Securing IoT Applications with mbed TLS

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Part#4: Datagram Transport Layer Security (DTLS)

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Why DTLS?

- Simple: Provide communication security for datagram protocols.
- For example: Constrained Application Protocol (CoAP) running over UDP
- Useful also for securing non-IP-based communication, such as low-power WAN protocols.
- We will talk about the DTLS internals and then do a hands-on with the Keil µVision 5 IDE using the PSK example from webinar #1 and the hardware-based RNG support, as developed in webinar #3, as a starting point. Then, DTLS support will be added.

DTLS

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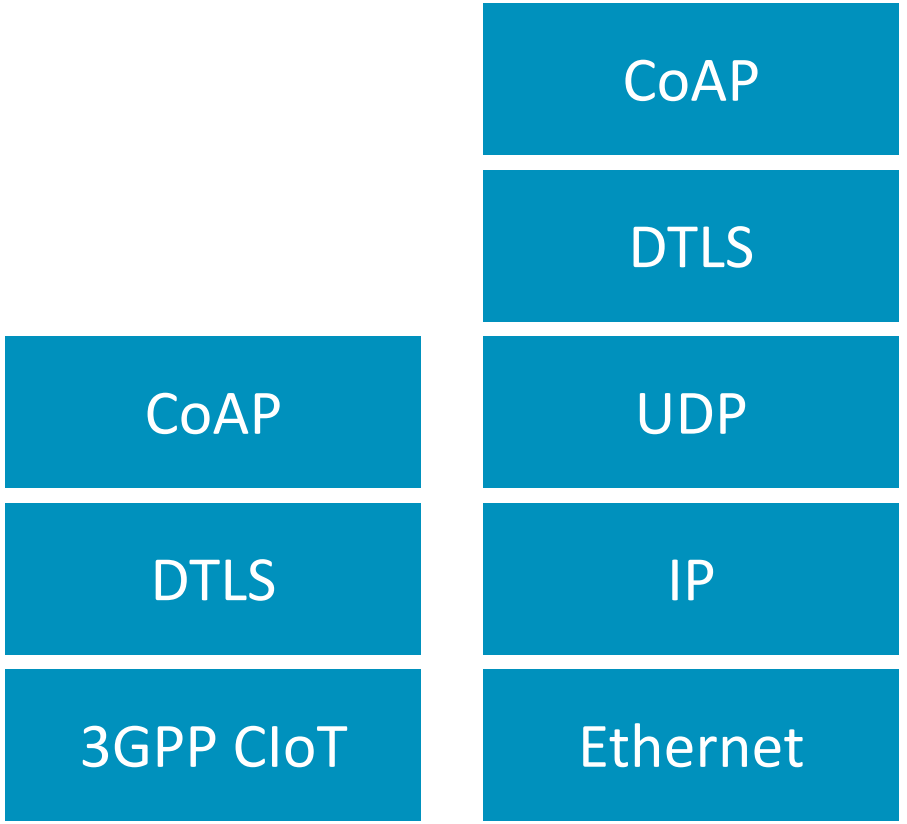
DTLS

- The design of DTLS is intentionally similar to TLS.
- DTLS 1.2 is documented in RFC 6347. Version 1.3 is in development.
- DTLS operates on top of an unreliable datagram transport
  - most importantly over UDP, but
  - works also over non-IP!



