
Bitcoin & Ethereum Cross-chain Atomic Swap

A Trustless Method of Exchanging Bitcoin For Ether Between Two Peers

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I certify that except where due acknowledgement has been given, the work presented in this thesis is that of the author alone; the work has not been submitted previously, in whole or in part, to qualify for any other academic award; and the content of the thesis is the result of work which has been carried out since the official commencement date of the approved research program.

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Neuchâtel, 26 July 2019

Abstract

Atomic swaps are practical for exchanging different cryptocurrencies in avoiding any trusted third-parties. This project shows a swap between Bitcoin and Ethereum blockchain using payment channels tools like hashlock or timelock. When the protocol is followed by the both participants, it guarantees the swap without any risk. In the opposite, there is no scenario where someone can control both coins.

Keywords : Bitcoin, Ethereum, Atomic Swap

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Chapter 1

Introduction

1.1 Motivation

Firstly, the main problem when two parties want to exchange some goods is the problem of trust. For dealing an exchange that works, we need a certain level of trust must be apply. Particularly, when the transaction depends by no one. To illustrate this, we cannot simply assure that a party A will get a good after paying some money to a party B and vice versa. A trusted third party or escrow may resolve this problem to arbitrate a transaction without no one try to swindle the other. But in compensation for this, an extra cost may be added to the transaction and there is still no guarantee that the escrow is a trusted source. Secondly, the most of crypto-based exchanges are still fully centralized even though the main goal of cryptocurrencies is to create a decentralized system of finance. When two parties would like to exchange two different coins, they must pass by a crypto-fund commerce but these platforms remain in generally exclusively of the main centralized exchanges. Anyone who uses these exchanges may potentially risks a various of additional problems like inherent risk of being hacked, or having a breach of user confidentiality, some delays etc... To figure there problems out, the necessity of an implementation of cross-chain payments or atomic swap has been made for assuring a trustless and decentralized system that exists authorizing the blockchain application to interact with another blockchain.

1.2 Purpose of the thesis

1.3 Challenge

Chapter 2

Bitcoin, A Peer-to-Peer Network

Chapter 3

Ethereum, A Decentralized Computing Platform

Launched in 2015, Ethereum is a decentralized software platform that enables to the developer to build their own Smart Contracts and Decentralized Application (DApp) and allows to avoid any downtime, fraud, control or interference from a third party. The basis of Ethereum was to made a platform system using Turing-complete programming language running in the blockchain instead of using the script language from Bitcoin. Developers can create distributed applications and publish them into the blockchain that run on the Ethereum Virtual Machine (EVM). Ethereum work on the system of using accounts and balances in a manner called state transitions and doesn't use the Unspent Transaction Output (UTXOs) from Bitcoin. Ethereum is a programmable blockchain.

3.1 Ether

The currency refereed for making operation and transactions in Ethereum is the **ether**, which is a fundamental token. The smallest unit in Ethereum is the **wei** where $1 \text{ wei} = 10^{-18} \text{ ethers}$ but it exist a multiple of units. The utility of wei is comes from the representation of the data for the users who use it for paying the gas in transaction and Smart Contract.

3.2 Gaz and Fees

Gas is a unit that measures the amount of computational effort, more precisely Gaz are used to calculate the amount of fees that need to be paid into the network in order to execute an operation. Ethereum Gas is the mechanism of the Ethereum system, we cannot avoid that. A simple transaction or even Smart Contract that creates operations in the Blockchain cost Gas. The fees allow to prevent to break the system e.g. in introducing infinite loop into the code. The amount of fee to pay is defined by $GasLimit \cdot GasPrice$. The fee has the main of rewarding the miners who mine transaction and then put them into block for securing the blockchain.

Gas Limit are the limit because there is an maximum amount of gas that we agree to spend for a transaction. This is here for avoiding e.g. if there is an error in the code and produce to overpay accidentally to much amount without our will.

Gas Price, is the amount that will increase or decrease the speed of the confirmation of the transaction by the miners in the blockchain. On spending less fees on a transaction, this won't be interesting for the miners, thus your transaction should take more time to be mined. In the opposite, higher the amount of fees, more the transaction will be mined quickly because more attractive for them.

3.3 Account

In Ethereum, it exists two type of account. The Regular Account which represents the owned account and Smart Contract account. An account is often confused with **address** but both terms have the same meaning. A regular account can be controller by an external part of the blockchain (e.g. a user). An account to function need to hold a private key for signing transactions that allows to send ether and the public key that allows to receiver ether.

An account introduce the concept of **Account state** that is defined by :

- **Nonce** : Represent simply the transaction count of an account.
- **Balance** : The ether balance owned by an account
- **Storage Root** : The storage contents of the account by default empty.
- **Code** : For contract accounts, this represent the code of the contract account stored.

3.4 Transaction

In Ethereum there are two terms to distinct for defining a transaction, **Transaction** and **Message**. A **transaction** is a piece of data, signed by a regular account. It represents either a Message or a new Autonomous Object. Transactions are stored into each block of the blockchain. That's means that a transaction can be either a message or a new contract. A **message** is a piece of data and an amount of Ether that is transferred between two accounts. A message is created by contracts interacting with each other, or by a transaction from it. The main difference is that a regular account sends a Transaction and a contract account sends message.

3.5 Ethereum Virtual Machine

EVM is the heart of Ethereum mechanism. This machine is a Turing complete system provided by Ethereum and capable to execute codes into the Ethereum blockchain with a environment runtime for compiling smart contract and then execute them altering the state of the blockchain. The code of the smart contract is compiled into Bytecode by the EVM compiler for being executed and then managed in transactions initiated by accounts in the blockchain for integrate the new state. Transactions which have been executed are chained and immutable and represent the system state that is mined and stored on the blockchain. As soon as a new transaction is executed and mined, this produce a transition of a new state.

The EVM is implemented on a stack-based architecture. To compute code on the EVM, the code must be written in low-level stack-based bytecode language which we can define as an intersection between BitcoinScript and Assembly language. The size of the stack item is 256-bits (32-byte) that is also the size of the word size of the machine that is ordered in set of bytes which information can be stored or operate with the machine. This facilitate Keccak-256 cryptographic hash scheme and also allows the use of the Elliptic Curves Cryptography (ECC) to sign scheme for validating the origin and integrity of transactions.

Every node runs the EVM in Ethereum networks and can executes all same instructions from other nodes for achieving and maintaining the consensus about the state of the system. The computations are slowly and has a cost but this supplies some advantages like greater data integrity, and censorship-resistance. It's why Ethereum is called a **World Computer**.

3.6 Smart Contract

A contract is a collection of code and data that is possessed by specific address on the Ethereum blockchain. Contract accounts can pass messages between themselves with Turing complete computation. For living on the blockchain, contract must be implemented in a specific binary format called EVM bytecode. We said smart when conditions of execution are fulfilled, they are automatically executed on the blockchain taking all the specifications, limitations coded into the contract. Smart Contracts are typically written in some high level language like Solidity and then compiled into bytecode to be uploaded on the blockchain.

3.7 Solidity

Solidity is a language that look like JavaScript which enable the development of contracts and compile them to EVM bytecode format. It is the most popular and the easiest language to learn from the Ethereum Community and developed by Ethereum foundation. Solidity use huge number of programming perceptions that are implemented in other languages. Solidity supports the high typing, variables, string manipulations, classes, functions, arithmetic inheritance, complex structure user, library and a lot of others features. Solidity was influenced by C++, Python, or JavaScript.

