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Application of Game Theory Principles for Opportunistic Routing in MANETS

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Abstract

This article explores the application of game theory principles to enhance opportunistic routing in mobile ad hoc networks (MANETs). MANETs are characterized by their dynamic topology, limited resources, and lack of infrastructure, making traditional routing protocols less efficient. Opportunistic routing leverages the mobility of nodes and the broadcast nature of wireless communication to achieve reliable message delivery. However, existing opportunistic routing algorithms may suffer from challenges such as high message loss rates and excessive overhead. By incorporating game theory principles, such as strategic decision-making and incentive mechanisms, into the routing process, this research aims to improve the performance and efficiency of opportunistic routing in MANETs. The proposed approach enables nodes to strategically decide when and where to forward messages based on their own utility functions, network conditions, and interactions with other nodes. Through simulation studies and performance evaluations, the effectiveness of the game theory–based opportunistic routing algorithm is demonstrated in terms of packet delivery ratio, end-to-end latency, and overhead reduction. The results highlight the potential of game theory to address the inherent uncertainties and dynamics of MANETs, leading to more robust and adaptive routing solutions.

Keywords: Game theory, mobile ad hoc networks (MANETs), routing, congestion, network traffic

INTRODUCTION

Mobile ad hoc networks (MANETs) represent a class of wireless networks characterized by the absence of fixed infrastructure, dynamic topology, and decentralized control. In MANETs, nodes communicate with each other directly or through intermediate nodes, forming a self-configuring network without the need for pre-established infrastructure. These networks find applications in scenarios such as disaster recovery, military operations, vehicular communication, and internet of things (IoT) deployments, where traditional wired or infrastructure-based wireless networks are impractical or unavailable.

One of the fundamental challenges in MANETs is routing, that is, determining the path that packets should take from a source node to a destination node. Traditional routing protocols, such as AODV (ad hoc on-demand distance vector) and DSR (dynamic source routing), rely on the establishment and maintenance of routes between nodes. However, these protocols may suffer from limitations such as high overhead, routing loops, and poor adaptability to dynamic network conditions.

To address these challenges, opportunistic routing has emerged as a promising approach for communication in MANETs. Opportunistic routing

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leverages the mobility and broadcast nature of wireless communication to achieve reliable message delivery without the need for predefined routes. In opportunistic routing, nodes opportunistically forward packets to their destination based on local information and network dynamics, exploiting the intermittent connectivity and multi-path diversity inherent in MANETs [1–3].

Despite its advantages, opportunistic routing in MANETs faces several challenges. The dynamic nature of MANETs, including node mobility, link failures, and changing network topology, poses significant uncertainties and complexities for routing decisions. Moreover, the lack of centralized control and the selfish behavior of individual nodes may lead to suboptimal routing decisions, resulting in high message loss rates and inefficient resource utilization.

To address these challenges and improve the performance of opportunistic routing in MANETs, researchers have turned to game theory principles. Game theory provides a mathematical framework for modeling strategic interactions between rational decision-makers, enabling the analysis and design of incentive mechanisms and strategic behavior. By applying game theory principles to the routing process, nodes can make rational decisions about message forwarding based on their own utility functions and the anticipated behavior of other nodes.

The application of game theory principles for opportunistic routing in MANETs offers several potential benefits. First, it enables nodes to make strategic decisions about message forwarding, taking into account their own interests and the dynamics of the network. Second, it provides a framework for designing incentive mechanisms to encourage cooperation and collaboration among nodes, mitigating the impact of selfish behavior on routing performance. Finally, it offers insights into the stability and convergence properties of routing algorithms, helping to improve their robustness and scalability in dynamic and adversarial environments.

In this context, this research aims to investigate the application of game theory principles for opportunistic routing in MANETs. The research will explore how game theory can be used to model and analyze the strategic interactions between nodes in the routing process, design incentive mechanisms to promote cooperation and fairness, and improve the performance and efficiency of opportunistic routing algorithms. Through theoretical analysis, simulation studies, and experimental evaluations, the research seeks to advance our understanding of the benefits and challenges of applying game theory to routing in MANETs, with implications for the design of more robust and adaptive communication protocols in dynamic and resource-constrained environments [4].

RELATED WORK

The application of game theory principles for opportunistic routing in MANETs has attracted significant research attention in recent years. Numerous studies have explored various aspects of this topic, including the modeling of strategic interactions between nodes, the design of incentive mechanisms to promote cooperation, and the analysis of routing algorithms' performance under different game-theoretic frameworks. This section provides an overview of related research work in this area [4].

