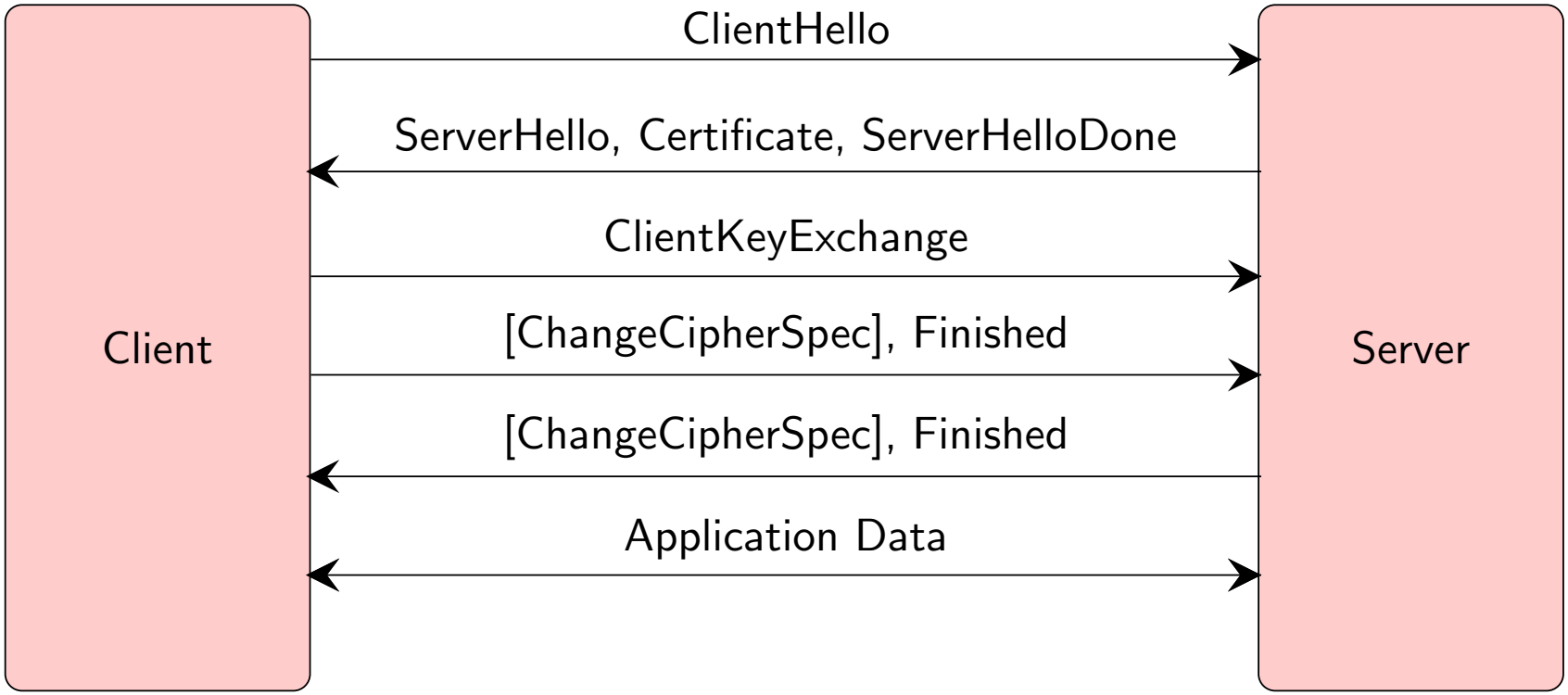
MTAT.07.017
Applied Cryptography

Transport Layer Security (TLS)
Advanced Features

University of Tartu

Spring 2019

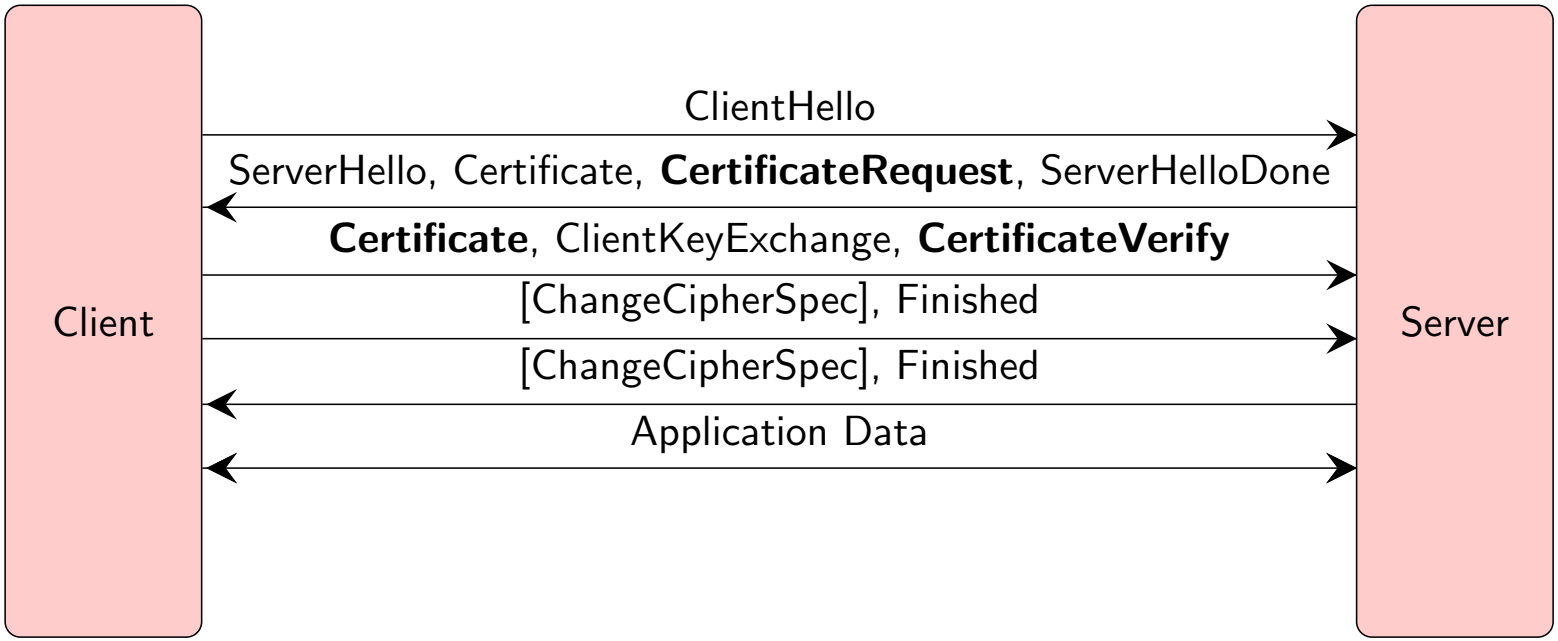
Server-Authenticated TLS



Client usually is authenticated on the application level by some shared secret (e.g., password). This can go wrong:

- Server can be impersonated
- Server can be compromised
- Password can be reused in another service
- Password can be guessed
- Password can be phished

