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TLS For IoT

Transport Layer Security Protocol For Internet Of Things

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Abstract. The abstract should summarize the contents of the paper using at least 70 and at most 150 words. It will be set in 9-point font size and be inset 1.0 cm from the right and left margins. There will be two blank lines before and after the Abstract. ...

Keywords: TLS, IoT, cryptography, protocol, lightweight cryptography

1 Intoduction

TODO: Intruduce the topic: explain what is IoT; what is TLS; what are the issues with using RAW TLS with IoT(power, computation, limited resources).

1.1 Goals

2 Symmetric vs Asymmetric Cryptography (Background Section)

Asymmetrical Cryptography (AC) more expensive than Symmetrical Cryptography (SC) in terms of performance. This is mainly due to two facts: larger key sizes are required for AC system to achieved the same level of security as in a SC system and CPUs are slower at performing the underlying mathematical operations involved in AC, namely exponentiation requires O(log e) multiplications for an exponent e. For example, the 2016 NIST report [2] suggests that an AC would need to use a secret key with size of 15360 bits to have equivalent security to a 256-bit secret key for a SC algorithm. This situation is ameliorated by Elliptic Curve Cryptography (ECC), which requires keys of 512 bits, it is still slower than SC, though. The 2017 BSI report [1] (from the German federal office for information security) suggests similar numbers.

Another argument for avoiding as much as possible of the AC functionality is that it requires extra storage space to be used and this might be a problem for some Internet Of Things (IoT) devices, like class 1 devices according to the

terminology of constrained-code networks [?] which have about 10KB of RAM and 100KB of persistent memory. I measured the resulitng size of the complied mbedTLS 2.6.0 library [3] when compiled with and without the RSA module (located in the rsa.c file), from which I concluded that using that module adds an extra of 32KB.

3 Related Work

TODO: talk about RAW PK

For the reasons specifed above, the main key exchange mechanism used in IoT are Pre-Shared Key (PSK)s. SK3[?] proposes a key management architecture for resource-constrained devices, which allows devices that have no previous, direct security relation to use TLS or DTLS using one of two approaches: shared symmetric keys or raw public keys. The resource-constrained device is a server that offers one or more resources, such as temperature readings. The idea in both approaches is to introduce a third-party trust anchor (TA) that both, the client and the server use to establish trust relationships between them.

The first approach is similar to Kerberos[?], without requiring any changes to the original protocol. A client can request a PSK Kc from the TA, which will generate it and send it back to the client via a secure channel, alongside a psk_identity which has the same meaning and is used in the same way as defined in RFC PSK[?]. When connecting to the server, the client will then send the psk_identity that it received in the the (D)TLS handshake and the server will derive the Kc, using the P_hash() function defined in [7].

The second approach consists in the requesting an APK (the authors never defined what this acronym stands for, but I assume they mean "Authorization Public Key") from the TA. In his request, the client includes his Raw Public Key (RPK), which is used for authorization. The TA creates an authorizaton certificate, protects it with a MAC and sends it to the client alongside the server's Public Key (PubK). The client then sends this APK (instead of the RPK) when connecting to the server, which verifies the APK (to authorize the client) and proceeds with the handshake in the RPK mode, as defined in [?]. To achieve this, a new certificate structure is defined, alongside a new certificate_type. The new certificate strucure is just the RFC7250 [12] structure, with an additonal MAC.

The has function used for key derivation is SHA256. The authors evaluated the performance of their solution with and without SHA2 hardware acceleration and concluded that while it had significant impact on key derivation, it had little impact on the total handshake time (711.11 ms instead of 775.05 ms), since most of the time was spent in sending data over the network and other parts of the handshake, the longest one being the ChangeCiperSpec message which required the longest processing time of 17.79ms.

