In-EVM Mina State Verification
Proof System Description

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1 Introduction

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To prove Mina blockchain's state on the Ethereum Virtual Machine, we use Redshift SNARK[1]. RedShift is a transparent SNARK that uses PLONK[2] proof system but replaces the commitment scheme. The authors utilize FRI[3] protocol to obtain transparency for the PLONK system.

However, FRI cannot be straightforwardly used with the PLONK system. To achieve the required security level without huge overheads, the authors introduce *list polynomial commitment* scheme as a part of the protocol. For more details, we refer the reader to [1].

The original RedShift protocol utilizes the classic PLONK[2] system. To provide better performance, we generilize the original protocol for use with PLONK with custom gates [4], [5] and lookup arguments [6], [7].

2 RedShift Protocol

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Notations:

$N_{\texttt{wires}}$	Number of wires (‘advice columns‘)
$N_{\texttt{perm}}$	Number of wires that are included in the permutation argument
$N_{\texttt{sel}}$	Number of selectors used in the circuit
$N_{\texttt{const}}$	Number of constant columns
$\mathbf{f}_i$	Witness polynomials, $0 \leq i < N_{\texttt{wires}}$
$\mathbf{f}_{c_i}$	Constant-related polynomials, $0 \leq i < N_{\texttt{const}}$
$\mathbf{gate}_i$	Gate polynomials, $0 \leq i < N_{\texttt{sel}}$
$\sigma(\text{col} : i, \text{row} : j) = (\text{col} : i', \text{row} : j')$	Permutation over the table

For details on polynomial commitment scheme and polynomial evaluation scheme, we refer the reader to [1].

Preprocessing:

1. $\mathcal{L}' = (\mathbf{q}_0, ..., \mathbf{q}_{N_{\texttt{sel}}})$
2. Let ω be a 2^k root of unity
3. Let δ be a T root of unity, where $T \cdot 2^S + 1 = p$ with T odd and $k \leq S$
4. Compute $N_{\texttt{perm}}$ permutation polynomials $S_{\sigma_i}(X)$ such that $S_{\sigma_i}(\omega^j) = \delta^{i'} \cdot \omega^{j'}$
5. Compute $N_{\texttt{perm}}$ identity permutation polynomials: $S_{id_i}(X)$ such that $S_{id_i}(\omega^j) = \delta^i \cdot \omega^j$
6. Let $H = \{\omega^0, ..., \omega^n\}$ be a cyclic subgroup of $\mathbb{F}^*$
7. Let $Z(X) = \prod a \in H^*(X - a)$

Protocol (Prover):

1. Choose masking polynomials:

$$h_i(X) \leftarrow \mathbb{F}_{<k}[X] \text{ for } 0 \leq i < N_{\texttt{wires}}$$

Remark: For details on choice of k, we refer the reader to [1].

2. Define new witness polynomials:

$$f_i(X) = \mathbf{f}_i(X) + h_i(X)Z(X) \text{ for } 0 \leq i < N_{\texttt{wires}}$$

3. Send commitments to f_i to $\mathbf{V}$
4. Get $\beta, \gamma \leftarrow \mathbb{F}$ from $\mathbf{V}$
5. For $0 \leq i < N_{\texttt{perm}}$

$$\begin{aligned} p_i &= f_i + \beta \cdot S_{id_i} + \gamma \\ q_i &= f_i + \beta \cdot S_{\sigma_i} + \gamma \end{aligned}$$

6. Define:

$$\begin{aligned} p'(X) &= \prod_{0 \leq i < N_{\texttt{perm}}} p_i(X) \in \mathbb{F}_{<N_{\texttt{perm}} \cdot n}[X] \\ q'(X) &= \prod_{0 \leq i < N_{\texttt{perm}}} q_i(X) \in \mathbb{F}_{<N_{\texttt{perm}} \cdot n}[X] \end{aligned}$$

7. Compute $P(X), Q(X) \in \mathbb{F}_{<n+1}[X]$, such that:

$$\begin{aligned} P(\omega) = Q(\omega) &= 1 \\ P(\omega^i) &= \prod_{1 \leq j < i} p'(\omega^i) \text{ for } i \in 2, \ldots, n+1 \\ Q(\omega^i) &= \prod_{1 \leq j < i} q'(\omega^i) \text{ for } i \in 2, \ldots, n+1 \end{aligned}$$

