University of Glasgow | School of Computing Science

Honours Individual Project Dissertation

Level 4 Project Report Template

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Abstract

Every abstract follows a similar pattern. Motivate; set aims; describe work; explain results.

“XYZ is bad. This project investigated ABC to determine if it was better. ABC used XXX and YYY to implement ZZZ. This is particularly interesting as XXX and YYY have never been used together. It was found that ABC was 20% better than XYZ, though it caused rabies in half of subjects.”

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Signature: Ivan Nikitin Date: 25 March 2022

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2.1 The evolution of the transport layer

In the following section we provide a background on transport layer protocols and recent advancements in the space applicable to the body of work conducted. Together, the protocols described comprise most of the traffic on the Internet. Hence, smaller use-case protocols that do exist were not seen as applicable.

First described by Cerf and Kahn (1974), the Transmission Control Protocol (TCP) has been the main protocol of the Internet suite since its initial implementation. TCP provides a *reliable* and *ordered* delivery of bytes. That is, TCP ensures that data is not lost, altered or duplicated and is delivered in the same order that it was sent. This is achieved by assigning a sequence number to each transmitted packet and requiring an *acknowledgment* (commonly referred to as ACK) from the receiving side. If an ACK is not received, the data is re-transmitted. On the receiving side, the sequence numbers can also be used to order packets as intended by the sender.

As TCP is a connection based protocol, connection establishment must take place before any data can be transmitted. The receiving side (the server) must bind to and listen on a network port and the sender (the client) must initiate the connection using the process of a *three-way handshake* as shown in Figure 2.1. In the first step of the handshake, the client sends a segment with a *synchronise sequence number* (SYN) that indicates the start of the communication and the sequence number that the segment starts with. The server responds with an acknowledgment - ACK, and the sequence number it will start its segment with - SYN. Hence, this step is often referred to as the SYN-ACK. In the third and final step, the client must acknowledge the response. At this point, the connection on which data can be transferred is established.

In order to achieve *secure communication*, TLS (Rescorla 2018) is often used in the TCP stack. In order to do this a separate TLS handshake has to occur in order to specify the version of TLS to use, decide on the cipher suites, authenticate the server via its public key and certificate authority's signature, and generate a session key that can be used for symmetric encryption during communication. In the TLS handshake the first step is for the client to send a *ClientHello* message that specifies the highest version of TLS that the client supports, a list of suggested cipher suites, compression methods and a random number. The server responds with a *ServerHello* message that contains the selected TLS version, cipher suite, compression method and its own random number. The server then sends its certificate and *ServerKeyExchange* message along with the *ServerHelloDone* message indicating that it has completed its part of the negotiation process. The client will respond with the *ClientKeyExchange* message (CKE) which, depending on the chosen cipher suite, may contain a public key. This is followed by the client sending a *ChangeCipherSpec* message indicating that all communication from this point is authenticated and encrypted along with a finished message. The server responds with the same message and the TLS connection is established.

Due to the establishment of communication and properties guaranteed by TCP, such as reliability through retransmission, an inherent trade-off is created, and latency is lengthened. Hence, in use-cases where reliability and connection state is not required, the User Datagram Protocol (UDP) (Postel 1980) is preferred. UDP uses a connectionless communication model that aims to

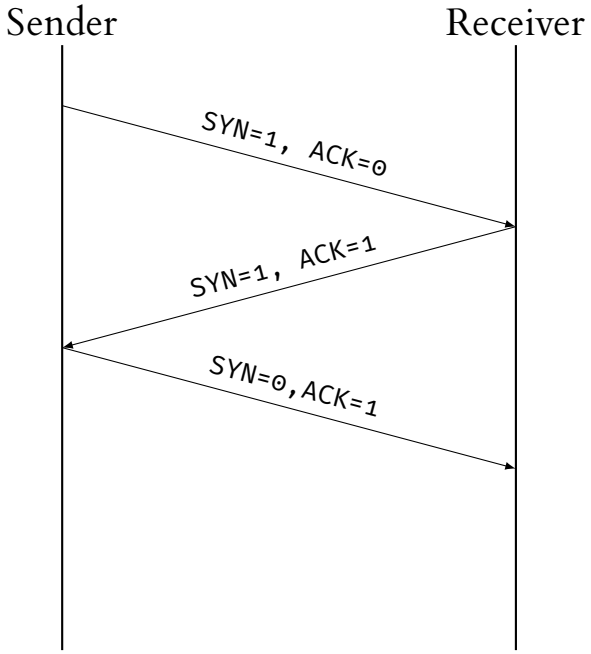


Figure 2.1: *The TCP handshake needed for connection establishment. The values of the SYN and ACK fields being set indicate the kind of segment sent. For example, for the SYN-ACK stage both the SYN and ACK fields are set.*

have a minimal number of semantics. The only mechanisms provided by UDP are port numbers and checksums in order to ensure data integrity. This is preferable for real-time systems as using TCP for these would cause an overhead to latency and retransmission of packets that are no longer needed by the application.

