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BLOCKCHAIN NOTARIZATION: EXTENSIONS TO THE OPENTIMESTAMPS PROTOCOL

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INTRODUCTION

- Notarization of digital documents is traditionally achieved by a trusted certification authority.
- A notary public could be malevolent and represents a single point of failure.
- An application built upon a distributed system reaching consensus in a decentralized way can greatly strengthen the notarization process.
- The Bitcoin blockchain, the most reliable decentralized system, can be used as a notary in a procedure called timestamping.
- The open-source protocol OpenTimestamps aims to be a standard for timestamping and solves a scalability issue.

OUTLINE

Definition (distributed system)

A distributed system is a system whose components are located on different networked computers, which communicate and coordinate their actions by passing messages to one another. The components interact with one another in order to achieve a common goal.

Thus, the main challenge of distributed systems is to achieve distributed consensus in the presence of a number of faulty processes.

THE CONSENSUS PROBLEM

- Networks are composed by many agents, called nodes.
- Nodes are either honest or byzantine.
- They could also be correct and faulty, but not as alternatives to honest and byzantine.

Definition (consensus)

There are n nodes, of which at most f might crash, i.e., at least $n - f$ nodes are correct. Node i starts with a proposed value v_i. The nodes must decide for one of those values, satisfying the following properties:

- *Agreement: All correct nodes decide for the same proposal.*
- *Termination: All correct nodes terminate in finite time.*
- *Validity: The decision value must be the proposal of some proposer.*

BYZANTINE AGREEMENT IN AN ASYNCHRONOUS NETWORK

- Is it possible to achieve distributed consensus in an asynchronous network in presence of byzantine nodes ?
- The Byzantine General's Problem is the abstraction of such situation.

Definition (byzantine general's problem)

A commanding general must send an order to his $n - 1$ lieutenant generals such that the following conditions are satisfied:

- *All loyal lieutenants obey the same order.*
- *If the commanding general is loyal, then every loyal lieutenant obeys the order he sends.*

IMPOSSIBILITY RESULT

- Achieving distributed consensus in an asynchronous network in presence of byzantine nodes is a very hard problem.
- Fisher, Lynch and Paterson [12] formally proved that it is impossible to reach distributed consensus in an asynchronous network with one faulty process, even for a binary variable.
- So how Satoshi Nakamoto reaches consensus in Bitcoin, a decentralized, distributed, peer-to-peer network ?

OUTLINE

DOUBLE-SPENDING PROBLEM

- In a digital cash scheme, a single digital token, being just a file that can be duplicated, can be spent twice.
- Nakamoto's intuition has been to relax the agreement property in the consensus definition to hold probabilistically and no more deterministically.
- Nakamoto solves the double spending problem combining cryptography and social incentives. For a better understanding we need to show some Bitcoin's mechanics.

TRANSACTIONS IN BITCOIN

- A bitcoin is defined as a chain of digital signatures.
- Coins cannot be combined, subdivided or transferred, but only entirely consumed as transaction inputs (TxIn) to create new output coins (TxOut).
- A TxOut can be in two states: spent or unspent.
- The UTXO is the set of current unspent transactions.
- A TxOut consists of an amount of bitcoins and a locking script, a cryptographic puzzle which determines the spending conditions.
- A TxIn consists of a pointer referencing the UTXO that it consumes and an unlocking script, the solution to solve the locking one.

