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Authentication Mechanisms for ONC RPC

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ABSTRACT

This document describes two authentication mechanisms created by Sun Microsystems that are commonly used in conjunction with the ONC Remote Procedure Call (ONC RPC Version 2) protocol.

WARNING

The DH authentication as defined in Section 2 in this document refers to the authentication mechanism with flavor AUTH_DH currently implemented in ONC RPC. It uses the underlying Diffie-Hellman algorithm for key exchange. The DH authentication defined in this document is flawed due to the selection of a small prime for the BASE field (Section 2.5). To avoid the flaw a new DH authentication mechanism could be defined with a larger prime. However, the new DH authentication would not be interoperable with the existing DH authentication.

As illustrated in [10], a large number of attacks are possible on ONC RPC system services that use non-secure authentication mechanisms. Other secure authentication mechanisms need to be developed for ONC RPC. RFC 2203 describes the RPCSEC_GSS ONC RPC security flavor, a secure authentication mechanism that enables RPC protocols to use Generic Security Service Application Program Interface (RFC 2078) to provide security services, integrity and privacy, that are independent of the underlying security mechanisms.

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1. Introduction

The ONC RPC protocol provides the fields necessary for a client to identify itself to a service, and vice-versa, in each call and reply message. Security and access control mechanisms can be built on top of this message authentication. Several different authentication protocols can be supported.

This document specifies two authentication protocols created by Sun Microsystems that are commonly used: Diffie-Hellman (DH) authentication and Kerberos (Version 4) based authentication.

As a prerequisite to reading this document, the reader is expected to be familiar with [1] and [2]. This document uses terminology and definitions from [1] and [2].

2. Diffie-Hellman Authentication

System authentication (defined in [1]) suffers from some problems. It is very UNIX oriented, and can be easily faked (there is no attempt to provide cryptographically secure authentication).

DH authentication was created to address these problems. However, it has been compromised [9] due to the selection of a small length for the prime in the ONC RPC implementation. While the information provided here will be useful for implementors to ensure interoperability with existing applications that use DH authentication, it is strongly recommended that new applications use more secure authentication, and that existing applications that currently use DH authentication migrate to more robust authentication mechanisms.

2.1 Naming

The client is addressed by a simple string of characters instead of by an operating system specific integer. This string of characters is known as the "netname" or network name of the client. The server is not allowed to interpret the contents of the client's name in any other way except to identify the client. Thus, netnames should be unique for every client in the Internet.

It is up to each operating system's implementation of DH authentication to generate netnames for its users that insure this uniqueness when they call upon remote servers. Operating systems already know how to distinguish users local to their systems. It is usually a simple matter to extend this mechanism to the network. For example, a UNIX(tm) user at Sun with a user ID of 515 might be assigned the following netname: "unix.515@sun.com". This netname contains three items that serve to insure it is unique. Going backwards, there is only one naming domain called "sun.com" in the Internet. Within this domain, there is only one UNIX(tm) user with user ID 515. However, there may be another user on another operating system, for example VMS, within the same naming domain that, by coincidence, happens to have the same user ID. To insure that these two users can be distinguished we add the operating system name. So one user is "unix.515@sun.com" and the other is "vms.515@sun.com". The first field is actually a naming method rather than an operating system name. It happens that today there is almost a one-to-one correspondence between naming methods and operating systems. If the world could agree on a naming standard, the first field could be the name of that standard, instead of an operating system name.

2.2 DH Authentication Verifiers

Unlike System authentication, DH authentication does have a verifier so the server can validate the client's credential (and vice-versa). The contents of this verifier are primarily an encrypted timestamp. The server can decrypt this timestamp, and if it is within an accepted range relative to the current time, then the client must have encrypted it correctly. The only way the client could encrypt

it correctly is to know the "conversation key" of the RPC session, and if the client knows the conversation key, then it must be the real client.

The conversation key is a DES [5] key which the client generates and passes to the server in the first RPC call of a session. The conversation key is encrypted using a public key scheme in this first transaction. The particular public key scheme used in DH authentication is Diffie-Hellman [3] with 192-bit keys. The details of this encryption method are described later.

The client and the server need the same notion of the current time in order for all of this to work, perhaps by using the Network Time Protocol [4]. If network time synchronization cannot be guaranteed, then the client can determine the server's time before beginning the conversation using a time request protocol.

