

Multi-client Partially Non-Interactive and Instantaneous One-way Payment Channel for Ethereum

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Abstract. Ethereum is a distributed computing platform and operating system featuring smart contract functionality. Transactions are faster than other blockchain but not instant and each of them cost some “gas”. This gas is used to quantify the amount of fee to pay for computation.

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1 Introduction

2 Multi-clients payment channels

Partially non-interactive multi-clients payment channels are composed of clients $c \in \mathcal{C}$ and one provider \mathcal{P} . \mathcal{C} is the set of all clients registered in the multi-clients payment channel. Clients can send money to the provider through the channel $c \rightarrow \mathcal{P}$ but cannot receive through the channel $\mathcal{P} \nrightarrow c$.

A payment channel is by definition a structure composed of two layers of states. The first layer of states is registered to the blockchain, i.e. “on-chain” or contract states $\mu \in M$, and the second layer of states is kept “off-chain” between the participants, i.e. channel states $\sigma \in \Sigma$.

It is possible to transition from a state σ to another state σ' . We denote state transition with \rightarrow , i.e. $\sigma \rightarrow \sigma'$. Modifiers $\omega \in \Omega$ are used to create transition on channel states $\sigma \in \Sigma$. A transition in Σ depends on modifiers and contract states. We denote a transition from $\sigma, \sigma' \in \Sigma$ that depends on $\mu \in M$ and $\omega \in \Omega$ as

$$\sigma \xrightarrow{\mu+\omega} \sigma'$$

Contract state transitions are triggered by external events $e \in \mathcal{E}$ or messages $m \in \mathcal{M}$. Transitions between two states $\mu, \mu' \in M$ are denoted $\mu \rightarrow \mu'$. If the transition is due to an external event e we write $\mu \xrightarrow{e} \mu'$. If the transition is due to a message m we write $\mu \xrightarrow{m} \mu'$. Generic transitions are noted as $\mu \rightarrow \mu'$.

A message m can be “applied” to a state μ , we denote this operation with $m(\mu)$, i.e. $\mu \xrightarrow{m} \mu'$. Messages are created based on a channel states. Each channel

state $\sigma \in \Sigma$ can derive its corresponding message $m \in \mathcal{M}$

$$\forall \sigma \in \Sigma, \exists m \mid m \in \mathcal{M}$$

In reality it is not necessary to derive all messages. External events (top ups) affect the channel state but no messages are created because the previous generated message is still valid and usable to trigger a valid state transition in M .

2.1 Contract state variables

We define variables to access the contract state $\mu \in M$ for a client $c \in \mathcal{C}$.

Current on-chain index, $I(c)$ For each client the current index i must be retrievable, $\forall c \in \mathcal{C}, \exists I(c) \in \mu \geq 0$. The index for a client must start from 0.

Current on-chain balance, $B_\mu(c)$ For each client the current balance amount must be retrievable, $\forall c \in \mathcal{C}, \exists B_\mu(c) \in \mu \geq 0$.

2.2 Contract states

Each client $c \in \mathcal{C}$ in the contract is defined by an on-chain state $\mu \in M$. States $\mu \in M$ are a tuple

$$(I(c), B_\mu(c))$$

2.3 Channel state variables

We define variables to represent: (i) the lifetime of a single channel in the multi-clients channel architecture, (ii) the total amount deposited for a client over the lifetime, (iii) the total amount own by the provider over the lifetime, and (iv) the minimal and full available amount for the client.

Channel lifetime, $L(c \rightarrow \mathcal{P})$ It exists one lifetime and only one per element in $\mathcal{C} \times \mathcal{P}$ and begins when the first deposit is made, i.e. one lifetime per client $c \in \mathcal{C}$.

Total deposit, $D(c)$ Total deposit of a client c represents the total amount received from the beginning of the lifetime. Each top up increases the total deposit.

Total sent, $\sum c \rightarrow \mathcal{P}$ Total amount sent to the provider by a client c represents the sum of all transaction since the beginning of the lifetime. Each transaction increases the total sent.

