Leveraging Nash Equilibrium and Integer Linear Programming for Real-Time Fraud Detection and Optimization in Blockchain Networks

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Abstract: A blockchain network is a distributed, decentralized, digital ledger that records transactions in more than one computer within a network. Blockchain organizes data in a uniquely secure, transparent and distributed manner that enhances the reliability of the completed transaction providing it with applications such as cryptocurrency, supply chain, voting, decentralized finance and many more. The mobile applications of the blockchain network have several issues which include scalability effects in large transactions, computation resources, longer verification times, security threats, compatibility issues with the platforms, and problems of distributed decision-making issues. Solving these problems calls for rationality in the use of resources, mitigation of transaction inconsistencies, and better defined rules. In this work, we combine Nash Equilibrium with Integer Linear Programming to solve different scenarios in applications of the blockchain network. We contrast the stated Algorithms in various settings to identify which strategy offers the best solution to all of the aforementioned issues, such as low scalability, high energy utilization, substantial latency, and communication discordance among different blockchain networks. The combination of both of these techniques provides a proactive solution to improve the reliability, optimization, and communications capability of blockchain systems, thus paving the way for blockchain technology to fully revolutionize industries around the world.

1 INTRODUCTION

Blockchain is an actualization of a distributed database across nodes, relevant in applications of cryptocurrencies, smart IoT devices, and supply chain. Regarding the problems of blockchain network such as scalability, low throughput, high energy consumption, and lack of communication, this paper proposes to use Nash Equilibrium with Integer Linear Programming (ILP). During high congestion and transaction imbalances, the Nash Equilibrium is fair and reliable in resource allocation (Tang et al., 2023). However, ILP improves this by bringing the efficiency of complex decision making, while also directing resources and handling transactions (Song et al., 2023).

Given a shift in perception towards the participants, Nash Equilibrium is used to study blockchain systems by considering individuals as selfish players whose actions shape system performance. This approach demonstrates how resources can be utilized in decentralized conditions where traditional control measures fail because there is no central power (Wang et al., 2023a). In total, utilizing Nash Equilibrium, behavior expectations of participants in many-developer and multi-researcher systems can be predicted, peak usage performance can be optimized, transaction crowd can be minimized, and fairness,system integrity can be maintained (Bappy et al., 2024).

ILP offers a mathematically rich formalism that proves to be suitable for tasks in blockchain networks, such as power supply distribution, storage organization, or fraud detection (Wu et al., 2024). It makes sound decisions because aspects related to things such as capacity and resources are factored in to arrive at the best solution within the limits of certain parameters (Ebrahimi et al., 2024). This optimization is important especially where timely decision making is important in countering network threats. In addition to enhancing organizational efficiency, ILP addresses emerging risks to ensure greater security of blockchains.

The key contributions of this work are:

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- Comparison of ILP and Nash-like approach for optimization in blockchain networks
- Fraudulent transaction detection based on multiple thresholds
- Determining cost-minimization strategies considering multiple factors
- Performance improvisation in blockchain networks integrating both algorithms for different scenarios
- Adaptive decision-making framework for blockchain efficiency.

Concisely, this paper proposes a framework using Nash equilibrium and ILP to improve the reliability and efficiency of a blockchain system (Liu et al., 2023). This integration solves many operational problems and contributes to innovations in areas such as supply chain and decentralized finance (Zhang and Wang, 2024). The approach is meant to improve efficiency in managing transactions and resources and to guarantee the longevity and robustness of decentralized applications around the world (Mssassi and Abou El Kalam, 2024).

The remainder of the paper is structured as follows. The surveyed literature is presented in Section 2. Section 3 details the methodology used in this study. The implementation process is described in Section 4. Section 5 presents the results and the discussion, analyzing the findings in detail. Finally, conclusions carried with future scope are drawn in Section 6.

2 LITERATURE SURVEY

Tang et al. suggested a blockchain framework to improve trust with the specified tourism service level agreements (Tang et al., 2023). Song et al. used blockchain in the management of construction funds (Song et al., 2023), and Wang et al. elucidated on the use of blockchain in data control (Wang et al., 2023a). Similarly, Bappy et al. applied parallelism as a way to deal with a simultaneous transaction request to optimize (Bappy et al., 2024). Some authors presented ShardingSim, a CB SB simulator to enhance scalability and performance (Wu et al., 2024).