The way a server determines if a client timestamp is valid is somewhat complicated. For any other transaction but the first, the server just checks for two things:

(1) the timestamp is greater than the one previously seen from the same client. (2) the timestamp has not expired.

A timestamp is expired if the server's time is later than the sum of the client's timestamp plus what is known as the client's "ttl" (standing for "time-to-live" - you can think of this as the lifetime for the client's credential). The "ttl" is a number the client passes (encrypted) to the server in its first transaction.

In the first transaction, the server checks only that the timestamp has not expired. Also, as an added check, the client sends an encrypted item in the first transaction known as the "ttl verifier" which must be equal to the time-to-live minus 1, or the server will reject the credential. If either check fails, the server rejects the credential with an authentication status of AUTH_BADCRED, however if the timestamp is earlier than the previous one seen, the server returns an authentication status of AUTH_REJECTEDCRED.

The client too must check the verifier returned from the server to be sure it is legitimate. The server sends back to the client the timestamp it received from the client, minus one second, encrypted with the conversation key. If the client gets anything different than this, it will reject it, returning an AUTH_INVALIDRESP authentication status to the user.

2.3 Nicknames and Clock Synchronization

After the first transaction, the server's DH authentication subsystem returns in its verifier to the client an integer "nickname" which the client may use in its further transactions instead of passing its netname. The nickname could be an index into a table on the server which stores for each client its netname, decrypted conversation key and ttl.

Though they originally were synchronized, the client's and server's clocks can get out of synchronization again. When this happens the server returns to the client an authentication status of AUTH_REJECTEDVERF at which point the client should attempt to resynchronize.

A client may also get an AUTH_BADCRED error when using a nickname that was previously valid. The reason is that the server's nickname table is a limited size, and it may flush entries whenever it wants. A client should resend its original full name credential in this case and the server will give it a new nickname. If a server crashes, the entire nickname table gets flushed, and all clients will have to resend their original credentials.

2.4 DH Authentication Protocol Specification

There are two kinds of credentials: one in which the client uses its full network name, and one in which it uses its "nickname" (just an unsigned integer) given to it by the server. The client must use its fullname in its first transaction with the server, in which the server will return to the client its nickname. The client may use its nickname in all further transactions with the server. There is no requirement to use the nickname, but it is wise to use it for performance reasons.

The following definitions are used for describing the protocol:

```
enum authdh_namekind {
   ADN_FULLNAME = 0,
   ADN_NICKNAME = 1
};

typedef opaque des_block[8]; /* 64-bit block of encrypted data */

const MAXNETNAMELEN = 255;   /* maximum length of a netname */
```

The flavor used for all DH authentication credentials and verifiers is "AUTH_DH", with the numerical value 3. The opaque data constituting the client credential encodes the following structure:

```
union authdh_cred switch (authdh_namekind namekind) {
case ADN_FULLNAME:
   authdh_fullname fullname;
case ADN_NICKNAME:
   authdh_nickname nickname;
};
```

The opaque data constituting a verifier that accompanies a client credential encodes the following structure:

```
union authdh_verf switch (authdh_namekind namekind) {
case ADN_FULLNAME:
   authdh_fullname_verf fullname_verf;
case ADN_NICKNAME:
   authdh_nickname_verf nickname_verf;
};
```

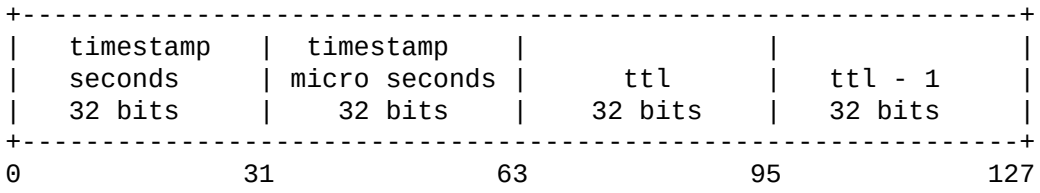
The opaque data constituting a verifier returned by a server in response to a client request encodes the following structure:

```
struct authdh_server_verf;
```

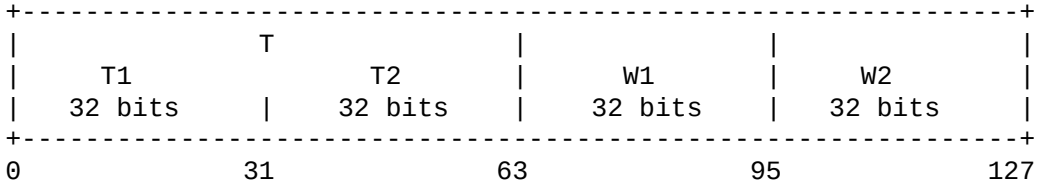
These structures are described in detail below.

