one was communicating, elaborate
procedures for authentication would be unnecessary. However, in most
systems, and in timesharing and distributed processing environments
in particular, the rights of individuals are often circumscribed by
security policy. In particular, authorization (identity based access
control) and accountability (audit) provisions could be circumvented
if masquerading attempts were impossible to prevent or detect.

Almost all practical authentication mechanisms suitable for use in
distributed environments rely on knowledge of some secret
information. Most differences lie in how one presents evidence that
they know the secret. Some schemes, in particular the familiar simple
use of passwords, are quite susceptible to attack. Generally, the
threats to authentication may be classified as:

  - forgery, attempting to guess or otherwise fabricate evidence;

  - replay, where one can eavesdrop upon another's authentication
    exchange and learn enough to impersonate them; and

  - interception, where one slips between the communicants and is
    able to modify the communications channel unnoticed.

Most such attacks can be countered by using what is known as strong
authentication. Strong authentication refers to techniques that
permit one to provide evidence that they know a particular secret
without revealing even a hint about the secret. Thus neither the
entity to whom one is authenticating, nor an eavesdropper on the
conversation can further their ability to impersonate the
authenticating principal at some future time as the result of an
authentication exchange.

Strong authentication mechanisms, in particular those used here, rely
on cryptographic techniques. In particular, DASS uses public key
cryptography. Note that interception attacks cannot be countered by
strong authentication alone, but generally need additional security
mechanisms to secure the communication channel, such as data
encryption.

1.4.2 Principals and Their Roles

All authentication is on behalf of principals. In DASS the following
types of principals are recognized:

  - user principals, normally people with accounts who are
    responsible for performing particular tasks. Generally it is
    users that are authorized to do things by virtue of having
    been granted access rights, or who are to be held accountable
    for specific actions subject to being audited.

  - server principals, which are accessed by users.

  - node principals, corresponding to locations where users and
    servers, or more accurately, processes acting on behalf of
    principals can reside.

   Principals can act in one of two capacities:

     - the claimant is the active entity seeking to authenticate
       itself, and

     - the verifier is the passive entity to whom the claimant is
       authenticating.

   Users normally are claimants, whereas servers are usually verifiers,
   although sometimes servers can also be claimants.

   There is another kind of principal:

     - certification authorities (CA's) issue certificates which
       attest to another principal's public key.

1.4.3 Representation, Delegation and Representation Transfer

   Of course, although it is users that are responsible for what the
   computer does, human beings are physically unable to directly do
   anything within a computer system. In point of fact, it is a
   process executing on behalf of a user that actually performs
   useful work. From the point of view of performing security
   controlled functions, the process is the agent, or
   representative, of the user, and is authorized by that user to do
   things on his behalf. In the terms used in the ISO Authentication
   Framework, the user is said to have a representation in the
   process.

   The representation has to come into existence somehow. Delegation
   refers to the act of creating a representation. A user is said to
   create a representation for themselves by delegating to a process. If
   the user creates another process, say by doing an rlogin on a
   different computer, a representation may be needed there as well. This
   may be accomplished automatically by a process known as representation
   transfer. DASS uses the term delegation to also mean the act of
   creating additional representations on a remote systems.

   A representation is instantiated in DASS as credentials. Credentials
   include the identity of the principal as well as the cryptographic
   "state" needed to engage in strong authentication procedures. Claimant
   information in credentials enable principals to authenticate
   themselves to others, whereas verifier information in credentials
   permit principals to verify the claims of others. Credentials
   intended primarily for use by a claimant will be referred to as
   claimant credentials in the text which follows. Credentials intended
   primarily for use in verification will be referred to as verifier
   credentials. A particular set of credentials may or may not contain

all of the data necessary to be used in both roles. That will depend
on the mechanisms by which the credentials were created.

In some contexts, but not here, the concept of representation
and/or delegation is sometimes referred to as proxy. This term is
used in ECMA TR/46. We avoid use of the term because of possible
confusion with an unrelated use of the term in the context of
DECnet.

1.4.4 Key Distribution, Replay, Mutual Authentication and Trust

Strong authentication uses cryptographic techniques. The
particular mechanisms used in DASS result in the distribution of
cryptographic keys as a side effect. These keys are suitable for
use for providing a data origin authentication service and/or a
data confidentiality service between a pair of authenticated
principals.

Replay detection is provided using timestamps on relevant
authentication messages, combined with remembering previously
accepted messages until they become "stale". This is in contrast
to other techniques, such as challenge and response exchanges.

Authentication can be one-way or mutual. One-way authentication is
when only one party, in DASS the claimant, authenticates to the other.
Mutual authentication provides, in addition, authentication of the
verifier back to the claimant. In certain communications schemes, for
example connectionless transfer, only one-way authentication is
meaningful. DASS supports mutual authentication as a simple extension
of one-way authentication for use in environments where it makes
sense.

DASS potentially can allow many different "trust relationships"
to exist. All principals trust one or more CA's to safeguard the
certification process. Principals use certificates as the basis
for authenticating identities, and trust that CA's which issue
certificates act responsibly. Users expect CA's to make sure that
certificates (and related secrets) are only made for principals
that the CA knows or has properly authenticated on its own.

1.5 An Authentication Walkthrough

The OSI Authentication Framework characterizes authentication as
occurring in six phases. This section attempts to describe DASS
in these terms.

1.5.1 Installation

   In this phase, principal certificates are created, as is the
   additional information needed to create claimant and verifier
   credentials. OSI defines three sub-phases:

   - Enrollment. In DASS, this is the definition of a principal in
     terms of a key, name and UID.

   - Validation, confirmation of identity to the satisfaction of
     the CA, after which the CA generates a certificate.

   - Confirmation. In DASS, this is the act of providing the user
     with the certificate and with the CA's own name, key and UID,
     followed up by the user creating a trusted authority for that
     CA. A trusted authority is a certificate for the CA signed by
     the user.

   Included in this step in DASS is the posting of the certificate so as
   to be available to principals wishing to verify the principal's
   identity. In addition, the user principal saves the trusted authority
   so as to be available when it creates credentials.

1.5.2 Distribution

   DASS distributes certificates by placing them in the name service.

1.5.3 Acquisition

   Whenever principals wish to authenticate to one another, they access
   the Name Service to obtain whatever public key certificates they need
   and create the necessary credentials. In DASS, acquisition means
   obtaining credentials.

   Claimant credentials implement the representation of a principal in a
   process, or, more accurately, provide a representation of the
   principal for use by a process. In making this representation, the
   principal delegates to a temporary delegation key. In this fashion
   the claimant's long term principal key need not remain in the system.

   Claimant credentials are made by invoking the get credentials
   primitive. Claimant credentials are a DASS specific data structure
   containing:

   - a name

   - a ticket, a data structure containing

   . a validity interval,

   . UID, and

   . (temporary) delegation public key, along with a

   . digital signature on the above made with the principal
    private key

  – the delegation private key

Optionally in addition, there may be credential information relating
to the node on which the user is logged in and the account on that
node. A detailed description of all the information found in
credentials can be found in section 3. Verifier credentials are made
with initialize_server. Verifier credentials consist of a principal
(long term) private key. The rationale is that these credentials are
usually needed by servers that must be able to run indefinitely
without re-entry of any long term key.

In addition, claimants and verifiers have a trusted authority, which
consists of information about a trusted CA. That information is its:

 – name (this will appear in the "issuer" field in principal
  certificates),

 – public key (to use in verifying certificates issued by that
  CA), and

 – UID.

Trusted authorities are used by principals to verify certificates for
other principals' public keys. CAs are arranged in a hierarchy
corresponding to the naming hierarchy, where each directory in the
naming hierarchy is controlled by a single CA. Each CA certifies the
CA of its parent directory, the CAs of each of its child directories,
and optionally CAs elsewhere in the naming hierarchy (mainly to deal
with the case where the directories up to a common ancestor lack
CAs). Even though a principal has only a single CA as a trusted
authority, it can securely obtain the public key of any principal in
the namespace by "walking the CA hierarchy".

1.5.4 Transfer

 The DASS exchange of authentication information is illustrated in
 Figure 1-1. During the transfer phase, the DASS claimant sends an
 authentication token to the verifier. Authentication tokens are made
 by invoking the create_token primitive. The authentication token is

cryptographically protected and specified as a DASS data structure in
ASN.1. The authentication token includes:

  – a ticket,

  – a DES authenticating key encrypted using the intended
    verifier's public key

  – one of the following:

    . if delegation is not being performed, a digital signature on
      the encrypted DES key using the delegation private key, or

    . if delegation is being performed, sending the delegation
      private key, DES encrypted using the DES authenticating key

  – an authenticator, which is a cryptographic checksum made using
    the DES authenticating key over a buffer containing

    . a timestamp

    . any application supplied "channel bindings". For example,
      addresses or other context information. The purpose of this
      field is to thwart substitution and replay attacks.

  – additional optional information concerning node authentication
    and context.

As a side effect, after init_authentication_context, the caller
receives a local authentication context, a data structure containing:

  – the DES key, and

  – if mutual authentication is being requested, the expected
    response.

In order to construct an authentication token, the claimant needs to
access the verifier's public key certificate from the Name Service
(labeled CDC, for Certificate Distribution Center, in the figure).

Note that while an authenticator can only be used once, it is
permissible to re-establish the same local authentication context
multiple times. That is, the ticket and DES key establishment
components of the authentication token may have a relatively long
lifetime. This permits a performance improvement in that repeated
applications of public key operations can be alleviated if one caches
authentication contexts, along with other components from a
successfully used authentication token and the associated verified

principal public key value. It is a relatively inexpensive operation
to create (and verify) "fresh" authenticators based on cached
authentication context.

```
      Claimant Actions    │ Communications │  Verifier Actions

          verifier name   │                │
                │         │                │
                │         │           +---+
                │         │           │   │
                \------------------->│   │
                          │          │   │
      trusted             │          │CDC│
     authorities   +-----------+     │   │
        │        │ │ Verify    │<-----------│   │
        \--->│Certificate│     │   +---+
             +-----------+     │
      Claimant           │     │
     credentials   Verifier    │     Verifier
        │         Public Key   │     Credentials
        │              │       │          │
        │              V       │          V
        │        +-----------+ │   +-----------+
        │        │  Make     │ Authentication │  Check    │  Replay
        \--->│  Token    │---------------->│  Token    │<-->Cache
                 +-----------+     +-----------+
      DES <---/      │       │     │ │   │   \----->DES
      key            │       │     │ │  \Claimant      key
                     │       │     │/Public Key
                     │       │    / │  │    trusted
                     │       │   Claimant /│  V   authorities
       authentication│     +---+ Name  /  +-----------+      │
          context    │     │ │  │<------/  │ Verify    │<----/
                     │     │ │  │certificate│Certificate│
                     │     │CDC│-----------│   │-->accept/
                     │     │ │  │          +-----------+  reject
                     │     │ │  │              │    \
                     V     +---+          authentication\
                 +-----------+  mutual     context     V
        /--│  Accept   │  authentication     │    claimant
        V  │  Mutual   │<-------------------│  Make     │credentials
    accept/ +-----------+  response          │ Response  │(delegation)
    reject                                   +-----------+
```
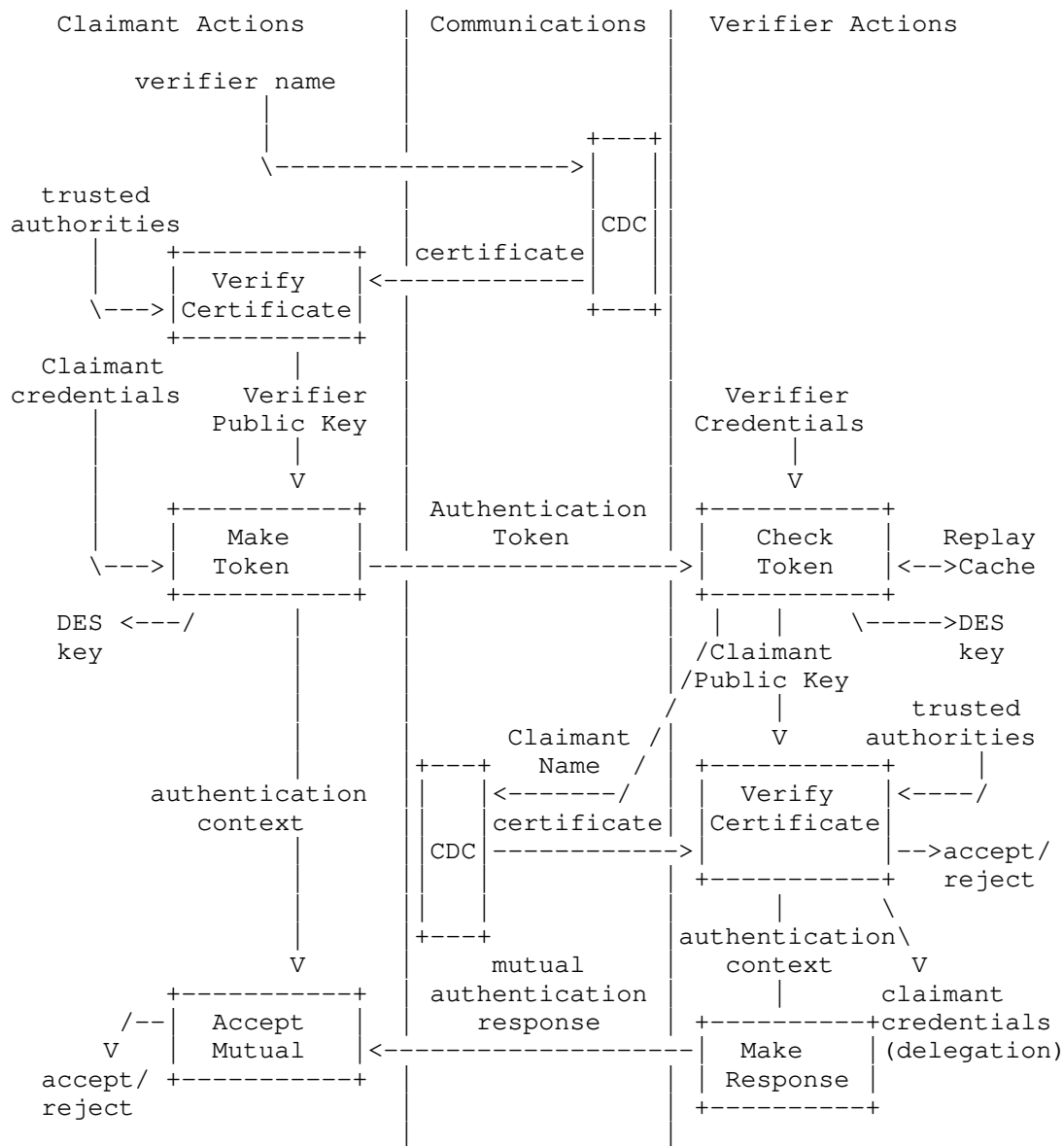
Figure 1 - Authentication Exchange Overview

1.5.5 Verification

   Upon receipt of an authentication token, the verifier extracts the
   DES key using its verifier credentials, accesses the Name Service
   (labeled CDC for Certificate Distribution Center) to obtain the
   certificates needed to perform cryptographic checks on the incoming
   information, and verifies all of the signatures on the received
   certificates and the authentication token. Verification can result
   in creation of new claimant credentials if delegation is performed.

   As part of this process, verified authenticators are retained for a
   suitable timeout period.

1.5.6 Unenrolment

   This is the removal of information from the Name Service. The only
   other form of revocation supported by DASS is certificate timeout.
   Every certificate contains an expiration time (expected in ordinary
   use to be about a year from its signing date). DASS does not
   currently support the revocation lists in X.509.

2. Services Used

   Aside from operating system services needed to maintain its internal
   state, DASS relies on a global distributed database in which to store
   its certificates, a reliable source of time, and a source of random
   numbers for creating cryptographic keys.

2.1 Time Service

   DASS requires access to the current time in several of its
   algorithms. Some of its uses of time are security critical. In
   others, network synchronization of clocks is required. DASS does
   not, however, depend on having a single source of time which is both
   secure and tightly synchronized.

   The requirements on system provided time are:

    - For purposes of validating certificates and tickets, the
      system needs access to know the date and time accurate to
      within a few hours with no particular synchronization
      requirements. If this time is inaccurate, then valid requests
      may be rejected and expired messages may be accepted.
      Certificate expiration is a backup revocation mechanism, so
      this can only cause a security compromise in the event of
      multiple failures. In theory, this could be provided by
      having a local clock on every node accurate to within a few
      hours over the life of the product to provide this function.

If an insecure network time service is used to provide this
time, there are theoretical security threats, but they are
expected to be logistically impractical to exploit.

   - For purposes of detecting replay of authentication tokens, the
     system needs access to a strictly monotonic time source which
     is reasonably synchronized across the network (within a few
     minutes) for the system to work, but inaccuracy does not
     present a security threat except as noted below. It may
     constitute an availability threat because valid requests may
     be rejected. In order to get strict monotonicity in the
     presence of a rapid series of requests, time must be returned
     with high precision. There is no requirement for a high
     degree of accuracy. Inaccurate time could present a security
     threat in the following scenario: if a client's clock is made
     sufficiently fast that its tokens are rejected, someone
     harvesting those tokens from the wire could replay them later
     and impersonate the client. In some environments, this might
     be an easier threat than harvesting tokens and preventing
     their delivery.

   - For purposes of aging stale entries from caches, DASS requires
     reasonably accurate timing of intervals. To the extent that
     intervals are reported as shorter than the actually were,
     revocation of certificates from the naming service may not be
     as timely as it should be.

2.2 Random Numbers

   In order to generate keys, DASS needs a source of "cryptographic
   quality" random numbers. Cryptographic quality means that
   knowing any of the "random numbers" returned from a series and
   knowing all state information which is not protected, an attacker
   cannot predict any of the other numbers in the series. Hardware
   sources are ideal, but there are alternative techniques which may
   also be acceptable. A 56 bit "truly random" seed (say from a
   series of coin tosses) could be used as a DES key to encrypt an
   infinite length known text block in CBC mode to produce a pseudo-rand
   sequence provided the key and current point in the sequence were
   adequately protected. There is considerable controversy
   surrounding what constitutes cryptographic quality random
   numbers, and it is not a goal of this document to resolve it.

2.3 Naming Service

   DASS stores creates and uses "certificates" associated with every
   principal in the system, and encrypted credentials associated
   with most. This information is stored in an on-line service

associated with the principal being certified. The long term
vision is for DASS to use an X.500 naming service, and DASS will
from its inception authenticate X.500 names. To avoid a
dependence on having an X.500 naming service available (and to
gain the benefits of a "login agent" that controls password
guessing), an alternative certificate distribution center
protocol is also described.

The specific requirements DASS places on the naming service are:

  - It must be highly available. A user's naming service entry
    must be available to any node where the user is to obtain
    services (or service will be denied). A server's naming
    service entry must be available from any node from which the
    service is to be invoked (or service will be denied).

  - It must be timely. The presence of "stale" information in the
    naming service may cause some problems. When a password
    changes, the old password may remain valid (and the new
    password invalid) to the extent the naming service provides
    stale information. When a user or server is added to the
    network, it will not be able to participate in authentication
    until the information added to the naming service is available
    at the node doing the authentication. In the unusual
    circumstance that a key changes, the entity whose key has
    changed will not be able to use the new key until the new
    certificate is uniformly available.

  - It must be secure with regard to certain specific properties.
    In general, the security of DASS protected applications does
    not depend on the security of the naming service. It is
    expected that the availability needs of the naming service
    will prevent it from being as secure as some applications need
    to be. There are two aspects of DASS security which do depend
    on the security of the naming service: timely revocation of
    certificates and protection of user secrets against dictionary
    based password guessing. DASS depends on the removal of
    certificates from the naming service in order to revoke them
    more quickly than waiting for them to time out. For this
    mechanism to provide any actual security, it must not be
    possible for a network entity to "impersonate" the naming
    service and the naming service must be able to enforce access
    controls which prevent a revoked certificate from being
    reinstated by an unauthorized entity. In the long run, it is
    expected that DASS itself will be used to secure the naming
    service, which presents certain potential recursion problems
    (to be addressed in the naming service design). If the naming
    service is not authenticated (as is expected in early

versions) attacks where a revoked certificate is "reinstated"
through impersonation of the naming service are possible.

The specific functions DASS requests of the naming service are
simple:

- Given an X.500 name, store a set of certificates associated
  with that name.

- Given an X.500 name, retrieve the set of certificates
  associated with that name.

- Given an X.500 name, store a set of encrypted credentials
  associated with that name.

- Given and X.500 name, retrieve a set of encrypted credentials
  associated with that name.

Implementation over a particular naming service may implement more
specialized functions for reasons of efficiency. For example, the
certificates associated with a name may be separated into several
sets (child, parent, cross, self) so that only the relevant ones may
be retrieved. In order that access to the naming service itself be
secure, the protocols should be authenticated. Certificates should
generally be readable without authentication in order to avoid
recursion problems. Requests to read encrypted credentials should be
specialized and should include proof of knowledge of the password in
order that the naming service can audit and slow down false password
guesses.