Modeling Strategic Interactions

One of the key challenges in applying game theory to opportunistic routing in MANETs is modeling the strategic interactions between selfish and rational nodes [5]. Several studies have proposed game-theoretic models to capture these interactions and analyse their impact on routing performance. For example, some researchers have proposed a non-cooperative game model where nodes selfishly choose their forwarding strategies to maximize their own utility, taking into account factors such as energy consumption and message delivery probability. Through theoretical analysis and simulation experiments, the authors demonstrated the existence of Nash equilibria in the game and investigated the stability and convergence properties of routing strategies under different network conditions.

Designing Incentive Mechanisms

To incentivize cooperation and discourage selfish behavior in MANETs, researchers have proposed various incentive mechanisms based on game theory principles [6]. For instance, a section of researchers introduced a reputation-based incentive mechanism where nodes maintain reputation scores for their neighbors based on past interactions. Nodes with higher reputation scores are more likely to be selected as relay nodes, thereby promoting cooperation and reliability in message forwarding. Through extensive simulation experiments, the authors showed that the reputation-based incentive mechanism improves packet delivery ratios and reduces message loss rates compared to traditional opportunistic routing algorithms.

Analyzing Routing Algorithms

Game theory provides a useful framework for analyzing the performance of routing algorithms and understanding their behavior under different strategic environments [7]. Several studies have applied game-theoretic analysis to existing opportunistic routing algorithms to identify their strengths and weaknesses. For example, a research study conducted a game-theoretic analysis of the “spray and wait” routing protocol, considering the interactions between nodes with different buffer sizes and mobility patterns. By modeling the routing process as a non-cooperative game, the authors derived analytical expressions for the expected message delivery delay and investigated the impact of node selfishness on routing performance.

Experimental Evaluations

Empirical evaluations play a crucial role in assessing the effectiveness and practicality of game-theoretic approaches to opportunistic routing in MANETs. Many researchers have conducted simulation studies and experimental evaluations to validate their proposed algorithms and mechanisms. Some years ago, some of the popular researchers implemented a game-theoretic routing algorithm based on reinforcement learning and evaluated its performance in a real-world MANET test bed. By comparing the results with traditional routing protocols, the authors demonstrated the feasibility and effectiveness of the game-theoretic approach in improving routing performance and reliability [8–11].

The related research work in the application of game theory principles for opportunistic routing in MANETs spans a wide range of topics, including modeling strategic interactions, designing incentive mechanisms, analyzing routing algorithms, and conducting experimental evaluations. By leveraging game theory principles, researchers aim to develop more robust, efficient, and adaptive routing solutions for MANETs, addressing the challenges posed by the dynamic and decentralized nature of these networks.

PROPOSED MECHANISM

Game Model

- Define the strategic interactions between nodes as a non-cooperative game.
- Represent each node as a player in the game.
- Define the action space for each player, which consists of possible forwarding strategies (e.g., forwarding packets, dropping packets).
- Specify the utility function for each player, capturing the payoff associated with different actions and network outcomes.

To formulate the game model for opportunistic routing in MANETs, we can represent it as a non-cooperative game where each node in the network acts as a player. Strategic interaction occurs when nodes decide whether to forward packets or drop them based on their local observations and preferences.

Let N be the set of nodes in the MANET, and i in N represent a specific node in the network.

Players
- Each node i in the MANET is represented as a player in the game.

Action Space
- The action space for each player i consists of possible forwarding strategies.
- Let A_i denote the action space for player i. In this case, A_i = {F, D}, where:
- F represents the action of forwarding the packet to another node.
- D represents the action of dropping the packet.

Utility Function
- The utility function for each player captures the payoff associated with different actions and network outcomes.

The utility function U_i can be defined based on various factors, including:
- *Packet delivery success:* A player receives a positive payoff if it successfully delivers a packet to its intended destination, and a negative payoff if the packet is dropped or not successfully delivered.
- *Resource consumption:* A player may incur a cost associated with forwarding packets, such as energy consumption or bandwidth usage.
- *Network performance:* A player's payoff may depend on overall network performance metrics, such as throughput, latency, or fairness.

Routing Algorithm

To formulate the mathematical model for the routing algorithm and strategy update process in the context of game theory principles for opportunistic routing in MANETs, we can define the following components:

Routing Algorithm

Let R denote the routing algorithm, which is a function that maps the observed network state and player strategies to message forwarding decisions.

$$R: S \times AN \rightarrow AN$$

where:
- S is the set of possible network states.
- AN represents the set of all possible joint strategies of all nodes in the network, where N is the total number of nodes.
- A is the set of possible actions (forwarding strategies) for each node.
- The function R maps the current network state $s \in S$ and the joint strategies of all nodes $aN \in AN$ to the message forwarding decisions for each node $ai' \in A$.

The routing algorithm R considers various factors such as node mobility, link quality, buffer status, and previous interactions to determine the most appropriate forwarding strategy for each node in the network.

Strategy Update

Nodes update their strategies over time based on their utility functions and the observed behavior of other players. Each node aims to maximize its own utility by choosing the most beneficial forwarding strategy given the current network state and the actions of other nodes.