Client Certificate Authentication

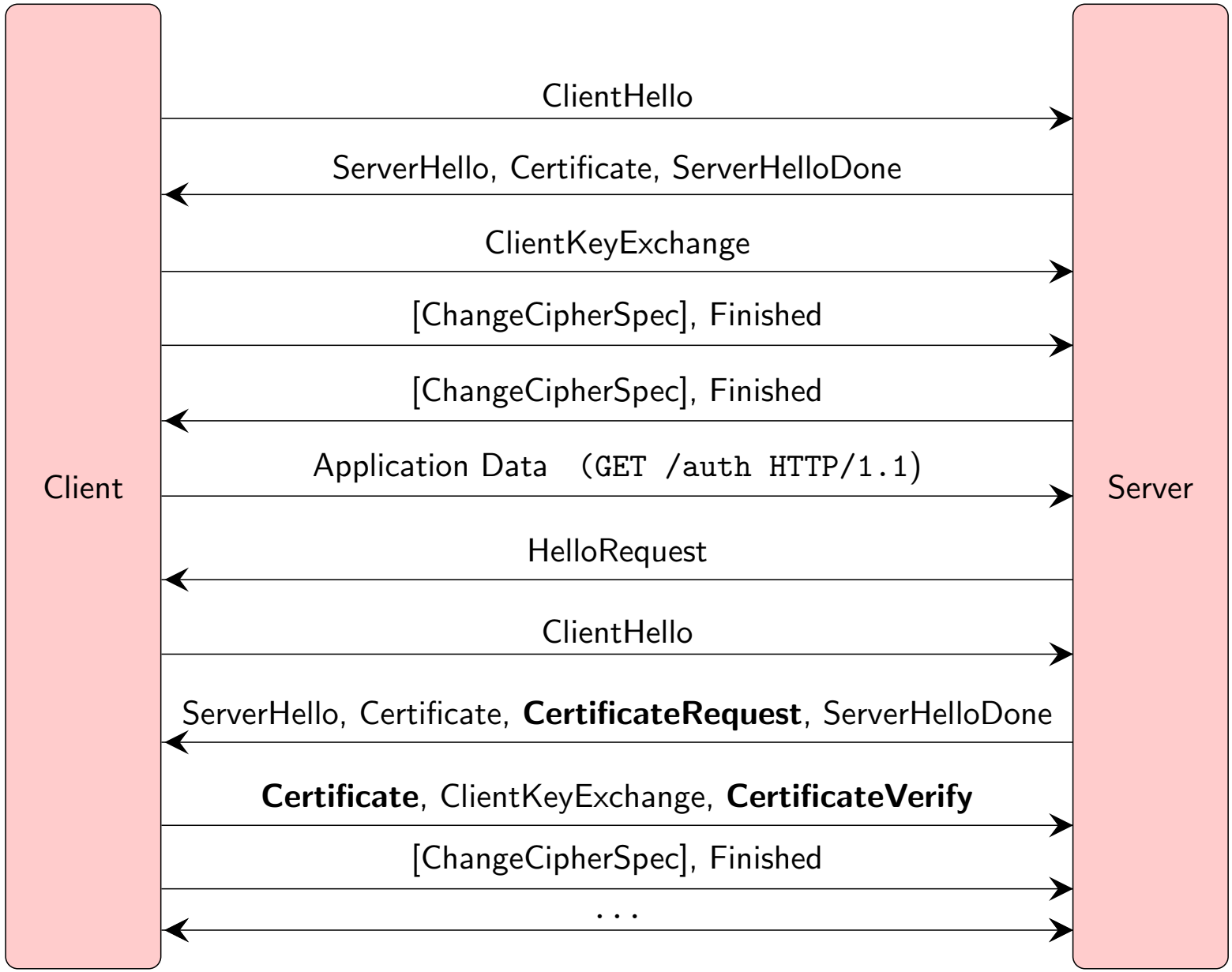


- `CertificateVerify` – signature over all handshake messages
- Can `CertificateVerify` be reused in another handshake?
- Why `CertificateVerify` is after `ClientKeyExchange`?
- Client's `Certificate` is sent before `ChangeCipherSpec`
- Client proves his identity by signing and not by decrypting

