Ethereum’s Fee Market Reform of EIP 1559

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# Current Fee Market Mechanism

<table>
<thead>
<tr>
<th>Users</th>
<th>Transactions</th>
<th>Miners</th>
</tr>
</thead>
<tbody>
<tr>
<td>Submit <strong>transactions</strong> to a common pool that is viewed by <strong>miners</strong></td>
<td>Each transaction requires some predefined gas</td>
<td>Select which transactions to include</td>
</tr>
<tr>
<td><strong>Users bids</strong> = gas prices: how much they are willing to pay for each unit of gas</td>
<td>Including a transaction poses <strong>risks</strong>: increases block size and propagation time → risk for <strong>stale blocks</strong></td>
<td>Choose to include only transactions that cover their <strong>intrinsic marginal costs</strong></td>
</tr>
</tbody>
</table>
Current Mechanism: **Generalized First Price Auction**

- A typical transaction requires 21k gas units.
- Block size is 20M gas units (about 950 transactions).
- Users with similar transactions but different valuations for their transactions/urgency to process their transactions.
- Typically: n users to bid for k slots with n >> k.
Current Mechanism: Problems

- Extremely volatile transaction fees
- Unnecessary transaction delays
- Unnecessary guesswork for the right fee

Random day: September 27

- Over 25% of blocks report a price ratio above 12!
Current Mechanism: **Problems**

- Extremely volatile transaction fees
- Unnecessary transaction delays
- Unnecessary guesswork for the right fee

Random week: September 21-27

- Median gas prices fluctuate from 400 Gwei to 100 Gwei.
Proposed Reform: EIP 1559

Idea: set a target block load and a dynamic minimum gas price, called basefee which

- increases when blocks are above target (“too full”)
- decreases when blocks are below target load (“too empty”)
Proposed Reform: **EIP 1559**

- Set a **target block load** and a dynamic **minimum gas price** to achieve this
- Parameters

<table>
<thead>
<tr>
<th>User bids</th>
<th>Protocol</th>
<th>Miners</th>
<th>Transaction</th>
</tr>
</thead>
<tbody>
<tr>
<td>$f = \text{feecap}$</td>
<td>$T/2 = \text{target load}$</td>
<td>$e = \text{minimum marginal cost}$</td>
<td>✔️ or ✗</td>
</tr>
<tr>
<td>$p = \text{premium}$</td>
<td>$b = \text{basefee}$</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- **feecap**: the highest price the user is willing to pay
- **basefee**: a dynamic minimum gas price that is burnt
- **premium**: the maximum tip the miner may receive from the transaction
Proposed Reform: EIP 1559

- **Examples**

<table>
<thead>
<tr>
<th>User</th>
<th>Protocol</th>
<th>Miner</th>
<th>Transaction</th>
<th>Why?</th>
</tr>
</thead>
<tbody>
<tr>
<td>f = 10, p = 2</td>
<td>b = 6</td>
<td>e = 2</td>
<td>✓ included</td>
<td>f &gt; b + e, p &gt; e</td>
</tr>
<tr>
<td>f = 10, p = 1</td>
<td>b = 6</td>
<td>e = 2</td>
<td>✗ not included</td>
<td>f &gt; b + e <strong>but</strong> p &lt; e</td>
</tr>
<tr>
<td>f = 10, p = 2</td>
<td>b = 9</td>
<td>e = 2</td>
<td>✗ not included</td>
<td>p &gt; e <strong>but</strong> f &lt; b + e</td>
</tr>
</tbody>
</table>

- **Condition for inclusion:**

  \[
  \min(f - b_t, p) > e
  \]

- **Left side:** miner’s tip
Proposed Reform: **EIP 1559**

If condition is met, then

- user pays **transactions fees** at most its feecap
- **basefee** is burnt
- **miner’s tip** at most the premium set by the user
Goals of EIP 1559

- Price discovery for the transaction fee (quickly match demand fees)
- Price-taking behavior (transparency, efficiency): next-block inclusion
- Not a goal: lower fees (but yes, lower variance of fees)
- Not a goal: always the same fee

Goal of this work

- Test the basefee dynamics theoretically and experimentally under different assumptions
Basefee: Dynamic Adjustment

The basefee, $b_{t+1}$, at block height $t+1$ is

$$b_{t+1} = b_t \left( 1 + d \times \frac{g_t | b_t - T/2}{T/2} \right)$$

- $d = \text{adjustment parameter or step size (think } d = 12.5\%)$
- $T/2 = \text{target block size (think } T = 952\%)$
- $g_t | b_t = \text{number of included transactions in block } B_t, t>0 \text{ given that the basefee is } b_t$.

