Ethereum Transactions

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World State and Transactions

- World state consists of a trie storing key/value pairs
  - For accounts, key is 20-byte account address
  - Account value is [nonce, balance, storageRoot, codeHash]
- Transactions cause state transitions
- $\boldsymbol{\sigma}_t$ = Current state, $\boldsymbol{\sigma}_{t+1}$ = Next state, T = Transaction

$$\boldsymbol{\sigma}_{t+1} = \Upsilon(\boldsymbol{\sigma}_t, T)$$

- Transactions are included in the blocks
- Given genesis block state and blockchain, current state can be reconstructed
- A transaction can only be initiated by an EOA, not a contract
- Ethereum transactions are of two types
  - Contract creation
  - Message calls (ETH transfers or contract method invocations)
- A message call transaction can result in further message calls
- As of the London upgrade (block 12965000), there are three types of transactions in Ethereum

Legacy Transaction Format

Legacy Transaction Format

- Type 0 or legacy transaction
  - `rlp([nonce, gasPrice, gasLimit, to, value, data, v, r, s])`
- `nonce`
  - Number of transactions sent by the sender address
  - Prevents transaction replay
  - First transaction has `nonce` equal to 0
- `gasPrice, gasLimit`
  - Each operation in a transaction execution costs some *gas*
  - gasprice = Number of Wei to be paid per unit of gas used during transaction execution
  - gasLimit = Maximum gas that can be consumed during transaction execution
  - gasprice*gasLimit Wei are deducted from sender's account
  - Any unused gas is refunded to sender's account at same rate
  - Any unrefunded Ether goes to miner

Fee Schedule

- A tuple of 31 values which define gas costs of operations
- Partial fee schedule (full schedule in Appendix G of yellow paper)

Name	Value	Description
G_{base}	2	Paid for operations in set W_{base}.
$G_{verylow}$	3	Paid for operations in set $W_{verylow}$.
G_{low}	5	Paid for operations in set W_{low}.
G_{mid}	8	Paid for operations in set W_{mid}.
G_{high}	10	Paid for operations in set W_{high}.
G_{call}	700	Paid for a CALL operation.
$G_{transaction}$	21000	Paid for every transaction.
$G_{txdatazero}$	4	Paid for every zero byte of data or code for a transaction.
$G_{txdatanonzero}$	68	Paid for every non-zero byte of data or code for a transaction.
G_{txcreate}	32000	Paid by all contract-creating transactions
$G_{codedeposit}$	200	Paid per byte for a CREATE operation
$G_{selfdestruct}$	5000	Amount of gas to pay for a SELFDESTRUCT operation.
$R_{selfdestruct}$	24000	Refund given for self-destructing an account.
G_{sha3}	30	Paid for each SHA3 operation.

Legacy Transaction Format

- Type 0 or legacy transaction
  - `rlp([nonce, gasPrice, gasLimit, to, value, data, v, r, s])`
- `to`
  - For contraction creation transaction, `to` is empty
    - RLP encodes empty byte array as `0x80`
    - Contract address = Right-most 20 bytes of Keccak-256 hash of `RLP`([senderAddress, nonce])
  - For message calls, `to` contains the 20-byte address of recipient
- `value`
  - The number of Wei being transferred to recipient
  - In message calls, the receiving contract should have `payable` functions

Legacy Transaction Format

- Type 0 or legacy transaction
  - `rlp([nonce, gasPrice, gasLimit, to, value, data, v, r, s])`
- `init/data`
  - This field is also called **calldata**
  - Contract creation transactions have EVM code in `init` field
  - Execution of `init` code returns a `body` which will be installed
  - Message calls specify a function and its inputs in `data` field
    - The first 4 bytes of the data field specify the function
    - The remaining bytes specify the inputs to the function
    - The first 4 bytes of the Keccak hash of the function signature is used
  - Transfer of ether between EOAs is considered a message call
    - Sender can insert arbitrary info in `data` field
- `v, r, s`
  - (`r`, `s`) is the ECDSA signature on hash of remaining Tx fields
  - Note that the sender's address is not a header field
  - `v` enables recovery of sender's public key

