Shapley Value-based Approach for Distributing Revenue of Matchmaking of Private Transactions in Blockchains

Extended Abstract

Rasheed
IIIT Hyderabad
Hyderabad, India
mohammad.ahmed@research.iiit.ac.in

Parth Nimish Desai
IIIT Hyderabad
Hyderabad, India
parth.desai@research.iiit.ac.in

Yash Chaurasia
IIIT Hyderabad
Hyderabad, India
cyashvk@protonmail.com

Sujit Gujar
IIIT Hyderabad
Hyderabad, India
sujit.gujar@iiit.ac.in

ABSTRACT

In the context of blockchain, MEV refers to the maximum value that can be extracted from block production through the inclusion, exclusion, or reordering of transactions. Searchers often participate in order flow auctions (OFAs) to obtain exclusive rights to private transactions, available through entities called *matchmakers*, also known as order flow providers (OFPs). Most often, distributing the revenue generated through such auctions among transaction creators (TCs) is desirable. In this work, we formally introduce the *matchmaking* problem in MEV, its desirable properties, and associated challenges. Using cooperative game theory, we formalize the notion of fair revenue distribution in matchmaking and present its potential possibilities and impossibilities. Precisely, we define a characteristic form game, referred to as RST-Game, for the TCs. We propose to distribute the revenue using the Shapley value of RST-Game. We show that the corresponding problem could be SUBEXP (i.e. $2^{o(n)}$, where n is the number of transactions). Further, we propose a randomized algorithm for computing the approximate Shapley value in RST-Game and empirically demonstrate that the proposed RSYP estimates Shapley value that is very close to the actual Shapley value and also distributes the share amongst TCs fairly. RST-Game

CCS CONCEPTS

• **Theory of computation** → *Solution concepts in game theory.*

KEYWORDS

Blockchain, MEV, Matchmaking, Shapley Value

ACM Reference Format:
Rasheed, Parth Nimish Desai, Yash Chaurasia, and Sujit Gujar. 2025. Shapley Value-based Approach for Distributing Revenue of Matchmaking of Private Transactions in Blockchains: Extended Abstract. In *Proc. of the 24th International Conference on Autonomous Agents and Multiagent Systems (AAMAS 2025), Detroit, Michigan, USA, May 19 – 23, 2025*, IFAAMAS, 3 pages.

Proc. of the 24th International Conference on Autonomous Agents and Multiagent Systems (AAMAS 2025), Y. Vorobeychik, S. Das, A. Nowé (eds.), May 19 – 23, 2025, Detroit, Michigan, USA. © 2025 International Foundation for Autonomous Agents and Multiagent Systems (www.ifaamas.org).

1 INTRODUCTION

Maximal Extractable Value (MEV) in the blockchain context refers to "the maximum value that can be extracted from block production in excess of the standard block reward and gas fees by including, excluding, and arranging the order of transactions in a particular way". Towards generating such MEV, Searchers buy transactions through order flow providers (OFPs) via an auction mechanism Order Flow Auction (OFA). OFPs, which we call *matchmaker*, deploy *Matchmaking* to distribute the revenue through OFA to TCs in exchange for the value that their transactions generate [18]. Though multiple authors have raised a need for such distribution, as claimed in [8, 9], designing a matchmaking mechanism is an open problem. This paper addresses how a matchmaker should distribute the revenue among TCs in a *fair* manner. Some transactions add more value to the system; thus, revenue should be shared proportional to how much value they add to the system. Naturally, Shapley value becomes an ideal solution for revenue distribution.

Contributions. (i) We define a cooperative game, RST-Game, over TCs based on the revenue generated, (ii) we prove that the Shapley value of TCs in the RST-Game is polynomial-time computable when the searcher valuations are additive, (iii) we motivate that computing Shapley value in the RST-Game when the searchers are single-minded bidders is possibly SUBEXP, (iv) we propose a randomized algorithm – Randomized ShapleY Procedure (RSYP) that closely estimates the exact Shapley value of TCs, (v) we empirically show the efficacy of RSYP by comparing its outputs with the brute-force approach.

2 RELATED WORK

MEV Auctions. [17] study various strategic interactions and auction setups of block builders with proposers. They evaluate how access to MEV opportunities and improved relay connectivity impact bidding performance. [12] propose an Ethereum gas auction model using the First Price Sealed-Bid Auction (FPSBA) between different bots and miners.