Minimal available amount, $A_m(c)$ Minimal amount available for a client c is computed with the latest channel state σ . Without querying the contract state μ it is impossible to know if a bigger amount is now available. The minimal available amount is computed with

$$A_m(c) = D(c) - \sum c \rightarrow \mathcal{P}$$

Client available amount, $A(c)$ The full amount available into a single channel for a client $c \in \mathcal{C}$ is computed with

$$A(c) = D(c) - \sum c \rightarrow \mathcal{P} + (B_\mu(c) - B_\sigma(c)), \quad B_\mu(c) \geq A(c)$$

It is worth noting that $B_\mu(c) - B_\sigma(c)$ is added to the difference of total deposit and total sent in case of on-chain changements, like top up.

2.4 Channel states

Each client $c \in \mathcal{C}$ is defined by their channel state $\sigma \in \Sigma$. States $\sigma \in \Sigma$ are composed of: (i) a validity index, (ii) the latest observed on-chain balance of the client, (iii) the total deposit of the client, and (iv) the total owned by the provider. We denote a state $\sigma \in \Sigma$ as

$$(i, B_\sigma(c), D(c), \sum c \rightarrow \mathcal{P})$$

2.5 Messages

Messages $m \in \mathcal{M}$ are exchanged between clients \mathcal{C} and provider \mathcal{P} . A message is related to one and only one element in $\mathcal{C} \times \mathcal{P}$.

Minimal message A minimal message $m \in \mathcal{M}$ between a client c and the provider \mathcal{P} is composed of four components: (i) a validity index, (ii) the latest observed balance, (iii) the total of deposit, and (iv) the total owned by the provider. We denote a message $m \in \mathcal{M}$ as

$$(i, B_\sigma(c), D(c), \sum c \rightarrow \mathcal{P})$$

Message derivation Messages are derived from channel states Σ as

$$\begin{aligned} \sigma &\implies m \\ (i, B_\sigma(c), D(c), \sum c \rightarrow \mathcal{P}) &\implies (i + 1, B_\sigma(c), D(c), \sum c \rightarrow \mathcal{P}) \end{aligned}$$

2.6 Modifiers

Modifiers $\omega \in \Omega$ are input parameters that modify channel states σ . They encapsulate the channel capabilities. In this multi-clients payment channel the capability is sending money through the channel from clients to provider, i.e. $c \rightarrow \mathcal{P}$.

Payment, $\omega(a)$ This modifier is used to increase the balance $O(\mathcal{P})$ of the provider of a amount from a client c .

3 State transitions

3.1 Contract state, $\mu \rightarrow \mu'$

Contract states $\mu \in M$ can transition $\mu \rightarrow \mu'$ because of a message $m \in \mathcal{M}$ or external events.

Settlement $(i, B_\mu(c)) \xrightarrow{m} (i+1, B_\mu(c) \downarrow) \mid m = (i+1, B_\sigma(c), D(c), \sum c \rightarrow \mathcal{P})$. It is worth noting that with this rule it is not possible to settle a zero amount because the balance amount $B_\mu(c)$ must go down!

$$\begin{aligned} O(\mathcal{P}) &= B_\mu(c) - A(c) \\ &= B_\mu(c) - (D(c) - \sum c \rightarrow \mathcal{P} + (B_\mu(c) - B_\sigma(c))) \end{aligned}$$

$O(\mathcal{P})$ is the amount owned by the provider at the settlement time. The provider can settle the amount in the balance minus the remaining funds of the client c .

$$\begin{aligned} B_\mu(c) \downarrow &= B_\mu(c) - O(\mathcal{P}) \\ &= B_\mu(c) - (B_\mu(c) - (D(c) - \sum c \rightarrow \mathcal{P} + (B_\mu(c) - B_\sigma(c)))) \end{aligned}$$

The new client balance is the current contract balance minus the the amount due to the provider.

Full refund $(i, B_\mu(c)) \xrightarrow{m} (i+1, 0) \mid m = (i+1, B_\sigma(c), D(c), \sum c \rightarrow \mathcal{P})$. It is a full refund if the client available funds in the channel for the client are equal to the current contract balance

$$\begin{aligned} B_\mu(c) &\stackrel{?}{=} A(c) \\ &\stackrel{?}{=} D(c) - \sum c \rightarrow \mathcal{P} + (B_\mu(c) - B_\sigma(c)) \end{aligned}$$

Partial refund $(i, B_\mu(c)) \xrightarrow{m} (i+1, 0) \mid m = (i+1, B_\sigma(c), D(c), \sum c \rightarrow \mathcal{P})$. It is a partial refund if the client available funds in the channel are smaller than the current contract balance

$$B(c) \stackrel{?}{>} A(c)$$

In that case the provider amount is

$$O(\mathcal{P}) = B_\mu(c) - A(c)$$

Top up $(i, B_\mu(c)) \xrightarrow{e} (i, B_\mu(c) \uparrow)$. Top up increases the contract balance for a client $c \in \mathcal{C}$. Validity index i must not be incremented during the top up.