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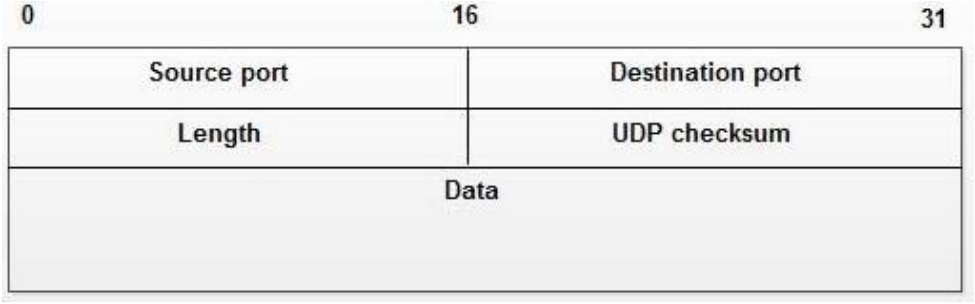
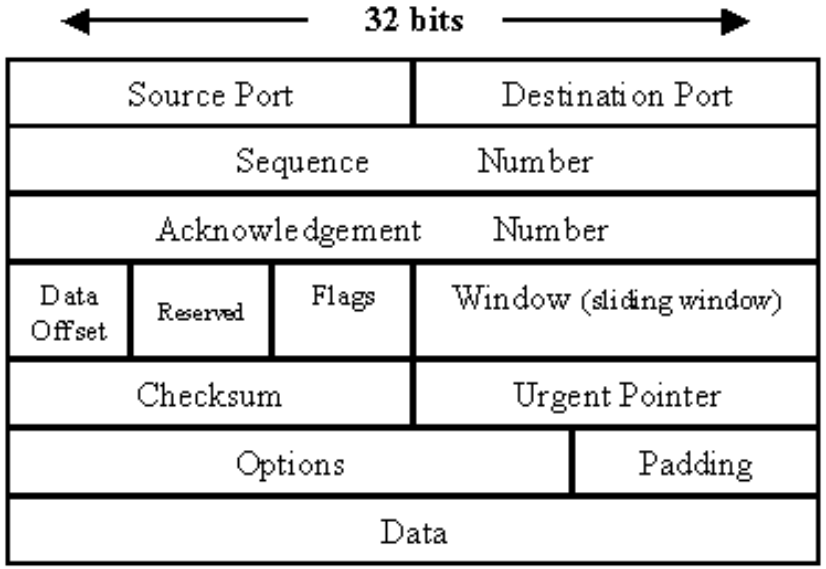
Transport Layer Comparison

Or: Why is UDP is “lightweight”?

	Features	TCP	UDP
1.	Connection establishment and teardown	Yes	No
2.	Congestion Control	Yes	No
3.	Fragmentation	Yes	No
4.	Rate Control	Yes	No
5.	Return-Routability Check	Yes	No





Guidance for lightweight implementations of TCP in the Internet of Things devices is available.

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Fragmentation and Maximum Transmission Unit (MTU)

Concepts

- UDP-based applications need to have awareness of the MTU supported by the path (the so-called **Path MTU**).
- **Path MTU discovery**
  - originally defined in RFC 1191
  - Later re-defined with Packetization Layer Path MTU Discovery (PLPMTUD), defined in RFC 4821
- **Minimum MTU** for use of IP:
  - 576 bytes for IPv4, and
  - 1280 bytes for IPv6

Mbed TLS APIs

mbedtls_ssl_set_mtu() – configure MTU by application

mbedtls_ssl_get_record_expansion() – determine overhead for DTLS headers and encryption

mbedtls_ssl_get_max_out_record_payload() – maximum application data size of a DTLS connection

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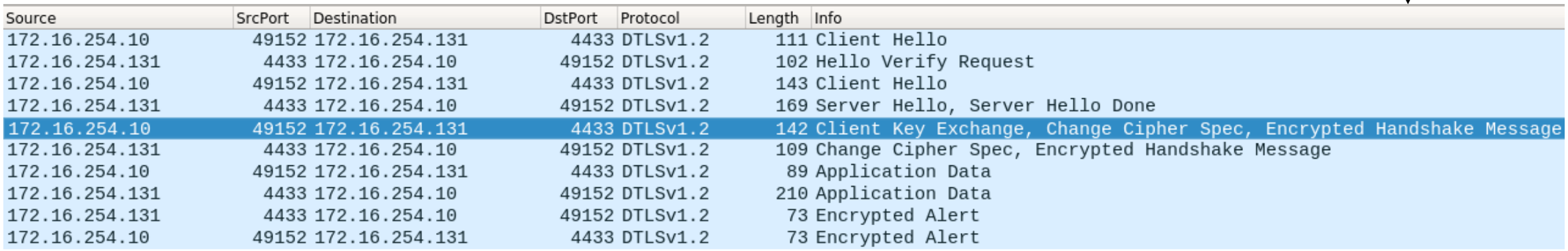
Features added with Mbed TLS v.2.13

- Grouping outgoing handshake messages in a single datagram
- Support for fragmentation of outgoing handshake messages
- Reordering handshake packets that have been received out of order



Source	SrcPort	Destination	DstPort	Protocol	Length	Info
172.16.254.10	49152	172.16.254.131	4433	DTLSv1.2	111	Client Hello
172.16.254.131	4433	172.16.254.10	49152	DTLSv1.2	102	Hello Verify Request
172.16.254.10	49152	172.16.254.131	4433	DTLSv1.2	143	Client Hello
172.16.254.131	4433	172.16.254.10	49152	DTLSv1.2	169	Server Hello, Server Hello Done
172.16.254.10	49152	172.16.254.131	4433	DTLSv1.2	142	Client Key Exchange, Change Cipher Spec, Encrypted Handshake Message
172.16.254.131	4433	172.16.254.10	49152	DTLSv1.2	109	Change Cipher Spec, Encrypted Handshake Message
172.16.254.10	49152	172.16.254.131	4433	DTLSv1.2	89	Application Data
172.16.254.131	4433	172.16.254.10	49152	DTLSv1.2	210	Application Data
172.16.254.131	4433	172.16.254.10	49152	DTLSv1.2	73	Encrypted Alert
172.16.254.10	49152	172.16.254.131	4433	DTLSv1.2	73	Encrypted Alert