The following sections describe the interfaces to specific naming
services:

2.3.1 Interface to X.500

Certificates associated with a particular name are stored as
attributes of the entry as specified in X.509. X.509 defines
attributes appropriate for parent and cross certificates
(CrossCertificatePair, CACertificate) for some principals; we will
have to define a DASSUserPrincipal object class including these
attributes in order to properly use them with ordinary users.
Retrieval is via normal X.500 protocols. Certificates should be
world readable and modifiable only by appropriate authorities.

Encrypted credentials are stored with the entry of the principal
under a yet to be defined attribute. The credentials should be
encoded as specified in section 4. In the absence of extensions to
the X.500 protocol to control password guessing, the encrypted

   credentials should be world readable and updatable only by the named
   principal and other appropriate authorities.

2.3.2 Interface to CDC

   The CDC (Certificate Distribution Center) is a special purpose name
   server created to service DASS until an X.500 service is available in
   all of the environments where DASS needs to operate. The CDC uses a
   special purpose protocol to communicate with DASS clients. The
   protocol was designed for efficiency, simplicity, and security. CDCs
   use DASS as an authentication mechanism and to protect encrypted
   credentials from unaudited password guessing.

   Each DASS client maintains a list of CDCs and the portion of the
   namespace served by that CDC. Each directory has a master replica
   which is the only one which will accept updates. The CDCs maintain
   consistency with one another using protocols beyond the scope of this
   document. When a DASS client wishes to make a request of a CDC, it
   opens a TCP or DECnet connection to the CDC and sends an ASN.1 (BER)
   encoded request and receives a corresponding ASN.1 (BER) encoded
   response. Clients are expected to learn the IP or DECnet address and
   port number of the CDC supporting a particular name from a local
   configuration file. To maximize performance, the requests bundle
   what would be several requests if made in terms of requests for
   individual certificates. It is intended that all certificates needed
   for an authentication operation be retrievable with at most two CDC
   requests/responses (one to the CDC of the client and one to the CDC
   of the server).

   Documented here is the protocol a DASS client would use to retrieve
   certificates and credentials from a CDC and update a user password.
   This protocol does not provide for updates to the certificate and
   credential databases. Such updates must be supported for a practical
   system, but could be done either by extensions to this protocol or by
   local security mechanisms implemented on nodes supporting the CDC.
   Similarly, availability can be enhanced by replicating the CDC.
   Automating the replication of updates could be implemented by
   extensions to this protocol or by some other mechanism. This
   specification assumes that updates and replication are local matters
   solved by individual CA/CDC implementations.

   Requests and responses are encoded as follows:

2.3.2.1 ReadPrinCertRequest

   This request asks the CDC to return the child certificates and
   selected incoming cross certificates for the specified object. The
   format of the request is:

```
    ReadPrinCertRequest ::= [4] IMPLICIT SEQUENCE {
        flags [0] BIT STRING DEFAULT {},
        index [1] IMPLICIT INTEGER DEFAULT 0,
        resolveFrom [2] Name OPTIONAL,
        principal Name,
        crossCertIssuers ListOfIssuers OPTIONAL
        }
    ListOfIssuers ::= SEQUENCE OF Name
```

The first 24 bits of flags, if present, contain a protocol version
number. Clients following this spec should place the value 2.0.0 in
the three bytes. Servers following this spec should accept any value
of the form 1.x.x or 2.x.x. flags bits beyond the first 24 are
reserved for future use (should not be supplied by clients and should
be ignored by servers).

index is only used if the response exceeds the size of a single
message; in that case, the query is repeated with index set to the
value that was returned by ReadPrinCertResponse. resolveFrom and
principal imply a set of entities for which certificates should be
retrieved. resolveFrom (if present) must be an ancestor of principal
and child certificates will be retrieved for principal and all names
which are ancestors of principal but descendants of resolveFrom. The
encoding of names is per X.500 and is specified in more detail in
section 4. The CDC returns the certificates in order of the object
they came from, parents before children.

crossCertIssuers is a list of cross certifiers that would be believed
in the context of this authentication. If supplied, the CDC may
return a chain of certificates starting with one of the named
crossCertIssuers and ending with the named principal. One of
resolveFrom or crossCertIssuers must be present in any request; if
both are present, the CDC may return either chain.

2.3.2.2 ReadPrinCertResponse

   This is the response a CDC sends to a ReadPrinCertRequest. Its
   syntax is:

```
    ReadPrinCertResponse ::= [5] IMPLICIT SEQUENCE {
        status [0] IMPLICIT CDCstatus DEFAULT success,
        index [1] INTEGER OPTIONAL,
        resolveTo [2] Name OPTIONAL,
        certSequence [3] IMPLICIT CertSequence,
        indexInvalidator [4] OCTET STRING (SIZE(8)) OPTIONAL,
        flags [5] BIT STRING OPTIONAL
        }
    CertSequence ::= SEQUENCE OF Certificate
```

   status indicates success or the cause of the failure.

   index if present indicates that the request could not be fully
   satisfied in a single request because of size limitations. The
   request should be repeated with this index supplied in the request to
   get more.

   resolveTo will be present if index is present and should be supplied
   in the request for more certificates. certSequence contains
   certificates found matching the search criteria.

   indexInvalidator may be present and indicates the version of the
   database being read. If a set of certificates is being read in
   multiple requests (because there were too many to return in a single
   message), the reader should check that the value for indexInvalidator
   is the same on each request. If it is not, the server may have
   skipped or duplicated some certificates. This field must not be
   present if the version number in the request was missing or version
   1.x.x.

   The first 24 bits of flags, if present, indicate the protocol version
   number. Implementers of this version of the spec should supply 2.0.0
   and should accept any version number of the form 1.x.x or 2.x.x.

2.3.2.3 ReadOutgoingCertRequest

   This requests from the CDC a list of all parent and outgoing cross
   certificates for a specified object. A CDC is capable of storing
   cross certificates either with the subject or the issuer of the cross
   certificate. In response to this request, the CDC will return all
   parent and cross certificates stored with the issuer for the named
   principal and all of its ancestors. Its syntax is:

        ReadOutgoingCertRequest ::= [6] IMPLICIT SEQUENCE {
            flags [0] BIT STRING DEFAULT {},
            index [1] IMPLICIT INTEGER DEFAULT 0,
            principal Name
            }

   The first 24 bits of flags is a protocol version number and should
   contain 2.0.0 for clients implementing this version of the spec.
   Servers implementing this version of the spec should accept any
   version number of the form 1.x.x or 2.x.x. The remaining bits are
   reserved for future use (they should not be supplied by clients and
   they should be ignored by servers).

   index is used for continuation (see ReadPrinCertRequest).

   principal is the name for which certificates are requested.

2.3.2.4 ReadOutgoingCertResponse

   This is the response to a ReadOutgoingCertRequest. Its syntax is:

        ReadOutgoingCertResponse::= [7] IMPLICIT SEQUENCE {
            status [0] IMPLICIT CDCStatus DEFAULT success,
            index [1] INTEGER OPTIONAL,
            certSequence [2] IMPLICIT CertSequence,
            indexInvalidator [3] OCTET STRING (SIZE(8))
        OPTIONAL,
            flags [4] BIT STRING OPTIONAL
            }

        CertSequence ::= SEQUENCE OF Certificate

   status indicates success of the cause of failure of the operation.

   index is used for continuation; see ReadPrinCertRequest.

   certSequence is the list of parent and outgoing cross certificates.

   indexInvalidator is used for continuation; see ReadPrinCertResponse
   (the same rules apply with respect to version numbers).

   The first 24 bits of flags, if present, contain the protocol version
   number. Clients implementing this version of the spec should supply
   the value 2.0.0. Servers should accept any values of the form 1.x.x
   or 2.x.x. The remaining bits are reserved for future use (they
   should not be supplied by clients and should be ignored by servers).

2.3.2.5 ReadCredentialRequest

   This request is made to retrieve an principal's encrypted
   credentials. To prevent unaudited password guessing, this structure
   includes an encrypted value that proves that the requester knows the
   password that will decrypt the structure. The syntax of the request
   is:

        ReadCredentialRequest ::= [2] IMPLICIT SEQUENCE {
            flags [0] BIT STRING DEFAULT {}
            principal Name,
            logindata [2] BIT STRING DEFAULT {},
            token [3] BIT STRING OPTIONAL
            }

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   The first 24 bits of flags contains the version number of the
   protocol. The value 2.0.0 should be supplied. Any value of the form
   1.x.x or 2.x.x should be accepted. Any additional bits are reserved
   for future use (should not be supplied by clients and should be
   ignored by servers).

   principal is the name of the principal for whom encrypted credentials
   are desired.

   logindata is an encrypted value. It may only be present if the
   version number is 2.0.0 or higher. It must be present to read
   credentials which are protected by the login agent functionality of
   the CDC. It is constructed as a single RSA block encrypted under the
   public key of the CDC. The public key of the CDC is learned by some
   local means. Possibilities include a local configuration file or by
   using DASS to read and verify a chain of certificates ending with the
   CDC [the CDC serving a directory should have its public key listed
   under a name consisting of the directory name with the RDN
   "CSS=X509"; the OID for the type CSS is 1.3.24.9.1]. The contents of
   the block are as follows:

    - The low order eight bytes contain a randomly generated DES key
      with the last byte of the DES key placed in the last byte of
      the RSA block. This DES key will be used by the CDC to
      encrypt the response. Key parity bits are ignored.

    - The next to last eight bytes contain a long Posix time with
      the integer time encoded as a byte string using big endian
      order.

    - The next eight bytes (from the end) contain a hash of the
      password. The algorithm for computing this hash is listed in
      section 4.4.2. The CDC never computes this hash; it simply
      compares the value it receives with the value associated with
      the credentials.

    - The next sixteen bytes (from the end) contain zero.

    - The remainder of the RSA block (which should be the same size
      as the public modulus of the CDC) contains a random number.
      The first byte should be chosen to be non-zero but so the
      value in the block does not exceed the RSA modulus. Servers
      should ignore these bits. This random number need not be of
      cryptographic strength, but should not be the same value for
      all encryptions. Repeating the DES key would be adequate.

    - The byte string thus constructed is encrypted using the RSA
      algorithm by treating the string of bytes as a "big endian"

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        integer and treating the integer result as "big endian" to
        make a string of bytes.

     token will not be present in the initial implementation but a space
     is reserved in case some future implementation wants to authenticate
     and audit the node from which a user is logging in.

2.3.2.6 ReadCredentialProtectedResponse

     This is the second possible response to a ReadPrinLoginRequest. It
     is returned when the encrypted credentials are protected from
     password guessing by the CDC acting as a login agent. Its syntax is:

     ReadCredentialProtectedResponse::=[16] IMPLICIT SEQUENCE {
             status [0] IMPLICIT CDCStatus DEFAULT success,
             encryptedCredential [1] BIT STRING,
             flags [2] BIT STRING OPTIONAL
             }

     status indicates that the request succeeded or the cause of the
     failure.

     encryptedCredential contains the DASSPrivateKey structure (defined in
     section 4.1) encrypted under a DES key computed from the user's name
     and password as specified in section 4.4.2 and then reencrypted under
     the DES key provided in the ReadPrinLoginRequest.

     The first 24 bits of flags, if present, contains the version number
     of the protocol. Implementers of this version of the spec should
     supply 2.0.0 and should accept any version number of the form 2.x.x.
     Other bits are reserved for future use (they should not be supplied
     and they should be ignored).

2.3.2.7 WriteCredentialRequest

     This is a request to update the encrypted credential structure. It
     is used when a user's key or password changes. The syntax of the
     request is:

         WriteCredentialRequest ::= [17] IMPLICIT SEQUENCE {
             flags [0] BIT STRING DEFAULT {},
             authtoken [2] BIT STRING OPTIONAL,
             principal [3] Name,
             logindata [4] BIT STRING DEFAULT {},
             furtherSensitiveStuff [5] BIT STRING
             }

     The first 24 bits of flags is a version number. Clients implementing

   this version of the spec should supply 2.0.0. Servers should accept
   any value of the form 2.x.x. Additional bits are reserved for future
   use (clients should not supply them and servers should ignore them).

   token, if present, authenticates the entity making the request. A
   request will be accepted either from a principal proving knowledge of
   the password (see logindata below) or a principal presenting a token
   in this field and satisfying the authorization policy of the CDC.
   This field need not be present if logindata includes the hash2 of the
   password (anyone knowing the old password may set a new one).

   principal is the name of the object for which encrypted credentials
   should be updated.

   logindata is encrypted as in ReadPrinLoginRequest. It proves that
   the requester knows the old password of the principal to be updated
   (unless the token supplied is from the user's CA) and includes the
   key which encrypts furtherSensitiveStuff.

   furtherSensitiveStuff is an encrypted field constructed as follows:

    - The first eight bytes consist of the hash2 defined in section
      4.4.2 with the last byte of the hash2 value stored first. The
      CDC stores this value and compares it with the values supplied
      in future requests of ReadCredentialRequest and
      WriteCredentialRequest.

    - The next (variable number of) bytes contains a DASSPrivateKey
      structure (defined in section 4.1). This is the new
      credential structure that will be returned by the CDC on
      future ReadCredentialRequests.

    - The result is padded with zero bytes to a multiple of eight
      bytes.

    - The entire padded string is encrypted using the key from
      logindata or token using DES in CBC mode with zero IV.

   the new eight byte "hash2" defined in section 4.4.2 concatenated with
   the DASSPrivateKey structure encrypted under the new "hash1" all
   encrypted under the DES key included in logindata.

2.3.2.8 HereIsStatus

   This is the response message to ill-formed requests and requests that
   only return a status and no data. It's syntax is:

```
      HereIsStatus ::= [1] IMPLICIT SEQUENCE {
           status [0] IMPLICIT CDCStatus DEFAULT success
           }
```

   status indicates success or the cause of the failure.

2.3.2.9 Status Codes

   The following are the CDCStatus codes that can be returned by
   servers. Not all of these values are possible with all calls, and
   some of the status codes are not possible with any of the calls
   described in this document.

```
      CDCStatus ::= INTEGER {

           success(0),
           accessDenied(1),

           wrongCDC(2),      --this CDC does not store the
                             --requested information

           unrecognizedCA(3),
           unrecognizedPrincipal(4),

           decodeRequestError(5),--invalid BER
           illegalRequest(6),    --request not recognised

           objectDoesNotExist(7),
           illegalAttribute(8),

           notPrimaryCDC(9),--write requests not accepted
                            --at this CDC replica

           authenticationFailure(11),
           incorrectPassword(12),

           objectAlreadyExists(13),
           objectWouldBeOrphan(15),

           objectIsPermanent(16),

           objectIsTentative(17),
           parentIsTentative(18),

           certificateNotFound(19),
           attributeNotFound(20),

           ioErrorOnCertifDatabase(100),
```

```
          databaseFull(101),

          serverInternalError(102),
          serverFatalError(103),

          insufficientResources(104)
          }
```

3. Services Provided

   This section specifies the services provided by DASS in terms of
   abstract interfaces and a model implementation. A particular
   implementation may support only a subset of these services and may
   provide them through interfaces which combine functions and supply
   some parameters implicitly. The specific calling interfaces are in
   some cases language and operating system specific. An actual
   implementation may choose, for example, to structure interfaces so
   that security contexts are established and then passed implicitly in
   calls rather than explicitly including them in every call. It might
   also bundle keys into opaque structures to be used with supplied
   encryption and decryption routines in order to enhance security and
   modularity and better comply with export regulations. Annex B
   describes a Portable API designed so that applications using a
   limited subset of the capabilities of DASS can be easily ported
   between operating systems and between DASS and Kerberos based
   environments. The model implementation describes data structures
   which include cached values to enhance performance. Implementations
   may choose different contents or different caching strategies so long
   as the same sequence of calls would produce the same output for some
   caching policy.

   DASS operates on four kinds of data structures: Certificates,
   Credentials, Tokens, and Certification Authority State. Certificates
   and Tokens are passed between implementations and thus their exact
   format must be architecturally specified. This detailed bit-for-bit
   specification is in section 4. Credentials generally exist only
   within a single node and their format is therefore not specified
   here. The contents of all of these data structures is listed below
   followed by the algorithms for manipulating them.

   There are three kinds of services provided by DASS: Certificate
   Maintenance, Credential Maintenance, and Authentication. The first
   two kinds exist only in support of the third. Certificate maintenance
   functions maintain the database of public keys in the naming service.
   These functions tend to be fairly specialized and may not be
   supported on all platforms. Before authentication can take place,
   both authenticating principals must have constructed credentials
   structures. These are built using the Credential Maintenance calls.

The Authentication functions use credential information and
certificates, produce and consume authentication tokens and tell the
two communicating parties one another's names.

3.1 Certificate Contents

For purposes of this architecture, a certificate is a data structure
posted in the naming service which proclaims that knowledge of the
private key associated with a stated public key authenticates a named
principal. Certificates are "signed" by some authority, are readable
by anyone, and can be verified by anyone knowing the public key of
the authority. DASS organizes the CA trust hierarchy around the
naming hierarchy. There exists a trusted authority associated with
each directory in the naming hierarchy. Generally, each authority
creates certificates stating the public keys of each of its children
(in the naming hierarchy) and the public key of its parent (in the
naming hierarchy). In this way, anyone knowing the public key of any
authority can learn the public key of any other by "walking the
tree". In order that principals may authenticate even when all of
their ancestor directories do not participate in DASS, authorities
may also create "cross-certificates" which certify the public key of
a named entity which is not a descendent. Rules for finding and
following these cross-certificates are described in the Get_Pub_Keys
routines. Every principal is expected to know the public key of the
CA of the directory in which it is named. This must be securely
learned when the principal is initialized and may be maintained in
some form of local storage or by having the principal sign a
certificate listing the name and public key of its parent and posting
that certificate in the naming service.

The syntax and content of DASS certificates are defined in terms of
X.509 (Directory – Authentication Framework). While that standard
prescribes a single syntax for certificates, DASS considers
certificates to be of one of six types:

  – Normal Principal certificates are signed by a CA and certify
    the name and public key of a principal where the name of the
    CA is a prefix of the name of the principal and is one
    component shorter.

  – Trusted Authority certificates are signed by an ordinary
    principal and certify the name and public key of the
    principal's CA (i.e., the CA whose name is a prefix of the
    principal's name and is one component shorter).

  – Child certificates are signed by a CA and certify the name and
    public key of a CA of a descendent directory (i.e., where the
    name of the issuing CA is a prefix of the name of the subject

CA and is one component shorter).

- Parent certificates are signed by a CA and certify the name
  and public key of the CA of its parent directory (i.e., whose
  name is a prefix of the name of the issuer and is one
  component shorter).

- Cross certificates are signed by a CA and certify the name and
  public key of a CA of a directory where neither name is a
  prefix of the other.

- Self certificates are signed by a principal or a CA and the
  issuer and subject name are the same. They are not used in
  this version of the architecture but are defined as a
  convenient data structure in which in which implementations
  may insecurely pass public keys and they may be used in the
  future in certain key roll-over procedures.

It is intended that some future version of the architecture relax the
restrictions above where prefixes must be one component shorter.
Being able to handle certificates where prefixes are two or more
components shorter complicates the logic of treewalking somewhat and
is not immediately necessary, so such certificates are disallowed for
now.

The syntax of certificates is defined in section 4. For purposes of
the algorithms which follow, the following is the portion of the
content which is used (names in brackets refer to the field names in
the ASN.1 encoded structure):

- UID of the issuer (optional)

- Full name of the issuer (the authority or principal signing)
  [issuer]

- UID of the subject (optional)

- Full name of the subject (the authority or principal whose key
  is being certified) [subject]

- Public Key of the subject [subjectPublicKey]

- Period of validity (effective date and expiration date)
  [valid]

- Signature over the entire content of the certificate created
  using the private key of the issuer.

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When parsing a certificate, the reader compares the two name fields
to determine what type of certificate it is. For Parent and Trusted
Authority certificates, the names are ignored for purposes of all
further processing. For Child and Normal Principal certificates, only
the suffix by which the child's name is longer than the parent's is
used for further processing. The reason for this is so that if a
branch of the namespace is renamed, all of the certificates in the
moved branch remain valid for purposes of DASS processing. The only
purposes of having full names in these certificates are (1) to comply
with X.509, (2) for possible interoperability with other
architectures using different algorithms, and (3) to allow principals
to securely store their own names in trusted authority certificates
in the case where they do not have enough local storage to keep it.

3.2 Encrypted Private Key Structure

In order that humans need only remember a password rather than a full
set of credentials, and also to make installation of nodes and
servers easier, there is a defined format for encrypting RSA secrets
under a password and posting in the naming service. This structure
need only exist when passwords are used to protect RSA secrets; for
servers which keep their secrets in non-volatile memory or users who
carry smart cards, they are unnecessary.

This structure includes the RSA private/public key pair encrypted
under a DES key. The DES key is computed as a one-way hash of the
password. This structure also optionally includes the UID of the
principal. It is needed only if a single RSA key is shared by
multiple principals (with multiple UIDs).

Since this structure is posted in the name service and may be used by
multiple implementations, its format must be architecturally defined.
The exact encoding is listed in section 4.

3.3 Authentication Tokens

This section of the document defines the contents of the
authentication tokens which are produced and consumed by Create_token
and Accept_token. With DASS, the token passed from the client to the
server is complex, with a large number of optional parts, while the
token passed from server to client (in the case of mutual
authentication only) is small and simple.