2.4.1 The Full Network Name Credential and Verifier (Client)

First, the client creates a conversation key for the session. Next, the client fills out the following structure:



The fields are stored in XDR (external data representation) format. The timestamp encodes the time since midnight, January 1, 1970. These 128 bits of data are then encrypted in the DES CBC mode, using the conversation key for the session, and with an initialization vector of 0. This yields:



where T1, T2, W1, and W2 are all 32-bit quantities, and have some correspondence to the original quantities occupying their positions, but are now interdependent on each other for proper decryption. The 64 bit sequence comprising T1 and T2 is denoted by T.

The full network name credential is represented as follows using XDR notation:

```
struct authdh_fullname {
   string name<MAXNETNAMELEN>;  /* netname of client             */
   des_block key;               /* encrypted conversation key    */
   opaque w1[4];                /* W1                            */
};
```

The conversation key is encrypted using the "common key" using the ECB mode. The common key is a DES key that is derived from the Diffie-Hellman public and private keys, and is described later.

The verifier is represented as follows:

```
struct authdh_fullname_verf {
   des_block timestamp;         /* T (the 64 bits of T1 and T2) */
   opaque w2[4];                /* W2                           */
};
```

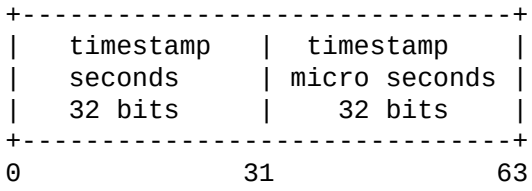
Note that all of the encrypted quantities (key, w1, w2, timestamp) in the above structures are opaque.

The fullname credential and its associated verifier together contain the network name of the client, an encrypted conversation key, the ttl, a timestamp, and a ttl verifier that is one less than the ttl. The ttl is actually the lifetime for the credential. The server will accept the credential if the current server time is "within" the time indicated in the timestamp plus the ttl. Otherwise, the server rejects the credential with an authentication status of AUTH_BADCRED. One way to insure that requests are not replayed would be for the server to insist that timestamps are greater than the previous one seen, unless it is the first transaction. If the timestamp is earlier than the previous one seen, the server returns an authentication status of AUTH_REJECTEDCRED.

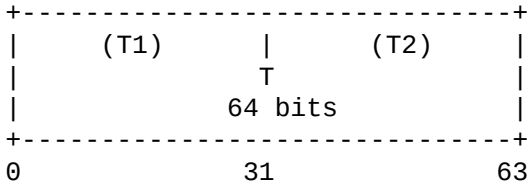
The server returns a authdh_server_verf structure, which is described in detail below. This structure contains a "nickname", which may be used for subsequent requests in the current conversation.

2.4.2 The Nickname Credential and Verifier (Client)

In transactions following the first, the client may use the shorter nickname credential and verifier for efficiency. First, the client fills out the following structure:



The fields are stored in XDR (external data representation) format. These 64 bits of data are then encrypted in the DES ECB mode, using the conversation key for the session. This yields:



The nickname credential is represented as follows using XDR notation:

```
struct authdh_nickname {
   unsigned int nickname;       /* nickname returned by server   */
};
```

The nickname verifier is represented as follows using XDR notation:

```
struct authdh_nickname_verf {
   des_block timestamp;         /* T (the 64 bits of T1 and T2) */
   opaque w[4];                 /* Set to zero                  */
};
```

The nickname credential may be reject by the server for several reasons. An authentication status of AUTH_BADCRED indicates that the nickname is no longer valid. The client should retry the request using the fullname credential. AUTH_REJECTEDVERF indicates that the nickname verifier is not valid. Again, the client should retry the request using the fullname credential.

2.4.3 The Nickname Verifier (Server)

The server never returns a credential. It returns only one kind of verifier, i.e., the nickname verifier. This has the following XDR representation:

```
struct authdh_server_verf {
   des_block timestamp_verf; /* timestamp verifier (encrypted)    */
   unsigned int nickname;    /* new client nickname (unencrypted) */
};
```

The timestamp verifier is constructed in exactly the same way as the client nickname credential. The server sets the timestamp value to the value the client sent minus one second and encrypts it in DES ECB mode using the conversation key. The server also sends the client a nickname to be used in future transactions (unencrypted).