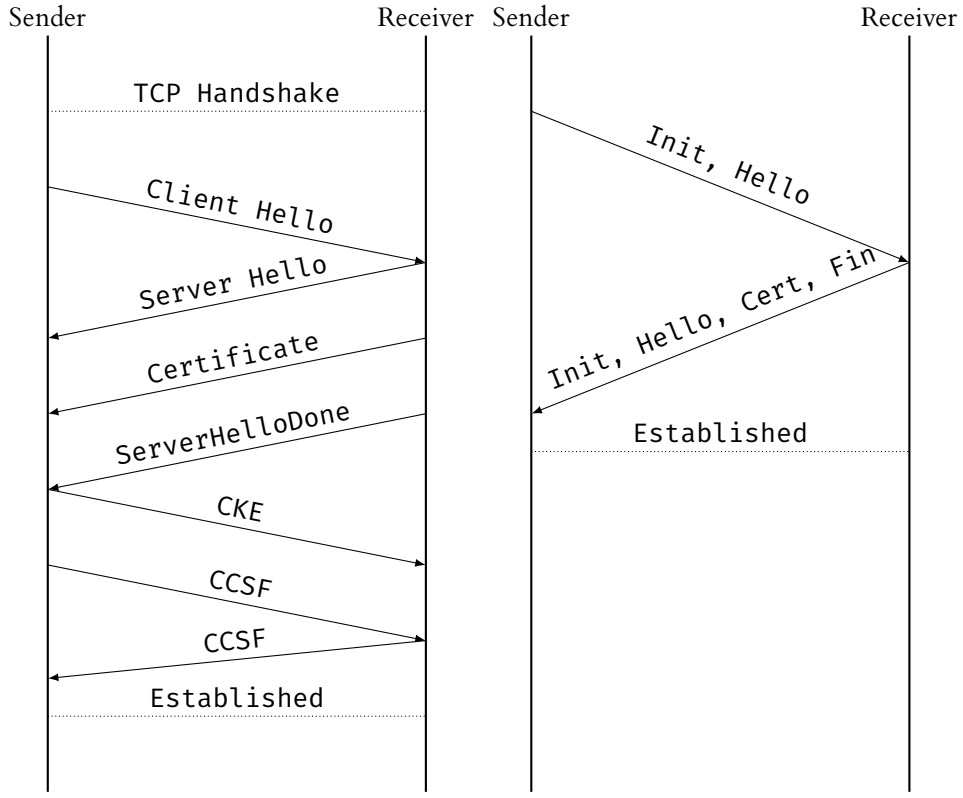
QUIC is a relatively new general-purpose transport layer protocol originally designed by Roskind (2012) at Google as part of the Chromium web engine. In 2015 the first draft of the QUIC protocol was submitted to the IETF and was later standardised (Iyengar and Thomson 2021).

The aim of QUIC is to improve upon, and eventually make obsolete, TCP by using the concept of multiplexing, which is a method of combining several signals or channels of communication over one shared medium. QUIC establishes multiplexed connections between the communicating endpoints using UDP.

QUIC facilitates data exchange on the UDP connection through the concept of *streams*. Streams are an ordered byte-stream abstraction used by the application to send data of any length. Streams are created by either the sending or receiving side and can be both unidirectional and bidirectional. Each side can send data concurrently on the stream and can open any number of streams (specifically, a field for the maximum number of streams is set during the connection). Hence, subject to the constraints imposed by flow control, QUIC allows an arbitrary number of streams to send arbitrary amounts of data on the UDP connection.

By doing so, QUIC also achieves secondary goal of lifting congestion control algorithms from the kernel space to the user space. Hence, congestion control algorithms can evolve without having to be tied down to kernel level semantics and constraints.