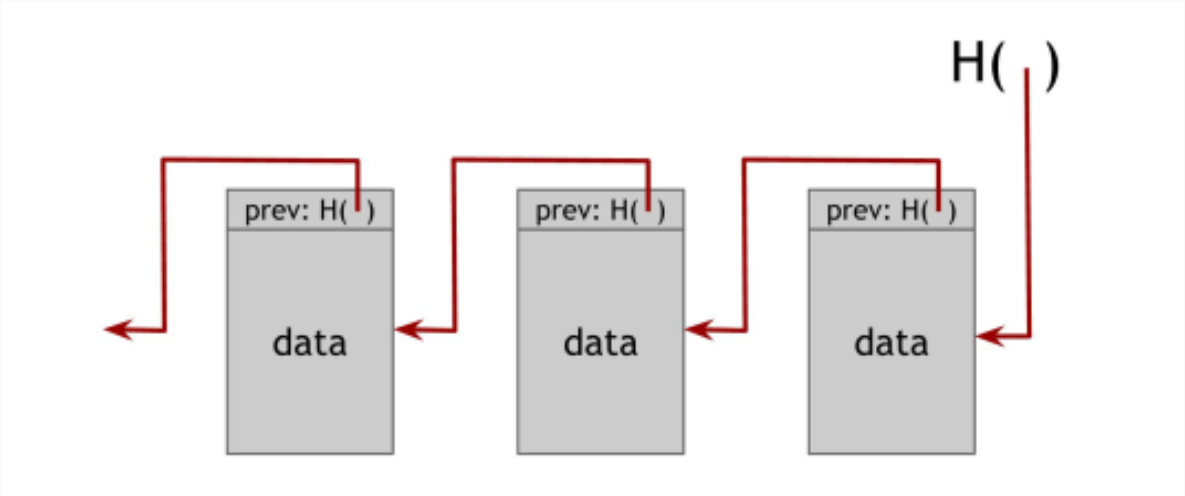

Figure 1: Blockchain as a hash pointer linked list.

- Transactions are recorded in a distributed ledger, the blockchain, formally a hash pointer linked list.
- The cryptographic link between blocks requires computing power to be created.
- A block is valid only if it includes valid transactions.

MINING & PROOF OF WORK

- Special nodes, called miners, compete to finalize a new block of transactions, providing proof-of-work, which consists of finding a special number x called nonce s.t.

$$\text{SHA256}(\text{SHA256}(\underbrace{\ldots \| \text{prev\_block\_header\_hash} \| \ldots \| x}_{\text{Candidate Block Header}})) < \frac{2^{224}}{d}.$$

- The miner who first find it is rewarded with the issuance of new bitcoins in a special coinbase transaction.
- Miners solve the double spending problem:
  - A double spending transaction invalidates a block.
  - The bitcoin reward would have removed.
  - The winning miner would have wasted his work.
  - Proof-of-work ensures blockchain immutability.

OUTLINE

NOTARIZATION

- Notarization is the official fraud-deterrend process that assures the parties of a transaction that a document is authentic and can be trusted.
- Traditionally, it is achieved by a trusted certification authority which represents a single point of failure.
- Need to decentralize the source of trust to be reliable even if the security of such central authority is violated, using the Bitcoin blockchain as a notary for timestamping.

Definition (timestamp)

A timestamp is a proof that some data d existed prior to a certain time t and in a certain state.

COMMITMENT OPERATIONS

- To create a timestamp, data d has to cause an event that could not have been generated without the existence of d, must be attested to time t and can be publicly observed.
- A good timestamp must become invalid even if a single bit of the input data is modified.
- What is published on the blockchain is a commitment to d.

Definition (commitment operation)

A function $C : X \to Y$ is a commitment operation if given $x_1 \in X$ it is not feasible to compute $x_2 \in X$ s.t. $x_1 \neq x_2, C(x_1) = C(x_2)$.

- A hash function is the right commitment operation for timestamping.

Definition (hash function)

A function that maps input data of arbitrary length into a fixed length output is called hash function. Moreover, the following properties may hold:

- *preimage resistance (one-wayness): given $h(x)$ it is not feasible to compute x;*
- *second-preimage resistance: given x it is not feasible to compute y s.t. $x \neq y$, $h(x) = h(y)$;*
- *collision resistance: it is not feasible to find x, y s.t. $x \neq y$, $h(x) = h(y)$.*

TIMESTAMPING PROCEDURE

- A generic data file can be hashed to produce a short unique identifier, a sort of digital fingerprint.
- Such a digital fingerprint can be associated to a particular Bitcoin transaction, called null data transaction.
- These transactions make use of OP_RETURN, an opcode script which allows to add up to 80 bytes of arbitrary data in a transaction (irrelevant amount).
- Such transaction commits to a specific field of the block header, called merkleroot, which is the root of a binary tree that summarize all the transactions in a block.
- Blockchain immutability provides timestamping, proving the data file existance at that moment in time in that specific status.