6LoWPAN[?] is a protocol that allows devices with limited processing ability and power to transmit information wirelessly using the IPv6 protocol. The protocol defines IP Header Compression(IPHC) for the IP header and Next Header

Compression (NHC) for the IP extension headers and the UDP header in [**?**]. The compression relies on the shared compress between the communicating peers. There is also a proposal for TCP header compression for 6LoWPAN[**?**], which if adopted, in many cases can compress the mandatory `20 bytes` TCP header into `6 bytes`. This means that the same ideas presented in the paragraphs below can be applied to TCP as well. (REWERITE ME)

[] uses this same idea, but with the goal of compressing DTLS headers. 6LoWPAN does not provide ways to compress the UDP payload and layers above, there is however, a proposed standard[**?**] for generic header compression for 6LoWPANs that can be used to compress the UDP payload. The authors propose a way to compress DTLS headers and messages using this mechanism.

The paper [] defines how the Datagram TLS (DTLS) Record header, the DTLS Handshake header, the ClientHello and the ServerHello messages can be compressed, but notes that the same compression techniques can be used to compress the remaining Handshake messages. They explore two cases for the header compression: compressing both, the Record header and the Handshake header and compressing the Record header only, which is useful after the handshake has completed and the fragment field of the Record layer contains application data, instead of a handshake message.

All of the cases follow the same basic idea, for this reason I'll only exemplify one of them. Each DTLS fragment is carried over in the UDP payload. In this case, the UDP payload carries a header-like payload (the DTLS record header). The authors use the same value for the `LOWPAN_NHC Encoding` field (defined in [**?**]) as in `RFC7400` and define the format of the `In-line Next Header Fields` (defined in [**?**]), which is the compressed DTLS content.

I will exemplify the case where both, the record and the Handshake headers are compressed. In this case `LOWPAN_NHC Encoding` will contain the `LOWPAN_GHC_RHS` structure (depicted in **??**), which is the compressed form of the Record and Handshake headers. The parts that are not compressed will be contained in the `Payload` part. The first four bits represent the ID field and in this case they're fixed to `1000`, so that the decompressor knows what is being compressed (*i.e* how to interpret the structure that follows the ID bits). If the `F` field contains the bit `0`, it means that the handshake message is not fragmented, so the `fragment_offset` and `fragment_length` fields are elided from the Handshake header (common case when a handshake message is not bigger than the maximum header size), meaning that they're not going to be sent at all (*i.e.* they're not going to be present in the `Payload` part). If the `F` bit has the value `1` the `fragment_offset` and `fragment_length` fields are carried inline (*i.e.* they're present in the `Payload` part). The remaining two fields define similar behavior for other header fields. The `length` field in the Record and Handshake headers are always elided, since they can be inferred from the lower layers.

4 Background

TODO: Tell that first I describe the parts of TLS that are common to both and then specialize for TLS 1.2 and TLS 1.3

5 The TLS Protocol

TLS stands for Transport Layer Security, it's a **client-server** protocol that runs on top a **connection-oriented and reliable transport protocol**, such as **TCP**. Its main goal is to provide **privacy** and **integrity** between the two communicating peers. Privacy implies that a third party will not be able to read the data, while integrity means that a third party will not be able to alter the data.

In the TCP/IP Protocol Stack, Transport Layer Security (TLS) is placed between the **Transport** and **Application** layers. It's designed to make the application developer's life easier: all the developer has to do is create a "secure" connection, instead of a "normal" one.

TODO: Re-write what's below. It's good to include something like this, but I need to work on the wording. From the top-level view, in a typical connection, there are three basic steps that TLS is responsible for:

1. **Negotiate security parameters** - the communicating peers agree on a set of security parameters to be used in a TLS connection, such as the algorithm used for bulk data encrytion, as well as the secret keys.
2. **Authenticate one to another** - usually only the server authenticates to the client.
3. **Communicate securely** - use the negotiated security parameters to encrypt and authenticate the data, communicating securely one with another.

SSL vs TLS: What's The Difference? You will find the names Secure Sockets Layer (SSL) and TLS used interchangeably in the literature, so I think it's important to distinguish both. TLS is an evolution of the SSL protocol. The protocol changed its name from SSL to TLS when it was standardized by the Internet Engineering Task Force (IETF).SSL was a proprietary protocol owned by Netscape Communications, and The IETF decided that it was a good idea to standarize it, which resulted in RFC 2246 [8], specifying TLS 1.0, which was nothing more than a new version SSL 3.0, very few changes were made. In this document, I'll be concentrating on TLS 1.2 and TLS 1.3 protocols. The first one is the most recently standardized version of TLS and the latter is currently and in-draft version with many improvements and optimizations relevant for the topic of this dissertation. Despite the protocol name not suggesting it TLS 1.3 is very different from TLS 1.2, in fact, it should've probably been called TLS 2.0 instead. For this reason, I will first describe what is common to both protocols and then go into the relevant details about each one.

