GSI protocol specifications

Purpose of the document

This document describes the XRootD implementation of the GSI protocol [1][2]; the XRootD protocol is described in [3].

The protocol version described in the document corresponds at the head of the GIT master branch at the time of writing, which is supposed to go in v4.9 (internal version of the GSI protocol 10400). This includes the verification of the server identity, as explained in the related section. Notable changes with respect versions prior to v4.9 (internal version lesser or equal to 10300) are described in Appendix C.

Related documents

The cryptographic functions used by the GSI protocol implementation are provided by XrdCrypto [4]. A set of utilities used in common with the PWD authentication modules is provided by XrdSut [5].

Versions

0.0	26 August 2018	Created; Data structures; protocol interface
0.1	16 October 2018	Client handshake steps
0.2	17 October 2018	Server handshake steps
0.3	22 October 2018	More about delegation
0.4	25 October 2018	More about delegation; add sketch of delegation Chain
0.5	21 December 2018	Document XrdSutBuffer / XrdSutBucket serialization, introduction of DH parameters signing, and IV enabling

Authentication protocol interface

Authentication protocols in XRootD are provided as plug-ins. Protocols are identified by a string of max XrdSecPROTOIDSIZE-1 characters. XrdSecPROTOIDSIZE is defined in XrdSec/XrdSecEntity.hh and its value is 8. The ID for the GSI protocol is gsi .

The authentication protocol plug-in must provide a concrete implementation of the the class XrdSecProtocol, defined in XrdSec/XrdSecInterface.hh , in addition to C functions to load and initialize the protocol.

Once the protocol is loaded and initialized, clients will call the method

```
virtual XrdSecCredentials *getCredentials(XrdSecParameters   *parm=0,
                                          XrdOucErrInfo      *einfo=0)=0;
```

to get a buffer of information to be sent to the server, and servers will call

```
virtual int  Authenticate  (XrdSecCredentials  *cred,
                            XrdSecParameters  **parms,
                            XrdOucErrInfo      *einfo=0)
```

on the buffer of information received by the client. The application using the authentication framework and mediating the exchange, has no knowledge of the content of the buffers exchanged, which are produced and analyzed inside the plug-in code.

Data structures

XRootD authentication handshakes use a generic data structure to exchange information between the two parties, client and server. The generic structure, called XrdSecBuffer, is defined in XrdSec/XrdSecInterface.hh . It contains a generic buffer and its size .

The structure XrdSecCredentials, defined in the same file, is typedef from XrdSecBuffer and assumes that the first XrdSecPROTOIDSIZE-1 characters of the buffer contain the protocol name (or ID).

Buffers and Buckets

Internally, `XrdSec` protocol implementations organize the buffer according to needs. The `gsi` protocol interprets the buffer as a serialization of the class `XrdSutBuffer`, defined in [`XrdSut/XrdSutBuffer.hh`](XrdSut/XrdSutBuffer.hh) . The buffer is further organised in buckets (class `XrdSutBucket`; see [`XrdSut/XrdSutBucket.hh`](XrdSut/XrdSutBucket.hh)), which contain the information to be processed.
The members of `XrdSutBuffer` are, in the order:

`XrdSutBuckList`	`fBuckets`	// list of buckets
`XrdOucString`	`fOptions`	// string with options
`XrdOucString`	`fProtocol`	// string with the protocol name or ID
`kXR_int32`	`fStep`	// 32 bit integer with a counter indicating the step of the handshake

The `XrdSutBuckList` class implements a light single-linked list to store and navigate through buckets. The `XrdSutBucket` structure contains:

`kXR_int32`	`type`	// 32 bit integer with the type of the bucket
`kXR_int32`	`size`	// 32 bit integer with the size in bytes
`char*`	`buffer`	// the content of the bucket

`XrdSutBuffer` serialization

The content of XrdSutBuffer is serialized into a buffer of length

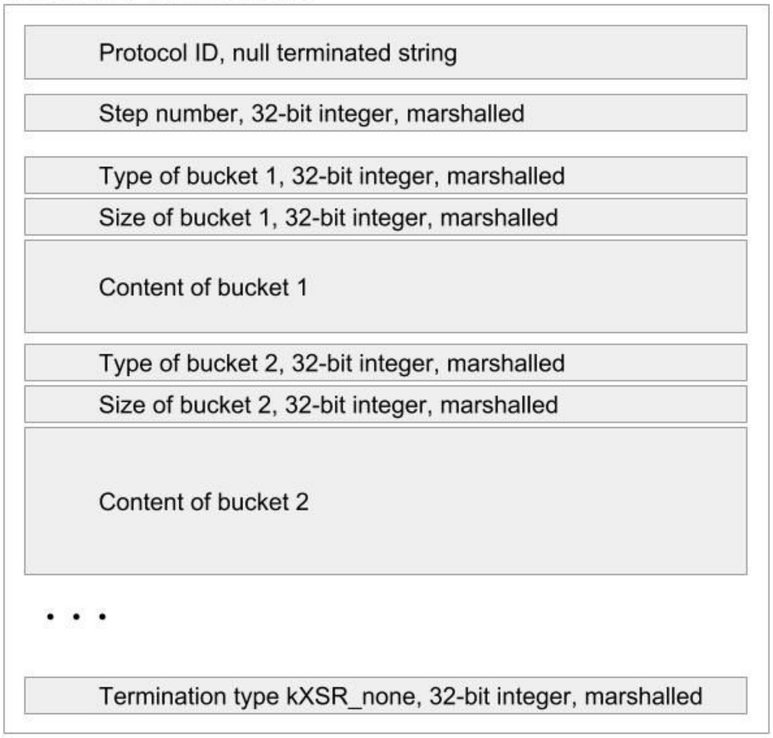
$$\mathtt{fProtocol\_length} + 1 + 2 \cdot S_{32} + N_{\mathtt{buckets}} \cdot 2 \cdot S_{32} + \mathtt{Sum\_of\_bucket\_sizes}$$

(number in bytes). Here S_{32} is `sizeof(kXR_int32)=4`, and $N_{\mathtt{buckets}}$ is the number of bucket in the `XrdSutBuckList` list.
The buffer contains, in order:

1. `fProtocol_length + 1` bytes with the protocol ID; max `XrdSecPROTOIDSIZE;` this is interpreted as a string;
2. S_{32} bytes with the step number, marshalled;
3. For each bucket:
   a. S_{32} bytes with the bucket type, marshalled;
   b. S_{32} bytes with the bucket size, marshalled;
   c. the content of the bucket.
4. S_{32} bytes with the termination type `KXRS_none`, marshalled;

The composition of the buffer is shown graphically in Figure 1.

Figure 1. XrdSutBuffer serialized


Protocol ID, null terminated string
Step number, 32-bit integer, marshalled
Type of bucket 1, 32-bit integer, marshalled
Size of bucket 1, 32-bit integer, marshalled
Content of bucket 1
Type of bucket 2, 32-bit integer, marshalled
Size of bucket 2, 32-bit integer, marshalled
Content of bucket 2
• • •
Termination type kXSR_none, 32-bit integer, marshalled

Bucket types

Bucket types are given by the `enum kXRSBucketTypes` in [`XrdSut/XrdSutAux.hh`]() and reported in Table 1 in Appendix B.

Class members of XrdSecProtocolgsi

The class XrdSecProtocolgsi (XrdSecgsi/XrdSecProtocolgsi.hh) has the following members:

int	options	
XrdCryptoFactory	*sessionCF	Chosen crypto factory
XrdCryptoCipher	*sessionKey	Session Cipher, as result of the handshake
XrdSutBucket	*bucketKey	Bucket with the key in export form
XrdCryptoMsgDigest	*sessionMD	Message Digest (unused during handshake)
XrdCryptoRSA	*sessionKsig	RSA key to sign
XrdCryptoRSA	*sessionKver	RSA key to verify
X509Chain	*proxyChain	Chain with the delegated proxy on servers
bool	srvMode	TRUE if server mode
gsiHSVars	*hs	Temporary handshake information

Ciphers

The shared cipher is generated using the Diffie-Hellman key agreement method [6]. Default ciphers, in order of preference, are:

```
aes-128-cbc bf-cbc des-ede3-cbc.
```

An initialization vector (IV) of 16 bytes (OpenSSL constant EVP_MAX_IV_LENGTH) is generated for each encryption and prepended to the encrypted buffer. To length of the IV is communicated by the client to the server with the name of the chosen cipher (see relevant section).

Delegation options

The proxy delegation options are controlled internally by the settings saved in the Options field of the gsiHSVars instance attached to the protocol. The enum kgsiHandshakeOpts in XrdSecgsi/XrdSecProtocolgsi.hh defines the meaning of the bits, reported in Table 2.

Table 2. Settings controlling proxy delegation

Name	Value	Set by	Comment
`kOptsDlgPxy`	1	S	Ask for a delegated proxy
`kOptsFwdPxy`	2	C	Forward local proxy
`kOptsSigReq`	4	C	Accept to sign delegated proxy
`kOptsSrvReq`	8	S	Server request for delegated proxy
`kOptsPxFile`	16	S	Save delegated proxies in file
`kOptsPxCred`	64	S	Save delegated proxies as credentials

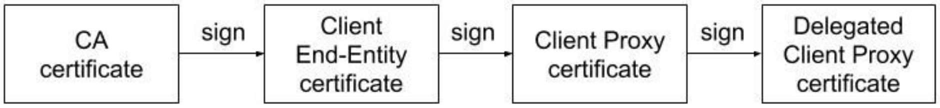
Handshake

Description

The authentication handshake is part of the login process. It is initiated by the server when configured to require strong authentication.

For `gsi` the goal of the handshake is to mutually verify the credentials - the server verifies the client proxy certificate, the client verifies the server certificate, and to create a shared secret to encrypt the rest of the handshake and further communication.

