The Rabbit Embedded Security Pack

The Rabbit Embedded Security Pack is a Dynamic C add-on module. It is composed of three main software packages:

- SSL/TLS[1]
- AES
- Wi-Fi Enterprise Mode Authentication

SSL is essentially an encryption framework protocol and AES is one of the strongest encryption standards that can be selected for use within an SSL-secured communications channel. The AES software package can also be used independently from the SSL software. SSL is discussed in Section 1 and the AES protocol is discussed in Section 2.

Wi-Fi Enterprise mode authentication uses the most secure protocols available to ensure mutual authentication and efficient dynamic key distribution. Also known as WPA-Enterprise and/or WPA2-Enterprise, this topic is discussed in Section 3.

The Rabbit Embedded Security Pack is available for purchase on the Rabbit web site:

`www.rabbit.com/store/index.shtml`

Documentation for the security pack is also available online (follow the link for Dynamic C):

`www.rabbit.com/docs/`

Uses for the Rabbit Embedded Security Pack are many. Any application that needs to transmit data over an unsecured network is a potential candidate. The Rabbit Embedded Security Pack provides security, and more importantly, peace of mind. It protects your data from eavesdroppers and tampering.

The following are potential applications for the Rabbit Embedded Security Pack.

- Internet-enabled vending machines
- Internet-enabled home automation systems
- Network-enabled medical devices
- Web-configurable telephone switches
- Remote-entry configuration
- Internet-enabled monitoring and billing

1. The IETF TLS 1.0 is the most widely-used standard for SSL, replacing Netscape's SSL version 3. By default, many browsers have both SSL 3.0 and TLS 1.0 enabled. The Rabbit Embedded Security Pack supports both. The terms "SSL" and "TLS" are used interchangeably in the software naming conventions and code comments, as well as in this document.

1. Secure Sockets Layer (SSL) Protocol

SSL is the security protocol used in almost all secure Internet transactions. Essentially, SSL transforms TCP into a secure communications channel without the need for either of the communicating parties to meet to exchange keys.

The goals of SSL are:

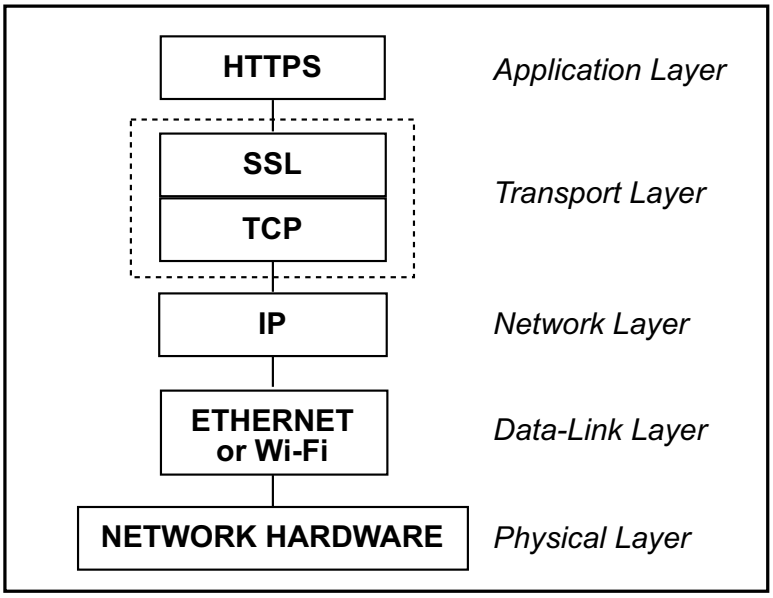
- **Authentication** - provided by a collection of identification data in a standardized format that is called a Certificate.
- **Confidentiality** - provided by a combination of public key and symmetric key cryptography.
- **Data Integrity** - provided by message digest algorithms (a.k.a., hashing algorithms).

SSL defines a framework by which a secure communications channel can be established; it allows negotiation of the cryptographic algorithms to be used for each transaction. The Rabbit Embedded Security Pack supports:

- RSA for public key cryptography (key exchange and authentication)
- AES and RC4 for symmetric key cryptography (data privacy)
- MD5 and SHA-1 for message digest algorithms (data integrity)

SSL is designed to work with a transport layer protocol, typically TCP. Figure 1 shows how the SSL protocol fits into the overall TCP/IP reference model.

Figure 1. How SSL Fits Into the 5-Layer TCP/IP Reference Model



SSL uses a client/server model. The Rabbit Embedded Security Pack implements an SSL/TLS server for use with HTTPS. There is also a TLS client implemented for internal use only with Wi-Fi Enterprise mode authentication.

1.1 Overview of SSL Information

The SSL information is arranged to help the reader start developing secure applications right away.

Section 1.2 lists the hardware and software requirements.

Section 1.3 gives a complete start-to-finish walk-through that details the creation of a digital certificate and setting up a secure HTTP server using that certificate.

Section 1.4 covers the basics of the SSL handshake and SSL sessions.

Section 1.5 covers details specific to the Rabbit implementation of SSL.

Section 1.6 is a reference for the certificate utility that covers the advanced interface in detail (the wizard interface is covered in the walk-through).

The appendices are primarily for reference.

Appendix A: introduces cryptography and some of the principles behind the design of SSL.

Appendix B: gives an in-depth explanation of digital certificates, which will help advanced users with certificate management and use.

Appendix C: WPA supplicant license agreement.

Appendix D: lists references for further study.

1.2 Hardware and Software Requirements

Starting with Revision C (see part # / rev. letter in footer of first page: 020-0143 Rev.C)), this manual assumes a minimum configuration of a Rabbit 4000 running Dynamic C 10.54. Revision B of this manual should be consulted if you are using a Rabbit 3000A or have a Dynamic C version earlier than 10.54.

The following minimum requirements must be met to run SSL on a Rabbit-based board.

- Starting with the Rabbit 3000 Rev. A, all Rabbit microprocessors support SSL
- Dynamic C v. 8.30 - 9.6x to support Rev. A of the Rabbit 3000
- Dynamic C v. 10 or better to support the Rabbit 4000.
- Dynamic C v. 10.54 or better to support the improvements documented in this manual.
- Minimum 256KB flash (512KB recommended)
- Minimum 256KB RAM (512 KB recommended)
- Network connectivity with TCP/IP
- Single thread only with 2–4KB stack in µC/OS applications (some SSL functions are not re-entrant)

1.3 SSL Walk-Through

This walk-through explains the setup and execution of a simple HTTPS server on a Rabbit-based device. There are six steps:

1. Section 1.3.1 “Create a Digital Certificate”

2. Section 1.3.2 “Import the Certificate”

3. Section 1.3.3 “Set Up TCP/IP for the Sample Application”

4. Section 1.3.4 “Set Up the Application to Use SSL”

5. Section 1.3.5 “Set Up the Web Browser”

6. Section 1.3.6 “Run the Application”

1.3.1 Create a Digital Certificate

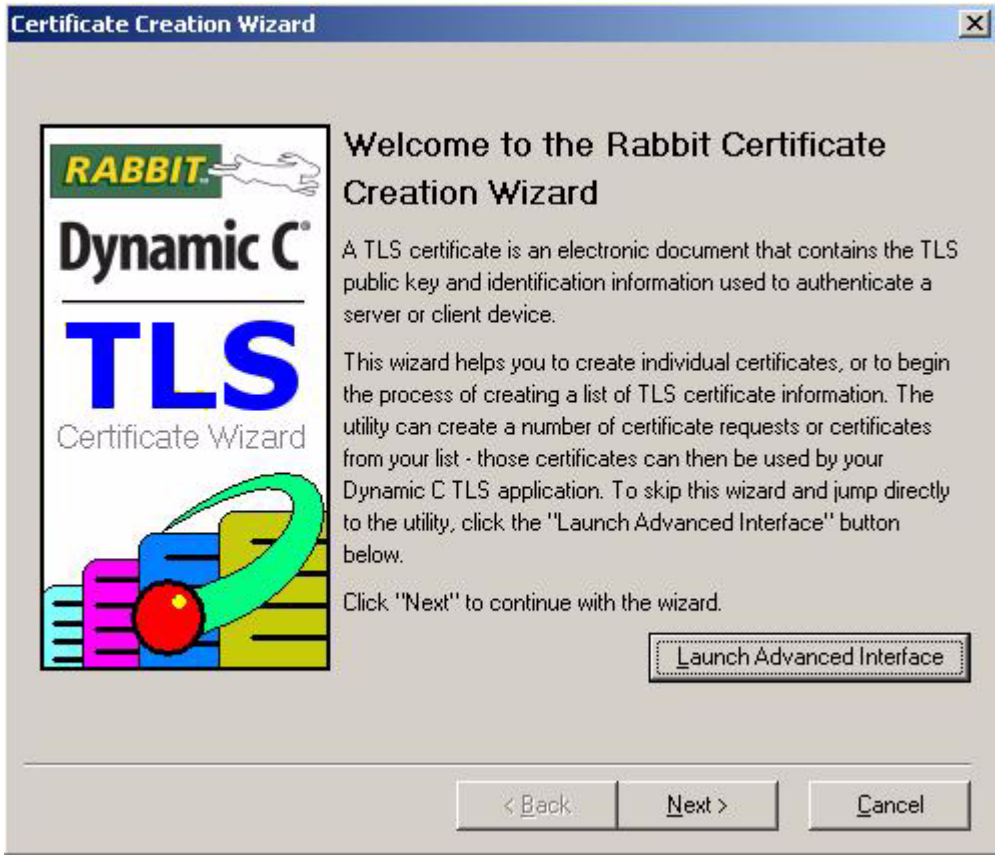
The first step in setting up an SSL-enabled server is to create your digital certificate. This can be done using the Rabbit Certificate Utility, which is included in the Rabbit Embedded Security Pack. The utility can be found in `..\Utilities\SSL_Utilities` under the root Dynamic C installation directory. Start the utility by double-clicking `certificate.exe`.

This walk-through shows you how to create your own Certificate Authority (CA) and its accompanying root CA certificate,[2] and how to create a certificate signed by that root CA. A certificate signed by a root CA certificate is only one of the three types of certificates that can be created using the Rabbit Certificate Utility. See Appendix B: "SSL Certificates" for more information on certificates and certificate types.

1. Start the Wizard

The utility opens with a welcome screen using the wizard interface. The wizard interface contains everything you need to create your own certificates. The advanced interface is accessed by clicking "Launch Advanced Interface" on the welcome screen. The advanced interface is covered in Section 1.6.2.

Figure 2.



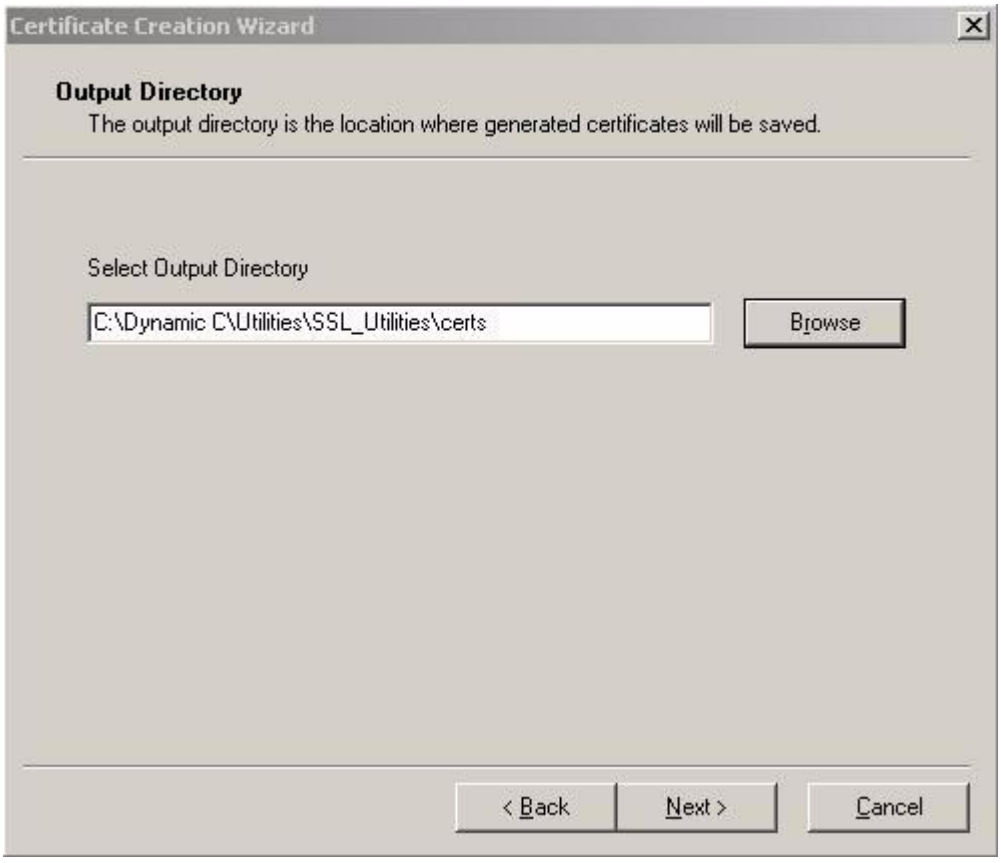
This walk-through uses the wizard interface, not the advanced interface of the utility, so click "Next" to continue.

2. A Certificate Authority (CA) provides the service of verifying the identity of a certificate owner using conventional means, then signs that owner's certificate using their own private key. The root CA certificate is a self-signed certificate that originates from a trusted source, and represents the ultimate guarantee that a certificate being checked is genuine. See Appendix B: for more information.

2. Set the Output Directory

The second panel of the wizard interface displays the output directory edit box. The output directory is where the utility will save the generated certificates. Several files will be generated for each certificate, so it is always a good idea to use an empty directory for your certificate output. (The generated files are described in Section 1.6.7.)

Figure 3.



By default, the edit box displays `\Utilities\SSL_Utilities\certs` relative to the Dynamic C installation directory, as shown in the screen shot above.

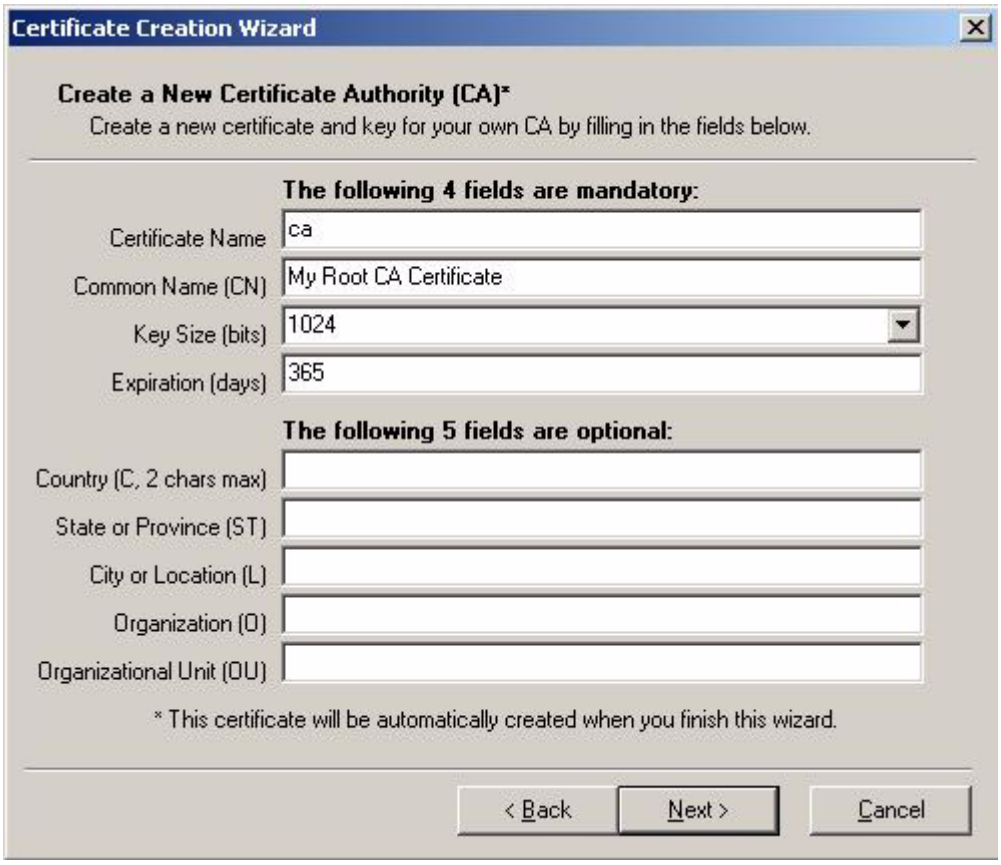
Use the "Browse" button to set the output directory to `\Samples\TCPIP\SSL\HTTPS\cert`, relative to the Dynamic C installation directory.

Click "Next."

3. Select the Signing Options and Create a Root CA Certificate

On the third panel, click the radio button labeled “Create your Own Certificate Authority (CA)”. Then click “Next”. You should see the “Create a New Certificate Authority (CA)” panel, where you can enter the information for your new Certificate Authority (CA) that will be stored in your root CA certificate.

Figure 4.



Enter “ca” in the Certificate Name field. This text will be used as a base name for the certificate files, so it should only contain characters that are valid in file names. For the Common Name, enter “My Root CA Certificate”.

The other two fields, Key Size and Expiration, display with their default values of 1024 bits and 365 days, respectively.[3] Increasing the expiration interval for the CA is recommended. See Section 1.6.8.4 for advice on the expiration date to use. See Section 1.6.8.3 for more information on the key size.

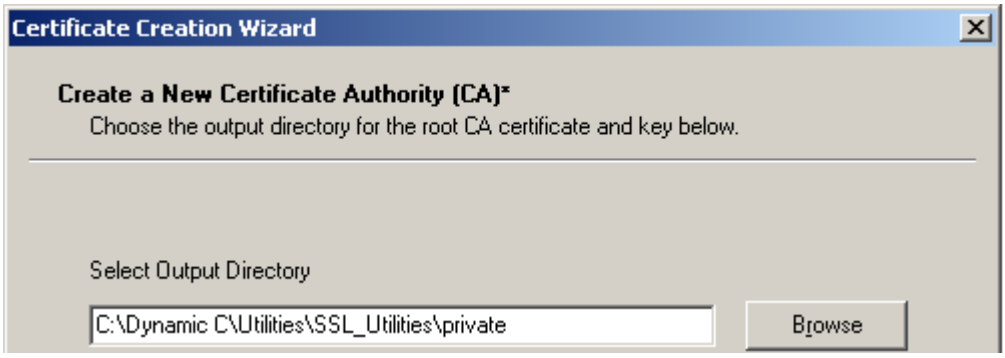
You may fill in the optional fields if desired, then click “Next.”

3. Prior to Dynamic C 10.54, the key and expiration values also defaulted to 1024 and 365, but were not modifiable.

4. Select the Output Directory for the Root CA Certificate

The default path for an output directory for your new root CA certificate is shown here in Figure 5.

Figure 5.



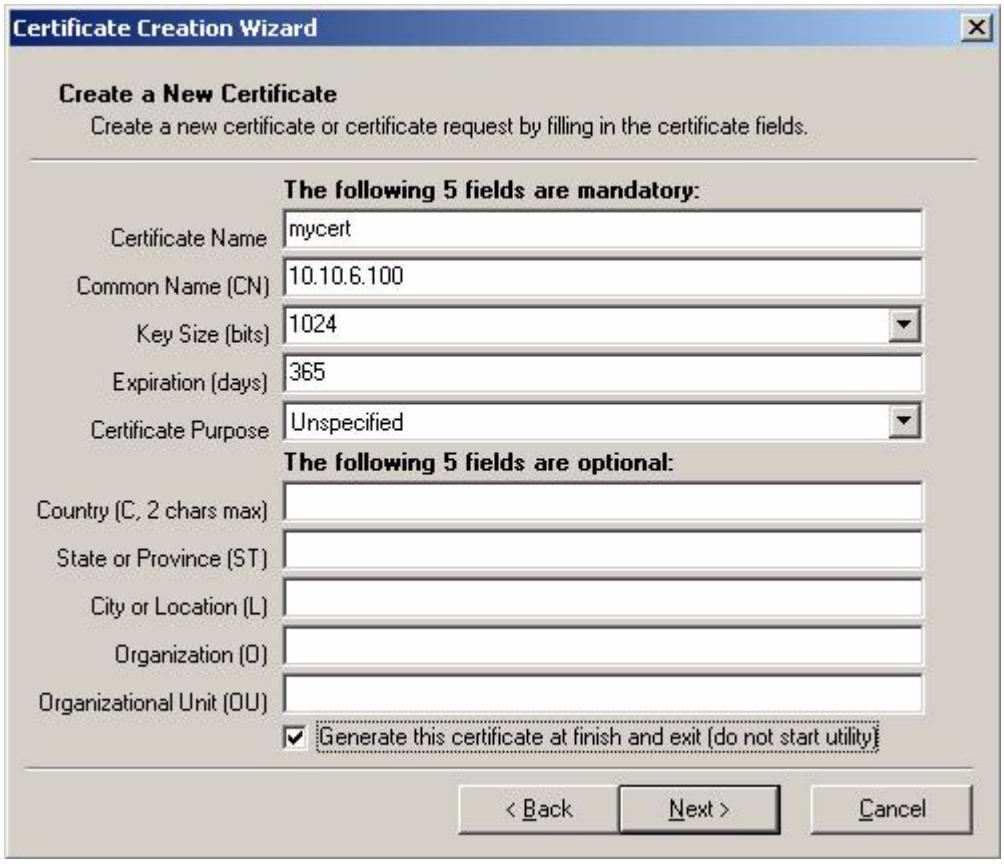
Select this default by clicking "Next."

