The Units of Permissionless Consensus: Towards Mobile and Edge Computing

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Abstract—...

Index Terms—IEEE, IEEEtran, journal, LaTeX, paper, template.

I. INTRODUCTION

LONG has been the time when consensus started to be defined as a fundamental problem of distributed systems [1]–[3]. Generally, consensus means reaching an agreement between multiple parties in the potential presence of faulty individuals. As per multiagent systems, interacting over computer networks, consensus is thought to be the result of a coordination effort such that those parties agree on some value at a given moment. Achieving consensus implies that the system shall be reliable and fault-tolerant. However, the consensus problem has been limited by some assumptions on the networks. The well-known "secure Byzantine-Fault-Tolerant multiparty consensus systems" that have been designed over the years are usually meant to work only with a set of known participants, faulty or not [4]. The other side of the coin is the permissionless consensus challenge, consisting of achieving agreement in an environment where the participants are unknown and untrusted [5], [6]. Plus, there are other intrinsic particularities of this type of networks, for example, their openness, and the lack of any kind of central authority. This adds another layer of complexity to the problem, as the participants are not only unknown and untrusted but can also join or leave the network at any time, freely choosing if they want to participate in the consensus protocol or not. Nevertheless, the problem of permissionless consensus can still be seen as a special case of the more general consensus and can still be formalized in the same way. In this paper, we will focus on consensus in permissionless systems, especially in the context of blockchain networks. We will reason about its meaningfulness, ultimately by trying to identify the units that may underpin consensus. We will also discuss the current state-of-the-art, with a particular interest in the shift of the consensus layer of these distributed networks to mobile and edge computing environments, for which computationally expensive consensus algorithms are impractical and unfair.

II. RELATED WORK

A. Classical Consensus

The establishment of a definition for the problem of reaching agreement in a distributed system was pioneered by Lamport et al. in [1]. The authors defined consensus as the problem of agreeing on a single value among a set of processes, in the presence of faulty entities. The first consensus algorithms were designed for synchronous systems, where the communication between the processes is reliable, and the delay is bounded. However, these initial attempts failed to cover the different types of faulty behaviour. Along with the establishment of the famous Byzantine Generals Problem, the first solutions, not only for dealing with treason, but also for unreliable communication channels, or any other kind of arbitrary Byzantine behaviour, were also proposed by Lamport in [2], [3]. The solution was a synchronous mechanism that used a set of leaders to reach consensus. Multiple practical implementations and optimizations to this solution have been proposed in the literature.

B. Asynchronous Byzantine Consensus

The first asynchronous consensus algorithm was later proposed by Castro and Liskov in [4]. And naturally, after that work, many other asynchronous consensus algorithms have appeared. However, all of them are based on the assumption that the number of faulty processes is less than a certain threshold. Additionally, the assumption of a known set of participants is also made, as well as their roles in the consensus protocol. These are very strong assumptions that limit the challenges that can be addressed, for example, the impossibility to know the participants beforehand as they may participate anonymously, or dynamically.

C. Permissionless Consensus

The advancements of the internet more than potentiated the revolution and what we now call the permissionless consensus problem was finally born. Without forgetting the previous attempts, the first practical permissionless consensus algorithm was proposed by Nakamoto in [5]. It is a proof-of-work consensus protocol that resembles a "replicated state machine" where the independent participants reach agreement not only about transactional values, but also about their order - naturally forming the underlying structure of what is now known as a blockchain. "Proof-of-work is essentially one-CPU-one-vote" and this is the novelty introduced by Bitcoin [7], [8]. The focus shifted for decentralized systems and after proof-of-work many other consensus mechanisms have been proposed, based on different consensus units, like proof-of-stake, proof-of-space, proof-of-burn, etc. The chaotic diversity of new consensus protocols gave also room for endless reviews, overviews and comparisons [9]–[14]. The authors of these surveys often put multiple dimensions into comparison, like fault tolerance, scalability, or energy consumption, and,

among those, some focused their efforts on mechanisms that may work in resource-constrained networks [15]–[18]. This paper will try to identify the common conclusions from these comparisons, while looking into the state-of-the-art and novel approaches for running permissionless consensus protocols in mobile and edge devices.