TODO: Explain what RFCs are?

5.1 Security Services

TLS provides the following 3 security services:

- **authentication** - both, **peer entity** and **data origin** (or **integrity**) authentication.
  - **peer entity authentication** - we can be sure that were talking to certain entity, for example, `www.google.com`. This is achieved thought the use of **asymmetrical** or Public Key Cryptography (PKC) (for example, `RSA` and `DSA`) or **symmetric key cryptography**, using a PSK.
- **confidentiality** - the data transmitted between the communicating entities (the client and the server) is encrypted. Symmetric cryptography is used of data encryption (for exmaple, `AES`).
- **integrity** (also called **data origin authentication**) - we can be sure that the data was not modified or forged, *i.e.*, be sure that the data that were receiving is coming from the expected entity (for example, we can be sure that the `index.html` file sent to us when we connected to `www.google.com` in fact came from `www.google.com` and that it was not modified (i.e tampered with) en route by an attacker (**data integrity**). This is achieved through the use of a keyed Message Authentication Code (MAC) or an Authenticated Encryption With Associated Data (AEAD) cipher.

Despite using PKC, TLS does **not** provide **non-repudiation services**: neither **non-repudiation with proof of origin**, which addresses the user denying having sent a message, not **non-repudiation with proof of delivery**, which addresses the user denying the receipt of a message. This is due to the fact, that instead of using **digital signatures**, either a keyed MAC or an AEAD cipher is used, both of which require a **shared secret** to be used.

You are not required to use all of the 3 security services in every situation. You can think of TLS as a framework that allows you to select which security services you want to use for a communication session. As an example, you might ignore certificate validation, which means you're ignoring the **authentication** guarantee. There are some differences regarding this claim between TLS 1.2 and TLS 1.3, for example, while in the first you have a `null` cipher (no authentication, no confidentiality, no integrity), in the latter this is not true, since it deprecated all non-AEAD ciphers in favor of AEAD ones.

Cipher Spec vs Cipher Suite The meaning of these terms differs in TLS 1.2 and TLS 1.3. For TLS 1.2, **cipher spec** defines the message encryption algorithm and the message authentication algorithm, while the **cipher suite** is the **cipher spec**, alongside the definition of the **key exchange** algorithm and the Pseudo-Random Function (PRF) (used in key generation). In TLS 1.3, the **cipher spec** has been removed altogether, since the **ChangeCipherSpec** protocol has been removed. The concept of **cipher suite** has been updated to define the pair of AEAD algorithm and hash function to be used with HMAC-based Extract-and-Expand Key Derivation Function (HKDF): in TLS 1.3 the **key exchange** algorithm is negotiated via extensions. You'll find more details on this below.

5.2 TLS (Sub)Protocols

In reality TLS is composed of several protocols(illustrated in 2), a brief description of each one of which follows:

- **TLS Record Protocol** - the lowest layer in TLS. It's the layer that runs directly on top of **TCP/IP** and it serves as an **encapsulation for the remaining sub-protocols** (`4` in case of TLS 1.2 and `3` in case of TLS 1.3). To the **Record Protocol**, the remaining sub-protocols are what `TCP/IP` is to `HTTP`. A TLS Record is comprised of 4 fields, with the first 3 comprising the TLS Record header: a 1-byte record `type`, specifying the type of record that's encapsulated (ex: value `0x16` for the handshake protocol), a 2-byte `TLS version` field, a 2-byte `length` field (which means that a maximum TLS Record size is of `16384` bytes), specifying the length of the data in the record, excluding the header itself and a `fragment` field whose size in bytes is specified by the `length` field, which contains data that's transparent to the Record layer and should be dealt by a higher-level protocol, specified by the `type` field. This is illustrated in figure **??**.
- **TLS Handshake Protocol** - the core protocol of TLS. Allows the communicating peers to **authenticate** one to another and negotiate a **cipher suite** (**cipher suite** and key exchange algorithm in case of TLS 1.3) which will be used to provide the security services. For TLS 1.2, **compression** method is also negotiated here.
- **TLS Alert Protocol** - allows the communicating peers to signal potential problems.
- **TLS Application Data Protocol** - used to transmit data securely.
- **TLS Change Cipher Spec Protocol** (removed in TLS 1.3) - used to activate the initial **cipher spec** or change it during the connection.