We use the features like **Modifier** or **Mapping** of the languages for implementing the contracts in this project. In the following chapters we show few examples of using different features that Solidity offers us but we cannot explain all unfortunately.

3.7.1 Structs

Solidity provides a way to define new types in the form of structs. A struct in solidity is just a custom type. A struct is defined with a name and associated properties inside as variables. Implementation of a struct is shown in the following listing ??:

```

1 struct Voter { // Struct
2     uint weight;
3     bool voted;
4     address delegate;
5     uint vote;
6 }

```

Listing 3.1. Example of a struct type Voter which has several variables inside.

3.7.2 Mapping

In Solidity, a mapping are represented as such hash tables which consists of having a key type and a value type pairs. The following listing ?? define how a mapping look like :

```

1 mapping(address => uint) public balances;

```

Listing 3.2. Creation of a mapping, which accepts first the key type an address, and the value type will be uint, the mapping is referenced as 'balances' for the name.

3.7.3 Modifier

Function modifiers are a special function which can't be called directly but allows to modify a behavior or automatically check a condition prior to executing the function. The modifiers is always called before the call of the function itself.

```

1 modifier minimumFund() {
2     require(msg.value > 0, "No funds sent !");
3     _;
4 }

```

Listing 3.3. Implementation of modifier that checks if the user has a minimum of Ether to send.

3.7.4 Globally variables

Solidity provides us a list of special globally variable and function that we can use. One of them is the variable `msg` and `block` we describe below :

- **block.blockhash** : hash of the given block - only works for 256 most recent blocks excluding current
- **block.number** : current block number
- **msg.sender** : sender address the message currently call
- **msg.value** : uint containing the number of wei sent with the message

3.7.5 Require

`Require` is a function of control allowing to verify a condition. If the condition is false, `require` will call the `REVERT` EVM opcode which stops the execution of the transaction. The advantage of this function is when the condition are not fulfilled, it doesn't consume all of the gas and revert the state changes. The character `_` is used in modifiers. It returns the flow of execution to the original function that is annotated.

3.7.6 Event

Events are dispatched signals that the smart contracts can execute. DApp connected to Ethereum JSON-RPC API, can listen to these events and receipt them taking data inside. The advantage of the events is they can be indexed, so that means the event history is searchable later.

Chapter 4

Atomic Swap, A Method of Exchanging Different Cryptocurrencies

Definition: Atomic Swap is the process of peer-to-peer exchange of two cryptocurrencies between two parties, without using any third-party service like crypto exchange.

In few explication, an atomic cross-chain swap is a smart contract distributed where two parties or more exchange two cryptocurrencies across different blockchains. It is called cross-chain because you are no longer dependant on the blockchain. An atomic swap protocol guarantees if both parties follow the protocol, then all swaps take place. But if one of the two parties deviates from the protocol, then no conforming party and the no coalition produce automatically the cancel of the swap. At any moment, no one can control both coins, hence no coalition has an incentive to deviate from the protocol.

4.1 Atomicity

Atom comes from Greek and means ‘a’ -not/un, ‘tom’ -cut, in other word, no divisible or cuttable. It means that an atomic transactions cannot be splittable into parts. We use the familiar expression **all or nothing** in atomic where it is the same applied concept in bitcoin. For example, Alice pays Bob in one transaction, they all know that either Bob will be paid or either bob won’t. There is only two ways, the transaction is confirmed or not but there is no way for having an half-confirmation. That’s the reason why the atomicity is fundamental in atomic swap, to protect both parties, there must be no scenario in which one part can control both coins at the same time.

An other example, no atomic transaction for illustrating is when Alice wants buy something in a web store. First, she needs to transfer the money to the site and then waits for the store send her the object back. Here there always is a chance that Alice doesn’t get her purchase.

4.2 Difference with Payment Channels

In Bitcoin, Payment Channel is class of techniques designed to allow users to make multiple Bitcoin transactions without committing all of the transactions to the Bitcoin block chain. In a typical payment channel, only two transactions are added to the block chain but an unlimited or nearly unlimited number of payments can be made between the participants.¹ It is faster, cheaper transactions between parties because each transaction doesn't need to be written to the blockchain. Therefore there is only the net result of multiple transactions.

Atomic swap is not a payment channel but uses tools of it like Hashed Timelock Contracts (HTLC), a technique that can allow payments to be securely routed across multiple payment channels that we describe below (see chapter 4.3). It is a concept from the Bitcoin community that is used in the Lightning Network.

4.3 Security by Hashed Timelock Contracts

Atomic swaps uses HTLC (Hashed Timelock Contracts), which are part of the scripting language used by most major cryptocurrencies in existence right now. Both parties involved in a cross-chain transaction submit their individual transactions to the appropriate blockchain.

HTLC is a kind of smart contracts that allows to eliminate counterparty risk using tools like hashlock and timelock. It enables time-bound transactions between the two parties. A time-bound means when a recipient at the other end of the transaction is required to acknowledge the transaction, the person needs to provide a cryptographic proof. The person also needs to provide that cryptographic proof within a time-frame. In case of failing so will automatically make the transaction null and void. In practical terms, this means that recipients of a transaction have to acknowledge payment by generating cryptographic proof within a certain timestamp. Otherwise, the transaction isn't valid. The cryptographic proof of payment that the receiver generates can then be used to trigger other actions in other payments, making HTLC a powerful technique for producing conditional payments in Bitcoin.

There are many benefits for HTLC :

1. It prevents the person who is making the payment from having to wait indefinitely to find out whether or not his or her payment goes through.
2. The person who makes the payment will not have to waste his or her money if the payment is not accepted. It will simply be returned.
3. The recipient actually helps to validate the payment on the blockchain because cryptographic proof of payment is required for the recipient to accept the payment.
4. The hashes that are created for the HTLC can be easily added to blockchains.
5. The structure of the method allows the people sending and receiving the payments do not have to trust each other or even know each other to make sure that the contract will be executed properly. In other words, each party is protected from counterparty risk.

¹Micropayment channel: Bitcoin.org Developer Guide

To work, A Hashed Timelock Contract implements several elements from existing cryptocurrency transactions. The concept of signatures, HTLC uses multiple signatures that consists of using a private key and public key to verify and validate transactions. The main elements that make HTLC a powerful method are the concept of **hashlock** and **timelock**.

4.3.1 Hashlock

A hashlock is a type of encumbrance that restricts the spending of an output until a specified piece of data is publicly revealed. Hashlocks have the useful property that once any hashlock is opened publicly, any other hashlock secured using the same key can also be opened. The hashlock is a scrambled version of a cryptographic key generated by the originator of a transaction.

4.3.2 Absolute Timelock

```
1 IF
2     <provider pubkey> CHECKSIGVERIFY
3 ELSE
4     <expiry time> CHECKLOCKTIMEVERIFY DROP
5 ENDIF
6 <client pubkey> CHECKSIG
```

Listing 4.1. Example of locking script with CheckLockTimeVerify.

4.3.3 Relative Timelock

The second one is CheckSequenceVerify (CSV). It is not dependent on time. Instead, it uses the number of blocks generated as a measure to keep track of when to finalize a transaction.

```
1 IF
2     <provider pubkey> CHECKSIGVERIFY
3 ELSE
4     <expiry time> CHECKSEQUENCEVERIFY DROP
5 ENDIF
6 <client pubkey> CHECKSIG
```

Listing 4.2. Example of locking script with CheckSequenceVerify.