secp256k1 Revisited

- Ethereum uses the same curve as Bitcoin for signatures
- $y^2 = x^3 + 7$ over $\mathbb{F}_p$ where

$$p = \underbrace{\texttt{FFFFFFFF} \ \cdots \ \texttt{FFFFFFFF}}_{\text{48 hexadecimal digits}} \ \texttt{FFFFFFFE} \ \texttt{FFFFFC2F}$$

$$= 2^{256} - 2^{32} - 2^9 - 2^8 - 2^7 - 2^6 - 2^4 - 1$$

- $E \cup \mathcal{O}$ has cardinality n where

$$n = \begin{array}{l} \texttt{FFFFFFFF FFFFFFFF FFFFFFFF FFFFFFFE} \\ \texttt{BAAEDCE6 AF48A03B BFD25E8C D0364141} \end{array}$$

- Private key is $k \in \{1, 2, \ldots, n-1\}$
- Public key is kP where P is the base point of secp256k1
- Note that $p \approx 2^{256}$ and $n > 2^{256} - 2^{129}$

Public Key Recovery in ECDSA

- **Signer:** Has private key k and message m
  1. Compute $e = H(m)$
  2. Choose a random integer j from $\mathbb{Z}_n^*$
  3. Compute $jP = (x, y)$
  4. Calculate $r = x \bmod n$. If $r = 0$, go to step 2.
  5. Calculate $s = j^{-1}(e + kr) \bmod n$. If $s = 0$, go to step 2.
  6. Output (r, s) as signature for m
- **Verifier:** Has public key kP, message m, and signature (r, s)
  1. Calculate $e = H(m)$
  2. Calculate $j_1 = es^{-1} \bmod n$ and $j_2 = rs^{-1} \bmod n$
  3. Calculate the point $Q = j_1 P + j_2(kP)$
  4. If $Q = \mathcal{O}$, then the signature is invalid.
  5. If $Q \neq \mathcal{O}$, then let $Q = (x, y) \in \mathbb{F}_p^2$. Calculate $t = x \bmod n$. If $t = r$, the signature is valid.
- If $Q = (x, y)$ was available, then

$$kP = j_2^{-1}\left(Q - j_1 P\right)$$

- But we only have $r = x \bmod n$ where $x \in \mathbb{F}_p$

Recovery ID

- Since $p < 2^{256}$ and $n > 2^{256} - 2^{129}$, four possible choices for (x, y) given r
- Recall that (x, y) on the curve implies $(x, -y)$ on the curve
- Recovery ID encodes the four possibilities

Rec ID	x	y
0	r	even
1	r	odd
2	$r + n$	even
3	$r + n$	odd

- For historical reasons, recovery id is in range 27, 28, 29, 30
- Prior to Spurious Dragon hard fork at block 2,675,000 `v` was either 27 or 28
  - Chances of 29 or 30 is less than 1 in 2^{127}
  - `v` was not included in transaction hash for signature generation

Chain ID

- In EIP 155, transaction replay attack protection was proposed
- Chain IDs were defined for various networks

CHAIN_ID	Chain
1	Ethereum mainnet
3	Ropsten
61	Ethereum Classic mainnet
62	Ethereum Classic testnet

- After block 2,675,000, Tx field $\mathtt{v}$ equals 2 $\times$ CHAIN_ID + 35 or 2 $\times$ CHAIN_ID + 36
- Transaction hash for signature generation included CHAIN_ID
- Transactions with $\mathtt{v}$ equal to 27 to 28 still valid but insecure against replay attack

References

- Yellow paper https://ethereum.github.io/yellowpaper/paper.pdf
- EIP-2718 https://eips.ethereum.org/EIPS/eip-2718
- EIP-1559 https://eips.ethereum.org/EIPS/eip-1559
- EVM Opcodes https://www.evm.codes/
- Spurious Dragon hard fork https://blog.ethereum.org/2016/11/18/hard-fork-no-4-spurious-dragon/
- EIP 155: Simple replay attack protection https://github.com/ethereum/EIPs/blob/master/EIPS/eip-155.md
- Online Keccak hash https://emn178.github.io/online-tools/keccak_256.html