MEV redistributions. [2] model the MEV setting as a dynamical system and compute a certain fraction of MEV should go to the miner and remaining to TCs. The goal is to determine what fraction of the miners would ensure equilibrium. [13] discuss rebates in the context of liquidity providers in constant function market makers. [4] propose MEV redistribution as a dynamical system in which lending and staking portfolios of block proposer are chosen as a parameter that determines how much of the MEV extracted in a block is redistributed to staking. None of these talk about methods to redistribute amongst TCs.

Game Theory and Blockchains Researchers explored various game theoretic concepts in blockchains. E.g., the authors of [5, 6, 15] use concepts from mechanism design to design transaction fee mechanisms and fairness. [3, 11] study scalability issues in blockchains through game theory.[16] discusses on achieving fairness for Bitcoin in a transaction fee-only model. [10] studies the equilibrium behavior of the miners. In this work, we explore the use of cooperative game theory in matchmaking.

3 PRELIMINARIES

Consider a set of transactions $\mathcal{T} = \{t_1, t_2, \dots t_n\}$ that can generate MEV, and a set of searchers $\mathcal{S} = \{s_1, s_2, \dots s_m\}$, and a matchmaker M. s_i has valuation $v_{s_i} : 2^{\mathcal{T}} \rightarrow \mathbb{R}_{+}$. *Matchmaking* executes in two steps: (i) the allocation of transactions to searchers. M conducts an auction among the searchers and collects payments p_{s_i}s from winning searchers as per the prescribed rule, (ii) the distribution of revenue generated through OFA,$\mathcal{R} = \sum_i p_{s_i}$, among the TCs.

Definition 1 (Matchmaking). *We define matchmaking as mechanism $\mathcal{M}$ which takes, $(\mathcal{T}, \mathcal{S}, (v_{s_i})_{s_i \in \mathcal{S}})$ as inputs, conducts auction amongst $\mathcal{S}$ for $\mathcal{T}$, and outputs rewards Γ_j to $t_j \in \mathcal{T}$ such that $\sum_{t_j \in \mathcal{T}} \Gamma_j \leq \mathcal{R}$.*

Searcher-Matchmaker Auctions. The searcher-matchmaker auction is commonly seen in two forms: (i) the searcher values each transaction separately and (ii) the searchers bid for a bundle of transactions. The former can be seen as searchers with *additive valuations* and the latter as searchers with *single-minded valuations*.

4 OUR APPROACH

`RST-Game`. `RST-Game` is a cooperative game $(\mathcal{T}, v)$ with the transactions $\mathcal{T}$ being the players. $v(T)$ where $T \subseteq \mathcal{T}$ is the value of transactions in T. For each t_j, its marginal contribution to each $T \subseteq \mathcal{T} \setminus t_j$, requires finding the revenue with $T \cup t_j$ and T. Γ_j^{SHAP} is computed as $\frac{\varphi_j}{\sum_{i \in [n]} \varphi_i}$. For e.g., consider `RST-Game` with 3 searchers and 4 transactions, with (bundle, bid) of searchers as (1,2,10), (3,4,9), (2,4,8). If M deploys ICA-SM [1] for searchers, the winners are s_1, s_2 and their payments are $(8/\sqrt{(2)}) * \sqrt{2} = 8$ each and total revenue is 16. $\Gamma_{t_1}^{SHAP} = \Gamma_{t_3}^{SHAP} = 0.154$, $\Gamma_{t_2}^{SHAP} = \Gamma_{t_4}^{SHAP} = 0.346$.

`RST-Game` with Additive Searchers. Each searcher $s_i \in \mathcal{S}$ submits bid b_{s_i}, where $b_{s_i} \in \mathbb{R}^n$ is an n-tuple where $b_{s_i}[j]$ is s_i searcher's bid for transaction t_j. M reduces this auction to n independent second-price auctions. For each transaction, $t_j \in \mathcal{T}$, M determines the searcher with the highest bid for t_j as the winner. The winner pays the amount of the second-highest bid.