Chapter 5

Protocol

We describe a protocol for an on-chain atomic swap between Bitcoin and Ethereum, but the protocol can be generalized for Ethereum and any other cryptocurrencies that fulfill the same requirements as Bitcoin (e.g. Litecoin), see ???. This protocol is heavily based on the BIP-199 (Bitcoin Improvement Proposal (BIP)) [Bowe and Hopwood, 2017] for the Bitcoin part. For Ethereum the concept is roughly the same but with less prerequisites than Bitcoin. For sending funds, each participant must generate a specific address to lock fund on each chain (cross-chain) where each other party can take control of the funds from the other chain (swap) only.

5.1 Limitations

The most important process of the protocol is the **liveness**. Liveness means that participant must be online for respecting the protocol (at least one participant is still online). In the worst scenario where someone doesn't follow the protocol, it can happen the coalition end up and loose the funds. This happen only if a party is not remained online during the swap or it has not claimed the funds in time.

In an other side, there is an other factor to take on board which is the **Fees**. Each blockchain have different fees because there are built with different internal parameters and transaction complexity. It is also due to a factor, the blockspace that depend of the demand. In this project, we use the Bitcoin Blockchain like a tool, more precisely, we use some advanced features that increase the cost of the transaction for bitcoin side. In general, the transaction is more expensive on Bitcoin than Ethereum, because Ethereum the cost transactions doesn't depend by the user.

The difficult problem with cross chain swaps is the off chain coordination required to have the two parties meet and agree on conditions. This consist to an accord between the two peers by the speed of the protocol (i.g. to considerate that a confirmation is confirmed) but the speed is influenced with the slowness and a number of confirmation required for validating a confirmation in each blockchain side. The protocol is slow but it can be extended by way of setups. The only things we can change from the setups is the ranges of fees that can consume but in any case we cannot deviate the worst scenario that consists to have an amount of fee in each chain.

5.2 Scenario

Alice and Bob want to exchange 1 Alice tokens for 10 Bob tokens. The problem is that they are not in the same blockchain, Alice token is defined in Bitcoin blockchain, whereas Bob token is only present Ethereum blockchain.

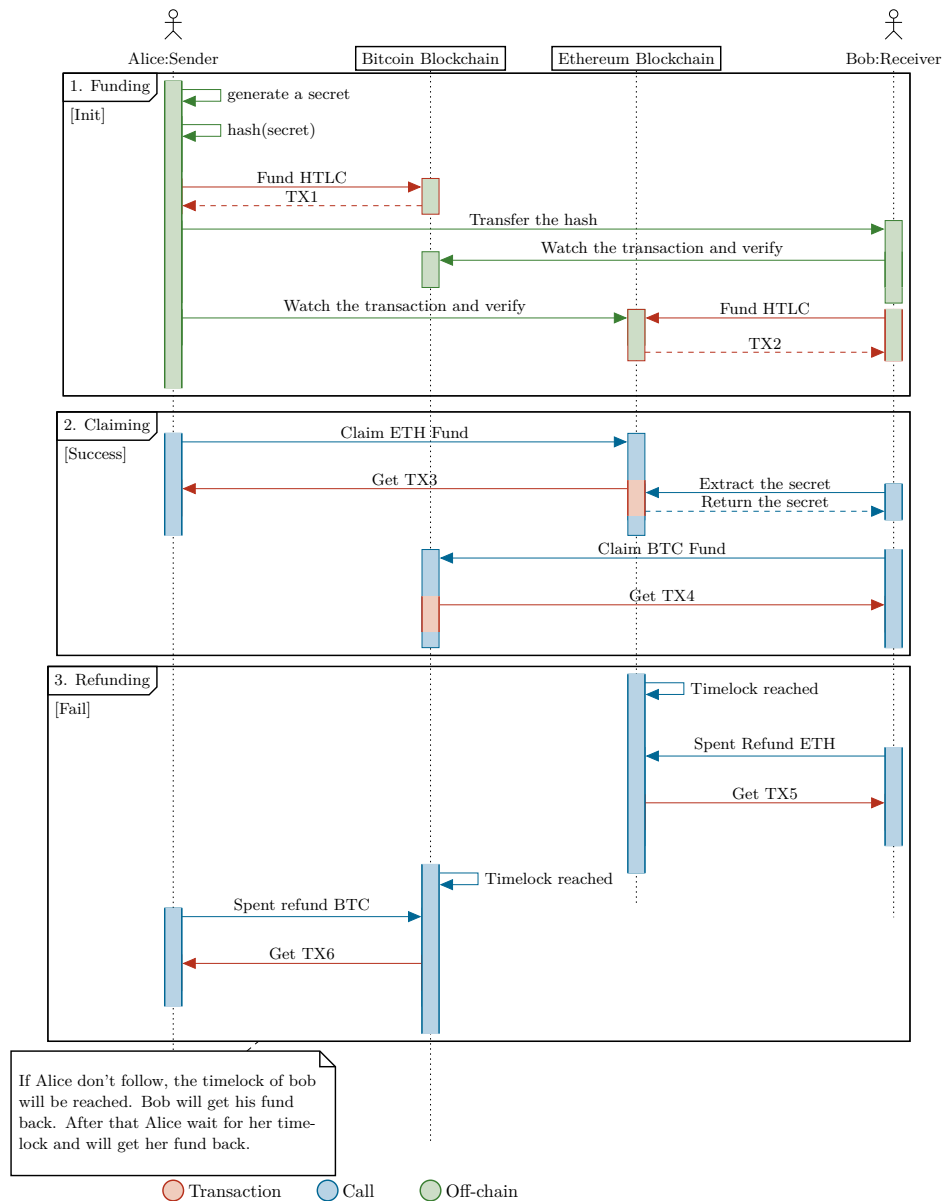


Figure 5.1. Sequence of atomic swap protocol.

Let's see the process in the figure 5.1 :

1. Alice generates a random set of bytes called value or preimage. The proof should

- have a size of 32 bytes.
2. Alice hashes the obtained proof to generate the secret.
3. Alice is the instigator of the swap, she starts by initiating the locking script, TX1 in Bitcoin chain.
4. Upon doing this, Alice broadcasts TX1 to the Bitcoin chain and transfer the secret to Bob.
5. Bob defines locking script transaction TX2 to Ethereum using the hash.
6. Only Alice can unlock the ETH in this address because she has the value which generates that particular hash. It's the claiming transaction.
7. Alice can get her ETH by signing a transaction for Bob's contract address and Bob can retrieve the BTC by signing a transaction TX3 for Alice contract address.
8. When Alice signs Bob's contract address with the value, she unlocks the address and reveals the value to Bob as well.
9. Bob, now knowing the value, signs off the transaction TX4 for Alice's address and retrieves his BTC.

To summarize the process, the scenario describes the participants and their incentives. Alice the sender owns Bitcoin (BTC) and Bob the receiver owns ether (ETH), they want to swap funds. Alice and Bob have already negotiated the price in advance and are agreed (i.e. amount of bitcoin for amount of ether to swap). They are only two possible ways of execution path for both parties :

- **The protocol succeed** - Alice get her ETH and Bob his BTC.
- **The protocol failed** - both parties keep their fund (they will lost some amounts because they need to pay some fees for each transaction).

5.2.1 Successful swap

For having a successful swap, both parties must follow the protocol. They will be four transactions in total, 2 transactions for Bitcoin blockchain and 2 transactions for Ethereum blockchain :

1. Lock the funds in Bitcoin and make it ready for the swap.
2. Lock the funds in Ethereum and make it ready for the swap.
3. Unlock the funds in Ethereum.
4. Unlock the funds in Bitcoin.