8. Compute and send commitments to P and Q to $\mathbf{V}$
9. Get $\alpha_0, \ldots, \alpha_5 \leftarrow \mathbb{F}$ from $\mathbf{V}$
10. Define polynomials ($F_0, \ldots, F_4$ - copy-satisfability):

$$\begin{aligned} F_0(X) &= L_1(X)(P(X) - 1) \\ F_1(X) &= L_1(X)(Q(X) - 1) \\ F_2(X) &= P(X)p'(X) - P(X\omega) \\ F_3(X) &= Q(X)q'(X) - Q(X\omega) \\ F_4(X) &= L_n(X)(P(X\omega) - Q(X\omega)) \\ F_5(X) &= \sum_{0 \leq i < N_{\texttt{sel}}} (\mathbf{q}_i(X) \cdot \texttt{gate}_i(X)) + \sum_{0 \leq i < N_{\texttt{const}}} (\mathbf{f}_{c_i}(X)) + PI(X) \end{aligned}$$

11. Compute:

$$F(X) = \sum_{i=0}^{5} \alpha_i F_i(X)$$
$$T(X) = \frac{F(X)}{Z(X)}$$

12. Split $T(X)$ into separate polynomials $T_0(X), ..., T_{N_{\mathtt{perm}}}(X)$

13. Send commitments to $T_0(X), ..., T_{N_{\mathtt{perm}}}(X)$ to **V**

14. Get $y \leftarrow \mathbb{F}/H$ from **V**

15. Run evaluation scheme with the committed polynomials and y.
Remark: Depending on the circuit, evaluation can be done also on $y\omega, y\omega^{-1}$.

16. Send proof π to **V**

2.1 Non-Interactive Verification

1. Let $f_{0,\mathtt{comm}}, \ldots, f_{N_{\mathtt{wires}},\mathtt{comm}}$ be commitments to $f_0(X), \ldots, f_{N_{\mathtt{wires}}}(X)$

2. transcript = setup_values$||f_{0,\mathtt{comm}}|| \ldots ||f_{N_{\mathtt{wires}},\mathtt{comm}}$

3. $\beta, \gamma = H(\text{transcript})$

4. Let $P_{\mathtt{comm}}, Q_{\mathtt{comm}}$ be commitments to $P(X), Q(X)$

5. transcript = transcript$||P_{\mathtt{comm}}||Q_{\mathtt{comm}}$

6. $\alpha_0, \ldots, \alpha_5 = H(\text{transcript})$

7. Let $T_{0,\mathtt{comm}}, ..., T_{N_{\mathtt{perm,comm}}}$ be commitments to $T_0(X), ..., T_{N_{\mathtt{perm}}}(X)$

8. transcript = transcript$||T_{0,\mathtt{comm}}||...||T_{N_{\mathtt{perm,comm}}}$

9. $y = H_{\mathbb{F}/H}(\text{transcript})$

10. Run evaluation scheme verification with the committed polynomials and y to get values $f_i(y), P(y), P(y\omega), Q(y), Q(y\omega), T_j(y)$.
Remark: Depending on the circuit, evaluation can be done also on $f_i(y\omega), f_i(y\omega^{-1})$ for some i.

11. Calculate:

$$F_0(y) = L_1(y)(P(y) - 1)$$
$$F_1(y) = L_1(y)(Q(y) - 1)$$
$$p'(y) = \prod p_i(y) = \prod f_i(y) + \beta \cdot S_{id_i}(y) + \gamma$$
$$F_2(y) = P(y)p'(y) - P(y\omega)$$
$$q'(y) = \prod q_i(y) = \prod f_i(y) + \beta \cdot S_{\sigma_i}(y) + \gamma$$
$$F_3(y) = Q(y)q'(y) - Q(y\omega)$$
$$F_4(y) = L_n(y)(P(y\omega) - Q(y\omega))$$
$$F_5(y) = \sum_{0 \le i < N_{\mathtt{sel}}} (\mathbf{q}_i(y) \cdot \mathtt{gate}_i(y)) + \sum_{0 \le i < N_{\mathtt{const}}} (\mathbf{f}_{c_i}(y)) + PI(y)$$
$$T(y) = \sum_{0 \le j < N_{\mathtt{perm}+1}} y^{n \cdot j} T_j(y)$$

12. Check the identity:

$$\sum_{i=0}^{5} \alpha_i F_i(y) = Z(y)T(y)$$

3 Optimizations

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