The authentication token potentially contains a large number of
parts, most of which are optional depending on the type of
authentication. The following defines the content and purpose of each
of the parts, but does not describe the actual encoding (in the
belief that such details would be distracting). The encoding is in

   section 4.

   The authentication process begins when the initiator calls
   Create_token with the name of the target. This routine returns an
   authentication token, which is sent to the target. The target calls
   Accept_token passing it the token. Both routines produce a second
   "mutual authentication token". The target returns this to the
   initiator to prove that it received the token.

3.3.1 Initial Authentication Token

   The components of the initial authentication token are (names in
   brackets refer to the field names within the ASN.1 encoded structures
   defined in section 4):

    a) Encrypted Shared Key – [authenticatingKey] – This is a Shared
       (DES) key encrypted under the public key of the target. Also
       included in the encrypted structure is a validity interval and
       a recognizable pattern so that the receiver can tell whether
       the decryption was successful.

    b) Login Ticket – [sourcePrincipal.userTicket] – This is a
       "delegation certificate" signed by a principal's long term
       private key delegating to a short term public key. Its "active
       ingredients" are:

      1) UID of delegating principal [subjectUID]

      2) Period of validity [validity]

      3) Delegation public key [delegatingPublicKey]

      4) Signature by private key of principal
         The existence of this signature is testimony that the
         private key corresponding to the delegation public key
         speaks for the user during the validity interval.
         This data structure is optional and will be missing if the
         authentication is only on behalf of a Local Username on a
         node (i.e., proxy) rather than on behalf of a real principal
         with a real key.

    c) Shared Key Ticket – [sourcePrincipal.sharedKeyTicketSignature]
       – This is a signature of the Encrypted Shared Key by the
       Delegation Public key in the Login Ticket. The existence of
       this signature is testimony that the DES key in the encrypted
       shared key speaks for the user.

       This data structure is optional and will be missing if the

authentication is only on behalf of a Local Username on a node
(i.e., proxy) rather than on behalf of a real principal with a
real key. It will also be missing if delegation is taking
place.

   d) Node Ticket – [sourceNode.nodeTicketSignature] – This is a
      signature of the Encrypted Shared key and a "Local Username"
      on the host node by the node's private key. The existence of
      this signature is testimony by the node that the DES key in
      the encrypted shared key speaks for the named account on that
      node.

   e) Delegator – [sourcePrincipal.delegator] – This data structure
      contains the private login key encrypted under the Shared key.
      It is optional and is present only if the initiator is
      delegating to the destination.

   f) Authenticator – [authenticatorData] – This data structure
      contains a timestamp and a message digest of the channel
      bindings signed by the Shared Key. It is always present.

   g) Principal name – [sourcePrincipal.userName] – This is the name
      of the initiating principal. It is optional and will be
      missing for strong proxy where bits on the wire are at a
      premium and where the destination is capable of independently
      constructing the name.

   h) Node name – [sourceNode.nodeName] – This is the name of the
      initiating node. It is optional and will be missing for strong
      proxy where bits on the wire are at a premium and the name is
      present elsewhere in the message being passed.

   i) Local Username – [sourceNode.username] – This is the local
      user name on the initiating node. It is optional and will be
      missing for strong proxy where bits on the wire are at a
      premium and where the name is present elsewhere in the message
      being passed.

3.3.2 Mutual Authentication Token

   The authentication buffer sent from the target to the initiator (in
   the case of mutual authentication) is much simpler. It contains only
   the timestamp taken from the authenticator encrypted under the Shared
   Key. It is ASN.1 encoded to allow for future extensions.

3.4 Credentials

   DASS organizes its internal state with Credentials structures. There
   are many kinds of information which can be stored in credentials.
   Rather than making a different kind of data structure for each kind
   of data, DASS provides a single credentials structure where most of
   its fields are optional. Operating systems must provide some
   mechanism for having several processes share credentials. An example
   of a mechanism for doing this would be for credentials to be stored
   in a file and the name of the file is used as a "handle" by all
   processes which use those credentials. Some of the calls which follow
   cause credentials structures to be updated. It is important to the
   performance of a system that updates to credentials (such as occur
   during the routines Verify_Principal_Name and Verify_Node_Name, where
   the caches are updated) be visible to all processes sharing those
   credentials.

   In many of the calls which follow, the credentials passed may be
   labeled: claimant credentials, verifier credentials or some such.
   This indicates whose credentials are being passed rather than a type
   of credentials. DASS supports only one type of credentials, though
   the fields present in the credentials of one sort of principal may be
   quite different from those present in the credentials of another.

   An implementation may choose to support multiple kinds of credentials
   structures each of which will support only a subset of the functions
   available if it is not implementing the full architecture. This
   would be the case, for example, if an implementation did not support
   the case where a server both received requests from other principals
   and made requests on its own behalf using a single set of
   credentials.

   The following are a list of the fields that may be contained in a
   credentials structure. They are grouped according to common usage.

3.4.1 Claimant information

   This is the information used when the holder of these credentials is
   requesting something. It includes:

    a) Full X.500 name of the principal

    b) Public Key of the principal

    c) Login Ticket - a login ticket contains:

      1) the UID of the principal

    2) a period of validity (effective date & expiration date)

    3) a delegation public key

    4) a signature of the ticket contents by the principal's long
       term key

  d) Delegation Private Key (corresponding to the public key in c3)

  e) Encrypted Shared Key (present only when credentials were
    created by accept_token; this information is needed to verify
    a node ticket after credentials are accepted)

3.4.2 Verifier information

This is the information needed by a server to decrypt incoming
requests. It is also used by generate_server_ticket to generate a
login ticket.

  a) RSA private key.

3.4.3 Trusted Authority

This is information used to seed the walk of the CA hierarchy to
reliably find the public key(s) associated with a name.
Normally, the trusted authority in a set of credentials will be
the directory parent of the principal named in Claimant
information. In some circumstances, it may instead be the
directory parent of the node on which the credentials reside.

  a) Full X.500 name of a CA

  b) Corresponding RSA Public Key

  c) Corresponding UID

3.4.4 Remote node authentication

This information is present only for credentials generated by
"Accept_token". It includes information about any remote node which
vouched for the request.

  a) Full X.500 name of the node

  b) Local Username on the node

  c) Node ticket.

3.4.5 Local node credentials

   This information is added by Combine_credentials, and is used by
   Create_token to add a node signature to outbound requests.

   a) Full X.500 name of the node

   b) Local Username on the node

   c) RSA private key of the node

3.4.6 Cached outgoing contexts

   There may be one (or more) such structures for each server for which
   this principal has created authentication tokens. These represent a
   cache: they may be discarded at any time with no effect except on
   performance. For each association, the following information is kept:

   a) Destination RSA Public Key (index)

   b) Encrypted Shared key

   c) Shared Key Ticket (optional, included if there has been a
      non-delegating connection)

   d) Node Ticket

   e) Delegator (optional, included if there has been a delegating
      connection)

   f) Validity interval

   g) Shared Key

3.4.7 Cached Incoming Contexts

   There may be one such structure for each client from which this server
   has received an authentication token. These represent a cache: they
   may be discarded at any time with no effect except on performance. (An
   implementation may choose to keep one System-wide Cache (and list of
   incoming timestamps). While it is unlikely that the same Encrypted
   Shared Key will result from encryption of Shared keys generated by
   different clients or for different servers, an implementation must
   ensure that an entry made for one client/server can not be reused by
   another client/server. Similarly an implementation may choose to keep
   separate caches for the Shared Key/Validity Interval/Delegation Public
   Key, the Nodename/UID/key/username and the Principal name/UID/key.)
   For each association, the following information is kept:

    a) Encrypted Shared key (index)

    b) Shared Key

    c) Validity Interval

    d) Full X.500 name of Client Principal

    e) UID of Client Principal

    f) Public Key of Client Principal

    g) Name of Client Node

    h) UID of Client Node

    i) Public Key of Client Node

    j) Local Username on Client node

    k) Delegation Public key of Client Principal's Login Ticket

    The Name, UID and Public key of the Principal are all entered
    together once the Login Ticket has been verified. Similarly the Node
    name, Node key and Username are entered together once the Node Ticket
    has been verified. These pieces of information are only present if
    they have been verified.

3.4.8 Received Authenticators

    A record of all the authenticators received is kept. This is used to
    detect replayed messages. (This list must be common to all targets
    that could accept the same authenticator (channel bindings will
    prevent other targets from accepting the same authenticator). This
    includes different 'servers' sharing the same key.) The entries in
    this list may be deleted when the timestamp is old enough that they
    would no longer be accepted. This list is kept separate from the
    Cached incoming context in order that the information in the cached
    incoming context can be discarded at any time. An implementation
    could choose to save these timestamps with the cached incoming
    context if it ensures that it can never purge entries from the cache
    before the timestamp has aged sufficiently. This list is accessed
    based on an extract from the signature from the Authenticator. The
    extract must be at least 64 bits, to ensure that it is very unlikely
    that 2 authenticators will be received with matching signatures.

    a) Extract from Signature from Authenticator

   b) Timestamp

   If an implementation runs out of space to store additional
   authenticators, it may either reject the token which would have
   overflowed the table or it may temporarily narrow the allowed clock
   skew to allow it to free some of the space used to hold "old"
   authenticators. The first strategy will always falsely reject
   tokens; the second may cause false rejection of tokens if the allowed
   clock skew gets narrowed beyond the actual clock skew in the network.

3.5 CA State

   The CA needs to maintain some internal state in order to generate
   certificates. This internal state must be protected at all times, and
   great care must be taken to prevent its being disclosed. A CA may
   choose to maintain additional state information in order to enhance
   security. In particular, it is the responsibility of the CA to
   assure that the same UID is not serially reused by two holders of a
   single name. In most cases, this can be done by creating the UID at
   the time the user is registered. To securely permit users to keep
   their UIDs when transferring from another CA, the CA must keep a
   record of any UIDs used by previous holders of the name. Since
   actions of a CA are so security sensitive, the CA should also
   maintain an audit trail of all certificates signed so that a history
   can be reconstructed in the event of a compromise. Finally, for the
   convenience of the CA operator, the CA should record a list of the
   directories for which it is responsible and their UIDs so that these
   need not be entered whenever the CA is to be used. The state
   includes at least the following information:

    – Public Key of CA

    – Private Key of CA

    – Serial number of next certificate to be issued

3.6 Data types used in the routines

   There are several abstract data types used as parameters to the
   routines described in this section. These are listed here

    a) Integer

    b) Name
       Names unless otherwise noted are always X.500 names. While
       most of the design of DASS is naming service independent, the
       syntax of certificates and tokens only permits X.500 names to
       be used. If DASS is to be used in an environment where some

other form of name is used, those names must be translated
into something syntactically compliant with X.500 using some
mechanism which is beyond the scope of this architecture. The
only other form of name appearing in this architecture is a
"local user name", which corresponds to the simple name of an
"account" on a node. As a type, such names appear in
parameter lists as "Strings".

   c) String
      A String is a sequence of printable characters.

   d) Absolute Time
      A UTC time. The precision of these Times is not stated. A
      precision of the order of one second in all times is
      sufficient.

   e) Time Interval
      A Time interval is composed of 2 times. A Start Time and an
      End Time, both of which are Absolute Times

   f) Timestamp
      A Timestamp is a time in POSIX format. I.e., two 32 bit
      Integers. The first representing seconds, and the second
      representing nanoseconds.

   g) Duration
      A Duration is the length of a time interval.

   h) Octet String
      A sequence of bytes containing binary data

   i) Boolean
      A value of either True or False

   j) UID
      A UID is an bit string of 128 bits.

   k) OID
      An OID is an ISO Object Identifier.

   l) Shared key
      A Shared key is a DES key, a sequence of 8 bytes

   m) CA State
      A structure of the form described in '3.5

   n) Credentials
      A structure of the form described in '3.4

     o) Certificate
        An ASN.1 encoding of the structure described in '3.1

     p) Authentication Token
        An ASN.1 encoding of the structure described in '3.3.1

     q) Mutual Authentication Token
        An ASN.1 encoding of the structure described in '3.3.2

     r) Encrypted Credentials
        An ASN.1 encoding of the structure described in '3.2

     s) Public key
        A representation of an RSA Public key, including all the
        information needed to encode the public key in a certificate.

     t) Set of Public key/UID pairs
        A set of Public key/UID pairs. This Data type is only used
        internally in DASS – it does not appear in any interface used
        to other architectures.

3.7 Error conditions

   These routines can return the following error conditions (an
   implementation may indicate errors with more or less precision):

     a) Incomplete chain of trustworthy CAs

     b) Target has no keys which can be trusted.

     c) Invalid Authentication Token

     d) Login Ticket Expired

     e) Invalid Password

     f) Invalid Credentials

     g) Invalid Authenticator

     h) Duplicate Authenticator

3.8 Certificate Maintenance Functions

   Authentication services depend on a set of data structures maintained
   in the naming service. There are two kinds of information:
   Certificates, which associate names and public keys and are signed by
   off-line Certification Authorities; and Encrypted Credentials, which

    contain RSA Private Keys and certain context information encrypted
    under passwords. Encrypted Credentials are only necessary in
    environments where passwords are used. Credentials may alternatively
    be stored in some other secure manner (for example on a smart card).

    The certificate maintenance services are designed so that the most
    sensitive – the actual signing of certificates – may be done by an
    off-line authority. Once signed, certificates must be posted in the
    naming service to be believed. The precise mechanisms for moving
    certificates between off-line CAs and the on-line naming service are
    implementation dependent. For the off-line mechanisms to provide any
    actual security, the CAs must be told what to sign in some reliable
    manner. The mechanisms for doing this are implementation dependent.
    The abstract interface says that the CA is given all of the
    information that goes into a certificate and it produces the signed
    certificate. There are requirements surrounding the auditing of a
    CA's actions. The details of what actions are audited, where the
    audit trail is maintained, and what utilities exist to search that
    audit trail are not specified here. The functions a CA must provide
    are:

3.8.1 Install CA

    Install_CA(
                        keysize   Integer,   --inputs
                        CA_state   CA State, --outputs
                        CA_Public_Key   Public Key)

    This routine need only generate a public/private key pair of the
    requested size. Keysize is likely to be in implementation constant
    rather than a parameter. The value is likely to be either 512 or
    640. Key sizes throughout will have to increase over time as
    factoring technology and CPU speeds improve. Both keys are stored as
    part of the CA_state; the public key is returned so that other CAs
    may cross-certify this one. The 'Next Serial number' in the CA state
    is set to 1.

3.8.2 Create Certificate

    Create_certificate(
                                               --inputs
                        Renewal   Boolean,
                        Include_UID   Boolean,
                        Issuer_name   Name,
                        Issuer_UID   UID,
                        Effective_date   Absolute Time,
                        Expiration_date   Absolute Time,
                        Subject_name   Name,

```
                    Subject_UID             UID,
                    Subject_public_key      Public Key,
                                                    --updated
                    CA_state                CA State,
                                                    --outputs
                    Certificate             Certificate)
```

   This procedure creates and signs a certificate. Note that the
   various contents of the certificate must be communicated to the CA in
   some reliable fashion. The Issuer_name and UID are the name and UID
   of the directory on whose behalf the certificate is being signed.

   This routine formats and signs a certificate with the private key in
   CA_state. It audits the creation of the certificate and updates the
   sequence number which is part of CA_state. The Issuer and Subject
   names are X.500 names. If the CA state includes a history of what
   UIDs have previously been used by what names, this call will only
   succeed in the collision case if the Renewal boolean is set true. If
   the Include_UID boolean is set true, this routine will generate a
   1992 format X.509 certificate; otherwise it will generate a 1988
   format X.509 certificate.