The root CA certificate will be created when you finish the wizard. This is the certificate you will need to install in your browser later to allow the browser to accept the certificate you will create next. Remember where your root CA certificate is for the browser setup.

5. Create the Device Certificate

Now you will create the certificate that will be loaded onto your device.

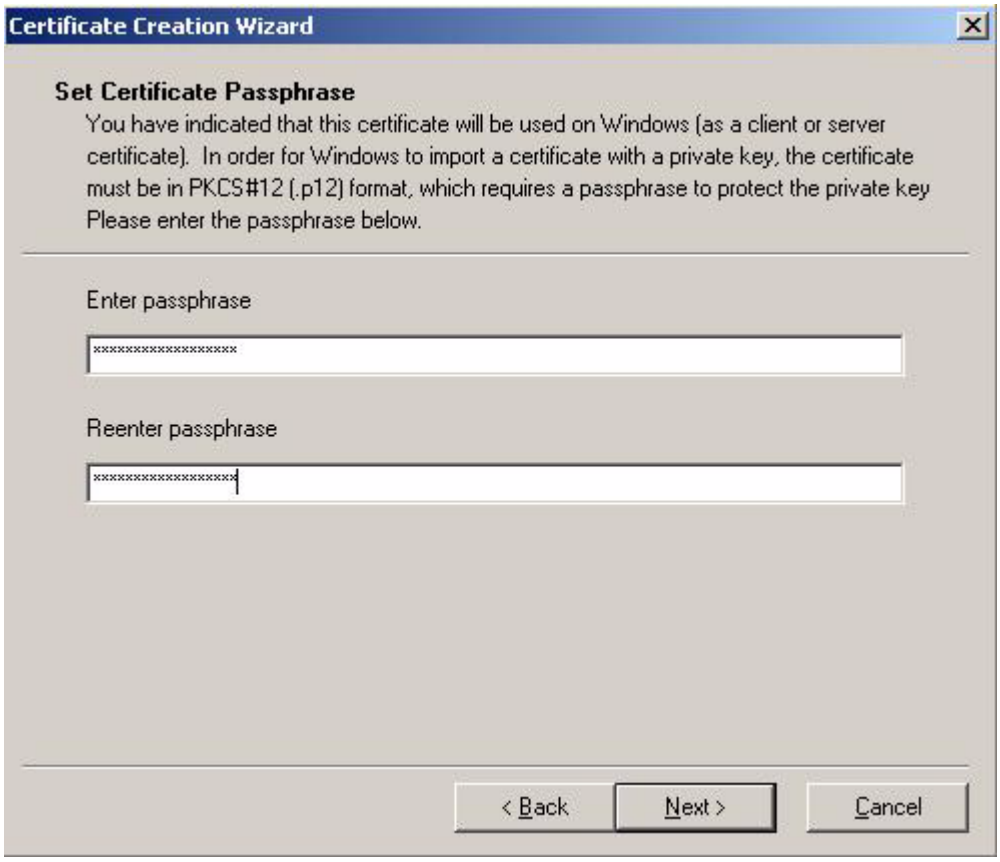
Figure 6.



For the Certificate Name, enter “mycert”. This will be used to generate file names, so only enter valid file name characters. For the Common Name, enter the IP address of your device (e.g., 10.10.6.100), or if you access your device using a text URL, enter the base Domain Name[4] you access your device from. For example, if you access your device from “http://www.foo.com/index.html”, your certificate’s Common Name should be “www.foo.com” with no slashes or extra information. The next three fields (Key Size, Expiration and Certificate Purpose) display with their default values. As mentioned in Step 3, prior to Dynamic C 10.54, the key and expiration default values of 1024 bits and 365 days, respectively, were not modifiable. The Certificate Purpose, prior to Dynamic C 10.54, was always “Unspecified.” The other two choices “Client” or “Server” were added in Dynamic C 10.54 for the support of Wi-Fi Enterprise mode authentication.

Selecting “Client” or “Server” will bring up a window, similar to the one shown in Figure 7, where you are asked to enter and then reenter a passphrase.

Figure 7. Setting a Passphrase for Use with Windows-Compatible Certificates



If you leave the Certificate Purpose at its default value of “Unspecified” you will not need a passphrase. “Unspecified” is the correct choice for this walk-through.

Next, fill in the optional fields as desired.

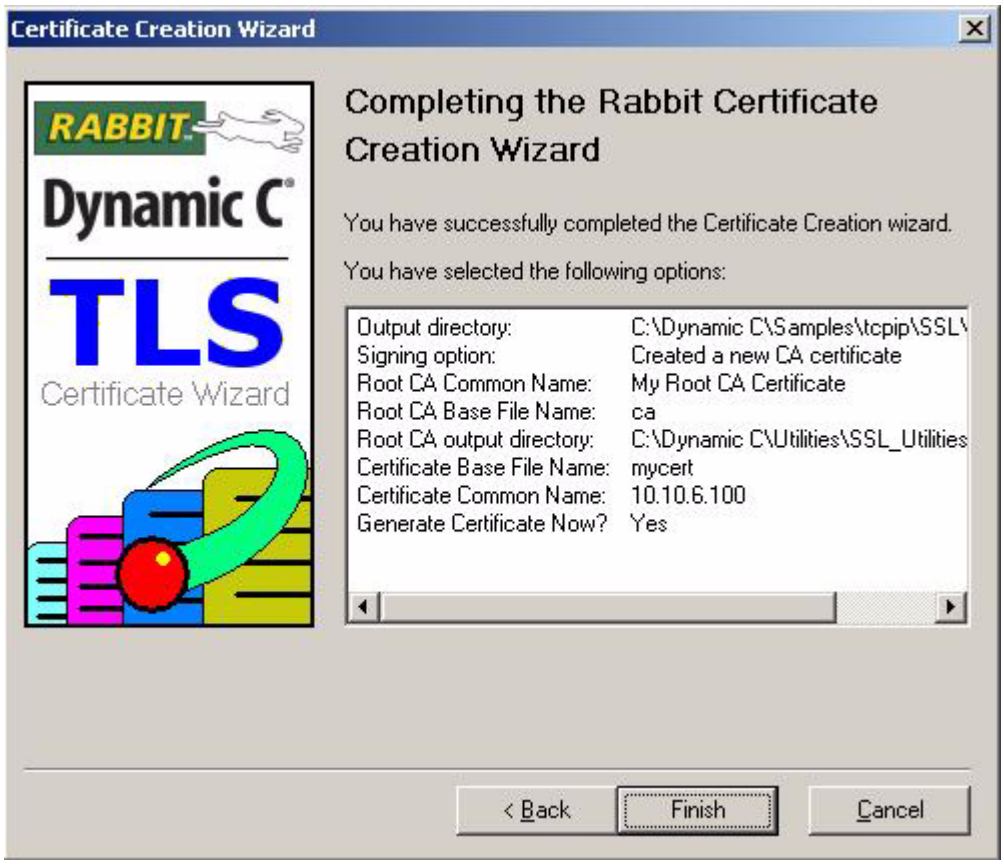
Check the checkbox at the bottom of the panel to generate the certificate and exit the utility when you are finished. Click “Next.”

4. The base Domain Name is also known as TLD (Top Level Domain).

6. Create the Certificates

Check the summary on the final panel of the wizard to make sure all the information is correct.

Figure 8.



Once you have verified your certificate information, click "Finish" to generate both the root CA certificate and the digital certificate that will be installed on the Rabbit-based device. The certificates will be saved in the output directories you selected in Step 2 and Step 4.

Prior to Dynamic C 10.54, the generated file called *mycert.dcc* (assuming the file name you chose for your certificate was *mycert*) is the certificate file you will need in your Dynamic C application. With the release of Dynamic C 10.54, both PEM and DER-formatted certificate files can be used directly by Dynamic C as either an #ximport'd file or a Zserver resource.

If you are using the DCC-formatted file, be aware that it contains the key information as well as the certificate information, thus the generated key files are not used in the Dynamic C application. The files `mycert.key` and `mycertkey.pem` are two formats of the private key, and these should be kept secret to preserve the security of your certificate, i.e., it is a good idea to protect these with some form of encryption.

This is only true if you are using the DCC-formatted file. If you are using Dynamic C 10.54 or later, you will be using the key file `mycertkey.pem` in the Dynamic C application in the same way you passed the PEM or DER-formatted certificate file; this means the key file must not be encrypted. If it was encrypted, the Dynamic C libraries would not be able to decrypt it to use the information it contains.

If you have followed the walk-through, you have a root CA certificate to install in the browser, which will provide the trust for the certificate you install on your Rabbit device. However, if you create a self-signed certificate, you may want to install that self-signed certificate in both the browser and the Rabbit device to avoid warnings from the browser.

If you are using Dynamic C 10.54 or later, be aware that the file *mycerts.pem* is the signed PEM format version of your certificate and thus is the one that needs to be installed on the Rabbit device. The "s" is added so it will not be confused with the certificate request *mycert.pem*. The certificate request file may be sent to a commercial signing company, such as VeriSign.

1.3.2 Import the Certificate

The digital certificate needs to be imported into the SSL server application; in this walk-through, that is `SSL_STATIC.C`. In Dynamic C open the file `\Samples\TCPIP\SSL\HTTPS\SSL_STATIC.C`. Locate the `#ximport` statement for the certificate import, and modify the line to point to your certificate.

```
#ximport "cert\mycert.dcc" SSL_CERTIFICATE
```

As long as you follow the above instructions to generate your certificate, you should not have to modify the `#ximport` statement. But if you are using Dynamic C 10.54 you will want your own application to make use of its improved certificate handling system. Use of .dcc format, while still supported for backward compatibility, is not recommended since key exchange is three times slower with this format. The .pem format is recommended in all cases. See Section 1.6 for more information on certificate import options.

The sample program `\Samples\TCPIP\wifi\CONFIG_FAT.C` demonstrates the improved method of handling certificates:

```
#ximport "samples/tcpip/ssl/https/cert/servers.pem" server_pub_cert
#ximport "samples/tcpip/ssl/https/cert/serverkey.pem" server_priv_key
...
printf("Loading HTTPS server certificate...\n\n");
SSL_new_cert(&my_cert, server_pub_cert, SSL_DCERT_XIM, 0);
SSL_set_private_key(&my_cert, server_priv_key, SSL_DCERT_XIM);
https_set_cert(&my_cert);
```

(Error handling was removed in the above code.)

Dynamic C 10.54 supports additional flexibility for certificate storage. The certificate can be #ximport, or stored in a FAT filesystem, or in the User ID block.

1.3.3 Set Up TCP/IP for the Sample Application

The Rabbit Embedded Security Pack implementation of SSL requires a TCP/IP connection in order to function. Open the `TCP_CONFIG.LIB` library and follow the instructions provided in the library to set up your device for use with TCP/IP. Check that the device's address matches the Common Name of the certificate you created above. If the device is accessed through a proxy or DNS, then the certificate does not need to match the IP address since the browser will use the external address to access the device—however, the certificate's Common Name must match that address.

The SSL server (`SSL_STATIC.C`) uses SSL through HTTPS, so we need to make sure the HTTPS port is enabled. Where normal HTTP uses TCP port 80, the standard HTTPS port is TCP port 443. Looking at the sample program, you will see that there is a call to `tcp_reserveport(443)` just below the call to `tcp_reserveport(80)`. This assures that both the HTTP and HTTPS ports are reserved for the server.

1.3.4 Set Up the Application to Use SSL

This section does not require any action. The sample application, `SSL_STATIC.C`, already contains the code needed for an SSL server. See Section 1.5.5 for an explanation of the code necessary to make an application SSL-enabled.

In `SSL_STATIC.C`, there are two servers enabled, with one of them reserved for HTTPS. This means that incoming requests will be handled according to the port they come in on. Requests on port 80 will be handled by the normal HTTP server, whereas requests on port 443 will be handled by the HTTPS server, that is, the server secured using SSL.

1.3.5 Set Up the Web Browser

The sample program is now ready to compile and run. However, there are some steps to take to set up the browser before attempting to communicate with the Rabbit-based device. The following steps are optional in the sense that not following them will not necessarily prevent communication from happening between the browser and the device, but will cause the browser to generate warnings. If you do not mind the warnings, skip ahead to the last step in this walk-through: Section 1.3.6 "Run the Application".

1. Enable TLS 1.0 (optional)

Most modern browsers support the TLS standard. By default, however, some browsers may have TLS disabled, and only have SSLv3 enabled for SSL communication. The Rabbit Embedded Security Pack comes with both TLS 1.0 and SSLv3 support.

TLS is considered more secure than SSLv3. You can enable TLS by locating the security options in your browser and enabling TLS 1.0. (This option can be found in Microsoft Internet Explorer under Tools | Internet Options under the "Advanced" tab; click the checkbox next to "Use TLS 1.0" if it is not already checked).

2. Install your root CA certificate (optional)
In the first part of this walk-through, you created your own Certificate Authority (CA) root certificate and used it to sign your certificate, which at this point resides on your device (assuming you compiled and downloaded the sample program). The certificate will be accepted by the browser if it meets certain criteria. These include:

- a valid digital signature
- a valid date
- a matching Common Name and URL address
- the certificate in the correct format

The first criterion is covered by the signing certificate (your root CA certificate in this case). The latter three criteria have also been covered: the valid date range was set during certificate creation (the default is 365 days validity from the date of creation); the Common Name and the address were also matched during certificate creation; and the certificate utility took care of the formatting.

If you chose "ca" for the name of your root certificate, then the certificate file will be called *ca.der*. In Windows, this file type is associated with Internet Explorer, and you can install it by opening it with a double-click. Opening the file will display the "Certificate" dialog box, which will display information about the certificate. In the lower right corner of the window there is a button labeled "Install Certificate." Click this button, and the Certificate Import Wizard will open. Click "Next." The second panel will prompt you for a certificate store. Select the default option, click "Next" again, and then click "Finish." The wizard then asks if you want to install the certificate in the root certificate store. If all the information looks correct, click "OK" and your certificate will be installed.

You can verify that your certificate has been installed by opening Internet Explorer (this applies to version 6 and should be similar for other versions), and navigating to Tools | Internet Options..., and clicking the "Content" tab. Look for the "Certificate" button, click it, then click the "Trusted Root Certification Authorities" tab. Search the list for your certificate, and double-click it to view the certificate details. You can also use the list to remove your certificate.

> **WARNING:** DO NOT remove any certificates you did not install yourself unless you know what you are doing, since doing so will prevent you from viewing Web sites protected by certificates signed by those authorities.

Firefox and other browsers use different methods for installing root certificates. Refer to the documentation for each of those browsers for instructions. If you have problems installing your root CA certificate in a specific browser, please contact your distributor or Rabbit partner, or use Rabbit's Tech Support e-mail form at `www.rabbit.com/support/`.

1.3.6 Run the Application

Once the sample program has been compiled, downloaded, and started, you can access your device from a browser by typing "https://<my device URL>" where <my device URL> is the IP address or URL of your device. Remember to use the https (note the 's') prefix at the beginning of the URL to access HTTPS pages. For example, if your device is accessed from www.foo.com, the complete address would then be ***https***://www.foo.com. The https prefix tells the browser to make requests on the HTTPS TCP port 443 instead of the standard HTTP port 80.

1.3.7 Expected Behavior

If you are running the SSL_STATIC.C sample program, the SSL handshake process begins once you type in the address of the device and hit enter. If you followed the walk-through and also installed the proper root CA certificate in your browser, you should see the "lock" icon appear in the lower right corner of your browser. The static page should then display. You can double-click the lock icon to look at your certificate, which will bring up the certificate browser. You can look to see that all the information is there and correct, and you can also follow the certification path (the "Certification Path" tab) back to your installed root CA certificate.

If you did not match the common name of your digital certificate to the device address (see Figure 6), or if you did not install your root CA certificate (Step 2 in Section 1.3.5), the browser will issue a warning indicating a problem with the certificate, along with details about what has failed. It will allow you to either cancel the page load or ignore the warning. Since it is your device, you can just ignore the warning and continue to the page load. The page is still secured with SSL; you have simply opted to trust the device's certificate (and therefore its identity) despite the browser's warnings of a possible problem.

1.3.8 Troubleshooting

If you followed the walk-through and your page is not displaying or there are other problems, the following tips may help you to troubleshoot the problem.

- Make sure you are using *https://* and not *http://*. One of the most common causes of problems with loading HTTPS pages from a Rabbit-based device is one of the most obvious. Make sure that the URL in your browser starts with https:// and not http://.
- *Check that your TCP/IP settings are correct.* This may seem obvious, but since SSL relies on TCP/IP for the network connection, if your TCP/IP settings are not correct, SSL will not work.

  Try using an ordinary HTTP sample such as STATIC.C to verify the network connection.
- *Make sure your proxy or firewall is configured correctly.* If your device is behind a proxy or firewall, you may need to configure the proxy or firewall to forward port 443 for HTTPS.
- *Check the certificate.* If the certificate is not properly formed, or was signed by an unknown Certificate Authority, the browser may simply fail to load the page. First, check that your root CA certificate is correctly installed in your browser. Also, check that your root CA certificate does not have a Common Name (CN) that matches any other certificate in the root certificate store. If it does, any certificates you have signed using it will be rejected by the browser as having an invalid digital signature. You can also look at your digital certificate directly. It will be found along with your DCC file, with the extension DER. Double-click the DER file to bring up the certificate browser to allow you to verify that the certificate is correct.

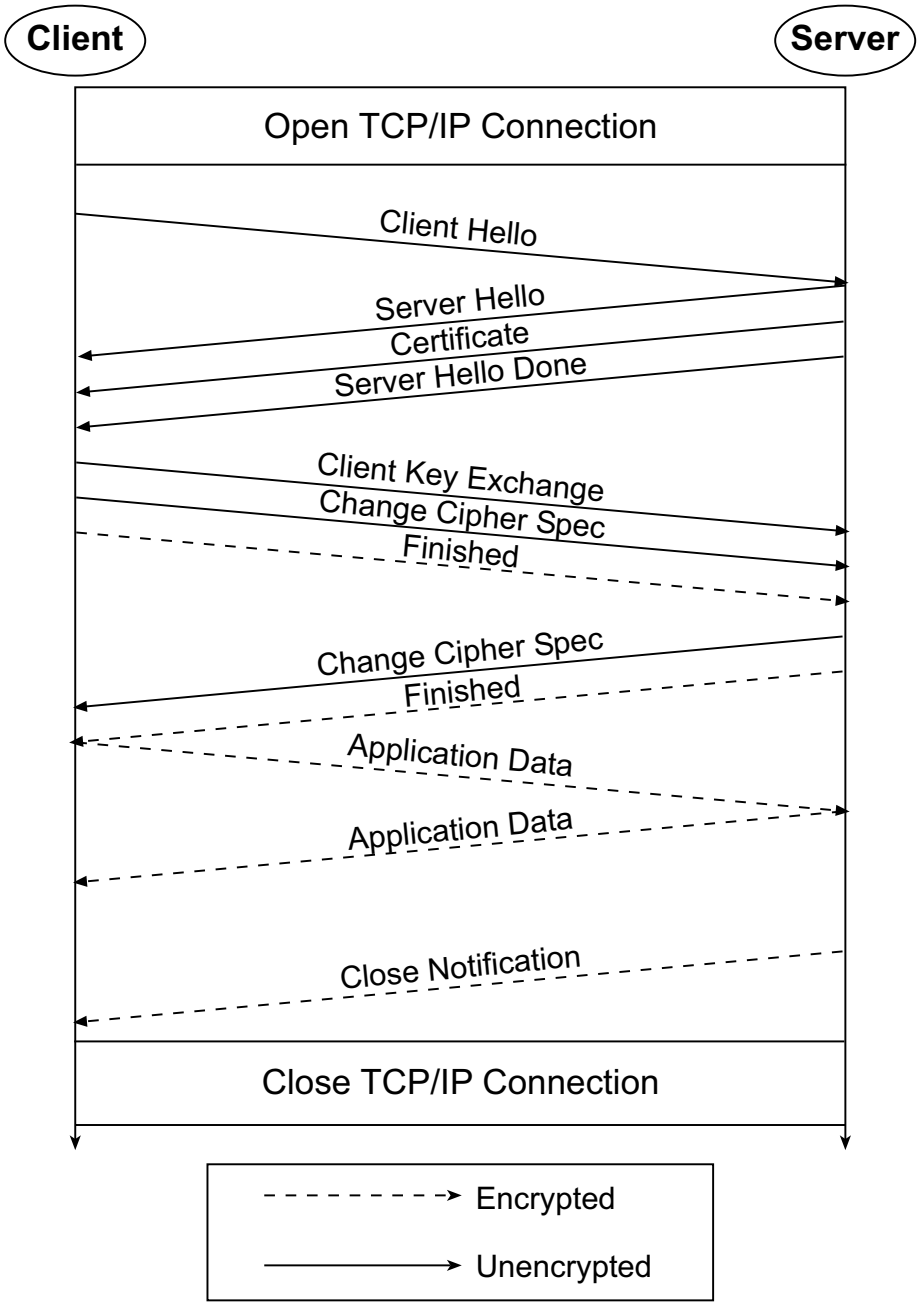
1.4 SSL Basics

This section covers the establishment of an SSL connection and communicating using that connection.