Using blockchain technology, Ebrahimi et al. introduced a framework for the privacy and security of Federated Learning (Ebrahimi et al., 2024). To illustrate this cause, Liu et al. proposed an anonymous authentication system for secure crowd-sourcing of mobile devices (Liu et al., 2023). Specifically, based on game theory, Zhang et al. proposed a Proof of Sampling (PoSP) system to prevent dishonesty (Zhang and Wang, 2024). Mssassi and Abou El Kalam in their research used game theory to improve cooperation in the blockchain network (Mssassi and Abou El Kalam, 2024), and Stodt and Reich used taxation and game theory to control imperfect behavior (Stodt and Reich, 2023). Li et al. analyzed the evolutionary game to enhance compliance in blockchain-based financial contracts (Li et al., 2023).

Blockchain has improved reliability and effectiveness in different areas. Shukla et al. presented an electronic voting using blockchain (Punith et al., 2022), while Wang et al. provided techniques for anonymity in payment in financial operations (Jie et al., 2023). Shashank et al. integrated IoT with blockchain for secure health monitoring by researchers (Shashank et al., 2023). Li et al. examined the application of blockchain technology to improve government efficiency (Li et al., 2024). Notara is a blockchain-based asset notarization system (Toyos-Marfurt et al., 2024) for the credibility of the public sector by Toyo-Marfurt et al. Finally, Yin et al. introduced a decentralized resource management system for multi-agent systems using blockchain (Yin et al., 2024).

To improve the believability and protect smart contracts of PEVM-based PoA private blockchains, Wang et al. introduced a proxy layer (Wang et al., 2023b). Narang & Verma have addressed the aspect of how blockchain can enhance the chances of food safety and accurate supply chain data (Krishna and Rekha, 2022). In 2020, Shi et al. formulated a range of mathematical models that can be applied to incorporate blockchain into research of operations in plywood supply chains (Shi et al., 2022). Dhanala and Radha proposed a recruitment management architecture based on a blockchain layer for candidate data and to improve the quality of credential data (Dhanala and Radha, 2020).

3 METHODOLOGY

3.1 System Architecture

Fig.1 illustrates the process flow of Real-Time Frauds and Optimization in blockchain networks and consists of the fraud detection process, task distribution process, and optimization process. The system takes input data, which are most probably transaction or system data from a blockchain network. The fraud detection module employs the identification of fraudulent and non-fraudulent patterns in these data. As for the

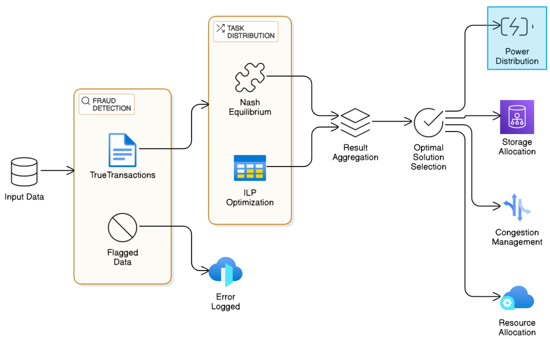

Figure 1: Architecture Diagram

reliable transactions, the true transactions are passed to the Task Distribution component. This particular module guarantees that tasks associated with different scenarios are directed to the right optimization processes. Used here is Nash Equilibrium logic which, given a game theory, the system is able to ration and strategically allocate tasks and resources.

Further, ILP Optimization is a technique, employed to apply mathematical modeling and integer linear programming to determine the most optimal solution with regard to transaction processing within the constraints of the system. The outcomes of these optimization processes shall be collected in the Final Action Outcome step to have the best action to take originating from the Nash equilibrium and the ILP Optimization. Compiling the results from all the assessments, the system identifies the Optimal Solution that best addresses the current requirements in fraud detection and tasking distribution, such as Power Distribution, Storage Allocation, Congestion Control, and Resource Distribution. These individual elements are described fairly effectively below.