3.8.3 Create Principal

   Create_principal(
                                                    --inputs
                    Password   String,
                    keysize   Integer,
                    Principal_name   Name,
                    Principal_UID   UID,
                    Parent_Public_key   Public Key,
                    Parent_UID   UID,
                                                    --outputs
                    Encrypted_Credentials Encrypted Credentials,
                    Trusted_authority_certificate Certificate)
```

   This procedure creates a new principal by generating a new
   public/private key pair, encrypting the public and private keys under
   the password, and signing a trusted authority certificate for the
   parent CA.  In an implementation not using passwords (e.g., smart
   cards), an alternative mechanism must be used for initially creating
   principals.  If a principal has protected storage for trusted
   authority information, it is not necessary to create a trusted
   authority certificate and store it in the naming service.  Some
   procedure analogous to this one must be executed, however, in which
   the principal learns the public key and UID of its CA and its own
   name.

This routine creates two output structures with the following steps:

a) Generate a public/private key pair using the indicated
   keysize. An implementation will likely fix the keysize as an
   implementation constant, most likely 512 or 640 bits, rather
   than accepting it as a parameter.  Key sizes generally will
   have to increase over time as factoring technology and CPU
   speeds improve.

b) Form the encrypted credentials by using the public key,
   private key, and Principal_UID and encrypting them using a
   hash of the password as the key.

c) Generate a trusted authority certificate (which is identical
   in format to a "parent" certificate) getting fields as
   follows:

   1) Certificate version is X.509 1992.

   2) Issuer name is the Principal name (which is an X.500 name).

   3) Issuer UID is the Principal UID.

   4) Validity is for all time.

   5) Subject name is constructed from the Principal name by
      removing the last simple name from the hierarchical name.

   6) Subject UID is the CA_UID.

   7) Subject Public Key is the CA_Public_Key

   8) Sequence number is 1.

   9) Sign the certificate with the newly generated private key of
      the principal.

3.8.4 Change Password

    Change_password(                                    --inputs
                    Encrypted_credentials Encrypted Credentials,
                    Old_password          String,
                    New_password          String,
                                                        --outputs
                    Encrypted_credentials Encrypted Credentials)

    If credentials are stored encrypted under a password, it is possible
    to change the password if the old one is known.  Note that it is

insufficient to just change a user's password if the password has
been disclosed.  Anyone knowing the old password may have already
learned the user's private key.  If a password has been disclosed,
the secure recovery procedure is to call create_principal again
followed by create_certificate to certify the new key.

Using DASS, it may not be appropriate for users to periodically
change their passwords as a precaution unless they also change their
private keys by the procedure above.  The only likely use of the
change_password procedure is to handle the case where an
administrator has chosen a password for the user in the course of
setting up the account and the user wishes to change it to something
the user can remember.  A future version of the architecture may
smooth key roll-over by having the change_password command also
generate a new key and sign a "self" certificate in which the old key
certifies the new one.  As a separate step, a CA which notices a self
certificate posted in the naming service could certify the new key
instead of the old one when the user's certificate is renewed.  While
this procedure is not as rapid or as reliable as having the user
directly interact with the CA, it offers a reasonable tradeoff
between security and convenience when there is no evidence of
password compromise.

This routine simply decrypts the encrypted credentials structure
supplied using the password supplied. It returns a bad status if the
format of the decrypted information is bad (indicating an incorrect
password). Otherwise, it creates a new encrypted credentials
structure by encrypting the same data with the new password. It would
be highly desirable for the user interface to this function to
provide the capability to randomly generate passwords and prohibit
easily guessed user chosen passwords using length, character set, and
dictionary lookup rules, but such capabilities are beyond the scope
of this document.  If encrypted credentials are stored in some local
secure storage, the above function is all that is necessary (in fact,
if the storage is sufficiently secure, no password is needed;
credentials could be stored unenciphered).  If they are stored in a
naming service, this function must be coupled with one which
retrieves the old encrypted credentials from the naming service and
stores the new.  The full protocol is likely to include access
control checks that require the principal to acquire credentials and
produce tokens.  For best security, the encrypted credentials should
be accessible only through a login agent.  The role of the login
agent is to audit and limit the rate of password guessing.  If
passwords are well chosen, there is no significant threat from
password guessing because searching the space is computationally
infeasible.  In the context of a login agent, change password will be
implemented with a specialized protocol requiring knowledge of the
password and (for best security) a trusted authority from which the

   public key of the login agent can be learned.  See section 2.3.2 for
   the plans for the non-X.500 credential storage facility.

3.8.5 Change Name

   Change_name(
                                                 --inputs
                    Claimant_Credentials  Credentials,
                    New_name               Name,
                    CA_Public_Key          Public Key,
                    CA_UID                 UID,
                                                 --outputs
                    Trusted_Authority_Certificate Certificate)


   DASS permits a principal to have many current aliases, but only one
   current name.  A principal can authenticate itself as any of its
   aliases but verifies the names of others relative to the name by
   which it knows itself.  Aliases can be created simply by using the
   create_certificate function once for each alias.  To change the name
   of a principal, however, requires that the principal securely learn
   the public key and UID of its new parent CA.  As with
   create_principal, if a principal has secure private storage for its
   trusted authority information, it need not create a certificate, but
   some analogous procedure must be able to install new naming
   information.

   This routine produces a new Trusted Authority Certificate with
   contents as follows:

    a) Issuer name is New_name (an X.500 name)

    b) Issuer_UID is Principal UID from Credentials.

    c) Validity is for all time.

    d) Subject name is constructed from the Issuer name by removing
       the last simple name from the hierarchical name, and
       converting to an X.500 name.

    e) Subject UID is CA_UID

    f) Subject Public Key is CA_Public_Key

    g) Sequence number is 1.

    h) The certificate is signed with the private key of the
       principal from the credentials. Note that this call will only
       succeed if the principal's private key is in the credentials,

which will only be true if the credentials were created by
calling Create_server_credentials.

3.9 Credential Maintenance Functions

   DASS credentials can potentially have information about two
   principals.  This functionality is included to support the case
   where a user on a node has two identities that might be
   recognized for purposes of managing access controls.  First,
   there is the user's network identity; second, there is an
   identity as controlling a particular "account" or "username" on
   that node.  There are two reasons for recognizing this second
   identity: first, access controls might be specified such that
   only a user is only permitted access to certain resources when
   coming through certain trusted nodes (e.g., files that can't be
   accessed from a terminal at home); and second, before the
   transition strategy to global identities is complete, as a way to
   refer to USER@NODE in a way analogous to existing mechanisms but
   with greater security.

   The mapping of global usernames to local user names on a node is
   outside the scope of DASS.  This is done via a "proxy database"
   or some analogous local mechanism.  What DASS provides are
   mechanisms for adding node oriented credentials into a user's
   credentials structure, carrying the dual authentication
   information in authentication tokens, and extracting the
   information from the credentials structure created by
   Accept_token.

   Some applications of DASS will not make use of the node
   authentication related extensions.  In that case, they will never
   use the Combine_credentials, Create_credentials, Get_node_info,
   or Verify_node_name functions.

   The "normal" sequence of events surrounding a user logging into a
   node are as follows:

    a) When the user logs in, he types either a local user ID known
       to the node or a global name (the details of the user
       interface are implementation specific).  Through some sort of
       local mapping, the node determines both a global name and a
       local account name.  The user also enters a password
       corresponding to the global name.

    b) The node calls network_login specifying the user's global name
       and the supplied password.  The result is credentials which
       can be used to access network services but which have not yet
       been verified to be valid.

   c) The node calls verify_principal_name using its own credentials
      to verify the authenticity of the user's credentials (these
      node credentials must have previously been established by a
      call to initialize_server during node initialization).

   d) If that test succeeds, the node adds its credentials to those
      of the user by calling combine_credentials.

   The set of facilities for manipulating credentials follow:

3.9.1 Network login

   Network_login(
                                             --inputs
                    Name                  Name,
                    password              String,
                    keysize               Integer,
                    expiration            Time interval,
                    TA_credentials        Credentials,--optional
                                             --outputs
                    Claimant_credentials  Credentials)

   This function creates credentials for a principal when the principal
   "logs into the network".

   Name is the X.500 name of the principal.

   Password is a secret which authenticates the principal to the
   network.

   Keysize specifies the size of the temporary "login" or "delegation"
   key.  In a real implementation, it is expected to be an
   implementation constant (most likely 384 or 512 bits).

   Expiration sets a lifetime for the credentials created.  For a normal
   login, this is likely to be an implementation constant on the order
   of 8-72 hours.  Some mechanism for overriding it must be provided to
   make it possible (for example) to submit a background job that might
   run days or even months after they are submitted.

   TA_credentials   are used if the encrypted credentials are protected
   by a login agent. If they are missing, the password will be less well
   protected from guessing attacks.

   This routine does not (as one might expect) securely authenticate the
   principal to the calling procedure.  Since the password is used to
   obtain the principal's private key, this call will normally fail if
   the principal supplies an invalid password.  A penetrator who has

compromised the naming service could plant fake encrypted credentials
under any name and impersonate that name as far as this call is
concerned. A caller that wishes to authenticate the user in addition
to obtaining credentials to be able to act on the user's behalf
should call Verify_principal_name (below) with the created
credentials and the credentials of the calling process.

This routine constructs a credentials structure from information
found in the naming service encrypted using the supplied password.

 a) If the encrypted credentials structure is protected with a
    login agent, retrieve the public key of the login agent:

   1) If TA_credentials are available, use them in a call to
      Get_Pub_Keys to get the public key of the login agent (whose
      name is derived from the name of the principal by truncating
      the last element of the RDN and adding CSS=X509).

   2) If TA_credentials are not available, look up the public key
      of the login agent in the naming service.

    Login agents limit and audit password guesses, and are
    important when passwords may not be well chosen (as when users
    are allowed to choose their own).  To fully prevent the
    password guessing threat, principals may only log onto nodes
    that already have TA_credentials which can be used to
    authenticate the login agent.  To support nodes which have no
    credentials of their own and to allow this procedure to
    support node initialization, it is possible to network login
    without TA credentials.

    A principal who logs into a node that lacks TA credentials is
    subject to the following subtle security threat:  A penetrator
    who impersonates the naming service could post his own public
    key and address as those of the login agent.  This procedure
    would then in the process of logging in reveal the the
    penetrator enough information for the penetrator to mount an
    unaudited password guessing attack against the principal's
    credentials.

 b) Retrieve the encrypted credentials from the naming service or
    login agent.  In the case of the login agent, the password is
    one-way hashed to produce proof of knowledge of the password
    and the hashed value is supplied to the login agent encrypted
    under its public key as part of the request.

 c) Decrypt the encrypted credentials structure using a the
    supplied password. Verify that the decryption was successful

by verifying that the resulting structure can be parsed
according the the ASN.1 rules for Encrypted_Credentials and
that the two included primes when multiplied together produce
the included modulus. If the decryption was unsuccessful then
the routine returns the 'Invalid password' error status. The
decryption results in both the Private Key and the Public Key.

d) Generate a public/private key pair for the Delegation Key,
   using the indicated keysize. Key size is likely to be an
   implementation constant rather than a supplied parameter, with
   likely values being 384 and 512 bits.  Key sizes generally
   will have to increase over time as factoring technology and
   CPU speeds improve.  Delegation keys can be relatively shorter
   than long term keys because DASS is designed so that
   compromise of the delegation key after it has expired does not
   result in a security compromise.  An important advantage of
   making key size an implementation constant is that nodes can
   generate key pairs in advance, thus speeding up this procedure.
   Key generation is the most CPU intensive RSA procedure and
   could make login annoyingly slow.

e) Construct a Login Ticket by signing with the user's private
   key a combination of the public key, a validity period
   constructed from the current time and the expiration passed in
   the call, and the principal UID found in the encrypted-key
   structure.

f) Forget the user's private key.

g) Retrieve from the naming service any trusted authority
   certificates stored with the user's entry. Discard any that
   are not signed by the user's public key and UID.  An
   implementation in which the login node has credentials of its
   own may choose its trusted authority information instead of
   retrieving and verifying trusted authority certificates from
   the naming service.  This will have a subtle effect on the
   security of the resulting system.

h) Construct a credentials structure from:

   1) Claimant credentials:

      (i)  Name of the principal from calling parameter
      (ii) Login Ticket as constructed in (e)
      (iii)Delegation Private key as constructed in (d)
      (iv) Public key from the encrypted credentials structure

   2) No verifier credentials

   3) Trusted Authorities: for the most recently signed trusted
      authority certificate (There is normally only one Trusted
      Authority Certificate.  If there is more than one then an
      implementation may choose to maintain a list of all the valid
      keys. They should all refer to the same CA (UID and name).):

     (i)  Name of the CA from the subject field of the certificate
     (ii) Public Key of the CA from the subject public key field
     (iii)UID of the CA from the subject UID field

   4) no remote node credentials

   5) no local node credentials

   6) no cached outgoing associations

   7) no cached incoming associations

## 3.9.2 Create Credentials

```
Create_credentials(
                                          --outputs
                  Claimant_credentials  Credentials)
```

   This routine creates an "empty" credentials structure. It is needed
   in the case of a user logging into a node and obtaining node oriented
   credentials but no global username credentials. Because the
   "combine_credentials" call wants to modify a set of user credentials
   rather than create a new set, this call is needed to produce the
   "shell" for combine_credentials to fill in.

   It is unlikely that any real implementation would support this
   function, but rather would have some functions which combine
   network_login, create_credentials, and combine_credentials in
   whatever ways are supported by that node.

3.9.3 Combine Credentials

```
Combine_credentials(
                                          --inputs
                  node_credentials     Credentials,
                  localusername        String,
                                          --updated
                  user_credentials     Credentials)
```

   This routine is provided by implementations which support the notion
   of local node credentials. After the node has verified to its own

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   satisfaction that the user_credentials are entitled to access to a
   particular local account, this call adds node credential information
   to the user_credential structure. This function may be applied to
   user_credentials created by network_login, create_credentials, or
   accept_token.

    a) Fill in the local node credentials substructure of
       user_credentials as follows:

      1) Full name of the node: from Full name of the Principal in
         node_credentials

      2) Local username on the node: from proxy lookup

      3) RSA private key of the node: from verifier credentials in
         node_credentials

    b) Optionally, change the trusted authorities to match the
       trusted authorities from the node credentials. This is an
       implementation option, done most likely as a performance
       optimization. The only case where this option is required is
       where no trusted authorities existed in the user credentials
       (because they were created by create_credentials of
       accept_token). Server credentials should generally keep their
       own trusted authorities.

   It is likely that an implementation will choose not to replicate its
   node credentials in every credentials structure that it supports, but
   rather will maintain some sort of pointer to a single copy. This
   algorithm is stated as it is only for ease of specification.

3.9.4 Initialize_server

   initialize_server(

                                            --inputs
                  Name   Name,
                  password   String,
                  TA_credentials   Credentials, --optional
                                            --outputs
                  Server_credentials Credentials)

   Somehow a server must get access to its credentials. One way is for
   the credentials to be stored in the naming service like user
   credentials encrypted under a service password. The service then
   needs to gain at startup time access to a service password. This may
   be easier to manage and is not insecure so long as the service
   password is well chosen. Alternately, the service needs some
   mechanism to gain access directly to its credentials. The credentials

created by this call are intended to be very long lived. They do not
time out, so a node or server might store them in Non-Volatile memory
after "initial installation" rather than calling this routine at each
"boot". These credentials are shared between all servers which use
the same key. This routine works as follows:

 a) Retrieve from the naming service or login agent the encrypted
    credentials structure corresponding to the supplied name. See
    Network_login for a discussion of the use of TA_credentials
    and login agents.

 b) Decrypt that structure using a one-way hash of the supplied
    password. Verify that the decryption was successful. Verify
    that the public key in the structure matches the private key.

 c) Retrieve from the naming service any trusted authority
    certificates stored under the supplied name. Discard any which
    do not contain the UID from the encrypted credentials
    structure or are not signed by the key in the encrypted
    credentials structure.

 d) Construct a credentials structure from:

   1) Claimant credentials:
      (i)   Name of the principal from the calling parameter
      (ii) UID of the principal from the encrypted-key structure
      (iii) No login ticket
      (iv) No login secret key

   2) Verifier credentials:
      (i)   Server secret key from the encrypted-key structure

   3) Trusted Authorities: from the most recently signed Trusted
      Authority Certificate:
      (i)   Name of CA from the Subject Name field
      (ii) UID of the CA from the Subject UID field
      (iii) Public Key of the CA from the Subject Public Key field

   4) no node credentials

   5) no cached outgoing associations

   6) no cached incoming associations

3.9.5 Generate Server Ticket

```
    generate_server_ticket(
                                                    --inputs
                      expiration          Time interval,
                                                    --updated
                      Server_credentials  Credentials)
```

Server credentials created by initialize_server can be used to accept
incoming authentication tokens and can act as node_credentials for
outgoing authentications, but cannot create user_credentials of their
own. If a server initiates connections on its own behalf, it must
have a ticket just like any other user might have. That ticket has
limited lifetime and the right to act on behalf of the server can be
delegated. The server cannot, however, delegate the right to receive
connections intended for it. An implementation must come up with a
policy for the expiration of server tickets and how long before
expiration they are renewed. A likely policy is for this procedure
to be implicitly called by Create_token if there is no current ticket
present in the credentials. If so, this interface need not be
exposed.

This routine is implemented as follows:

 a) Generate an RSA public/private key pair.

 b) Compute a validity interval from the current time and the
    expiration supplied.

 c) Construct a login ticket from the RSA public key (from a),
    validity interval (from b), the UID from the credentials, and
    signed with the server key in the credentials. (Discard
    previous Login Ticket if there was one).

 d) Discard all information in the Cached Outgoing Contexts.

3.9.6 Delete Credentials

```
    delete_credentials(
                                                    --updated
                      credentials         Credentials)
```

Erases the secrets in the credentials structure and deallocates the
storage.

3.10 Authentication Procedures

   The guts of the authentication process takes place in the next two
   calls. When one principal wishes to authenticate to another, it calls
   Create_token and sends the token which results to the other. The
   recipient calls Accept_token and creates a new set of credentials.
   The other calls in this section manipulate the received credentials
   in order to retrieve its contents and verify the identity of the
   token creator.

3.10.1 Create Token

   Create_token(
                                        --inputs
                    target_name   Name,
                    deleg_req_flag   Boolean,
                    mutual_req_flag   Boolean,
                    replay_det_req_flag Boolean,
                    sequence_req_flag   Boolean,
                    chan_bindings   Octet String,
                    Include_principal_name Boolean,
                    Include_node_name   Boolean,
                    Include_username   Boolean,
                                        --updated
                    claimant_credentials Credentials,
                                        --outputs
                    authentication_token Authentication token,
                    mutual_authentication_token
                              Mutual Authentication token,
                    Shared_key   Shared Key,
                    instance_identifier Timestamp)

   This routine is used by the initiator of a connection to create an
   authentication token which will prove its identity. If the claimant
   credentials includes node/account information, the token will include
   node authentication.

   target_name is the X.500 name of the intended recipient of the token.
   Only an entity with access to the private key associated with that
   name will be able to verify the created token and generate the
   mutual_authentication_token.

   deleg_req_flag indicates whether the caller wishes to delegate to the
   recipient of the token. If it is set, the delegated_credentials
   returned by Accept_token will be capable of generating tokens on
   behalf of the caller. Node based authentication information cannot be
   delegated. The mutual_req_flag, replay_det_req_flag , and
   sequence_req_flag are put in the authentication token and passed to

the target. This information is included in the token to make it
easier to implement the GSSAPI over DASS. DASS itself makes no use
of this information.

In most applications, the purpose of a token exchange is to
authenticate the principals controlling the two ends of a
communication channel. chan_bindings contains an identifier of the
channel which is being authenticated, and thus its format and content
should be tied to the underlying communication protocol. DASS only
guarantees that the information has been communicated reliably to the
named target. If DASS is used with a cryptographically protected
channel (such as SP4), this data should contain a one-way hash of the
key used to encrypt the channel. If that channel is multiplexed, the
data should also include the ID of the subchannel. If the channel is
not encrypted, the network must be trusted not to modify data on a
connection. The source and target network addresses and a connection
ID should be included in the chan_bindings at the source and checked
at the target. A token exchange also results in the two ends sharing
a key and an instance identifier. If that key and instance
identifier are used to cryptographically protect subsequent
communications, then chan_bindings need not have any cryptographic
significance but may be used to differentiate multiple entities
sharing the public keys of communicating principals. For example, if
a service is replicated and all replicas share a public key,
chan_bindings should include something that identifies a single
instance of the service (such as current address) so that the token
cannot be successfully presented to more than one of the servers.

include_principal_name, include_node_name, and include_username are
flags which determine whether the principal name, node name, and/or
username from the credentials structure are to be included in the
token. This information is made optional in a token so that
applications which communicate this information out of band can
produce "compressed" tokens. If this information is included in the
token, it will be used to populate the corresponding fields in the
credentials structure created by Accept_token. claimant_credentials
are the credentials of the calling procedure. The secrets contained
therein are used to sign the token and the trusted authorities are
used to securely learn the public key of the target. The cached
outgoing contexts portion of the credentials may be updated as a side
effect of this call.

The major output of this routine is an authentication_token which
can be passed to the target in order to authenticate the caller.

In addition to returning an authentication token, this routine
returns a mutual_authentication_token, a shared_key, and an
instance_identifier. The mutual authentication token is the same as

the one generated by the Accept_token call at the target. If the
protocol using DASS wishes mutual authentication, the target should
return this token to the source. The source will compare it to the
one returned by this routine using Compare_Mutual_Token (below) and
know that the token was accepted at its proper destination.

The DES key and instance identifier can be used to encrypt or sign
data to be sent to this target. The key and instance will be given to
the target by Accept_token, and the key will only be known by the two
parties to the authentication. If a single set of credentials is used
to authenticate to the same target more than once, the same DES key
is likely to be returned each time. If the parties wish to protect
against the possibility of an outside agent mixing and matching
messages from one authenticated session with those of another, they
should include the instance identifier in the messages. The instance
identifier is a timestamp and it is guaranteed that the DES
key/instance identifier pair will be unique.

An implementation may wish to "hide" the DES key from calling
applications by placing it in system storage and providing calls
which encrypt/decrypt/sign/verify using the key.

The primary tasks of this routine are to create its output
parameters. As a side effect, it may also update claimant_credentials
It's algorithm is as follows:

 a) The login ticket is checked. If it has passed the end of its
    lifetime an 'Login Ticket Expired' error is returned. If there
    is a login ticket, but no corresponding private key then an
    'Invalid credentials' error is returned (this is the case if
    the credentials were created by an authentication-without-
    delegation operation). If there is no login ticket or an
    expired one and if the long term private key is present in the
    credentials, an implementation may choose to automatically call
    create_server_ticket to renew the ticket.

 b) Create new timestamp using the current time. (This timestamp
    must be unique for this Shared Key. The timestamp is a 64 bit
    POSIX time, with a resolution of 1 nanosecond An implemen tation
    must ensure that timestamps cannot be reused.)

 c) The public key and UID of target_name are looked up by calling
    get_pub_keys, using the target_name and the Trusted Authority
    section of the claimant_credentials structure. If none is
    found, an error status is returned. Otherwise, the cached
    outbound connections portion of credentials are searched
    (indexed by target Public Key) for a cached Shared key with a
    validity interval which has not expired. If a suitable one is

found skip to step g, else create a cache entry as follows:

d) Destination Public Key is the one found looking up the target.
   A Shared Key is generated at random. A validity interval is
   chosen according to node policy but not to exceed the validity
   interval of the ticket in the credentials (if any).

e) Create the Encrypted Shared Key, using the public key of the
   Target, and place in the cache.

f) If node authentication credentials are available in the
   credentials structure, create a "Node Ticket" signature using
   the node secret and include it in the cache.

g) If delegation is requested and no delegator is present in the
   cache, create one by encrypting the delegation private key
   under the Shared key. The delegation private key is
   represented as an ASN.1 data structure containing only one of
   the primes (p).

h) If delegation is not requested and no Shared Key Ticket is in
   the cache, create one by signing the requisite information
   with the delegation private key.

i) Create the Authenticator. The contents of the Authenticator
   (including the channel bindings) are encoded into ASN.1, and
   the signature is computed. The Authenticator is then
   re-encoded, without including the Channel Bindings but using
   the same signature.

j) Create output_token as follows:
   1) Encrypted Shared Key from cache
   2) Login Ticket from Claimant Credentials (if present)
   3) Shared Key Ticket from cache (if no delegation and if
      present)
   4) Node Ticket from cache (if present)
   5) Delegator from cache (if delegation and if present)
   6) Authenticator
   7) Principal name from credentials (if present and parameter
      requests this)
   8) Node name from credentials (if present and parameter request
      this)
   9) Local Username from credentials (if present and parameter
      requests this)

k) Compute Mutual_authentication_token by encrypting the
   timestamp from the authenticator using the Shared key.

   l) The instance_identifier is the timestamp. This and the Shared
      key are returned for use by the caller for further encryption
      operations (if these are supported).

3.10.2 Accept_token

   Accept_token(

                                              --inputs
                   authentication_token Authentication Token,
                   chan_bindings   Octet String,
                                              --updated
                   verifying_credentials Credentials,
                                              --outputs
                   accepted_credentials Credentials,
                   deleg_req_flag   Boolean,
                   mutual_req_flag   Boolean,
                   replay_det_req_flag   Boolean,
                   sequence_req_flag   Boolean,
                   mutual_authentication_token
                                         Mutual authentication token
                   shared_key   Shared Key,
                   instance_identifier   Timestamp)

   This routine is used by the recipient of an authentication token to
   validate it. authentication_token is the token as received;
   chan_bindings is the identifier of the channel being authenticated.
   See the description of Create_token for information on the
   appropriate contents for chan_bindings. DASS does not enforce any
   particular content, but checks to assure that the same value is
   supplied to both Create_token and Accept_token.

   Verifying_credentials are the credentials of the recipient of the
   token. They must include the private key of the entity named as the
   target in Create_token or the call will fail. The cached incoming
   contexts section of the verifying credentials may be modified as a
   side effect of this call.

   Accepted_credentials will contain additional information about the
   token creator. If delegation was requested, these credentials can be
   used to make additional calls to Create_token on the creator's
   behalf. Whether or not delegation was requested, they can also be
   used in the calls which follow to gain additional information about
   the token creator.

   The deleg_req_flag indicates whether the accepted_credentials include
   delegation which can be used by the recipient to act on behalf of the
   principal. Mutual_req_flag, replay_det_req_flag, and
   sequence_req_flag are passed through from Create_token in support of

the GSSAPI. DASS makes no use of these fields.

The mutual_authentication_token can be returned to the token creator
as proof of receipt. In many protocols, this will be used by a client
to authenticate a server. Only the genuine server would be able to
compute the mutual_authentication_token from the token.

The shared_key and instance_identifier can be used to encrypt or sign
data between the two authenticating parties. See Create_token.

This routine verifies the contents of the authentication token in the
context of the verifying credentials (In particular, the Private Key
of the server is used. Also, the Cached Incoming Contexts and
Incoming Timestamp list is used.) and returns information about it.
The algorithm updates a cache of information. This cache is not
updated if the algorithm exits with an error. The algorithm is as
follows:

 a) If there is a Login Ticket, but no Shared Key Ticket or
    Delegator then exit with error 'Invalid Authenticator'. If
    there is a Shared Key Ticket or Delegator, but no Login Ticket
    then exit with error 'Invalid Authentication Token'.

    Look up the Encrypted Shared key in the Cached Incoming Contexts
    of the credentials structure. (This cache entry is used during
    the execution of this routine. An implementation must ensure that
    references to the cache entry can not be affected by other users
    modifying the cache. One way is to use a copy of the cache entry,
    and update it at exit.) If it is not found then create
    a new cache entry as follows:

    1) Encrypted Shared Key, from the Authentication Token.

    2) Shared Key and Validity Interval, by decrypting the
       Encrypted Shared Key using the server private key in
       credentials. If the decryption fails then exit with error
       'Invalid Authentication Token'.

 b) Check that the Validity Interval (in the cache entry) includes
    the current time; return 'Invalid Authentication Token' if not.

    Check the Timestamp is within max-clock-skew of the current
    time, return 'invalid Authentication Token' if not.

    Reconstruct the Authenticator including the Channel Bindings
    passed as a parameter.

Check that the reconstructed Authenticator is signed by the
Shared key. If not then exit with error 'Invalid
Authentication Token'.

Look up the Authenticator Signature in the Received
Authenticators. If the same Signature is found in the list
then exit with error 'Duplicate Authenticator'. Otherwise add
the Signature and timestamp to the list.

If there is a Login Ticket and the Delegation Public key is in
the cache entry, then check that the same key is specified in
the Login Ticket, if not then exit with error 'Invalid
Authentication Token'. Place the Delegation Public key in the
cache if it is not already there.

If there is a Login Ticket, the Delegation Public key was not
previously in the cache entry, and there is a Shared Key
Ticket in the Authentication Token, then check that the Shared
Key Ticket is signed by the Delegation Public Key in the Login
Ticket. If not then exit with error 'Invalid Authentication
Token'.

If a delegator is present in the message then decrypt the
delegator using the Shared key. If the private key does not
match the Delegation Public key then exit with error
'Invalid Authentication Token' (The prime in the delegator
is used to find the other prime (from the modulus). The division
must not have a remainder. Neither prime may be 1. The two
primes are then used to reconstruct any other information
needed to perform cryptographic operations.).

Build the delegation credentials data structure as follows:

1) Claimant credentials:
  (i) Login Ticket from the Authentication token
  (ii) Delegation Private key from the decrypted delegator if
       the token is delegating.
  (iii)Encrypted Shared Key from the Authentication token.
2) There are no verifier credentials.
3) Trusted authorities are copied from the verifying_credentials
   passed to this routine (If an implementation is able to
   obtain the original Trusted Authorities of the Principal then
   it may do so instead of using the server's Trusted
   Authorities.).
4) Remote node credentials (Node name, Username, Node Ticket)
5) There are no local node credentials.
6) There are no cached contexts.

   c) The returned boolean values are obtained from the
      Authenticator.

   d) Mutual_authentication_token is computed by encrypting the
      timestamp from the Authenticator with the Shared key from the
      cache.

   e) Instance_identifier is the timestamp from the Authenticator.
      This and the Shared key are returned to the caller for further
      encryption operations (if these are supported).

3.10.3 Compare Mutual Token