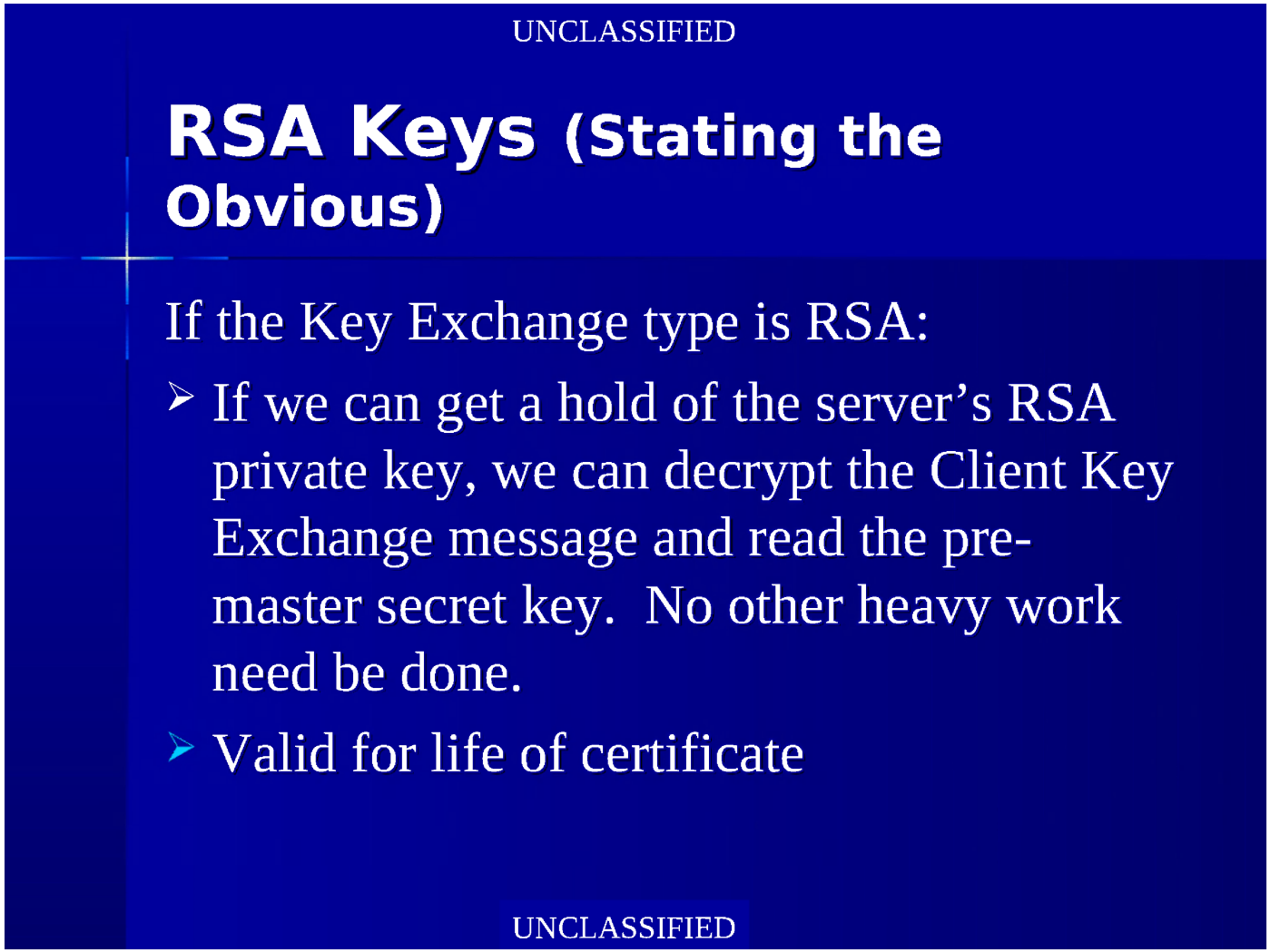
Renegotiation

- Any party can initiate negotiation of a new TLS session:
  - Client by sending `ClientHello`
  - Server by sending `HelloRequest`
- Handshake messages of the new TLS session are protected by the cipher suite negotiated in the previous TLS session
- Used by server to renegotiate stronger cipher suite or to request client certificate authentication if on application level client tries to access resources that require such security measure
- Client initiated renegotiation usually disabled on the server

