Securing IoT applications with Mbed TLS
Hannes Tschofenig

Part#2: Public Key-based authentication
Agenda

• For Part #2 of the webinar we are moving from Pre-Shared Secrets (PSKs) to certificated-based authentication.

• TLS-PSK ciphersuites have
  • great performance,
  • low overhead,
  • small code size.

• Drawback is the shared key concept.

• Public key cryptography was invented to deal with this drawback (but itself has drawbacks).
Public Key Infrastructure and certificate configuration
Public Key Infrastructure
Various PKI deployments in existence

Structure of our PKI

The client has to store:

• Client certificate plus corresponding private key.
• CA certificate, which serves as the trust anchor.

The server has to store:

• Server certificate plus corresponding private key.
  (Some information for authenticating the client)
Generating certificates (using OpenSSL tools)

- When generating certificates you will be prompted to enter info.
- The CA cert will end up in the trust anchor store of the client.
- The Common Name used in the server cert needs to be resolvable via DNS UNLESS you use the server name indication extension.
- If the information in the Common Name does not match what is expected in the TLS handshake (based on configuration) then the exchange will (obviously) fail.

You are about to be asked to enter information that will be incorporated into your certificate request. What you are about to enter is what is called a Distinguished Name or a DN. There are quite a few fields but you can leave some blank. For some fields there will be a default value, If you enter '.', the field will be left blank.

```
Country Name (2 letter code) [AU]: .
State or Province Name (full name) [Some-State]: .
Locality Name (eg, city) []: .
Organization Name (eg, company) [Internet Widgits Pty Ltd]: .
Organizational Unit Name (eg, section) []: .
Common Name (e.g. server FQDN or YOUR name) []: CA
Email Address []: .
```
Generating CA certificate

Listing supported curves

> openssl ecparam -list_curves

Self-signed CA Cert

> openssl ecparam -genkey -name secp256r1 -out ca.key
> openssl req -x509 -new -SHA256 -nodes -key ca.key -days 3650 -out ca.crt
Generating server certificate

Generate Server Private Key

```bash
> openssl ecparam -genkey -name secp256r1 -out server.key
```

Create CSR

```bash
> openssl req -new -SHA256 -key server.key -nodes -out server.csr
```

Print CSR:

```bash
> openssl req -in server.csr -noout -text
```

CA creates Server Cert

```bash
> openssl x509 -req -SHA256 -days 3650 -in server.csr -CA ca.crt -CAkey ca.key -CAcreateserial -out server.crt
```
Generating client certificate

Generate Client Private Key

> openssl ecparam -genkey -name secp256r1 -out client.key

Create CSR

> openssl req -new -SHA256 -key client.key -nodes -out client.csr

CA creates Client Cert

> openssl x509 -req -SHA256 -days 3650 -in client.csr -CA ca.crt -CAkey ca.key -CAcreateserial -out client.crt
Operational PKI challenges worth mentioning

- Certificates contain an expiry date, which needs to be checked.
- Certificates may also get revoked.
- Certificates and trust anchors may need to be replaced.

- These topics are not covered in this webinar.
TLS protocol
Public key crypto

• Two popular types of asymmetric crypto systems emerged, namely RSA and Elliptic Curve Cryptography (ECC).

• The TLS_ECDHE_ECDSA_WITH_AES_128_CCM_8 ciphersuite is recommended by many standards. It uses
  • Ephemeral Elliptic Curve Diffie-Hellman (ECDHE), and
  • The Elliptic Curve Digital Signature Algorithm (ECDSA).

• New to ECC?
  • Talk: "A gentle introduction to elliptic-curve cryptography" by Tanja Lange and Dan Bernstein.
  • Book: “Guide to Elliptic Curve Cryptography” by Vanstone, et al.
Recall: Key length

<table>
<thead>
<tr>
<th>Symmetric</th>
<th>ECC</th>
<th>DH/DSA/RSA</th>
</tr>
</thead>
<tbody>
<tr>
<td>80</td>
<td>163</td>
<td>1024</td>
</tr>
<tr>
<td>112</td>
<td>233</td>
<td>2048</td>
</tr>
<tr>
<td>128</td>
<td>283</td>
<td>3072</td>
</tr>
<tr>
<td>192</td>
<td>409</td>
<td>7680</td>
</tr>
<tr>
<td>256</td>
<td>571</td>
<td>15360</td>
</tr>
</tbody>
</table>

Preferred for IoT security
Two Phase Design of TLS

Phase 1 – “Handshaking Protocols”

- **TLS-PSK**
  - Used symmetric keys for authentication
  - Covered in 1st webinar

- **TLS-ECDHE-ECDSA**
  - Uses public key cryptography and (in our case) certificates for authentication.
  - Covered in today’s webinar.