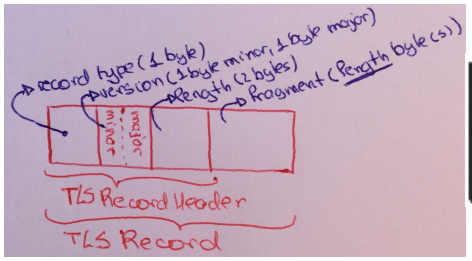


Fig. 1. TLS Record header

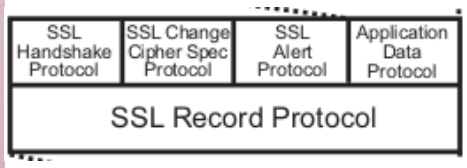


Fig. 2. TLS (Sub)protocols and Layers

TLS Connections and Sessions TODO: define what it means to be cryptographically protected?

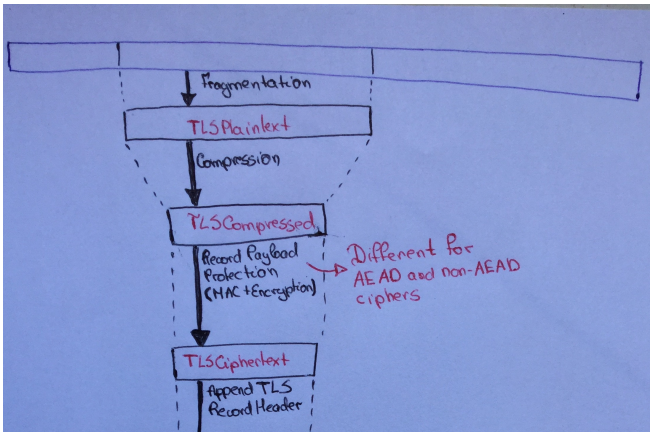
It's important to distinguish between a **TLS session** and a **TLS connection**.

– **TLS sesion** - assosciation between two communicationg peers that's created by the **TLS Handshake Protocol**, wich defines a set of negotiated paramters (cyrptographic and others, depending on the TLS version, such as the compression algorithm) that are used by the **TLS connections associated with that session**. A single **TLS session** can be shared among multiple **TLS connections** and its main purpuse is to avoid the expensive negotiation of new parameters for each **TLS connection**. For example, let's say you download an Hypertext Markup Language (HTML) page over Hypertext Transfer Protocol Secure (HTTPS) and that page referrences some images from that same server, also using HTTPS, instead of your web browser negotiating a new TLS session again, it can re-use the the one you established to download the HTML page in the first place, saving time and computational resources. Session resumption can be done using various approaches, such as **session identifiers**, described throughout `Section 7.4` of `RFC 5246` [7], **session tickets**, defined in `RFC 5077` [**?**]. TODO: Re-write example better.
– **TLS connection** - used to actually transmit the cryptographically protected data. For the data to be cryptographically protected, some parameters, such as the `secret keys` used to encrypt and authenticate the transmitted data need to be established; this is done when a **TLS session** is created, during the **TLS Handshake Protocol**.