When participants unlock the funds, they take control of the output of the contract in the other chain. here is the most simple and optimal way to perform the protocol. Here, no timelock is required but both participant must care about the minimum number of transaction and for the minimal transaction, the funding transaction (locking fund). Confirmations vary between each chain, so it needs to be considered if both parties are expecting the funding transaction to be considered final and are sure to keep going the protocol.

5.2.2 Swap aborted

The swap is aborted only if one party wants not to continue the process. To get the refund of the locked funds, Alice or Bob must wait for the timelock is reached. When Alice

starts, there are no ETH but only BTC locked into a contract. If Bob doesn't follow, so Alice wait her timelock and after that she can spent refund. The length of time on each lock is important to ensure that the game can only be played fairly. Alice's time lock should be longer and Bob's lock should be much shorter. This is because Alice knows the hash lock secret and therefore has a major advantage. It is very important because if Alice's timelock had the shorter refund time, Alice could wait until that time expires, refund herself the Bitcoin and after that then enter the secret preimage into Ethereum to claim the ETH that Bob sent. Alice would have both coins and Bob would loose his ETH.

5.2.3 Worst scenario

There is possibility that the protocol can be broken again if a party doesn't follow the rules from the Bitcoin part. If the swap process succeed with Alice claiming ETH funds and Bob doesn't claim his BTC fund before the Alice's timelock, then Alice can spent her refund as soon as her timelock is reached. It will conclude that Bob would lost his funds and Alice would get both coins. In Ethereum this can't happend because when the timelock is reached, claim fund are automatically blocked and Alice cannot claim the fund, only Bob spent the refund to avoid that situation. To resolve this problem, we must implement a protocol that force Bob to be not offline or compensate Bob if Alice doesn't follow correctly the protocol.

5.3 Prerequisites

In the chapter 5.2, we describe the conditional process that must be followed to guarantee a swap with atomicity. Bitcoin has a small stack-based script language that allows for conditional execution and timelocks. Whereas Ethereum use the programming language that allows hashing and timelocks too. The challenge is then to implement the BIP-199 in Ethereum.

5.3.1 Bitcoin

The bitcoin transactions in this protocol use Segregated Witness for making broadcast. For any other cryptocurrencies with a bitcoin style UTXO model (e.g. Litecoin), these requirements must be fulfilled for having the same compatibility with this protocol (i.e. Bitcoin Cash is not compatible.)

Pre-image

Generation of a valid pre-image $\alpha \in \mathbb{Z}_{256}$ of 32 bytes size to a given $h = \mathcal{H}_{256}(\alpha)$ where \mathcal{H}_{256} is the SHA256 algorithm.

Public key hash

For a public key Q to a given $h_Q = \mathcal{H}_{160}(Q)$ where \mathcal{H}_{160} is the SHA256 follow by the RIPEMD-160 algorithm. h_Q is the version of Q that is given to other participant so that they can send it bitcoins. It's shorter than the original public key, and it may provide an extra layer of security for the bitcoins compared for giving the public key direct.

Hashlock

Hashlock is for revealing the secret to the other participant. It is a primitive that includes a value to reveal some data (pre-image) that is associated to given hash and handle the spent the HTLC.

Timelock

The timelock is to enable a execution paths that is predefined by an amount of time. This amount of time is expressed in a number of block **nLocktime** where $t = nLocktime$. We use number of block instead of the amount of time in second for avoiding a problem called **leap second**.

Multi signatures

The signatures of both participants are required for creating HTLC only accessible by them if they agree.

5.3.2 Ethereum

Ethereum doesn't use the same Model as Bitcoin (UTXO) but is based on **Account Model**. Every cryptocurrencies that with this style model can fulfilled there requirements for having the same for having the same compatibility with this protocol. In comparison to Bitcoin, Ethereum use smart contract that handles also timelock and hashlock. However, we doesn't need the **Public key hash** for the verification. We use instead, the **msg.sender** from Smart contract that allows verification.

5.3.3 Elliptic Curve

Bitcoin and Ethereum do use the same elliptic curves. They use the **secp256k1** curve from Standards for Efficient Cryptography (SEC) with the Elliptic Curve Digital Signature Algorithm (ECDSA) algorithm. The curve is described as follow :

$$\begin{aligned}
 p &: \text{a prime number; } p = 2^{256} - 2^{32} - 2^9 - 2^8 - 2^7 - 2^6 - 2^4 - 1 \\
 a &: \text{an element of } \mathbb{F}_p; a = 0 \\
 b &: \text{an element of } \mathbb{F}_p; b = 7 \\
 E &: \text{an elliptic curve equation; } y^2 = x^3 + bx + a \\
 G &: \text{a base point; } G' = \\
 & \quad (0x79BE667EF9DCBBAC55A06295CE870B07029BFCD2DCE28D959F2815B16F81798, \\
 & \quad 0x483ADA7726A3C4655DA4FBFC0E1108A8FD17B448A68554199C47D08FFB10D4B8)
 \end{aligned} \tag{5.1}$$

5.4 Hashed Timelock Contract

The overall protocol is as follow : Alice moves her bitcoin into an address where each participant controls a type of transaction using Bitcoin scripting language. Bob do the same into a Ethereum Smart contract that is then used to reveal the secret depending of

Alice who claims the ether. Bitcoin and Ethereum transactions are designed in such a way that if a participant follows the protocol he can't terminate with a loss. If the deal goes through, Alice spends the ether by revealing the secret, thus allowing Bob to spend the locked bitcoin. If the deal is aborted, Bob spends the ether after the second timelock, thus allowing Alice to spend the bitcoin after the first timelock. In both cases, the participants must add transactions fees. The full protocol is described in Table 5.1.