Optionally, after a successful handshake, a delegate client proxy certificate can be produced to enable further authentication handshakes initiated by the server on behalf of the client, for example in the case of a Third Party Copy.
According to the protocol, a delegate client proxy certificate is a proxy certificate generated by the server using as a base the client proxy certificate, and then signed by the client using the private key of its proxy. The full chain for a delegated client proxy certificate is, therefore,


CA certificate
sign
Client End-Entity certificate
sign
Client Proxy certificate
sign
Delegated Client Proxy certificate

To overcome problems with the early versions of openSSL, the XRootD `gsi` implementation supported the option to recreate the full client proxy on the server side by sending over the private key of the client proxy certificate; while still supported, this is to be considered deprecated.

Implementation dissection

The authentication handshake is started by the server and continues until a consensus is reached, failure or success. In the case of a successful handshake, the relevant information about the authenticated client is saved in a instance of the `XrdSecEntity` class owned by the `XrdSecProtocol` instance .

Class gsiHSVars

During the handshake, both parts keep the relevant state of the handshake in a instance of the class `gsiHSVars`, defined in `XrdSecgsi/XrdSecProtocolgsi.hh`. The class `gsiHSVars` contains the following members:

int	Iter	Iteration number
time_t	TimeStamp	Time of last call
XrdOucString	CryptoMod	Crypto module in use
int	RemVers	Version run by remote counterpart
XrdCryptoCipher	*Rcip	Reference cipher
XrdSutBucket	*Cbck	Bucket with the certificate in export form
XrdOucString	ID	Handshake ID (dummy for clients)
XrdSutPFEntry	*Cref	Cache reference
XrdSutPFEntry	*Pent	Pointer to relevant file entry
X509Chain	*Chain	Chain to be eventually verified
XrdCryptoX509Crl	*Crl	Pointer to CRL, if required
X509Chain	*PxyChain	Proxy Chain on clients
bool	RtagOK	Rndm tag checked / not checked
bool	Tty	Terminal attached / not attached
Int	LastStep	Step required at previous iteration
int	Options	Handshake options;
int	HashAlg	Hash algorithm of peer hash name;

`XrdSutBuffer`	`*Parms`	Buffer with server parms (on first iteration)

Global and Main buffers

The message exchanged between client and server corresponds to the serialization of a global buffer, internal name `bpar` . The buffer `bpar` contains *control/auxiliary* information and a buffer with the main information of the handshake serialized (internal name `bmai`).

The *control/auxiliary* information consists in: protocol version number; list of cryptographic modules; hash of the client certificate issuer; client options (delegation).

Steps

The handshake consists in a set of steps. In the implementation the steps are described by dedicated enum variables, defined in `XrdSecgsi/XrdSecProtocolgsi.hh` .

The client steps are enumerated by the enum `kgsiClientSteps`. They describe the handshake steps from the client point of view, and are encoded in the messages send by the client to the server. They are reported in Table 3.

Table 3. Client steps enum types as defined in `XrdSecProtocolgsi.hh`.The Rtag column indicates if an Rtag, signed with the server private key, is present. The last column indicates whether the main buffer bmai is encrypted with the session cipher.

Client step	Code	Description	Rtag	Encrypted
kXGC_none	0			
kXGC_certreq	1000	Request server certificate	Y	N
kXGC_cert	1001	Packet with client (proxy) certificate	Y	Y
kXGC_sigpxy	1002	Packet with signed client proxy certificate	Y	Y

The server steps are enumerated by the enum `kgsiServerSteps`. They describe the handshake steps from the server point of view, and are encoded in the messages send by the server to the client. They are reported in Table 4.

Table 4. Server steps enum types as defined in XrdSecProtocolgsi.hh. The Rtag column indicates if an Rtag, signed with the client private key, is present. The last column indicates whether the main buffer bmai is encrypted with the session cipher.

Server step	Code	Description	Rtag	Encrypted
kXGS_none	0			
kXGS_init	2000	fake code used the first time	N	N
kXGS_cert	2001	packet with server certificate	Y	N
kXGS_pxyreq	2002	packet with client proxy request to be signed	Y	Y

Client side

Common pre-step processing

The information exchanged is first deserialized and then interpreted. The following steps are performed by the client on the buffer received by the server:

1. Update the `TimeStamp` and the internal counter `Iter` in `gsiHSVars`;
2. Deserialize the received buffer (internal name `bpar`);
3. Check the protocol ID string to be "`gsi`";
4. Determine the step required by the server
    a. If `bpar->GetStep()` is null, assume it is `kXGS_init`
5. Make sure that `XrdSecEntity::name` if filled for the protocol instance; honour the env `XrdSecUSER` settings if needed.

The remaining analysis of the received buckets depends on the server step.

Step processing

Step: kXGS_init

Received buffer

The received buffer contains the protocol initialization string:

```
"v:<version>,c:<crypto module>,ca:<hash of server CA>"
```

where:

<version>	protocol version run by the server	int
<crypto module>	pipe '|' separate list of crypto modules	string
<hash of server CA>	pipe '|' separated hashes for the server CA	string

Additional input information

The client also honours possible settings via the login URL. The following variables are checked:

xrd.gsiusrpxy	location of the user proxy	UsrProxy
xrd.gsiusrcrt	location of the user certificate	UsrCert
xrd.gsiusrkey	location of the user certificate key	UsrKey

The last column indicates the name of the internal variable overwritten by the corresponding URL setting.

Actions performed

The client performs the following actions:

1. Parse the protocol initialization string and saves the extracted information in the internal handshake state structure;
2. Resolve, if any, the place-holders in user certificate, key and proxy file paths (`UsrCert`, `UsrKey` and `UsrProxy`, respectively)
3. Loads the local proxy certificate from `/tmp/x509up_u<uid>` or the path defined by the env `X509_USER_PROXY`
    a. If no valid proxies are found, initialize the proxy using the end-user certificate from `$HOME/.globus/usercert.pem` or the path defined by the env `X509_USER_CERT`
        i. If needed - and the process is attached to a TTY - the password for the end-user certificate private key will be prompted; the private key is taken from `$HOME/.globus/userkey.pem` or `X509_USER_KEY` .
    b. Saved in the local `gsiHSVars` state variable for optimized subsequent use
4. Loads the RSA private key of the proxy is loaded in `sessionKsig` and used for signatures .

Preparation of the reply to kXGS_init

The client creates the main handshake information buffer `bmai` as a copy of the received global buffer `bpar` .

The following information is **added** the global buffer `bpar`:

1. A bucket of type `kXRS_cryptomod` with the name of the chosen cryptographic module; `ssl` is the only one available currently;
2. A bucket of type `kXRS_version` with the client version, 32-bit `int`, marshalled;
3. A bucket of type `kXRS_issuer_hash` with the hash of the issuer of the user certificate

   a. For compatibility arguments, more than one hash can be given; these must be separated by a ‘|’.
4. A bucket of type kXRS_clnt_opts with the client options as defined by the Options field of the client gsiHSVars instance, a 32-bit integer, marshalled.

The client sets the next step, internally nextstep, for the server to be kXGC_certreq.

Step: kXGS_cert

Received buffer

The information is contained in both the global and main buffers as described in Tables 5a and 5b.

Table 5a. Content of the global buffer bpar for step kXGS_cert

Bucket Type	*Bucket content*	*Example, comments*
kXRS_cryptomod	const char *	ssl
kXRS_cipher_alg	const char *	aes-128-cbc:bf-cbc:des-ede3-cbc
kXRS_cipher	Raw buffer	DH parameters, signed
kXRS_md_alg	const char *	sha256:sha1
kXRS_x509	const char *	Server certificate, PEM format
kXRS_main	const char *	bmai (see Table 5b), plain text

Table 5b. Content of the global buffer bmai for step kXGS_cert

Bucket Type	*Bucket content*	*Example, comments*
kXRS_signed_rtag	Raw buffer	Client challenge signed
kXRS_rtag	const char *	Server challenge

Actions performed

The client performs the following actions:

1. Check the cached timestamp against the current timestamp; allow for 300 seconds skew;
2. Get from the global buffer the bucket of type kXRS_cipher_alg with the cipher algorithm list supported by the server; chosen the first one supported locally; update the

bucket with the name of the chosen algorithm; the length of the IV which will prefix encrypted buffers is passed as '`#<IV_length>`', for example: `aes-128-cbc#16`

3. Get from the global buffer the bucket of type `kXRS_x509` with the server certificate and used it to finalize the server certificate chain; verify the chain validity.
    a. Drop bucket `kXRS_x509` from the global buffer;
4. Verify the server identity: check the server hostname against the certificate Distinguished Name (DN) and, possibly, the Alternative names;
5. Extract the public key from the server certificate and save it in `sessionKver` ;
6. Get from the global buffer the bucket of type `kXRS_cipher` with the server public parameters for DH key agreement, initialize the session cipher and store it in `sessionKey`;
    a. Drop bucket `kXRS_cipher` from the global buffer;
7. Get from the global buffer the bucket of type `kXRS_md_alg` with the message digest algorithm list supported by the server; chosen the first one supported locally; update the bucket with the name of the chosen algorithm
8. Get from the global buffer the bucket of type `kXRS_main` and deserialize it .

Preparation of the reply to kXGS_cert

The following information is **added** the global buffer `bpar`:

1. A bucket of type `kXRS_puk` with the client public key, extracted from the client certificate and exported into a string in PEM format, i.e. base64 encoded data surrounded by header lines.
2. A bucket of type `kXRS_cipher` with the client public parameters for DH key agreement, signed with the client private key;
3. A bucket of type `kXRS_x509` with the client proxy certificate;

The following information is **added** the global buffer `bmai`:

1. A bucket of type `kXRS_user` with the name of the user.

The client sets the next step, internally `nextstep`, for the server to be `kXGC_cert`.