Further reading:

- Release of Mbed TLS v.2.13
- UDP Usage Guidelines (RFC 8085)
- Mbed TLS over low-bandwidth, unreliable datagram networks

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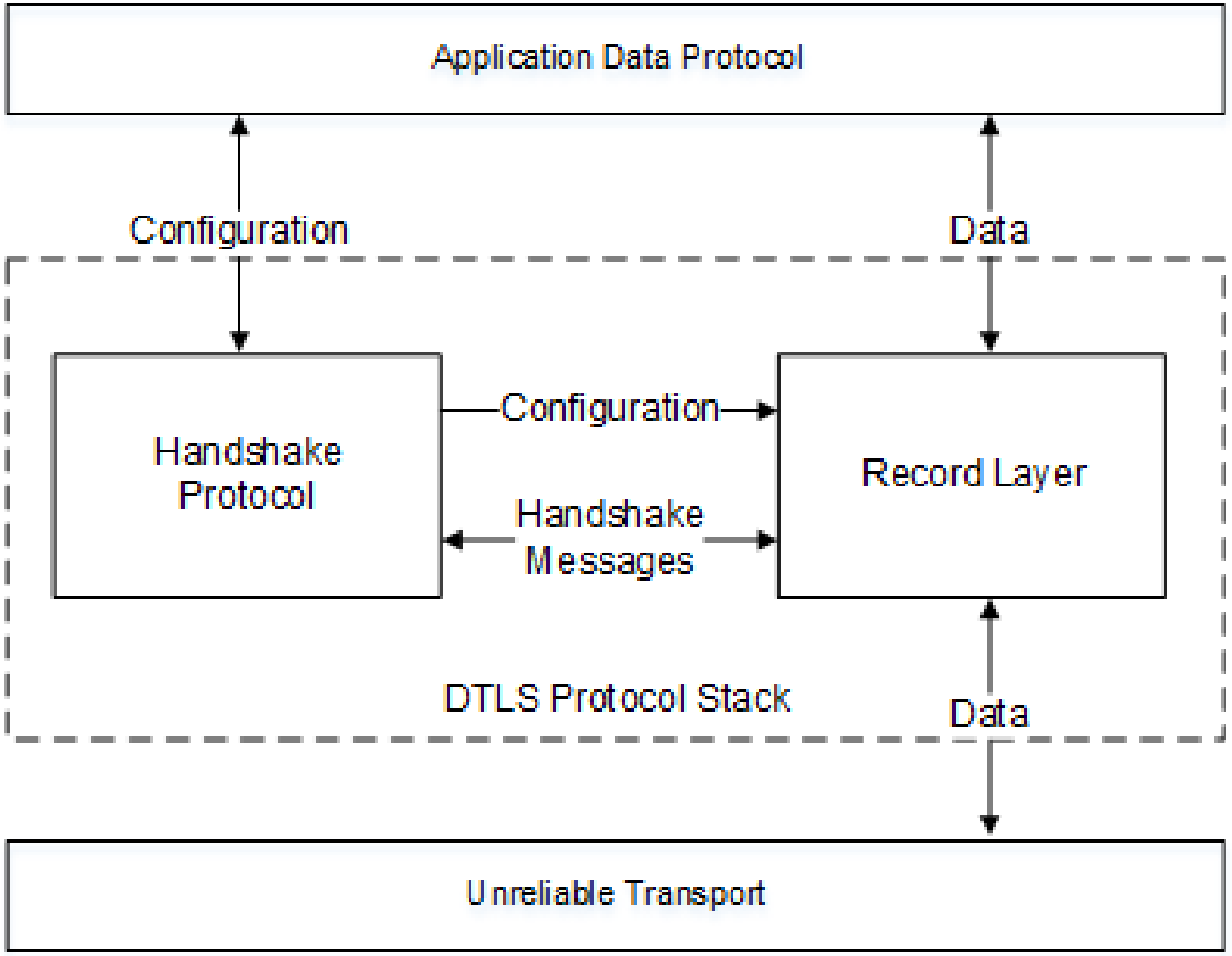
DTLS 1.2 Stack