1.4.1 The Handshake

SSL communication takes place in an SSL *session*. The session is established using a handshake process similar to the TCP 3-way handshake. The entire handshake, including establishing the TCP/IP socket, is shown in Figure 9. As can be seen in the figure, the TCP/IP connection is established first, and then the SSL handshake begins.The SSL session is established when both the client and server are communicating using the negotiated parameters and ciphers. The SSL session ends when either side is done transmitting application data and notifies the other machine that it is done sending data.

Figure 9. SSL Handshake



1.4.1.1 The Client Hello and Public-Key Operation

All SSL handshakes begin with a *Client Hello* message. This message is sent by the client to the server with whom it wishes to communicate. The message contains the client's version of SSL, a random number used later in key derivation, as well as a collection of ciphersuite *offers*. The offers are identifiers that specify the ciphers and hashing algorithms the client is willing to use.

A possible offer could be that the client is willing to speak to the server using TLS, RSA for the public-key operation, RC4 with 128-bit keys for the symmetric cryptography, and HMAC-MD5 to generate the message MAC (it uses HMAC since the offer is TLS).

When establishing the initial connection, the server chooses an offer it is willing to use, and communicates that offer back to the client along with its certificate and a random value of its own. The client then verifies the identity of the server using the certificate and extracts the server's public key. Using the public key, the client encrypts the *pre-master secret*, a random value that will be used to generate the symmetric keys independently, and sends the encrypted message to the server, which decrypts the message using its private key.

The Rabbit Embedded Security Pack supports:

- SSL 3.0 and TLS 1.0 for a secure communications channel
- RSA for public key cryptography
- AES and RC4 for symmetric key cryptography
- MD5 and SHA-1 for message digest algorithms

1.4.1.2 Symmetric-Key Derivation

Once the server receives the pre-master secret from the client, both the server and the client generate the *same* symmetric keys using the pre-master secret and the random numbers exchanged above using the TLS pseudo-random function (PRF), which expands a secret and some data into a block of arbitrary length.[5] This way, only the small pre-master secret is encrypted using public-key cryptography, limiting the impact of the expensive operation on performance.

1.4.1.3 Handshake Finish

As soon as the keys are generated, the client and server exchange *change cipher spec* messages to indicate that they each now have symmetric keys and all further communications will be conducted using the symmetric algorithm chosen in the initial stages of the handshake. At this point, the server and client take all the handshake messages received and sent, and generate a block of data used to verify that the handshake was not tampered with. These data, generated using the TLS PRF, are sent in a final handshake message, *Finish*. If the data in the finish message do not match the locally generated finish data, then the connection is terminated by whoever failed the finish verification test.

1.4.2 SSL Session

Once the handshake is finished, the server and client begin to communicate over the newly established secure channel. Each message is hashed, encrypted, and sent. If at anytime there is a failure, either in the decryption, encryption, hashing, verification, or communication, an SSL alert is sent (using the symmetric

5. SSLv3 uses its own algorithm to generate the key material. The algorithm is based on an early version of HMAC, and has no known security vulnerabilities.

encryption) by the entity experiencing the failure. Most alerts are fatal, causing the communication to stop immediately. See Section 1.4.3 for more information on alerts.

When the client or server is done communicating, a special alert, *close_notify*, is sent to ensure that all communications have ceased and the connection can be closed. This alert prevents an adversary from performing a *truncation attack*, fooling the server or client into thinking that all the data to be exchanged have been sent, when actually there are some data left (this can be a problem in situations such as banking transactions, where it is necessary for *all* information to be received).

After the close_notify alert is sent, the server caches the session information using a unique identifier established during the handshake. This information is used if the client attempts another communication to do what is called a *session renegotiation*.

An important feature of SSL is its ability to do these session renegotiations. The session information cached by the server can be used to resume an SSL session where it left off, avoiding the expensive public-key operation. This is especially valuable for applications such as Web servers that may connect and reconnect many times (such as each time a user clicks a link on a Web page and is sent to a new page).

1.4.3 SSL Alerts

One of the most important components of SSL is its error-handling system. SSL errors are called *alerts*, and represent possible attacks. Alerts are messages sent across the SSL communication channel, and may be encrypted. The SSL specification details about 20 different alerts and gives guidelines on how to handle them when received, and when to generate and send them. Error handling is implementation-specific, and is covered in Section 1.5.7.

1.5 SSL on the Rabbit

The walk-through in Section 1.3 stepped through the creation of a secure HTTP server on a Rabbit-based target using the sample program `SSL_STATIC.C`. The walk-through was designed to get an SSL server up and running quickly and so did not provide all of the information of interest to developers about the implementation. This section discusses some of those details.

1.5.1 Full-Compliance Vs. Communication

The SSL standards define what ciphersuites and features must be included for full compliance. Note that *communication* is different from *compliance*. An implementation without the mandatory features specified in the TLS RFC can still usually communicate with a TLS-compliant implementation, but is not *guaranteed* to be able to communicate with all implementations.

First, SSL *must* be implemented over a communications channel that will assure all data is received in the order it was sent, a communications channel such as TCP. An unreliable protocol such as UDP *will not work* with SSL.

The TLS RFC states that certain algorithms are mandatory for an implementation to be fully TLS-compliant. Diffie-Hellman, DSS (Digital Signature Standard), and the 3DES cipher are examples of such algorithms. However, these algorithms are not necessary for the TLS communication itself since nearly all TLS implementations already support RSA, MD5/SHA-1, and bulk ciphers other than 3DES, such as RC4 and AES.

For performance reasons, the Rabbit SSL supports RC4 for bulk encryption by default and RSA for public-key and digital signing operations. These algorithms have definite performance advantages over Diffie-Hellman and 3DES, and are more than adequate to be compatible with the vast majority of SSL client implementations.

1.5.2 SSLv2 Compatibility

The TLS RFC and SSLv3 specification also describe some "advanced" features that may be necessary for communication. The first of these is the SSLv2 backward-compatible handshake. SSLv2 uses a completely different message format to establish a connection. For backward compatibility, most SSLv3 and TLS implementations can recognize an SSLv2 client hello message. The contents of the SSLv2 message can be mapped directly to an SSLv3/TLS client hello and parsed by the server. The server will reply to the client hello with an SSLv3 or TLS handshake message, effectively upgrading the security from SSLv2 to a newer protocol, or causing an error if the server is actually an SSLv2 application. Nearly all browsers will use the SSLv2 client hello to initiate communication.

Rabbit SSL supports the SSLv2 backward-compatible handshake (note that this does not mean full SSLv2 support).

1.5.3 Session Renegotiation

The SSL standards also describe how to perform *session renegotiation*, a very important SSL feature. Session renegotiation allows a client and server who have previously negotiated an SSL connection to continue where they left off after a break in communication (which may include closing the TCP/IP socket connection). SSL achieves this by using large numbers called *session identifiers* (session IDs) negotiated in the initial handshake. The server and client save all the required information (such as cipher state and the master secret for key derivation) associated with a session when a connection goes down (that is, the socket is closed or reset). This information is stored with the session ID. When the client re-initiates contact, the session ID identifies the client, and the existing state is used, thereby avoiding the costly public-key operation. This can improve performance dramatically for applications such as Web servers, where connections are opened and closed frequently. Security is not affected by session renegotiation unless either entity is compromised, since both the server and the client already have the secret information known only by them (the symmetric keys have already been exchanged).

Rabbit SSL fully supports session renegotiation.

1.5.4 Browser Support

One of the primary uses of SSL on the Rabbit is to secure HTTP communications by providing an HTTPS server implementation to communicate with standard Web browsers. The Dynamic C implementation of SSL should work with any browser that supports SSLv3. Browsers earlier than Internet Explorer version 4 and Netscape version 5 are not officially supported, but may work with the Rabbit SSL implementation. TLS is only supported on newer browsers—starting with Internet Explorer version 5 and Netscape Communicator version 6. Officially, the Dynamic C implementation of SSL is supported only on browsers newer than Internet Explorer version 5 and Netscape Communicator version 6.

1.5.5 Sockets and HTTPS Configuration

The application needs to know that some servers will use HTTPS. The use of HTTPS is controlled by a few macros, some of which will be familiar to you if you have already worked with the `HTTP.LIB` library. The most important macro is `USE_HTTP_SSL`, which enables the use of SSL for HTTP servers, thus making them potential HTTPS servers.

Most SSL implementations are created with an API that is very similar to that of traditional network sockets. In fact, SSL is intended to replace sockets and require no other functional changes to add security to applications already using TCP/IP sockets. In theory, any application that uses sockets could be made secure just by replacing the socket function calls with SSL socket function calls.

To replace the socket functions, the Dynamic C application must contain the following code in the following order:

```
#define USE_HTTP_SSL
#use "dcrtcp.lib"
#use "http.lib"
```

The HTTP_MAXSERVERS macro specifies the *total* number of HTTP *and* HTTPS servers to be used by the application. The HTTP_SSL_SOCKETS macro specifies the number of HTTPS servers to be used by the application. HTTP_SSL_SOCKETS should always be #defined to "1" or more.

Normally, one HTTPS server is sufficient. Only define a greater number if it is likely that two (or more) browsers will attempt to connect at the same time. This would be very unlikely in an embedded application.

The number of plain HTTP servers is given by the difference between HTTP_MAXSERVERS and HTTP_SSL_SOCKETS. Note that HTTP_SSL_SOCKETS cannot be greater than HTTP_MAXSERVERS. For example, say we want two normal HTTP servers and one HTTPS server. This would be done by using the following code in your program.

```
#define HTTP_MAXSERVERS 3       // There are 3 total servers
#define USE_HTTP_SSL            // Tell HTTP.LIB to use SSL
...
#define HTTP_SSL_SOCKETS 1      // Tell HTTP.LIB to use 1 of the 3 servers for HTTPS
```

1.5.6 Resource Protection

The SSL-enabled server implemented by SSL_STATIC.C will accept connections from anyone, secured or not. The client is not forced to use the secured port to communicate with the device because they have the option of logging in using plain HTTP. For this reason, the Rabbit Embedded Security Pack provides a mechanism to protect resources using the ZSERVER.LIB library. Any resources allocated using the sspec_xxxx functions with a server mask of SERVER_HTTPS will be accessible only via HTTPS, and will not load if accessed in any other way. See the SSL_FORM.C sample program for more information on resource protection.

The following example illustrates resource protection using sspec_addform. The form *myform* (simply a collection of 5 variables) is initialized in the call, with the name "myform.html" and a size of 5. The important thing to note is the server mask parameter, SERVER_HTTPS. This indicates to HTTP.LIB that this form can *only* be accessed using an HTTPS server. In this way, "myform.html" will only be accessible from the Web browser over an SSL-secured connection. Attempting to access the form without specifying HTTPS will result in a "404 Not Found" HTTP error.

```
// Declare form variables and form pointer
auto FormVar myform[5];
auto int form;

// Initialize the form and add it to the RAM resource list
   form = sspec_addform("myform.html", myform, 5, SERVER_HTTPS);
```

1.5.7 Error Handling

One important aspect of the SSL implementation is its ability to handle errors. Errors are especially important because they represent possible attacks, and therefore need to be handled appropriately to prevent the compromise or loss of data. In addition to the SSL alert mechanism (which is used to communicate errors between the client and server), you can access SSL error codes in an HTTPS CGI handler using `https_getError()`. For backwards compatibility, you can also access the macro `SSL_errno`; however, this is discouraged since it is not possible to distinguish between errors from different server instances.

An application can use this information to take appropriate action when an error occurs. SSL error codes are listed in `ERRNO.LIB`, starting at the 900-series codes.

1.5.8 SSL Sample Programs

The `SAMPLES\TCPIP\SSL\HTTPS\` directory has sample programs that illustrate various aspects of SSL. At the top of each file is information specific to that program. To run one of the samples, open it in Dynamic C, then press the F9 function key. This compiles the program and runs it on the target. The Rabbit-based device must be connected to a PC using the programming cable.

- `SSL_AUTHENTICATION.C`: demonstrates HTTP authentication over HTTPS, which encrypts both the authentication data (username and password) and the Web page itself.
- `SSL_CGI.C`: demonstrates the use of CGI functionality over HTTPS with a page-hit counter.
- `SSL_FORM.C`: demonstrates secure form submission using HTTPS using a sample thermostat control form.
- `SSL_SSI.C`: demonstrates server-side include (SSI) functionality by creating several "devices" (graphic icons) whose state can be changed by clicking on graphic buttons on the Web page.
- `SSL_STATIC.C`: This is the most basic SSL/HTTPS sample program. It establishes an SSL session and transmits a static HTML Web page to the browser over HTTPS.
- `SSL_STATIC_CERT.C`: demonstrates use of the certificate handling API to parse and register a certificate with an HTTPS server.
- `SSL_ZIMPORT.C`: demonstrates HTTPS integrated with the `#zimport` functionality to compress and store a large text-based Web page and the ability to download that page securely over HTTPS.

1.5.9 Configuration Macros

Both the HTTP library and the SSL library use configuration macros that allow you to customize your application.

`USE_HTTP_SSL`

If this macro is defined the HTTP library will use SSL. It must be defined in an application that wants to function as a secure HTTP server.

`HTTP_SSL_SOCKETS`

This macro tells the HTTP library how many of the available HTTP sockets will be secured with SSL. `HTTP_SSL_SOCKETS` should be #defined to 1 or more, however “1” is sufficient for most cases.

SSL_MAX_CONNECTIONS

Defaults to 1 (or 2 if WPA_USE_EAP is defined for WPA Enterprise). Must be set to the maximum concurrent SSL/TLS transactions in progress at any one time. It must be at least equal to HTTP_SSL_SOCKETS (plus one if using WPA Enterprise).

SSL_USE_AES

By default RC4 is enabled and AES is disabled. Define SSL_USE_AES to enable AES as an option for bulk session encryption.

SSL_DONT_USE_RC4

This macro removes the RC4 encryption algorithm from being compiled into SSL, and as such prevents any SSL session from using RC4 as the bulk encryption algorithm. If this macro is defined in the application, the macro SSL_USE_AES must be defined.

SSL_DISABLE_LEGACY_DCC

This macro disables the legacy ".dcc" file import type of the function SSL_new_cert(). If you #define this macro, then the SSL_CERT_XIM and SSL_CERT_XMEM import types will not be available. The purpose of this macro is to reduce code size.

SSL_DISABLE_USERBLOCK

To remove code that supports storing DER/PEM certificates in the user ID block (SSL_DCERT_UID), include the following statement:

```
#define SSL_DISABLE_USERBLOCK
```

The purpose of this macro is to reduce code size.

X509_NO_RTC_AVAILABLE

Verification of certificates will normally include examination of the validity dates of the certificate. This requires a correctly set real-time clock. If such a clock is not available, or is set to the wrong wall-clock date/time, then certificate verification will fail. To avoid this (at the cost of reduced security) you can #define X509_NO_RTC_AVAILABLE in order to bypass the date/time check.

The sample program /Samples/RTCLOCK/RTC_TEST.C, located in the Dynamic C installation directory, demonstrates use of the available real-time clock functions.

SSL_CERTIFICATE

This macro is deprecated in Dynamic C 10.54. In prior versions of Dynamic C, the SSL library assumed this macro was the physical address where the length and contents of the SSL certificate were stored. It was necessary for the application program to contain something similar to the following line of code:

```
#ximport "cert\mycert.dcc" SSL_CERTIFICATE
```

As of Dynamic C 10.54, use SSL_new_cert() and https_set_cert() to install server certificates. The sample progam SSL_STATIC_CERT.C (described in Section 1.5.8) uses this method.

1.5.10 Socket Wrapper Functions

The following HTTP API function calls are for CGI programs. Applications cannot access the socket in an HTTPS server directly, so wrapper functions are included that allow the writing and reading of data directly to and from the socket. These functions use the socket associated with a particular HTTP or HTTPS server. If the server is an HTTP server, the socket used will be plain TCP/IP. If it is an HTTPS server, the socket will be secured with SSL. It is recommended that for new development these function calls be used instead of direct socket access.

All of the following functions are in `\lib\...\tcpip\http.lib\` in the Dynamic C installation directory.

http_get_sock	http_sock_fastread
https_set_cert	http_sock_fastwrite
http_sock_mode	http_sock_readable
http_sock_bytesready	http_sock_writable
http_sock_gets	http_sock_xfastwrite

http_get_sock

```
tcp_Socket * http_get_sock( HttpState *state );
```

DESCRIPTION

This function allows direct access to an HTTP or HTTPS server's TCP socket. This will always return the TCP socket associated with the server, even if that server is HTTPS. This is intended for read-only operations. Since this function returns a pointer to the actual socket, changing fields will directly affect the connection, and could lead to problems, especially with HTTPS servers.

PARAMETERS

state HTTP state pointer, as provided in the first parameter to the CGI function.

RETURN VALUE

Pointer to the actual TCP socket.

LIBRARY

HTTP.LIB

https_set_cert

```
void https_set_cert( SSL_Cert_t far * cert);
```

DESCRIPTION

Register a device certificate with all HTTPS server instances. Client hosts (such as web browsers) will verify this certificate, and may refuse to connect if there is no certificate, or the device certificate is not valid.

This must be called at least once, otherwise there may be no default. Alternatively, you can use the following line at the top of your main program:

```
#ximport "cert.dcc" SSL_CERTIFICATE
```

where “cert.dcc” is the name (and path) of the certificate file to use. The file must be in .dcc format. This usage is deprecated as of Dynamic C 10.54, since `http_set_cert()` provides a more flexible interface.

PARAMETER

cert Pre-parsed certificate, as generated by `SSL_new_cert()`.

LIBRARY

HTTP.LIB

SEE ALSO

SSL_new_cert

http_sock_mode

```
void http_sock_mode( HttpState* state, http_sock_mode_t mode );
```

DESCRIPTION

HTTP socket wrapper function for socket mode. This function can be used by CGI applications to set the mode of a socket associated with a particular HTTP server.

PARAMETERS

state HTTP state pointer, as provided in the first parameter to the CGI function.

mode HTTP mode to use for the socket. Valid values for `mode` are:

- `HTTP_MODE_ASCII` - Sets the associated socket to ASCII mode.
- `HTTP_MODE_BINARY` - Sets the associated socket to BINARY.

RETURN VALUE

None

LIBRARY

`HTTP.LIB`

http_sock_bytesready

```
int http_sock_bytesready( HttpState *state );
```

DESCRIPTION

HTTP wrapper function for `sock_bytesready()`. This function may be used by CGI applications to determine if there is data waiting on the socket associated with a particular HTTP server.

PARAMETERS

state HTTP state pointer, as provided in the first parameter to the CGI function.

RETURN VALUE

`-1`: no bytes waiting to be read
`0`: in ASCII mode, a blank line is waiting to be read,
or, for UDP, an empty datagram is waiting to be read
`>0`: number of bytes waiting to be read

LIBRARY

`HTTP.LIB`

http_sock_gets

```
int http_sock_gets( HttpState *state, byte *dp, int len );
```

DESCRIPTION

HTTP wrapper function for `sock_gets()`. This function can be used by CGI applications to retrieve a string waiting on an ASCII-mode socket associated with a particular HTTP server.