3.2 Related Work and Contribution

Based on the works described above, our research extends the studies of (Wang et al., 2023a), (Bappy et al., 2024),(Zhang and Wang, 2024),(Mssassi and Abou El Kalam, 2024) and (Yin et al., 2024) to optimize the deployment of the blockchain resources presented in Table 1. Wang et al. pay attention to data storage management and offer the findings that we generalize to apply to the aspects of computational power, network capacity, and safeguard. Bappy et al. increase the correlation between parallelism and the relation between activities that are dependent on each other, which in turn can be applied to our Nash equilibrium and ILP models that allocate the resources better.

(Zhang and Wang, 2024) use the Nash equilibrium for decentralized systems, the knowledge of

Table 1: Key Methods from Literature and Their Relation to the Current Study

Paper	Methods	Inference
(Wang et al., 2023a)	Data storage management in blockchain systems, focusing on optimizing storage usage.	It can be expanded to cover data storage management in this study to improve the model's versatility by adding storage resources to blockchain.
(Bappy et al., 2024)	Performance optimization in blockchain, focusing on parallelism and dependency management.	The paper recommend for parallelism and computational optimization to be employed to minimize the time taken in computation the Nash Equilibrium and ILP models of optimization of resources.
(Zhang and Wang, 2024)	Nash Equilibrium-based protocol for decentralized systems using verification.	Nash Equilibrium is then adopted in this study to allocate scarce resources in blockchain networks, so that competing nodes can get the best distribution.
(Mssassi and Abou El Kalam, 2024)	Game theory to design incentives for mitigating malicious behavior in blockchain networks.	This work employs Nash Equilibrium concerning resource distribution in blockchain; in the same manner that game theory proclaims motivations for proper conduct which guarantees optimum ripple without rivalry.
(Yin et al., 2024)	Resource optimization in distributed systems combined with blockchain technology.	This paper addresses the problem of how to better coordinate the resource partition and distribution in a blockchain system when it is deployed over multiple nodes so that the extents of processing, bandwidth, and security offered by the system can be enhanced.

which helps us to flow resources by avoiding complicated clashes.(Mssassi and Abou El Kalam, 2024) discussed game theory and opportunistic fair scheduling of resources, while we utilized Nash Equilibrium to model node interactions or allocate resources.(Yin et al., 2024) aim at the distributed node resources, and propose the basic theory for the Nash: Equilibrium, ILP we employed for fair and efficient resource allocation.

Taken together, these papers provide a solid ground for our further investigation of improvements in blockchain systems. We apply their extension to state their methodology into broader areas such as game theory and optimization techniques to design better solutions that can be used for coordinated system resource allocation, security analysis, and performance in decentralized blockchains.

3.3 Fraud Detection

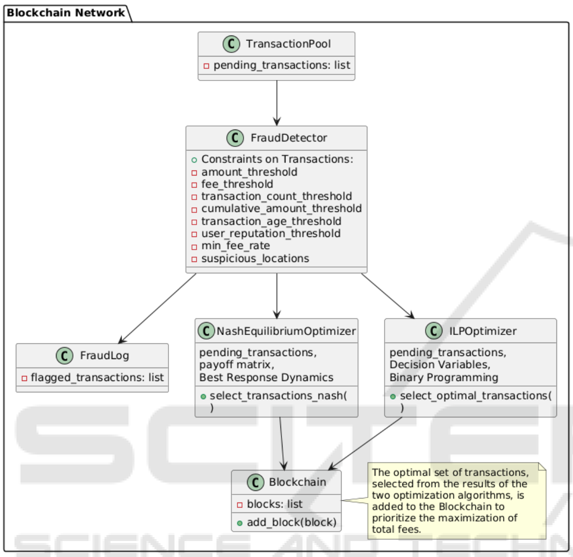

Figure 2: WorkFlow of Fraud Detection Process

In Fraud Detection, thresholds are determined by the transactional properties of the behavior, the user's history, and the requirements of the necessary sector. For the financial area, the amount threshold warns of large payments and therefore of potentially fraudulent operations. In e-commerce, a fee threshold means that when the fee is small, it is recognized that it may be part of an effort to evade detection. The frequency threshold concerns user transaction behavior and will trigger some kind of alert of anomalous activities such as money laundering. In the banking sector, the number of total amount triggers pits the users with total transaction volume above the fixed amount regarding fraudulent transfers. The transaction age threshold validates the age of the transactions, with the ability to hold old transactions that may be related to fraud, especially in insurance fraud. The user reputation threshold determines the trustworthiness, identifying unreliable users and is essential for such internet-based services as peer-to-peer lending, where user credibility is essential. The minimum_fee_rate is compared with amounts where transaction fees are compared with amounts and in this case, it will highlight transactions below a specified value as possibly fraudulent. The new thresholds feature of suspicious locations raises red flags to such transactions originating from areas considered risky; ideal for industries like bitcoin trading or global remittance services where some regions are more vulnerable to fraud. These thresholds vary in consideration of the tendency of the past, the recent user activities and the risks of the sector to allow only genuine transactions while blocking the fraudsters.