- Four protocols use the record layer, namely
  - Handshake Protocol
  - Change Cipher Spec Protocol (not shown)
  - Alert Protocol (not shown)
  - Application Data Protocol



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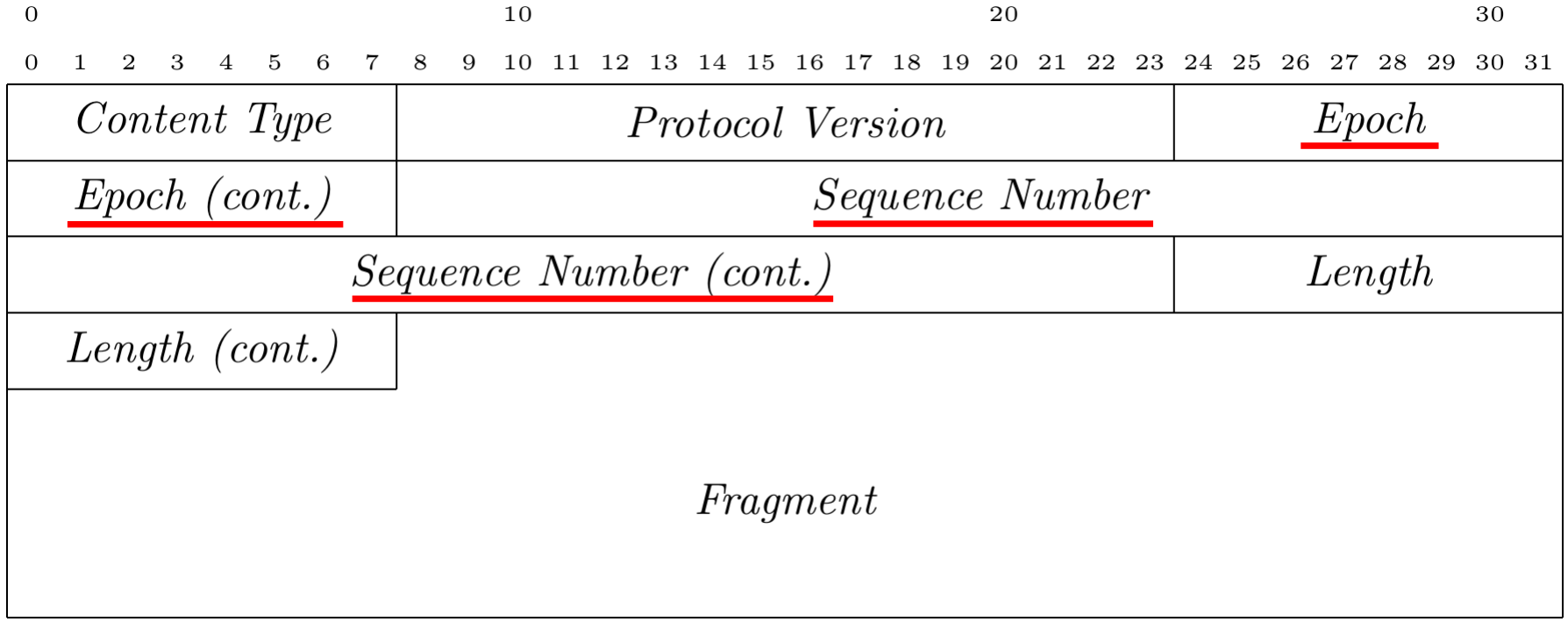
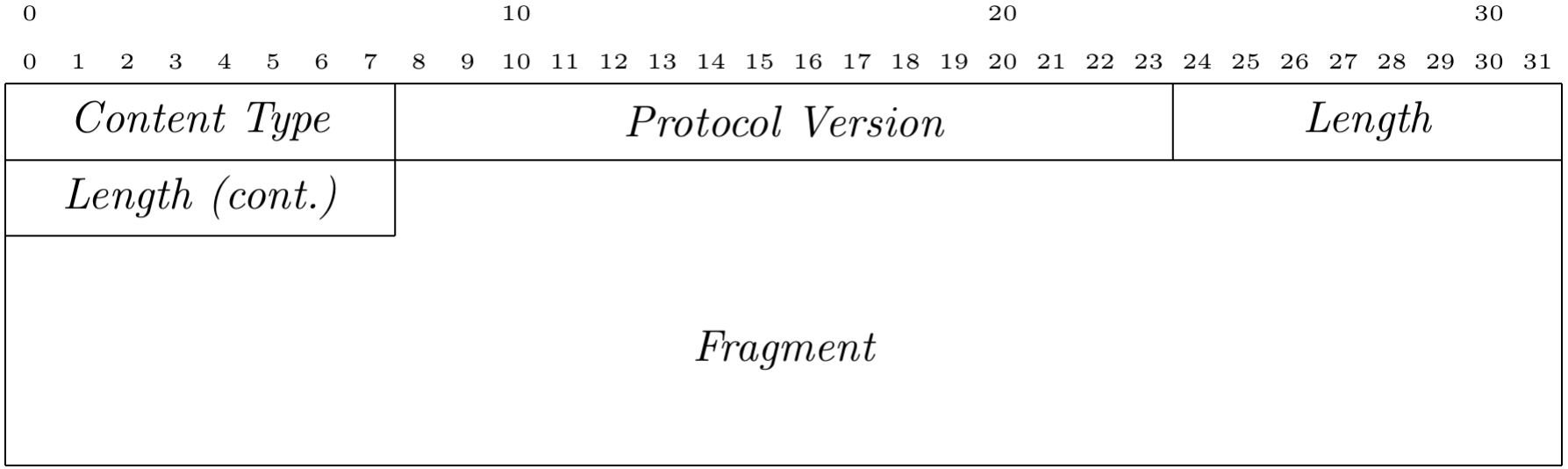
Record Layer