Certificate request on renegotiation

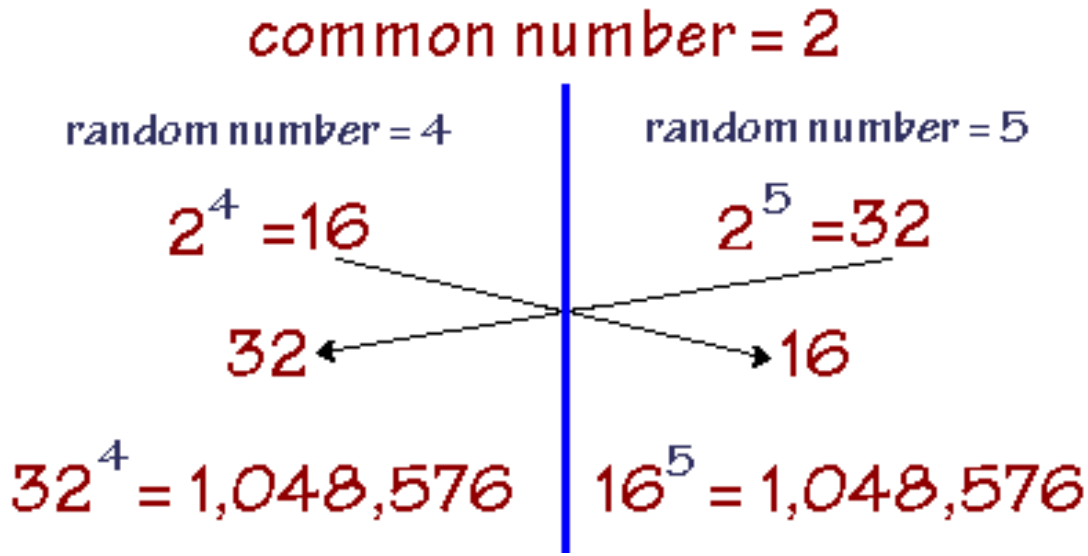


TLS decryption



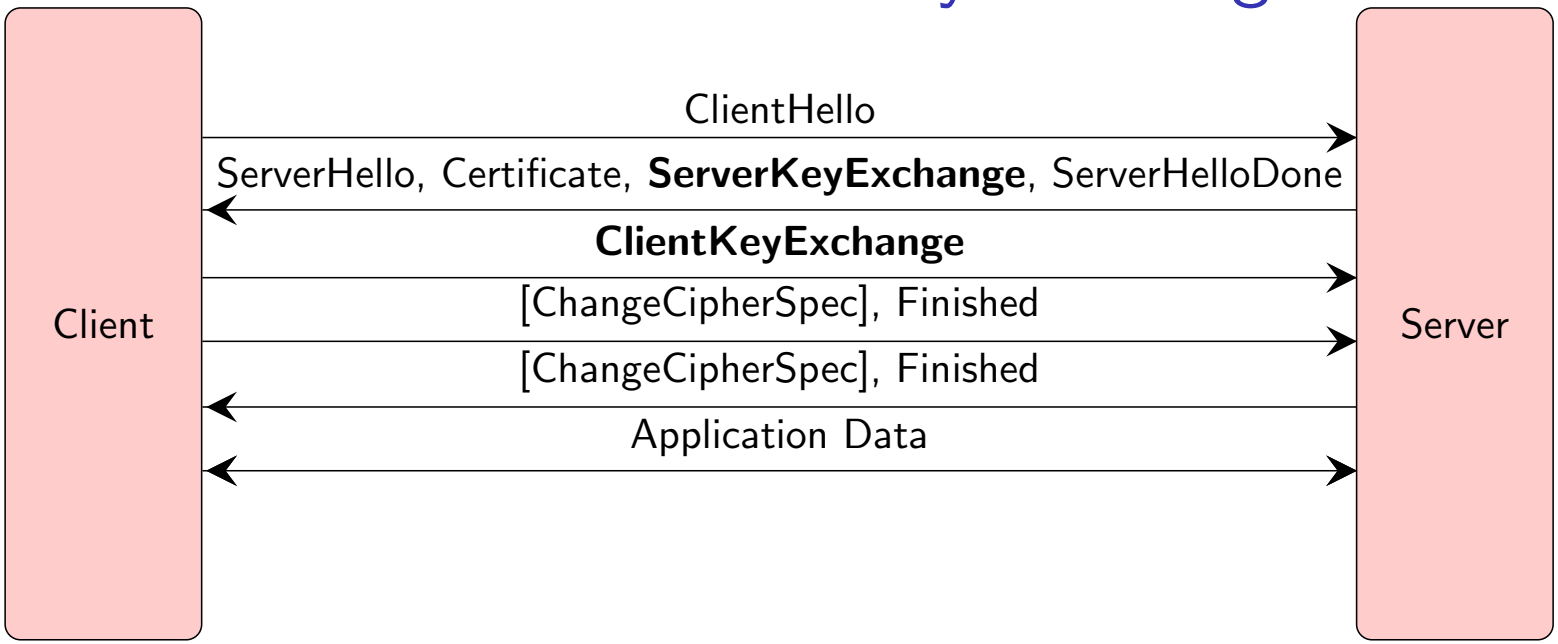
https://www.eff.org/document/20141228-spiegel-scarletfever-program-attack-secure-sockets-layer-ssl-tls