PARAMETERS

state	HTTP state pointer, as provided in the first parameter to the CGI function.
dp	Pointer to return buffer
len	Maximum size of return buffer

RETURN VALUE

`0`: if buffer is empty, or if no "`\r`" or "`\n`" is read, but buffer had room *and* the connection can get more data!
`>0`: is the length of the string
`-1`: error

LIBRARY

HTTP.LIB

http_sock_fastread

```
int http_sock_fastread( HttpState *state, byte *dp, int len );
```

DESCRIPTION

HTTP wrapper function for `sock_fastread()`, that is for non-blocking reads (root). This function can be used to read data from a socket associated with a particular HTTP server. This function is intended for use in CGI applications.

PARAMETERS

state	HTTP state pointer, as provided in the first parameter to the CGI function.
dp	Pointer to return buffer
len	Maximum size of return buffer

RETURN VALUE

`>0`: the number of bytes read
`-1`: error

LIBRARY

`HTTP.LIB`

http_sock_fastwrite

```
int http_sock_fastwrite( HttpState *state, byte *dp, int len );
```

DESCRIPTION

HTTP wrapper function for `sock_fastwrite()`, that is, for non-blocking writes. This function can be used to write data from a root buffer to a socket associated with a particular HTTP server. This function is intended for use in CGI applications.

PARAMETERS

state	HTTP state pointer, as provided in the first parameter to the CGI function.
dp	Pointer to buffer containing data to be written.
len	Maximum number of bytes to write to the socket.

RETURN VALUE

`>0`: the number of bytes written
`-1`: error

LIBRARY

`HTTP.LIB`

http_sock_readable

```
int http_sock_readable( HttpState * state );
```

DESCRIPTION

HTTP wrapper function for `sock_readable()`. This wrapper function may be used by CGI applications to determine if a socket is readable or not.

The return value is more than a simple boolean: it also indicates the amount of data the socket is guaranteed to deliver with a `sock_fastread()` call that immediately follows (provided that the buffer length is at least that long).

Note that a TCP socket may be readable after it is closed, since there may be pending data in the buffer that has not been read by the application, and it is also possible for the peer to keep sending data

PARAMETERS

state HTTP state pointer, as provided in the first parameter to the CGI function.

RETURN VALUE

0: socket is not readable. It was aborted by the application or the peer has closed the socket and all pending data has been read by the application. This can be used as a definitive “EOF” indication for a receive stream.

non-zero: the socket is readable. The amount of data that the socket would deliver is this value minus 1; which may turn out to be zero if the socket's buffer is temporarily empty, or the socket is not yet connected to a peer.

LIBRARY

HTTP.LIB

http_sock_writable

```
int http_sock_writable( HttpState * state );
```

DESCRIPTION

HTTP wrapper function for `sock_writable()`. This wrapper function may be used by CGI applications to determine if a socket is writable or not.

The return value is more than a simple boolean: it also indicates the amount of data the socket is guaranteed to accept with a `sock_fastwrite()` call that immediately follows.

Note that a TCP socket may be writable before it is established. In this case, any written data is transferred as soon as the connection is established.

PARAMETERS

state HTTP state pointer, as provided in the first parameter to the CGI function.

RETURN VALUE

0: socket is not writable. It was closed by the application or it may have been aborted by the peer.

non-zero: the socket is writable. The amount of data that the socket would accept is this value minus 1; which may turn out to be zero if the socket's buffer is temporarily full. On a freshly-established socket, and at any other time when all data has been acknowledged by the peer, the return value (minus one) indicates the maximum socket transmit buffer size.

LIBRARY

HTTP.LIB

http_sock_xfastwrite

```
int http_sock_xfastwrite( HttpState *state, long dp, long len);
```

DESCRIPTION

HTTP wrapper function for `sock_xfastwrite()` for non-blocking writes. This function can be used to write the contents of an xmem buffer to a socket associated with a particular HTTP server.

PARAMETERS

state	HTTP state pointer, as provided in the first parameter to the CGI function.
dp	Buffer containing data to be written, as an xmem address obtained from, for example, `xalloc()`.
len	Maximum number of bytes to write to the socket.

RETURN VALUE

`>0`: the number of bytes written
`-1`: error

LIBRARY

`HTTP.LIB`

1.5.11 Certificate Handling API Functions

The API functions described in this section are useful for Wi-Fi Enterprise mode authentication and can also be used for manipulating certificates meant for validating the identity of an SSL-secured HTTP server (i.e., HTTPS server).

SSL_extract_cert	SSL_get_store_cert_len
SSL_free_cert	SSL_new_cert
SSL_get_cert_len	SSL_set_private_key
SSL_get_chain_size	SSL_store_cert

SSL_extract_cert

```
int SSL_extract_cert( SSL_Cert_t far * cert, char far * cert_buf,
   size_t N);
```

DESCRIPTION

Extract a DER (binary) format certificate from a certificate object or certificate chain. This is normally used only when transmitting a certificate over a network connection.

PARAMETERS

cert	Pointer to certificate object; e.g., from SSL_new_cert().
cert_buf	Return buffer xmem address, will contain the certificate. This must be sized appropriately: the size of the certificate may be obtained from SSL_get_cert_len() or SSL_get_chain_size().
N	Certificate number in chain. 0 is the first certificate.

RETURN VALUE

0 on success, non-zero on failure
-EINVAL: if certificate pointer is NULL

LIBRARY

SSL_CERT.LIB

SEE ALSO

SSL_get_chain_size, SSL_get_cert_len, SSL_free_cert, SSL_set_private_key, SSL_new_cert

SSL_free_cert

```
int SSL_free_cert( SSL_Cert_t far * cert);
```

DESCRIPTION

Free any resources allocated for this certificate. This frees the entire chain (if any). This basically allows the certificate object to be re-used for a new certificate or certificate chain.

PARAMETERS

cert	Pointer to certificate object; e.g., from `SSL_new_cert()`.

RETURN VALUE

0

LIBRARY

SSL_CERT.LIB

SEE ALSO

SSL_extract_cert, SSL_get_chain_size, SSL_get_cert_len, SSL_set_private_key, SSL_new_cert

SSL_get_cert_len

```
size_t SSL_get_cert_len( SSL_Cert_t far* cert, size_t N);
```

DESCRIPTION

Get certificate length (of DER formatted part, not the extra information in the DCC format) of the Nth certificate (starting at 0) in the chain.

PARAMETERS

cert	Pointer to certificate object; e.g., from `SSL_new_cert()`.
N	Certificate number on the chain, starting at 0, whose length will be returned.

RETURN VALUE

Length of certificate, or
`-EINVAL`: if “cert” is NULL.

LIBRARY

`SSL_CERT.LIB`

SEE ALSO

`SSL_extract_cert`, `SSL_get_chain_size`, `SSL_free_cert`, `SSL_set_private_key`, `SSL_new_cert`, `SSL_get_store_cert_len`

SSL_get_chain_size

```
size_t SSL_get_chain_size( SSL_Cert_t far* cert, long * oal );
```

DESCRIPTION

Return the total size of a certificate chain. This does not include any extra such as the length fields which are required in TLS when sending the chain. It is simply the sum of the lengths of each certificate in binary form.

PARAMETERS

cert	Pointer to certificate object; e.g., from `SSL_new_cert()`.
oal	Pointer to value where total length is stored.

RETURN VALUE

Number of certificates found in the chain.

LIBRARY

SSL_CERT.LIB

SEE ALSO

SSL_extract_cert, SSL_get_cert_len, SSL_free_cert, SSL_set_private_key, SSL_new_cert

SSL_get_store_cert_len

```
int SSL_get_store_cert_len( SSL_Cert_t far * cert, size_t N,
   size_t * priv_data_len);
```

DESCRIPTION

Get length of storage required for the use of the SSL_store_cert() function. This length includes an initial 4-byte length field, the certificate itself, and the length of any private key data if it exists.

PARAMETERS

cert	Pointer to a certificate object, e.g., from SSL_new_cert().
N	Certificate number on the chain, starting at 0.
priv_data_len	If not NULL, used to return the size of the private key data. This may currently be either 0 or sizeof(RSA_key).

RETURN VALUE

Length of storage area required, or a negative number if the certificate is invalid.

LIBRARY

SSL_CERT.LIB

SEE ALSO

SSL_store_cert, SSL_get_chain_size, SSL_get_cert_len

SSL_new_cert

```
int SSL_new_cert( SSL_Cert_t * cert, long addr, SSL_Cert_Import_t
   import_type, int append);
```

DESCRIPTION

Create a new certificate or certificate chain for use with TLS/SSL. This function populates the certificate structure (SSL_Cert_t) with information used by the extract functions (also in SSL_CERT.LIB). The import file may be any of the following import types:

- SSL_CERT_XIM - Legacy (.dcc) certificate is #ximported.
- SSL_CERT_XMEM - Legacy (.dcc) certificate is in an XMEM buffer.
- SSL_DCERT_XIM - DER or PEM format certificate is #ximported.
- SSL_DCERT_UID - DER or PEM format certificate is in the User ID block.
- SSL_DCERT_Z - DER or PEM format zserver resource.

NOTE: Some parts of the certificate structure will be dynamically allocated, thus SSL_free_cert() should be called to release memory when the certificate chain is no longer required.

For DER or PEM format certificates: since the private key information is not necessarily stored in the certificate, then, if required, it must be provided by a subsequent call to SSL_set_private_key(cert,...). Note that PEM format files may contain both the certificate and the private key. In such cases, the same file may be passed to both SSL_new_cert() and SSL_set_private_key().

See SSL_store_cert() for a convenient way of storing certificates in the User block (non-volatile storage available on all Rabbit core modules). If that function is used, the certificate may be read from the User block by using the import type SSL_DCERT_UID. In this case, any private key data associated with the certificate at the time of storage will be extracted automatically, hence there would be no need to subsequently call SSL_set_private_key().

If you #define SSL_DISABLE_LEGACY_DCC, then the SSL_CERT_XIM and SSL_CERT_XMEM import types will not be available. Similarly, #define SSL_DISABLE_USERBLOCK to remove code which supports storing DER/PEM certificates in the user ID block (SSL_DCERT_UID). SSL_DCERT_Z is only available if ZSERVER.LIB is included.

PARAMETERS

cert Certificate data structure to be populated. Initially, should be memset to zero. Subsequently, call this routine with the "append" flag, or call SSL_free_cert() to recycle.

addr The address or name of the certificate input file. The interpretation of this field depends on the import type:

- SSL_CERT_XIM or SSL_DCERT_XIM - symbol defined on the #ximport directive
- SSL_CERT_XMEM - address of first byte of .dcc certificate. Note that this format defines its own length, hence a length field is unnecessary.
- SSL_DCERT_UID - offset from beginning of User ID block. This is the location of a long integer which contains the length of the immediately following certificate data.
- SSL_DCERT_Z - char far *, pointer to null-term string name of Zserver resource containing the DER or PEM certificate.

import_type The import type of public input file (SSL_CERT_XIM etc. as documented for the "addr" parameter).

append If true, then new certificate is added to the end of the existing chain in "cert." This is used to construct a chain of trusted certificates. It can also be used to create a verification chain when sending or receiving certificate lists. Note that all certificates in a chain will be freed when SSL_free_cert() is called.

RETURN VALUE

0 on success, non-zero on failure
- EBUSY: user block is busy, try again later
- EINVAL: not a supported import type

LIBRARY

SSL_CERT.LIB

SEE ALSO

SSL_extract_cert, SSL_get_chain_size, SSL_get_cert_len, SSL_free_cert, SSL_set_private_key, SSL_store_cert

SSL_set_private_key

```
int SSL_set_private_key( SSL_Cert_t far* cert, long addr,
   SSL_Cert_Import_t import_type);
```

DESCRIPTION

Set private key information in a certificate object. The first certificate in a chain may have private key information associated with it. This allows the TLS library to use the certificate as "our" certificate.

Legacy certificates (i.e., ".dcc" format) include private key information, thus it is not necessary to call this function. The new DER or PEM format is split into two parts: the certificate proper, and the private key information. In this case, it is necessary to call this function in order to associate the correct private key information with the certificate.

PARAMETERS

cert Certificate data structure to be augmented. This should have been initialized using `SSL_new_cert()` with the DER or PEM certificate itself, as the first or only member of the chain. This parameter can also be NULL, in which case the private key is only checked for basic validity.

addr The address or name of the private key input file. See `SSL_new_cert()` for details.

import_type The import type of private key input file. One of the following is allowed (this is a subset of the allowable formats for `SSL_new_cert()`):

import_type	Interpretation of "addr" Parameter
`SSL_DCERT_XIM`	symbol defined with the #ximport directive
`SSL_DCERT_UID`	offset from beginning of User ID block. This is the location of a long integer that contains the length of the immediately following certificate data.
`SSL_DCERT_Z`	pointer to null-terminated string name (char far *) of Zserver resource containing the DER or PEM certificate.

RETURN VALUE

0 on success, non-zero on failure

LIBRARY

`SSL_CERT.LIB`

SEE ALSO

`SSL_extract_cert`, `SSL_get_chain_size`, `SSL_get_cert_len`, `SSL_free_cert`, `SSL_new_cert`

SSL_store_cert

```
int SSL_store_cert( SSL_Cert_t far * cert, size_t offset, size_t N,
   size_t * next_offs);
```

DESCRIPTION

Store a DER (binary) format certificate from a certificate object or certificate chain in the userID block.

This is typically used to store root CA certificates or other digital certificates in non-volatile storage, particularly on small boards where there is no FAT filesystem available.

If there is any private RSA key data associated with this certificate, it is also stored, and will be available automatically when the certificate is subsequently imported from the User block.

The most common usage is to somehow receive the certificate (e.g., via HTTPS file upload), parse and verify the certificate using `SSL_new_cert()`, then call this routine to store the result in the User block. When this certificate is subsequently used, it is obtained using `SSL_new_cert()` with the same "offset" value, and `SSL_DCERT_UID` import type. For example:

```
SSL_Cert_t cert;
memset(&cert, 0, sizeof(cert));

SSL_new_cert(&cert, ....);              // appropriate initial import
SSL_set_private_key(&cert, ....);       // optional
SSL_store_cert(&cert, MY_CERT_OFFSET, 0, NULL);
SSL_free_cert(&cert);

// then, whenever the certificate is required (even after reboot etc.)
memset(&cert, 0, sizeof(cert));
SSL_new_cert(&cert, MY_CERT_OFFSET, SSL_DCERT_UID, 0);

// ...private key (if any) automatically restored, hence
// for HTTPS server certificate we can simply...
https_set_cert(&cert);
```

This function (`SSL_store_cert()`) will *not* be available if you include the statement:

```
#define SSL_DISABLE_USERBLOCK.
```

SSL_store_cert (cont'd)

PARAMETERS

cert	Pointer to certificate object, e.g., from SSL_new_cert().
offset	Offset of where to store the certificate in the User block. Your application is responsible for managing the storage layout in the User block. This library assumes that the entire certificate (plus a 4-byte length field, and possibly the private RSA key data) can be stored at the given offset. The size of the required storage may be obtained by calling SSL_get_store_cert_len(). Note that this offset value is the same value as passed to SSL_new_cert() when it is desired to read the stored certificate using the SSL_DCERT_UID import type.
N	Certificate number in chain. 0 is the first certificate.
next_offs	If not NULL, this is used to return the offset in the User block which immediately follows the end of the stored certificate. This is useful when storing several certificates (or other data) in the User block. The value will always be: offset + SSL_get_store_cert_len(cert,N,NULL)

RETURN VALUE

0 on success, non-zero on failure
-EINVAL: certificate pointer is NULL
-ENOMEM: insufficient system malloc() storage for temporary buffer
-EBUSY: indicates the User block is stored on a serial flash, but the serial flash is already in use. Try again later.

LIBRARY

SSL_CERT.LIB

SEE ALSO

SSL_get_chain_size, SSL_get_cert_len, SSL_free_cert, SSL_set_private_key, SSL_new_cert, SSL_get_store_cert_len

1.6 Rabbit Certificate Utility

The Rabbit Certificate Utility helps you create digital certificates for your devices. The utility can be found in the `Utilities\SSL_Utilities` directory in the root Dynamic C installation directory. Start the certificate utility by double-clicking `certificate.exe`.

Certificates are currently used for three purposes on the Rabbit:

1. As a server certificate when using HTTPS
2. As a client certificate when using WPA Enterprise with EAP-TLS
3. As a trusted authority for verifying the validity of other certificates (informally, these are often called "CA certificates").

Note that the certificate itself does not distinguish between "client" and "server." These terms refer to the role the certificate plays in the SSL/TLS connection.

This section covers all aspects of the certificate utility, and is intended as a reference. For more information on certificates and choosing signing options, see Appendix B: "SSL Certificates".

1.6.1 The Wizard Interface

The first time you run the Rabbit Certificate Utility, the wizard interface is active and a welcome screen is displayed. The wizard interface is used to accomplish the following tasks:

- Generation of a signed certificate
- Generation of a certificate request
- Creation of a Certificate Authority (CA)
- Generation of a root CA certificate

Follow the wizard's on-screen instructions to create a certificate, as demonstrated in the SSL walk-through in Section 1.3.

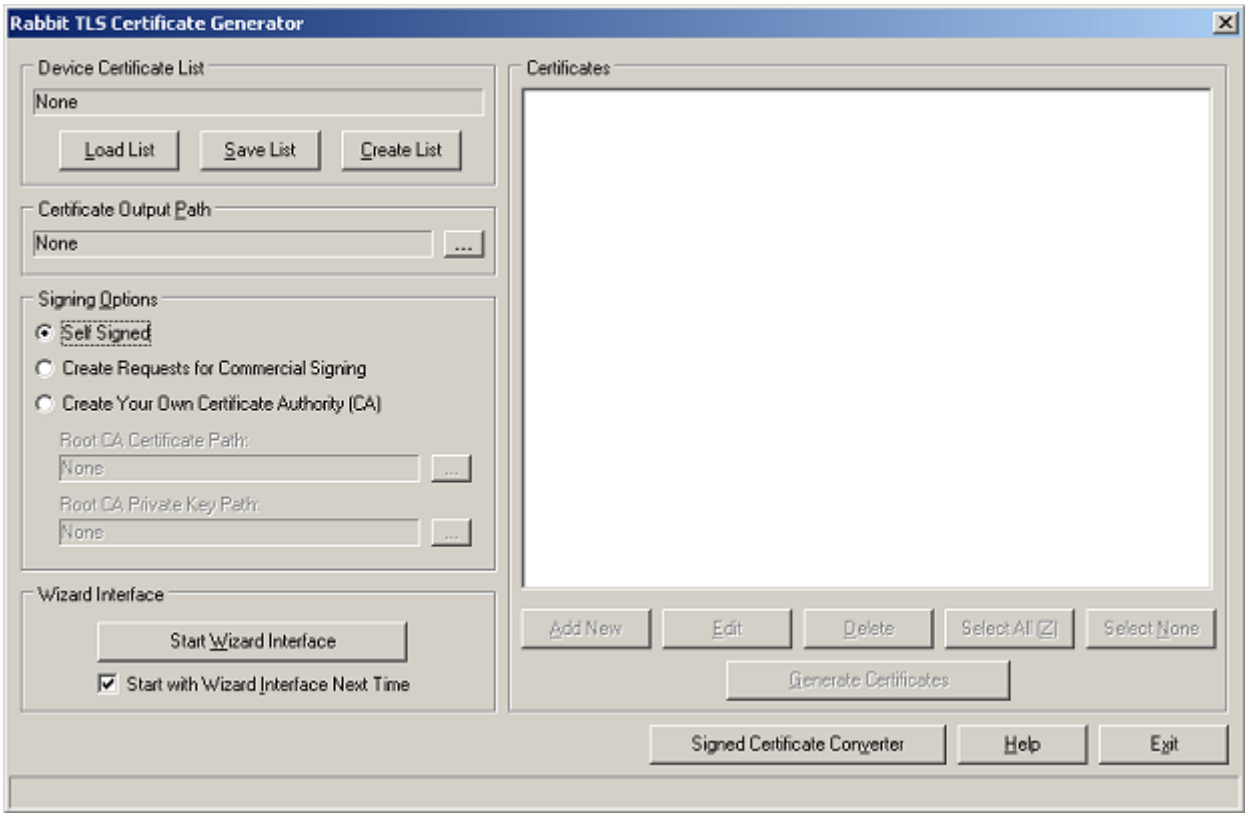
You have the option to create a certificate and then exit the wizard after the certificate and key files have been generated, or you can input the certificate information using the wizard and then use the advanced interface to generate the actual certificate and key files. The former is accomplished by checking the "Generate this certificate at finish and exit" check-box on the "Create a New Certificate" panel, as shown in Figure 6. If you leave the box unchecked, the advanced interface will start with the certificate information and signing option you selected with the wizard.