DTLS

Sequence numbers to allow decryption of individual records. Note: No stream ciphers supported. *Epoch* to recognize key changes.



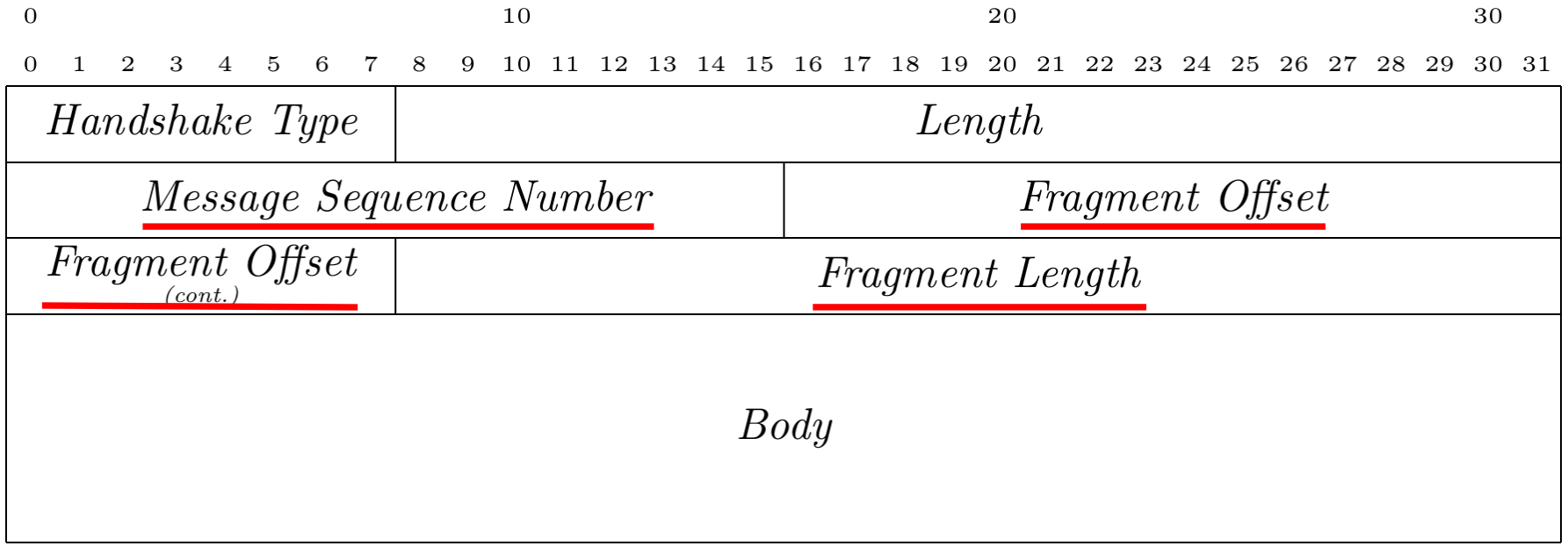
TLS



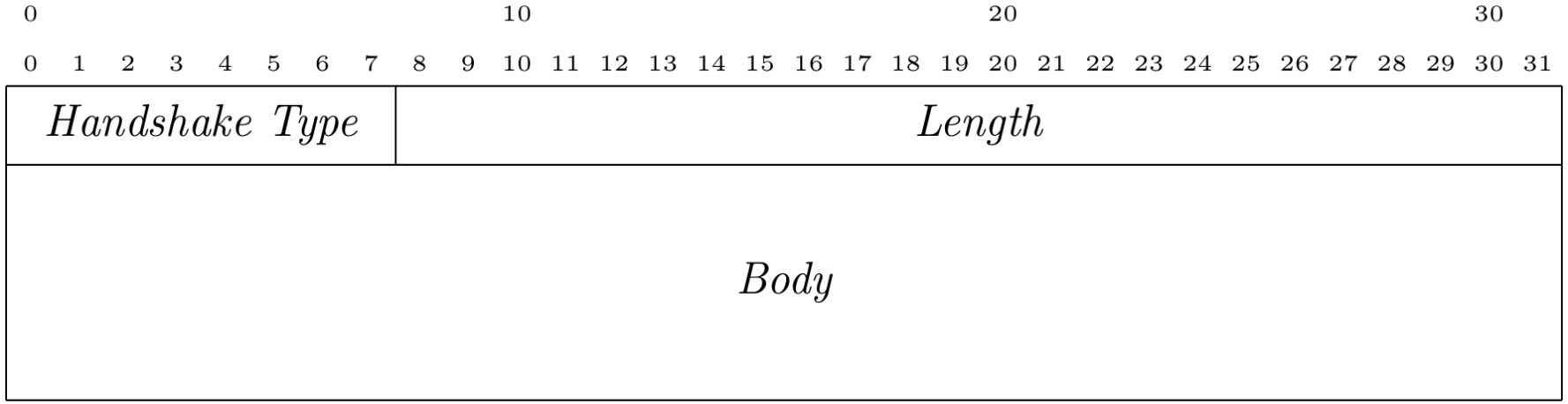
Handshake Protocol

DTLS

Sequence numbers to detect reordering. *Fragmentation Offset and Length for avoiding IP (or lower layer) fragmentation.*