This a stochastic process with the Markov property.
Edge Cases

- Proofs of convergence difficult due to edge cases.

- E.g.: all users have similar valuation, and basefee jumps (by a step of d) from below to above and vice versa.

- Here: 3000 arrivals per block with equally spaced valuations in 200-230.
Basefee: Dynamics

- Pointwise convergence: not possible
- Convergence in expectation? If block size is unlimited, then

\[
E[g_l \mid b_l] = E\left[ \sum_{i=1}^{N} X_i \mid b_l \right] = E[N]E[X \mid b_l] = \lambda \cdot (1 - F(b_l + \epsilon)),
\]

where \( \lambda \) is the Poisson arrival rate of transactions and \( F \) is the distribution of valuations.
**Basefee: Dynamics**

- Pointwise convergence: not possible
- Convergence in expectation? If we ignore the limit in block size for a while, then the sequence of conditional expectations is

\[
\mathbb{E}[b_{t+1} \mid b_t] = b_t + b_t \left( \frac{d}{T/2} \left[ \lambda \left(1 - F(b_t + \epsilon)\right) - T/2 \right] \right)
\]

which yields a single fixed point candidate

\[
b^* = F^{-1}(1 - T/2\lambda) - \epsilon
\]
Theorem

- Consider the deterministic process $b_{t+1} = b_t \times (1 + r_t)$ with

$$b_{t+1} = b_t + b_t \times \frac{d}{T/2} \left( \min \{ T, \lambda(1 - F(b_t + \epsilon)) \} - T/2 \right)$$

- Then

$$b_{t+1} \to [(1 - d)b^*, (1 + d)b^*]$$
Proof

- One-dimensional deterministic dynamical system
- Sign analysis on the rate of change

\[ r_t = d \times \left( \frac{\min\{T, \lambda(1-F(b_t+\epsilon))\} - T/2}{T/2} \right) \]

with \( r_t > 0 \) for \( b_t < b^* \) and \( r_t < 0 \) for \( b_t > b^* \).

- Bounded oscillations: starting at a \( b_t > b^* \)

\[ b_{t+1} > b_t(1-d) > b^*(1-d) \]

and analogously when starting at a \( b_t < b^* \).
Relaxing the assumptions

- Block size = T, then

$$
\mathbb{E}[g_t \mid b_t] = \mathbb{E} \left[ \min \left\{ T, \sum_{i=1}^{N} X_i \right\} \mid b_t \right] \leq \min \left\{ T, \mathbb{E} \left[ \sum_{i=1}^{N} X_i \mid b_t \right] \right\}
$$

$$
= \min \left\{ T, \lambda (1 - F(b_t + \epsilon)) \right\}.
$$

- Hence

$$
\mathbb{E}[b_{t+1} \mid b_t] \leq b_t \left( 1 + \frac{d}{T/2} \left[ \min \left\{ T, \lambda (1 - F(b_t + \epsilon)) \right\} - T/2 \right] \right)
$$

and the same proof applies in an upper bound sense.
Non-Strategic Users

- Poisson arrivals of constant rate suggest that price discovery occurs fast and the basefee stabilizes there.

- Users bid their valuation as feecap and miner’s cost as premium.

\[
\text{payoff} = \text{value} - \text{waiting cost (per block)} - \text{transaction fee}
\]
Non-Strategic Users: Ex-post Rationality

- Some users receive negative utility but only before the basefee reaches its stationary level.

\[
\text{payoff} = \text{value} - \text{waiting cost (per block)} - \text{transaction fee}
\]
Non-Strategic Users: Demand Shocks

- Poisson arrivals with demand shocks suggest that price discovery occurs fast and the basefee stabilizes there.

- What is the speed of convergence?

payoff = value - waiting cost (per block) - transaction fee
Strategic Users

- **Non-strategic Users** (fixed bids according to their parameters)

**Strategic Users** (bid their valuation as feecap and min premium + increment seen in previous block)

*early on*: strategic users bid against each other instead of their true value
Strategic Users: Inclusion Rates

- First blocks only strategic users
- When the basefee stabilizes, strategic and non-strategic users are included in the same ratio

- Figure: numbers of included

but: when basefee settles, strategic behaviour does not help
Strategic Users: Valuations

- **First blocks**: strategic premium determines inclusion
- **Stationary blocks**: basefee and valuation determine inclusion

**Figure**: values of included

*but*: when basefee settles, strategic behaviour does not help
Open Questions - Current Work

- Study the mode of convergence (if any) of the dynamic update rule
- Continue to study different scenarios (already promising results)
- Transition period
- (Floating) Escalator
- ...

All code and notebooks open-sourced in the [abm1559 library (Github)](https://github.com/abm1559)
Thank you