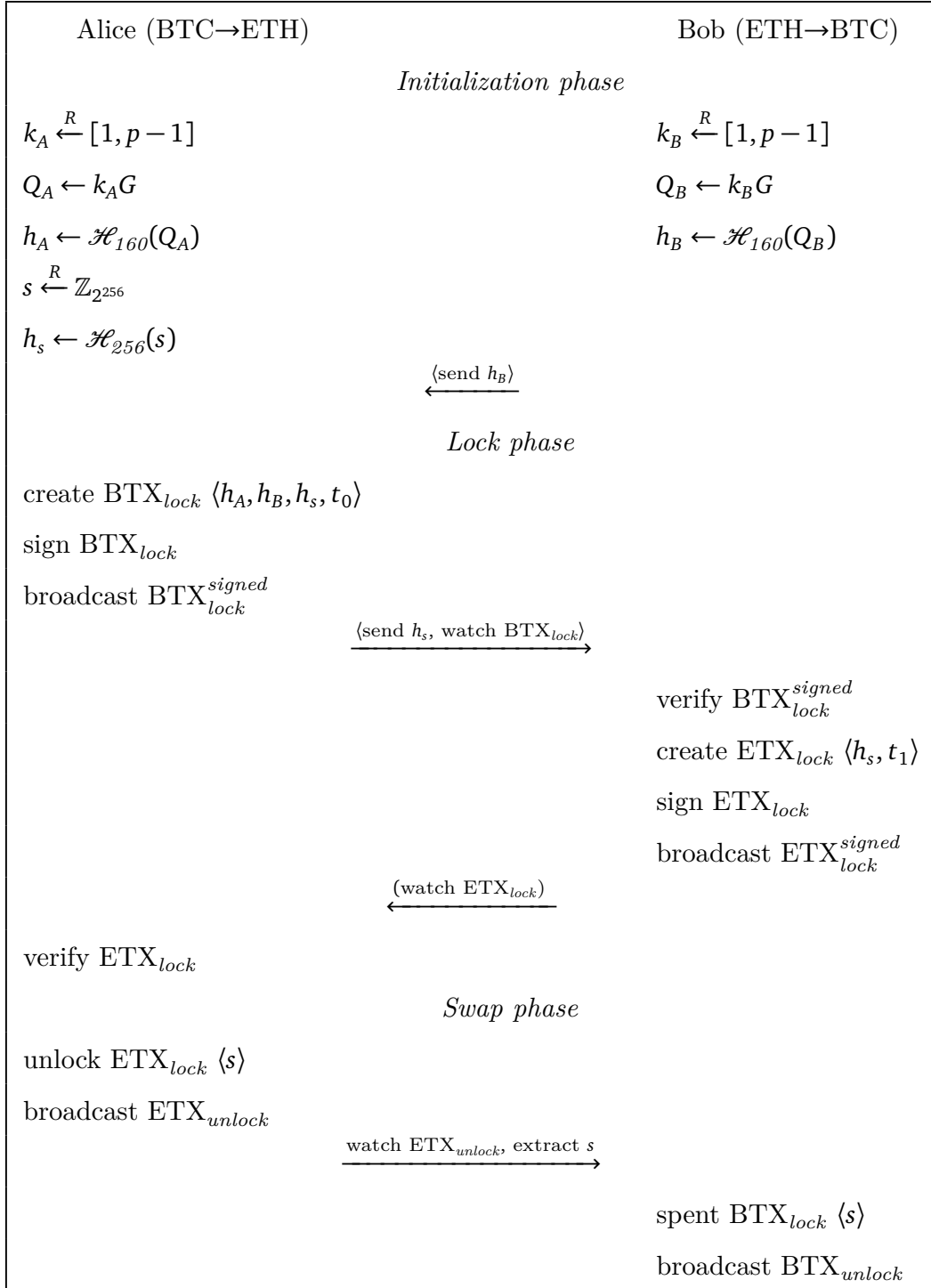


Table 5.1. Full protocol of cross-chain atomic swap between Bitcoin and Ethereum with Alice and Bob with initialization, lock, and swap phases.

5.4.1 Time parameters

$$\begin{aligned} t_0 &: \text{Alice's timelock} \\ t_1 &: \text{Bob's timelock} \end{aligned} \tag{5.2}$$

We use two timelocks t_0 and t_1 that are defined during lock swap. t_0 sets the time window during which it is safe to execute the trade. When t_0 is passed, the refund may start. t_1 sets the response time during which Alice is required to react and reveal her preimage to get her ether. After t_1 , Bob can get his ether back and allow Alice to redeem her bitcoin.

5.4.2 Bitcoin Script

Swaplock

Pay To Script Hash (P2SH) is used to lock funds and defines the two base execution paths :

1. swap execution [success].
2. refund execution [fail].

The script is defined with Bob's h_B public key hash, Alice's h_A public key hash and the preimage h_s in the Listing 5.1:

```

1  OP_IF
2      OP_SHA256 <h_s> OP_EQUALVERIFY OP_DUP
3      OP_HASH160 <h_B>
4  OP_ESLE
5      <t_0> OP_CHECKSEQUENCEVERIFY OP_DROP OP_DUP
6      OP_HASH160 <h_A>
7  OP_ENDIF
8  OP_EQUALVERIFY
9  OP_CHECKSIG

```

Listing 5.1. Swaplock script.

The Swaplock is executed when `OP_IF` reads a true value from the stack. It expects a secret value, an ECDSA signature and the Public Key Hash (PKH). It hashes the secret and checks that it matches a given hash, then it checks PKH followed by the signature against the given public key.

Claim Fund

Bob takes control of bitcoin in using the pre-image s and his public key hash h_B from Alice to redeem the **Swaplock** P2SH. To redeem the HTLC this way, Bob use the following script in the input of a transaction::

```
1    <sigB> <hB> <s> OP_TRUE
```

Listing 5.2. Bob's script signature

Spend Refund

With this contract Alice can spend this output with her public key hash h_A after the timelock t_0 with the script signature :

```
1    <sigA> <hA> OP_FALSE
```

Listing 5.3. Alice's script signature

5.4.3 Ethereum Smart Contract

Ethereum doesn't use script language Bitcoin but the programming language for the smart contract. The smart contract allows to create functions from the uml diagram in figure 5.2 :

Function lock()

Function that will create a contract with all the prerequisites and lock it with the address of the sender Bob and the address of the receiver Alice.

Function unlock()

Function when it is called, check if the pre-image s is correct and then transfer the fund to Alice.

Function refund()

Function when it is called, check if the timelock t_1 is reached and then transfer the fund to Bob.

5.4.4 Transactions

All the transaction are described in the figure 5.3.

Funding transaction

The funding transaction is the transaction sending fund to the contract address. BTX_{lock} , bitcoin transaction with 1 or more inputs from Alice and the output (vout) to the **Swaplock P2SH**. ETX_{lock} , ethereum transaction from Bob that sends funds to the Smart Contract address.

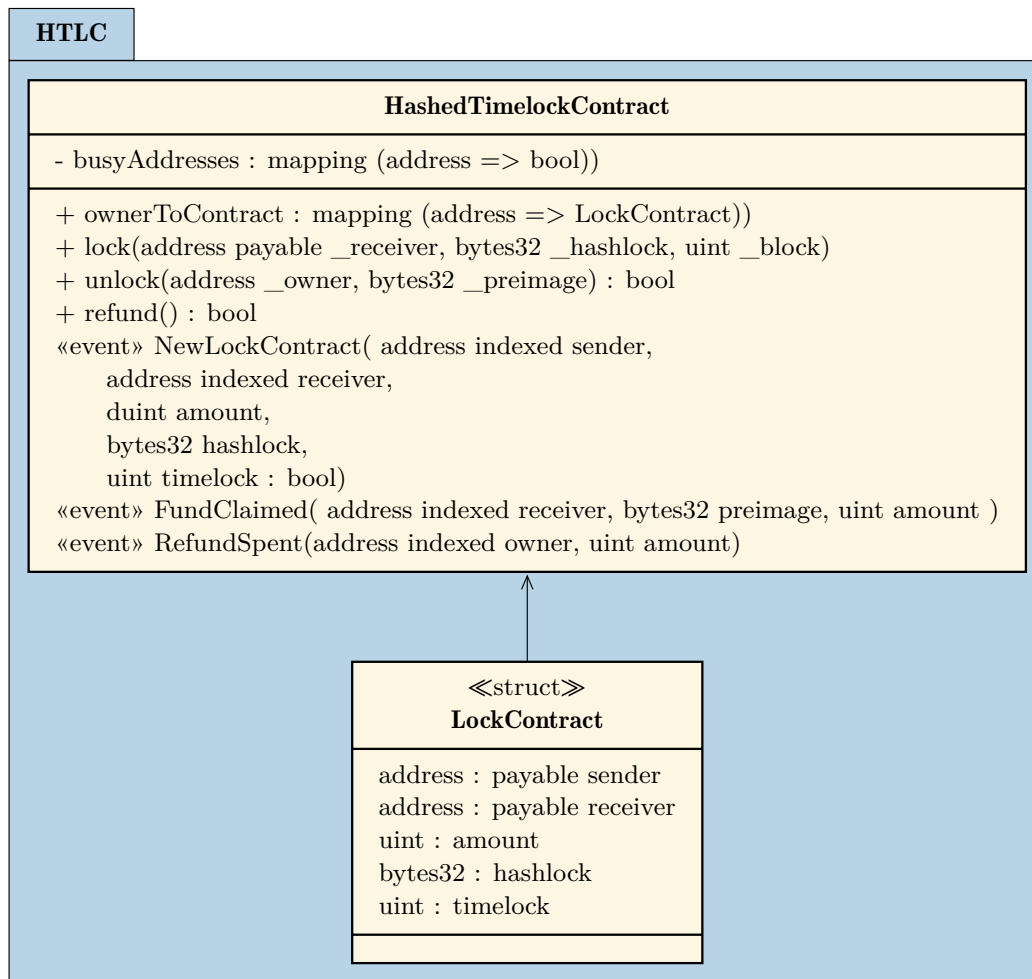


Figure 5.2. UML class diagram of the Smart Contract reference Implementation in Ethereum.