TLS



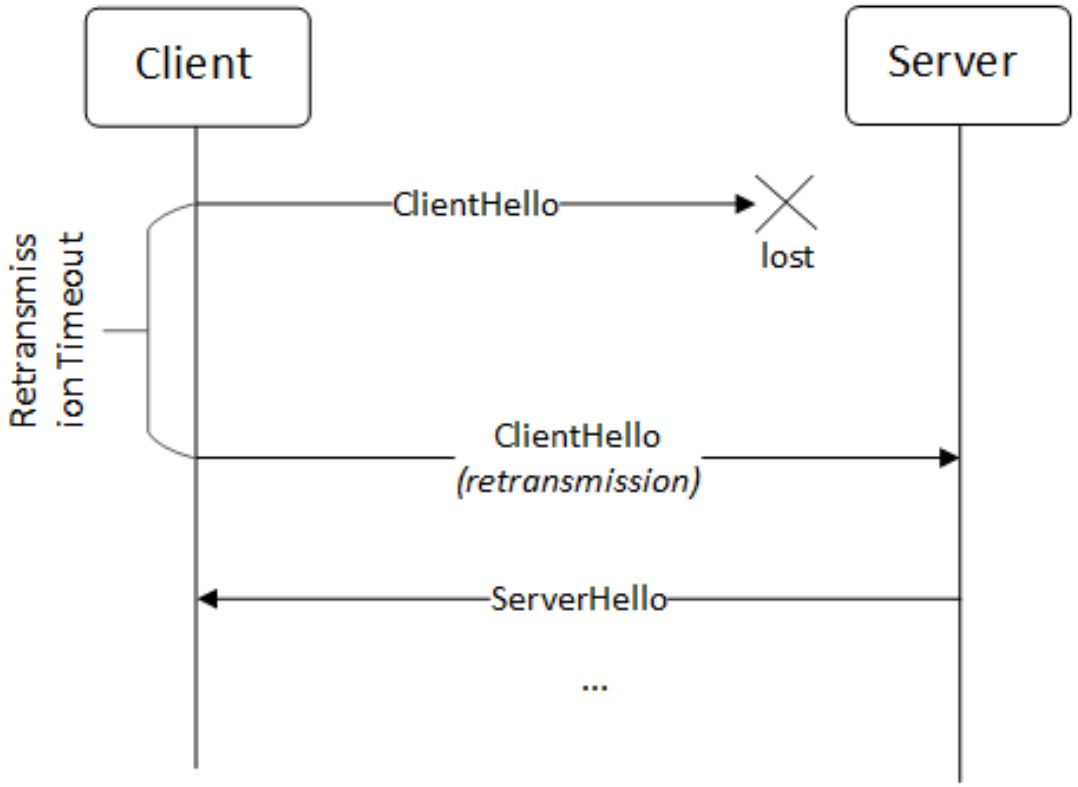
Retransmission Timers

Concept and Implementation

Registering Timer Callbacks

- In mbed TLS a pair of callbacks is provided with mbedtls_ssl_set_timer_cb():
  - void mbedtls_timing_set_delay(void *data, uint32_t int_ms, uint32_t fin_ms);
  - int mbedtls_timing_get_delay(void *data);
- Note that the retransmissions happens at the levels of entire ”flights” rather than individual messages.

DTLS Retransmission Mechanism



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Retransmission Timers

How long should the sender wait till retransmission happens?

RFC 6347

- …. initial timer value of 1 second
- Double the value at each retransmission
- up to no less than 60 seconds.

RFC 7925

- … initial timer value of 9 seconds
- Double the value at each retransmission
- up to no less then 60 seconds.

The minimum and maximum can be set using mbedtls_ssl_conf_handshake_timeout().

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Denial of Service