OUTLINE

OPENTIMESTAMPS: PROTOCOL DESCRIPTION

- However, blockchain timestamping lacks of a standardization and is not efficient, requiring a transaction per document.
- OpenTimestamps is an open-source protocol that aims to be a standard for blockchain timestamping.
- It defines a set of rules for conveniently creating provable timestamps and later independently verifying them.
- A proof made with OpenTimestamps consists in a list of commitment operations applied in sequence to the document, ending with one or more time attestations.
- It also proposes a solution to the scalability problem.

OPENTIMESTAMPS: A SCALABILITY SOLUTION

- OpenTimestamps allows to aggregate up to an infinite number of document in a single transaction.
- The trick is to compose documents in a merkle tree and to timestamp only the root of that tree.

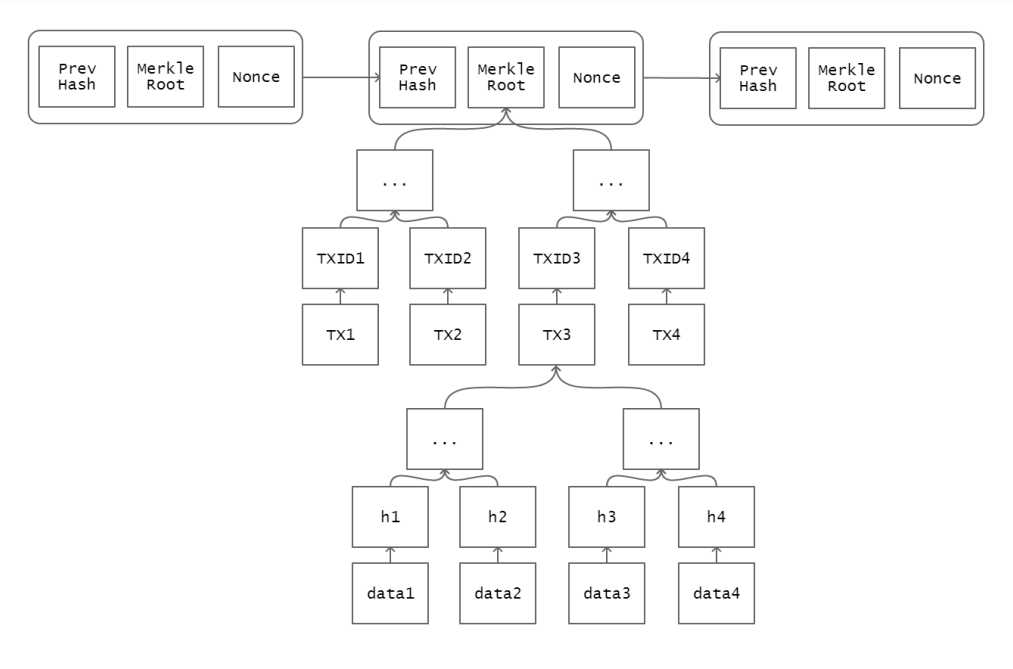

Figure 2: OTS scalability solution.

OPENTIMESTAMPS AS A SCALABILITY SOLUTION

- Moreover, aggregation servers collect hash values and periodically aggregate them in a single merkle tree.
- Aggregation servers are efficient but not convenient: to obtain a proof you must wait for the transaction to be included in a block.
- To provide proofs almost instantly, OpenTimestamps makes use of public calendar servers.
- Aggregation servers submit the merkleroot to a calendar server, which promise that every submitted digest will be timestamped with Bitcoin.
- Proofs made this way are incomplete, but they can be upgraded once the blockchain has completed the timestamp, adding the path up the the block header.

A PRACTICAL USE CASE: AIM OF THE PROJECT

- The author, in partnership with DGI (Digital Gold Institute) and ANIA (Associazione Nazionale fra le Imprese Assicuratrici) worked on a practical use case of blockchain timestamping.
- The aim of the project is to provide a fully operating timestamping service.
- It is build upon OpenTimestamps, improving and extending the original protocol with additional features.
- For example, any insurance company could make use of it to grant authenticity of its associates policies.
- Simply, it could be useful whenever a digital signature is involved.