Phase 2 – “Record Protocol”

- AES-128-CCM-8 to protect HTTP
Full TLS handshake

Certificate requested by the server and provided by the client (optional msgs)

Used when client provided certificate to demonstrate possession of private key.

Server Certificate

ClientHello


Certificate*, ClientKeyExchange, CertificateVerify*, [ChangeCipherSpec], Finished

[ChangeCipherSpec], Finished

Application Data

Legend:
*: optional message
[]: Not a handshake message.

Used by some ciphersuites to convey information to generate the premaster secret.

May need to be signed by the server.

Note: Most Web deployments use server-to-client authentication only.
ECDHE-ECDSA Exchange

Client

- Generate EC Diffie-Hellman key pair
- Place ephemeral ECDH public key in the ClientKeyExchange message
- CertificateVerify demonstrate possession of the long-term private key corresponding to the public key in the client's Certificate message.

Server

- Generate EC Diffie-Hellman key pair
- Ephemeral ECDH public key is put in ServerKeyExchange message.
- Sign ServerKeyExchange message with long term private key.

- ECDHE derived key becomes pre_master_secret, which is then used in master_secret calculation
Hands-on
Platform

• For this hands-on session we are using the Keil MCBSTM32F400 Evaluation Board, which uses the STM32F407IG MCU.

• This MCU uses an Arm Cortex M4 processor. More information can be found in this datasheet.

• Keil RTX5 serves as the real-time OS. Mbed TLS and networking middleware.
Demo setup

Development laptop

TLS client

Keil MCBSTM32F400

TLS server
config.h settings for TLS-ECDHE-ECDSA

• According to RFC 7925 we use
  • TLS 1.2: `MBEDTLS_SSL_PROTO_TLS1_2`
  • TLS-ECDHE-ECDSA-WITH-AES-128-CCM-8 as a ciphersuite, which requires `MBEDTLS_KEY_EXCHANGE_ECDHE_ECDSA_ENABLED`
  • AES, CCM, and SHA256, (`MBEDTLS_AES_C, MBEDTLS_CCM_C, MBEDTLS_SHA256_C`)
  • ECC support: `MBEDTLS_ECDH_C, MBEDTLS_ECDSA_C MBEDTLS_ECP_C, MBEDTLS_BIGNUM_C`
  • ASN.1 and certificate parsing support
  • NIST Curve P256r1 (`MBEDTLS_ECP_DP_SECP256R1_ENABLED`)
  • Server Name Indication (SNI) extension (`MBEDTLS_SSL_SERVER_NAME_INDICATION`)
• We enable optimizations (`MBEDTLS_ECP_NIST_OPTIM`) and deterministic ECDSA (RFC 6979) with `MBEDTLS_ECDSA_DETERMINISTIC`
Mbed TLS client application code

1. Initialize TLS session data
2. Initialize the RNG
3. Establish TCP connection
4. Configure TLS
5. Run TLS handshake protocol
6. Exchange application data
7. Tear down communication and free state

Parse CA certificate, client certificate and private key of client.

- Load CA certificate
- Load client certificate and private key
- Configure SNI
- Configure curve(s)

Verify the server certificate
Server-side command line

> programs/ssl/ssl_server2 auth_mode=required crt_file=server.crt key_file=server.key ca_file=ca.crt

Parameters:

- **auth_mode** determines the behaviour of a missing client certificate or a failed client authentication. Allowed values are “none”, “optional” and “required”.

- **cert_file** indicates the file that contains the server certificate.

- **key_file** indicates the file that contains the private key of the server.