Handling integrity check failures

TLS

- The connection is immediately terminated when a record is received that does not pass the integrity check,
- Injecting bad records in TCP is just as hard as injecting a TCP RST to tear down the connection.
- This denies attackers an opportunity to do more than one guess at the message authentication key, while not introducing any new DoS vectors.

DTLS

- Injecting bad records is very easy; an attacker only needs to know the source and destination IP and port.
- Section 4.1.2.7 of the DTLS 1.2 spec recommends not to tear down the connection.

Denial of Service, cont.

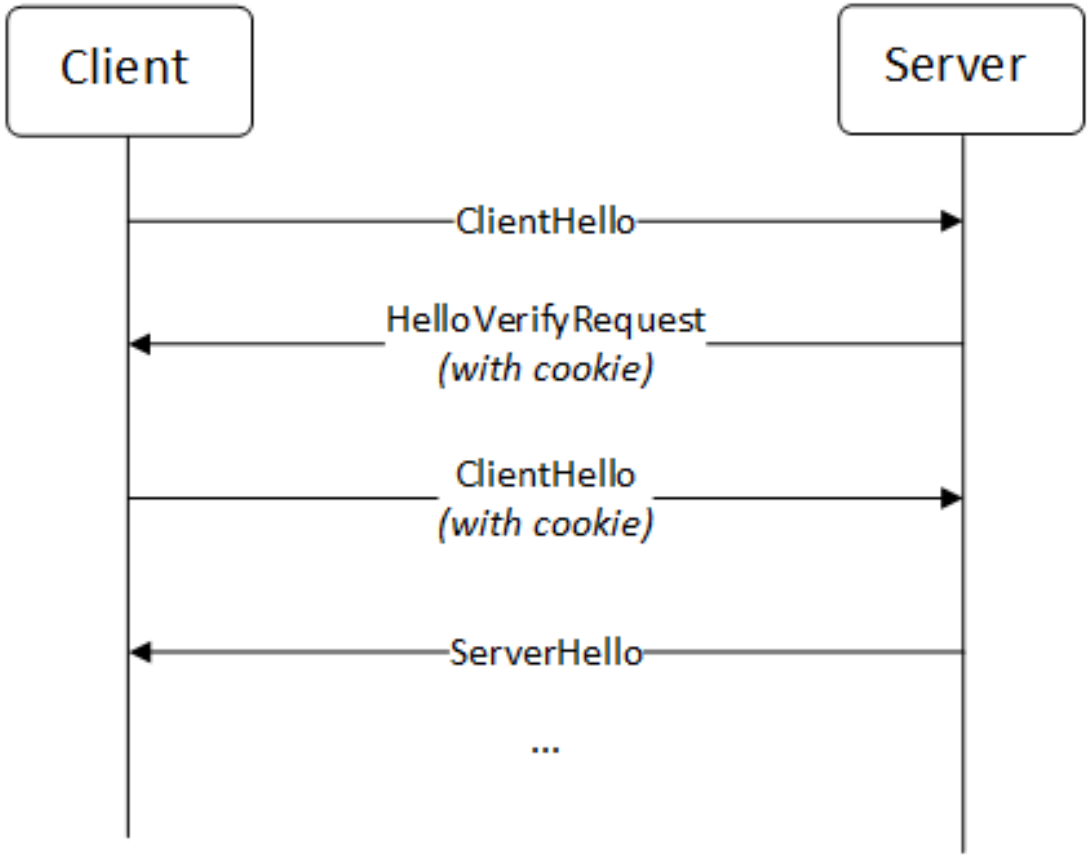
- It is possible to set a limit to the number of bad records before the connection is torn down.
- This is controlled by
  - the compile-time flag **`MBEDTLS_SSL_DTLS_BADMAC_LIMIT`** (enabled by default), and
  - the run-time setting mbedtls_ssl_conf_dtls_badmac_limit**()** (unlimited by default).