Step: kXGS_pxyreq

Received buffer

The information is contained in both the global and main buffers as described in Tables 6a and 6b.

Table 6a. Content of the global buffer `bpar` for step `kXGS_pxyreq`

Bucket Type	*Bucket content*	*Example, comments*
`kXRS_cryptomod`	const char *	`ssl`
`kXRS_main`	Raw buffer	`bmai` encrypted with `sessionKey`

Table 6b. Content of the global buffer bmai for step kXGS_pxyreq

Bucket Type	*Bucket content*	*Example, comments*
kXRS_x509_req	const char *	Proxy request, PEM format
kXRS_signed_rtag	Raw buffer	Client challenge signed

Actions performed

The client performs the following actions:

1. Check the cached timestamp against the current timestamp; allow for 300 seconds skew;
2. Get from the global buffer the bucket of type kXRS_main, decrypt with sessionKey and deserialize it
3. If delegation option kOptsSigReq is set
    a. Get from the main buffer the bucket of type kXRS_x509_req with the proxy request; extract the request into a XrdCryptoX509Req instance
    b. Sign the request with the client proxy private key
    c. Export the signed request into a bucket of type kXRS_x509; add the bucket to the main buffer .
4. Else, if delegation option kOptsFwdPxy is set
    a. Export the private key of the client proxy as string; add it to the main buffer as bucket of type kXRS_x509 ;

Preparation of the reply to kXGS_pxyreq

The client sets the next step, internally nextstep, for the server to be kXGC_sigpxy.
In case of errors in the processing of the proxy request, a bucket with the error message is **added** the global buffer bpar.

Common post-step processing

The following actions are performed after the processing of the step peculiarities:

1. The step nextstep is set both in the global buffer and in the main buffer;
2. If a random challenge was present in the received main buffer, in the form of a bucket of type kXRS_rtag, sign the challenge with the private key sessionKsig; the bucket type is updated to kXRS_signed_rtag ;
3. A new random challenge is added to the main bucket as a bucket of type kXRS_rtag ;
4. The new random challenge and the current time stamp are saved to a local cache;

5. The main buffer is serialized; the result of the serialization is used to update - or add - a bucket of type `kXRS_main` into the global buffer.
6. The main bucket is encrypted with session cipher `sessionKey`
    a. This does not apply to the first client step when `sessionKey` is not yet defined
7. The global buffer is serialized; a new instance of `XrdSecCredentials` is created with the result of the serialization, to be handled over to the server .

Errors / failures

The client signals an error condition returning from `getCredentials()` with a null buffer. An error code is filled in the `XrdOucErrInfo` instanced passed as argument to `getCredentials()`. The following error codes can be issued by the client. They are defined in [XrdSecgsi/XrdSecProtocolgsi.hh]() and schematically described in Table 5.

Table 5. Errors issued by clients

Error	Code	Situation
kGSErrParseBuffer	10000	The received buffer could not be parsed
kGSErrDecodeBuffer	10001	Not enough memory for the global buffer
kGSErrBadProtocol	10003	Protocol ID does not match the expected one (gsi)
kGSErrCreateBucket	10004	Bucket can not be created; type in message string
kGSErrSerialBuffer	10007	Main buffer serialization fails
kGSErrBadRndmTag	10011	Random tag check failed
kGSErrNoCipher	10013	No cipher when expected
kGSErrBadOpt	10015	Unrecognized step
kGSErrNoBuffer	10019	No input parameters when expected
kGSErrNoPublic	10021	Problem extracting public component of cipher
kGSErrAddBucket	10022	Bucket can not be added; type in message string
kGSErrInit	10024	Error during protocol initialization
kGSErrError	10026	Generic error

Server side

Common pre-step processing

The information exchanged is first deserialized and then interpreted. The following steps are performed by the server on the buffer received by the client:

1. Update the `TimeStamp` in `gsiHSVars`;
2. Deserialize the received buffer (internal name `bpar`);
3. Check the protocol ID string to be "`gsi`";
4. Determine the step required by the client

The remaining analysis of the received buckets depends on the client step.

Step processing

Step: kXGC_certreq

Received buffer

The information is contained in both the global and main buffers as described in Tables 7a and 7b.

Table 7a. Content of the global buffer `bpar` for step `kXGC_certreq`

Bucket Type	*Bucket content*	*Example | default | comments*
`kXRS_version`	kXR_int32	`10400`, marshalled
`kXRS_cryptomod`	const char *	`ssl`
`kXRS_issuer_hash`	const char *	`5168735f.0|4339b4bc.0`
`kXRS_clnt_opts`	kXR_int32	
`kXRS_main`	const char *	`bmai` (see Table 7b), plain text

Table 7b. Content of the global buffer `bmai` for step `kXGC_certreq`

Bucket Type	*Bucket content*	*Example, comments*
`kXRS_rtag`	const char *	Challenge for the server

Actions performed

The server performs the following actions:

1. Extract from the global buffer the bucket of type kXRS_cryptomod with the list of cryptographic module names supported by the client; load the first supported crypto module available;
2. Extract from the global buffer the bucket of type kXRS_version with gsi protocol version run by the client; unmarshal the content; save the client gsi protocol version in the gsiHSvars instance;
3. Extract from the global buffer the bucket of type kXRS_issuer_hash with the hash of the issuer of the client certificate; load the related CA certificate;
4. Load the RSA private key of the server certificate in sessionKsig , to be used for signatures .
5. Extract from the global buffer the bucket of type kXRS_main with the main bucket; deserialize it;
6. Extract from the global buffer the bucket of type kXRS_clnt_opts with the client options; unmarshal the content; save the options in the gsiHSvars instance;

Preparation of the reply to kXGC_certreq

The following information is **added** the global buffer bpar:

4. A bucket of type kXRS_cipher with the server public part of the cipher;
5. A bucket of type kXRS_cipher_alg with the '|' separated list of supported cipher algorithms, preferred first;
6. A bucket of type kXRS_md_alg with the '|' separated list of supported message digest algorithms, preferred first;
7. A bucket of type kXRS_x509 with the server certificate;

The server sets nextstep for the server to be kXGS_cert. Return kgST_more .

Step: kXGC_cert

Received buffer

The information is contained in both the global and main buffers as described in Tables 8a and 8b.

Table 8a. Content of the global buffer bpar for step kXGC_cert

Bucket Type	*Bucket content*	*Example, comments*
kXRS_cryptomod	const char *	ssl
kXRS_cipher_alg	const char *	aes-128-cbc#16
kXRS_md_alg	const char *	sha256

`kXRS_cipher`	Raw buffer	DH paramaters, signed
`kXRS_puk`	const char *	Client public key, PEM format
`kXRS_main`	Raw buffer	Encrypted with `sessionKey`

Table 8b. Content of the global buffer `bmai` for step `kXGC_cert`

Bucket Type	*Bucket content*	*Example, comments*
`kXRS_signed_rtag`	const char *	Server challenge signed with client private key
`kXRS_rtag`	const char *	Challenge for the server
`kXRS_x509`	const char *	Client proxy certificate, PEM format

Actions performed

The server performs the following actions:

1. Check the cached timestamp against the current timestamp; allow for 300 seconds skew;
2. Get from the global buffer the bucket of type `kXRS_cipher_alg` with the cipher algorithm chosen by the client; cross-check that it is supported locally
    a. Drop bucket `kXRS_cipher_alg` from the global buffer;
3. Get from the global buffer the bucket of type `kXRS_puk` with the client public key in PEM format and import it into `sessionKver`;
4. Get from the global buffer the bucket of type `kXRS_cipher` with the client public parameters for DH key agreement; decrypt the bucket with `sessionKver;` initialize the session cipher and store it in `sessionKey`;
    a. Drop bucket `kXRS_cipher` from the global buffer;
    b. Disable any delegation options if the DH public parameters are not signed;
5. Extract from the global buffer the bucket of type `kXRS_main` with the main bucket; decrypt the bucket with `sessionKey`; deserialize the main buffer;
6. Get from the global buffer the bucket of type `kXRS_x509` with the client proxy certificate and used it to finalize the client proxy certificate chain; verify the chain validity.
    a. Drop bucket `kXRS_x509` from the global buffer;
7. Extract the public key from the client certificate and make sure that it matches the one extracted from the dedicated bucket and previously saved in `sessionKver` ;
8. Get from the global buffer the bucket of type `kXRS_md_alg` with the message digest algorithm chosen by the client; load it in `sessionMD` .
9. If a lookup of the `gridmap` file is required, check the `gridmap` file and fill `Entity.name` with the result; in case of failure, use the DN - or the DN hash, if required;

10. If the extraction of the VOMS attributes is required, call the chosen function and fill the relevant fields in `Entity` with the result;
11. If authorization is required, run the relevant options.
12. If delegate proxies are requested
    a. Save the client proxy certificate chain;
    b. Prepare the proxy request (see dedicated section), save it into a bucket of type `kXRS_x509_req` and add it to the main buffer `bmain`.

Preparation of the reply to kXGC_cert

If delegate proxies are requested

1. Set `nextstep` for the server to be `kXGS_pxyreq`.
2. Return `kgST_more` ;

Otherwise, set `nextstep` for the server to be `kXGS_none`; return `kgST_ok` or `kgST_error`.

Step: kXGC_sigpxy

Received buffer

The information is contained in both the global and main buffers as described in Tables 9a and 9b.

Table 9a. Content of the global buffer `bpar` for step `kXGC_sigpxy`

Bucket Type	*Bucket content*	*Example, comments*
`kXRS_cryptomod`	const char *	`ssl`
`kXRS_main`	Raw buffer	Encrypted with `sessionKey`

Table 8b. Content of the global buffer `bmai` for step `kXGC_cert`

Bucket Type	*Bucket content*	*Example, comments*
`kXRS_x509`	const char *	Client delegated proxy certificate, PEM format
`kXRS_signed_rtag`	const char *	Server challenge signed with client private key

.