Compared to TCP/TLS, QUIC combines the transport and cryptographic handshakes in order to minimise the time needed for connection establishment. A comparison of the handshakes can be seen in Figure 2.2. TLS is still used to secure QUIC as described by Thomson and Turner



(a) TCP/TLS *(b) QUIC*

Figure 2.2: *Handshakes required to establish secure data transmission in the TCP/TLS stack (a) and the QUIC stack (b). In the case of TCP/TLS we can see that the handshake is substantially more complex and that the TLS handshake requires the full TCP handshake before it can proceed. In both cases these handshakes can be made quicker. In the case of TLS, version 1.3 allows for one less round trip before data can be sent, and in the case of QUIC 0-RTT connection re-establishment may be used in come cases, allowing to send data in the first packet.*

(2021) unless a different cryptographic protocol is specified. The initial QUIC handshake keeps the same handshake messages as TLS, however it uses its own framing format, replacing the TLS record layer. This ensures that the connection is always authenticated and encrypted, unlike in TLS where the initial handshake is still vulnerable. The combination also means that QUIC typically starts sending data after just one round-trip achieving security by default and lower latency.

2.2 The Internet of Things

It is hard to give a set criteria or definition for which devices qualify as IoT devices. Generally, an IoT device is usually a device possessing some processing power that may have embedded censors. The key aspect of IoT devices is that they facilitate exchange of data with other devices and systems over the Internet. The modern version of IoT can be attributed to Weiser's (1991) work on ubiquitous computing, although the term itself first appeared in a speech by Peter T. Lewis in 1985. IoT has a multitude of applications in various fields including smart home automation, healthcare, consumer applications and others.

In terms of classifications within networking, IoT technologies can generally be split into wireless and wired, with the former further being split into short range, medium range and long range.

Short range wireless IoT technologies include bluetooth mesh networks, Z-wave, ZigBee and Wi-Fi, as well as other lesser used technologies. Due to the inherent advantages that come with short range wireless communication in IoT applications such as smart homes, this category of IoT technologies was the primary focus for the project, as discussed in later chapters. Medium range networks are used heavily in mobile devices with technologies such as LTE and 5G. The technologies again present an interest due to the amount of traffic that the Internet sees from mobile devices. Long range networks, on the other hand, are quite specific in their applications. For example, VSAT – a satellite communication technology that uses small dish antennas. Due to the limited application of long range technologies when compared to the previous categories, these were left out of the analysis.

In terms of wired technologies used by IoT devices, ethernet remains the dominant general purpose networking standard. Although wired technologies provide advantages in terms of data transfer speed, they do limit deployments due to the physical wiring constraints.

Due to the uses of IoT, the form factor of these devices has to be physically small. Many of these devices have to run for long periods of time on a single lithium battery, hence needing to consume as least energy as possible. Additionally, many use cases of IoT devices require a large number of them connected in a network. For example, Ericsson (2018) estimated that 0.5 connected devices were used per square meter in a smart factory, with demand growing. This adds an additional economical constraint to IoT devices – they need to be made from relatively cheap components.

These constraints mean that IoT devices are limited when it comes to hardware resources. Hardware limitations come in three main forms – CPU power, memory and storage. Storage in the form of flash memory provides the hardest to solve problems when it comes to secure data transfer. The keys required for protocols such as TLS are often large and need to be stored. For example, the *ESP*8266 controller, a widely used IoT chip, comes with 4Mb of flash memory. After the installation of the firmware and binaries needed for the device to perform its function, little to no memory may remain for additional storage.

Efforts to classify the security issues in the IoT space (Alaba et al. 2017; Gupta and Lingareddy 2021; Swamy et al. 2017) and create a taxonomy have generally shown several main topics: issues with privacy due to authentication and authorisation, and general security concerns due to poor encryption at the transport layer.

Insecure firmware in IoT devices come from both the issues with firmware updates and generally insecure code. Most software written for IoT devices is written in the C programming language, which while providing the needed efficiency, is also a source of insecure code that can lead to potential attacks, such as buffer overflows.

On the other hand, to ensure privacy and general security we must ensure data integrity and confidentiality. The data that is sent must not be tampered with, nor snooped on during communication. This requires secure methods for authentication, authorisation and transport level encryption.

Hence, finding a way to circumvent the hardware constraints presented by IoT devices and still provide secure data transfer is paramount to the safe adoption of IoT.

2.3 The Rust programming language

3 Methodology

4 Evaluation

4.1 Performance

4.2 Binary sizes

5 Conclusion

A | Data

5 Bibliography

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