```
   Compare_mutual_token(

                                          --inputs
                   Generated_token    Mutual authentication token,
                   Received_token     Mutual authentication token,
                                         --outputs
                   equality_flag      Boolean)
```

This routine compares two mutual authentication tokens and tells
whether they match. In the expected use, the first is the token
generated by Create_token at the initiating end and the second is the
token generated by Accept_token at the accepting end and returned to
the initiating end. This routine can be implemented as a byte by
byte comparison of the two parameters.

3.10.4 Get Node Info

```
   get_node_info(

                                          --inputs
                   accepted_credentials  Credentials,
                                          --outputs
                   nodename              Name,
                   username              String)
```

This routine extracts from accepted credentials the name of the node
from which the authentication token came and the named account on
that node. Because this information is not cryptographically
protected within the token, this information can only be regarded as
a "hint" by the receiving application. It can, however, be verified
using Verify_node_name in a cryptographically secure manner. This
information will only be present if these are accepted credentials
and it the caller of Create_token set the include_node_name and/or
include_username flags.

An actual implementation is not likely to have get_node_info and
verify_node_name as separate calls. They are specified this way

because there are different ways this information might be used. For
most applications, the nodename and username will be included in the
token, and a single function might extract and verify them (it might
in fact be part of accept token). For other applications, the
nodename and username will not be in the token but rather will be
computed from other information passed during connection initiation
so a call would have to take these as inputs. Still other
applications such as ACL evaluators that want to support the renaming
and aliasing capabilities of DASS would defer verifying node
information until they came upon an ACL which allowed access only
from a particular node. They would then verify that the name on the
ACL was an authenticatable alias for the node which created the
token. All of these uses can be defined in terms of calls to
get_node_info and verify_node_name.

3.10.5 Get Principal UID

    get_principal_uid(

                                               --inputs
                    accepted_credentials Credentials,
                                               --outputs
                    uid   UID)

    This routine extracts a principal UID from a set of credentials.

    As with Get_Node_Info, this interface is not likely to appear in an
    actual implementation, but rather will be bundled with other
    routines. It is specified this way because there might be a variety
    of algorithms by which credentials are evaluated and all of them can
    be defined in terms of these primitives.

    In DASS, it is possible for a principal to have many aliases. This
    can happen either because the principal was given multiple names to
    limit the number of CAs that need to be trusted when authenticating
    to different servers or because the principal's name has changed and
    the old name remains behind as an alias. Accept_token returns the
    name by which the principal identified itself when creating its
    credentials. A service may know the user by some alias. The normal
    way to handle this is for the service to know the principal's UID
    (which is constant over name changes) and to compare it with the UID
    in the token to identify a likely alias situation. It gets the UID
    from the token using this routine. It then confirms the alias by
    calling verify_principal_name.

    The UID is in a signed portion of accepted credentials, but the
    signature may not have been verified at the time this call is issued.
    The information returned by this routine must therefore be regarded
    as a hint. If a call to Verify_principal_name succeeds, however,

then the caller can securely know that the name given to that routine
and the UID returned by this one are the authenticated source of the
token.

3.10.6 Get Principal Name

```
get_principal_name(
                                              --inputs
                   accepted_credentials  Credentials,
                                              --outputs
                   name                  Name)
```

This routine extracts a principal name from a set of credentials.
This name is the name most recently associated with the principal. It
may be the name that the principal supplied when the credentials were
created (in which case it may not have been verified yet) or it may
be a different name that has been verified.

As with Get_Node_Info and Get_Principal_UID, this routine is not
likely to appear in an actual implementation, but will be bundled in
some fashion with related procedures. The name returned by this
procedure is not guaranteed to have been cryptographically verified.
Verify_Principal_Name performs that function.

3.10.7 Get Lifetime