Diffie-Hellman Key Exchange



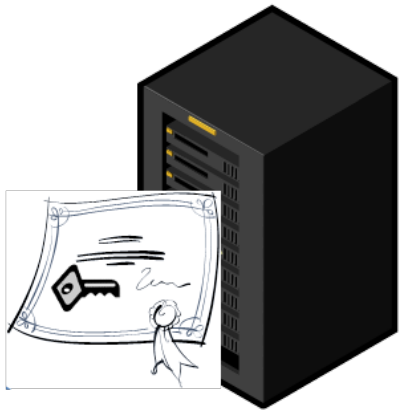
- $(2^5)^4 = 2^{5 \cdot 4} = (2^4)^5$
- In practice multiplicative group of integers modulo p is used
- Discrete logarithm problem
  - hard to find x, given $2^x = 32 \mod p$
- Secure against passive eavesdropping

Diffie-Hellman Key Exchange



- `ServerKeyExchange` contains DH group, server's DH public key and server's RSA signature over DH public key, client randomness and server randomness
- `ClientKeyExchange` contains client's DH public key
- How is "pre-master secret" calculated?
- Handshake requires two public key operations (DH + RSA)
- Used by `TLS_(EC)DHE_RSA_WITH_*` cipher suites
- Achieves perfect forward secrecy

Perfect Forward Secrecy



Benefits:

- Attacker who has compromised RSA private key cannot decrypt previous TLS traffic
- Attacker who has compromised RSA private key has to execute active MITM attack
- Attacker has to crack x asymmetric keys to decrypt x sessions made to the server

PFS is achieved by using the long-term private key to authenticate a short-term key that is used to encrypt the actual data.

Extensions

- `ClientHello` can contain length-prefixed extensions
- `ServerHello` will contain response to client's extensions
- Most popular extensions:
  - Server Name Indication (SNI) extension (RFC 3546)

```
▼ Extension: server_name
    Type: server_name (0x0000)
    Length: 17
  ▼ Server Name Indication extension
      Server Name list length: 15
      Server Name Type: host_name (0)
      Server Name length: 12
      Server Name: www.eesti.ee
```

  - TLS Session Tickets (RFC 5077)

```
▼ Extension: SessionTicket TLS
    Type: SessionTicket TLS (0x0023)
    Length: 180
    Data (180 bytes)
```

  - Elliptic Curves (RFC 4492)

```
▼ Extension: elliptic_curves
    Type: elliptic_curves (0x000a)
    Length: 8
    Elliptic Curves Length: 6
  ▼ Elliptic curves (3 curves)
      Elliptic curve: secp256r1 (0x0017)
      Elliptic curve: secp384r1 (0x0018)
      Elliptic curve: secp521r1 (0x0019)
```

  - Heartbeat (RFC 6520)

Task: TLS client – 5p

Implement TLS v1.2 client that can obtain HTTP response.

```
$ ./tls_client.py https://127.0.0.1:4433/
--> client_hello()
<--- handshake()
        <--- server_hello()
        [+] server randomness: 57359448EF20879409852D451B1A3089D620A95944BF8092
        [+] server timestamp: 2019-04-26 11:46:00
        [+] TLS session ID:
        [+] Cipher suite: TLS_RSA_WITH_RC4_128_SHA
<--- handshake()
        <--- certificate()
        [+] Server certificate length: 554
<--- handshake()
        <--- server_hello_done()
--> client_key_exchange()
--> change_cipher_spec()
--> finished()
<--- change_cipher_spec()
<--- handshake()
        <--- finished()
--> application_data()
GET / HTTP/1.0
<--- application_data()
HTTP/1.0 200 OK

Hello!
[+] Closing TCP connection!
```

