Transport Layer Security

“TLS is cryptographic protocol that provides communication security over the Internet.”

- Provides confidentiality, integrity and server authentication
- Most successful and widely used cryptographic protocol (!!!)
- Any application protocol can be encapsulated in TLS
TLS History

- SSL 1.0 – never publicly released
- SSL 2.0 – Netscape (1995)
- SSL 3.0 – Netscape (1996)
- TLS 1.0 (SSL 3.1) – RFC 2246 (1999)
- TLS 1.1 – RFC 4346 (2006)
- **TLS 1.2** – RFC 5246 (2008)
- TLS 1.3 – RFC draft (2016)

No fundamental changes between versions

http://www.ietf.org/rfc/rfc5246.txt
TLS Record Layer

[Type][Version][Length][Data]

- **Type**: content type of encapsulated data:
  - Handshake message (0x16)
  - Change cipher spec message (0x14)
  - Alert message (0x15)
  - Application data (0x17)
- **Protocol version**: 0x0303 (for TLS v1.2)
- **Length**: length of the data (2 bytes)
- **Data**: encapsulated content
  - Can contain several same type messages

Header is never encrypted!
• Client verifies server’s X.509 certificate
• Client extracts from the certificate server’s public key
• Client encrypts random symmetric key using public key
• Only the server can decrypt symmetric key
• Now the client and server share the same symmetric key
• Symmetric key used for actual data encryption/authentication
Dissecting TLS with Wireshark
Alert Message

Signals about TLS related issues to other party

[Level][Description]

- Level (1 byte):
  - Warning (0x01)
  - Fatal (0x02)

- Description (1 byte):

  close_notify(0),
  unexpected_message(10),
  bad_record_mac(20),
  decryption_failed(21),
  handshake_failure(40),
  bad_certificate(42),
  unsupported_certificate(43),
  certificate_revoked(44),
  certificate_expired(45),
  illegal_parameter(47),
  unknown_ca(48),
  access_denied(49),
  decrypt_error(51),
  user_canceled(90),
  ...
Change Cipher Spec Message

TLSv1 Record Layer: Change Cipher Spec Protocol: Change Cipher Spec
Content Type: Change Cipher Spec (20)
Version: TLS 1.0 (0x0301)
Length: 1
Change Cipher Spec Message

Signals to other party that from now on the negotiated cipher suite will be used to protect outgoing messages
[0x01]
Application Data

Contains (most likely encrypted) application data in a form as required by the application protocol (e.g., HTTP request/response etc.)

[Application Data]
Handshake Message

Negotiates TLS protocol security parameters
[Type] [Length] [Body]

- **Type**: message type:
  
  hello_request(0), client_hello(1), server_hello(2), certificate(11), server_key_exchange (12), certificate_request(13), server_hello_done(14), certificate_verify(15), client_key_exchange(16), finished(20)

- **Length**: length of the body (3 bytes)
- **Body**: message body
  - Can be split over several records
Handshake Message: client_hello

- Highest TLS version supported (2 bytes)
- Client randomness (32 bytes)
  - Timestamp in first 4 bytes
- Session ID length (1 byte) + session ID
- Cipher suites length (2 bytes)
- List of cipher suites supported:
  - 0x0005 – TLS_RSA_WITH_RC4_128_SHA
  - 0x002f – TLS_RSA_WITH_AES_128_CBC_SHA
  - 0x0035 – TLS_RSA_WITH_AES_256_CBC_SHA
  - 0x0039 – TLS_DHE_RSA_WITH_AES_256_CBC_SHA
- Compression methods length (1-byte)
- List of compression methods supported:
  - 0x00 – null (mandatory)
  - 0x01 – DEFLATE (gzip)
- Extensions (optional)
Handshake Message: server_hello

TLSv1 Record Layer: Handshake Protocol: Server Hello
  Content Type: Handshake (22)
  Version: TLS 1.0 (0x0301)
  Length: 74

Handshake Protocol: Server Hello
  Handshake Type: Server Hello (2)
  Length: 70
  Version: TLS 1.0 (0x0301)

Random
  gmt_unix_time: May 3, 2013 17:55:01.000000000 EEST
  random_bytes: 6dbfaec346d39439ac083b8c0df9f485b327c:
  Session ID Length: 32
  Session ID: 6a9137403d3be6f28e95ca0b0053734f6edad2813
  Cipher Suite: TLS_RSA_WITH_RC4_128_SHA (0x0005)
  Compression Method: null (0)

- TLS version selected (2 bytes)
- Server randomnessness (32 bytes)
  - Timestamp in first 4 bytes
- Session ID length (1 byte) + session ID
- Cipher suite selected (2 bytes)
- Compression method selected (1 byte)
- Extensions (optional)
Handshake Message: certificate

- Length of certificate list (3 bytes)
- List of certificates
  - Certificate length (3 bytes)
  - DER encoded certificate
- The first is server’s certificate
- Other certificates are optional
  - Usually intermediate CA certificates
Handshake Message: server_hello_done

- Empty message body
- Tells that there will be no more messages from the server in this protocol round
Handshake Message: `client_key_exchange`

- **Content Type:** Handshake (22)
- **Version:** TLS 1.0 (0x0301)
- **Length:** 262

