Celo Light Client

1 Introduction

We assume we are given groups of prime order r $\mathbb{G}_1, \mathbb{G}_2, \mathbb{G}_t$, and denote by $\mathbb{F}$ the finite field of the same size. We are also given generators $g_1 \in \mathbb{G}_1, g_2 \in \mathbb{G}_2$. We write $\mathbb{G}_1$ and $\mathbb{G}_2$ additively, and $\mathbb{G}_t$ multiplicatively.

We denote by H a hash function taking as input strings of arbitrary length and outputting elements of $\mathbb{G}_2$. We model H as a random oracle in the security proof, mainly as that is needed for security of the BLS signature scheme.

BLS signature scheme:

- The message m is an arbitrary string
- The secret key sk is a uniformly chosen element of $\mathbb{F}$, and the corresponding public key is $\mathsf{pk} := \mathsf{sk} \cdot g_1$.
- The signature σ of m under sk is

$$\sigma = \mathbf{Sign}(\mathsf{m}, \mathsf{sk}) := \mathsf{sk} \cdot H(\mathsf{m})$$

BLS has the extremely useful property that $\mathbf{Sign}(\mathsf{m}, \mathsf{sk}_1 + \ldots \mathsf{sk}_t) = \sum_{i\in[t]} \mathbf{Sign}(\mathsf{m}, \mathsf{sk}_i)$

Thus, a set of users with private keys $\{\mathsf{sk}_i\}_{i\in[t]}$ and public keys $\{\mathsf{pk}_i\}_{i\in[t]}$ can sign m separately and their signatures can be aggregated to a single signature under public key $\mathsf{pk}_{\mathsf{agg}} := \sum_{i\in[t]} \mathsf{pk}_i$.

Registered key owners: To avoid the so-called "rogue key-attack" when aggregating BLS signatures, we must only allow signatures with public keys pk_i such that a proof of knowledge of sk has been provided. Thus, when a key pk is authorized to partcipate in commitees, such a zk proof of knowledge of sk, e.g. Schnorr, must be provided.

2 The light client protocol

We refer to stake holders by their registered public key. Thus, when we refer to a *commitee*, we mean a set of public keys $\{\mathsf{pk}\}$.

Denote by C_i the commitee of the i'th epoch.[1] The light client $\mathbf{V}$ will only verify the identity of the current epoch commitee. It will satisfy the following completeness and soundness properties

[1] We are assuming here an idealized consensus functionality where this value is well-defined; e.g. not dealing with forks when describing the light client.

Completeness (liveness): If all commitees up to epoch T have had a 2/3-honest majority, then $\mathbf{V}$ will obtain the correct value C_T

Soundness: If all commitees $\{C_i\}_{\in[T]}$ have more than 1/3 honest players then $\mathbf{V}$ will not be convinced of a wrong value C_T.

Last block header of epoch The structure of the last block header of an epoch is important for the light client protocol; and so we describe some of its details.

1. It will contain a string $\mathsf{m} = (S_1, S_2)$, for the two sets $S_1 = \{\mathsf{pk}_i\}_{i\in[s]}, S_2 = \left\{\mathsf{pk}'_i\right\}_{i\in[s]}$ of the keys we add and remove from the validator set, i.e. $C_T = (C_{T-1} \setminus S_1) \cup S_2$.
2. It will contain a string $x \in \{0,1\}^t$ signifying what validators from C_{T-1} signed m.
3. Let $\mathsf{pk}_{\mathsf{agg}} := \sum_{i\in[t]} \mathsf{pk}_i$, where $C_{T-1} = \{pk_i\}_{\in[t]}$. The header contains the signature $\sigma = \mathbf{Sign}(\mathsf{m}, \mathsf{sk}_{\mathsf{agg}})$.

Light client verification $\mathbf{V}$ receives, for $i \in [T-1]$

1. A message $\mathsf{m}_i = (S_{i,1}, S_{i,2})$.
2. A string $x_i \in \{0,1\}^t$
3. A signature σ_i.

$\mathbf{V}$ starts with the validator set C_1 which we assume is hard coded in the genesis block and agreed upon.