Actions performed

The server performs the following actions:

1. Extract from the global buffer the bucket of type `kXRS_main` with the main bucket; decrypt the bucket with `sessionKey`; deserialize the main buffer;
2. Get from the global buffer the bucket of type `kXRS_x509` ; this will contain either the client proxy private key or the full delegate proxy certificate (signed request); use to finalize the delegate client proxy certificate chain;
3. Honour the export options for the delegate proxies
   a. Export the delegated proxy as string and save it to `Entity.creds` ;
   b. If a file is required, extract the bucket with the user name, type `kXRS_user`; prepare the file name, resolving the relevant place-holders, and save the delegated proxy to file.

Preparation of the reply to kXGC_sigpxy

Set `nextstep` for the server to be `kXGS_none`; return `kgST_ok` or `kgST_error`.

Common post-step processing

The following actions are performed after the processing of the step peculiarities:

8. The step `nextstep` is set both in the global buffer and in the main buffer;
9. If a random challenge was present in the received main buffer, in the form of a bucket of type `kXRS_rtag`, sign the challenge with the private key `sessionKsig`; the bucket type is updated to `kXRS_signed_rtag` ;
10. A new random challenge is added to the main bucket as a bucket of type `kXRS_rtag` ;
11. The new random challenge and the current time stamp are saved to a local cache;
12. The main buffer is serialized; the result of the serialization is used to update - or add - a bucket of type `kXRS_main` into the global buffer.
13. The main bucket is encrypted with session cipher `sessionKey`
    a. This does not apply to the first client step when `sessionKey` is not yet defined
14. The global buffer is serialized; a new instance of `XrdSecCredentials` is created with the result of the serialization, to be handled over to the client .

Errors / failures

Servers signals an error condition returning `kgST_error` from `Authenticate()`. An error code is filled in the `XrdOucErrInfo` instanced passed as argument to `Authenticate()`. The following error codes can be issued by the client. They are defined in `XrdSecgsi/XrdSecProtocolgsi.hh` and schematically described in Table 10.

Table 10. Errors issued by servers. An error message is also printed.

Error	Code	Situation
kGSErrParseBuffer	10000	The received buffer could not be parsed
kGSErrDecodeBuffer	10001	Not enough memory for the global buffer
kGSErrBadProtocol	10003	Protocol ID does not match the expected one (gsi)
kGSErrCreateBucket	10004	Bucket can not be created; type in message string
kGSErrSerialBuffer	10007	Main buffer serialization fails
kGSErrBadRndmTag	10011	Random tag check failed
kGSErrBadOpt	10015	Unrecognized step
kGSErrNoPublic	10021	Problem extracting public component of cipher
kGSErrAddBucket	10022	Bucket can not be added; type in message string
kGSErrInit	10024	Error during protocol initialization
kGSErrError	10026	Generic error; typically during sanity checks

(Delegated) Proxy certificates

Proxy certificates are X509 certificates of limited duration, signed by an end-entity certificate, and containing dedicated extensions [2]. A delegated proxy is a X509 proxy certificate issued by a X509 proxy certificate.

The creation of a proxy requires the following steps:

1. Load the end-entity certificate and private key
2. Create a X509 certificate request
3. Generate a private/public key pair; assign it to the X509 request
4. Generate a unique subject name for the proxy certificate:
    a. Duplicate the end-entity certificate subject name
    b. Generate a unique serial number

   c. Add, to the duplicate certificate subject name, the unique serial number as new entry named “CN”
   d. Set the generated subject name in the X509 request

5. Create the extension `certProxyInfo`
   a. Set the policy language on the extension to *inheritALL* [1]
      i. Policy language *independent* [1] and *limited proxy* not implemented
   b. Set the path length constraint, if required
   c. Set the extension OID to “1.3.6.1.5.5.7.1.14”
   d. Flag the extension as critical
   e. Format the extension data for addition to X509 request
   f. Create a stack of extensions; add the extension to the stack, add the stack to the X509 request
   g. Sign the X509 request with the public key of the X509 request
6. Build the proxy certificate
   a. Create an empty X509 certificate
   b. Set the version number to 3 (meaning: ‘extension are present’)
   c. Set serial number, subject name and key from the X509 request
   d. Set the issuer name to the the subject name of the end-entity certificate
   e. Adjust the validity according to needs
   f. Transfer all the extensions from the end-entity certificate
   g. Add the `certProxyInfo` extension from the X509 request
   h. Sign the proxy with the end-entity certificate key

The process can be repeated starting from a X509 proxy certificate instead of a X509 end-entity certificate; that is what is done to generated a delegate proxy.

Server identity verification

A crucial part to avoid man-in-the-middle attacks is the client verification of server identity. The basic idea is that the client knows the name of the server it is contacting and expects to find this name in the DN of the server certificate. Complications arise when hostname aliases are used, and/or when the same server certificate is used by more servers, making use of the Subject Alternative Name (SAN) support.

Support for SAN matching is introduced in v4.9, together with alternative ways to resolve the hostname on the client, without necessarily relying on the DNS.
Despite the version, the client has the possibility to defined exceptions via the environment variable `XrdSecGSISRVNAMES`, a comma-separated list of allowed/disallowed names, supporting wild-cards.

References

[1] RFC 3280, Internet X.509 Public Key Infrastructure Certificate and Certificate Revocation List (CRL) Profile

[2] RFC 3820, Internet X.509 Public Key Infrastructure (PKI) Proxy Certificate Profile

[3] XRootD Protocol Reference (Version 3.1.0, Version 4.x.y)

[4] XrdCrypto: interface to cryptographic functionality for XRooTD; in preparation.

[5] XrdSut: set of utilities used for authentication purposes; in preparation.

[6] RFC 2631: Diffie-Hellman Key Agreement Method

Appendix A - Relevant parts of header files

XrdSecEntity.hh

```
#define XrdSecPROTOIDSIZE 8

class  XrdSecEntity
{
public:
         char   prot[XrdSecPROTOIDSIZE];  // Protocol used
         char   *name;                    // Entity's name
         char   *host;                    // Entity's host name dnr dependent
         char   *vorg;                    // Entity's virtual organization
         char   *role;                    // Entity's role
         char   *grps;                    // Entity's group names
         char   *endorsements;            // Protocol specific endorsements
         char   *moninfo;                 // Additional information for monitoring
         char   *creds;                   // Raw client credentials or certificate
         int     credslen;                // Length of the 'creds' field
         int     rsvd;                    // Reserved field
XrdNetAddrInfo  *addrInfo;                // Connection details from getProtocol
const    char   *tident;                  // Trace identifier always preset
         void   *sessvar;                 // Plugin settable storage pointer
                                          // that is common to the session. Free
                                          // it in your XrdSfsFileSystem::Disc()
                                          // implementation, as needed.
         XrdSecEntity(const char *pName = "")
                     {Reset();
                      strncpy(prot, pName, XrdSecPROTOIDSIZE-1);
                      prot[XrdSecPROTOIDSIZE-1] = '\0';
                     }
        ~XrdSecEntity() {}
         void Reset() {
            memset( prot, 0, XrdSecPROTOIDSIZE );
            name = 0; host = 0; vorg = 0;
            role = 0; grps = 0; endorsements = 0;
            moninfo = 0; creds = 0; credslen = 0;
            rsvd = 0; addrInfo = 0; tident = 0; sessvar = 0;
       }
};
```