TLS Record Processing A TLS record must go through some processing before it can tbe sent over the netwrok. This processing involves the following steps (`4` for TLS 1.2 and `3` for TLS 1.3):

1. **Fragmentation** - the TLS `Record Layer` takes arbitrary-length data and **fragments** it into manageable pieces: each one of the resulting fragments is called a `TLS Plaintext`. Client message boundaries are not preserved, which means that multiple messages of the same type may be placed into the same fragment or a single message may be fragmented across several records.
2. **Compression** (removed in TLS 1.3) - the `TLS Record Layer` compresses the `TLSPlaintext` structure according to the negotiated compression method, outputting `TLSCompressed`. Compression is optional. If the negotiated compression method is `null`, `TLSCompressed` is the same as `TLSPlaintext`.
3. **Cryptographic Protection** - in case of TLS 1.2, either an AEAD cipher or a separate encryption and MAC functions transform a `TLSCompressed` fragment into a `TLSCipherText` fragment. In case of TLS 1.3, the `TLSPlaintext` fragment is transformed into a `TLSCipherText` by applying an AEAD cipher.
4. Append the **TLS Record Header** - encapsulate `TLSCipherText` in a `TLS Record`.

The process described above, as well as the structure names are depicted in figure 3. Step `2` is not present in TLS 1.3. The structure names are exactly as the appear in the TLS specifications.



5.3 TLS Keying Material

Secret keys are at the base of most cryptographic operations. In order for both communicating peers to be able to encrypt and decrypt data using symmetric cyrpto aglorithms, they need to **share** the same key somehow. In TLS, both, the client and a server derive the **same set of keys** independetely, through the exchanged messages in the TLS Handshake Protocol.

When communicating with one anohter, the client uses one key to encrypt the data to be sent to the server and another different key to decrypt the data that it receives from the server. This means that in order to deal with data encryption and decryption, both of the communicating entities have two keys: one to encrypt the outgoing data and one to decrypt the incoming data. Those keys have different names in TLS 1.2 and TLS 1.3, but they serve the same basic purpose. In this general description, I'll refer to them as `client_write key` (used by the client to encrypt the data to be sent), `client_read_key`(used by the client to decrypt the incoming data from the server), `server_write_key`(used by the server to encrypt the data to be sent) and `server_read_key`(used by the server to decrypt the incoming data from the client). Note, that the following relationships must hold: `client_write_key == server_write_key` and `client_read_key == server_write_key`.

Besides the secret keys mentioned previously, in TLS 1.2 you might also have other ones, depending on the cipher suite in use. TODO: Describe this in a little more detail, giving examples, when describing TLS 1.2 Key Managment.

TLS 1.3's keying material generation is a little more complex, since different keys are used to encrypt data throughout the Handshake Protocol, as well a new key is generated for the Application Data protocol. This can be explained by the fact that while in TLS 1.2 the data only begins to be encrypted after the handshake is complete, in the Application Data protocol, the encryption begins earlier, TLS 1.3, with some of the Hanshake messages encrypted, as well as features such as **early client/server data** and **0-RTT Data**.

With this the common description of the TLS of protocols ends and we'll jump into the specifics of the two verions. I'll be mostly concentrating on the **Handshake Protocol**, since this is where my work will be concentrated and it's the main part, where the most interesting and important things happen.

5.4 TLS 1.2

The latest standardized version of TLS is 1.2 and it's defined in `RFC 5246` [7]. TODO: DESCRIBE TLS 1.2 in genreal, put images of handshakes here, later refer to them in the specific parts, just like the tls RFCs do.

6 TLS 1.2 Keying Material Generation

The generation of secret keys, used for various cryptographic operations involves the following steps (in order):

- Generate the **premaster secret**
- From the **premaster secret** generate the **master secret**
- From the **master secret** generate the various secret keys, which will be used in the cryptographic operations.

TODO: talk about all of the keys present in TLS 1.2 HERE

7 TLS 1.2 Key Exchange Methods

The way the **permaster secret** is generated depends on the key exchange method used. In fact, this is the only phase of the keying material generation phase that is variable for a fixed cipher suite (because a cipher suite defines the PRF function to be used), the rest remains exactly the same. The derivation of the **master secret** from the **premaster secret**, as well as the derivation of the bulk encryption keys, MAC keys and Initialization Vector (IV)s from the **master secret** that follows **is not impacted by the key exchange method** in use.