For each $i \in \{2, \ldots, T\}$ $\mathbf{V}$

1. Checks that x_i has at least $2/3 \cdot t$ set bits, and sets $D_i \subset [t]$ to be the indices of the set bits of x_i.
2. Computes $\mathsf{pk} := \sum_{j\in D_i} \mathsf{pk}_j$.
3. computes $C_{i+1} = (C_i \setminus S_{i,1}) \cup S_{i,2}$.

3 Hash to group

The BLS signature scheme uses $H : \{0,1\}^* \to \mathbb{G}_2$ as a hash function that outputs random elements in $\mathbb{G}_2$. It is modeled as a random oracle.

It is instantiated using a composition of a Pedersen hash defined over the curve $E_{\texttt{Ed/CP}}$ from [BCG+18], and a few Blake2 hashes.

Pedersen hash The Pedersen hash takes input strings of arbitrary length and outputs elements in the group $G_{E_{\mathtt{Ed/CP}}}$ of $E_{\mathtt{Ed/CP}}$ - **PedersenHash** : $\{0,1\}^* - > G_{E_{\mathtt{Ed/CP}}}$. Each group element is defined by $(x,y) \in \mathbb{F}_p^2$, where p has a bit size of 377, and therefore a byte size of 48. We then define **ULPSerialize**$(x,y) : \mathbb{F}_p^2 \to \{0,1\}^{392}$ as:

$$\begin{cases} x||1 & y \equiv 0 \mod 2 \\ x||2 & y \equiv 1 \mod 2 \end{cases}$$

Finally, we define **ULPedersenHash** : $\{0,1\}^* \to \{0,1\}^{392}$ as **ULPSerialize** $\circ$ **PedersenHash**.

Hash to field To hash into the group $\mathbb{G}_2$, where each element in defined by $(x,y) \in \mathbb{F}_{p^2}^2$, we first have to hash into the field $\mathbb{F}_{p^2}$. We invoke **Blake2s** multiple times to get enough random-looking bits to generate $x = (x_0, x_1)$ and take each inner element modulo p. We generate extra bits reduce modulo bias. Then, we see if x is a valid x on the curve, by trying to find a matching y.

Specifically, given a function we define **ULFieldHash**$(m) : \{0,1\}^* \to \mathbb{F}_p$ as follows:

First, we calculate 1024 random-looking bits using:

$$\mathbf{Blake2s}(\mathtt{0x00000000}||m) \mid\mid \mathbf{Blake2s}(\mathtt{0x00000001}||m) \mid\mid$$
$$\mathbf{Blake2s}(\mathtt{0x00000002}||m) \mid\mid \mathbf{Blake2s}(\mathtt{0x00000003}||m)$$

We then divide it into two 512 bits for x_0 and x_1, and for each we parse the bits as a little-endian integer and take it $\mod p$.

Hash to $\mathbb{G}_2$ We use the try-and-increment method - we initialize a counter, hash the counter together with the message as a possible x value, attempt to find a matching y and if we succeed, we multiply by the cofactor.

Algorithm 1: Try-and-increment hashing to the group

Input : m, a message

1 $hm :=$ **ULPedersenHash**(m)
2 Initialize $c := 0$
3 Serialize c as a little-endian 32-bit unsigned integer, and store in cb
4 $x :=$ **ULFieldHash**$(c||hm)$
5 Attempt finding a matching y by calculating $\sqrt{x^2+1}$. If not successful, increment c and go back to step 2.
6 If successful, take the larger y, and return $\mathtt{cofactor} \cdot (x,y)$. .

References

[BCG+18] Sean Bowe, Alessandro Chiesa, Matthew Green, Ian Miers, Pratyush Mishra, and Howard Wu. Zexe: Enabling decentralized private computation. *IACR ePrint*, 962, 2018.