Denial of Service Settings

Avoiding Amplification Attacks

- A small one-shot message requires state allocation, computation and leads to a large response.
- Perform return-routability check with HelloVerifyRequest (HVR) message.
  - Message is stateless at the server
  - State encapsulated in cookie and must be returned by the client in 2nd ClientHello.
  - Adds one extra roundtrip
- HVR can be disabled via compile-time flag **`MBEDTLS_SSL_DTLS_HELLO_VERIFY`**

HelloVerifyRequest



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Replay Protection

- For application data protection DTLS provides limited additional properties besides authentication, integrity and confidentiality.
- Just like UDP, DTLS delivers datagrams.
- Unlike UDP, DTLS can detect and discard duplicated datagrams, if needed.
- In Mbed TLS, this feature is controlled by
  - the compile-time flag **`MBEDTLS_SSL_DTLS_ANTI_REPLAY`**,
  - and the run-time setting mbedtls_ssl_conf_dtls_anti_replay**()**,
  - both enabled by default.

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DTLS Integration into the Application Code

1. Use **mbedtls_net_connect**() with **`MBEDTLS_NET_PROTO_UDP`**
   (instead of MBEDTLS_NET_PROTO_TCP).

   You may also need to give your stack extra time for setting up the networking interface.

2. Use **mbedtls_ssl_config_defaults**() with **`MBEDTLS_SSL_TRANSPORT_DATAGRAM`**
   (instead of MBEDTLS_SSL_TRANSPORT_STREAM).

3. Potentionally adjust application interaction with **mbedtls_ssl_read**() / **mbedtls_ssl_write**() interaction.

DTLS Configuration: Config.h

- Add **`MBEDTLS_SSL_PROTO_DTLS`** to enable DTLS support

- (Note: On the server-side you also have to enable cookie support and implement the appropriate callbacks.)

Hardware and Testbed Setup

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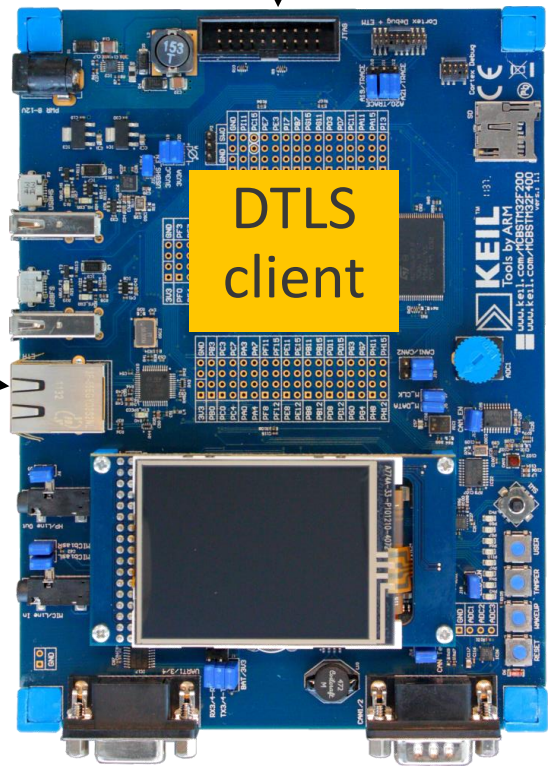
Development laptop

Wireshark

DTLS Server

DTLS (over Ethernet)



Keil MCBSTM32F400 Evaluation Board (with STM32F407IG MCU)

```
ssl_server2 debug_level=5 psk_identity="client"
psk=5790848063193968307081682401368484262399
force_version=dtls1_2 tickets=0
```

Hands-on code now uses CMSIS-RTOS2 and Keil RTX5.

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Hands-on

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Conclusion

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Summary

- DTLS is popular in IoT deployments. It is, for example, used to secure CoAP.
- The good news: DTLS is similar to TLS.
- Even better: It is easy to configure timer callbacks and other DTLS options.