2.5 Diffie-Hellman Encryption

In this scheme, there are two constants "BASE" and "MODULUS" [3]. The particular values Sun has chosen for these for the DH authentication protocol are:

```
   const BASE = 3;
   const MODULUS = "d4a0ba0250b6fd2ec626e7efd637df76c716e22d0944b88b";
```

Note that the modulus is represented above as a hexadecimal string.

The way this scheme works is best explained by an example. Suppose there are two people "A" and "B" who want to send encrypted messages to each other. So, A and B both generate "secret" keys at random which they do not reveal to anyone. Let these keys be represented as SK(A) and SK(B). They also publish in a public directory their "public" keys. These keys are computed as follows:

```
   PK(A) = ( BASE ** SK(A) ) mod MODULUS
   PK(B) = ( BASE ** SK(B) ) mod MODULUS
```

The "**" notation is used here to represent exponentiation. Now, both A and B can arrive at the "common" key between them, represented here as CK(A, B), without revealing their secret keys.

A computes:

```
CK(A, B) = ( PK(B) ** SK(A)) mod MODULUS
```

while B computes:

```
CK(A, B) = ( PK(A) ** SK(B)) mod MODULUS
```

These two can be shown to be equivalent:

```
(PK(B) ** SK(A)) mod MODULUS = (PK(A) ** SK(B)) mod MODULUS
```

We drop the "mod MODULUS" parts and assume modulo arithmetic to simplify things:

```
PK(B) ** SK(A) = PK(A) ** SK(B)
```

Then, replace PK(B) by what B computed earlier and likewise for PK(A).

```
(BASE ** SK(B)) ** SK(A) = (BASE ** SK(A)) ** SK(B)
```

which leads to:

```
BASE ** (SK(A) * SK(B)) = BASE ** (SK(A) * SK(B))
```

This common key CK(A, B) is not used to encrypt the timestamps used in the protocol. Rather, it is used only to encrypt a conversation key which is then used to encrypt the timestamps. The reason for doing this is to use the common key as little as possible, for fear that it could be broken. Breaking the conversation key is a far less damaging, since conversations are relatively short-lived.

The conversation key is encrypted using 56-bit DES keys, yet the common key is 192 bits. To reduce the number of bits, 56 bits are selected from the common key as follows. The middle-most 8-bytes are selected from the common key, and then parity is added to the lower order bit of each byte, producing a 56-bit key with 8 bits of parity.

Only 48 bits of the 8-byte conversation key are used in the DH Authentication scheme. The least and most significant bits of each byte of the conversation key are unused.

3. Kerberos-based Authentication

Conceptually, Kerberos-based authentication is very similar to DH authentication. The major difference is, Kerberos-based authentication takes advantage of the fact that Kerberos tickets have

encoded in them the client name and the conversation key. This RFC does not describe Kerberos name syntax, protocols and ticket formats. The reader is referred to [6], [7], and [8].

3.1 Naming

A Kerberos name contains three parts. The first is the principal name, which is usually a user's or service's name. The second is the instance, which in the case of a user is usually NULL. Some users may have privileged instances, however, such as root or admin. In the case of a service, the instance is the name of the machine on which it runs; that is, there can be an NFS service running on the machine ABC, which is different from the NFS service running on the machine XYZ. The third part of a Kerberos name is the realm. The realm corresponds to the Kerberos service providing authentication for the principal. When writing a Kerberos name, the principal name is separated from the instance (if not NULL) by a period, and the realm (if not the local realm) follows, preceded by an "@" sign. The following are examples of valid Kerberos names:

```
billb
jis.admin
srz@lcs.mit.edu
treese.root@athena.mit.edu
```

3.2 Kerberos-based Authentication Protocol Specification

The Kerberos-based authentication protocol described is based on Kerberos version 4.

There are two kinds of credentials: one in which the client uses its full network name, and one in which it uses its "nickname" (just an unsigned integer) given to it by the server. The client must use its fullname in its first transaction with the server, in which the server will return to the client its nickname. The client may use its nickname in all further transactions with the server. There is no requirement to use the nickname, but it is wise to use it for performance reasons.