Claim Transaction

The claim transaction is a transaction that allows the sender to spend the funds. BTX_{unlock} , bitcoin transaction with 1 inputs consuming **Swaplock P2SH** (BTX_{lock}) and 1 output vout to Bob. ETX_{unlock} , ethereum transaction from the **Smart Contract** that call the function **unlock** to send the funds to Alice.

Refund transaction

The refund transaction is a transaction that allows the sender to abort the swap and get his funds back. BTX_{refund} , bitcoin transaction with 1 inputs consuming **Swaplock P2SH** (BTX_{lock}) and 1 output vout to Alice. ETX_{refund} , ethereum transaction from **Smart Contract** that call the function **refund** to send back the funds to Bob.

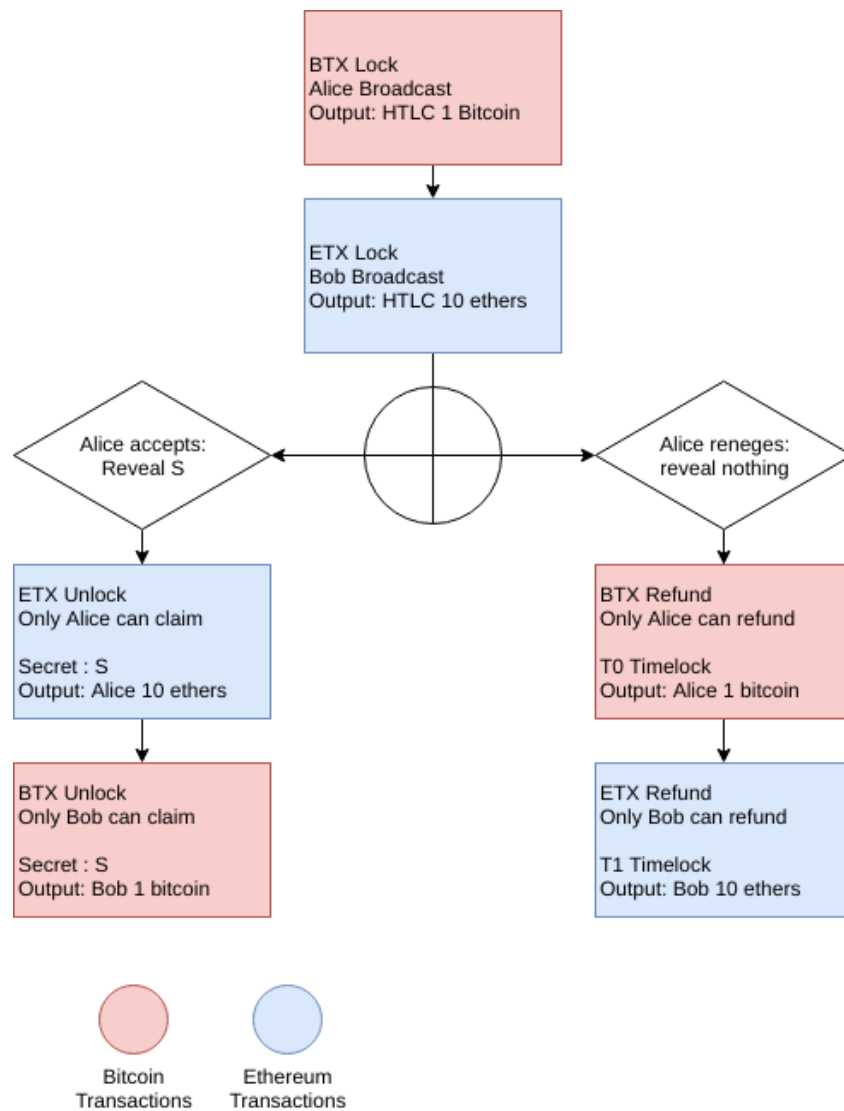


Figure 5.3. List of transactions.

Chapter 6

Implementation in Bitcoin with bitcoinjs-lib

For this project, we describe a very simple method of constructing and executing smart contracts that sacrifice some privacy and potentially some security. The implementation is spread into five main components (i) a generation of a wallet, (ii) how estimate the fees in Bitcoin, (iii) implementation of the funding transaction, (iv) implementation of the claiming transaction, and (v) implementation of the refunding transaction. Note that the current implementation is not ready for the production. This implementation is a more a educational work than an implementation for production and needs to be reviewed and tested more deeply before being used in production.

This chapter refers to the implementation available on GitLab at <https://gitlab.com/Skogarmadr/atomic-swap/tree/master> of the writing of the this report. Note that the sources may change or evolve from the last version of the code. So, the last version is updated in the GitLab.

6.1 Configuration

The project employs NodeJS with modern Javascript, for the simplicity of use and the installation of dependance modules. The library used is `bitcoinjs-lib` to manage all parts of Bitcoin. The incentive of this library are, (i) compatible with Typescript, (ii) still active, (iii) has a large number of contributors and releases and (iv) has a folder full of clear examples.

There is `config.json` file that contents all the data needed for the environnement works (i.e. Alice and Bob entropy for getting back the key pair). It is important to note that in production must saved only in client side because it is private data. Note also that the project work with the `Tesnet Network` because he is still in development and not testing for the production.

```

1 {
2   "alice": {
3     "entropy": "d399c2cbabdc9fa8790ec5111bb05da6",
4     "phrase": "squeeze sock real fish size stage tomorrow suffer
               baby talk blast erupt",
5     "seed": "4973ee8e81e0047a633f3b0d3cec61ec3b028846ffb648f509d5
              5be97e72a2e502e35148b463770cea5394bb7fe53a72344f7b5ffe08f
              3b208c27adb33f95d92",
6     "prvWIF": "cPmUdWJYPESULvX3s2tFBfwJ5FWiWHm2wcx8pmiPiK6a2
              yKsrrb6",
7     "xprv": "tprv8ZgxMBicQKsPd4RZif2NZzSMcFYdtEbCL8nSovoBYzTobGy9
              Pyjx6kK1BhZjYGRyvoMgyshBSNBrAkaaax6fGF7Yaoq2i74ZEdjR2
              NfVKcQ",
8     "xpub": "tpubD6NzVbkrYhZ4WXTMcJgxyQ6UBH4a3Zn6uSPE6SqUyGGCRmDv
              2NZYHEvsMqqNbbzKJYh2Lacgh37J2EMbDrmxtBSZfP5hbQBRMmDfshtPH
              3G"
9   },
10  "use_testnet": true,
11  "APINETWORK" : "BTCTEST/"
12 }

```

Listing 6.1. Example of a config file for Bitcoin.