XrdSecInterface.hh

```
struct XrdSecBuffer
{
       int   size;    //!< Size of the buffer or length of data in the buffer
       char *buffer;  //!< Pointer to the buffer
       XrdSecBuffer(char *bp=0, int sz=0) : size(sz), buffer(bp), membuf(bp) {}
      ~XrdSecBuffer() {if (membuf) free(membuf);}
private:
        char *membuf; // Stable copy of the buffer address
};

typedef XrdSecBuffer XrdSecCredentials;
typedef XrdSecBuffer XrdSecParameters;

class XrdSecProtocol
{
public:

//------------------------------------------------------------------------------
//! Structure holding the entity's identification. It is filled in by a
//! successful call to Authenticate() (i.e. it returns 0).
//------------------------------------------------------------------------------

XrdSecEntity               Entity;

//------------------------------------------------------------------------------
//! Authenticate a client.
//!
//! @param  cred   Credentials supplied by the client.
//! @param  parms  Place where the address of additional authentication data is
//!                to be placed for another autrhentication handshake.
//! @param  einfo  The error information object where error messages should be
//!                placed. The messages are returned to the client. Should einfo
//!                be null, messages should be written to stderr.
//!
//! @return > 0 -> parms  present (more authentication needed)
//!         = 0 -> Entity present (authentication suceeded)
//!         < 0 -> einfo  present (error has occured)
//------------------------------------------------------------------------------

virtual int                Authenticate  (XrdSecCredentials  *cred,
                                          XrdSecParameters  **parms,
                                          XrdOucErrInfo      *einfo=0)=0;

//------------------------------------------------------------------------------
//! Generate client credentials to be used in the authentication process.
//!
```

```
//! @param  parm   Pointer to the information returned by the server either in
//!                the initial login response or the authmore response.
//! @param  einfo  The error information object where error messages should be
//!                placed. The messages are returned to the client. Should einfo
//!                be null, messages should be written to stderr.
//!
//! @return Success: Pointer to credentials to sent to the server. The caller
//!                  is responsible for deleting the object.
//!         Failure: Null pointer with einfo, if supplied, containing the
//!                  reason for the failure.
//-----------------------------------------------------------------------------

virtual XrdSecCredentials *getCredentials(XrdSecParameters   *parm=0,
                                          XrdOucErrInfo      *einfo=0)=0;

//-----------------------------------------------------------------------------
//! Encrypt data in inbuff using the session key.
//!
//! @param  inbuff   buffer holding data to be encrypted.
//! @param  inlen    length of the data.
//! @param  outbuff  place where a pointer to the encrypted data is placed.
//!
//! @return < 0 Failed, the return value is -errno of the reason. Typically,
//!             -EINVAL    - one or more arguments are invalid.
//!             -NOTSUP    - encryption not supported by the protocol
//!             -ENOENT    - Context not innitialized
//!         = 0 Success, outbuff contains a pointer to the encrypted data.
//!             The caller is responsible for deleting the returned object.
//-----------------------------------------------------------------------------

virtual int     Encrypt(const char    *inbuff,  // Data to be encrypted
                              int      inlen,   // Length of data in inbuff
                        XrdSecBuffer **outbuff  // Returns encrypted data
                             )
{
  (void) inbuff; (void) inlen; (void) outbuff;
  return -ENOTSUP;
}

//-----------------------------------------------------------------------------
//! Decrypt data in inbuff using the session key.
//!
//! @param  inbuff   buffer holding data to be decrypted.
//! @param  inlen    length of the data.
//! @param  outbuff  place where a pointer to the decrypted data is placed.
//!
//! @return < 0 Failed,the return value is -errno (see Encrypt).
//!         = 0 Success, outbuff contains a pointer to the decrypted data.
//!             The caller is responsible for deleting the returned object.
//-----------------------------------------------------------------------------
```

```
virtual int     Decrypt(const char  *inbuff,   // Data to be decrypted
                              int    inlen,    // Length of data in inbuff
                      XrdSecBuffer **outbuff   // Buffer for decrypted data
                              )
{
  (void) inbuff; (void) inlen; (void) outbuff;
  return -ENOTSUP;
}

//------------------------------------------------------------------------------
//! Sign data in inbuff using the session key.
//!
//! @param  inbuff   buffer holding data to be signed.
//! @param  inlen    length of the data.
//! @param  outbuff  place where a pointer to the signature is placed.
//!
//! @return < 0 Failed,the return value is -errno (see Encrypt).
//!         = 0 Success, outbuff contains a pointer to the signature.
//!             The caller is responsible for deleting the returned object.
//------------------------------------------------------------------------------

virtual int     Sign(const char  *inbuff,   // Data to be signed
                           int    inlen,    // Length of data in inbuff
                   XrdSecBuffer **outbuff   // Buffer for the signature
                           )
{
  (void) inbuff; (void) inlen; (void) outbuff;
  return -ENOTSUP;
}

//------------------------------------------------------------------------------
//! Verify a signature using the session key.
//!
//! @param  inbuff   buffer holding data to be verified.
//! @param  inlen    length of the data.
//! @param  sigbuff  pointer to the signature data.
//! @param  siglen   length of the signature data.
//!
//! @return < 0 Failed,the return value is -errno (see Encrypt).
//!         = 0 Success, signature is correct.
//!         > 0 Failed to verify, signature does not match inbuff data.
//------------------------------------------------------------------------------
virtual int     Verify(const char  *inbuff,   // Data to be decrypted
                             int    inlen,    // Length of data in inbuff
                       const char  *sigbuff,  // Buffer for signature
                             int    siglen)   // Length if signature
{
  (void) inbuff; (void) inlen; (void) sigbuff; (void) siglen;
  return -ENOTSUP;
}

//------------------------------------------------------------------------------
//! Get the current encryption key (i.e. session key)
//!
//! @param  buff     buffer to hold the key, and may be null.
//! @param  size     size of the buffer.
//!
//! @returns <  0 Failed, returned value if -errno (see Encrypt)
//!          >= 0 The size of the encyption key. The supplied buffer of length
//!               size hold the key. If the buffer address is supplied, the
//!               key is placed in the buffer.
//!
//------------------------------------------------------------------------------

virtual int     getKey(char *buff = 0, int size = 0)
{
  (void) buff; (void) size;
  return -ENOTSUP;
}

//------------------------------------------------------------------------------
//! Set the current encryption key
//!
//! @param  buff     buffer that holds the key.
//! @param  size     size of the key.
//!
//! @returns: < 0 Failed, returned value if -errno (see Encrypt)
//!           = 0 The new key has been set.
//------------------------------------------------------------------------------

virtual int     setKey(char *buff, int size)
{
  (void) buff; (void) size;
  return -ENOTSUP;
}

//------------------------------------------------------------------------------
//! Delete the protocol object. DO NOT use C++ delete() on this object.
//------------------------------------------------------------------------------

virtual void    Delete()=0; // Normally does "delete this"

//------------------------------------------------------------------------------
//! Constructor
//------------------------------------------------------------------------------

              XrdSecProtocol(const char *pName) : Entity(pName) {}
```

```
protected:
//------------------------------------------------------------------------------
//! Destructor (prevents use of direct delete).
//------------------------------------------------------------------------------

virtual      ~XrdSecProtocol() {}
};
```

XrdSutBucket.hh

```
class XrdSutBucket
{
public:
   kXR_int32   type;
   kXR_int32   size;
   char       *buffer;

   XrdSutBucket(char *bp=0, int sz=0, int ty=0);
   XrdSutBucket(XrdOucString &s, int ty=0);
   XrdSutBucket(XrdSutBucket &b);
   virtual ~XrdSutBucket() {if (membuf) delete[] membuf;}

   void Update(char *nb = 0, int ns = 0, int ty = 0); // Uses 'nb'
   int Update(XrdOucString &s, int ty = 0);
   int SetBuf(const char *nb = 0, int ns = 0);         // Duplicates 'nb'

   void Dump(int opt = 1);
   void ToString(XrdOucString &s);

   // Equality operator
   int operator==(const XrdSutBucket &b);

   // Inequality operator
   int operator!=(const XrdSutBucket &b) { return !(*this == b); }

private:
   char *membuf;
};
```

XrdSutBuckList.hh

```
class XrdSutBuckListNode {
private:
   XrdSutBucket       *buck;
   XrdSutBuckListNode *next;
public:
   XrdSutBuckListNode(XrdSutBucket *b = 0, XrdSutBuckListNode *n = 0)
        { buck = b; next = n;}
   virtual ~XrdSutBuckListNode() { }

   XrdSutBucket       *Buck() const { return buck; }

   XrdSutBuckListNode *Next() const { return next; }

   void SetNext(XrdSutBuckListNode *n) { next = n; }
};

class XrdSutBuckList {

private:
   XrdSutBuckListNode *begin;
   XrdSutBuckListNode *current;
   XrdSutBuckListNode *end;
   XrdSutBuckListNode *previous;
   int                 size;

   XrdSutBuckListNode *Find(XrdSutBucket *b);

public:
   XrdSutBuckList(XrdSutBucket *b = 0);
   virtual ~XrdSutBuckList();

   // Access information
   int                 Size() const { return size; }
   XrdSutBucket       *End() const { return end->Buck(); }

   // Modifiers
   void                PutInFront(XrdSutBucket *b);
   void                PushBack(XrdSutBucket *b);
   void                Remove(XrdSutBucket *b);

   // Pseudo - iterator functionality
   XrdSutBucket       *Begin();
   XrdSutBucket       *Next();
};
```

XrdSutBuffer.hh

```
class XrdSutBuffer {
private:
   XrdSutBuckList         fBuckets;
   XrdOucString           fOptions;
   XrdOucString           fProtocol;
   kXR_int32              fStep;

public:
   XrdSutBuffer(const char *prot, const char *opts = 0)
                 {fOptions = opts; fProtocol = prot; fStep = 0;}
   XrdSutBuffer(const char *buffer, kXR_int32 length);
   virtual ~XrdSutBuffer();

   int         AddBucket(char *bp=0, int sz=0, int ty=0)
                 { XrdSutBucket *b = new XrdSutBucket(bp,sz,ty);
                   if (b) { fBuckets.PushBack(b); return 0;} return -1; }
   int         AddBucket(XrdOucString s, int ty=0)
                 { XrdSutBucket *b = new XrdSutBucket(s,ty);
                   if (b) { fBuckets.PushBack(b); return 0;} return -1; }
   int         AddBucket(XrdSutBucket *b)
                 { if (b) { fBuckets.PushBack(b); return 0;} return -1; }

   int         UpdateBucket(const char *bp, int sz, int ty);
   int         UpdateBucket(XrdOucString s, int ty);

   // Remove from the list, to avoid destroy by ~XrdSutBuffer
   void        Remove(XrdSutBucket *b) { fBuckets.Remove(b); }

   void        Dump(const char *stepstr = 0);
   void        Message(const char *prepose = 0);
   int         Serialized(char **buffer, char opt = 'n');
   void        Deactivate(kXR_int32 type);  // Deactivate bucket (type=-1 for cleanup)

   // To fill / access buckets containing 4-byte integers (status codes, versions ...)
   kXR_int32   MarshalBucket(kXR_int32 type, kXR_int32 code);
   kXR_int32   UnmarshalBucket(kXR_int32 type, kXR_int32 &code);

   XrdSutBucket *GetBucket(kXR_int32 type, const char *tag = 0);
   XrdSutBuckList *GetBuckList() const { return (XrdSutBuckList *)&fBuckets; }
   int         GetNBuckets() const     { return fBuckets.Size(); }
   const char *GetOptions() const      { return fOptions.c_str(); }
   const char *GetProtocol() const     { return fProtocol.c_str(); }
   int         GetStep() const         { return (int)fStep; }
   void        SetStep(int s)   { fStep = (kXR_int32)s; }
   void        IncrementStep()  { fStep++; }
};
```