The following definitions are used for describing the protocol:

```
enum authkerb4_namekind {
   AKN_FULLNAME = 0,
   AKN_NICKNAME = 1
};
```

The flavor used for all Kerberos-based authentication credentials and verifiers is "AUTH_KERB4", with numerical value 4. The opaque data constituting the client credential encodes the following structure:

```
union authkerb4_cred switch (authkerb4_namekind namekind) {
case AKN_FULLNAME:
   authkerb4_fullname fullname;
case AKN_NICKNAME:
   authkerb4_nickname nickname;
};
```

The opaque data constituting a verifier that accompanies a client credential encodes the following structure:

```
union authkerb4_verf switch (authkerb4_namekind namekind) {
case AKN_FULLNAME:
   authkerb4_fullname_verf fullname_verf;
case AKN_NICKNAME:
   authkerb4_nickname_verf nickname_verf;
};
```

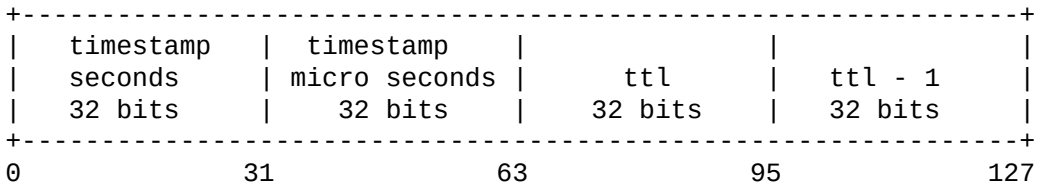
The opaque data constituting a verifier returned by a server in response to a client request encodes the following structure:

```
struct authkerb4_server_verf;
```

These structures are described in detail below.

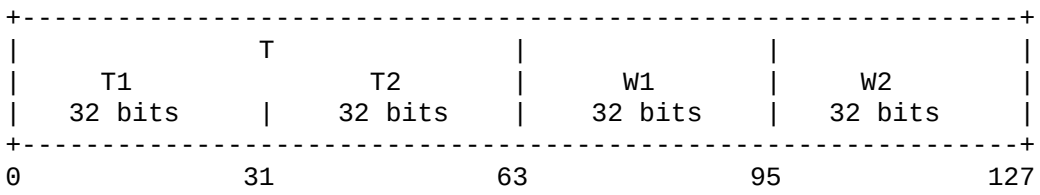
3.2.1 The Full Network Name Credential and Verifier (Client)

First, the client must obtain a Kerberos ticket from the Kerberos Server. The ticket contains a Kerberos session key, which will become the conversation key. Next, the client fills out the following structure:



The fields are stored in XDR (external data representation) format. The timestamp encodes the time since midnight, January 1, 1970. "ttl" is identical in meaning to the corresponding field in Diffie-Hellman authentication: the credential "time-to-live" for the

conversation being initiated. These 128 bits of data are then encrypted in the DES CBC mode, using the conversation key, and with an initialization vector of 0. This yields:



where T1, T2, W1, and W2 are all 32-bit quantities, and have some correspondence to the original quantities occupying their positions, but are now interdependent on each other for proper decryption. The 64 bit sequence comprising T1 and T2 is denoted by T.

The full network name credential is represented as follows using XDR notation:

```
struct authkerb4_fullname {
   opaque ticket<>;         /* kerberos ticket for the server */
   opaque w1[4];            /* W1                             */
};
```

The verifier is represented as follows:

```
struct authkerb4_fullname_verf {
   des_block timestamp;         /* T (the 64 bits of T1 and T2) */
   opaque w2[4];                /* W2                           */
};
```

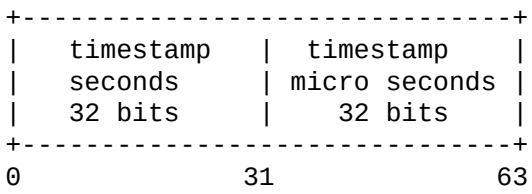
Note that all of the client-encrypted quantities (w1, w2, timestamp) in the above structures are opaque. The client does not encrypt the Kerberos ticket for the server.

The fullname credential and its associated verifier together contain the Kerberos ticket (which contains the client name and the conversation key), the ttl, a timestamp, and a ttl verifier that is one less than the ttl. The ttl is actually the lifetime for the credential. The server will accept the credential if the current server time is "within" the time indicated in the timestamp plus the ttl. Otherwise, the server rejects the credential with an authentication status of AUTH_BADCRED. One way to insure that requests are not replayed would be for the server to insist that timestamps are greater than the previous one seen, unless it is the first transaction. If the timestamp is earlier than the previous one seen, the server returns an authentication status of AUTH_REJECTEDCRED.