You have quite a few choices when it comes to key exchange methods. Some of them are defined in the base spec (RFC5246 [7]), while others in separate RFCs (such as the ECC based key exchange, specified in RFC4492 [5]).

The base spec specifies 4 key exchange methods, one using Rivest-Shamir-Adleman (RSA) and 3 using Diffie-Hellman (DH):

- static RSA (RSA) [removed in TLS 1.3] - the client generates the premaster secret (PMS), encrypts it with the server's PubK (which it obtained from the server's X.509certificate), sending it to the server, which decrypts it using the corresponding Private Key (PrivK). This key exchange method offers authenticity, but does not offer Perfect Forward Secrecy (PFS).
- anonymous DH (DH_annon) [removed in TLS 1.3] - a DH key exchange is performed and an **ephemeral** key is generated, but the exchanged DH parameters are **not authenticated**, making the resulting key exchange vulnerable to Man In The Middle (MITM) attacks. TLS 1.2 spec states that cipher suites using DH_annon **must not** be used, unless the application layer explicitly requests so. This key exchange offers PFS, but no authenticity.
- fixed/static DH (DH) [removed in TLS 1.3] - the server's/client's public DH parameter is embedded in its certificate. This key exchange method offers authenticity, but does not offer PFS.
- epehemeral DH (DHE) - each run of the protocol, uses different pubic DH parameters, which are generated dynamically. This results in a different, epehemeral key being generated every time. The public parameters are then digitally signed in some way, usually using the sender's private RSA (DHE_RSA)) or \gls{dsa} DHE_DSS) key. This key exchange offers both authenticity and PFS.

When either of the DH variants is used, the value resulting from the exchange is used as the PMS (without the leading 0's). Usually, only the server's authenticity is desired, but client's can also be achieved if it provides the server its certificate. Whenever the server is authenticated, the server is secure against MITM attacks. Table **??** summarizes the security properties offered by each key exchange method.

Table 1. Key exchange methods and security properties

Key Exch Meth	Authentication	PFS
RSA	X	
DH_anon		X
DH	X	
DHE	X	X

Note that in TLS 1.3, all of static RSA and DH cipher suites have been removed: all of the PubK exchange methods now provide PFS. Even though, anonymous DH has also been removed from TLS 1.3, you can still have unauthenticated connections by either using **raw public keys** [12] or by not verifying the certificate chain and any of it's contents.

TODO: NOTE: I did't cover specifics of how the client generates the premaster secret, etc

The ECC-based key exchange (Elliptic Curve Diffie-Hellman (ECDH) and Elliptic Curve Diffie-Hellman Ephemeral (ECDHE)) and authentication (Elliptic Curve Digital Signature Algorithm (ECDSA)) algorithms are defined in `RFC4292` [**?**], which is also referenced in `RFC5246` [**?**]. The document introduces five new ECC-based key exchange algorithms, all of which use ECC to compute the **premaster secret**, differing only in whether the negotiated keys are epehemeral (ECDH) or long-term (ECDHE), as well as the mechanism (if any) used to authenticate them. Three new ECDSA **client authentication** mechanisms are also defined, differing in the algorithms that the certificate must be signed with, as well as the key exchange algorithms that they can be used with. Those features are negotiated through the TLS Extension Mechanism.

7.1 TLS 1.2 Handshake Protocol

In this phase the client and the server agree on which version of the TLS protocol to use, authenticate one to another and negotiate items like the cipher suites and the compression method to use. Figure 4 shows the message flow for the full TLS 1.2 handshake. Note that `*` indicates situation-dependent messages that are not always sent, while `ChangeCiperSpec` is a separate protocol, rather than a message type.