1.6.2 The Advanced Interface

You may go directly to the advanced interface from the first wizard panel by clicking on the "Launch Advanced Interface" button. Note that if you want to create your own CA certificate, you will have to go through the entire wizard (which includes creating a certificate for your Rabbit device) and you will have to select "Create Your Own Certificate Authority (CA)" on the signing options panel.

The advanced interface window is shown in Figure 10. The file and signing options are on the left-hand side, and the certificate edit pane is on the right. Fly-over hints are available on all parts of the advanced interface window: move the mouse over an area of interest and an explanatory comment will appear along the bottom of the window.

Figure 10. Initial Advanced Interface Window



Before certificates can be generated using the advanced interface, the following information must be specified:

- A device certificate list (see Section 1.6.3)
- A certificate output path (see Section 1.6.4)
- A signing option (see Section 1.6.5)

1.6.3 Creating and Loading Device Certificate Lists

To begin the certificate signing process, you must create or load a Device Certificate List (DCL). These lists (i.e., files with the extension ".dcl") contain certificate information for zero or more certificates. They are provided as a way of grouping and generating certificates en masse.

If you entered the advanced interface after using the wizard (i.e., you did not check the "Generate Certificate and Exit" checkbox from the wizard), you were asked to specify a certificate list. This list along with the information entered via the wizard will display in the advanced interface window.

If you are using the advanced interface for the first time and did not enter through the certificate process in the wizard, there will be no list or path information displayed. However, your choices are stored on exit, so they will be available the next time you start the utility.

The options "Load List" and "Create List" allow you to load an existing list or name a new one. Either option will result in the path and filename of the list displaying in the "Device Certificate List" text box, as well as activating the "Certificates" edit pane. When the edit pane is active, certificates may be created and

added to the current certificate list. This functionality is covered in Section 1.6.6. Once you are done editing your certificate list, click the "Save List" button to save your changes.

To generate the certificate and related key files, an output directory and a signing option must be selected.

1.6.4 Certificate Output Directory

To set up an output directory, click the "..." button next to the text box under "Certificate Output Path" on the left side of the window. Note that several files will be generated for each certificate, so it is a good idea to use an empty directory for your certificate output.

1.6.5 Signing Options

To select a signing option, click its radio button. The signing options are:

- Self Signed - This is the default. Certificates will be generated signed using their own private keys. These certificates can be used for testing, or if the user does not mind the warning messages generated by browsers when attempting to connect to a device. Note that these certificates may be installed in a Web browser's certificate store to eliminate the warnings (see Section 1.3.5 for more information). If you are deploying a large number of devices each with different certificates, then the "Create Your Own Certificate Authority (CA)" option may be a better choice.
- Create Requests for Commercial Signing - This option allows you to create certificate requests for sending to a commercial Certificate Authority (CA) for signing. This option has the advantage of your certificate being automatically trusted by any Web browser or implementation (assuming you used a trusted CA to sign your certificate for you). Use this option if your device will be accessible on the Internet and you want any browser to trust the certificate immediately.
- Create Your Own Certificate Authority (CA) - This option causes the root CA certificate and key path fields to be enabled, allowing you to specify a root CA certificate and its matching private key (both in PEM format).

  If you have already created a root CA certificate that you want to use, then you will need to load that certificate and that root certificate's matching private key file using the "..." buttons next to the respective path text boxes for the certificate and key.

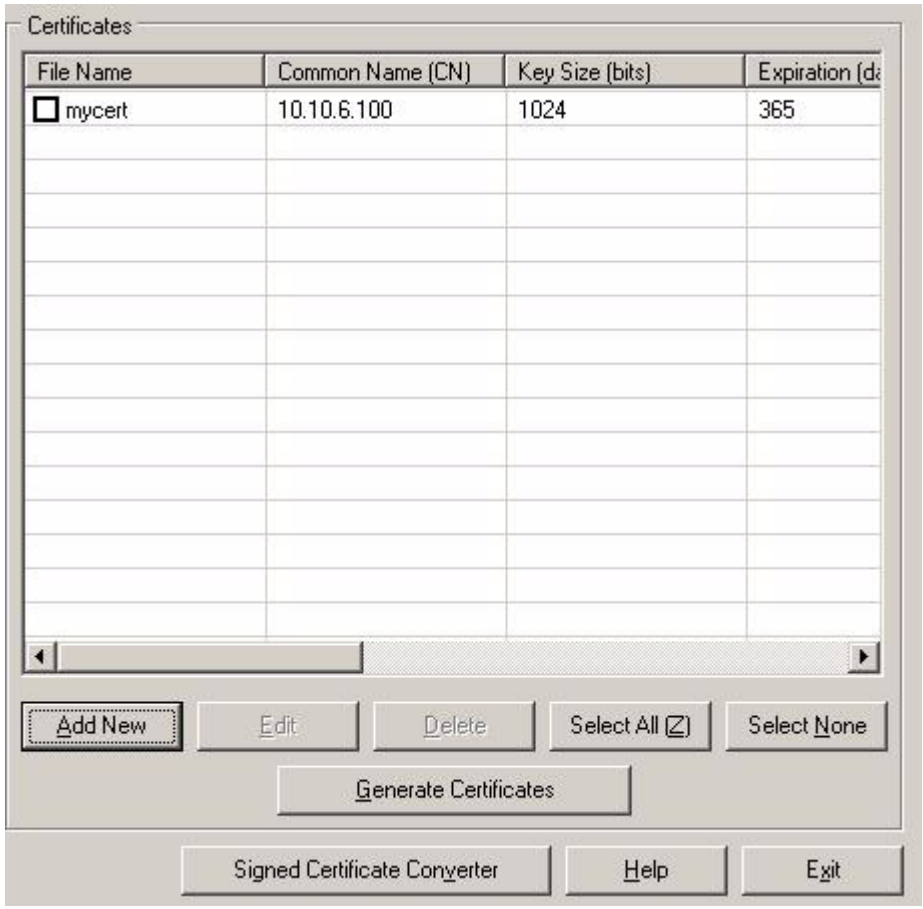
  To create a new root CA certificate, use the wizard interface and select the "Create Your Own Certificate Authority (CA)" option on the signing options panel, and leave the "Generate this certificate at finish and exit..." checkbox unchecked. Once you finish the wizard, you will see that the root CA certificate and key paths now point to your newly created root certificate and key. The DER version of this certificate is what you will need to install in your browser later for the browser to accept the signed certificate as trustworthy. Take note of where your root CA certificate is located for the browser setup later.

1.6.6 The Certificate Edit Pane

The certificate edit pane (labeled “Certificates”) shows certificates in the current list that may be edited or generated. The fields for each certificate are represented by columns, with each row representing a single certificate. Before you choose a list, this pane and the associated buttons will be disabled. Creating or loading a new list will enable the edit pane, and you will be able to add, edit, and delete certificates from the list.

Figure 11 is a screenshot of the edit pane of the advanced interface. It shows a single certificate.

Figure 11. Advanced Interface with Certificate List



To create a new certificate, click the “Add New” button. This will bring up the “Add Certificate to List” dialog box. Fill in the mandatory and desired optional fields (which are described in Section 1.6.8) and click “OK” to add the new certificate to the list. Note that the list is sorted alphabetically according to the file name, and may update after editing or creating a certificate.

To edit a certificate, either double-click it or highlight the certificate and press enter or click “Edit.”

You can remove certificates from the list by highlighting them and clicking “Delete,” or hitting the delete key. This action cannot be undone. If the certificate has been generated (described in Section 1.6.7), the PEM and DER files, etc., will still be in the specified output directory; the certificate will only be deleted from the certificate list.

1.6.7 Generating Certificates

Once you are satisfied with your certificate list, you can generate your certificates. To do this, check the checkbox next to each certificate you wish to generate (the "Select All" and "Select None" buttons help to speed up this process), and click the "Generate Certificates" button. If all went well, a message box will be displayed, indicating success and the number of certificates generated.

The generated certificates are saved in the selected output directory. The Certificate Name is the base name used for all the files generated for each certificate.

Each generated certificate will result in the following files:

<basename>.pem - This is the certificate request file. It is the file you need if you selected "Create Requests for Commercial Signing" as the signing option. It is not used by either the browser or the Dynamic C application.

<basename>.dcc - This is the Dynamic C Certificate file. Prior to Dynamic C 10.54, this file type was the only one that could be imported into a Dynamic C application. It is deprecated as of Dynamic C 10.54.

<basename>.der - This is one of two formats of the signed certificate. Starting with Dynamic C 10.54, this file can be imported into your Dynamic C application. This is a browser-compatible version of the certificate.

<basename>s.pem - This is one of two formats of the signed certificate. Starting with Dynamic C 10.54, this file can be imported into your Dynamic C application. The "s" was added after the basename so it will not be confused with the certificate request *<basename>.pem)*.

<basename>.key - This is one of two formats of the private key. This file is in a binary format which is used in the process of converting certificates into the deprecated .dcc format, but Dynamic C cannot directly use this format. Always use the <basename>key.pem file when importing into a Dynamic C application.

<basename>key.pem - This is one of two formats of the private key. Starting with Dynamic C 10.54, this file can be imported into your Dynamic C application.

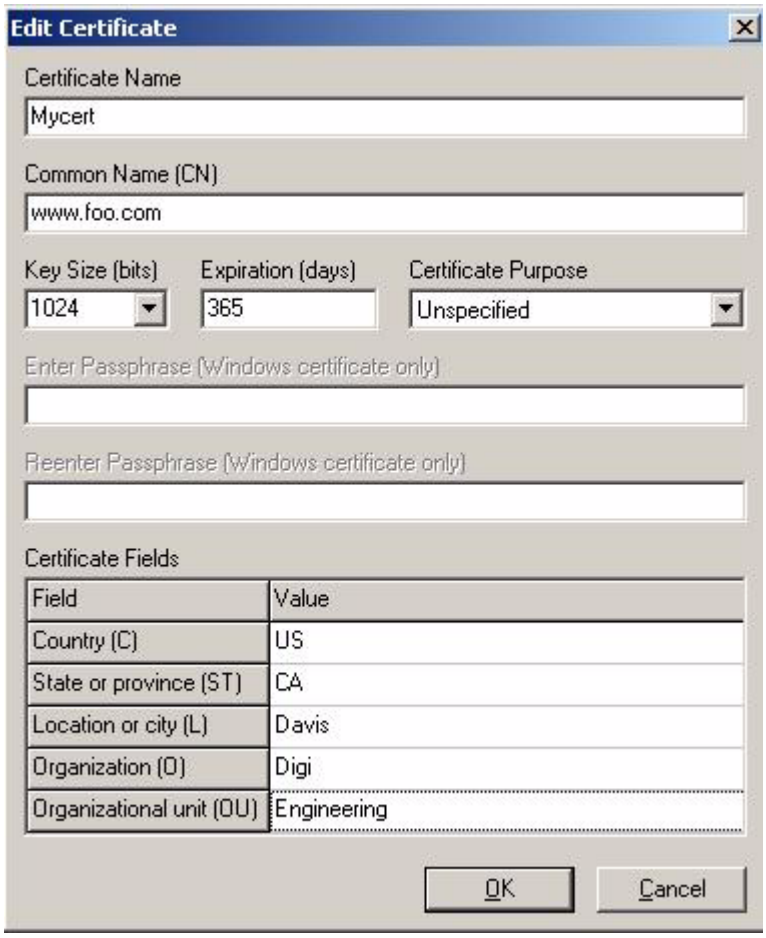
Notes:

1. The .dcc file format includes the certificate itself, plus a simplified version of the private key. The simplified version is three times slower to process than the .der or .pem format private key, which is why this format is deprecated as of Dynamic C 10.54.
2. The .der and .key formats are binary, and are the most compact and efficient. Unlike .pem or .dcc, the certificate (.der) and private key (.key) files cannot be directly combined.
3. The .pem format is ASCII (printable) and may include both certificate and private key in the same file. The certificate utility creates separate files (...s.pem and ...key.pem). You can manually concatenate these files into a single .pem file if this would simplify the application.
4. Often private key files (.key or .pem) are themselves encrypted via a passphrase. Dynamic C and the certificate utility require plaintext (unencrypted) key files. Since private keys must be hidden from any entity other than the subject (owner) of the corresponding certificate, it is necessary to ensure that key files are always transmitted over a secure communication channel, such as an SSL/TLS connection. When stored, they must be stored on protected media; accessible only to the certificate subject. On a Rabbit board, it is assumed that the flash memory satisfies this requirement, although in critical applications it may be necessary to provide physical security, since the private key could be extracted from flash memory if the board was connected to a programming cable.

1.6.8 The Edit Certificate Dialog

This dialog box allows you to edit certificate information.The mandatory fields are the Certificate Name, the Common Name, Key Size, Expiration and Certificate Purpose. Prior to Dynamic C 10.54, the last three fields were not available to modify: the key size and expiration values were always 1024 bits and 365 days, respectively, and the Certificate Purpose was always unspecified.

Figure 12. Edit Certificate Dialog



1.6.8.1 Certificate Name

The Certificate Name represents the base file name that will be used for all the generated files related to that certificate, so it should not include an extension or any characters (such as punctuation) that cannot be part of file names.

1.6.8.2 Common Name

Choose the Common Name to match the domain you will access the device from, such as www.foo.com. Do not include pages or other information. The Common Name may also be the IP address of the device, if that is how the device will be accessed. The important thing is that the Common Name matches the address you will access the device from in your browser.

1.6.8.3 Selecting Key Size

To date, 512-bit RSA keys have been factored (cracked), but not 768-bit or larger. Nevertheless, 512-bit keys are very secure since enormous resources are required to crack these keys. For most embedded applications, it is hardly worth using larger keys unless the system is extremely sensitive. If the number of key bits is doubled, the time to establish each SSL/TLS connection increases about 5 to 8 fold. As of Dynamic C 10.54, on an RCM5400W, at 74 MHz, with .pem or .der format private keys, a 512-bit key will take approximately 0.3 seconds, whereas a 1024-bit key will take 1.5 seconds for RSA key exchange and authentication.

The default maximum key length supported is a 1024-bit key. If you choose to create certificates with longer key lengths or if you want to support such certificates you must override the default value as follows:

```
#define MP_SIZE 258
```

The key length is `MP_SIZE`, minus 2, then multiplied by 8. Practical definitions for `MP_SIZE` are:

MP_SIZE	Max. key length
66	512
130	1024
258	2048

It is not recommended to use greater than 1024-bit keys, since there is currently no practical security benefit, and the slow session establishment is counterproductive. The exceptions are:

- If the certificate is valid for more than a few years, then an increased key size provides some insurance against technology advances.
- The requirement for setting `MP_SIZE` relates to the key length used by the signing CA(s). Some Authentication Servers use CA certificates with longer key sizes (e.g., a Microsoft IAS Authentication Server uses a 2048-bit key size). Such long CA keys do not appreciably slow down operations on the Rabbit, since only the small public exponent is used, however it is important to set `MP_SIZE` to the largest expected RSA key size to be encountered in any context.

1.6.8.4 Expiration Date

The default expiration date is approximately one year from the creation date. Both the CA and subject certificates must be valid for the entire expected period of use. There is no point in specifying a later expiration date for the subject certificate than the (signing) CA certificate's expiration date.

For an embedded application, where it may be difficult to update certificates remotely, consider increasing the valid period for both the CA and the subject. For a 10-year (or more) validity, consider using the next larger key size.

1.6.8.5 Certificate Purpose

If the Certificate Purpose is “Client (Wi-Fi auth. with Windows)” or “Server (Wi-Fi auth. with Windows)” you will need to enter a passphrase. If the Certifcate Purpose is left as “Unspecified” in the Edit Certificate dialog then no passphrase is needed, and its fields are grayed out. “Unspecified” will be the correct choice for most embedded applications.

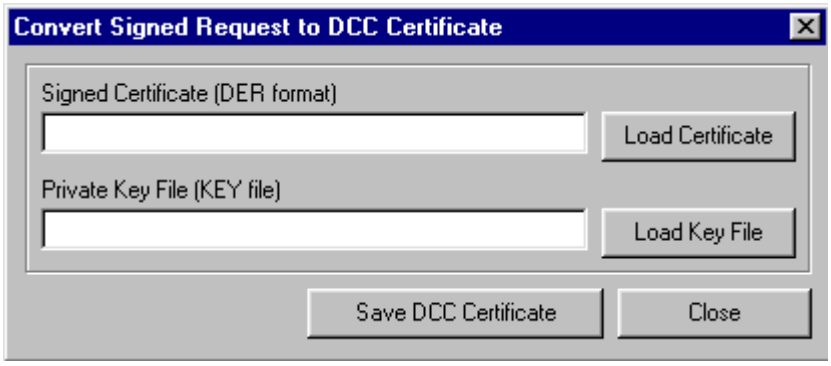
1.6.8.6 Optional Fields

The other fields in the Edit Certificate dialog are optional, however, they are usually important for any clients (such as web browsers) since they give standard subject information. The optional fields are also highly recommended when the certificate is used as a client certificate in Wi-Fi Enterprise with EAP-TLS.

1.6.9 The Signed Certificate Converter

If you chose the “Create Requests for Commercial Signing” signing option, you create certificate requests that are then sent to the commercial CA for signing. You should receive a signed certificate from your CA in the form of one or more files. One of these files should be the DER-formatted version of your signed certificate.

Figure 13.



Prior to Dynamic C 10.54, in order for Dynamic C to be able to use your certificate, you needed to create a Dynamic C Certificate (DCC) file by combining your signed DER certificate and the KEY file generated when you created your original request. To create a DCC certificate file, click the “Signed Certificate Converter” button in the utility to bring up the Signed Certificate Converter dialog.

To create your DCC file, load your DER certificate file by clicking “Load Certificate” and its matching KEY file by clicking “Load Key File.” Click “Save DCC Certificate” to select the file name and output directory for your DCC file.

As of Dynamic C 10.54, the libraries can use DER and PEM files directly, thus it is no longer necessary to create a DCC file from the commercially-signed certificate.

1.6.10 OpenSSL Libraries

The certificate utility uses the OpenSSL libraries and a command-line utility for the back-end work of actually generating the certificates. Primarily, the utility uses two Rabbit utilities, `mk_ca.exe` and `mkreq.exe`, which are located in the same directory as `certificate.exe`. These do the actual generation of certificates using Dynamic C Certificate List (DCL) files. Note that these utilities are the only Rabbit code linked against the OpenSSL libraries. The GUI utility simply executes them as from a command line.

The utility installation directory also includes the OpenSSL DLLs and the OpenSSL command-line utility (used for signing certificates and converting between different certificate formats). See `www.openssl.org/` for more information about OpenSSL. The OpenSSL license agreement stipulates that the following disclaimers be present in our documentation since we are using OpenSSL to generate certificates.

> "This product includes software developed by the OpenSSL Project for use in the OpenSSL Toolkit. (`www.openssl.org/`).
>
> "This product includes cryptographic software written by Eric Young (eay@cryptsoft.com)."

NOTE: No OpenSSL code is present in any of the Dynamic C SSL libraries or the certificate utility (which simply executes command-line executables that *are* linked with OpenSSL). The Dynamic C SSL libraries and the certificate GUI utility are 100% proprietary to Digi International.

1.6.11 Cygwin

The command-line utilities were built using GCC under the Cygwin environment, and therefore require the presence of the Cygwin runtime library `Cygwin1.dll`. Note that this may cause conflicts if you have Cygwin installed on your machine.

See `http://www.cygwin.com` for more information on Cygwin.

2. Advanced Encryption Standard (AES)

AES[6] converts text (called plaintext) into a random-looking form called ciphertext. AES is one of the cryptographic algorithms that can be used within an SSL connection. In addition, AES can be used outside of an SSL connection as a stand-alone utility for encrypting files or other data. You can use AES within an SSL-protected channel to ensure a secure web transaction, while you might use AES alone to encrypt a file stored in the Rabbit's NAND flash or on an SD card. AES is also an integral part of WPA2 (CCMP).

Standalone AES can be used independent of any medium.This makes for a flexible solution to privacy concerns.

Unsecured data at Site 1 → Data secured using AES at Site 1
→ **Any Transmission Method** →
Data Decrypted using AES at Site 2 → Unsecured Data at Site 2

The ability to use any transmission method is a significant feature of any cryptographic algorithm. Once data has been encrypted, it can be sent via serial, TCP/IP, FTP, or shipped on an SD card. You can even yell the sequence of bits out the window and the data is still secure until decrypted by the cryptographic algorithm.