XrdSutAux.hh (excerpt)

```
#define XrdSutMAXBUF      4096
#define XrdSutMAXPPT      512
#define XrdSutMAXBUCKS    10
#define XrdSutMAXINT64LEN 25
#define XrdSutPRINTLEN    100

enum kXRSBucketTypes {
   kXRS_none     =     0,      // end-of-vector
   kXRS_inactive =     1,      // inactive (dropped at serialization)
   kXRS_cryptomod = 3000,      // 3000    Name of crypto module to use
   kXRS_main,                  // 3001    Main buffer
   kXRS_srv_seal,              // 3002    Server secrets sent back as they are
   kXRS_clnt_seal,             // 3003    Client secrets sent back as they are
   kXRS_puk,                   // 3004    Public Key
   kXRS_cipher,                // 3005    Cipher
   kXRS_rtag,                  // 3006    Random Tag
   kXRS_signed_rtag,           // 3007    Random Tag signed by the client
   kXRS_user,                  // 3008    User name
   kXRS_host,                  // 3009    Remote Host name
   kXRS_creds,                 // 3010    Credentials (password, ...)
   kXRS_message,               // 3011    Message (null-terminated string)
   kXRS_srvID,                 // 3012    Server unique ID
   kXRS_sessionID,             // 3013    Handshake session ID
   kXRS_version,               // 3014    Package version
   kXRS_status,                // 3015    Status code
   kXRS_localstatus,           // 3016    Status code(s) saved in sealed buffer
   kXRS_othercreds,            // 3017    Alternative creds (e.g. other crypto)
   kXRS_cache_idx,             // 3018    Cache entry index
   kXRS_clnt_opts,             // 3019    Client options, if any
   kXRS_error_code,            // 3020    Error code
   kXRS_timestamp,             // 3021    Time stamp
   kXRS_x509,                  // 3022    X509 certificate
   kXRS_issuer_hash,           // 3023    Issuer hash
   kXRS_x509_req,              // 3024    X509 certificate request
   kXRS_cipher_alg,            // 3025    Cipher algorithm (list)
   kXRS_md_alg,                // 3026    MD algorithm (list)
   kXRS_afsinfo,               // 3027    AFS information
   kXRS_reserved               //         Reserved
};
```