Task: TLS client

Client has to support `TLS_RSA_WITH_RC4_128_SHA` cipher suite

- Template contains fully implemented `PRF()`, `derive_master_secret()`, `derive_keys()`, `encrypt()`, `decrypt()` and client/server finished hash calculation code
  - Make sure you provide correct inputs to these functions (!!!)
- Your TLS client should work on `www.facebook.com`
- Grading:
  - 2 points if a server accepts your `ClientKeyExchange` message
  - 2 points if a server accepts your `Finished` message
  - 1 point if your code can show HTTP response
- You can use `tls_server` binary for development (port 4433)
- Wireshark "Decode As" – "TCP Destination 4433" – "SSL"

Debugging

```
$ ./tls_server --port 4433
[+] Connection from 127.0.0.1:38452
<--- handshake()
        <--- client_hello()
        [+] version: 0303
        [+] client randomness: 5AE1C2C0A89495A695EFD7945EEBE629CE3AE6E42673172266072BF54EEE1BB9
        [+] client timestamp: 2019-04-26 15:14:56
        [+] TLS session ID:
        [+] Cipher suites:
            TLS_RSA_WITH_RC4_128_SHA
        [+] Compression methods:
                null
        [+] Extensions length: 0
--> server_hello()
        [+] server randomness: 5AE1C2C036B7A4C11ABF8450E64B3EC52D188A936C12DEC1FCEDF8BE5DA551F1
        [+] server timestamp: 2019-04-26 15:14:56
        [+] TLS session ID:
        [+] Cipher suite: TLS_RSA_WITH_RC4_128_SHA
--> certificate()
        [+] Server certificate length: 554
--> server_hello_done()
<--- handshake()
        <--- client_key_exchange()
        [+] PreMaster length: 128
        [+] PreMaster (encrypted): b333386d576b129a7a486a0515f390258572d252f0db2380e14adeaff4a75c81efbac6f4ccc4929557b0197e6938
        [+] PreMaster: 030362b7dc1497d02d377d34c30a446839214f32d48f5163a2979d614019ed8778048ff8c60cd97757b88a8bd6afdc5a
<--- change_cipher_spec()
        [+] Applying cipher suite:
                [+] master_secret = PRF(030362b7dc1497d02d377d34c30a446839214f32d48f5163a2979d614019ed8778048ff8c60cd97757b88a8
                [+] master_secret: c182ff31961f326b777b9ec627ba4b17b2ea9b0a606ba1c04be2d0b8347aa3a3d92fe7de13880f07dbbfb9909fbe
                [+] client_mac_key: 0cdc5de9428c8f56ffa6e62df3b2f837ce866623
                [+] server_mac_key: a304d7dae33435a757e0eb4efb2ca062354aefbf
                [+] client_enc_key: 82f955c772a4e9b39c009188a149976f
                [+] server_enc_key: e9caad52b25f872a96b8d2d5657c7835
<--- handshake()
        <--- finished()
        [+] client_verify (received): cb0a97cbaf1fddacda50160c
        [+] client_verify (calculated): cb0a97cbaf1fddacda50160c
--> change_cipher_spec()
--> finished()
<--- application_data()
GET / HTTP/1.0
--> application_data()
HTTP/1.0 200 OK

Hello!
[+] Closing TCP connection!
```