2.1 Getting Started

To get started right away using AES with SSL, run the program `SSL_STATIC.C` located in `\Samples\TCPIP\SSL\` relative to the Dynamic C installation directory. The complex part of SSL has to do with certificate creation, as detailed in Section 1.3.1. The Dynamic C code itself is uncomplicated, as shown in the following code snippet.

```
// This macro determines the number of HTTP servers that will use SSL (i.e., HTTPS servers).
//  In this case, we defines one of the available HTTP servers to be HTTPS.
#define HTTP_SSL_SOCKETS 1

//  This macro tells the HTTP library to use SSL
#define USE_HTTP_SSL

//  Defining these macros tells SSL to enable AES and disable RC4.
//  IMPORTANT: At least one cipher (RC4 or AES) must be enabled.
#define SSL_USE_AES
#define SSL_DONT_USE_RC4

//  Import the certificate
#ximport "cert\mycert.dcc" SSL_CERTIFICATE
```

To summarize, using AES from within an SSL-protected communications channel is accomplished by defining the appropriate configuration macros when setting up SSL.

To get started right away using AES as a stand-alone utility, run the program AES_KAT.C located in `\Samples\AES_Encryption\` relative to the Dynamic C installation directory. For more information on the Dynamic C code for stand-alone AES, see Section 2.4.

6. The National Institute of Standards and Technology (NIST) announced AES in the following document: http://csrc.nist.gov/publications/fips/fips197/fips-197.pdf

2.2 Rabbit Specifics

The Rabbit Embedded Security Pack contains an implementation of the Rijndael block cipher, (a superset of the AES bock cipher) meaning that the implementation supports additional block and key sizes and is not limited to the 128-bit block size and the 128-, 192- and 256-bit keys supported by AES. A block cipher is a method of encryption in which a cryptographic key and algorithm are applied to a fixed-size group of contiguous bytes (called a block) rather than to one byte or bit at a time, as is the case with stream ciphers.

The Dynamic C AES software supports two AES operating modes: Cipher Feedback (CFB) and, starting with library version 1.05, Cipher Block Chaining (CBC). Operating modes are used to encrypt messages that are longer than the block size.

Wikipedia and other easily found informational Web sites have detailed descriptions of the different AES operating modes. Another good resource is “Applied Cryptography, 2nd Edition” by Bruce Schneier (pg. 200) for a complete explanation of the encryption/decryption process.

2.3 AES Sample Program Summaries

The sample programs provided in the `\Samples\AES_Encryption\` directory will encrypt and decrypt data outside of an SSL connection.

To state the obvious, you need data to encrypt in order to use AES. There are two things that must be known about the data: its length and location. The data’s format is not important. In other words, the data can be an #ximported file, read in from a FAT file, a buffer, an array, etc. As noted above, in an AES algorithm, all data is in fixed-length groups of bits, called blocks. The two supported operating modes (CFB and CBC) cause the AES block cipher to act like a stream cipher.

The AES sample programs are listed below, along with brief descriptions of their operation. Together these samples illustrate the different ways to use AES as a stand-alone utility in a Dynamic C application.

- `AES_KAT.C` - This program uses the block encryption function AESencrypt(). This function works on one block of data. When using AES, the block size must be 16 bytes. The program conducts three tests for each of the 128-, 196-, and 256-bit keys, for a total of nine tests. The plaintext is encrypted, checked against the expected ciphertext, and then decrypted and checked against the original plaintext.

  The program `AES_BENCH.C` is the same as `AES_KAT.C`, plus it provides speed bench marks.

- `AES_STREAMTEST.C` - This program employs the CFB mode of operation. Both CFB and CBC are streaming modes of operation for the AES block cipher, and as such they both require an initialization vector (IV). The IV as well as the key must be known for decryption of the ciphertext.

  See Figure 14 for a pictorial description of CFB.

- `AES_CBC.C` - This program employs the CBC mode of operation, another streaming mode of operation for the AES block cipher. An important difference between CFB and CBC is that CBC does not allow partial blocks; that is, partial blocks must be padded when using the CBC mode of operation

  See Figure 15 for a pictorial description of CBC.

Figure 14. Cipher Feedback (CFB)

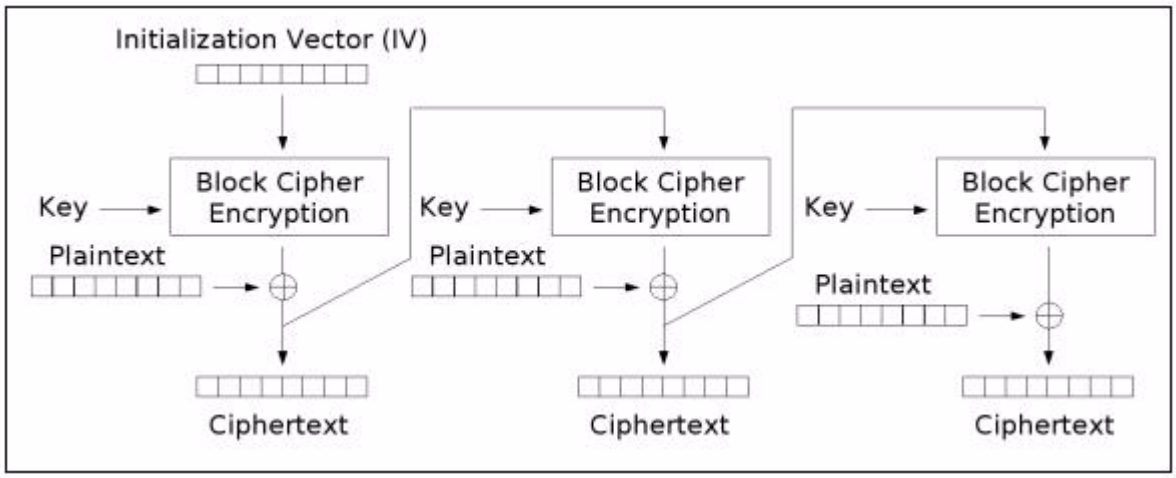
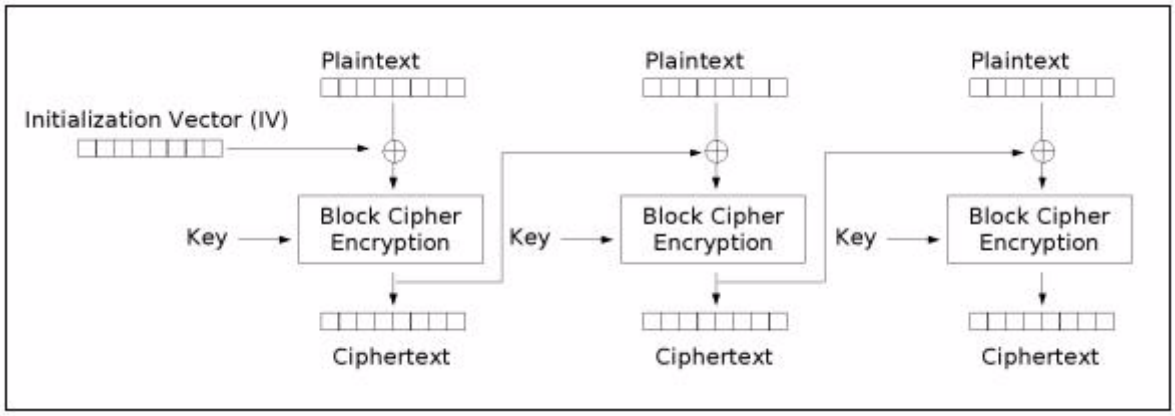


Figure 15. Cipher Block Chaining (CBC)



2.4 Sample Program Code

In this section, we examine the code necessary to use AES as a stand-alone utility within a Dynamic C application.

First and foremost, the Dynamic C application must use the AES library, and thus must contain the statement:

```
#use "aes_crypt.lib"
```

The sample program `AES_STREAMTEST.C` also includes the MD5 library in order to hash a passphrase. The reason for using a passphrase is that it is easier to remember than the long string of numbers necessary for the key.

To use one of the streaming modes of operation, an application must define the structure AESstreamState and initialize it by calling the function AESinitStream(). A separate state structure is needed for encryption and decryption. The sample program AES_streamtest.c shows this in a direct manner:

```
AESstreamState encrypt_state;
AESstreamState decrypt_state;
...
AESinitStream(&encrypt_state, key, init_vector);
AESinitStream(&decrypt_state, key, init_vector);
...
AESencryptStream(&encrypt_state, data, 10);
AESdecryptStream(&decrypt_state, data, 10);
```

The sample program AES_CBC.C arranges the code in order to save memory:

```
auto char text[256];
auto AESstreamState state;
...
AESinitStream(&state, key1, iv1)
memcpy(text, plntxt1, sizeof(plntxt1));
AESencryptStream_CBC(&state, text, AES_CBC_BLOCK_SIZE * 2);
...
AESinitStream(&state, key1, iv1);
memcpy(text, cyptxt1, sizeof(cyptxt1));
AESdecryptStream_CBC(&state, text, AES_CBC_BLOCK_SIZE);
```

As you can see, the same state structure is re-used by separate calls to AESinitStream(). In addition to the state structure, AESinitStream() requires both a key and an initialization vector.

Another important thing to note in the above code for AES_CBC.C is the call to memcpy(). The reason for this function call is to ensure that there are no partial blocks. Both the plaintext and ciphertext are copied into an array that is a multiple of the allowed block size and then that array is passed to the encryption/decryption functions, along with a size limit that tells the function how much data in the array to work on. The size limit also must be a multiple of the allowed block size.

The program AES_KAT.C does not call AESinitStream() because AES_KAT.C is not using one of the streaming operating modes. AES_KAT.C calls the functions that implement data encryption/decryption directly. There is no need to call a stream initialization function; however, because key expansion is done there, the application must call a function named AESexpandKey() to accomplish key expansion before calling one of the raw encryption or decryption functions.

The next section describes in more detail the AES functions available to a Dynamic C application.

2.5 AES Macros and API Functions

The API is defined in AES_CRYPT.LIB, located in the folder \Lib\...\AES_ENCRYPTION\ relative to the Dynamic C installation directory.

2.5.1 Configuration Macros

The following configuration macros are available when using AES:

AES_DEBUG

Define this macro to check that no partial blocks exist when using CBC mode. After the development/debug cycle you can comment out the macro to remove the check, thus speeding up the application.

AES_ONLY

You can #define AES_ONLY before #use AES_CRYPT.LIB if you are adhering to AES block and key size limitations. This saves some code space.

2.5.2 API Functions

The functions described here are included with the latest AES software. New releases of Dynamic C modules may contain new API functions. You can check if your version of the AES module contains a particular function by checking the Function Lookup feature in the Dynamic C Help menu. If you see functions described in this manual that you want but do not have, please consider updating your version of the Rabbit Embedded Security Pack module. To do so, go to: www.rabbit.com/products/dc/ or call 1.530.757.8400.

The following functions are used to initialize the data structure AESstreamState, which holds information for the stream-based operating modes of AES.

- AESinitStream
- AESinitStream192
- AESinitStream256

The following functions should be called by an application wanting to operate in the CFB mode:

- AESdecryptStream
- AESencryptStream

The following functions should be called by an application wanting to operate in the CBC mode:

- AESdecryptStream_CBC
- AESdecryptStream_CBC_XMEM
- AESencryptStream_CBC
- AESencryptStream_CBC_XMEM

The following functions are the encryption and decryption routines, as well as the function that expands a key into round keys:

- AESdecrypt
- AESdecrypt4
- AESencrypt
- AESencrypt4
- AESexpandKey

The following functions are available with Dynamic C in /Lib/.../Crypto/ relative to the Dynamic C installation directory. These functions are limited to the basic 128-bit AES algorithms and are the most highly optimized of the available functions.

- AESdecrypt4x4
- AESdecryptStream4x4_CBC
- AESencrypt4x4
- AESencryptStream4x4_CBC
- AESexpandKey4
- AESinitStream4x4

AESdecrypt

```
void AESdecrypt( char * data, char * expandedkey, int nb, int nk );
```

DESCRIPTION

Decrypts a block of data in place.

PARAMETERS

data	Pointer to a block of data to be decrypted.
expandedkey	Pointer to a set of round keys (generated by AESexpandKey).
nb	The block size to use. Block is 4 * nb bytes long.
nk	The key size to use. Cipher key is 4 * nk bytes long.

LIBRARY

AES_CRYPT.LIB

AESdecrypt4

```
void AESdecrypt4( char * data, char * expandedkey, int nk );
```

DESCRIPTION

Decrypts a block of data in place. This function assumes that the block size (nb) is 4 words (i.e., 16 bytes). This is always the case for AES, in which case this function is more efficient than the general purpose `AESdecrypt()`.

PARAMETERS

data	Pointer to a block of data to be decrypted
expandedkey	Pointer to a set of round keys (generated by `AESexpandKey`)
nk	The key size to use. Cipher key is 4*nk bytes long. This parameter should be “4”, “6” or “8” for AES-128, AES-192 or AES-256 respectively.

LIBRARY

AES_CRYPT.LIB

AESdecrypt4x4

```
void AESdecrypt4x4( char far * expandedkey, char far * crypt,
   char far * plain );
```

DESCRIPTION

Decrypts a block of data using an implementation of the Rijndael AES cipher with a 128-bit key and block size.

The encrypted block of data may be overwritten by the decrypted block of data.

PARAMETERS

expandedkey A set of round keys (generated by `AESexpandKey4()`) from a 16-byte (128-bit) key.

Total of 176 bytes (44 longwords)

Note: when using an AESstreamState structure (e.g. "state") then call this function using:

```
AESdecrypt4x4(state->expanded_key, plain, crypt);
```

crypt A block of 16 bytes of ciphertext to be decrypted; "crypt" and "plain" may point to the same place.

plain A block of 16 bytes of resulting plaintext data; "crypt" and "plain" may point to the same place.

LIBRARY

AES_CORE.LIB

AESdecryptStream

```
void AESdecryptStream( AESstreamState * state, char * data,
  int count );
```

DESCRIPTION

Decrypts an array of bytes in place using cipher feedback (CFB) mode.

PARAMETERS

state	Pointer to the AESstreamState structure.
data	An array of bytes that will be decrypted in place.
count	Size of data array

LIBRARY

AES_CRYPT.LIB

AESdecryptStream_CBC

```
void AESdecryptStream_CBC( AESstreamState * state, char * data,
   int count );
```

DESCRIPTION

Decrypts an array of bytes in place using cipher-block chaining (CBC) mode.

PARAMETERS

state	Pointer to the AESstreamState structure
data	An array of bytes that will be decrypted in place. Must be padded to be an integer multiple of 16-byte blocks.
count	Size of data array. Must be a multiple of _AES_CBC_BLK_SZ_.

LIBRARY

AES_CRYPT.LIB

AESdecryptStream4x4_CBC

```
int AESdecryptStream4x4_CBC( AESstreamState * state, long message,
  long output, unsigned int count);
```

DESCRIPTION

Perform an AES-CBC decryption operation.

See `Samples\Crypt\AES_STREAMTEST.C` for a sample program and a detailed explanation of the encryption/decryption process.

PARAMETERS

state	The `AESstreamState` structure, initialized via `AESinitStream4x4()`. This memory must be allocated in the program code before calling `AESdecrptyStream4x4_CBC()`: `static AESstreamState decrypt_state;`
message	Cipher-text message (an xmem buffer)
output	Output buffer, for return of decrypted text (in xmem). Must be as large as the cipher-text buffer. May be the same as the cipher-text buffer.
count	Length of the message. Must a multiple of `_AES_CBC_BLK_SZ_` (16).

RETURN VALUE

0 on success, non-zero on failure

LIBRARY

`AES_CORE.LIB`

AESdecryptStream_CBC_XMEM

```
int AESdecryptStream_CBC_XMEM( AESstreamState * state, long message,
   long output, unsigned int count );
```

DESCRIPTION

Perform an AES-CBC decryption operation.

PARAMETERS

state	Pointer to an AES stream state structure.
message	The cipher-text message (an xmem buffer)
output	The output buffer, for return of decrypted text (in xmem). Must be as large as the cipher-text buffer. May be the same as the cipher-text buffer.
count	Length of the message. Must be a multiple of _AES_CBC_BLK_SZ_.

RETURN VALUE

0 on success, non-zero on failure

LIBRARY

AES_CRYPT.LIB

AESencrypt

```
void AESencrypt( char * data, char * expandedkey, int nb, int nk );
```

DESCRIPTION

Encrypts a block of data in place. Note that AES (as such) only allows a block size of 128 bits (nb=4) and key sizes of 128-, 192- and 256-bits (nk=4, 6 or 8). Rijndael allows different block and key sizes; however, performance will be slower if the block size is anything but 128 bits (nb=4).

You can #define AES_ONLY before #use AES_CRYPT.LIB if you are adhering to AES. This saves some code space.

PARAMETERS

data	Pointer to a block of data to be encrypted; the block of data must be nb*4 bytes.
expandedkey	Pointer to a set of round keys (generated by AESexpandKey, with the same nb and nk parameters!)
nb	The block size to use. Block is 4 * nb bytes long. Must be 4 if you have defined the macro AES_ONLY.
nk	The key size to use. Cipher key is 4 * nk bytes long. Must be 4, 6 or 8 if you have defined the macro AES_ONLY.

LIBRARY

AES_CRYPT.LIB

AESencrypt4

```
void AESencrypt4( char * data, char * expandedkey, int nk );
```

DESCRIPTION

Encrypts a block of data in place. This function works the same as AESencrypt() except that it is optimized for the most common case of a 16-byte block size (the only size supported for AES).

You can #define AES_ONLY before #use AES_CRYPT.LIB if you are adhering to AES. This saves some code space.

PARAMETERS

data	Pointer to a block of data to be encrypted.
expandedkey	Pointer to a set of round keys (generated by AESexpandKey())
nk	Key size in longwords. Must be 4, 6 or 8 for AES.

LIBRARY

AES_CRYPT.LIB

AESencrypt4x4

```
void AESencrypt4x4( char far * expandedkey, char far * plain,
   char far * crypt );
```

DESCRIPTION

Encrypts a block of data using an implementation of the Rijndael AES cipher with 128-bit key and block size. The block of data may be overwritten by the encrypted block of data.

PARAMETERS

expandedkey A set of round keys (generated by `AESexpandKey4()`) from a 16-byte (128-bit) key.

Total of 176 bytes (44 longwords)

Note: when using an AESstreamState structure (e.g., "state") then call this function using:

```
AESencrypt4x4(state->expanded_key, plain, crypt);
```

plain A block of 16 bytes of data to be encrypted; "crypt" and "plain" may point to the same place.

crypt A block of 16 bytes of resulting encrypted data; "crypt" and "plain" may point to the same place.

RETURN VALUE

None.

LIBRARY

AES_CORE.LIB

AESencryptStream

```
void AESencryptStream( AESstreamState * state, char * data,
   int count );
```

DESCRIPTION

Encrypts an array of bytes in place using cipher feedback (CFB) mode. Before calling this function, you must initialize the AESstreamState struct by calling AESinitStream() or one of the other initialization functions.

PARAMETERS

state	Pointer to the AESstreamState structure.
data	An array of bytes that will be encrypted in place.
count	Size of data array.

LIBRARY

AES_CRYPT.LIB

AESencryptStream_CBC

```
void AESencryptStream_CBC( AESstreamState *state, char *data,
   int count );
```

DESCRIPTION

Encrypts an array of bytes in place using cipher-block chaining (CBC) mode. Before calling this function, you must initialize the AESstreamState struct by calling AESinitStream() or one of the other initialization functions.

PARAMETERS

state	Pointer to the AESstreamState structure.
data	Pointer to an array of bytes that will be encrypted in place. Must be padded to be an integer multiple of 16-byte blocks.
count	Size of data array. Must be a multiple of _AES_CBC_BLK_SZ_.

LIBRARY

AES_CRYPT.LIB

AESencryptStream4x4_CBC

```
int AESencryptStream4x4_CBC( AESstreamState * state, long message,
   long output, unsigned int count);
```

DESCRIPTION

Perform an AES-CBC encryption operation on XMEM data. Encryption is not “in-place.”

See Samples\Crypt\AES_STREAMTEST.C for a sample program and a detailed explanation of the encryption/decryption process.

PARAMETERS

state — An AES stream state structure, initialized via AESinitStream4x4().