The payment acceptance and confirmation of a blockchain network have been described in Fig.2; Different types of limitations related to the transactions for detecting any abnormality have been described. They include the amount_threshold, fee_threshold, and transaction_count_threshold that restricts the size and fees of the transactions. Also, there are limitations like cumulative_amount_threshold to measure the user activity and transaction history, transaction_age_threshold, user_reputation_threshold, and suspicious_locations to map transactions from potentially bad regions. The following fraud detection, two optimization algorithms are applied: Nash Equilibrium with Best Response Dynamics and Integer Linear Programming SBA Magnet in Delhi. These are used to identify the set of transactions that is best suited to the objectives of the network. The transactions are then selected for integration into the blockchain to enhance the overall fee given the capability to occupy more available space when the transactions are associated with higher fees than the current blockchain capacity. This guarantees that the blockchain is both safe and costly in the effectiveness of the blocks with the processed transactions being passed over to the next module. The singularity approach that combines the incorporation of sophisticated fraud detection systems and optimization software enables blockchain networks to achieve enhanced security, service efficiency, and financial sustainability under conditions characterized by complexity, decentralization, and dynamism.

3.4 Optimization Algorithms: Nash Equilibrium and Integer Linear Programming (ILP)

Out of the different methods available like linear programming or the greedy algorithm, the Nash equilibrium optimization technique is selected for performing the optimization task as shown in Fig. 3 because the Nash equilibrium strategy works well with scenarios that entail interconnection and interactions among

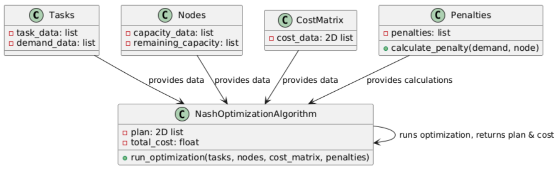

Figure 3: WorkFlow of Nash Equilibrium

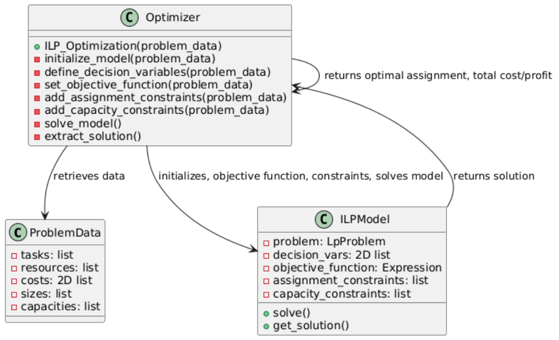

Figure 4: WorkFlow of Integer Linear Programming

the numerous decision players, including nodes or plants. In this model, each player (node or plant) best responds locally to the current state and anticipates the response of others to arrive at a Nash equilibrium in which no player can make himself better off by changing his strategy while others remain passive. The Nash Optimization Algorithm presented in Fig. 3 elaborated the capacities, demands, and cost matrices of the nodes as well as penalties for demands unmet or capacities over-utilized to derive the best plan and total cost. This considerably decentralizes the system because it ensures that everyone can move in harmony with everyone else, maintaining an organic harmony from top to bottom, which minimizes conflict and maximizes the smooth running of the whole system.

As illustrated in Fig. 4, the choice of the optimization technique is ILP since it presents the best solution decisions when problems are formulated using linear equations with integer variables. The technique focuses on trying to improve an explicit measure of performance, possibly by increasing or decreasing it, under certain conditions of capacity, demand, or resources, among others. Since decision variables can only take certain predefined values in ILP, the method performs best on problems that involve the assignment of transactions to agents or the allocation groups of power supplies. Through the solution of such linear models, ILP provides an assured solution that meets the problem constraints without the waste of resources. The approach is widely applied to blockchain-based applications for tasks related to the organization of the work of numerous transactions, as well as managing the cache and storage, for which certain and efficient resource allocation is vital for the functioning and stability of the systems.