```
get_lifetime(
                                              --inputs
                   Claimant_credentials  Credentials,
                                              --outputs
                   lifetime              Duration)
```

This routine computes the life remaining in a set of credentials.
Its most common use would be to know to renew credentials before they
expire.

Returns the remaining lifetime of the login ticket in the
credentials. This can either be the done on the node where the
original login took place, or at a server which has been delegated
to. It indicates how much longer these credentials can be used for
further delegations. This routine will return 0 if the login ticket
has passed the end of its life, if there is no login ticket, or if
the credentials do not contain the private key certified by the
ticket (i.e., where they were created by an authentication-without-
delegation operation).

3.10.8 Verify Node Name

    Verify_node_name(
                                              --inputs
                    nodename   Name,
                    username   String,
                                              --updated
                    verifying_credentials Credentials,
                    accepted_credentials Credentials,
                                              --outputs
                    Name matches   Boolean)

    This routine tests whether the originating node of an authentication
    token can be authenticated as having the provided name. Like a
    principal, a node may have multiple aliases. One of them may be
    returned by Get_node_info, but this call allows a suspected alias to
    be verified. The verifying credentials supplied with this call must
    be the same credentials as were used in the Accept_token call. The
    procedure for completing this request is as follows:

     a) If there is no Node Ticket in the claimant credentials then
        return False.

     b) Search the incoming context cache of the verifying credentials
        for an entry containing the same encrypted shared key as the
        encrypted shared key subfield of the claimant information of
        the accepted credentials. In the steps which follow,
        references to "the cache" refer to this entry. If none is
        found, initialize such an entry as follows:

       1) Encrypted shared key from the encrypted shared key subfield
          of the claimant information of the accepted credentials.

       2) The shared key and validity interval are determined by
          decrypting the encrypted shared key using the RSA private
          key in the verifier information of the server credentials.
          If this procedure is called after a call to Accept_token
          using the same server credentials (as is required for
          correct use), the shared key and validity interval must
          correctly decrypt. If called in some other context, the
          results are undefined. The validity interval is not
          checked.

       3) Initialize all other entries in the cache to missing.

     c) If there is a "local username on client node" in the cache and
        it does not match the username supplied as a parameter, return
        False.

    d) If there is a "name of client node" in the cache and it
     matches the nodename supplied as a parameter:

      1) Set the "Full name of the node" subfield of the remote node
       authentication field of the accepted credentials to be the
       nodename supplied as a parameter.

      2) Set the "Local Username on the node" subfield of the remote
       node authentication field of the accepted credentials to be
       the username supplied as a parameter.

      3) return True.

    e) Call the Get_Pub_Keys subroutine with the server_credentials,
     the nodename supplied as a parameter, and Try_Hard=False.

    f) If "Public Key of Client Node" is missing from the cache,
     check all of the Public keys returned to see if one verifies
     the node ticket. If one does, set the "Public Key of Client
     Node" and "UID of Client Node" fields in the cache to be the
     PK/UID pair that verified the ticket and set the "Local
     Username on Client node" field to be the username supplied as
     a parameter..

    g) If any of the Public Key/UID pairs match the "Public Key of
     Client Node" and "UID of Client Node" fields in the cache,
     then:

      1) Set the "name of client node" in the cache equal to the
       nodename supplied as a parameter.

      2) Set the "Full name of the node" subfield of the remote node
       authentication field of the accepted credentials to be the
       nodename supplied as a parameter.

      3) Set the "Local Username on the node" subfield of the remote
       node authentication field of the accepted credentials to be
       the username supplied as a parameter.

      4) Return True.

    h) If none of them match, call Get_Pub_Keys again with
     Try_Hard=True and repeat steps 6 & 7. If Step 7 fails a
     second time, return False.

3.10.9 Verify Principal Name

     Verify_principal_name(
                                              --inputs
                    principal_name   Name,
                                             --updated
                    verifier_credentials Credentials,
                    claimant_credentials Credentials,
                                              --outputs
                    Name matches   Boolean)

     This routine tests (in the context of the verifier credentials)
     whether the claimant credentials are authenticatable as being those
     of the named principal. This procedure is called with a set of
     accepted credentials to authenticate their source, or with a set of
     credentials produced by network_login to authenticate the creator of
     those credentials. If the claimant credentials were created by
     Accept_token, then the verifier credentials supplied in this call
     must be the same as those used in that call. The procedure for
     completing this request is as follows:

      a) If there is no Login Ticket in the claimant credentials, then
         return False.

      b) If the current time is not within the validity interval of the
         Login Ticket, then return False.

      c) If there is an Encrypted Shared Key present in the Claimant
         information field of the claimant credentials, then find or
         create a matching cache entry in the Cached Incoming Contexts
         of the verifier credentials. In the description which
         follows, references to "the cache" refer to this entry. If
         the cache entry must be created, its contents is set to be as
         follows:

        1) Encrypted shared key from the encrypted shared key subfield
           of the claimant information of the accepted credentials.

        2) The shared key and validity interval are determined by
           decrypting the encrypted shared key using the RSA private
           key in the verifier information of the server credentials.
           If this procedure is called after a call to Accept_token
           using the same server credentials (as is required for
           correct use), the shared key and validity interval must
           correctly decrypt. If called in some other context, the
           results are undefined. The validity interval is not
           checked.

     3) Initialize all other entries in the cache to missing.

   d) If there is a cache entry and if the "Public Key of Client
      Principal" field is present and if the "UID of Client
      Principal" field is present and matches the UID in the Login
      Ticket, then:

     1) Set the Public Key of the principal field in the Claimant
       information to be the Public Key of Client Principal.

     2) If the "Full name of the principal" field is missing from
       the claimant information of the claimant credentials, then
       set it to the "Name of Client Principal" field from the
       cache.

   e) If there is a cache entry and if the "Name of Client
      Principal" field is present and if it matches the principal
      name supplied to this routine and if the UID in the cache
      matches the UID in the Login Ticket, return True.

   f) Call the Get_Pub_Keys subroutine with the name and verifier
      credentials supplied to this routine and Try_Hard=FALSE.
      Ignore any keys retrieved where the corresponding UID does not
      match the UID in the claimant credentials.

   g) If the Public Key of the principal is missing from the
      claimant information of the claimant credentials, then attempt
      to verify the signature on the login ticket with each public
      key returned by Get_Pub_Keys. If verification succeeds:

     1) Set the Public Key of the principal in the claimant
       information of the claimant credentials to be the Public Key
       that verified the ticket.

     2) If the Full name of the principal in the claimant
       information of the claimant credentials is missing, set it
       to the name supplied to this routine.

     3) If there is a cache entry, set the Name of Client Principal
       to be the name supplied to this routine, the UID of Client
       Principal to be the UID from the Login Ticket, and the
       Public Key of Client Principal to be the Public Key that
       verified the ticket.

     4) Return True.

   h) If the Public Key of the principal is present in the claimant
      information of the claimant credentials, then see if it

matches any of the public keys returned by Get_Pub_Keys. If
one of them matches:

   1) If the Full name of the principal in the claimant
      information of the claimant credentials is missing, set it
      to the name supplied to this routine.

   2) If there is a cache entry, set the Name of Client Principal
      to be the name supplied to this routine, the UID of Client
      Principal to be the UID from the Login Ticket, and the
      Public Key of Client Principal to be the Public Key that
      verified the ticket.

   3) Return True.

   i) If steps 7 & 8 fail, retry the call to Get_Pub_Keys with
      Try_Hard=TRUE, and retry steps 7 & 8. If they fail again,
      return false.

3.10.10 Get Pub Keys

   Get_Pub_Keys(

                                          --inputs
                   TA_credentials   Credentials
                   Try_Hard   Boolean,
                   Target Name   Name,
                                          --outputs
                   Pub_keys   Set of Public key/UID pairs

This common subroutine is used in the execution of Create_Token,
Verify_Principal_Name, and Verify_Node_Name. Given the name of a
principal, it retrieves a set of public key/UID pairs which
authenticate that principal (normally only one pair). It does this
by retrieving from the naming service a series of certificates,
verifying the signatures on those certificates, and verifying that
the sequence of certificates constitute a valid "treewalk".

The credentials structure passed into this procedure represent a
starting point for the treewalk. Included in these credentials will
be the public key, UID, and name of an authority that is trusted to
authenticate all remote principals (directly or indirectly).

The "Try_Hard" bit is a specification anomaly resulting from the fact
that caches maintained by this routine are not transparent to the
calling routines. It tells this procedure to bypass caches when
doing all name service lookups because the information in caches is
believed to be stale. In general, a routine will call Get_Pub_Keys
with Try_Hard set false and try to use the keys returned. If use of

those keys fails, the calling routine may call this routine again
with Try_Hard set true in hopes of getting additional keys.
Routinely calling this routine with Try_Hard set true is likely to
have adverse performance implications but would not affect the
correctness or the security of the operation.

The name supplied is the full X.500 name of the principal for whom
public keys are needed as part of some authentication process.

This procedure securely learns the public keys and UIDs of foreign
principals by constructing a valid chain of certificates between its
trusted TA and the certificate naming the foreign principal. In the
simplest case, where the TA has signed a certificate for the foreign
principal, the chain consists of a single certificate. Otherwise,
the chain must consist of a series of certificates where the first is
signed by the TA, the last is a certificate for the foreign
principal, and the subject of each principal in the chain is the
issuer of the next. What follows is first a definition of what
constitutes a valid chain of certificates followed by a model
algorithm which constructs all of (and only) the valid chains which
exist between the TA and the target name.

In order to limit the implications of the compromise of a single CA,
and also to limit the complexity of the search of the certificate
space, there are restrictions on what constitutes a valid chain of
certificates from the TA to the Name provided. The only CAs whose
compromise should be able to compromise an authentication are those
controlling directories that are ancestors of one of the two names
and that are not above a common ancestor. Therefore, only
certificates signed by those CAs will be considered valid in a
certificate chain. Normally, the CA for a directory is expected to
certify a public key and UID for the CA of each child directory and
one parent directory. A CA may also certify another CA for some
remote part of the naming hierarchy, and such certificates are
necessary if there are no CAs assigned to directories high in the
naming hierarchy.

A certificate chain is considered valid if it meets the following
criteria:

  a) It must consist of zero or more parent certificates, followed
     by zero or one   cross certificates, followed by zero or more
     child certificates.

  b) The number of parent certificates may not exceed the number of
     levels in the naming hierarchy between the TA name and the
     name of the least common ancestor in the naming hierarchy
     between the TA name and the target name.

   c) Each parent certificate must be stored in the naming service
      under the entry of its issuer.

   d) The subject of the cross certificate (if any) must be an
      ancestor of the target name but must be a longer name than the
      least common ancestor of the TA name and the target name.

   e) The cross certificate (if any) must have been stored in the
      naming service under the entry of its issuer or there must
      have been an indication in the naming service that
      certificates signed by this issuer may be stored with their
      subjects.

   f) The issuer of each parent certificate does not have stored
      with it in the naming service a cross certificate with the
      same issuer whose subject is an ancestor of the target name.

   g) Each child certificate must be stored in the naming service
      under the entry of its subject.

   h) The subject of each child certificate does not have associated
      with it in the naming service a cross certificate with the
      same subject whose issuer is the same as the issuer of any of
      the parent certificates or the cross certificate of the chain.

   i) The subject of each certificate must be the issuer of the
      certificate that follows in the chain. The equality test can
      be met by either of two methods:

     1) The public key of the subject in the earlier certificate
        verifies the signature of the later and the subject UID in
        the earlier certificate is equal to the issuer UID in the
        later; or

     2) The public key of the subject in the earlier certificate
        verifies the signature of the later, the earlier lacks a
        subject UID and/or the later lacks an issuer UID and the
        name of the subject in the earlier certificate is equal to
        the name of the issuer in the later.

   j) The Public Key of the TA verifies the signature of the first
      certificate.

   k) The UID of the TA equals the UID of the issuer of the first
      certificate or the UID is missing on one or both places and
      the name of the TA equals the name of the issuer of the first
      certificate.

   l) All of the certificates are valid X.509 encodings and the
      current time is within all of their validity intervals.

If a chain is valid, the name which it authenticates can be
constructed as follows:

 a) If the chain contains a cross certificate, the name
    authenticated can be constructed by taking the subject name
    from the cross certificate and appending to it a relative name
    for each child certificate which follows. The relative name
    is the extension by which the subject name in the child
    certificate extends the issuer name.

 b) If the chain does not contain a cross certificate, the name
    authenticated can be constructed by taking the TA name,
    truncating from it the last n name components where n is the
    number of parent certificates in the chain, and appending to
    the result a relative name for each child certificate. The
    relative name is the extension by which the subject name in
    the child certificate extends the issuer name.

In the common case, the authenticated name will be the subject
name in the last certificate. The authenticated name is
constructed by the rules above to deal with namespace
reorganization. If a branch of the namespace is renamed (due to,
for example, a corporate acquisition or reorganization), only the
certificates around the break point need to be regenerated.
Certificates below the break will continue to contain the old
names (until renewed), but the algorithms above assure the
principals in that branch will be able to authenticate as their
new names. Further, if the certificates at the branch point are
maintained for both the old and new names for an interim period,
principals in the moved branch will be able to authenticate as
either their old or new names for that interim period without
having duplicate certificates.

A final complication that the algorithm must deal with is the
location of cross certificates. If a key is compromised or for
some other reason it is important to revoke a certificate ahead
of its expiration, it is removed from the naming service. This
algorithm will only use certificates that it has recently
retrieved from the naming service, so revocation is as effective
as the mechanisms that prevent impersonation of the naming
service.   There are plans to eventually use DASS mechanisms to
secure access to the naming service; until they are in place,
name service impersonation is a theoretical threat to the
security of revocation. Opinions differ as to whether it is a
practical threat.   Child certificates are always stored with the

subject and will not be found unless stored in the name server of
the subject.   Parent certificates are always stored with the
issuer and will not be found unless stored in the name server of
the issuer. For best security, cross certificates should be
stored with the issuer because the name server for the subject
may not be adequately trustworthy to perform revocation. There
are performance and availability penalties, however, in doing so.
The architecture and the algorithm therefore support storing
cross certificates with either the issuer or the subject. There
must be some sort of flag in the name service associated with the
issuer saying whether cross certificates from that issuer are
permitted to be stored in the subject's name service entry, and
if that flag is set such certificates will be found and used.

In order to make revocation effective, DASS must assure that
naming service caches do not become arbitrarily stale (the
allowed age of a cache entry is included in the sum of times with
together make up the revocation time). If DASS uses a naming
service such as DNS that does not time out cache entries, it must
bypass cache on all calls and (to achieve reasonable performance)
maintain its own naming service cache. It may be advantageous to
maintain a cache in any case so the that the fact that the
certificates have been verified can be cached as well as the fact
that they are current.

3.10.10.1 Basic Algorithm

For ease of exposition, this first description will ignore the
operation of any caches. Permissible modifications to take
advantage of caches and enhance performance will be covered in
the next section. This path will be followed if the Try_Hard bit
is set True on the call.

Rather than trying construct all possible chains between the TA
and the name to be authenticated (in the event of multiple
certificates per principal, there could be exponentially many
valid chains), this algorithm computes a set of PK/UID/Name
triples that are valid for each principal on the path between the
TA and the name to be authenticated. By doing so, it minimizes
the processing of redundant information.

  a) Determining path and initialization

    Several state variables are manipulated during the tree walk.
    These are called:

1) Current-directory-name
   This is the name indicating the current place in the tree
   walk. Initially, this is the name of the TA.

2) Least-Common-Ancestor-Name
   This is the portion of the names which is common to both the
   CA and the Target. This is computed at initialization and
   does not change during the treewalk.

3) Trusted-Key-Set
   For each name which is an ancestor of either the TA or the
   Target but not of the Least-Common-Ancestor, a list of
   PK/UID/Name triples. This is initialized to a single triple
   from the TA information in the supplied credentials.

4) Search-when-descending
   This is a list of PK/UID/Name triples of issuers that will
   be trusted when descending the tree. This set is initially
   empty.

5) Saved-RDNs
   This is a sequence of Relative Distinguished Names (RDNs)
   stripped off the right of the target name to form
   Least-common-ancestor-name. This "stack" is initially empty
   and is populated during Step 3.

b) Ascending the "TA side" of the tree

   While Current-directory-name is not identical to
   Common-point-Name the algorithm moves up the tree. At each
   step it does the following operations.

1) Find all cross certificates stored in the naming service
   under Current-directory-name in which the subject is an
   ancestor of the principal to be authenticated or an
   indication that cross certificates from this issuer are
   stored in the subject entry. If there is an indication that
   such certificates are stored in the subject entry, copy all
   triples in Trusted-Key-Set for Current-directory-name into
   the "Search-when-descending" list. If any such certificates
   are found, filter them to include only those which meet the
   following criteria:

   (i) For some triple in the Trusted-Key-Set corresponding to
        the Current-directory-name, the public key in the triple
        verifies the signature on the certificate and either the
        UID in the triple matches the issuer UID in the
        certificate or the UID in the triple and/or the

certificate is missing and the name in the triple matches
the issuer name in the certificate.

(ii) No certificates were found signed by this issuer in which
the subject name is longer than the subject name in this
certificate (i.e., if there are cross certificates to two
different ancestors, accept only those which lead to the
closest ancestor).

(iii)The current time is within the validity interval of the
certificate.

2) If any cross certificates were found (whether or not they
were all eliminated as part of the filtering process), set
Current-directory-name to the longest name that was found in
any certificate and construct a set of PK/UID/Name triples
for that name from the certificates which pass the filter
and place them in the Trusted Key Set associated with their
subject. Exit the ascending tree loop at this point and
proceed directly to step 3. Note that this means that if
there are cross certificates to an ancestor of the target
but they are all rejected (for example if they have
expired), the treewalk will   not construct a chain through
the least common ancestor and will ultimately fail unless a
crosslink from a lower ancestor is found stored with its
subject. This is a security feature.

3) If no cross certificates are found, find all the parent
directory certificates for the directory whose name is in
the Current-directory-name. Filter these to find only those
which meet the following criteria:

(i) The current time is within the validity interval.

(ii) For some triple corresponding to the
Current-directory-name, the public key in the triple
verifies the signature on the certificate and either the
UID in the triple matches the issuer UID in the
certificate or the UID in the triple and/or the
certificate is missing and the name in the triple matches
the issuer name in the certificate.

4) Construct PK/UID/Name triples from the remaining
certificates for the directory whose name is constructed by
stripping the rightmost simple name from the
Current-directory-name and place them in the Trusted-Key-Set.

     5) Strip the rightmost simple name of the
       Current-directory-name.

     6) Repeat from step (a) (testing to see if
       current-directory-name is the same as Common-point-Name).

  c) Searching the "target side" of the tree for a crosslink:

    1) Initialization: set Current-directory-name to the name
      supplied as input to this procedure.

    2) Retrieve from the naming service all cross certificates
      associated with Current-directory-name. Filter to only
      those that meet the following criteria:

      (i) The current time is within their validity interval.

      (ii) The subject name is equal to Current-directory-name.

      (iii)For some PK/UID/Name triple in the
         "Search-when-descending" list compiled while ascending
         the tree, the Public Key verifies the signature on the
         certificate and either the UID matches the issuer UID in
         the certificate   or a UID is missing from the triple
         and/or the certificate and the Name in the triple matches
         the issuer name in the certificate.

      (iv) There are no certificates found meeting criteria (ii) and
         (iii) matching a PK/UID/Name triple in the
         Search-when-descending list whose subject is a directory
         lower in the naming hierarchy.

    3) If any qualifying certificates are found, construct
      PK/UID/Name triples for each of them; these should replace
      rather than supplement any triples already in the
      Trusted-key-set for that directory.

    4) If after steps (b) and (c), there are no PK/UID/Name triples
      corresponding to Current-directory-name in Trusted-Key-Set,
      shorten Current-directory-name by one RDN (pushing it onto
      the Saved-RDNs stack) and repeat this process until
      Current-directory-name is equal to
      Least-common-ancestor-name or there is at least one triple
      in Trusted-key-set corresponding to Current-directory-name.

  d) Descending the tree

    While the list Saved-RDNs is not Empty the algorithm moves

       down the tree. At each step it does the following operations.

       1) Remove the first RDN from Saved-RDNs and append it to the
          Current-directory-name.

       2) Find all the child directory certificates for the directory
          whose name is in the current-directory-name.

       3) Filter these certificates to find only those which meet the
          following criteria:

          (i)   The current time is within the validity interval.

          (ii) For some PK/UID/Name triple in the Current-key-set for
                the parent directory, the Public Key verifies the
                signature on the certificate and either the UID matches
                the issuer UID of the certificate   or the UID is missing
                from the triple and/or the certificate and the Name in
                the triple matches the issuer name in the certificate.

          (iii) The issuer name in the certificate is a prefix of the
                subject name and the difference between the two names is
                the final RDN of Current-directory-name.

       4) Take the key, UID, and name from each remaining certificate
          and form a new triple corresponding to
          Current-directory-name in Trusted-Key-Set. If this set is
          empty then the algorithm exits with the
          'Incomplete-chain-of-trustworthy-CAs' error condition.

       5) repeat from step (a), appending a new simple name to
          Current-directory-name.

     e) Find public keys:
        If there are no triples in the Trusted-Key-Set for the named
        principal, then the algorithm exits with the 'Target-has-no-keys-w
        error condition. Otherwise, the Public Key and UID are
        extracted from each pair, duplicates are eliminated, and this
        set is returned as the Pub_keys.

3.10.10.2 Allowed Variations - Caching

   Some use of caches can be implemented without affecting the semantics
   of the Get_Pub_Keys routine. For example, a crypto-cache could
   remember the public key that verified a signature in the past and
   could avoid the verification operation if the same key was used to
   verify the same data structure again. In some cases, however, it is
   impossible (or at least inconvenient) for a cache implementation to

be completely transparent.

In particular, for good performance it is important that certificates
not be re-retrieved from the naming service on every authentication.
This must be balanced against the need to have changes to the
contents of the naming service be reflected in DASS calls on a timely
basis. There are two cases of interest: changes which cause an
authentication which previously would have succeeded to fail and
changes which cause an authentication which previously would have
failed to succeed. These two cases are subject to different time
constraints.

In general, changes that cause authentication to succeed must be
reflected quite quickly - on the order of minutes. If a user
attempts an operation, it fails, the user tracks down a system
manager and causes the appropriate updates to take place, and the
user retries the operation, it is unacceptable for the operation to
continue to fail for an extended period because of stale caches.

Changes that cause authentication to fail must be reflected reliably
within a bounded period of time for security reasons. If a user
leaves the company, it must be possible to revoke his ability to
authenticate within a relatively short period of time - say hours.

These constraints mean that a naming service cache which contains
arbitrarily old information is unacceptable. To meet the second
constraint, naming service cache entries must be timed out within a
reasonable period of time unless in implementation verifies that the
certificate is still present (a crypto-cache which lasted longer
would be legal; rather than deleting a name service cache entry, in
implementation might instead verify that the entry was still present
in the naming service. This would avoid repeating the cryptographic
"verify").

In order to assure that information cached for even a few hours not
deny authentication for that extended period, it must be possible to
bypass caches when the result would otherwise be a failure. Since
the performance of authentication failures is not a serious concern,
it is acceptable to expect that before an operation fails a retry
will be made to the naming service to see if there are any new
relevant certificates (or in certain obscure conditions, to see if
any relevant certificates have been deleted).

If on a call to Get_Pub_Keys, the Try_Hard bit is True, then this
procedure must return results based on the contents of the naming
service no more than five minutes previous (this would normally be
accomplished by ignoring name service caches and making all
operations directly to the naming service). If the Try_Hard bit is

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     False, this procedure may return results based on the contents of the
     naming service any time in the previous few hours, in the sense that
     it may ignore any certificate added in the previous few hours and may
     use any certificate deleted in the previous few hours. Procedures
     which call this routine with Try_Hard set to false must be prepared
     to call it again with Try_Hard True if their operation fails possibly
     from this result.

     The exact timer values for "five minutes" and "a few hours" are
     expected to be implementation constants.

     In the envisioned implementation, the entire "ascending treewalk" is
     retrieved, verified, and its digested contents cached when a
     principal first establishes credentials. A mechanism should be
     provided to refresh this information periodically for principals
     whose sessions might be long lived, but it would probably be
     acceptable in the unlikely event of a user's ancestor's keys changing
     to require that the user log out and log back in. This is consistent
     with the observed behavior of existing security mechanisms.

     The descending treewalk, on the other hand, is expected to be
     maintained as a more conventional cache, where entries are kept in a
     fixed amount of memory with a "least recently used" replacement
     policy and a watchdog timer that assures that stale information is
     not kept indefinitely. A call to Get_Pub_Keys with Try_Hard set
     false would first check that cache for relevant certificates and only
     if none were found there would it go out to the naming service. If
     there were newer certificates in the naming service, they might not
     be found and an authentication might therefore fail.

     When Try_Hard is false, an implementation may assume that
     certificates not in the cache do not exist so long as that assumption
     does not cause an authentication to falsely succeed. In that case,
     it may only make that assumption if the certificates have been
     verified to not exist within the revocation time (a few hours).

3.11 DASSlessness Determination Functions

     In order to provide better interoperability with alternative
     authentication mechanisms and to provide backward compatibility with
     older (insecure) authentication mechanisms, it is sometimes important
     to be able to determine in a secure way what the appropriate
     authentication mechanism is for a particular named principal. For
     some applications, this will be done by a local mechanism, where
     either the person creating access control information must know and
     specify the mechanism for each principal or a system administrator on
     the node must maintain a database mapping names to mechanisms. Three
     applications come to mind where scaleability makes such mechanisms

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implausible:

  a) To transparently secure proxy-based applications (like rlogin)
     in an environment where some hosts have been upgraded to
     support DASS and some have not, a node must be willing to
     accept connections authenticated only by their network
     addresses but only if they can be assured that such nodes do
     not have DASS installed. Access to a resource becomes secure
     without administrative action when all nodes authorized to
     access it have been upgraded.

     In this scenario, the server node must be able to determine
     whether the client node is DASSless in a secure fashion.

  b) Similarly, in a mixed environment where some servers are
     running DASS and some are not, it may be desirable for clients
     to authenticate servers if they can but it would be
     unacceptable for a client to stop being able to access a
     DASSless server once DASS is installed on the client. In such
     a situation where server authentication is desirable but not
     essential, the client would like to determine in a secure
     fashion whether the server can accept DASS authentication.

  c) In a DASS/Kerberos interoperability scenario, a server may
     decide that Kerberos authentication is "good enough" for
     principals that do not have DASS credentials without
     introducing trust in on-line authorities when DASS credentials
     are available. In parallel with case 1, we want it to be true
     that when the last principal with authority to access an
     object is upgraded to DASS, we automatically cease to trust
     PasswdEtc servers without administrative action on the part of
     the object owner. For this purpose, the authenticator must
     learn in a secure fashion that the principal is incapable of
     DASS authentication.

 Reliably determining DASSlessness is optional for implementations of
 DASS and for applications. No other capabilities of DASS rely on
 this one.

 The interface to the DASSlessness inquiry function is specified as a
 call independent of all others. This capability must be exposed to
 the calling application so that a server that receives a request and
 no token can ask whether the named principal should be believed
 without a token. It might improve performance and usability if in
 real interfaces DASSlessness were returned in addition to a bad
 status on the function that creates a token if the token is targeted
 toward a server incapable or processing it. An application could
 then decide whether to make the request without a token (and give up

   server authentication) or to abort the request.

3.11.1 Query DASSlessness

   Query_DASSlessness(
                                                  --inputs
                    verifying_credentials Credentials,
                    principal_name   Name,
                                                  --outputs
                    alternate_authentication Set of OIDs)

   This function uses the verifying credentials to search for an
   alternative authentication mechanism certificate for the named
   principal or for any CA on the path between the verifying credentials
   and the named principal. Such a certificate is identical to an DASS
   X.509 certificate except that it lists a different algorithm
   identifier for the public key of the subject than that expected by
   DASS.

   This function is implemented identically to Get_Pub_Keys except:

    a) If in any set of certificates found, no valid DASS certificate
       is found and one or more certificates are found that would
       otherwise be valid except for an invalid subject public key
       OID, the OID from that certificate or certificates is returned
       and the algorithm terminates.

    b) On initial execution, Try_Hard=False. If the first execution
       fails to retrieve any valid PK/UID pairs but also fails to
       find any invalid OID certificates, repeat the execution with
       Try_Hard=True.

    c) If the either execution finds PK/UID pairs or if neither finds
       and invalid OID certificates, fail by returning a null set.

4. Certificate and message formats

4.1 ASN.1 encoding

   Some definitions are taken from X.501 and X.509.

   Dass DEFINITIONS ::=

   BEGIN

   --CCITT Definitions:

   joint-iso-ccitt   OBJECT IDENTIFIER ::= {2}

```
   ds                    OBJECT IDENTIFIER ::= {joint-iso-ccitt 5}
   algorithm             OBJECT IDENTIFIER ::= {ds 8}
   encryptionAlgorithm   OBJECT IDENTIFIER ::= {algorithm 1}
   hashAlgorithm         OBJECT IDENTIFIER ::= {algorithm 2}
   signatureAlgorithm    OBJECT IDENTIFIER ::= {algorithm 3}
   rsa                   OBJECT IDENTIFIER ::= {encryptionAlgorithm 1}

   iso                   OBJECT IDENTIFIER ::= {1}
   identified-organization OBJECT IDENTIFIER ::= {iso 3}
   ecma                  OBJECT IDENTIFIER ::= {identified-organization 12}
   member-company        OBJECT IDENTIFIER ::= {ecma 2}
   digital               OBJECT IDENTIFIER ::= {member-company 1011}


   --1989 OSI Implementors Workshop "Stable" Agreements

   oiw                   OBJECT IDENTIFIER ::= {identified-organization 14}
   dssig                 OBJECT IDENTIFIER ::= {oiw 7}
   oiwAlgorithm          OBJECT IDENTIFIER ::= {dssig 2}
   oiwEncryptionAlgorithm OBJECT IDENTIFIER ::= {oiwAlgorithm 1}
   oiwHashAlgorithm      OBJECT IDENTIFIER ::= {oiwAlgorithm 2}
   oiwSignatureAlgorithm OBJECT IDENTIFIER ::= {oiwAlgorithm 3}
   oiwMD2                OBJECT IDENTIFIER ::= {oiwHashAlgorithm 1}
                                             --null parameter
   oiwMD2withRSA         OBJECT IDENTIFIER ::= {oiwSignatureAlgorithm 1}
                                               --null parameter

   --X.501 definitions

   AttributeType ::= OBJECT IDENTIFIER
   AttributeValue ::= ANY
   AttributeValueAssertion ::= SEQUENCE {AttributeType,AttributeValue}

   Name ::= CHOICE {        --only one for now
                   RDNSequence
                    }
   RDNSequence ::= SEQUENCE OF RelativeDistinguishedName
   DistinguishedName ::= RDNSequence

   RelativeDistinguishedName ::= SET OF AttributeValueAssertion

   --X.509 definitions (with proposed 1992 extensions presumed)

   ENCRYPTED MACRO ::=
   BEGIN
   TYPE NOTATION   ::= type(ToBeEnciphered)
   VALUE NOTATION  ::= value(VALUE BIT STRING)
   END      -- of ENCRYPTED
```

```
    SIGNED MACRO     ::=
    BEGIN
    TYPE NOTATION    ::= type (ToBeSigned)
    VALUE NOTATION   ::= value (VALUE
    SEQUENCE{
            ToBeSigned,
            AlgorithmIdentifier,    --of the algorithm used to
                                    --generate the signature
            ENCRYPTED OCTET STRING  --where the octet string is the
                                    --result of the hashing of the
                                    --value of "ToBeSigned"
            }
                        )
    END     -- of SIGNED


    SIGNATURE MACRO ::=
    BEGIN
    TYPE NOTATION    ::= type (OfSignature)
    VALUE NOTATION   ::= value (VALUE
    SEQUENCE {
            AlgorithmIdentifier,    --of the algorithm used to compute
            ENCRYPTED OCTET STRING  -- the signature where the octet
                                    -- string is a function (e.g., a
                                    -- compressed or hashed version)
                                    -- of the value 'OfSignature',
                                    -- which may include the
                                    -- identifier of the algorithm
                                    -- used to compute the signature
            }
                        )
    END     -- of SIGNATURE



    Certificate ::= SIGNED SEQUENCE {
            version [0]             Version DEFAULT v1988,
            serialNumber    CertificateSerialNumber,
            signature               AlgorithmIdentifier,
            issuer          Name,
            valid           Validity,
            subject         Name,
            subjectPublicKey        SubjectPublicKeyInfo,
            issuerUID [1]   IMPLICIT UID OPTIONAL,  -- v1992
            subjectUID [2]  IMPLICIT UID OPTIONAL   -- v1992
            }

            --The Algorithm Identifier for both the signature field
```

```
        --and in the signature itself is:
        --      oiwMD2withRSA (1.3.14.7.2.3.1)

  Version ::= INTEGER {v1988(0), v1992(1)}


  CertificateSerialNumber ::= INTEGER


  Validity ::= SEQUENCE {
          NotBefore        UTCTime,
          NotAfter         UTCTime
          }



  AlgorithmIdentifier ::= SEQUENCE {
          algorithm        OBJECT IDENTIFIER,
          parameter        ANY DEFINED BY algorithm OPTIONAL
          }

  --The algorithms we support in one context or another are:
          --oiwMD2withRSA (1.3.14.7.2.3.1) with parameter NULL
          --rsa (2.5.8.1.1) with parameter keysize INTEGER which is
          --          the keysize in bits
          --decDEA (1.3.12.1001.7.1.2) with optional parameter
          --          missing
          --decDEAMAC (1.3.12.2.1011.7.3.3) with optional parameter
          --          missing

  SubjectPublicKeyInfo  ::=  SEQUENCE {
          algorithm        AlgorithmIdentifier,    -- rsa (2.5.8.1.1)
          subjectPublicKey        BIT STRING
                -- the "bits" further decode into a DASS public key
          }

  UID ::= BIT STRING

  -- the following definitions are for Digital specified Algorithms

  cryptoAlgorithm OBJECT IDENTIFIER ::= {digital 7}

  decEncryptionAlgorithm  OBJECT IDENTIFIER ::= {cryptoAlgorithm 1}
  decHashAlgorithm        OBJECT IDENTIFIER ::= {cryptoAlgorithm 2}
  decSignatureAlgorithm   OBJECT IDENTIFIER ::= {cryptoAlgorithm 3}
  decDASSLessness         OBJECT IDENTIFIER ::= {cryptoAlgorithm 6}

  decMD2withRSA   OBJECT IDENTIFIER ::= {decSignatureAlgorithm 1}
  decMD4withRSA   OBJECT IDENTIFIER ::= {decSignatureAlgorithm 2}
  decDEAMAC       OBJECT IDENTIFIER ::= {decSignatureAlgorithm 3}
```

```
   decDEA          OBJECT IDENTIFIER ::= {decEncryptionAlgorithm 2}
   decMD2          OBJECT IDENTIFIER ::= {decHashAlgorithm 1}
   decMD4          OBJECT IDENTIFIER ::= {decHashAlgorithm 2}


   ShortPosixTime ::= INTEGER   -- number of seconds since base time

   LongPosixTime ::= SEQUENCE {
           INTEGER,               -- number of seconds since base time
           INTEGER                -- number of nanoseconds since second
           }


   ShortPosixValidity ::=  SEQUENCE {
           notBefore      ShortPosixTime,
           notAfter       ShortPosixTime }

   -- Note: Annex C of X.509 prescribes the following format for the
   -- representation of a public key, but does not give the structure
   -- a name.