ARCHITECTURE OF THE SOLUTION

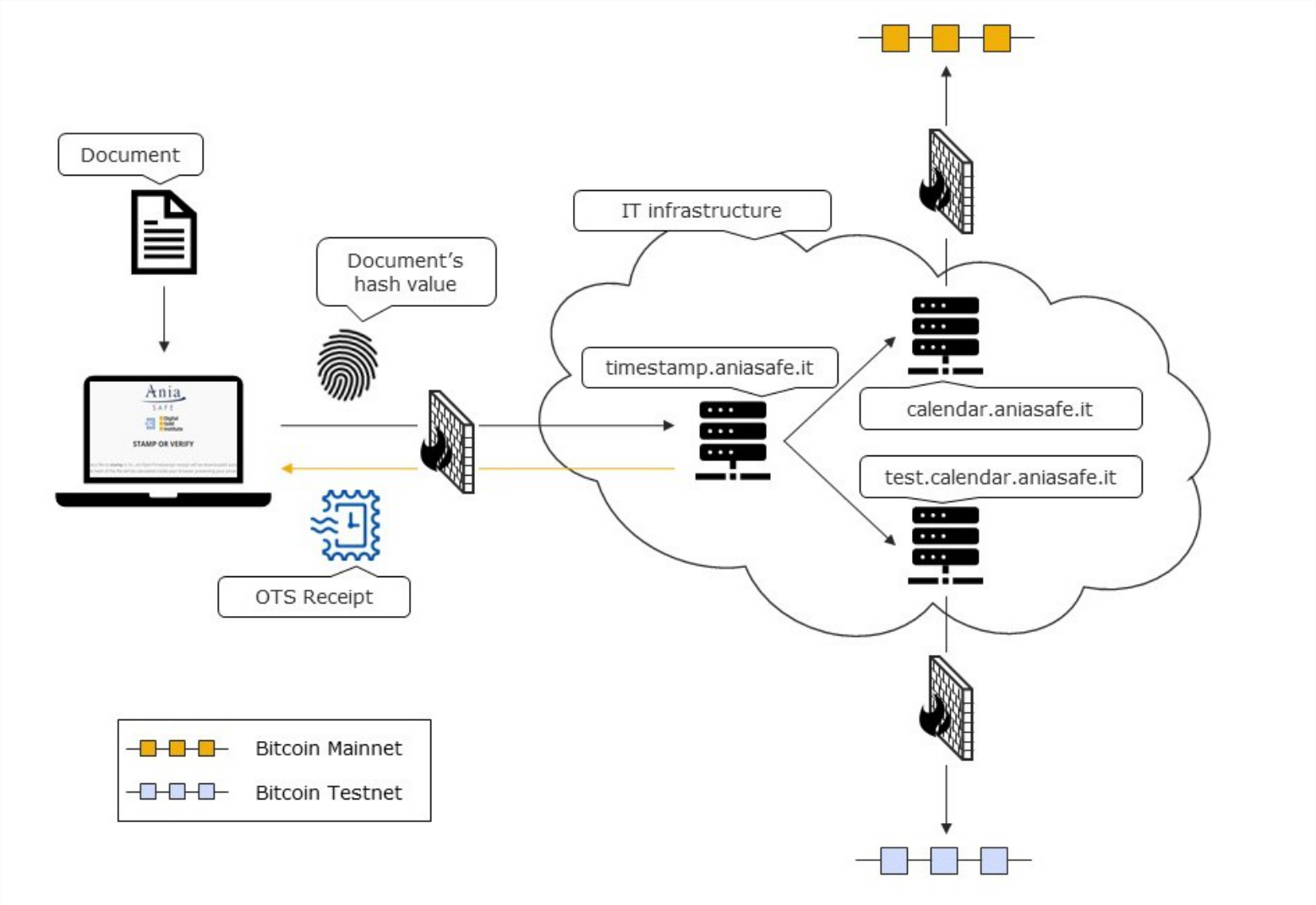

Figure 3: Architecture of the solution

WEB INTERFACE

- The web interface is hosted by the front-end server.
- A user can easily drag & drop a document to stamp, or an ots proof to verify.
- Notice that the hash value is computed inside user's browser, preserving privacy.
- Being a web interface, a user must trust a public block-explorer for verification.

CONTRIBUTIONS TO OPENTIMESTAMPS

- Cleaning of all the malfunctioning and inefficient block-explorers invoked during verification.
- Introduction of Esplora, a new block-explorer owned by Blockstream, greatly faster and more reliable.
- Creation of new classes and option parameters to correctly query Esplora's API.
- Possibility to timestamp on the Bitcoin testnet chain: useful tool for testing at zero cost, even if the chain is not reliable, having test-coins no real value.
- Introduction of multi-validation: now it is possible to verify multiple attestations on multiple chains simultaneously in a single function call.