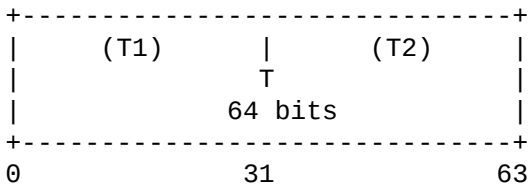
The server returns a authkerb4_server_verf structure, which is described in detail below. This structure contains a "nickname", which may be used for subsequent requests in the current session.

3.2.2 The Nickname Credential and Verifier (Client)

In transactions following the first, the client may use the shorter nickname credential and verifier for efficiency. First, the client fills out the following structure:



The fields are stored in XDR (external data representation) format. These 64 bits of data are then encrypted in the DES ECB mode, using the conversation key for the session. This yields:



The nickname credential is represented as follows using XDR notation:

```
struct authkerb4_nickname {
   unsigned int nickname;       /* nickname returned by server   */
};
```

The nickname verifier is represented as follows using XDR notation:

```
struct authkerb4_nickname_verf {
   des_block timestamp;         /* T (the 64 bits of T1 and T2) */
   opaque w[4];                 /* Set to zero                  */
};
```

The nickname credential may be reject by the server for several reasons. An authentication status of AUTH_BADCRED indicates that the nickname is no longer valid. The client should retry the request using the fullname credential. AUTH_REJECTEDVERF indicates that the nickname verifier is not valid. Again, the client should retry the

request using the fullname credential. AUTH_TIMEEXPIRE indicates that the session's Kerberos ticket has expired. The client should initiate a new session by obtaining a new Kerberos ticket.

3.2.3 The Nickname Verifier (Server)

The server never returns a credential. It returns only one kind of verifier, i.e., the nickname verifier. This has the following XDR representation:

```
struct authkerb4_server_verf {
   des_block timestamp_verf; /* timestamp verifier (encrypted)    */
   unsigned int nickname;    /* new client nickname (unencrypted) */
};
```

The timestamp verifier is constructed in exactly the same way as the client nickname credential. The server sets the timestamp value to the value the client sent minus one second and encrypts it in DES ECB mode using the conversation key. The server also sends the client a nickname to be used in future transactions (unencrypted).

3.2.4 Kerberos-specific Authentication Status Values

The server may return to the client one of the following errors in the authentication status field:

```
enum auth_stat {
    ...
    /*
     * kerberos errors
     */
    AUTH_KERB_GENERIC = 8,  /* Any Kerberos-specific error other
                               than the following                  */
    AUTH_TIMEEXPIRE = 9,    /* The client's ticket has expired     */
    AUTH_TKT_FILE = 10,     /* The server was unable to find the
                               ticket file.  The client should
                               create a new session by obtaining a
                               new ticket                          */
    AUTH_DECODE = 11,       /* The server is unable to decode the
                               authenticator of the client's ticket */
    AUTH_NET_ADDR = 12      /* The network address of the client
                               does not match the address contained
                               in the ticket                       */

    /* and more to be defined */
};
```

4. Security Considerations

The DH authentication mechanism and the Kerberos V4 authentication mechanism are described in this document only for informational purposes.

In addition to the weakness pointed out earlier in this document (see WARNING on page 1), the two security mechanisms described herein lack the support for integrity and privacy data protection. It is strongly recommended that new applications use more secure mechanisms, and that existing applications migrate to more robust mechanisms.

The RPCSEC_GSS ONC RPC security flavor, specified in RFC 2203, allows applications built on top of RPC to access security mechanisms that adhere to the GSS-API specification. It provides a GSS-API based security framework that allows for strong security mechanisms. RFC 1964 describes the Kerberos Version 5 GSS-API security mechanism which provides integrity and privacy, in addition to authentication. RFC 2623 [14] describes how Kerberos V5 is pluggued into RPCSEC_GSS, and how the Version 2 and Version 3 of the NFS protocol use Kerberos V5 via RPCSEC_GSS. The RPCSEC_GSS/GSS-API/Kerberos-V5 stack provides a robust security mechanism for applications that require strong protection.

5. REFERENCES

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