   DASSPublicKey ::=  SEQUENCE {
           modulus        INTEGER,
           exponent       INTEGER
           }

   DASSPrivateKey ::= SEQUENCE {
           p       INTEGER ,                    -- prime p
           q [0]   IMPLICIT INTEGER OPTIONAL ,  -- prime q
           mod[1]  IMPLICIT INTEGER OPTIONAL,   -- modulus
           exp [2] IMPLICIT INTEGER OPTIONAL,   -- public exponent
           dp [3]  IMPLICIT INTEGER OPTIONAL ,  -- exponent mod p
           dq [4]  IMPLICIT INTEGER OPTIONAL ,  -- exponent mod q
           cr [5]  IMPLICIT INTEGER OPTIONAL ,  -- Chinese
                                          --remainder coefficient
           uid[6]  IMPLICIT UID OPTIONAL,
           more[7] IMPLICIT BIT STRING OPTIONAL  --Reserved for
                                          --future use
           }


   LocalUserName    ::= OCTET STRING
   ChannelId              ::= OCTET STRING
   VersionNumber          ::= OCTET STRING (SIZE(3))
                      -- first octet is major version
                      -- second octet is minor version
                      -- third octet is ECO rev.
   versionZero  VersionNumber ::= '000000'H
```

```
   Authenticator ::= SIGNED SEQUENCE {
           type             BIT STRING,
                   -- first bit 'delegation required'
                   -- second bit 'Mutual Authentication Requested'
           whenSigned      LongPosixTime ,
           channelId  [3]  IMPLICIT ChannelId OPTIONAL
                   -- channel bindings are included when doing the
                   -- signature, but excluded when transmitting the
                   -- Authenticator
           }
                   -- uses decDEAMAC (1.3.12.2.1011.7.3.3)


   EncryptedKey ::= SEQUENCE {
           algorithm                AlgorithmIdentifier,
                       -- uses rsa (2.5.8.1.1)
           encryptedAuthKey         BIT STRING
                       -- as defined in section 4.4.5
           }

   SignatureOnEncryptedKey ::=  SIGNATURE EncryptedKey
              -- uses oiwMD2withRSA (1.3.14.7.2.3.1)
              -- Signature bits computed over EncryptedKey structure


   LoginTicket ::= SIGNED SEQUENCE {
           version [0]          IMPLICIT VersionNumber DEFAULT versionZero,
           validity             ShortPosixValidity ,
           subjectUID           UID ,
           delegatingPublicKey SubjectPublicKeyInfo
           }
           -- uses oiwMD2withRSA (1.3.14.7.2.3.1)

   Delegator ::= SEQUENCE {
           algorithm                AlgorithmIdentifier
                       -- decDEA encryption (1.3.12.1001.7.1.2)
           encryptedPrivKey         ENCRYPTED  DASSPrivateKey,
                       -- (only p is included)
           }

   UserClaimant ::=  SEQUENCE {
           userTicket [0]  IMPLICIT LoginTicket,
           evidence  CHOICE {
                   delegator [1]   IMPLICIT Delegator ,
                               -- encrypted delegation private key
                               -- under DES authenticating key
                               -- present if delegating
                   sharedKeyTicketSignature [2]
```

```
                         IMPLICIT SignatureOnEncryptedKey
                                 -- present if not delegating
                  } ,
            userName [3]    IMPLICIT Name OPTIONAL
                                 -- name of user principal
            }


   EncryptedKeyandUserName ::= SEQUENCE {
            encryptedKey    EncryptedKey ,
            username                 LocalUserName
            }

   SignatureOnEncryptedKeyandUserName ::=
            SIGNATURE EncryptedKeyandUserName
                    -- uses oiwMD2withRSA (1.3.14.7.2.3.1)
                    -- Signature bits computed over
                    -- EncryptedKeyandUserName structure
                    -- using node private key
            }

   NodeClaimant ::= SEQUENCE {
            nodeTicket Signature[0] IMPLICIT
                    SignatureOnEncryptedKeyandUserName,
            nodeName  [1]    IMPLICIT Name OPTIONAL,
            username  [2]    IMPLICIT LocalUserName OPTIONAL
            }

   AuthenticationToken ::= SEQUENCE {
            version [0]     IMPLICIT VersionNumber DEFAULT versionZero,
            authenticator [1]        IMPLICIT Authenticator ,
            encryptedKey [2]         IMPLICIT EncryptedKey OPTIONAL ,
                    -- required if initiating token
            userclaimant  [3]        IMPLICIT UserClaimant OPTIONAL ,
                    -- missing if only doing node authentication
                    -- required if not doing node authentication
            nodeclaimant [4]         IMPLICIT NodeClaimant OPTIONAL
                    -- missing if only doing principal authentication
                    -- required if not doing principal authentication
            }

   MutualAuthenticationToken ::= CHOICE {
            v1Response [0] IMPLICIT  OCTET STRING (SIZE(6))
                    -- Constructed as follows:  A single DES block
                    -- of eight octets is constructed from the two
                    -- integers in the timestamp.  First four bytes
                    -- are the high order integer encoded MSB
                    -- first; Last four bytes are the low order
```

```
                    -- integer encoded MSB first.  The block is
                    -- encrypted using the shared DES key, and
                    -- the first six bytes are the OCTET STRING.
                    -- With the [0] type and 6-byte length, the
                    -- MutualAuthenticationToken has a fixed
                    -- length of eight bytes.
          }
    END
```

4.2 Encoding Rules

   Whenever a structure is to be signed it must always be constructed
   the same way. This is particularly important where a signed structure
   has to be reconstructed by the recipient before the signature is
   verified. The rules listed below are taken from X.509.

    - the definite form of length encoding shall be used, encoded in
      the minimum number of octets;

    - for string types, the constructed form of encoding shall not
      be used;

    - if the value of a type is its default value, it shall be
      absent;

    - the components of a Set type shall be encoded in ascending
      order of their tag value;

    - the components of a Set-of type shall be encoded in ascending
      order of their octet value;

    - if the value of a Boolean type is true, the encoding shall
      have its contents octet set to 'FF'16;

    - each unused bits in the final octet of the encoding of a
      BitString value, if there are any, shall be set to zero;

    - the encoding of a Real type shall be such that bases 8, 10 and
      16 shall not be used, and the binary scaling factor shall be
      zero.

4.3 Version numbers and forward compatibility

   The LoginTicket and AuthenticationToken structures contain a
   three octet version identifier which is intended to ease
   transition to future revisions of this architecture. The default
   value, and the value which should always be supplied by
   implementations of this version of the architecture is 0.0.0

(three zero octets). The first octet is the major version. An
implementation of this version of the architecture should refuse
to process data structures where it is other than zero, because
changing it indicates that the interpretation of some subsidiary
data structure has changed. The second octet is the minor
version. An implementation of this version of the architecture
should ignore the value of this octet. Some future version of
the architecture may set a value other than zero and may specify
some different processing of the remainder of the structure based
on that different value. Such a change would be backward compatible
and interoperable. The third octet is the ECO revision. No
implementation should make any processing decisions based on the
value of that octet. It may be logged, however, to help in
debugging interoperability problems.

In the CDC protocol, there is also a three octet version
numbering scheme, where versions 1.0.0 and 2.0.0 have been
defined. Implementations should follow the same rules above and
reject major version numbers greater than 2.

ASN.1 is inherently extensible because it allows new fields to be
added "onto the end" of existing data structures in an
unambiguous way. Implementations of DASS are encouraged to
ignore any such additional fields in order to enhance backwards
compatibility with future versions of the architecture.
Unfortunately, commonly available ASN.1 compilers lack this
capability, so this behavior cannot reasonably be required and
may limit options for future extensions.

4.4 Cryptographic Encoding

Some of the substructures listed in the previous sections are
specified as ENCRYPTED OCTET STRINGs containing encrypted
information. DASS uses the DES, RSA, and MD2 cryptosystems Each
of those cryptosystems specifies a function from octet string
into another in the presence of a key (except MD2, which is
keyless). This section describes how to form the octet strings
on which the DES and RSA operations are performed.

4.4.1 Algorithm Independence vs. Key Parity

All of the defined encodings for DASS for secret key encryption
are based on DES. It is intended, however, that other
cryptosystems could be substituted without any other changes for
formats or algorithms. The required "form factor" for such a
cryptosystem is that it have a 64 bit key and operate on 64 bit
blocks (this appears to be a common form factor for a
cryptosystem). For this reason, DES keys are in all places

treated as though they were 64 bits long rather than 56. Only in
the operation of the algorithm itself are eight bits of the key
dropped and key parity bits substituted. Choosing a key always
involves picking a 64 bit random number.

4.4.2 Password Hashing

Encrypted credentials are encrypted using DES as described in the
next section. The key for that encryption is derived from the
user's password and name by the following algorithm:

 a) Put the rightmost RDN of the user's name in canonical form
    according to BER and the X.509 encoding rules. For any string
    types that are case insensitive, map to upper case, and where
    matching is independent of number of spaces collapse all
    multiple spaces to a single space and delete leading and
    trailing spaces.

    Note: the RDN is used to add "salt" to the hash calculation
    so that someone can't precompute the hash of all the words in
    a dictionary and then apply them against all names. Deriving
    the salt from the last RDN of the name is a compromise. If it
    were derived from the whole name, all encrypted keys would be
    obsoleted when a branch of the namespace was renamed. If it
    were independent of name, interaction with a login agent would
    take two extra messages to retrieve the salt. With this
    scheme, encrypted keys are obsoleted by a change in the last
    RDN and if a final RDN is common to a large number of users,
    dictionary attacks against them are easier; but the common
    case works as desired.

 b) Compute TEMP as the MD2 message digest of the concatenation of
    the password and the RDN computed above.

 c) Repeat the following 40 times: Use the first 64 bits of TEMP
    as a DES key to encrypt the second 64 bits; XOR the result
    with the first 64 bits of TEMP; and compute a new TEMP as MD2
    of the 128 bit result.

 d) Use the final 64 bits of the result (called hash1) as the key
    to decrypt the encrypted credentials. Use the first 64 bits
    (called hash2) as the proof of knowledge of the password for
    presentation to a login agent (if any).

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4.4.3 Digital DEA encryption

   DES encryption is used in the following places:

     - In the encryption of the encrypted credentials structure

     - To encrypt the delegator in authentication tokens

     - To encrypt the time in the mutual authenticator

   In the first two cases, a varying length block of information
   coded in ASN.1 is encrypted. This is done by dividing the block
   of information into 8 octet blocks, padding the last block with
   zero bytes if necessary, and encrypting the result using the CBC
   mode of DES. A zero IV is used.

   In the third case, a fixed length (8 byte) quantity (a timestamp)
   is encrypted. The timestamp is mapped to a byte string using
   "big endian" order and the block is encrypted using the ECB mode
   of DES.

4.4.4 Digital MAC Signing

   DES signing is used in the Authenticator. Here, the signature is
   computed over an ASN.1 structure. The signature is the CBC residue
   of the structure padded to a multiple of eight bytes with zeros. The
   CBC is computed with an IV of zero.

4.4.5 RSA Encryption

   RSA encryption is used in the Encrypted Shared Key. RSA encryption
   is best thought of as operating on blocks which are integers rather
   than octet strings and the results are also integers. Because an RSA
   encryption permutes the integers between zero and (modulus-1), it is
   generally thought of as acting on a block of size (keysizeinbits-1)
   and producing a block of size (keysizeinbits) where keysizeinbits is
   the smallest number of bits in which the modulus can be represented.

   DASS only supports key sizes which are a multiple of eight bits (This
   restriction is only required to support interoperation with certain
   existing implementations. If the key size is not a multiple of eight
   bits, the high order byte may not be able to hold values as large as
   the mandated '64'. This is not a problem so long as the two high
   order bytes together are non-zero, but certain early implementations
   check for the value '64' and will not interoperate with
   implementations that use some other value.).

   The encrypted shared key structure is laid out as follows:

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  – The DES key to be shared is placed in the last eight bytes

  – The POSIX format creation time encoded in four bytes using big
    endian byte order is placed in the next four (from the end)
    bytes

  – The POSIX format expiration time encoded in four bytes using
    big endian byte order is placed in the next four (from the
    end) bytes

  – Four zero bytes are placed in the next four (from the end)
    bytes

  – The first byte contains the constant '64' (decimal)

  – All remaining bytes are filled with random bytes (the security
    of the system does not depend on the cryptographic randomness
    of these bytes, but they should not be a frequently repeating
    or predictable value. Repeating the DES key from the last
    bytes would be good).

  The RSA algorithm is applied to the integer formed by treating the
  bytes above as an integer in big endian order and the resulting
  integer is converted to a BIT STRING by laying out the integer in
  'big endian' order.

  On decryption, the process is reversed; the decryptor should verify
  the four explicitly zero bytes but should not verify the contents of
  the high order byte or the random bytes.

4.4.6 oiwMD2withRSA Signatures

  RSA–MD2 signatures are used on certificates, login tickets, shared
  key tickets, and node tickets. In all cases, a signature is computed
  on an ASN.1 encoded string using an RSA private key. This is done as
  follows:

   – The MD2 algorithm is applied to the ASN.1 encoded string to
     produce a 128 bit message digest

   – The message digest is placed in the low order bytes of the RSA
     block (big endian)

   – The next two lowest order bytes are the ASN.1 'T' and 'L' for
     an OCTET STRING.

   – The remainder of the RSA block is filled with zeros

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- The RSA operation is performed, and the resulting integer is
  converted to an octet string by laying out the bytes in big
  endian order.

On verification, a value like the above or one where the message
digest is present but the 'T' and 'L' are missing (zero) should be
accepted for backwards compatibility with an earlier definition of
this crypto algorithm.

4.4.7 decMD2withRSA Signatures

This algorithm is the same as the oiwMD2withRSA algorithm as defined
above. We allocated an algorithm object identifier from the Digital
space in case the definition of that OID should change. It will not
be used unless the meaning of oiwMD2withRSA becomes unstable.

Annex A

Typical Usage

This annex describes one way a system could use DASS services (as
described in section 3) to provide security services. While this
example provided motivation for some of the properties of DASS, it is
not intended to represent the only way that DASS may be used. This
goes through the steps that would be needed to install DASS "from
scratch".

A.1 Creating a CA

A CA is created by initializing its state. Each CA can sign
certificates that will be placed in some directory in the name
service. Before these certificates will be believed in a wider
context than the sub-tree of the name space which is headed by that
directory, the CA must be certified by a CA for the parent directory.
The procedure below accomplishes this. For most secure operation, the
CA should run on an off-line system and communicate with the rest of
the network by interchanging files using a simple specialized
mechanism such as an RS232 line or a floppy disk. It is assumed that
access to the CA is controlled and that the CA will accept
instructions from an operator.

- Call Install_CA to create the CA State.
  This state is saved within the CA system and is never
  disclosed.

- If this is the first CA in the namespace and the CA is
  intended to certify only members of a single directory, we are
  done. Otherwise, the new CA must be linked into the CA

hierarchy by cross-certifying the parent and children of this
CA. There is no requirement that CA hierarchies be created
from the root down, but to simplify exposition, only this case
will be described. The newly created CA must learn its name,
its UID, the UID of its parent directory, and the public key
of the parent directory CA by some out of band reliable means.
Most likely, this would be done by looking up the information
in the naming service and asking the CA operator to verify it.
The CA then forms this information into a   parent certificate
and signs it using the Create_certificate function. It
communicates the certificate to the network and posts it in
the naming service.

 - This name, UID, and public key of the new CA are taken to the
   CA of the parent directory, which verifies it (again by some
   unspecified out-of-band mechanism) and calls
   Create_Certificate to create a child certificate using its own
   Name and UID in the issuer fields. This certificate is also
   placed in the naming service.

A CA can sign certificates for more than one directory. In this case
it is possible that a single CA will take the role of both CAs in the
example above. The above procedure can be simplified in this case, as
no interchange of information is required.

A.2 Creating a User Principal

A system manager may create a new user principal by invoking the
Create_principal function supplying the principal's name, UID, and
the public key/UID of the parent CA. The public key and UID must be
obtained in a reliable out of band manner. This is probably by
having knowledge of that information "wired into" the utility which
creates new principals. At account creation time, the system manager
must supply what will become the user's password. This might be done
by having the user present and directly enter a password or by having
the password selected by some random generator.

The trusted authority certificate and corresponding user public key
generated by the Create_principal function are sent to the CA which
verifies its contents (again by an out-of-band mechanism) and signs a
corresponding certificate. The encrypted credentials, CA signed
certificate, and trusted authority certificates are all placed in the
naming service. The process by which the password is made known to
the user must be protected by some out-of-band mechanism.

In some cases the principal may wish to generate its own key, and not
use the Encrypted_Credentials. (e.g., if the Principal is represented
by a Smart Card). This may be done using a procedure similar to the

one for creating a new CA.

A.3 Creating a Server Principal

   A server also has a public/private key pair. Conceptually, the same
   procedure used to create a user principal can be used to create a
   server. In practice, the most important difference is likely to be
   how the password is protected when installing it on a server compared
   to giving it to a user.

   A server may wish to retrieve (and store) its Encrypted Credentials
   directly and never have them placed in the naming service. In this
   case some other mechanism can be used (e.g., passing the floppy disk
   containing the encrypted credentials to the server). This would
   require a variant of the Initialize_Server routine which does not
   fetch the Encrypted Credentials from the naming service.

A.4 Booting a Server Principal

   When the server first boots it needs its name (unreliably) and
   password (reliably). It then calls Initialize_Server to obtain its
   credentials and trusted authority certificates (which it will later
   need in order to authenticate users). These credentials never time
   out, and are expected to be saved for a long time. In particular the
   associated Incoming Timestamp List must be preserved while there are
   any timestamps on it. It is desirable to preserve the Cached Incoming
   Contexts as long as there are any contexts likely to be reused.

   If a server wants to initiate associations on its own behalf then it
   must call Generate_Server_Ticket. It must repeat this at intervals
   if the expiration period expires.

   A node that wishes to do node authentication (or which acts as a
   server under its own name) must be created as a server.

A.5 A user logs on to the network

   The system that the user logs onto finds the user's name and
   password. It then calls Network_Login to obtain credentials for the
   user. These credentials are saved until the user wants to make a
   network connection. The credentials have a time limit, so the user
   will have to obtain new credentials in order to make connections
   after the time limit. The credentials are then checked by calling
   Verify_Principal_Name, in order to check that the key specified in
   the encrypted credentials has been certified by the CA.

   If the system does source node authentication it will call
   Combine_credentials, once the local username has been found. (This

can either be found by looking the principal's global name up in a
file, or the user can be asked to give the local name directly.
Alternatively the user can be asked to give his local username, which
the system looks up to find the global name).

A.6 An Rlogin (TCP/IP) connection is made

When the user calls a modified version of the rlogin utility, it
calls Create_token in order to create the Initial Authentication
Token, which is passed to the other system as part of the rlogin
protocol. The rlogind utility at the destination node calls
Accept_token to verify it. It then looks up in a local rhosts-like
database to determine whether this global user is allowed access to
the requested destination account. It calls Verify_principal_name
and/or Verify_node_name to confirm the identity of the requester. If
access is allowed, the connection is accepted and the Mutual
Authentication Token is returned in the response message.

The source receives the returned Mutual Authentication Token and uses
it to confirm it communicating with the correct destination node.

Rlogind then calls Combine_credentials to combine its node/account
information with the global user identification in the received
credentials in case the user accesses any network resources from the
destination system.

A.7 A Transport-Independent Connection

As an alternative to the description in A.6, an application wishing
to be portable between different underlying transports may call
create_token to create an authentication token which it then sends to
its peer. The peer can then call accept_token and
verify_principal_name and learn the identity of the requester.

Annex B

Support of the GSSAPI

In order to support applications which need to be portable across a
variety of underlying security mechanisms, a "Generic Security
Service API" (or GSSAPI) was designed which gives access to a common
core of security services expected to be provided by several
mechanisms. The GSSAPI was designed with DASS, Kerberos V4, and
Kerberos V5 in mind, and could be written as a front end to any or
all of those systems. It is hoped that it could serve as an
interface to other security systems as well.

Application portability requires that the security services supported

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   be comparable. Applications using the GSSAPI will not be able to
   access all of the features of the underlying security mechanisms.
   For example, the GSSAPI does not allow access to the "node
   authentication" features of DASS. To the extent the underlying
   security mechanisms do not support all the features of GSSAPI,
   applications using those features will not be portable to those
   security mechanisms. For example, Kerberos V4 does not support
   delegation, so applications using that feature of the GSSAPI will not
   be portable to Kerberos V4.

   This annex explains how the GSSAPI can be implemented using the
   primitive services provided by DASS.

B.1 Summary of GSSAPI

   The latest draft of the GSSAPI specification is available as an
   internet draft. The following is a brief summary of that evolving
   document and should not be taken as definitive. Included here are
   only those aspects of GSSAPI whose implementation would be DASS
   specific.

   The GSSAPI provides four classes of functions: Credential Management,
   Context-Level Calls, Per-message calls, and Support Calls; two types
   of objects: Credentials and Contexts; and two kinds of data
   structures to be transmitted as opaque byte strings: Tokens and
   Messages. Credentials hold keys and support information used in
   creating tokens. Contexts hold keys and support information used in
   signing and encrypting messages.

   The Credential Management functions of GSSAPI are "incomplete" in the
   sense that one could not build a useful security implementation using
   only GSSAPI. Functions which create credentials based on passwords
   or smart cards are needed but not provided by GSSAPI. It is
   envisioned that such functions would be invoked by security mechanism
   specific functions at user login or via some separate utility rather
   than from within applications intended to be portable. The
   Credential Management functions available to portable applications
   are:

    - GSS_Acquire_cred: get a handle to an existing credential
      structure based on a name or process default.

    - GSS_Release_cred: release credentials after use.

   The Context-Level Calls use credentials to establish contexts.
   Contexts are like connections: they are created in pairs and are
   generally used at the two ends of a connection to process messages
   associated with that connection. The Context-Level Calls of interest

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   are:

    - GSS_Init_sec_context: given credentials and the name of a
      destination, create a new context and a token which will
      permit the destination to create a corresponding context.

    - GSS_Accept_sec_context: given credentials and an incoming
      token, create a context corresponding to the one at the
      initiating end and provide information identifying the
      initiator.

    - GSS_Delete_sec_context: delete a context after use.

   The Per-Message Calls use contexts to sign, verify, encrypt, and
   decrypt messages between the holders of matching contexts. The Per-
   Message Calls are:

    - GSS_Sign: Given a context and a message, produces a string of
      bytes which constitute a signature on a provided message.

    - GSS_Verify: Given a context, a message, and the bytes
      returned by GSS_Sign, verifies the message to be authentic
      (unaltered since it was signed by the corresponding context).

    - GSS_Seal: Given a context and a message, produces a string of
      bytes which include the message and a signature; the message
      may optionally be encrypted.

    - GSS_Unseal: Given a context and the string of bytes from
      GSS_Seal, returns the original message and a status indicating
      its authenticity.

   The Support Calls provide utilities like translating names and status
   codes into printable strings.

B.2 Implementation of GSSAPI over DASS

B.2.1 Data Structures

   The objects and data structures of the GSSAPI do not map neatly into
   the objects and data structures of the DASS architecture.

   This section describes how those data structures can be implemented
   using the DASS data structures and primitives

   Credential handles correspond to the credentials structures in DASS,
   where the portable API assumes that the credential structures
   themselves are kept from applications and handles are passed to and

   from the various subroutines.

   Context initialization tokens correspond to the tokens of DASS. The
   GSSAPI prescribes a particular ASN.1 encoded form for tokens which
   includes a mechanism specific bit string within it. An
   implementation of GSSAPI should enclose the DASS token within the
   GSSAPI "wrapper".

   Context handles have no corresponding structure in DASS. The
   Create_token and Accept_token calls of DASS return a shared key and
   instance identifier. An implementation of the GSSAPI must take those
   values along with some other status information and package it as a
   "context" opaque structure. These data structures must be allocated
   and freed with the appropriate calls.

   Per-message tokens and sealed messages have no corresponding data
   structure within DASS. To fully support the GSSAPI functionality,
   DASS must be extended to include this functionality. These data
   structures are created by cryptographic routines given the keys and
   status information in context structures and the messages passed to
   them. While not properly part of the DASS architecture, the formats
   of these data structures are included in section C.3.

B.2.2 Procedures

   This section explains how the functions of the GSSAPI can be provided
   in terms of the Services Provided by DASS. Not all of the DASS
   features are accessible through the GSSAPI.

B.2.2.1 GSS_Acquire_cred

   The GSSAPI does not provide a mechanism for logging in users or
   establishing server credentials. It assumes that some system specific
   mechanism created those credentials and that applications need some
   mechanism for getting at them. A model implementation might save all
   credentials in a node-global pool indexed by some sort of credential
   name. The credentials in the pool would be access controlled by some
   local policy which is not concern of portable applications. Those
   applications would simply call GSS_Acquire_cred and if they passed
   the access control check, they would get a handle to the credentials
   which could be used in subsequent calls.

B.2.2.2 GSS_Release_cred

   This call corresponds to the "delete_credentials" call of DASS.

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B.2.2.3 GSS_Init_sec_context

   In the course of a normal mutual authentication, this routine will be
   called twice. The procedure can determine whether this is the first
   or second call by seeing whether the "input_context_handle" is zero
   (it will be on the first call). On the first call, it will use the
   DASS Create_token service to create a token and it will also allocate
   and populate a "context" structure. That structure will hold the key,
   instance identifier, and mutual authentication token returned by
   Create_token and will in addition hold the flags which were passed
   into the Init_sec_context call. The token returned by
   Init_sec_context will be the DASS token included in the GSSAPI token
   "wrapper". The DASS token will include the optional principal name.

   If mutual authentication is not requested in the GSSAPI call, the
   mutual authentication token returned by DASS will be ignored and the
   initial call will return a COMPLETE status. If mutual authentication
   is requested, the mutual authentication token will be stored in the
   context information and a CONTINUE_NEEDED status returned.

   On the second call to GSS_Init_sec_context (with input_context_handle
   non-zero), the returned token will be compared to the one in the
   context information using the Compare_mutual_token procedure and a
   COMPLETE status will be returned if they match.

B.2.2.4 GSS_Accept_sec_context

   This routine in GSSAPI accepts an incoming token and creates a
   context. It combines the effects of a series of DASS functions. It
   could be implemented as follows:

    - Remove the GSSAPI "wrapper" from the incoming token and pass
      the rest and the credentials to "Accept_token". Accept_token
      produces a mutual authentication token and a new credentials
      structure. If delegation was requested, the new credentials
      structure will be an output of GSS_Accept_sec_context. In any
      case, it will be used in the subsequent steps of this
      procedure.

    - Use the DASS Get_principal_name function to extract the
      principal name from the credentials produced by Accept_token.
      This name is one of the outputs of "GSS_Accept_sec_context.

    - Apply the DASS Verify_principal_name to the new credentials
      and the retrieved name to authenticate the token as having
      come from the named principal.

    - Create and populate a context structure with the key and

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timestamp returned by Accept_token and a status of COMPLETE.
Return a handle to that context.

- If delegation was requested, return the new credentials from
  GSS_Accept_sec_context. Otherwise, call Delete_credentials.

- If mutual authentication was requested, wrap the mutual
  authentication token from Accept_token in a GSSAPI "wrapper"
  and return it. Otherwise return a null string.

B.2.2.5 GSS_Delete_sec_context

   This routine simply deletes the context state. No calls to DASS are
   required.

B.2.2.6 GSS_Sign

   This routine takes as input a context handle and a message. It
   creates a per_msg_token by computing a digital signature on the
   message using the key and timestamp in the context block. No DASS
   services are required. If additional cryptographic services were
   requested (replay detection or sequencing), a timestamp or sequence
   number must be prepended to the message and sent with the signature.
   The syntax for this message is listed in section C.3.

B.2.2.7 GSS_Verify

   This routine repeats the calculation of the sign routine and verifies
   the signature provided. If replay detection or sequencing services
   are provided, the context must maintain as part of its state
   information containing the sequence numbers or timestamps of messages
   already received and this one must be checked for acceptability.

B.2.2.8 GSS_Seal

   This routine performs the same functions as Sign but also optionally
   encrypts the message for privacy using the shared key and
   encapsulates the whole thing in a GSSAPI specified ASN.1 wrapper.

B.2.2.9 GSS_Unseal

   This routine performs the same functions as GSS_Verify but also
   parses the data structure including the signature and message and
   decrypts the message if necessary.

B.3 Syntax

   The GSSAPI specification recommends the following ASN.1 encoding for
   the tokens and messages generated through the GSSAPI:

       --optional top-level token definitions to frame
       -- different mechanisms

       GSSAPI DEFINITIONS ::=
       BEGIN

       MechType ::= OBJECT IDENTIFIER
       -- data structure definitions
       ContextToken ::=
       -- option indication (delegation, etc.) indicated
       -- within mechanism-specific token
       [APPLICATION 0] IMPLICIT SEQUENCE {
            thisMech MechType,
            responseExpected BOOLEAN,
            innerContextToken ANY DEFINED BY MechType
              -- contents mechanism-specific
            }

       PerMsgToken ::=
       -- as emitted by GSS_Sign and processed by
       -- GSS_Verify
       [APPLICATION 1] IMPLICIT SEQUENCE {
            thisMech MechType,
            innerMsgToken ANY DEFINED BY MechType
              -- contents mechanism-specific
            }
       SealedMessage ::=
       -- as emitted by GSS_Seal and processed by
       -- GSS_Unseal
       [APPLICATION 2] IMPLICIT SEQUENCE {
            sealingToken PERMSGTOKEN,
            confFlag BOOLEAN,
            userData OCTET STRING
              -- encrypted if confFlag TRUE
            }

   The object identifier for the DASS MechType is 1.3.12.2.1011.7.5.

   The innerContextToken of a token is a DASS token or mutual
   authentication token.

   The innerMsgToken is a null string in the case where the message is
   encrypted and the token is included as part of a SealedMessage.

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   Otherwise, it is an eight octet sequence computed as the CBC residue
   computed using a key and string of bytes defined as follows:

    - Pad the message provided by the application with 1-8 bytes of
      pad to produce a string whose length is a multiple of 8
      octets. Each pad byte has a value equal to the number of pad
      bytes.

    - Compute the key by taking the timestamp of the association
      (two four byte integers laid out in big endian order with the
      most significant integer first), complementing the high order
      bit (to avoid aliasing with mutual authenticators), and
      encrypting the block in ECB mode with the shared key of the
      association.

   The userData field of a SealedMessage is exactly the application
   provided byte string if confFlag=FALSE. Otherwise, it is the
   application supplied message encrypted as follows:

    - Pad the message provided by the application with 1-8 bytes of
      pad to produce a string whose length = 4 (mod 8). Each pad
      byte has a value equal to the number of pad bytes.

    - Append a four byte CRC32 computed over the message + pad.

    - Compute a key by taking the timestamp of the association (two
      four byte integers laid out in big endian order with the most
      significant integer first), complementing the high order bit
      (to avoid aliasing with mutual authenticators), and encrypting
      the block in ECB mode with the shared key of the association.

    - Encrypt the message + pad + CRC32 using CBC and the key
      computed in the previous step.

   A note of the logic behind the above:

    - Because the shared key of an association may be reused by many
      associations between the same pair of principals, it is
      necessary to bind the association timestamp into the messages
      somehow to prevent messages from a previous association being
      replayed into a new sequence. The technique above of
      generating an association key accomplishes this and has a side
      benefit. An implementation may with to keep the long term
      keys out of the hands of applications for purposes of
      confinement but may wish to put the encryption associated with
      an association in process context for reasons of performance.
      Defining an association key makes that possible.

  - The reason that the association specific key is not specified
    as the output of Create_token and Accept_token is that the DCE
    RPC security implementation requires that a series of
    associations between two principals always have the same key
    and we did not want to have to support a different interface
    in that application.

  - The CRC32 after pad constitutes a cheap integrity check when
    data is encrypted.
  - The fact that padding is done differently for encrypted and
    signed messages means that there are no threats related to
    sending the same message encrypted and unencrypted and using
    the last block of the encrypted message as a signature on the
    unencrypted one.

Annex C

Imported ASN.1 definitions

    This annex contains extracts from the ASN.1 description of X.509 and
    X.500 definitions referenced by the DASS ASN.1 definitions.

    CCITT DEFINITIONS ::=

    BEGIN joint-iso-ccitt   OBJECT IDENTIFIER ::= {2} ds
    OBJECT IDENTIFIER ::= {joint-iso-ccitt 5} algorithm
    OBJECT IDENTIFIER ::= {ds 8}

    iso   OBJECT IDENTIFIER ::= {1} identified-
    organization OBJECT IDENTIFIER ::= {iso 3} ecma   OBJECT
    IDENTIFIER ::= {identified-organization 12} digital
    OBJECT IDENTIFIER ::= { ecma 1011 }

    -- X.501 definitions

    AttributeType ::= OBJECT IDENTIFIER AttributeValue ::= ANY
          -- useful ones are
                  --   OCTET STRING ,
                  --   PrintableString ,
                  --   NumericString ,
                  --   T61String ,
                  --   VisibleString

    AttributeValueAssertion ::= SEQUENCE {AttributeType,
                                            AttributeValue}

    Name ::= CHOICE {-- only one possibility for now --
                  RDNSequence}

