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CS 5110: Multi-Agent Systems

Final Project Results

Objective of the Code

The main objective of this final project was to develop a system that simulates and analyzes radio spectrum allocation in wireless communication networks, specifically targeting the management of spectrum resources between Authorized Users (AUs, who own frequencies) and Cognitive Users (CUs, who rent frequencies from AUs). The project's goal was to use game theory to evaluate approaches to spectrum allocation. We looked at metrics such as utility maximization, stability (Nash equilibrium), and efficiency (Pareto optimality), through a series of computations and visualizations. The system calculates the utility of each user based on their assigned frequency, the number of users sharing the frequency, and whether the user is broadcasting. The ultimate goal was to assess whether the allocation strategy used in the paper *Spectrum Allocation of Cognitive Radio Based on Game Theory* (Shu, Qiang, et al.) leads to optimal and stable outcomes.

Our code calculates utilities for each CU, as well as checks for Nash equilibrium (where no user wishes to change their situation) and Pareto optimality (where no user can be made better off without making another worse off). The visualization of our results gave us insights into how efficiently and fairly the frequencies are being allocated. Key metrics such as social welfare (the sum of all utilities) are also calculated and plotted to understand overall system performance.

Significance of Output

The output generated from the system has significant relevance to the field of wireless spectrum management. The simulation provides insights into the efficiency and fairness of spectrum allocation strategies, particularly in environments where multiple users share limited frequency resources.

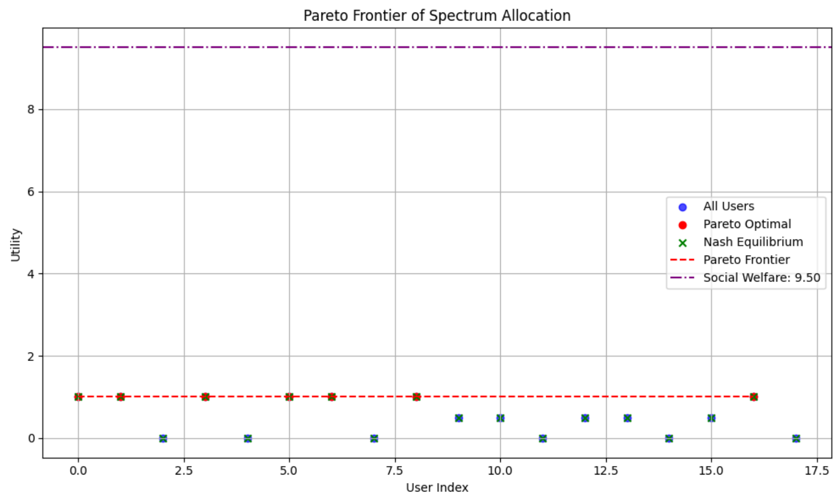

Figure 1*: Graphical representation of the performance of one run of the simulation*

- Utility Distribution and Pareto Frontier: The utility graph shows the benefits users receive and highlights the Pareto frontier, where no user can be better off without making another worse off. This demonstrates the efficiency of the allocation.
- Nash Equilibrium: Nash equilibrium points (marked with the green ‘x’, in this case they overlap the red Pareto marks) indicate stable allocations where no user has an incentive to change their frequency. This ensures the system is conflict free and practical.
- Social Welfare: The social welfare metric (purple dashed line) measures the overall efficiency, indicating how well the system maximizes total utility across all users.

Our output emphasizes the importance of balancing fairness, stability, and efficiency in designing radio spectrum allocation algorithms. We attempted to recreate the allocation algorithm described in the paper we based our project on, but the original researchers, unfortunately, did not include enough specific details to allow an exact duplication of their results. Several assumptions and simplifications had to be made to complete the implementation, which may have led to deviations from the behavior described in the original study. Our current algorithm contains some inefficiencies, indicated by idle users and variable utility levels. It is also not incredibly optimal, and would encounter problems with space and time complexity if applied at scale. If we were to spend more time on the project in the future, additional work could be done to address these concerns.

References

Shu, Qiang, et al. “Spectrum Allocation of Cognitive Radio Based on Game Theory.” *Proceedings of the 2024 6th Asia Pacific Information Technology Conference*, Association for Computing Machinery, 2024, pp. 58–62. *ACM Digital Library*, https://doi.org/10.1145/3651623.3651632.