As I explained before every TLS Handshake message is encapsulated within a TLS Record. The actual Handshake message is contained within the `fragment` of the TLS Record. The Record type for a Handshake message is `0x16`. The

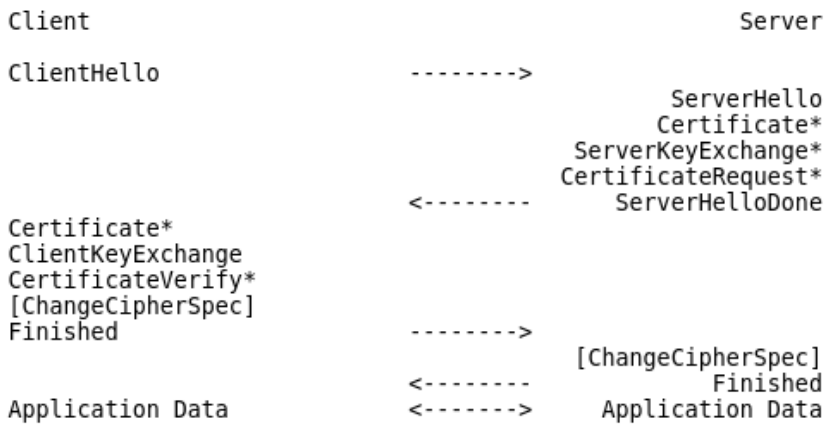


Fig. 4. TLS 1.2 message flow for a full handshake

Handshake message has the following structure: a 1-byte `msg_type` field (specifies the Handshake message type), a 2-byte `length` field (specifies the length of the `body`) and a `body` field, which contains a structure depending on the `msh_type` (similar to `fragment` field in a TLS Record).

Now, I will describe a typical handshake message flow. I will only be mentioning the most important field of each message.

TODO: I don't have space to put all of the structures and things sent in every handshake message type (ex: ClientHello.session_id)

The connections begins with the client sending a `ClientHello`, containing `.random`, `cipher_suites` and `compresison_methods`, among other fields. A 32-byte `random` (3-bytes gmt unix time + 27 cryptographically random bytes) value that are used as an input to the PRF when generating the **master secret**, which will cause to contains a **list** of cipher suites (`cipher_suites`) and compression methods (`compression_methods`) that the client supports, ordered by preference, with the most preferred one appearing first.

7.2 Do We Really Need Two Randoms: One From Client and One From Server?

TODO: YES, replay attacks.

TODO: Mention HelloRequest

Notes and Comments. This is an example of a paragraph. Note the styling.

7.3 TLS 1.3

Despite the protocol name not suggesting it TLS 1.3 is very different from TLS 1.2, in fact, it should've probably been called TLS 2.0 instead.

How Do Peers Distinguish Different TLS Versions? TODO: Talk about version numbers

7.4 TLS Extension Mechanism

TODO: Describe the Extended ClientHello/ServerHello. Use one description for both, TLS 1.2 and TLS 1.3

7.5 The Problem With Compression In TLS

TODO: explain why compression was removed (BEAST and CRIME attacks) and how it can be fixed.

7.6 Theory

TODO: Explain: public key crypto, certificates, AEAD ciphers

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Glossary

AC	Asymmetrical Cryptography. 1
AEAD	Authenticated Encryption With Associated Data. 5, 7
DH	Diffie-Hellman. 9, 10
DTLS	Datagram TLS. 3
ECC	Elliptic Curve Cryptography. 1, 9, 10
ECDH	Elliptic Curve Diffie-Hellman. 10
ECDHE	Elliptic Curve Diffie-Hellman Ephemeral. 10
ECDSA	Elliptic Curve Digital Signature Algorithm. 10
HKDF	HMAC-based Extract-and-Expand Key Derivation Function. 5
HTML	Hypertext Markup Language. 7
HTTPS	Hypertext Transfer Protocol Secure. 7
IETF	Internet Engineering Task Force. 4
IoT	Internet Of Things. 1
IV	Initialization Vector. 9
MAC	Message Authentication Code. 5, 7, 9
MITM	Man In The Middle. 9, 10
PFS	Perfect Forward Secrecy. 9, 10
PKC	Public Key Cryptography. 5
PMS	premaster secret. 9, 10
PRF	Pseudo-Random Function. 5, 9, 11
PrivK	Private Key. 9
PSK	Pre-Shared Key. 2, 5
PubK	Public Key. 2, 9, 10
RPK	Raw Public Key. 2
RSA	Rivest-Shamir-Adleman. 9, 10
SC	Symmetrical Cryptography. 1
SSL	Secure Sockets Layer. 4
TLS	Transport Layer Security. 4–11