6.2 Generation of a HD wallet

In this project we use always the same set of addresses, but in production the practice says that the user shouldn't reuse the same addresses. For that, we need a wallet. We decide to create our own wallet to see how a wallet is built from the beginning to the end. In order to do anything with Bitcoin, you need a private and a public pair. The public key can be used by other people to send you Bitcoin, and the private key can be used by you to send Bitcoin to someone else by verifying who created the transaction.

We generate our own mnemonic and with this we create two different BIP32 Hierarchical Deterministic (HD) wallets for Alice and Bob, each containing one distinct ECDSA key pairs. From each public key is derived one set of Bitcoin address for each type of PKH output. The code for generating a HD wallet is in Listing ??

```
1
2  const bip32 = require('bip32');
3  const bip39 = require('bip39');
4  const crypto = require('crypto');
5
6  // 128 bit entropy => 12 words mnemonics
7  // Generate random entropy
8  const alice_randomBytes = crypto.randomBytes(16);
9  const bob_randomBytes = crypto.randomBytes(16);
10
11  const alice_entropy = alice_randomBytes.toString('hex');
12  const bob_entropy = bob_randomBytes.toString('hex');
13
14  const funding_path = "m/44'/0'/0'/0/0";
15
16  // Get mnemonic from entropy
17  var mnemonic = bip39.entropyToMnemonic(alice_entropy);
18
19  // Get seed from mnemonic
20  var seed = bip39.mnemonicToSeedSync(mnemonic);
21
22  // Get BIP32 master from seed
23  var master = bip32.fromSeed(seed, NETWORK);
24
25  // Get child node
26  var child = master.derivePath(funding_path);
27
28  // Get child wif private key
29  var wif = child.toWIF();
30
31  // Get child extended private keys
32  var childXprv = child.toBase58();
33
34  // Get child EC public key
35  var ECPubKey = child.publicKey.toString('hex');
```

Listing 6.2. Generation of a HD wallet.

```

1  [
2  {
3      "username": "alice",
4      "wallet": [{
5          "wif": "cPg4ssEMrxSELzpD6hK52y1tfPcYfJvU1R153HhP2yWoyUNihitK",
6          "pubKey": "0307560f56d2652c309b732394fa1c460fae7231f12adb271532
9241028cca888a",
7          "pubKeyHash": "ea2da066b9fdadea872af0d4ac138b8c1d4181ae",
8          "p2pkh": "n2sB58biJzTCpbtzPgDvCPCSYbt9oRuCs",
9          "p2sh-p2wpkh": "2MwfFe3fmjoe7AMEMTxVZChMvKSJC9ocoB",
10         "p2wpkh": "tb1qagk6qe4elkk74pe27r22cyut3sw5rqdwyq5dk6"
11     }]
12 },
13 {
14     "username": "bob",
15     "wallet": [{
16         "wif": "cUpa4EZsjN4YL25ZfgqT9LR3jRzwPrD2Hc7E8HnPizX2A83PhMno",
17         "pubKey": "039d04be8039c20e3799af14a61c5cdc86d2103c4d45b80a7ac8
f25b4834722475",
18         "pubKeyHash": "a007223750ccd2cead48848a731f062839b1cc7a",
19         "p2pkh": "mv76xQGhSj2CChqkAg9tcCuMNVdDqCRuhA",
20         "p2sh-p2wpkh": "2N7PRqTkPDgtj2XQL3tXMZVQtHwLTs1KfnP",
21         "p2wpkh": "tb1q5qrjyd6senfvat2gsj98x8cx9qumrnR6qdska7"
22     }]
23 }
24 ]

```

Listing 6.3. Example of a wallet.

In the Listing 6.3, Wallet Import Format (WIF) is the version of the compressed private key. With that, we can get our Elliptic Curves (EC) key pair. With the key pair, we can derivate all data that we need (e.g. the address of each person).

6.3 Get free Testnet bitcoins

For making new transactions, we need bitcoin. Testnet Network is useful tool that offers Testnet Bitcoin, a valueless coin for testing our application without spend any money. For that, we need to get theses free Testnet Bitcoins. We use `faucet` to get theses bitcoin Testnet, they can be hard to found sometimes. The one we use is <https://tbtc.bitaps.com/> for the two reasons: (i) it give us 0.01 Bitcoin every 5 minutes and (ii) it is compatible with the Segregated Witness (SegWit) addresses.

6.4 Get data from the Testnet blockchain

To read data from a public blockchain, we use a block explorer that is a third-party REST API instead of running our own node in local and explore it ourself. Here, for this

project we use (<https://chain.so/api> because they have a solid API, a excellent documentation site, and you don't need an API key. This allows us to get e.g. the Unspent Transaction Output (UTXOs) for having got the balance of an address.d

```

1  async function getUnspentTx(address: string) {
2      try {
3          return $.get('https://chain.so/api/v2/get_tx_unspent/' +
                        APINETWORK + address);
4      } catch (error) {
5      }
6  }

```

Listing 6.4. Get Unspent Transactions Output from API.

6.5 Estimate fees

For building a valid transaction, there is an important part to not forget in Bitcoin transaction : the fee. The fee is important because if you set it too low then the transaction won't be attractive to miners, and might take a long time to appear in the blockchain or it might even never get accepted. This is not such a problem on the Network Testnet because there is less traffic, but that can be a big issue for the Bitcoin main network. We set the fee with a REST API that supplies a list of fee recommended per byte of transaction data. We use always the fastest fee rates because we don't need to be precious with the satoshis of Testnet Bitcoin. We need only test it and we don't want to wait one day for our transactions must be accepted. In production, the fee rate will depend on the need of the user, if he wants his transactions must be confirmed quickly or slowly.

```

1  const feeRate = await getFeeRateByTarget(0.5);
2  const estimatedTxSize = inputCount * 104 + outputCount * 32;
3  const estimatedTxSizeReceiver = 104 + 32;
4  const estimatedFeeAmount = Math.floor(feeRate * estimatedTxSize);
5  const estimatedFeeAmountReceiver = Math.floor(feeRate *
          estimatedTxSizeReceiver);

```

Listing 6.5. Get the estimation of fee amount.

To calculate the fee, we base us on the SegWit size of a transaction. We compute the number of `inputs` minimum equal to 1 and his `outputs` maximum equal to 2, more precisely if the sender has a rest. For the receiver, the size of the transaction is simpler, the HTLC has only 1 input and 1 output.

6.6 Funding transaction

For creating a funding transaction we base us on the Bitcoin Script from the protocol 5.4.2 in the chapter 5. First we need to construct a `csvCheckSigOutput` for the building of

our P2SH Script. Here, we use SegWit transaction, thus we will create instead a P2WSH. In a P2WSH context, a redeem script is called a witness script.

```

1  function csvCheckSigOutput(senderPubkeyHash: bitcoin.StackElement,
    receiverPubkeyHash: bitcoin.StackElement, hash: bitcoin.
    StackElement, sequence: number) {
2  return bitcoin.script.compile([
3      bitcoin.opcodes.OP_IF,
4      bitcoin.opcodes.OP_SHA256,
5      hash,
6      bitcoin.opcodes.OP_EQUALVERIFY,
7      bitcoin.opcodes.OP_DUP,
8      bitcoin.opcodes.OP_HASH160,
9      receiverPubkeyHash,
10     bitcoin.opcodes.OP_ELSE,
11     bitcoin.script.number.encode(sequence),
12     bitcoin.opcodes.OP_CHECKSEQUENCEVERIFY,
13     bitcoin.opcodes.OP_DROP,
14     bitcoin.opcodes.OP_DUP,
15     bitcoin.opcodes.OP_HASH160,
16     senderPubkeyHash,
17     bitcoin.opcodes.OP_ENDIF,
18     bitcoin.opcodes.OP_EQUALVERIFY,
19     bitcoin.opcodes.OP_CHECKSIG,
20     ]);
21 }

```

Listing 6.6. csvCheckSigOutput function that returns the redeemScript.