This memory must be allocated in the program code before calling AESencrptyStream():

```
static AESstreamState encrypt_state;
```

message — The message in plaintext (an xmem buffer)

output — The output buffer, for return of encrypted text (in xmem), must be as large as the plaintext buffer, and may be the same as the plaintext buffer.

count — The length of the message. Must be a multiple of _AES_CBC_BLK_SZ_ (16).

RETURN VALUE

0 on success, non-zero on failure (count was not multiple of 16)

LIBRARY

AES_CORE.LIB

AESencryptStream_CBC_XMEM

```
int AESencryptStream_CBC_XMEM( AESstreamState * state, long message,
   long output, unsigned int count );
```

DESCRIPTION

Perform an AES-CBC encryption operation on XMEM data. Encryption is not "in-place." Before calling this function, you must initialize the AESstreamState struct by calling AESinitStream() or one of the other initialization functions.

Enable AES_DEBUG while developing to detect block-size errors.

PARAMETERS

state	Pointer to an AESstreamState structure, initialized.
message	The message in plaintext (an xmem buffer)
output	The output buffer, for return of encrypted text (in xmem), must be as large as the plaintext buffer, and may be the same as the plaintext buffer.
count	The length of the message. Must a multiple of _AES_CBC_BLK_SZ_.

RETURN VALUE

0 on success, non-zero on failure

LIBRARY

AES_CRYPT.LIB

AESexpandKey

```
void AESexpandKey( char * expanded, char * key, int nb, int nk );
```

DESCRIPTION

Prepares a key for use by expanding it into a set of round keys. A key is a “password” to decipher encoded data.

Note: previous versions required the number of rounds to be specified. This is now calculated automatically.

PARAMETERS

expanded A buffer for storing the expanded key. The size of the expanded key is 4 * `nb` * (`rounds` + 1) where rounds is according to following table:

nk	Rounds	AES Usage
4	10	AES-128
6	12	AES-192
8	14	AES-256

Other key sizes are not supported.

key Pointer to the cipher key; key size should be 4 * `nk`

nb The block size to use; the block size will be 4 * `nb` bytes long. This parameter must be 4 for AES.

nk The key size to use; the key size will be 4 * `nk` bytes long. This parameter must be 4, 6 or 8 for AES.

rounds The number of cipher rounds to use.
(This parameter was removed in version 1.03 of the AES module. The number of rounds is now calculated automatically according to the above table.)

LIBRARY

AES_CRYPT.LIB

AESexpandKey4

```
void AESexpandKey4( char far * expanded, char far * key );
```

DESCRIPTION

Prepares a key for use by expanding it into a set of round keys. A key is a "password" to decipher encoded data.

This function is specific to AES with 128-bit key. See `AESexpandKey()` for a more general function (available with Rabbit Embedded Security Pack).

PARAMETERS

expanded A buffer for storing the expanded key. The size of the expanded key, for a 128-bit key, is 176 bytes. Other key sizes are not supported by this function.

Note: when using an AESstreamState structure (e.g., "state") then call this function using:

```
AESexpandKey4(state->expanded_key, key);
```

key The cipher key, 16 bytes

RETURN VALUE

None.

LIBRARY

AES_CORE.LIB

AESinitStream

```
void AESinitStream( AESstreamState * state, char * key,
   char * init_vector );
```

DESCRIPTION

Sets up a stream state structure to begin encrypting or decrypting a stream. A particular stream state can only be used for one direction.

A 128-bit key (16 bytes) is assumed.

PARAMETERS

state	Pointer to a `AESstreamState` structure to be initialized.
key	Pointer to the 16-byte cipher key. Using a null pointer will prevent an existing key from being recalculated.
init_vector	A 16-byte array representing the initial state of the feedback registers. Both ends of the stream must begin with the same initialization vector and key.

LIBRARY

AES_CRYPT.LIB

AESinitStream192

```
void AESinitStream192( AESstreamState * state, char * key,
   char * init_vector );
```

DESCRIPTION

Sets up a stream state structure to begin encrypting or decrypting a stream. A particular stream state can only be used for one direction.

A 192-bit key (24 bytes) is assumed.

PARAMETERS

state	Pointer to a `AESstreamState` structure to be initialized.
key	Pointer to the 24-byte cipher key. Using a null pointer will prevent an existing key from being recalculated.
init_vector	A 16-byte array representing the initial state of the feedback registers. Both ends of the stream must begin with the same initialization vector and key.

LIBRARY

AES_CRYPT.LIB

AESinitStream256

```
void AESinitStream256( AESstreamState * state, char * key,
   char * init_vector );
```

DESCRIPTION

Sets up a stream state structure to begin encrypting or decrypting a stream. A particular stream state can only be used for one direction.

A 256-bit key (32 bytes) is assumed.

PARAMETERS

state	Pointer to a `AESstreamState` structure to be initialized.
key	Pointer to the 32-byte cipher key. Using a null pointer will prevent an existing key from being recalculated.
init_vector	A 16-byte array representing the initial state of the feedback registers. Both ends of the stream must begin with the same initialization vector and key.

LIBRARY

AES_CRYPT.LIB

AESinitStream4x4

```
void AESinitStream4x4( AESstreamState far * state, char far * key,
   char far * init_vector);
```

DESCRIPTION

Sets up a stream state structure to begin encrypting or decrypting a stream using AES with a 128-bit key and block size.. A particular stream state can only be used for one direction.

See `Samples\Crypt\AES_STREAMTEST.C` for a sample program and a detailed explanation of the encryption/decryption process.

PARAMETERS

state	An `AESstreamState` structure to be initialized. This memory must be allocated in the program code before calling `AESinitStream4x4()`.
key	The 16-byte cipher key, using a null pointer, will prevent an existing key from being recalculated.
init_vector	A 16-byte array representing the initial state of the feedback registers. Both ends of the stream must begin with the same initialization vector and key. For security, it is very important never to use the same initialization vector twice with the same key.

RETURN VALUE

None.

LIBRARY

`AES_CORE.LIB`

3. Wi-Fi Enterprise Mode Authentication

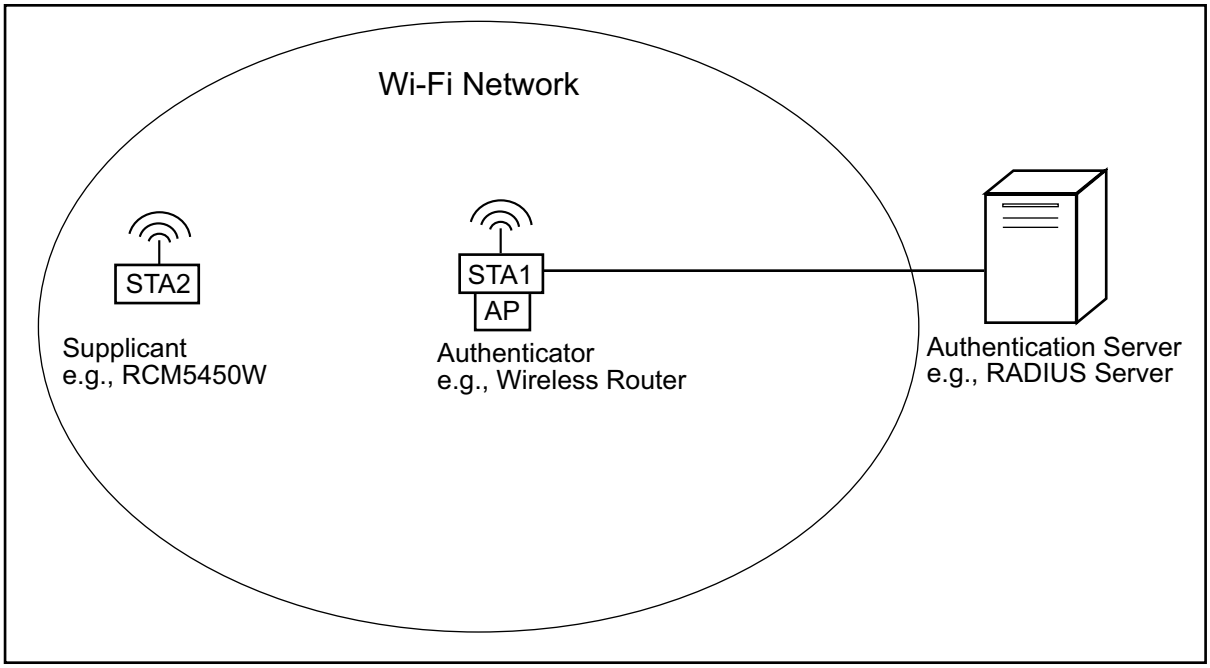
Enterprise mode authentication is defined in the IEEE 802.11i specification. Enterprise mode is one of two operating modes for 802.11i implementations. The major differences between the operating modes, as well as between WPA and WPA2, are summarized in Table 1.

Table 1. Comparison of 802.11i Operation Modes

	Personal Mode	Enterprise Mode
WPA	Authentication: PSK Encryption: TKIP/MIC	Authentication: IEEE 802.1X/EAP Encryption: TKIP/MIC
WPA2	Authentication: PSK Encryption: AES-CCMP	Authentication: IEEE 802.1X/EAP Encryption: AES-CCMP

Enterprise mode authentication is based on the IEEE 802.1X/EAP specification, which is a port-based access control protocol designed to prevent unauthorized access to services and resources offered by a Wi-Fi network. Figure 16 illustrates the three roles that are needed in order to perform Wi-Fi Enterprise mode authentication. A description of 802.1X is given in *An Introduction to Wi-Fi*, available online and with Dynamic C (see Appendix D: "References").

Figure 16. 802.1X Overview



The Rabbit-based board will always be the supplicant, a client-side role. Note that the supplicant/client role for Wi-Fi Enterprise mode authentication is entirely separate and unrelated to any client or server application that the Rabbit-based device may run after it has completed the authentication process.

The IEEE 802.1X specification is based on EAP (Extensible Authentication Protocol). EAP provides an authentication framework, meaning that it does not define how users are authenticated, but provides a

means for the actual authentication algorithm to be agreed upon and executed. These algorithms are called EAP methods.

3.1 EAP Methods

The Rabbit-based implementation of Wi-Fi Enterprise mode authentication supports two EAP methods:

- EAP-TLS
- PEAP (i.e., PEAPv0/EAP-MSCHAPv2)

Both of these EAP methods support mutual authentication, and they both require digital certificates for mutual authentication to succeed.

EAP-TLS uses certificates to authenticate both the client and the server; i.e., both the supplicant and the authentication server have their own digital certificates. In order for the supplicant to trust the certificate offered by the authentication server, the supplicant must have a way of recognizing the signer of that certificate. This is done by installing the root CA certificate that signed the authentication server's certificate into the supplicant. The server, by the same token, would have to be configured to recognize the signer of the client's certificate.

PEAP requires the authentication server to identify itself with a certificate in the same manner as EAP-TLS, but the client is authenticated using a challenge-based user name/password protocol.

3.1.1 Digital Certificates

The Rabbit Certificate Utility used to create digital certificates for secure HTTP servers (described in Section 1.3 and Section 1.6) may be used to create certificates for Wi-Fi Enterprise authentication purposes. In fact, if your application is running a secure HTTP server, you can use that same certificate for Wi-Fi Enterprise mode authentication.

Certificates exist in several different formats that are identified by their file extension: .der, .pem, or .dcc. They may be located in #ximport files, memory or the User block, and accessed as Zserver resources. Code details of certificate inclusion within a Dynamic C program are discussed in Section 3.1.1.1, Section 3.1.1.2, and Section 3.2.1.

Certificate files should be in either DER (binary) or PEM (Privacy Enhanced Mail) format. The PEM format must not have the private key encrypted; it must be saved without DES or any other encryption. The .pem format is automatically detected. If the file appears not to be in PEM format, then it is assumed to be .der encoded. Utilities such as openSSL allow these formats to be manipulated easily. If an unsupported format certificate or private key is provided, the most likely consequence will be inability to establish a connection or become authenticated.

The .DER format is the most compact and efficient, but PEM is readable ASCII and may combine the certificate and its associated private key.

3.1.1.1 Root CA Certificates

Root CA certificates are used to establish a mutually trusted authority for verifying any certificates (and public keys) received from the authentication server. Most embedded applications will use a single, locally-defined, CA. Alternatively, a recognized commercial CA certificate may be used if the authentication server is certified by one.

The run-time configuration function `ifconfig()` accepts the following parameter identifiers for specifying root CA certificates. If no root CA certificate is provided, the authentication server cannot be verified, which introduces the risk of "server spoofing."

- `IFS_WIFI_CA_CERT` - Set root CA certificate [SSL_Cert_t far *].
- `IFS_WIFI_CA_CERT_PATH` - Set root CA certificate as a Zserver resource path [char *].
- `IFS_WIFI_CA_CERT_XIM` - Set root CA certificate as #ximport DER/PEM-formatted file [longword].

The compile-time setting of the root CA certificate is done in the following way:

```
#ximport "certs/root.pem" root_ca_cert
#define IFC_WIFI_CA_CERT_XIM root_ca_cert
```

The macro `IFC_WIFI_CA_CERT_XIM` can be placed in the Defines window[7]; however, the #ximport statement cannot be placed thusly and must be in the program code.

The CA certificate should have a validity period equal or greater than the expected lifetime of the application, especially if it is hard-coded by #ximport.

All real-world applications will need to provide for certificates of all types to be updatable. For applications where physical access is difficult or expensive, there should be code to allow new certificates to be securely uploaded via HTTPS. Such certificates may be stored in the user ID block using, for example, the `SSL_store_cert()` utility function.

3.1.1.2 Subject Certificates

Client or server (i.e., subject) certificates generally require two parts: the certificate itself, and the corresponding private key. The commands that take two parameters provide the certificate in the first parameter, and the private key in the second. The PEM file format may contain both parts, thus the same PEM file resource may be used for both parameters and the library will extract the correct information.

To specify client-side certificates needed for EAP-TLS support, `ifconfig()` accepts the following parameter identifiers for run-time configuration:

- `IFS_WIFI_CLIENT_CERT` - Set client certificate [SSL_Cert_t far *].
- `IFS_WIFI_CLIENT_CERT_PATH` - Set client certificate as a Zserver resource. There are two parameters: the first is the certificate and the second one is the private key [char *, char *].
- `IFS_WIFI_CLIENT_CERT_XIM` - Set client certificate and private key as two #ximport DER/PEM-formatted files [longword, longword]. The first parameter is for the certificate, and the second one is for the private key.

7. The Defines window is located in Dynamic C's main menu under Options | Project Options.

The compile-time setting of the client-side certificate is done in the following way:

```
#ximport "certs/my_client.pem" my_client_cert
#define IFC_WIFI_CLIENT_CERT_XIM my_client_cert, my_client_cert
```

The macro IFC_WIFI_CLIENT_CERT_XIM can be placed in the Defines window; however, the #ximport statement cannot be placed thusly and must be in the program code. EAP-TLS requires both a client certificate and a CA certificate. PEAP requires only a CA certificate.

3.1.2 Username/Password Protocols

There exists extensive infrastructure support for username/password systems. Depending on your network configuration and application needs, running PEAP may be the most efficient use of resources.

The run-time configuration function ifconfig() accepts the following parameter identifiers:

- IFS_WIFI_IDENTITY - Set username string for EAP-TLS or PEAP [char *];
- IFS_WIFI_PASSWORD - Set password string for PEAP [char *].

The username and password information for PEAP can also be set at compile time.

```
#define IFC_WIFI_IDENTITY "my_user1d"
#define IFC_WIFI_PASSWORD "my_passw0rd"
```

The identity string is required by both EAP-TLS and PEAP. The password is only used by PEAP.

3.1.3 Device Compatibility

Just as all devices operating on the same network must agree on the SSID to use, all devices must agree on common security protocols. This means that the Rabbit-based board and the wireless access point (AP) it associates with must both be configured for Enterprise mode authentication using the same EAP methods. In addition, the authentication server (e.g., a RADIUS server) most be configured to recognize the appropriate credentials of the Rabbit-based board.

Setting up an authentication server is probably the most complex of the configuration tasks. This non-trivial process is hardware/software specific and best explained by the manufacturer of the access point and the authentication server. The setup for these devices will not be addressed in this document. The connection between the wireless access point and the authentication server is also not covered in this document.

3.1.4 Troubleshooting Tips

There are far more things that can go wrong with Wi-Fi Enterprise mode authentication than with simple setups like Ethernet or even WPA/PSK. It is recommended that when commissioning a Rabbit board with Wi-Fi Enterprise a successful association from a PC (such as a Windows laptop with a wireless card) be made to the target network. Ideally, you should also be able to associate from the Rabbit board to an open Wi-Fi network, in order to iron out any problems with the radio link.

Once basic radio operation is confirmed, and it is established that non-Rabbit devices can connect to the target network, then it is usually a matter of reviewing all the configuration items to ensure that everything is correct. Specifically, the encryption methods (TKIP or CCMP) must match; the SSID, user identity and (if applicable) password must be correct; the appropriate key management (802.1X) and EAP methods must be selected. Also, the certificates must be correct and not expired, and must be signed by the agreed upon certificate authority (CA). Finally, the maximum supported key size supported on the Rabbit must be

large enough to handle the key size used by the authentication server's certificates. See Section 1.6.8.3 for more information on changing the default key size of 1024.

If the Rabbit real-time clock (RTC) is not set correctly, certificates might appear to be expired. If no RTC is available, include this statement in your program:

```
#define X509_NO_RTC_AVAILABLE
```

Refer to Section 1.5.9 for more information on `X509_NO_RTC_AVAILABLE`.

3.2 Sample Programs

The Rabbit-based board can be configured for Wi-Fi Enterprise mode authentication at compile- or run-time. Either strategy requires the generation and installation of at least one certificate on the Rabbit device. The certificate generation task must be done prior to running any application that depends on Wi-Fi Enterprise mode authentication.

See Section 1.3 for step-by-step instructions on creating certificates and Section 1.6 for further information on the Rabbit Certificate Utility.

After any required certificates are generated and installed in the various necessary locations, and the configuration of the wireless AP and the corresponding authentication server is complete, you are ready to run the sample program `/Samples/tcpip/wifi/config_fat.c`, located relative to the Dynamic C installation directory.

3.2.1 Code Details

As discussed in Section 3.1.1.1 and Section 3.1.1.2, Wi-Fi Enterprise mode authentication can be done at compile- or run-time. The sample program `config_fat.c` demonstrates run-time configuration.

The binary structure, `SSL_Cert_t`, is created and manipulated using the API provided in `SSL_CERT.LIB`. This is convenient where programmatic manipulation is required, or certificates are stored in a form that is not directly supported by `ifconfig()`, or if the certificates are to be used with, say, an HTTPS server. For example, certificates may have the private key information stored separately from the corresponding certificate. CA (Certificate Authority) information may require more than one certificate in a certificate chain. Such chains can only be constructed using the API provided by `SSL_CERT.LIB`.

When using a binary structure form, make certain to explicitly cast pointers to the structure to far pointers. The compiler cannot do this automatically, since it does not know the expected type of the `ifconfig()` parameters. If this is not done, then memory corruption may result. For example,

```
static SSL_Cert_t ca_cert;
memset(&ca_cert, 0, sizeof(ca_cert));
SSL_new_cert(&ca_cert, ......);
ifconfig(IF_WIFI0, IFS_WIFI_CA_CERT, (SSL_Cert_t far *)&ca_cert,
           IFS_END);
```

Without the cast, a near pointer would be passed to `ifconfig()`, since the `ca_cert` structure does not have a "far" qualifier. This would cause serious errors. Note also the use of the static storage class for the ca_cert variable. This is important, since `ifconfig()` saves the pointer to that structure. If the storage class was set or defaulted to "auto", then the certificate structure would not be accessible as soon as the function returned. Again, this would also result in serious errors.

The following code snippet was taken from a function in `config_fat.c`. This function, `reconfig()`, closes the network connection and then uses information gleaned from user input via the web page to allow Wi-Fi Enterprise mode authentication when the subsequent network connection is requested. The web page input is stored in the `u_*` variables.