4 IMPLEMENTATION

4.1 Overview

For decentralized decision-making among agents in strategic interaction, we suggest Blockchain and the Nash equilibrium, which are then amalgamated with integer linear programming to solve resource allocation. As for the ILP formulation, we employ PuLP which allows us to define and solve ILP models for the transaction fees, distribution of power, and storage optimization; meanwhile, the NumPy package is used for providing numerical values to model interaction and constraints. Visualization of identified resource usage, congestion levels, and optimization outcomes is done using Matplotlib and Seaborn. The resource-sharing networks can be modeled by the NetworkX tool while logging, time, and datetime enables monitoring as well as timestamp. Hashlib is used to ensure cryptographic security and json for transactions. This framework also focuses on congestion control, cost minimization as well as profit maximization and math optimization and game theory functions in a strong Blockchain framework.

4.2 Power Distribution Scenario

In a blockchain system for power distribution, transactions are mailed as digital entries in transactions,checked to ensure compliance with capacity requirements by the nodes. Detection of fraud results in situations being flagged and, thereby, stopping fraudulent transactions. Once validated, the transactions are recorded in a secure and immutable block, which is then passed to an optimization model to distribute power from multiple plants to various regions using two approaches: An ILP and a Nash-like approach, which incorporates penalties. Special types of ILP-integrated models help minimize the entire cost of distribution while meeting demand and capacity constraints in each region and plant. The Nash-like approach targets the allocation of power by the ratio of plant costs and discourages the awarding of overcapacity. Use of a heat map and bar graphs to present the power distribution for both approaches, the total power supplied to each region, and the total power distributed by the plant. The latter helps to compare the efficiency and cost effectiveness of the two methods with a focus on the power distribution rates.

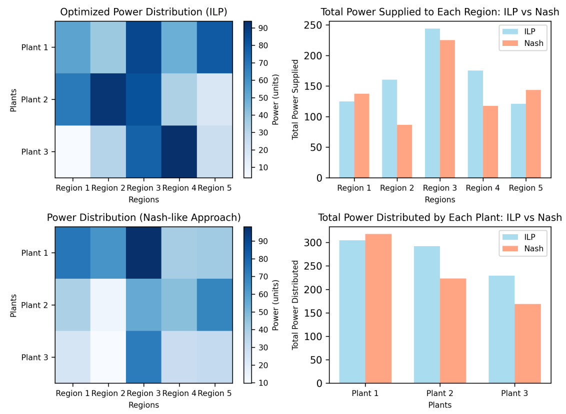

Figure 5: Power Distribution ILP VS NASH

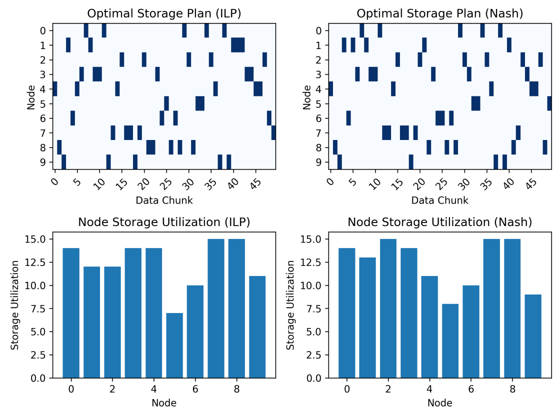

Figure 6: Storage Optimization ILP VS NASH

From Fig. 5. it is clear that the ILP approach decentralized more power among all plants and regions compared to the Nash approach except for Region 5 where Nash provides more power. Power flow under Nash is only tilted upwards from plants to regions; some regions consume more power than others like Region 3 for Plant 1 and Region 2 for Plant 2. However, for ILP, the materials are more evenly divided and more rationally allocated than for FRP, particularly for Plants 2 and 3. In general, ILP has a better distribution of power to plants and regions than that provided by the Nash.