We need to initiate and create the witnessScript for the P2WSH address that will be the HTLC address with the parameters required.

```

1  const senderKeyPair = bitcoin.ECPair.fromWIF(senderWif, NETWORK);
2  const senderP2wpkh = bitcoin.payments.p2wpkh({ pubkey: senderKeyPair.
    publicKey, network: NETWORK });
3  const senderAddress = senderP2wpkh.address as string;
4  const sequence = bip68.encode({ blocks: nbBlock });ddd
5  const witnessScript = csvCheckSigOutput(senderKeyPair.publicKey,
    pubKeyReceiver, revHash, sequence);
6  const p2wsh = bitcoin.payments.p2wsh({ redeem: { output:
    witnessScript }, network: NETWORK });
7  const p2wshAddress = p2wsh.address as string;

```

Listing 6.7. Initialization of the P2WSH address.

Now we must start building the transaction that will send bitcoins into the P2WSH address. We must add the unspent output as input from the sender address. Then we add outputs sending the desired amount to the receiver address, and the change back to our own address. We calculate how much change there is by subtracting the amount we're

sending and the fee that we have estimated from the unspent amount. Then we need to sign that input using the key pair of the sender.

```

1  const txb = new bitcoin.TransactionBuilder(NETWORK);
2
3  let totalBalance = 0;
4  let inputCount = 0;
5  const values = [utxos.length];
6
7
8  for (const utxo in utxos) {
9      if (utxo) {
10         totalBalance += Math.floor(parseFloat(utxos[utxo].value) * 1e8);
11         values[inputCount] = Math.floor(parseFloat(utxos[utxo].value) * 1
12             e8);
13         txb.addInput(utxos[utxo].txid, utxos[utxo].output_no, undefined,
14             senderP2wphk.output);
15         console.log("adding input: " + utxos[utxo].txid + " to funding
16             transaction");
17         inputCount++;
18     }
19 }
20
21 const estimatedTxSize = inputCount * 104 + 2 * 32;
22 const feeRate = await getFeeRateByTarget(0.5);
23
24 const estimatedFeeAmount = Math.floor(100 * estimatedTxSize);
25 const sendAmount = amountSatoshis + estimatedFeeAmount;
26
27 if (totalBalance - sendAmount > 0) {
28     if (totalBalance - sendAmount !== 0) {
29         txb.addOutput(senderAddress, (totalBalance - sendAmount));
30     }
31
32     txb.addOutput(p2wshAddress, sendAmount);
33
34     for (let i = 0; i < inputCount; i++) {
35         txb.sign(i, senderKeyPair, undefined, undefined, values[i]);
36     }
37
38     const fundingTransaction = txb.buildIncomplete();
39     console.log("");
40     console.log("==== Funding Transaction to " + p2wshAddress + " )
41         =====");
42     console.log("Transaction ID: " + fundingTransaction.getId());
43     console.log("Transaction (needed for broadcasting TX): " +
44         fundingTransaction.toHex());
45
46     await broadcastTx(fundingTransaction.toHex());
47 }

```

Listing 6.8. Creation of the funding transaction.

6.7 Claiming transaction

Once funds are sent to the P2SH addresses, we can spend them using the unlocking input scripts. We have already generated the witness script so we just need to get it and to create a transaction with it and sign it. First, we must prepare a transaction with the input and output. We generate the hash that will be used to produce the signatures. Then we will add the Witness Stack. For running the claiming branch of the script we must end the unlocking script by the boolean value `TRUE`.

```
1  const signatureHash = txRaw.hashForWitnessV0(0, p2wsh.redeem!.output
    !, totalBalance, hashType);
2
3  const witnessStack = bitcoin.payments.p2wsh({
4    redeem: {
5      input: bitcoin.script.compile([
6        bitcoin.script.signature.encode(receiverKeyPair.sign(
          signatureHash), hashType),
7        receiverKeyPair.publicKey,
8        Buffer.from(preimage, 'hex'),
9        bitcoin.opcodes.OP_TRUE
10     ]),
11    output: witnessScript
12  },
13  }).witness;
```

Listing 6.9. Preparation of the transaction to claim the funds.

6.8 Refunding transaction

For having a valid refunding transaction, the timelock must be reached. To start, initialize the unlocking script with the witness script from the swaplock. Then we must prepare a transaction with the input and output and the timelock used (`nSequence`).

```

1  const signatureHash = txRaw.hashForWitnessV0(0, p2wsh.redeem.output,
      totalBalance, hashType);
2
3  const witnessStack = bitcoin.payments.p2wsh({
4    redeem: {
5      input: bitcoin.script.compile([
6        bitcoin.script.signature.encode(senderKeyPair.sign(signatureHash)
7          , hashType),
8        senderKeyPair.publicKey,
9        bitcoin.opcodes.OP_FALSE
10       ]),
11      output: witnessScript
12    },
13  }).witness;
14  txRaw.setWitness(0, witnessStack);

```

Listing 6.10. Preparation of the transaction to spend refund.

6.9 Broadcast a transaction into the network

Once a transaction is build, we can get her in Hexadecimal form (only way to push a transaction). But this transaction for the moment is only known by us, we need to share it into the network for the miners confirm it and include it into a block. With the block explorer chain.so, its REST API offer us a POST request to push a transaction in the Testnet. See listing ??.

```

1  async function broadcastTx(txHex: string) {
2    try {
3      $.post('https://chain.so/api/v2/send_tx/' + APINETWORK, "
4        tx_hex=" + txHex).done(() => {
5          swal.fire("Transaction bitcoin broadcasted")
6        });
7    } catch (error) {
8      console.log(error);
9    }
10 }

```

Listing 6.11. Function to broadcast a raw transaction.

Chapter 7

Implementation in Ethereum with Solidity

sahsasahsahghjsahashash

Chapter 8

Observation

Test Web3 for testing.
Test [Buterin, 2013]. # Conclusion
Conclusion

List Of Abbreviations

BIP Bitcoin Improvement Proposal. 15

DApp Decentralized Application. 5, 9

EC Elliptic Curves. 30

ECC Elliptic Curves Cryptography. 7

ECDSA Elliptic Curve Digital Signature Algorithm. 19, 22, 28

EVM Ethereum Virtual Machine. 5, 6

HD Hierarchical Deterministic. 28

HTLC Hashed Timelock Contracts. 12

P2SH Pay To Script Hash. 22

PKH Public Key Hash. 22, 28

SegWit Segregated Witness. 30

UML Unified Modeling Language. 24, *Glossary*: Unified Modeling Language

WIF Wallet Import Format. 30

Glossary

Segregated Witness Segregated Witness is an update to the Bitcoin software, designed to fix a range of serious issues such as solving transaction malleability, a well-known weak spot in Bitcoin software and improving scalability[?]. 18

Unspent Transaction Output (UTXOs) UTXO is an unspent transaction output that can be spent as an input in a new transaction.. 5, 31

Web3 Web3 often refers to **web3js**, the Javascript implementation of the Ethereum JSON-RPC. It may also refer to other implementation in different languages. Overall it is the technology aiming to build the next and more decentralised version of the web 2.0 we know today. 39

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