- **ca_file** indicates the file that contains the CA certificate.
The cost of public key crypto
## Handshake message size

<table>
<thead>
<tr>
<th>Client</th>
<th>Server</th>
<th>Size</th>
</tr>
</thead>
<tbody>
<tr>
<td>ClientHello</td>
<td></td>
<td>121 bytes</td>
</tr>
<tr>
<td>ServerHello</td>
<td></td>
<td>87 bytes</td>
</tr>
<tr>
<td>Certificate</td>
<td></td>
<td>557 bytes</td>
</tr>
<tr>
<td>Server Key Exchange</td>
<td></td>
<td>215 bytes</td>
</tr>
<tr>
<td>Certificate Request</td>
<td></td>
<td>78 bytes</td>
</tr>
<tr>
<td>Server Hello Done</td>
<td></td>
<td>4 bytes</td>
</tr>
<tr>
<td>Certificate</td>
<td></td>
<td>570 bytes</td>
</tr>
<tr>
<td>Client Key Exchange</td>
<td></td>
<td>138 bytes</td>
</tr>
<tr>
<td>Certificate Verify</td>
<td></td>
<td>80 bytes</td>
</tr>
<tr>
<td>Change Cipher Spec</td>
<td></td>
<td>1 byte</td>
</tr>
<tr>
<td>Protocol</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TLS Finished</td>
<td></td>
<td>40 bytes</td>
</tr>
<tr>
<td>Change Cipher Spec</td>
<td></td>
<td>1 byte</td>
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- Example assumes a ECC-based ciphersuite with a 256 bit curve.
- Only a single certificate is exchanged in the Certificate message.
- (But mutual authentication is used, i.e., client and server exchange certificates.)
- Result: 1932 bytes
Performance comparison: Signature generation

ECDSA Performance (Signature Operation, $w=7$, NIST Optimization Enabled)

Prototyping Boards

Performance data from a contribution to the NIST lightweight crypto workshop 2015.
Performance optimization impact

Using ~50% more RAM increases the performance by a factor 8 or more.

Performance data from a contribution to the NIST lightweight crypto workshop 2015.
Improving performance with TLS extensions
Session resumption exchange
First phase

A session ID is allocated by the server.
Session resumption exchange
Second phase

Security state established with full exchange and “indexed” with session identifier.

Benefits:
• Few message exchanged
• Less bandwidth consumed
• Lower computational overhead
Negotiating the SessionTicket extension and issuing a ticket with the NewSessionTicket message.

The client caches the ticket along with the session information.
Session resumption without server-side state
Second phase

Benefits:
- Same as session resumption.
- Increased scalability due to distributed session state storage.

Ticket stores the session state including the master_secret, client authentication type, client identity, etc.

Specified in RFC 5077.
### TLS cached info

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TLS exchanges lots of fairly static information.

- Certificates
- List of acceptable certification authorities

Idea: Cache information on the client and avoid sending it unless it changes.


Allows to cache server certificate and certificate request.

Client-side certificate can be omitted by sending a Certificate URI extension instead, which is specified in [RFC 6066](https://tools.ietf.org/html/rfc6066).
Further TLS extensions for performance improvement

Raw public key (RPK) extension (RFC 7250) re-uses the existing TLS Certificate message to convey the raw public key encoded in the SubjectPublicKeyInfo structure.

Maximum Fragment Length (MFL) extension (RFC 6066) allows the client to indicate to the server how much maximum memory buffers it uses for incoming messages.

Trusted CA Indication extension (RFC 6066) allows clients to indicate what trust anchor they support.

Note: Re-using TLS code at multiple layers helps to lower the overall code requirements.
Hands-on
(Session Resumption)
config.h settings for session resumption

- No additions needed for plain session resumption.
- Only one parameter for RFC 5077 session resumption without server-side state: MBEDTLS_SSL_SESSION_TICKETS
Mbed TLS client application code

Initial exchange
1. Initialize TLS session data
2. Initialize the RNG
3. Establish TCP connection
4. Configure TLS
5. Run full TLS handshake protocol
6. Exchange application data
7. Encounter error

Subsequent exchanges
8. Set session state
9. Establish TCP connection
10. Run TLS session resumption
11. Exchange application data
12. Tear down communication and free state
Conclusion
Summary

• PSK-based ciphersuites provide great performance.
• Certificate-based ciphersuites provide an alternative where the private key is not shared.
• Public key crypto is more challenging to performance.
• This performance impact can partially be mitigated using TLS extensions, such as session resumption.
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