XrdSecProtocolgsi.hh

```
/******************************************************************************/
/*                               D e f i n e s                                */
/******************************************************************************/

typedef XrdOucString String;
typedef XrdCryptogsiX509Chain X509Chain;

#define XrdSecPROTOIDENT    "gsi"
#define XrdSecPROTOIDLEN    sizeof(XrdSecPROTOIDENT)
#define XrdSecgsiVERSION    10300
#define XrdSecNOIPCHK       0x0001
#define XrdSecDEBUG         0x1000
#define XrdCryptoMax        10

#define kMAXBUFLEN          1024

//
// Message codes either returned by server or included in buffers
enum kgsiStatus {
   kgST_error    = -1,      // error occured
   kgST_ok       =  0,      // ok
   kgST_more     =  1       // need more info
};

// Client steps
enum kgsiClientSteps {
   kXGC_none = 0,
   kXGC_certreq     = 1000, // 1000: request server certificate
   kXGC_cert,               // 1001: packet with (proxy) certificate
   kXGC_sigpxy,             // 1002: packet with signed proxy certificate
   kXGC_reserved            //
};

// Server steps
enum kgsiServerSteps {
   kXGS_none = 0,
   kXGS_init       = 2000,   // 2000: fake code used the first time
   kXGS_cert,                // 2001: packet with certificate
   kXGS_pxyreq,              // 2002: packet with proxy req to be signed
   kXGS_reserved             //
};

// Handshake options
enum kgsiHandshakeOpts {
   kOptsDlgPxy     = 1,      // 0x0001: Ask for a delegated proxy
   kOptsFwdPxy     = 2,      // 0x0002: Forward local proxy
   kOptsSigReq     = 4,      // 0x0004: Accept to sign delegated proxy
   kOptsSrvReq     = 8,      // 0x0008: Server request for delegated proxy
   kOptsPxFile     = 16,     // 0x0010: Save delegated proxies in file
   kOptsDelChn     = 32,     // 0x0020: Delete chain
   kOptsPxCred     = 64      // 0x0040: Save delegated proxies as credentials
};

// Error codes
enum kgsiErrors {
   kGSErrParseBuffer = 10000,       // 10000
   kGSErrDecodeBuffer,              // 10001
   kGSErrLoadCrypto,                // 10002
   kGSErrBadProtocol,               // 10003
   kGSErrCreateBucket,              // 10004
   kGSErrDuplicateBucket,           // 10005
   kGSErrCreateBuffer,              // 10006
   kGSErrSerialBuffer,              // 10007
   kGSErrGenCipher,                 // 10008
   kGSErrExportPuK,                 // 10009
   kGSErrEncRndmTag,                // 10010
   kGSErrBadRndmTag,                // 10011
   kGSErrNoRndmTag,                 // 10012
   kGSErrNoCipher,                  // 10013
   kGSErrNoCreds,                   // 10014
   kGSErrBadOpt,                    // 10015
   kGSErrMarshal,                   // 10016
   kGSErrUnmarshal,                 // 10017
   kGSErrSaveCreds,                 // 10018
   kGSErrNoBuffer,                  // 10019
   kGSErrRefCipher,                 // 10020
   kGSErrNoPublic,                  // 10021
   kGSErrAddBucket,                 // 10022
   kGSErrFinCipher,                 // 10023
   kGSErrInit,                      // 10024
   kGSErrBadCreds,                  // 10025
   kGSErrError                      // 10026
};

#define REL1(x)     { if (x) delete x; }
#define REL2(x,y)   { if (x) delete x; if (y) delete y; }
#define REL3(x,y,z) { if (x) delete x; if (y) delete y; if (z) delete z; }

#define SafeDelete(x) { if (x) delete x ; x = 0; }
#define SafeDelArray(x) { if (x) delete [] x ; x = 0; }
#define SafeFree(x) { if (x) free(x) ; x = 0; }

// External functions for generic mapping
typedef char *(*XrdSecgsiGMAP_t)(const char *, int);
typedef int (*XrdSecgsiAuthz_t)(XrdSecEntity &);
typedef int (*XrdSecgsiAuthzInit_t)(const char *);
typedef int (*XrdSecgsiAuthzKey_t)(XrdSecEntity &, char **);
// VOMS extraction
typedef XrdSecgsiAuthz_t XrdSecgsiVOMS_t;
typedef XrdSecgsiAuthzInit_t XrdSecgsiVOMSInit_t;
//
// This a small class to set the relevant options in one go
//
class XrdOucGMap;
class XrdOucTrace;
class gsiOptions {
public:
   short  debug;  // [cs] debug flag
   char   mode;   // [cs] 'c' or 's'
   char  *clist;  // [s] list of crypto modules ["ssl" ]
   char  *certdir;// [cs] dir with CA info [/etc/grid-security/certificates]
   char  *crldir; // [cs] dir with CRL info [/etc/grid-security/certificates]
   char  *crlext; // [cs] extension of CRL files [.r0]
   char  *cert;   // [s] server certificate [/etc/grid-security/root/rootcert.pem]
                  // [c] user certificate [$HOME/.globus/usercert.pem]
   char  *key;    // [s] server private key [/etc/grid-security/root/rootkey.pem]
                  // [c] user private key [$HOME/.globus/userkey.pem]
   char  *cipher; // [s] list of ciphers [aes-128-cbc:bf-cbc:des-ede3-cbc]
   char  *md;     // [s] list of MDs [sha256:md5]
   int    crl;    // [cs] check level of CRL's [1]
   int    ca;     // [cs] verification level of CA's [1]
   int    crlrefresh; // [cs] CRL refresh or expiration period in secs [1 day]
   char  *proxy;  // [c] user proxy  [/tmp/x509up_u<uid>]
   char  *valid;  // [c] proxy validity  [12:00]
   int    deplen; // [c] depth of signature path for proxies [0]
   int    bits;   // [c] bits in PKI for proxies [512]
   char  *gridmap;// [s] gridmap file [/etc/grid-security/gridmap]
   int    gmapto; // [s] validity in secs of grid-map cache entries [600 s]
   char  *gmapfun;// [s] file with the function to map DN to usernames [0]
   char  *gmapfunparms;// [s] parameters for the function to map DN to usernames [0]
   char  *authzfun;// [s] file with the function to fill entities [0]
   char  *authzfunparms;// [s] parameters for the function to fill entities [0]
   int    authzto; // [s] validity in secs of authz cache entries [-1 => unlimited]
   int    ogmap;  // [s] gridmap file checking option
   int    dlgpxy; // [c] explicitely ask the creation of a delegated proxy; default 0
                  // [s] ask client for proxies; default: do not accept delegated
                         proxies
   int    sigpxy; // [c] accept delegated proxy requests
   char  *srvnames;// [c] '|' separated list of allowed server names
   char  *exppxy; // [s] template for the exported file with proxies
   int    authzpxy; // [s] if 1 make proxy available in exported form in the
                           'endorsement'
                    //     field of the XrdSecEntity object for use in XrdAcc
   int    vomsat; // [s] 0 do not look for; 1 extract if any
   char  *vomsfun;// [s] file with the function to fill VOMS [0]
   char  *vomsfunparms;// [s] parameters for the function to fill VOMS [0]
   int    moninfo; // [s] 0 do not look for; 1 use DN as default
   int    hashcomp; // [cs] 1 send hash names with both algorithms;
                          0 send only the default [1]

   bool   trustdns; // [cs] 'true' if DNS is trusted [true]

   gsiOptions() { debug = -1; mode = 's'; clist = 0;
                  certdir = 0; crldir = 0; crlext = 0; cert = 0; key = 0;
                  cipher = 0; md = 0; ca = 1 ; crl = 1; crlrefresh = 86400;
                  proxy = 0; valid = 0; deplen = 0; bits = 512;
                  gridmap = 0; gmapto = 600;
                  gmapfun = 0; gmapfunparms = 0; authzfun = 0;
                  authzfunparms = 0; authzto = -1;
                  ogmap = 1; dlgpxy = 0; sigpxy = 1; srvnames = 0;
                  exppxy = 0; authzpxy = 0;
                  vomsat = 1; vomsfun = 0; vomsfunparms = 0; moninfo = 0; hashcomp =
1; trustdns = true; }
   virtual ~gsiOptions() { } // Cleanup inside XrdSecProtocolgsiInit
   void Print(XrdOucTrace *t); // Print summary of gsi option status
};

class XrdSecProtocolgsi;
class gsiHSVars;

// From a proxy query
typedef struct {
   X509Chain        *chain;
   XrdCryptoRSA     *ksig;
   XrdSutBucket     *cbck;
} ProxyOut_t;

// To query proxies
typedef struct {
   const char *cert;
   const char *key;
   const char *certdir;
   const char *out;
   const char *valid;
   int         deplen;
   int         bits;
} ProxyIn_t;

template<class T>
class GSIStack {
public:
   void Add(T *t) {
      char k[40]; snprintf(k, 40, "%p", t);
      mtx.Lock();
      if (!stack.Find(k)) stack.Add(k, t, 0, Hash_count); // We need an additional
                                                             count
      stack.Add(k, t, 0, Hash_count);
      mtx.UnLock();
   }
   void Del(T *t) {
      char k[40]; snprintf(k, 40, "%p", t);
      mtx.Lock();
      if (stack.Find(k)) stack.Del(k, Hash_count);
      mtx.UnLock();
   }
private:
   XrdSysMutex                  mtx;
   XrdOucHash<T> stack;
};

/******************************************************************************/
/*              X r d S e c P r o t o c o l g s i   C l a s s                 */
/******************************************************************************/

class XrdSecProtocolgsi : public XrdSecProtocol
{
friend class gsiOptions;
friend class gsiHSVars;
public:
        int                Authenticate  (XrdSecCredentials *cred,
                                          XrdSecParameters **parms,
                                          XrdOucErrInfo     *einfo=0);

        XrdSecCredentials *getCredentials(XrdSecParameters  *parm=0,
                                          XrdOucErrInfo     *einfo=0);

        XrdSecProtocolgsi(int opts, const char *hname, XrdNetAddrInfo &endPoint,
                                    const char *parms = 0);
        virtual ~XrdSecProtocolgsi() {} // Delete() does it all

        // Initialization methods
        static char      *Init(gsiOptions o, XrdOucErrInfo *erp);

        void              Delete();

        // Encrypt / Decrypt methods
        int               Encrypt(const char *inbuf, int inlen,
                                  XrdSecBuffer **outbuf);
        int               Decrypt(const char *inbuf, int inlen,
                                  XrdSecBuffer **outbuf);
        // Sign / Verify methods
        int               Sign(const char *inbuf, int inlen,
                               XrdSecBuffer **outbuf);
        int               Verify(const char *inbuf, int inlen,
                                 const char *sigbuf, int siglen);
        // Export session key
        int               getKey(char *kbuf=0, int klen=0);
        // Import a key
        int               setKey(char *kbuf, int klen);

        // Enable tracing
        static XrdOucTrace *EnableTracing();

private:
          XrdNetAddrInfo   epAddr;

   // Static members initialized at startup
   static XrdSysMutex      gsiContext;
   static String           CAdir;
   static String           CRLdir;
   static String           DefCRLext;
   static String           SrvCert;
   static String           SrvKey;
   static String           UsrProxy;
   static String           UsrCert;
   static String           UsrKey;
   static String           PxyValid;
   static int              DepLength;
   static int              DefBits;
   static int              CACheck;
   static int              CRLCheck;
   static int              CRLDownload;
   static int              CRLRefresh;
   static String           DefCrypto;
   static String           DefCipher;
   static String           DefMD;
   static String           DefError;
   static String           GMAPFile;
   static int              GMAPOpt;
   static bool             GMAPuseDNname;
   static int              GMAPCacheTimeOut;
   static XrdSecgsiGMAP_t  GMAPFun;
   static XrdSecgsiAuthz_t AuthzFun;
   static XrdSecgsiAuthzKey_t AuthzKey;
   static int              AuthzCertFmt;
   static int              AuthzCacheTimeOut;
   static int              PxyReqOpts;
   static int              AuthzPxyWhat;
   static int              AuthzPxyWhere;
   static String           SrvAllowedNames;
   static int              VOMSAttrOpt;
   static XrdSecgsiVOMS_t  VOMSFun;
   static int              VOMSCertFmt;
   static int              MonInfoOpt;
   static bool             HashCompatibility;
   static bool             TrustDNS;
   //
   // Crypto related info
   static int              ncrypt;                  // Number of factories
   static XrdCryptoFactory *cryptF[XrdCryptoMax];   // their hooks
   static int              cryptID[XrdCryptoMax];   // their IDs
   static String           cryptName[XrdCryptoMax]; // their names
   static XrdCryptoCipher *refcip[XrdCryptoMax];    // ref for session ciphers
   //
   // Caches
   static XrdSutCache   cacheCA;   // Info about trusted CA's
   static XrdSutCache   cacheCert; // Server certificates info cache
   static XrdSutCache   cachePxy;  // Client proxies cache;
   static XrdSutCache   cacheGMAPFun; // Cache for entries mapped by GMAPFun
   static XrdSutCache   cacheAuthzFun; // Cache for entities filled by AuthzFun
   //
   // Services
   static XrdOucGMap      *servGMap;  // Grid mapping service
   //
   // CA and CRL stacks
   static GSIStack<XrdCryptoX509Chain>    stackCA; // Stack of CA in use
   static GSIStack<XrdCryptoX509Crl>      stackCRL; // Stack of CRL in use
   //
   // GMAP control vars
   static time_t           lastGMAPCheck; // time of last check on GMAP
   static XrdSysMutex      mutexGMAP;     // mutex to control GMAP reloads
   //
   // Running options / settings
   static int              Debug;          // [CS] Debug level
   static bool             Server;         // [CS] If server mode
   static int              TimeSkew;       // [CS] Allowed skew in secs for time
                                                   stamps
   //
   // for error logging and tracing
   static XrdSysLogger     Logger;
   static XrdSysError      eDest;
   static XrdOucTrace     *GSITrace;

   // Information local to this instance
   int              options;
   XrdCryptoFactory *sessionCF;    // Chosen crypto factory
   XrdCryptoCipher *sessionKey;    // Session Key (result of the handshake)
   XrdSutBucket    *bucketKey;     // Bucket with the key in export form
   XrdCryptoMsgDigest *sessionMD;  // Message Digest instance
   XrdCryptoRSA    *sessionKsig;   // RSA key to sign
   XrdCryptoRSA    *sessionKver;   // RSA key to verify
   X509Chain       *proxyChain;    // Chain with the delegated proxy on servers
   bool             srvMode;       // TRUE if server mode
```

```
// Temporary Handshake local info
gsiHSVars     *hs;

// Parsing received buffers: client
int            ParseClientInput(XrdSutBuffer *br, XrdSutBuffer **bm,
                                String &emsg);
int            ClientDoInit(XrdSutBuffer *br, XrdSutBuffer **bm,
                            String &cmsg);
int            ClientDoCert(XrdSutBuffer *br,  XrdSutBuffer **bm,
                            String &cmsg);
int            ClientDoPxyreq(XrdSutBuffer *br,  XrdSutBuffer **bm,
                              String &cmsg);

// Parsing received buffers: server
int            ParseServerInput(XrdSutBuffer *br, XrdSutBuffer **bm,
                                String &cmsg);
int            ServerDoCertreq(XrdSutBuffer *br, XrdSutBuffer **bm,
                               String &cmsg);
int            ServerDoCert(XrdSutBuffer *br,  XrdSutBuffer **bm,
                            String &cmsg);
int            ServerDoSigpxy(XrdSutBuffer *br,  XrdSutBuffer **bm,
                              String &cmsg);

// Auxilliary functions
int            ParseCrypto(String cryptlist);
int            ParseCAlist(String calist);

// Load CA certificates
static int     GetCA(const char *cahash,
                     XrdCryptoFactory *cryptof, gsiHSVars *hs = 0);
static String  GetCApath(const char *cahash);
static bool    VerifyCA(int opt, X509Chain *cca, XrdCryptoFactory *cf);
static int     VerifyCRL(XrdCryptoX509Crl *crl,
                         XrdCryptoX509 *xca, XrdOucString crldir,
                         XrdCryptoFactory *CF, int hashalg);
bool           ServerCertNameOK(const char *subject, String &e);
static XrdSutCacheEntry *GetSrvCertEnt(XrdSutCERef   &gcref,
                                       XrdCryptoFactory *cf,
                                       time_t timestamp, String &cal);

// Load CRLs
static XrdCryptoX509Crl *LoadCRL(XrdCryptoX509 *xca, const char *sjhash,
                                 XrdCryptoFactory *CF, int dwld, int &err);

// Updating proxies
static int     QueryProxy(bool checkcache, XrdSutCache *cache, const char *tag,
                          XrdCryptoFactory *cf, time_t timestamp,
                          ProxyIn_t *pi, ProxyOut_t *po);
static int     InitProxy(ProxyIn_t *pi, XrdCryptoFactory *cf,
                         X509Chain *ch = 0, XrdCryptoRSA **key = 0);
```

```
   // Error functions
   static void    ErrF(XrdOucErrInfo *einfo, kXR_int32 ecode,
                       const char *msg1, const char *msg2 = 0,
                       const char *msg3 = 0);
   XrdSecCredentials *ErrC(XrdOucErrInfo *einfo, XrdSutBuffer *b1,
                           XrdSutBuffer *b2,XrdSutBuffer *b3,
                           kXR_int32 ecode, const char *msg1 = 0,
                           const char *msg2 = 0, const char *msg3 = 0);
   int            ErrS(String ID, XrdOucErrInfo *einfo, XrdSutBuffer *b1,
                       XrdSutBuffer *b2, XrdSutBuffer *b3,
                       kXR_int32 ecode, const char *msg1 = 0,
                       const char *msg2 = 0, const char *msg3 = 0);

   // Check Time stamp
   bool           CheckTimeStamp(XrdSutBuffer *b, int skew, String &emsg);

   // Check random challenge
   bool           CheckRtag(XrdSutBuffer *bm, String &emsg);

   // Auxilliary methods
   int            AddSerialized(char opt, kXR_int32 step, String ID,
                                XrdSutBuffer *bls, XrdSutBuffer *buf,
                                kXR_int32 type, XrdCryptoCipher *cip);
   // Grid map cache handling
   static XrdSecgsiGMAP_t            // Load alternative function for mapping
                  LoadGMAPFun(const char *plugin, const char *parms);
   static XrdSecgsiAuthz_t           // Load alternative function to fill XrdSecEntity
                  LoadAuthzFun(const char *plugin, const char *parms, int &fmt);
   static XrdSecgsiVOMS_t           // Load alternative function to extract VOMS
                  LoadVOMSFun(const char *plugin, const char *parms, int &fmt);
   static void    //Lookup info for DN
                  QueryGMAP(XrdCryptoX509Chain* chain, int now, String &name);

   // Entity handling
   void CopyEntity(XrdSecEntity *in, XrdSecEntity *out, int *lout = 0);
   void FreeEntity(XrdSecEntity *in);

   // VOMS parsing
   int ExtractVOMS(X509Chain *c, XrdSecEntity &ent);
};

class gsiHSVars {
public:
   int               Iter;          // iteration number
   time_t            TimeStamp;     // Time of last call
   String            CryptoMod;     // crypto module in use
   int               RemVers;       // Version run by remote counterpart
   XrdCryptoCipher  *Rcip;          // reference cipher
   XrdSutBucket     *Cbck;          // Bucket with the certificate in export form
   String            ID;            // Handshake ID (dummy for clients)
   XrdSutPFEntry    *Cref;          // Cache reference
   XrdSutPFEntry    *Pent;          // Pointer to relevant file entry
   X509Chain        *Chain;         // Chain to be eventually verified
   XrdCryptoX509Crl *Crl;           // Pointer to CRL, if required
   X509Chain        *PxyChain;      // Proxy Chain on clients
   bool              RtagOK;        // Rndm tag checked / not checked
   bool              Tty;           // Terminal attached / not attached
   int               LastStep;      // Step required at previous iteration
   int               Options;       // Handshake options;
   int               HashAlg;       // Hash algorithm of peer hash name;
   XrdSutBuffer     *Parms;         // Buffer with server parms on first iteration

   gsiHSVars() { Iter = 0; TimeStamp = -1; CryptoMod = "";
                 RemVers = -1; Rcip = 0;
                 Cbck = 0;
                 ID = ""; Cref = 0; Pent = 0; Chain = 0; Crl = 0; PxyChain = 0;
                 RtagOK = 0; Tty = 0; LastStep = 0; Options = 0; HashAlg = 0;
                 Parms = 0;}

   ~gsiHSVars() { SafeDelete(Cref);
                  if (Options & kOptsDelChn) {
                     // Do not delete the CA certificate in the cached reference
                     if (Chain) Chain->Cleanup(1);
                     SafeDelete(Chain);
                  }
                  if (Crl) {
                     // This decreases the counter and actually deletes the object
                     // only when no instance is using it
                     XrdSecProtocolgsi::stackCRL.Del(Crl);
                     Crl = 0;
                  }
                  // The proxy chain is owned by the proxy cache; invalid proxies are
                  // detected (and eventually removed) by QueryProxy
                  PxyChain = 0;
                  SafeDelete(Parms); }
   void Dump(XrdSecProtocolgsi *p = 0);
};
```

