Chapter 1

Technical Background

This chapter provides the technical background to the various terms and concepts used in this thesis. If the reader is already familiar with anything explained in a section in relation to blockchain, skipping it should not hinder in further reading. If the reader is unfamiliar, or wishes to refresh his memory, reading this chapter is advised.

A bottom-up approach is used in this chapter, which means that sections may use or require terms and concepts explained in a previous section, or previous sections. Each section aims to give an intuitive understanding via an example and offers a detailed explanation. A visual representation of how the various sections are linked can be found in appendix A.

The chapter first leads up to explaining blockchain, followed by an introduction to signature schemes. To end the chapter, RandHound and finally OmniLedger are explained.

1.1 Concensus protocol

By definition consensus is an opinion that everyone in a group agrees with or accepts. An agreement, in other words. A protocol, in the technical definition, is an established method for connecting computers so that they can exchange information. A consensus protocol is therefore a method to reach agreement between connected computers.

In relation to blockchain technology, a consensus protocol[1] is a protocol used to reach agreement over input to add to the ledger, and the order in which it should be added. Blockchain technology recognises various such protocols, operating in various ways under different assumptions and requirements.

Below brief explanations will be given of the consensus protocols used by Bitcoin and Stellar. The former uses a concept known as proof-of-work, the latter introduces a notion of trust.

1.1.1 Bitcoin

Conversely, the consensus protocol used by Bitcoin[5] does not require any trust in other participants. Instead it relies on a mechanism known as proof-of-work. In Bitcoin a reward goes to the participant that manages to create the next agreement. This agreement is a set of transactions, called a block, that fulfills the requirements set for the block. Once a participant has found such a block, he sends it to as many others as he can, so that his result will be on the chain, which makes the reward his. Other participant can easily verify that a block meets those requirements, after which they'll accept the result and forward it to others.

The protocol functions with the help of a one-way hash function. A one-way function is a function that makes it easy to compute f(x) given x, but makes calculating x from f(x) (near) impossible. A one-way hash function has the added property of producing output of a fixed length.

What happens in the protocol used by Bitcoin is that each participant will create a block. This block then serves as input for the one-way hash function. The goal is to have a block that results in a hash with a certain amount of leading zero's. Given the block, others can easily verify that hashing the block results in a hash with a sufficient amount of leading zero's.

Producing a wrong block, therefore, is not in the best interest of the participant. Others will quickly refure the block, and all the effort put into creating the block will be wasted.

Therefore the notion of proof-of-work for the Bitcoin consensus protocol is apt. Arriving at a sufficient result requires the participant to try various input blocks, with no way to compute one from the desired result.

1.1.2 Stellar

To understand the Stellar Consensus Protocol[4] (SCP) some definitions are needed. SCP introduces a quorum, a set of participants that is sufficient to reach agreement, and a quorum slice, a subset of a quorum that can convince one participant of the agreement.

The basis of SCP is that participant trust others in their quorum slice to behave honestly, hence the notion of trust in SCP. Assuming all participant behave honestly and under the same set of input and rules, each participant should arrive at the same conclusion. After a participant reaches his conclusion, he publishes it to the others in his quorum slice. In publishing his conclusion he votes for it, as do all others in his slice. The final conclusion is the one most voted for.

As long as there are sufficient reputable participants, the network can never be corrupted. Behaving dishonestly is further disincentivised by the protocol, since those participants are not trusted to be part of a quorum slice, and the influence of their opinion will then quickly be reduced. Conversely, reputable participants will be part of multiple quorum slices, which gives them a large influence over the decisions made.

To ensure that the whole network is indeed connected and reaches network wide consensus, SCP requires that there are no disjunct quorums. Since disjunct quorum can reach their opinion separate from the network, a different agreement undermines the network wide consensus. Participants wishing to join the network have to make sure that they join a quorum in such a way that no disjunct quorums are created.

1.2 Distributed Ledger

By definition, a distributed ledger[6] (DL) would be shared records. This remains true in the context of blockchain technology, but that is not all that it is. Although in use it acts as if there is one ledger that everybody uses, so that everybody agrees what has happened, the technique behind it works differently.

The most important property of a DL in the context of blockchain is the irrefutable state of truth it represents. Anything on the distributed ledger has happened exactly as described there, and no-one can alter those existing records. A DL may therefore be of interest to any group of parties looking to abolish ledger conflicts, to be able to trust that anything in the ledger has indeed happened, nothing more, nothing less, nothing else.