Theorem 1. *The Shapley value of `RST-Game` $(\mathcal{T}, v)$) can be computed in polynomial time if v is additive.*

`RST-Game` with Single-Minded Searchers Each searcher $s_i \in \mathcal{S}$ submits only a single subset $B_{s_i} \subseteq \mathcal{T}$ in bid $\{B_{s_i}, b_{s_i}\}$, where s_i's valuation v_{s_i} is single-minded. M reduces this auction to a combinatorial auction with single-minded bidders. For this setting, we prove the following:

Theorem 2. *(Informal) The number of unique marginal contributions in the computation of the Shapley value of TCs in `RST-Game` can be $\Omega(2^{\sqrt{n}})$.*

Conjecture 1. *The Shapley value of `RST-Game` $(\mathcal{T}, v)$) is SUBEXP in transaction creators n if v is single-minded.*

Approximating Shapley Value The occurrence of structures that potentially may lead worst cases to be could be typically rare[1]. Marginal contributions of many transactions with other subsets would be zero, leading to unique marginal contributions being just $O(n)$. Hence, we propose `RSYP` a randomized algorithm to compute the approximate Shapley value of each transaction. Algorithm 1 describes `RSYP`. Π be the set of all permutations of transactions and $\bar{\Pi}$ be set of k different permutations sampled from Π. For each transaction t_j, the approximate Shapley value $\tilde{\varphi}_j$ is computed using marginal contribution of t_j to each $\pi \in \Pi$, averaged over k. Among the winning transactions selected via greedy approximation, the fraction of revenue redistributed to transaction creator j is given by $\Gamma_{t_j}^{RSYP} = \frac{\tilde{\varphi}_{t_j}(v)}{\sum_{j \in [n]} \tilde{\varphi}_{t_j}(v)}$ using `RSYP`. We empirically show, for $k = O(n^2)$, $\forall t_j \in \mathcal{T}, \Gamma_{t_j}^{\mathsf{RSYP}}$ computed via `RSYP` approaches $\varphi_{t_j}(v)$.

Algorithm 1 `RSYP`

```
Input : Π̄, n, k
for j = 1 to n do
    MC_sum = 0
    for π ∈ Π̄ do
        MC = v(π(j) ∪ j) − v(π(j))
        MC_sum += MC
    end for
    φ_{t_j}(v) = MC_sum / k
end for
for j = 1 to n do
    Γ_{t_j}^{RSYP} = φ̃_{t_j}(v) / Σ_{j∈[n]} φ̃_{t_j}(v)
end for
Output :{ Γ_{t_j}^{RSYP} }_{j∈[n]}
```

We have empirically validated the efficacy of `RSYP` on simulated 10K instances. We observe, for smaller m values, where we could also compute the exact Shapley value, `RSYP` almost matches with the exact Shapley value. For space constraints, we skip proofs and experimental details. Both can be found in full version [14].

5 CONCLUSION

In this work, we explored the problem of matchmaking in MEV. We defined a cooperative game `RST-Game` over private transactions and proved that computing Shapley value for fair revenue distribution among TCs is SUBEXP. We proposed a randomized algorithm that approximates the Shapley value very well for $O(n^2)$ where n is the number of transactions.

[1] We often see some transactions being more lucrative than others to almost all of the searchers and occasionally, some transactions being relatively highly valued by only a few (specialized) searchers [7]

REFERENCES

[1] Liad Blumrosen and Noam Nisan. 2007. *Algorithmic Game Theory*. Cambridge University Press, United Kingdom.

[2] Pedro Braga, Georgios Chionas, Piotr Krysta, Stefanos Leonardos, Georgios Piliouras, and Carmine Ventre. 2024. Who gets the Maximal Extractable Value? A Dynamic Sharing Blockchain Mechanism. In *Proceedings of the 23rd International Conference on Autonomous Agents and Multi-Agent Systems (AAMAS 2024)* (Auckland, New Zealand) *(AAMAS '24)*. International Foundation for Autonomous Agents and Multiagent Systems, Richland, SC, 2171–2173.

[3] Lin Chen, Lei Xu, Zhimin Gao, Ahmed Imtiaz Sunny, Keshav Kasichainula, and Weidong Shi. 2024. A game theoretical analysis of non-linear blockchain system. *Distributed Ledger Technologies: Research and Practice* 3, 1 (2024), 1–24.

[4] Tarun Chitra and Kshitij Kulkarni. 2022. Improving proof of stake economic security via MEV redistribution. In *Proceedings of the 2022 ACM CCS Workshop on Decentralized Finance and Security*. Association for Computing Machinery, New York, NY, USA, 1–7.