III. THE NEED FOR PERMISSIONLESS CONSENSUS

A. Permissioned vs Permissionless

Following the line of the previous sections, it has been reasoned about the need for permissionless consensus when there are already well known and established consensus protocols that work in trusted environments [4], [19]. However, even those protocols have their own limitations, not only in terms of trust, fault-tolerance, centrality, permissions, or bottlenecks, but also in terms of scalability [19]. Trying to put some effort on decentralization, Byzantine-Fault-Tolerant consensus protocols are not known for their performance when the network grows in size. The more participants there are, the more messages need to be exchanged between them, and the more time it takes to reach consensus, even if assuring deterministic finality [20]. This is a problem that is not only related to the number of participants, but also to the communication fashion and bandwidth, and the computational capacity of the devices that participate in the consensus protocol. Summing up, the need for permissionless consensus is then justified by the fact that permissioned protocols are not compatible with the requirements of the new generation of distributed systems, especially in the context of blockchain networks. These requirements include dealing with today's sparse networks of anonymously and dynamically participating devices, without interrupting consensus and while battling Sybil attacks [9]. Fundamentally, the permissionless consensus problem is the need for a consensus protocol that can be run in a distributed and decentralized environment, where the participants are unknown and untrusted, and where the network is sparse and unpredictably unreliable.

B. Allowances and goals

Technically, permissionless environments allow for larger networks that depict lower connectivity between the participants. Operationally, everything is expected to happen in an asynchronous or partially synchronous fashion, and the number of transactions is expected to be smaller than the permissioned counterparts. Nevertheless, participation is free, and the governance is not centralized, but rather distributed and public. The identity of the participants is secured or semi-secure as it often relies on pseudonymity for protecting the nodes' identity, while enabling full transparency in regards to the rest of the network content and operation [21]. The goal of permissionless consensus, as generally for any consensus protocol, is to reach agreement on a single value, or a set of values. However, due to the nature of the protocols, the values that are agreed upon end up establishing the serialization of the transactions that are executed in the network, and so establishing time consciousness and total order of the events.

As pointed out by [21] and then referenced by [9], similarly to the permissioned counterparts, permissionless consensus protocols aim at achieving the following properties: Termination, Agreement, Validity, and Integrity. Without going into a lot of details, of these properties, Agreement and Integrity are the most important ones, as they are the ones that guarantee the correctness of the consensus protocols. Termination and Validity are generally related to any classic consensus problem.

C. The building blocks of permissionless consensus

Also described in [9], very concisely, the way to achieve an operating protocol, as seen in the mainstream blockchain networks, is by chaining the generation of the agreeable value, in this particular case, a block and its proof, with the dissemination of the information to the rest of the network, followed by the eventual validation and acceptance of the block by the rest of the nodes. This is the moment when consensus is reached. Nevertheless, during the whole process, a fair and somewhat predictable incentive mechanism is also needed, that rewards the participants for their honest effort in reaching consensus, and punishes the ones that are not behaving correctly. These incentives are of major importance in this very context of permissionless consensus. These building blocks form the basis of the inner functioning of Bitcoin itself [5], and are replicated with some variations in the other permissionless networks [6]. For example, there are some networks that do not have a proof-of-work mechanism, but rather a proof-of-stake, or a proof-of-space, or a proof-of-burn mechanism, etc. when it comes to the generation of the block and its existential and later verifiable proof. All of the other pillars are generally the same [9]. The next sections will try to give a more detailed overview of these block generation proof units.

IV. PROOF-OF-WORK AS A REFERENCE

A. The block generation

In the classical Nakamoto consensus protocol, the generation of a block, to be proposed for further network agreement, complies with the unit of computational work needed to create, or rather find, a verifiable proof of the effort spent on creating the block [5]. This essentially requires brute forcing the finding of a cryptographic hash value for the aggregation of the block information with a nonce such that this hash value satisfies a difficulty threshold, which gets adjusted dynamically over time, to maintain the network overall requirement for the block generation interval [9].

Mitigation of Sybil attacks

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Algorithm 1 BlockGeneration

1: **function**
2:     $BlockHeader \leftarrow Transaction\ Merkle\ Tree\ Root$
3:         $|\ Hash\ of\ the\ last\ Block$
4:         $|\ Timestamp$
5:         $|\ Other$
6:     /* the preceding zero bits in $target$
   depict the mining difficulty */
7:     **while** $Hash(BlockHeader\ |\ nonce) \geq target$ **do**
8:         Increment $nonce$
9:     **end while**
10:     **return** new block
11: **end function**

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