**RSA Encrypted PreMaster Secret**

- Encrypted PreMaster length: 256
- Encrypted PreMaster: 34f527956711a0e5100b30571910486042

Contains (two byte length-prefix) encrypted 48 byte random “pre-master secret”

- Encrypted using public key from the server certificate
- Encrypted according to PKCS#1 v1.5
- First two bytes in premaster secret contain TLS version
  - Must be checked by the server
  - Prevents some attacks (?)
- Next 46 bytes are truly random bytes
Handshake Message: finished

- The first encrypted message
- Serves to verify if encryption works
- Contains hash of concatenation of all previous handshake messages (excluding TLS record header)
  - Must be verified by other party to detect downgrade attacks
Encryption

- Plaintext compression leaks information (CRIME attack)
- How many symmetric keys are needed?
  - MAC & encrypt (+ IV for block ciphers)
    - Separate keys for both directions

How to derive these keys from 48 byte pre-master secret?
Key Derivation

- TLS defines PRF() (pseudo-random function)
  - Uses SHA-256()
  - Produces infinitely long pseudo-random output

- 48 byte “master secret” is derived:
  \[
  \text{PRF}(\text{premaster} + \text{"master secret"} + \text{client_random} + \text{server_random}, 48)
  \]

- From “master secret” is derived key block in the size needed:
  \[
  \text{PRF}(\text{master_secret} + \text{"key expansion"} + \text{server_random} + \text{client_random}, 136)
  \]

- Key block is split into keys needed:
  \[
  \begin{align*}
  \text{client_mac_key} &= \text{key_block}[0:20] \\
  \text{server_mac_key} &= \text{key_block}[20:40] \\
  \text{client_enc_key} &= \text{key_block}[40:56] \\
  \text{server_enc_key} &= \text{key_block}[56:72] \\
  \text{client_iv} &= \ldots \\
  \end{align*}
  \]
  
  ...
MAC Calculation

HMAC\_digest(key, seq + type + version + length + data)

- digest: digest algorithm from negotiated cipher suite
- key: client/server MAC key
- seq: client/server Sequence number (8 bytes)
  - Starts from 0
  - Incremented for every encrypted TLS record
- type: TLS record content type
- version: TLS protocol version (2 bytes)
- length: length of the content (2 bytes)
- data: content

Type, version and length are fields from TLS record header!
This way integrity for TLS record header is also provided!
Task

Implement TLS 1.2 client that can retrieve server’s certificate.

$ ./tls_getcert.py https://www.eesti.ee/ --certificate server.pem
--> client_hello()
<--- handshake()
  <--- server_hello()
    [+] server randomness: 0A801E9E809F15D7BCDB3A4F9640A3395480E7EF41FC9E6BD9B9438ECD67
    [+] server timestamp: 1975-08-02 02:43:26
    [+] TLS session ID: B268B48206AC28679B315CAB6CF5D0EEB5B0E50A973097EF1AFE20C23E8520F
    [+] Cipher suite: TLS_RSA_WITH_AES_256_CBC_SHA
  <--- handshake()
    <--- certificate()
      [+] Server certificate length: 1636
      [+] Server certificate saved in: server.pem
  <--- handshake()
    <--- server_hello_done()
--> alert()
  [+] Closing TCP connection!

$ openssl x509 -in server.pem -text | grep 'Subject:'
Subject: C=EE, ST=Harjumaa, L=Tallinn, O=Estonian Information System Authority, CN=*.eesti.ee
Task: Other Test Cases

$ ./tls_getcert.py https://www.ut.ee/
--> client_hello()
<--- handshake()
<--- server_hello()
[+] server randomness: 5AE09A3AD38FEBD7F6541A8E9E54813303D397CBFBD3CF667D615EFE73D5C6
[+] server timestamp: 2018-04-25 18:09:46
[+] TLS session ID: 87500CF65DA6B1DD5BA9C675697802254AA383EFD29A403E76C8EC33B723628B
[+] Cipher suite: TLS_RSA_WITH_RC4_128_SHA
<--- handshake()
<--- certificate()
[+] Server certificate length: 1604
<--- handshake()
<--- server_hello_done()

--> alert()
[+] Closing TCP connection!

$ ./tls_getcert.py https://danskebank.ee/
--> client_hello()
<--- handshake()
<--- server_hello()
[+] server randomness: 5AE0993AA7777BD76CF82BF906842C6B3A71B6E3E6378528CEDEA00CBABA53
[+] server timestamp: 2018-04-25 18:05:30
[+] TLS session ID: C37DDFE7B056C2FBD56BDFC93CC5934F78BB7C2668DA5A106E836F5D927FC639
[+] Cipher suite: TLS_RSA_WITH_AES_256_CBC_SHA
<--- certificate()
[+] Server certificate length: 1916
<--- server_hello_done()

--> alert()
[+] Closing TCP connection!
Task: Hints

- Compare your parsed output with output from Wireshark
  - Use capture filters ’host 1.2.3.4 and port 443’
- NB! One TLS record can contain several handshake messages
- Unix timestamp can be obtained using \texttt{int(time.time())}
- Unix timestamp can be printed using:
  \[
  \text{datetime.datetime.fromtimestamp(int(time.time())).strftime(''%Y-%m-%d %H:%M:%S')}\]