[5] Sankarshan Damle, Manisha Padala, and Sujit Gujar. 2024. Designing Redistribution Mechanisms for Reducing Transaction Fees in Blockchains. In *Proceedings of the 23rd International Conference on Autonomous Agents and Multiagent Systems* (Auckland, New Zealand) *(AAMAS '24)*. International Foundation for Autonomous Agents and Multiagent Systems, Richland, SC, 416–424.

[6] Sankarshan Damle, Varul Srivastava, and Sujit Gujar. 2024. No Transaction Fees? No Problem! Achieving Fairness in Transaction Fee Mechanism Design. In *Proceedings of the 23rd International Conference on Autonomous Agents and Multiagent Systems* (Auckland, New Zealand) *(AAMAS '24)*. International Foundation for Autonomous Agents and Multiagent Systems, Richland, SC, 2228–2230.

[7] EigenPhi. 2022. MEV Data | Eigen Phi — eigenphi.io. https://eigenphi.io/. [Accessed 1-10-2024].

[8] Flashbots. 2023. MEV-Share: programmably private orderflow to share MEV with users — collective.flashbots.net. https://collective.flashbots.net/t/mev-share-programmably-private-orderflow-to-share-mev-with-users/1264. [Accessed 10-10-2024].

[9] Flashbots Research Proposals. 2023. FRP-30: Quantifying Shareable MEV collective.flashbots.net. https://collective.flashbots.net/t/frp-30-quantifying-shareable-mev/1618. [Accessed 10-10-2024].

[10] Anurag Jain, Sanidhay Arora, Sankarshan Damle, and Sujit Gujar. 2022. Tiramisu: Layering Consensus Protocols for Scalable and Secure Blockchains. In *2022 IEEE International Conference on Blockchain and Cryptocurrency (ICBC)*. IEEE, Shanghai, China, 1–3. https://doi.org/10.1109/ICBC54727.2022.9805562

[11] Anurag Jain, Shoeb Siddiqui, and Sujit Gujar. 2021. We might walk together, but I run faster: Network Fairness and Scalability in Blockchains. In *Proceedings of the 20th International Conference on Autonomous Agents and MultiAgent Systems* (Virtual Event, United Kingdom) *(AAMAS '21)*. International Foundation for Autonomous Agents and Multiagent Systems, Richland, SC, 1539–1541.

[12] Congying Jin, Taotao Wang, Zhe Wang, Long Shi, and Shengli Zhang. 2023. First-Price Sealed-Bid Auction for Ethereum Gas Auction Under Flashbots. In *2023 IEEE International Conference on Metaverse Computing, Networking and Applications (MetaCom)*. Kyoto, Japan, 449–457. https://doi.org/10.1109/MetaCom57706.2023.00085

[13] Bruno Mazorra and Nicolás Della Penna. 2023. Towards Optimal Prior-Free Permissionless Rebate Mechanisms, with applications to Automated Market Makers and Combinatorial Orderflow Auctions. arXiv:2306.17024 [cs.GT] https://arxiv.org/abs/2306.17024

[14] Rasheed, Parth Desai, Yash Chaurasia, and Sujit Gujar. 2025. Shapley Value-based Approach for Redistributing Revenue of Matchmaking of Private Transactions in Blockchains. arXiv:2502.15420 [cs.GT] https://arxiv.org/abs/2502.15420

[15] Tim Roughgarden. 2024. Transaction fee mechanism design. *J. ACM* 71, 4 (2024), 1–25.

[16] Shoeb Siddiqui, Ganesh Vanahalli, and Sujit Gujar. 2020. BitcoinF: Achieving Fairness For Bitcoin In Transaction Fee Only Model. In *Proceedings of the 19th International Conference on Autonomous Agents and MultiAgent Systems* (Auckland, New Zealand) *(AAMAS '20)*. International Foundation for Autonomous Agents and Multiagent Systems, Richland, SC, 2008–2010.

[17] Fei Wu, Thomas Thiery, Stefanos Leonardos, and Carmine Ventre. 2024. Strategic Bidding Wars in On-chain Auctions. In *2024 IEEE International Conference on Blockchain and Cryptocurrency (ICBC)*. Dublin, Ireland, 503–511.

[18] zeroXbrock. 2022. Searching Post-Merge | Flashbots Writings. https://writings.flashbots.net/searching-post-merge. [Accessed 22-09-2024].