Invalid settlement $(i, B_\mu(c)) \rightarrow (i, B_\mu(c) \downarrow)$. This transition is invalid because the balance is decreased without incrementing the validity index i . The current set of transactions must be invalidate after the settlement.

Invalid top up $(i, B_\mu(c)) \rightarrow (i + 1, B_\mu(c) \uparrow)$ Increasing validity index i while increasing the contract balance invalidates the set of transaction i . The current set of transactions must be invalidate only during a settlement.

Invalid validity index $(i, B_\mu(c)) \rightarrow (i \downarrow, -)$ Decreasing the validity index i is always invalid. Validity index must not be decreased.

3.2 Channel state, $\sigma \rightarrow \sigma'$

Channel state transitions $\sigma \xrightarrow{\mu+\omega} \sigma'$ for $\sigma, \sigma' \in \Sigma$, i.e. applying a modifier ω on the current state μ to result on σ' . The contract state μ must be query on-chain. The base channel state is

$$\sigma = \begin{cases} \emptyset & \text{if no previous state exists} \\ (i, B_\sigma(c), D(c), \sum c \rightarrow \mathcal{P}) & \text{otherwise} \end{cases}$$

Payment, $\mu(I(c), B_\mu(c)) + \omega(a)$ Payments trigger transition in channel states from a base state σ to a destination state σ' noted $\sigma \xrightarrow{\mu+\omega(a)} \sigma'$. The destination state is computed as

$$\sigma' = \begin{cases} (I(c), B_\mu(c), B_\mu(c), a) & \text{if } \sigma = \emptyset \\ (I(c), B_\mu(c), D(c), \sum c \rightarrow \mathcal{P} + a) & \text{otherwise} \end{cases}$$

Top up, $\mu(I(c), B_\mu(c) \uparrow)$ Each top up event modify the contract state μ , then the channel state σ must be updated to keep track of the real balance.

$$\sigma' = \begin{cases} (I(c), B_\mu(c), B_\mu(c), 0) & \text{if } \sigma = \emptyset \\ (I(c), B_\mu(c), D(c) + (B_\mu(c) - B_\sigma(c)), \sum c \rightarrow \mathcal{P}) & \text{otherwise} \end{cases}$$

	ω	μ	m	σ
	$\omega(a)$	$(I(c), B_\mu(c))$	$(i, B_\sigma(c), D(c), \sum)$	$(i, B_\sigma(c), D(c), \sum)$
init		(0,10)		\emptyset
transact	+1		(1, 10, 10, 1)	(0, 10, 10, 1)
transact	+1		(1, 10, 10, 2)	(0, 10, 10, 2)
settle		(1,8)		
transact	+2		(2, 8, 10, 4)	(1, 8, 10, 4)
transact	+2		(2, 8, 10, 6)	(1, 8, 10, 6)
top up		(1,18)		(1, 18, 20, 6)
transact	+1		(2, 18, 20, 7)	(1, 18, 20, 7)
settle		(2,13)		

Table 1. State transitions during channel lifetime

	ω	μ	m	σ
	$\omega(a)$	$(I(c), B_\mu(c))$	$(i, B_\sigma(c), D(c), \sum)$	$(i, B_\sigma(c), D(c), \sum)$
init		(0, 3)		\emptyset
top up		(0,5)		(0, 5, 5, 0)
transact	+3		(1, 5, 5, 3)	(0, 5, 5, 3)
settle		(1,2)		
transact	+1		(2, 2, 5, 4)	(1, 2, 5, 4)
top up		(1,4)		(1, 4, 7, 4)
settle		(2,3)		
transact	+2		(3, 3, 7, 6)	(2, 3, 7, 6)

Table 2. Settlement after top up