4.3 Storage Optimization Scenario

The sale of storage to be performed on the blockchain goes first through a fraud filter mechanism and then through a profitability-based scheduler, such as transaction fees and efficiency, and then stored in blocks. These transactions in a block are then optimized using two approaches: Combinatorial demand-creation models include ILP and a Nash-like greedy strategy. ILP sets an optimization model to find globally optimal solutions due to balanced resource allocation, minimal storage, and lower latency cost. The Nash-like approach, on the other hand, enables nodes to self-organize the storage by letting nodes decide what they want to store for the faster locally optimal solution. Combined, ILP guarantees the optimal allocation of resources for the future to optimize expenditure throughout the while the Nash-like method is key when facing scenarios that are constantly unpredictable in the present.

From Fig. 6. the simulation results reveal that the proposed ILP approach attains a higher node utilization of 14.5% compared to the Nash approach with a maximum node utilization of 12.5 %. This means that the ILP strategy results in a relatively higher level of hospital utilization compared to Nash. As evidenced by the two plans, the node usage experiences some level of fluctuation, while in ILP, the data chunks are spread evenly across the nodes. However, decentralization of decision making in the Nash approach reduces total utility and indicates a lower efficiency of resource allocation and, in particular, a 2% decrease in overall utilization, with respect to the maximum values obtained using the two methods. This difference suggests the potential of the ILP to create an ideally efficient and balanced storage plan.

4.4 Dynamic High Congestion Management Scenario

Dynamic high congestion in the blockchain networks happens when transaction volume is above the Replace-by-Fee, resulting in a slow rate, higher fees, and network problems. This is sometimes attributed to things such as low block size, overall transactions, and Initial Coin Offering events. Congestion might cause users to pay more fees, which in turn aggravates the problem. Congestion is addressed by some solutions like Nash Equilibrium and Integer Linear Programming Optimization. Frequency line duplication works with the intent of locating many converging nodes that are easily recognizable, since their degree of connection can differentiate them from either one or a few neighbors. The execution time of both the ILPO strategy: The variance is compared with the partner selection approach as a function of variance, execution time, and global performance at different congestion levels.

Examining the four subgraphs in Fig.7. provides valuable information for understanding the relative performance of the Nash equilibrium and the ILP for congestion control. The result derived from the Nash Equilibrium approach reveals a mere, steady rise of variance compared to that depicted by ILP which fea-

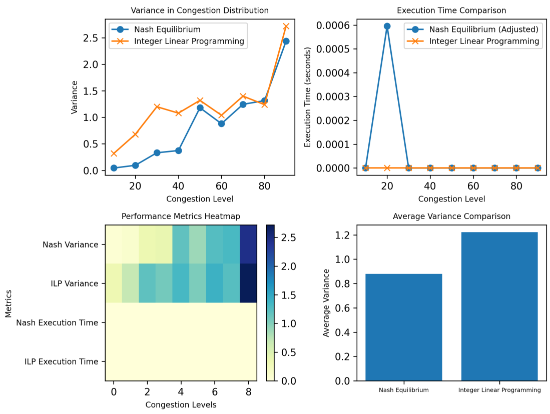

Figure 7: Dynamic Congestion Management NASH VS ILP

tures a steep rise and therefore is more sensitive to congestion. For execution time, Nash Equilibrium has much less fluctuation and keeps a very low moving average while ILP has a much higher moving average at higher congestion levels showing inefficiency at high congestion levels. The heatmap again validates the conclusion that the Nash equilibrium outperforms by achieving fewer variances and shorter execution times. In addition, the average variance for JE and NE is much closer, but the latter is much lower, which explains its efficiency in controlling congestion. In general, therefore, the Nash equilibrium approach is more effective and less sensitive to dynamic high congestion conditions.

4.5 Resource Allocation Scenario

Transactions for resource allocation come into a blockchain network as a request or transfer, typically handled by a smart contract. Since these transactions are done online, they are first filtered by a fraud detection system to filter out fraudulent ones. On verification, they are passed through an optimization model to determine the most appropriate transactions that would yield the highest profits with security and concerning transparency. The validated transactions are then routed to a task distribution module where the authors provide a solution that offers a comparison between two solutions for the management of multi-resource transactions; namely the Nash Equilibrium and the Integer Linear Programming. This module is capable of producing useful performance measures, including computation time and utility, and is efficient in portraying the findings. This is particularly helpful in observing how Nash equilibrium and ILP optimization function in various state circumstances.