The code in bold-face is specific to Wi-Fi Enterprise mode authentication. The `USE_EAP` macro is local to `config_fat.c`, i.e., it is not used by any Dynamic C library.

```
void reconfig(int iface){
   ...
   http_shutdown(0);
   ifdown(iface);
   while (ifpending(iface) == IF_COMING_DOWN)
      tcp_tick(NULL);

   ifconfig(iface,
      IFS_DHCP, dhcp,
      IFS_IPADDR, inet_addr(u_ip),
      IFS_NETMASK, inet_addr(u_netmask),
      IFS_ROUTER_SET, inet_addr(u_router),
      IFS_NAMESERVER_SET, inet_addr(u_nameserver),
      IFS_WIFI_SSID, strlen(u_ssid), u_ssid,
      IFS_WIFI_ENCRYPTION,
         encr & 4 ? IFPARAM_WIFI_ENCR_CCMP :
         encr & 2 ? IFPARAM_WIFI_ENCR_TKIP :
                    IFPARAM_WIFI_ENCR_NONE,
      IFS_WIFI_WPA_PSK_HEXSTR, u_hexkey,
      IFS_END);

#ifdef USE_EAP
   ifconfig(iface,
      IFS_WIFI_EAP_METHODS,
         (methods & 4 ? WPA_USE_EAP_TLS : 0) |
         (methods & 2 ? WPA_USE_EAP_PEAP : 0),
      IFS_WIFI_IDENTITY, u_peap_user,
      IFS_WIFI_PASSWORD, u_peap_pwd,
      IFS_WIFI_WPA_PROTOCOL,
         encr & 4 ? IFPARAM_WIFI_WPA_PROTOCOL_RSN :
                    IFPARAM_WIFI_WPA_PROTOCOL_ALL,
      IFS_WIFI_CA_CERT_PATH,
         u_cert_ca[0] ? u_cert_ca : NULL,
      IFS_WIFI_CLIENT_CERT_PATH,
         u_cert_client[0] ? u_cert_client : NULL,
         u_cert_client_k[0] ? u_cert_client_k :
            u_cert_client[0] ? u_cert_client : NULL,
      IFS_END);
#endif
   ifup(iface);
   printf("Waiting for interface to come back up...\n");
   ...
}
```

3.2.2 Configuration Macros

Some of the configuration macros described in this section are specific for Wi-Fi Enterprise mode authentication. Others are also used for Wi-Fi Personal mode authentication (i.e., pre-shared key).

WIFI_USE_WPA

This macro compiles in WPA support. It is necessary to include the statement:

```
#define WIFI_USE_WPA
```

whether using Enterprise or Personal mode authentication.

WPA_USE_EAP

This macro determines the EAP method to use and thus is only relevant when using Wi-Fi Enterprise mode authentication. The options are: `WPA_USE_EAP_TLS` and `WPA_USE_EAP_PEAP`, for EAP-TLS and PEAP, respectively. It is also allowable to define `WPA_USE_EAP` to both methods, as shown in the sample program `config_fat.c`:

```
#define WPA_USE_EAP (WPA_USE_EAP_TLS|WPA_USE_EAP_PEAP)
```

Defining `WPA_USE_EAP` includes a lot of extra code in the application. It is recommended that the application be developed initially using only open (or WEP) SSIDs, which will save a lot of time in the compile/test cycle.

Keep in mind that enabling EAP (802.1X) authentication will add about 200K of code to the application.

WIFI_AES_ENABLED

To enable AES-specific code required for WPA2 (CCMP) encryption, include the following statement:

```
#define WIFI_AES_ENABLED
```

3.2.3 Configuration Parameters for ifconfig()

This section details the parameters passed to the run-time configuration function `ifconfig()`. Where it makes sense, the `IFS_WIFI_*` parameters have compile-time counterparts in the form: `IFC_WIFI_*`.

3.2.3.1 Configuration of Enterprise Mode

The following parameters control the selection of the security protocol and EAP method.

IFS_WIFI_WPA_PROTOCOL
IFG_WIFI_WPA_PROTOCOL

Set/Get acceptable security protocol(s) [word/word *]. Default is to support both WPA and WPA2.

- `IFPARAM_WIFI_WPA_PROTOCOL_WPA` - WPA; aka, IEEE 802.11i/D3.0
- `IFPARAM_WIFI_WPA_PROTOCOL_WPA2` - WPA2; aka, IEEE 802.11i/D9.0
- `IFPARAM_WIFI_WPA_PROTOCOL_RSN` - WPA2; aka, IEEE 802.11i/D9.0
- `IFPARAM_WIFI_WPA_PROTOCOL_ALL` - A bitwise combination of all protocols

IFS_WIFI_EAP_METHODS
IFG_WIFI_EAP_METHODS
Set/Get acceptable EAP method [longword/longword *].

Note that methods that do not have compiled-in support via the WPA_USE_EAP macro will be ignored. Currently, EAP_TYPE_TLS and EAP_TYPE_PEAP are supported. Only one method may be selected, which implies that the type of authentication must be known in advance for the given SSID.

Valid values are:

- IFPARAM_EAP_PEAP - This parameter selects PEAP-MSCHAPV2. Using this method, requires the statement: `#define WPA_USE_EAP WPA_USE_EAP_PEAP`
- IFPARAM_EAP_TLS - This parameter selects EAP-TLS. Using this method, requires the statement: `#define WPA_USE_EAP WPA_USE_EAP_TLS`

IFS_WIFI_IDENTITY
IFG_WIFI_IDENTITY
Set/Get identity string for EAP [char */char **]. This is needed for both EAP-TLS and PEAP.

IFS_WIFI_PASSWORD
IFG_WIFI_PASSWORD
Set/Get password string for EAP [char */char **]. This is only needed for PEAP.

3.2.3.2 Configuration for Certificates and Keys

Most of the following parameters are for convenience when “hard-coding” certificates (e.g., from #ximported files). Pass a zero longword as the parameter in order to delete any resources that were allocated on a previous call (since the library manages the SSL_Cert_t structures that are created).

IFS_WIFI_CA_CERT
IFG_WIFI_CA_CERT
Set/Get CA certificate [SSL_Cert_t far */SSL_Cert_t far **].

The authentication server is not verified if no CA certificate is provided in the “Set” command, which introduces risk of “access server spoofing.”

IFS_WIFI_CA_CERT_XIM
Set CA certificate as #ximport DER/PEM format [longword].

IFS_WIFI_CA_CERT_PATH
Set CA certificate as a Zserver resource path [char *].

IFS_WIFI_CLIENT_CERT
IFG_WIFI_CLIENT_CERT
Set/Get client certificate [SSL_Cert_t far */SSL_Cert_t far **].

IFS_WIFI_CLIENT_CERT_XIM
Set client certificate and private key as two #ximport DER/PEM format files [longword, longword]. The first parameter is the certificate, the second one is for the private key.

IFS_WIFI_CLIENT_CERT_PATH
Set client certificate as Zserver file [char *,char *]. The first parameter is for the certificate, and the second one is for the private key. If the certificate parameter is NULL, then delete resources.

IFS_WIFI_SUBJECT_MATCH
Set substring to be matched against the subject of the authentication server certificate [char *].

The subject string is in following format (for example):

C=US/ST=CA/L=Davis/CN=Test1-AS/emailAddress=test1_as@rabbit.com

so this parameter string could be set to "/L=Davis/CN=Test" to allow all access servers with a location of "Davis" and a common name starting with "Test."

IFS_WIFI_ALTSUBJECT_MATCH
Set semicolon separated string of entries to be matched against the alternative subject name of the authentication server certificate [char *].

If this string is set, the server certificate is only accepted if it contains one of the entries in an alternative subject name extension.

altSubjectName string is in following format: TYPE:VALUE

Example: EMAIL:server@example.com
Example: DNS:server.example.com;DNS:server2.example.com

Following types are supported: EMAIL, DNS, URI.

Appendix A: Cryptography and Message Verification

This section discusses cryptography. It is intended as a reference for an interested user to gain some knowledge about the inner workings of SSL, which can aid in application development and debugging.

A.1 Cryptography

Cryptography is the science of encoding data such that the data cannot be easily recovered without knowing some secret key. Cryptography is as old as writing—there is evidence that ancient Romans and Egyptians had notions of cryptography and used them to protect military and political correspondence. Cryptography forms the basis for all secure computer communications today.

In order to provide a secure communication channel, SSL relies on a number of *ciphersuites*, collections of ciphers and hashing mechanisms to encrypt and verify data.

A.1.1 Symmetric-Key Cryptography

Symmetric-key cryptography is the oldest and most widely used way to encrypt data to hide it from an adversary. To use symmetric-key cryptography, both of the communicating entities need to know a single, secret, shared key, which is used to both encrypt and decrypt the data. Symmetric-key algorithms for computers are quite fast and usually quite simple. Common algorithms such as RC4 (developed by RSA Security) can be implemented in just a few lines of C code. Other common symmetric-key algorithms include DES, 3DES, and AES.

A.1.2 Public-Key Cryptography

The problem with symmetric-key cryptography is that there needs to be a way to share the key between the communicating entities before they can communicate securely. Historically, this has been done using trusted messengers who hand-carry the key from one side to the other. This, however, is not an acceptable solution for computer communications, and so SSL employs a *public-key* algorithm.

Developed in the 1970s, public-key algorithms use two separate keys, one to encrypt and the other to decrypt. For this reason, public-key cryptography is also called *asymmetric cryptography.* This way, the public key can be sent in plain-text over the network, and the client can encrypt data, knowing that only the person with the paired key can decrypt it.

It would be possible to implement a secure channel using only public-key cryptography. Each entity would have a key pair, and the public keys would be exchanged via plain text and used to encrypt messages back and forth. However, the problem is that public-key algorithms are excessively slow since they are based on multiplication that involves 100-digit-plus numbers, which requires millions of operations. They are so slow, in fact, that many companies implement public-key algorithms in hardware, where they can still take up to half a second!

SSL avoids the performance hit by using public-key operations only during the initial handshake to exchange a single message containing a secret. This secret is then used to generate symmetric keys that are used with the speedier symmetric-key algorithms. Common public-key algorithms include RSA and Diffe-Hellman.

A.1.3 The Importance of Randomness

SSL security relies on the fact that an adversary cannot decrypt messages without the key except by trying every possible key used to encrypt the data (for a 128-bit symmetric key, or a 1024-bit public key, this process would take hundreds or thousands of years using current technology). The problem is that we need to take precautions to ensure that the adversary cannot improve his chances at guessing the key. For this reason, all SSL symmetric keys are generated with the help of a *cryptographically secure pseudo-random number generator (PRNG)*. The PRNG normally uses an external entropy source such as circuit noise that is nearly impossible to predict. An early Netscape implementation of SSL 2.0 was compromised in just a few hours because the computer's date and time, clearly *not* truly unpredictable entropy sources, were used to seed the PRNG.

A.1.4 Message Verification with Hashing

In addition to hiding data using cryptography, SSL needs to verify that messages are not tampered with during transport. SSL achieves this through the use of *hashing* algorithms. For our purposes, a hash is a unique number generated directly from the data in a message. The idea behind message hashing is that it is impossible to generate the message from the hash, and hashing a message twice always produces the same value. For SSL, the important algorithms are SHA-1 (developed by the NSA) and MD5 (developed by Ron Rivest, the 'R' in RSA).

A.1.5 MD5, SHA-1, and HMAC

SSL uses the MD5 and SHA-1 hashing algorithms extensively. Most importantly, they are used to generate the Message Authentication Code (MAC) for each message. They are also used to verify the entire handshake and to generate the symmetric encryption keys.

For top performance, it is necessary that the implementations of MD5 and SHA-1 be as fast as possible.

TLS does not use MD5 and SHA-1 directly, but instead uses a keyed hashing scheme called HMAC. HMAC, which is presented in IETF RFC 2104, wraps a hashing algorithm and adds provable security properties to a hashing algorithm. SSLv.3 uses a variant of HMAC, and TLS uses HMAC itself for all message hashing and to generate the MAC.

A.1.6 P-HASH and PRF Algorithms

TLS requires two additional algorithms, which use HMAC, to generate the symmetric key. The first of these algorithms is P-HASH, which will expand a secret and a seed value into an arbitrarily large chunk of pseudo-random data using both HMAC-SHA1 and HMAC-MD5. Note that these data are pseudorandom and deterministic. The same secret and seed values will *always* generate exactly the same data.

The PRF algorithm is used to derive the symmetric key and in the handshake verification. It uses P-HASH to expand a secret into a chunk of data that can be divided into pieces for use as symmetric keys or as verification data.

Appendix B: SSL Certificates

For security to be possible on the Internet, there needs to be some notion of trust. This trust is achieved by being able to determine the identity of some entity on the Internet with some degree of confidence. Once this is possible, you can decide *who* to trust. A mechanism for identification on the Internet does exist, but how does it work? Most of the identification needed on the Internet for e-commerce and other purposes is provided by a single mechanism, the *digital certificate*.

There are three types of digital certificates:

- Root CA certificate
- Digital certificate, signed by a root CA certificate
- Digital certificate, self-signed

All three types of certificates can be generated using the utility program discussed in Section 1.6.

B.1 What is a Digital Certificate?

A certificate is a collection of identification data in a standardized format. The data is used to verify the identity of an entity (such as a Web server) on the Internet. The certificate is digitally *signed* by a Certificate Authority (CA), which is a trusted entity given the power to verify an individual or company wishing to provide a SSL-secured application. Any client wishing to communicate securely with that entity can verify its identity by polling a CA certificate database.

Digital certificates would be useless if there was not some way to verify their validity. In the physical world, there are certain physical traits that are difficult to fake, such as fingerprints or DNA, and some of these can be used to determine whether or not a person matches the information on their identification document (such as a photo on a driver's license). In the digital world, however, there is no way to tell one person (or machine) from another by physical traits. Anyone can claim to be the owner of a certificate. For this reason, digital certificates rely on what is called a *digital signature*.

The digital signature concept is based on public-key cryptography, which relies on separate public and private keys to encrypt a message. The public key is given out in the certificate itself, whereas the private key is kept secret by the owner. A digital signature is simply a message digest hash of the entire certificate (using either of the popular hashing algorithms, SHA-1 and MD5) that is encrypted using the owners *private* key. Normally, messages are encrypted using the public key, allowing only the owner of the private key to decode them. In reverse, however, the correct message hash can only be discerned using the public key to decode the digital signature. The way this works for validation is that the only person who could have encrypted the hash is the owner of the matching private key. Since the private key is kept secret and is difficult to duplicate then we can be sure with relatively high confidence that a digital certificate belongs to the owner of the private key. The problem is, there is no guarantee in the certificate itself that will tell you that the owner of the private key is who they say they are.

In the physical world there are certain measures taken to assure the validity of documents used for identification purposes, such as the holographic images on some drivers' licenses. These verification mechanisms usually rely upon the use of hard-to-duplicate items (such as holograms) so that the chances of the document being faked successfully are low. These items are controlled by some organization (such as the Department of Motor Vehicles) and they provide a centralized service that does the work necessary to vouch for an individual. If you trust the organization, then you can be relatively certain that anyone possessing a identification document provided by the organization is who they say they are. This concept of centralized trust allows two people who have never met and know no one in common to assure their

mutual identities (such as a person opening a bank account, the person has a DMV-issued identification card and the government assures the validity of the bank). The concept can be further extended to form a "chain of trust." In the case of the DMV, it is controlled by the government. Therefore, in theory, if you trust the government, you can trust the DMV, and therefore you can trust the documents produced by the DMV, forming a "chain" from the government to individuals.

This "chain of trust" is the concept used by SSL for authentication in computer networks. On the Internet, the governing bodies for identification are corporations (such as Verisign, the most recognizable of these companies) called *certificate authorities (CA)*. A CA provides the service of verifying the identity of a certificate owner using conventional means, then signs that owner's certificate using their own private key. The CA also has a certificate, called a *root certificate*, associated with the private key used for signing, that is publicly available for checking the authenticity of certificates. If you trust Verisign, then you can trust any certificate signed by them. Sometimes, a CA will issue secondary CA certificates, which means a third party can be responsible for signing certificates, and since that party has been authenticated by Verisign, you can then trust certificates signed by that party. In fact, anyone can be a CA, if they want to. All you need is a certificate, and the ability to sign other certificates using your private key. Anyone who trusts you can then trust the certificates you sign.

Certificates can also be *self-signed*. This means that the certificate is signed using its own paired private key. All CA root certificates are self-signed, and self-signed certificates can be useful for testing purposes, or in situations where authentication is not important.

Obviously, the entire digital certificate system relies on the "chains of trust". Without them, there would be almost no way to identify anyone for certain. Anyone could pose as anyone else. To prevent this, commercial CAs publish their certificates in popular Web browsers and Web servers. If you create your own CA, you will need to distribute your master certificate yourself, unless you are willing to pay Verisign to accept you as a third-party CA, or pay to have your certificate added to a browser (both are likely to be too expensive for most individuals and small companies).

B.2 What's in a Certificate?

A digital certificate contains the name and (sometimes) contact information for the owner, along with other information used to identify the owner. The "owner" is typically the physical owner (an individual or organization) of a networked device.

Certificates are encoded using the *Distinguished Encoding Rules* (DER) subset of the *Abstract Syntax Notation* (ASN.1). This flexible format allows some fields to be omitted, and custom fields to be created.

A certificate can be organized into sections[8] as follows:

- The owner's identification, usually a name and other information such as the location of the owner
- The issuer's information, usually a reference to the signer's certificate
- Validation information, such as dates when valid, serial number, and accepted uses
- The owner's public key (which has a matching private key that only the owner knows)
- The digital signature
- Custom sections and extensions

Each section serves a specific purpose, which is explained in further detail below.

8. Note that this breakdown does not match the actual fields in a digital certificate. However, this organization helps to clarify the functions of each of the different fields.

B.2.1 Owner's Identification

This section of the certificate contains the identification information for the certificate owner. Sometimes identified as the subject of the certificate, this section contains specific fields used for identification. Only one of these fields is mandatory, the *Common Name*, abbreviated CN. The Common Name identifies the certificate with a particular network address, usually either a URL or IP address. Web browsers will compare this field with the domain providing the certificate and issue a warning if the two do not match.

This section can contain a number of other fields as well, some of the more common being Country (C), Organization (O), Organizational Unit (OU), and Location (L). It is also possible to define custom fields.

B.2.2 Issuer's Information

The issuer's information is simply the issuer's root CA certificate identification section. On a self-signed certificate, this section is identical to the owner's identification section. On a certificate signed by a CA, the issuer's information matches the root CA certificate's identification section, allowing applications to find the matching root CA certificate in their local repository to do the authentication check.

B.2.3 Validation Information

The validation information consists of a few items that help verify and manage certificates. These include a date range in which the certificate is valid (usually a start date, before which the certificate is invalid, and end date, after which the certificate is also invalid), a version number, and a serial number.

This section also includes a constraints field that indicates the uses for which the certificate is valid. These may include server authentication and e-mail authentication, as well as other possible uses for which the certificate may be valid.

B.2.4 The Public Key

The certificate also contains the *public key* of its owner. This public key matches a secret *private key* that only the owner knows. The key pair is used both to verify the identity of the certificate owner, and to allow secret information to be exchanged between the certificate owner and another entity.

This section in the certificate consists of a field indicating the public-key algorithm used and the size of the key, and the public key itself. Most certificates today use the RSA public-key algorithm with key sizes ranging from 512 bits to 2048 bits.

B.2.5 The Digital Signature

Like the public key, the digital signature consists of a field indicating the algorithm used (usually either SHA-1 or MD5), and the signature itself. The signature is an encrypted hash of the entire certificate which can be decrypted using the public key. The signature is used to verify that the certificate has not been tampered with.

B.2.6 Custom Sections and Extensions

The flexible nature the DER format allows for custom sections to be added to certificates. These sections usually provide additional information not included in the identification section. Some examples include a "friendly name" (a more informative name than the Common Name) and application-specific *extensions* (an extension is simply a custom section specifically targeted at a particular application, such as a particular brand of Web browser). Extensions can hold any information needed by those applications.

Appendix C: WPA Supplicant License Agreement

Appendix D: References

The following is a list of recommended reading for those wanting more information on topics covered in this document:

1. Bruce Schneier, *Applied Cryptography*, 2nd edition. The standard layman's text on cryptographic algorithms and techniques.
2. Eric Rescorla, *SSL and TLS, Designing and Building Secure Systems*. A book that specifically covers SSL and how to write an implementation. Includes a discussion of HTTPS.
3. Digi International, *The Dynamic C TCP/IP User's Manual, Vol. 1*. Covers both run-time and compile-time configuration options for Wi-Fi and other supported network interfaces.
4. Digi International, *An Introduction to Wi-Fi*. Covers Wi-Fi security protocols and gives a detailed description of the authentication options for WPA and WPA2.
5. Digi International, *Rabbit 4000 Designer's Handbook*. Description of the User block.
6. IETF RFC2246. Draft specification for TLS v1.1.
7. IETF RFC2818. RFC specification for HTTPS.
8. IETF RFC2104. RFC specification for HMAC.
9. IETF RFC2202. RFC specification for HMAC test cases.
10. IETF RFC3447. RFC specification for public-key cryptography using RSA.
11. OpenSSL documentation. Open-source implementation of SSL/TLS.