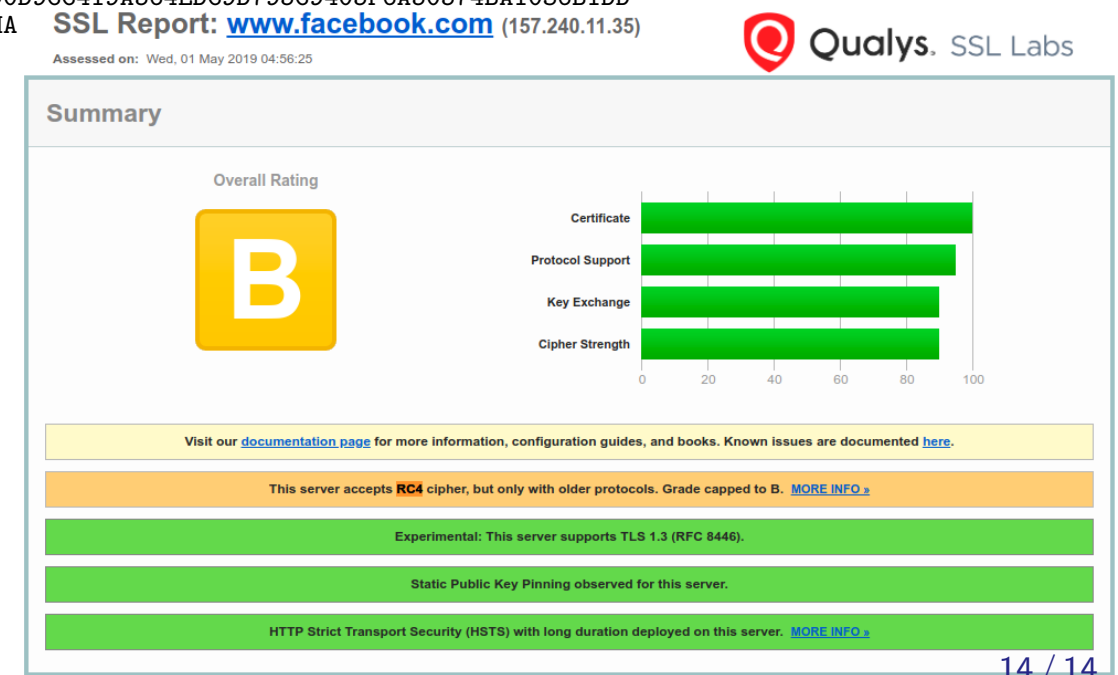
RC4 (TLS_RSA_WITH_RC4_128_SHA)

```
$ ./tls_client.py https://www.swedbank.ee/
--> client_hello()
<--- alert()
        [-] fatal: 40

$ ./tls_client.py https://www.nordea.ee/
--> client_hello()
<--- alert()
        [-] fatal: 40

$ ./tls_client.py https://www.eesti.ee/
--> client_hello()
<--- alert()
        [-] fatal: 40

$ ./tls_client.py https://www.facebook.com/
--> client_hello()
<--- handshake()
        <--- server_hello()
        [+] server randomness: 5D8ED830872A31CCE442E042D9B057657329122E6FC28B7F8EA1EFFDBF145F34
        [+] server timestamp: 2019-09-28 06:49:04
        [+] TLS session ID: E3279B254961AA66F89C90D9CC419A564EDC9D795C9405F6A50574BA1036B1DD
        [+] Cipher suite: TLS_RSA_WITH_RC4_128_SHA
<--- handshake()
        <--- certificate()
        [+] Server certificate length: 1792
<--- handshake()
        <--- server_hello_done()
--> client_key_exchange()
--> change_cipher_spec()
--> finished()
<--- change_cipher_spec()
<--- handshake()
        <--- finished()
--> application_data()
GET / HTTP/1.0
<--- application_data()
HTTP/1.1 301 Moved Permanently
Vary: Accept-Encoding
Location: https://www.facebook.com/
Content-Type: text/html; charset="utf-8"
Date: Wed, 01 May 2019 15:37:46 GMT
Connection: close
Content-Length: 0
[+] Closing TCP connection!
```



Most common pitfalls

- Server fails to verify MAC of client's *finished* message
  - Make sure client's *finished* message is encrypted using the correct keys. Compare keys – if they are different make sure key derivation receives the correct values of premaster secret, client and server randomness.
- Server fails to verify hash in client's *finished* message
  - Make sure all handshake messages sent and received are appended to the `handshake_messages` variable.
- Client fails to verify hash in server's *finished* message
  - Plaintext version of client's `finished` message must be appended to the `handshake_messages`.
- Server returns fatal *alert* "decryption failed" after receiving client's *finished* message
  - Make sure the server did not choose non-RC4 cipher suite.