In Fig. 8, the runs created for the Nash equilibrium have less computation time than those for ILP,

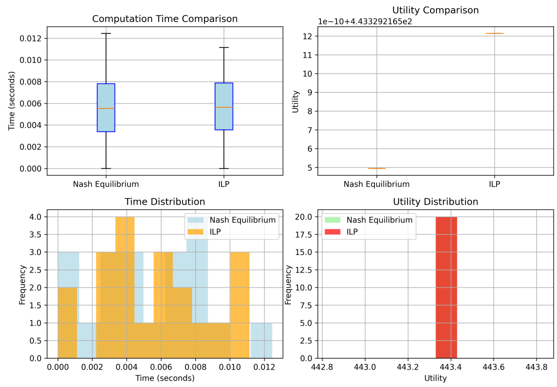

Figure 8: Resource Allocation NASH VS ILP

and there are runs where Nash equilibrium needs significantly less computation time than ILP. Nash equilibrium has a lower median computation time and is more centralized, showing that it delivered faster yet more uniform results. However, as we have seen from the results tables, ILP is less predictable with average computation time for some runs being much higher, which makes it less consistent. Although both methods offer the same amount of utility, Nash Equilibrium has slightly better average utility, and this utility varies less from the average, suggesting lower volatility. The utility distribution plots for both methods are relatively symmetric and close together, and while the means are nearly identical, the Nash equilibrium is slightly higher than coordination, but it is much faster to compute, so it is the better strategy in this case. However, the results show that the Nash equilibrium has better computational performance and is more useful compared to ILP.

5 RESULTS AND DISCUSSIONS

The use of ILP over Nash equilibrium helps to illustrate the important trade-off between efficiency and decentralization in block chain networks. ILP gives optimal decisions worldwide and promotes the redemption of constraints, yet it troubles with greater time consumption and limited extensibility. However, Nash equilibrium is real-time, expandable and less rigid in the dynamic setting, but it is known to produce inefficient results and poor costs. Both are elegant for different reasons as shown in Table 2, ILP more suited to the smaller scale, cost-optimize problem, while Nash equilibrium being far better placed to deal with the more complex real-time problems at scale.

The performance measures employed in the evaluation of Nash and ILP are utilization, capturing re-

Table 2: Comparison of ILP and Nash Equilibrium in Blockchain Network

Metric	ILP (Integer Linear Programming)	Nash Equilibrium
Solution Quality	Globally optimal solution	Suboptimal solution due to decentralized approach
Cost Efficiency	Minimizes total cost, strictly satisfies constraints	Higher cost due to suboptimal allocation
Adherence to Constraints	Strict adherence to all regional demands and plant capacities	May fail to strictly satisfy constraints (e.g., capacity breaches)
Computational Time	Higher execution time due to complex optimization	Faster execution time, better for real-time needs
Scalability	Less scalable for large networks due to computational overhead	Highly scalable due to decentralized nature
Resource Utilization	Balanced and optimal across resources	Uneven utilization, potential under/over utilization
Performance at High Congestion	Higher variance, less effective at handling congestion	Balanced congestion distribution, lower variance
Flexibility in Dynamic Conditions	Less flexible with changes in dynamic conditions due to optimization complexity	More flexible due to decentralized decision-making
Optimization Target	Focus on global optimization (minimizing overall costs)	Focus on local optimization per agent or node
Application Suitability	Best for smaller-scale problems with global optimization requirements	Suitable for larger-scale problems or where execution time is critical
Penalty for Suboptimal Allocation	None, since it provides an optimal solution	Penalties for suboptimal allocations and breaches
Use Case Example	Power Distribution and Storage Optimization in blockchain networks	Blockchain Congestion Management and Dynamic Resource Allocation in blockchain networks

Table 3: Results Based on Power Distribution Scenario

Metrics	Utilization	Fairness	Demand Satisfaction	Load Imbalance
Nash	0.4257	0.6157	0.5162	0.092
ILP	0.6294	0.6682	0.7529	0.0694

source usage; fairness, which ensures equality in resource allocation; demand satisfaction, which portrays user demand satisfaction by the particular system; load balance showing the workload distribution and the throughput which represents system processing capacity; and scalability which displays the system capability in handling intricate demands. These metrics are of pre-importance in evaluating performance, costs, equity, and flexibility, and useful in comparing the efficiency of various systems.