```
   RDNSequence ::= SEQUENCE OF RelativeDistinguishedName
   DistinguishedName ::= RDNSequence

   RelativeDistinguishedName ::= SET OF AttributeValueAssertion

   -- X.509 definitions

   Certificate ::= SIGNED SEQUENCE {
                   version [0]            Version DEFAULT 1988 ,
                   serialNumber          SerialNumber ,
                   signature             AlgorithmIdentifier ,
                   issuer                Name,
                   valid                 Validity,
                   subject               Name,
                   subjectPublicKey      SubjectPublicKeyInfo }

   Version ::=        INTEGER { 1988(0)} SerialNumber ::= INTEGER Validity
   ::=      SEQUENCE{
         notBefore              UTCTime,
         notAfter               UTCTime}

   SubjectPublicKeyInfo  ::=  SEQUENCE {
         algorithm              AlgorithmIdentifier ,
         subjectPublicKey       BIT STRING
         }

   AlgorithmIdentifier ::= SEQUENCE {
         algorithm       OBJECT IDENTIFIER ,
                   parameters ANY DEFINED BY algorithm OPTIONAL}

   ALGORITHM MACRO BEGIN TYPE NOTATION    ::= "PARAMETER" type VALUE
   NOTATION  ::= value (VALUE OBJECT IDENTIFIER) END -- of ALGORITHM

   ENCRYPTED MACRO BEGIN TYPE NOTATION    ::=type(ToBeEnciphered) VALUE
   NOTATION  ::= value(VALUE BIT STRING)
         -- the value of the bit string is generated by
         -- taking the octets which form the complete
         -- encoding (using the ASN.1 Basic Encoding Rules)
         -- of the value of the ToBeEnciphered type and
         -- applying an encipherment procedure to those octets-- END

   SIGNED MACRO    ::= BEGIN TYPE NOTATION    ::= type (ToBeSigned) VALUE
   NOTATION  ::= value(VALUE SEQUENCE{
         ToBeSigned,
         AlgorithIdentifier, -- of the algorithm used to generate
                             -- the signature
         ENCRYPTED OCTET STRING
         -- where the octet string is the result
```

```
        -- of the hashing of the value of "ToBeSigned" END -- of
   SIGNED


   SIGNATURE MACRO ::= BEGIN TYPE NOTATION   ::= type(OfSignature) VALUE
   NOTATION  ::= value(VALUE
        SEQUENCE{
                AlgorithmIdentifier,
                -- of the algorithm used to compute the signature
                ENCRYPTED OCTET STRING
                -- where the octet string is a function (e.g., a
                -- compressed or hashed version) of the value
                -- "OfSignature", which may include the identifier
                -- of the algorithm used to compute
                -- the signature--}
                    ) END -- of SIGNATURE


   -- X.509 Annex H (not part of the standard)

   encryptionAlgorithm OBJECT IDENTIFIER ::= {algorithm 1} rsa ALGORITHM
        PARAMETER KeySize
        ::= {encryptionAlgorithm 1}

   KeySize ::= INTEGER

   END
```


Glossary

   authentication
        The process of determining the identity
        (usually the name) of the other party in some communication
        exchange.

   authentication context
        Cached information used during a particular instance of
        authentication and including a shared symmetric (DES) key as
        well as components of the authentication token conveyed
        during establishment of this context.

   authentication token
        Information conveyed during a strong authentication exchange
        that can be used to authenticate its sender. An
        authentication token can, but is not necessarily limited to,
        include the claimant identity and ticket, as well as signed
        and encrypted secret key exchange messages conveying a
        secret key to be used in future cryptographic operations. An

        authentication token names a particular protocol data
        structure component.

   authorization
        The process of determining the rights
        associated with a particular principal.

   certificate
        The public key of a particular principal, together
        with some other information relating to the names of the
        principal and the certifying authority, rendered unforgeable
        by encipherment with the private key of the certification
        authority that issued it.

   certification authority
        An authority trusted by one or more principals to create and
        assign certificates.

   claimant
        The party that initiates the authentication process.
        In the DASS architecture, claimants possess credentials
        which include their identity, authenticating private key and
        a ticket certifying their authenticating public key.

   credentials
        Information "state" required by principals in order
        to for them to authenticate.   Credentials may contain
        information used to initiate the authentication process
        (claimant information), information used to respond to an
        authentication request (verifier information), and cached
        information useful in improving performance.

   cryptographic checksum
        Information which is derived by performing a cryptographic
        transformation on the data unit. This information can be
        used by the receiver to verify the authenticity of data
        passed in cleartext

   decipher
        To reverse the effects of encipherment and render a
        message comprehensible by use of a cryptographic key.

   delegation
        The granting of temporary credentials that allow a
        process to act on behalf of a principal.

   delegation key
        A short term public/private key pair used by a claimant
        to act on behalf of a principal for a bounded period. The
        delegation public key appears in the ticket, whereas the
        delegation private key is used to sign secret key exchange
        messages.

   DES
        Data Encryption Standard: a symmetric (secret key)
        encryption algorithm used by DASS. An alternate encryption
        algorithm could be substituted with little or no disruption
        to the architecture.

   DES key
        A 56-bit secret quantity used as a parameter to the
        DES encryption algorithm.

   digital signature
        A value computed from a block of data
        and a key which could only be computed by someone knowing
        the key. A digital signature computed with a secret key can
        only be verified by someone knowing that secret key. A
        digital signature computed with a private key can be
        verified by anyone knowing the corresponding public key.

   encipher
        To render incomprehensible except to the holder of a
        particular key. If you encipher with a secret key, only the
        holder of the same secret can decipher the message. If you
        encipher with a public key, only the holder of the
        corresponding private key can decipher it.

   initial trust certificate
        A certificate signed by a principal for its own use which
        states the name and public key of a trusted authority.

   global user name
        A hierarchical name for a user which is
        unique within the entire domain of discussion (typically the
        network).

   local user name
        A simple (non-hierarchical) name by
        which a user is known within a limited context such as on a
        single computer.

   principal
        Abstract entity which can be authenticated by name.
        In DASS there are user principals and server principals.

   private key
        Cryptographic key used in asymmetric (public key)
        cryptography to decrypt and/or sign messages. In asymmetric
        cryptography, knowing the encryption key is independent of
        knowing the decryption key. The decryption (or signing)
        private key cannot be derived from the encrypting (or
        verifying) public key.

   proxy
        A mapping from an external name to a local account
        name for purposes of establishing a set of local access
        rights. Note that this differs from the definition in ECMA
        TR/46.

   public key
        Cryptographic key used in asymmetric cryptography to
        encrypt messages and/or verify signatures.

   RSA
        The Rivest-Shamir-Adelman public key cryptosystem
        based on modular exponentiation where the modulus is the
        product of two large primes. When the term RSA key is used,
        it should be clear from context whether the public key, the
        private key, or the public/private pair is intended.

   secret key
        Cryptographic key used in symmetric cryptography to
        encrypt, sign, decrypt and verify messages. In symmetric
        cryptography, knowledge of the decryption key implies
        knowledge of the encryption key, and vice-versa.

   sign
        A process which takes a piece of data and a key and
        produces a digital signature which can only be calculated by
        someone with the key. The holder of a corresponding key can
        verify the signature.

   source
        The initiator of an authentication exchange.

   strong authentication
        Authentication by means of cryptographically derived
        authentication tokens and credentials. The actual working
        definition is closer to that of "zero knowledge" proof:

authentication so as to not reveal any information usable by
either the verifier, or by an eavesdropping third party, to
further their potential ability to impersonate the claimant.

target
     The intended second party (other than the source) to
     an authentication exchange.

ticket
     A data structure certifying an authenticating
     (public) key by virtue of being signed by a user principal
     using their (long term) private key. The ticket also
     includes the UID of the principal.

trusted authority
     The public key, name and UID of a
     certification authority trusted in some context to certify
     the public keys of other principals.

UID
     A 128 bit unique identifier produced according to OSF
     standard specifications.

user key
     A "long term" RSA key whose private portion
     authenticates its holder as having the access rights of a
     particular person.

verify
     To cryptographically process a piece of data and a
     digital signature to determine that the holder of a
     particular key signed the data.

verifier
     The party who will perform the operations necessary
     to verify the claimed identity of a claimant.

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Security Considerations

    Security issues are discussed throughout this memo.

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