In a DL system, each participant holds and keeps track of his own copy of the ledger. This happens independently, so ledger states are never directly compared. The mechanism used by the sytem ensures that each participants holds the exact same conclusion on his ledger, thereby assuring the irrefutable state of truth.

What happens in the system, is that each participant starts at the same basis: an empty ledger. Input is then presented to all participants, who will handle the input as the system describes. Having handled the input and produced the result, a consensus protocol is used to ensure network wide agreement. Once agreement has been reached, each participant adds input to his ledger as agreed upon, ensuring that each participant reaches the same next ledger state.

Since it may happen that participants join at a later time, mechanisms exist to ensure that the participant can catch-up to the current ledger. This is not done by presenting the ledger, but instead by presenting the input for each ledger state, and corresponding consensus. The new participant then uses that information to construct his ledger from the basis state up, eventually reaching the same ledger state as all other participants.

Blockchain is a form of a DL, using blocks of transactions to shape the ledger and various consensus protocols to agree upon blocks to be added. Since this thesis focusses on techniques used in blockchain, any references to a chain, ledger or anything similar will mean a blockchain, a specific form of a DL.

1.3 Sharding

Sharding is a concept mostly encountered in relation to databases. In that context, it refers to splitting up a large set of data in smaller pieces, shards. These shards can then be spread across distinct containers, be it a table, scheme or even different physical databases. Sharding databases can drastically improve performance and is a well-proven technique for large data sets. Google, for example, uses it for their own globally distributed database, Spanner[2].

In a more generic sense sharding refers to a partitioning of workload. By dividing a system into various parts, that each handle a particular subset of the workload, more work can be done simultaniously, which improves throughput and consequently performance. At the same time, it also means that the amount of resources requires remains limited, since it is not the whole system that has to act, but just a part of it.

Looking at sharding in blockchain[3], it is important to note that in traditional blockchain technologies, each participant handles each input. That means that in a particularly large network, each participant will have to handle a large set of transactions, which uses time and resources.

Sharding in a blockchain means dividing your participants into shards. Transactions will be handled by the shard or shards to which the participants in that particular transaction belong. A transaction that takes place between participants in different shards is known as a cross-shard transaction and requires a different method to handle than transactions happening whithin a shard. Assuming that there are not too many cross-shard transactions, sharding results in a higher throughput of transactions, since each group handles a subset of the transactions simultaniously.

Since blockchain requires that malicious participants cannot influence the result, is is important to note that a shard is somewhat of a mini blockchain, which means that sharding must happen in such a way that shards cannot be compromised.

1.4 Discrete Logarithm Problem

On the set of real numbers ($\mathbb{R}$) the $\log_b$ function has been defined as the solution to the following problem.

Definition 1.1. Given $a, b, n \in \mathbb{R}$, base b and power a of b, what is n such that $a = b^n$?

This same problem can also be defined over modulo p, which is known as the discrete logarithm problem over $\mathbb{Z}/p\mathbb{Z}$.

Definition 1.2 (Discrete Logarithm Problem over $\mathbb{Z}/p\mathbb{Z}$)**.** Given $a, b \in \mathbb{Z}/p\mathbb{Z}$, base b and power a of b, what is n such that $a = b^n \mod p$?

In a more generic sense, this problem can be defined over a group G.

Definition 1.3 (Discrete Logarithm Problem over group G)**.** Given $a, b \in G$, base b and power a of b, what is n such that $a = b^n$?

In particular, since an elliptic curve E is a group, the problem holds over elliptic curves. Taking elliptic curve E as group G, it follows that.

Definition 1.4 (Elliptic Curve Discrete Logarithm Problem)**.** Given elliptic curve E and points $P, Q \in E$, what is n such that $nP = Q$?

Although no actual proof exists, the assumption is that the discrete logarithm problem in a well chosen group G is a hard problem. The group must be well chosen, for there are groups that have a structure that allows for an algorithm to solve the problem, but there is a sufficiently large group of groups left for which no such algorithm exists.

In the context of computer science, this means that there is no known efficient algorithm to solve the problem, other than trying various solutions, quite like the mechanic used in the Bitcoin consensus protocol (section 1). More specifically, the problem being hard means that the runtime of the solution finding algorithm grows linearly to the group size. Or in other words, exponentially in the amount of digits of the group size.

Problems that are hard to solve in this sense of the word, lead to applications in cryptography. Since we can ensure a group large enough that trying all solutions becomes infeasible, it allows for cryptographic security.