OUTLINE

CONCLUSIONS AND FUTURE WORK

- The notarization process can be strengthen by means of a decentralized solution built upon a blockchain technology.
- The Bitcoin blockchain can be used as a notary for timestamping.
- Timestamping provides only proof-of-existence at a given date; it does not convey authorship, non-repudiation, veracity.
- OpenTimestamps provides a standardization for timestamping and it is scalable.
- Elliptic curve commitments could improve the timestamping process, allowing to push data into the payee public key or in a digital signature, avoiding fees.

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WEB INTERFACE: STAMPING

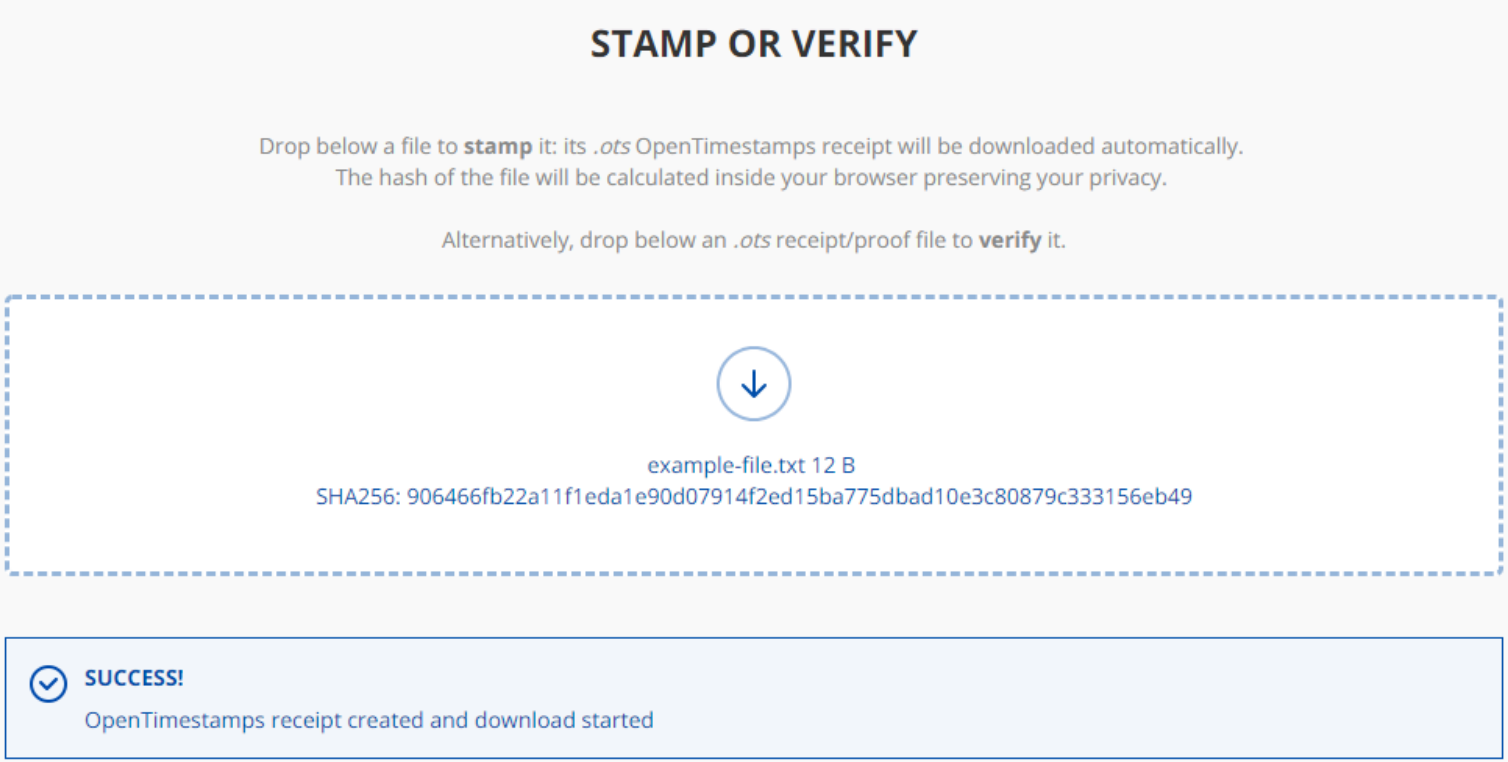

Figure 4: Stamping

WEB INTERFACE: VERIFYING

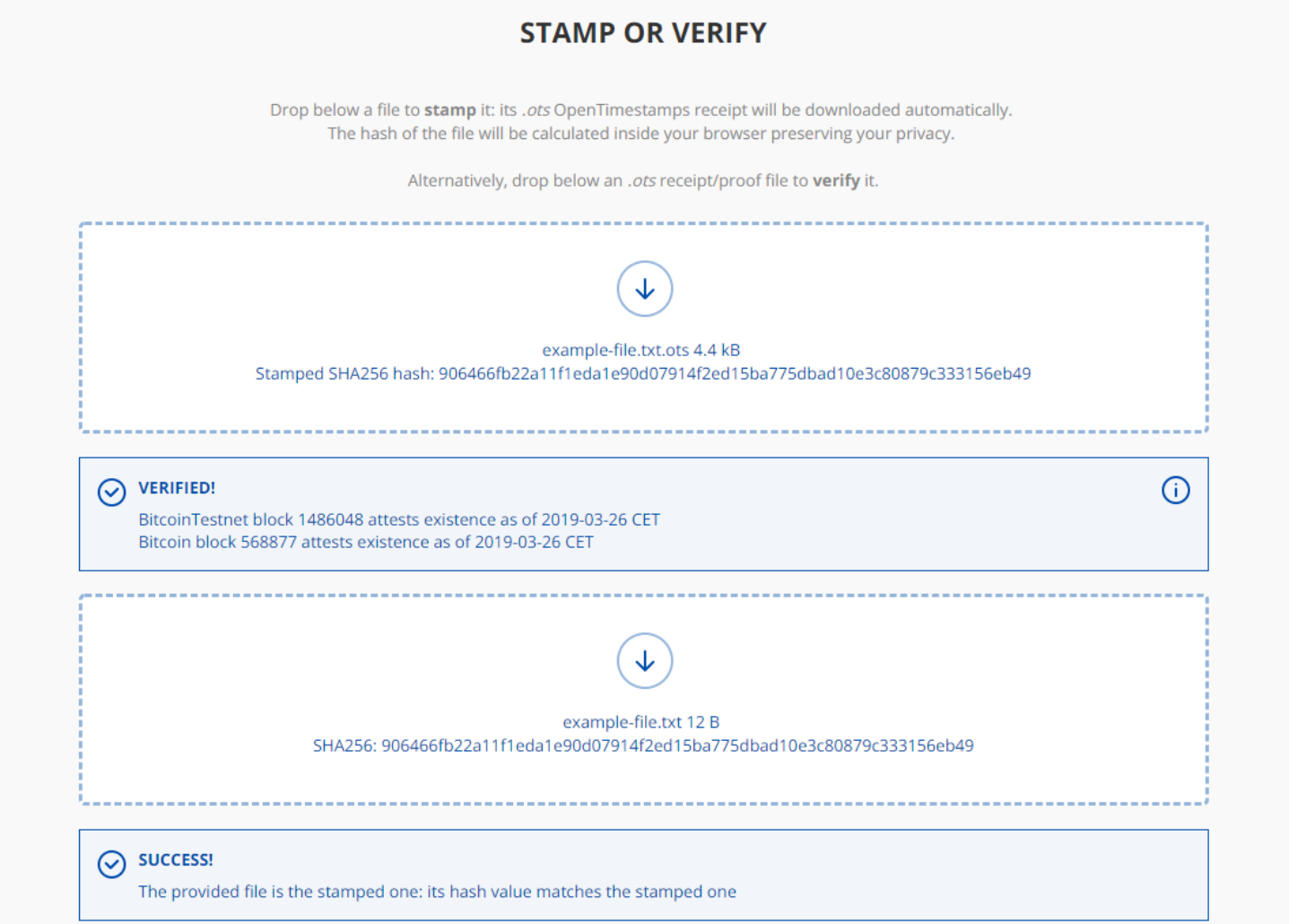

Figure 5: Multi-validation