Appendix B - Details of bucket types

Table 1. Bucket types as defined in `XrdSutAux.hh`. Last column indicates those used by `gsi`.

Name	Number	Description	Used by `gsi`
kXRS_none	0	end-of-vector	
kXRS_inactive	1	inactive (dropped at serialization)	y
kXRS_cryptomod	3000	Name of crypto module to use	y
kXRS_main	3001	Main buffer	y
kXRS_srv_seal	3002	Server secrets sent back as they are	y
kXRS_clnt_seal	3003	Client secrets sent back as they are	y
kXRS_puk	3004	Public Key	y
kXRS_cipher	3005	Cipher	y
kXRS_rtag	3006	Random Tag	y
kXRS_signed_rtag	3007	Random Tag signed by the client	y
kXRS_user	3008	User name	
kXRS_host	3009	Remote Host name	
kXRS_creds	3010	Credentials (password, ...)	
kXRS_message	3011	Message (null-terminated string)	
kXRS_srvID	3012	Server unique ID	
kXRS_sessionID	3013	Handshake session ID	
kXRS_version	3014	Package version	y
kXRS_status	3015	Status code	y
kXRS_localstatus	3016	Status code(s) saved in sealed buffer	
kXRS_othercreds	3017	Alternative creds (e.g. other crypto)	

kXRS_cache_idx	3018	Cache entry index	
kXRS_clnt_opts	3019	Client options, if any	
kXRS_error_code	3020	Error code	
kXRS_timestamp	3021	Time stamp	
kXRS_x509	3022	X509 certificate	y
kXRS_issuer_hash	3023	Issuer hash	
kXRS_x509_req	3024	X509 certificate request	y
kXRS_cipher_alg	3025	Cipher algorithm (list)	y
kXRS_md_alg	3026	MD algorithm (list)	y
kXRS_afsinfo	3027	AFS information	
kXRS_reserved	3028	Reserved	

Appendix C - Versions prior to 10400 / v4.9

Server host name verification

The way XrdSecProtocolgsi handles this changed in XRootD v4.9 . Before v4.9 the client relied on the DNS to de-alias the hostname and compares this with the common name found in the server certificate DN. SANs were ignored.

Transmission of DH parameters

Before v4.9 (internal GSI version 10400) the DH parameters were transmitted unsigned in a bucket of type `kXRS_puk` . Processing of the related steps on client and server side are described below.

Client: step kXGS_cert processing

Received buffer

The information is contained in both the global and main buffers.

Actions performed

The client performs the following actions:

9. Check the cached timestamp against the current timestamp; allow for 300 seconds skew;
10. Get from the global buffer the bucket of type `kXRS_cipher_alg` with the cipher algorithm list supported by the server; chosen the first one supported locally; update the bucket with the name of the chosen algorithm;
11. Get from the global buffer the bucket of type `kXRS_puk` with the server public key for DH key agreement, initialize the session cipher and store it in `sessionKey`;
    a. Drop bucket `kXRS_puk` from the global buffer;
12. Get from the global buffer the bucket of type `kXRS_x509` with the server certificate and used it to finalize the server certificate chain; verify the chain validity.
    a. Drop bucket `kXRS_x509` from the global buffer;
13. Verify the server identity: check the server hostname against the certificate Distinguished Name (DN) and, possibly, the Alternative names;
14. Extract the public key from the server certificate and save it in `sessionKver` ;
15. Get from the global buffer the bucket of type `kXRS_md_alg` with the message digest algorithm list supported by the server; chosen the first one supported locally; update the bucket with the name of the chosen algorithm
16. Get from the global buffer the bucket of type `kXRS_main` and deserialize it .

Preparation of the reply to kXGS_cert

The following information is **added** the global buffer `bpar`:

8. A bucket of type `kXRS_puk` with the client public part of the cipher;
9. A bucket of type `kXRS_x509` with the client proxy certificate;
10. A bucket of type `kXRS_user` with the name of the user;

The client sets the next step, internally `nextstep`, for the server to be `kXGC_cert`.

Server: step kXGC_cert processing

Received buffer

The information is contained in both the global and main buffers.

Actions performed

The server performs the following actions:

13. Check the cached timestamp against the current timestamp; allow for 300 seconds skew;
14. Get from the global buffer the bucket of type `kXRS_cipher_alg` with the cipher algorithm list supported by the server; chosen the first one supported locally; update the bucket with the name of the chosen algorithm
15. Get from the global buffer the bucket of type `kXRS_puk` with the server public part for session cipher initialize the session cipher and store it in `sessionKey`;
    a. Drop bucket `kXRS_puk` from the global buffer;
16. Extract from the global buffer the bucket of type `kXRS_main` with the main bucket; decrypt the bucket with `sessionKey`; deserialize the main buffer;
17. Get from the global buffer the bucket of type `kXRS_x509` with the client proxy certificate and used it to finalize the client proxy certificate chain; verify the chain validity.
    a. Drop bucket `kXRS_x509` from the global buffer;
18. Verify the server identity: check the server hostname against the certificate Distinguished Name (DN) and, possibly, the Alternative names;
19. Extract the public key from the server certificate and save it in `sessionKver` ;
20. If delegate proxies are requested save the client proxy certificate chain;
21. If a request for delegate proxy certificate is required, prepare it and save it into a bucket of type `kXRS_x509_req`;
22. Get from the global buffer the bucket of type `kXRS_md_alg` with the message digest algorithm chosen by the client; load it in `sessionMD` .
23. If a lookup of the `gridmap` file is required, check the `gridmap` file and fill `Entity.name` with the result; in case of failure, use the DN - or the DN hash, if required;

24. If the extraction of the VOMS attributes is required, call the chosen function and fill the relevant fields in `Entity` with the result;
25. If authorization is required, run the relevant options.