From the results provided in Tables 3 and 4, it can be concluded that ILP outperforms Nash in all observed measures depending on the optimization strategies for power distribution and storage. In the power distribution scenario, this algorithm exhibits superior resource usage, fairness, and demand satisfaction compared to Nash, with a better distribution of client transaction loads on sender nodes. Yet there is one important criticism disregarding the occurrence of the Nash equilibrium, firstly, it cannot ensure proper distribution of resources as well as fair play among all the players involved. For instance, in a situation where many nodes have to draw power from a single power source, Nash can result in certain nodes being favorably allocated a use a lot of power while others are starved of power. Likewise in the storage optimization scenario, ILP provides a more fair solution in which nodes at every point receive more resources and have better resource use efficiency than the centers, and a higher net-utility ratio. ILP also meets demand effectively and handles load differentiation better, making it the preferred method in models where the precision and efficient use of system resources are important. However, Nash equilibrium may be useful, especially when the decisions are needed more frequently and when the pay-offs are especially high for each individual. Specifically, therefore, the ILP is the most suitable for system environments where accuracy and societal improvement are paramount and where the precision of powering different units is important such as smart grid and cloud computing, especially in billing and management of resource data centers and other computing units.

Table 4: Results Based on Storage Optimization Scenario

Metrics	Utilization	Fairness	Demand Satisfaction	Load Imbalance
Nash	0.10	0.9216	1.0	0.2917
ILP	0.52	0.9833	1.0	0.1304

Table 5: Results Based on Dynamic High Congestion Management Scenario

Metrics	Throughput	Fairness	Scalability	Load Imbalance
Nash	0.914375	0.6296	1.0	0.14026
ILP	0.54	0.2192	0.28	0.162

Table 6: Results Based on Resource Allocation Scenario

Metrics	Throughput	Fairness	Scalability	Load Imbalance
Nash	0.92	0.9833	0.9020	0.1304
ILP	0.472	0.8243	0.4608	0.4618

The dynamic high-congestion management and resource allocation that are presented in Tables 5 and 6 show that the proposed Nash equilibrium is superior to the conventional implementation of the ILP approach in terms of total throughput, fairness, and scalability. Hence, the superior performance of Nash, especially in dynamic high-congestion management, makes it suitable for a large decentralized system. In addition, in the resource allocation situation, Nash performs favorably well in the throughput, fairness, and scalability values to support the applicability of the theory to systems where demand and availability vary greatly, scaling utilization better than ILP. In the case of dynamic optimal allocation of resources and especially in cases of quick changes in demand, Nash outperforms ILP in load balancing when the changes in demand are minimal. Since ILP is highly centralized in the computational process and involves high complexity, it is not an optimum solution for dynamic and large-scale applications with frequent changes in the environment, such as a high-congestion resource distribution. However, the Nash equilibrium serves the best purpose in dealing with decentralized problem solving, which is more scalable and effective in complex systems with a number of agents. This has made it the most suitable for use in large systems, decentralized systems, and dynamic systems, especially where congestion is a complication.

6 CONCLUSION

The analysis of the ILP and Nash equilibrium reflects that the selection of the appropriate methodology depends on the system requirements and the characteristics of the scenario. The proposed framework uses ILP in static, optimization-focused stages, such as power distribution and storage, where the strength of the approach, global optimum, and minimum resource wastage come in handy in conditions with little variation and maximum requirement for efficiency. On the other hand, when demand is unpredictable, roads over-saturated, and real-time response crucial, scalability, throughput, and fair resource sharing of Nash Equilibrium are valued, which is beneficial in complex environment with many agents and high demand for timely responses and adaptive behavior. Thus, the framework optimizes resource use by combining trends in the methodology of efficient large-scale organizations with decentralized structures, thus achieving some of the features of both methods needed for dynamic blockchain networks.

Future research may look at how usage of enhanced consensus algorithms or even studying the effect of integration with smart contracts in decision making more deeply. Further expansion of the framework for highly heterogeneous nets and the incorporation of efficient protection against destructive elements in decentralized structures might also improve its relevance. Last but not least, using empirical evaluations over various blockchain applications and the changing environment to identify areas for improvement for additional fine-tuning.

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