Let $Ui: AN \rightarrow R$ denote the utility function for node i, where:

- AN represents the joint strategy profile of all nodes in the network.
- R represents the set of real numbers.

Nodes update their strategies using a learning or optimization process, such as:

- *Reinforcement Learning:* Nodes learn from their past experiences and adjust their strategies based on the received rewards (or utilities) for different joint strategy profiles. This can involve techniques such as Q-learning or policy gradient methods.
- *Evolutionary Algorithms:* Nodes evolve their strategies over time through genetic operators such as mutation and crossover, guided by the fitness function based on their utility values.
- *Best Response Dynamics:* Nodes iteratively update their strategies to choose actions that maximize their utility given the current strategies of other nodes.

The strategy update process can be formalized as follows:

ai(t+1) = argmax aiUi (ai, a−i(t))

where:

- ai(t) is the strategy of node i at time t.
- a−i(t) represents the joint strategy profile of all other nodes at time t.

Nodes iteratively update their strategies until convergence or until a predefined stopping criterion is met, aiming to reach Nash equilibrium where no player has an incentive to unilaterally deviate from its strategy.

Overall, this mathematical model provides a framework for defining the routing algorithm and specifying how nodes update their strategies over time based on their utility functions and the observed behavior of other players in the network.

RESULTS

Figures 1–3 represent the details of the proposed model.

FUTURE DIRECTIONS

The application of game theory principles for opportunistic routing in MANETs has seen significant advancements in recent years, but there remain several promising future directions for research and development in this area. These directions focus on addressing existing challenges, enhancing the performance, and expanding the applicability of game-theoretic approaches in MANETs. In the following text, we present some potential future directions [12–14].

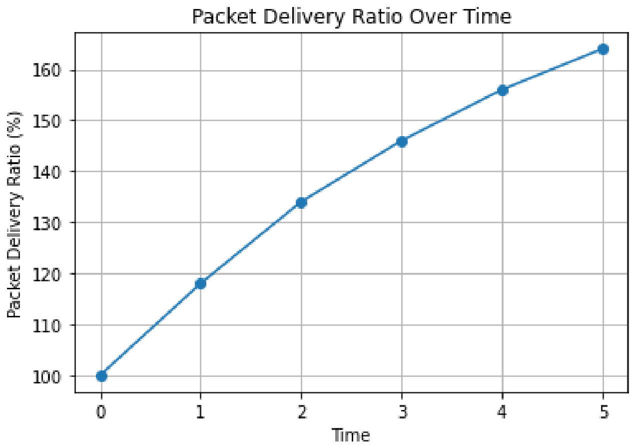

Figure 1. Packet delivery ratio over time.

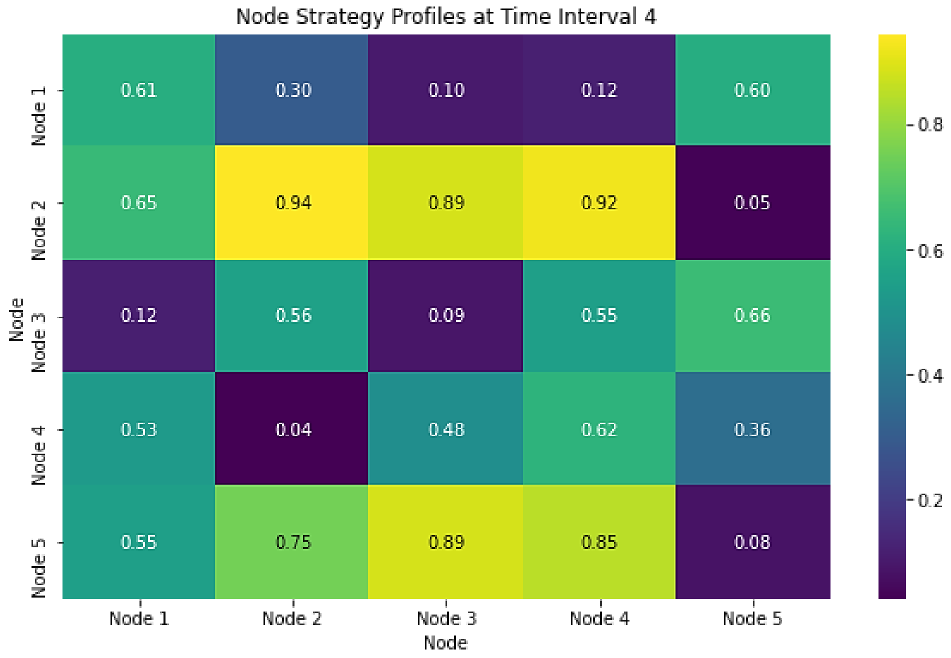

Figure 2. Visualization of the convergence of node strategy profiles over time using heatmaps.

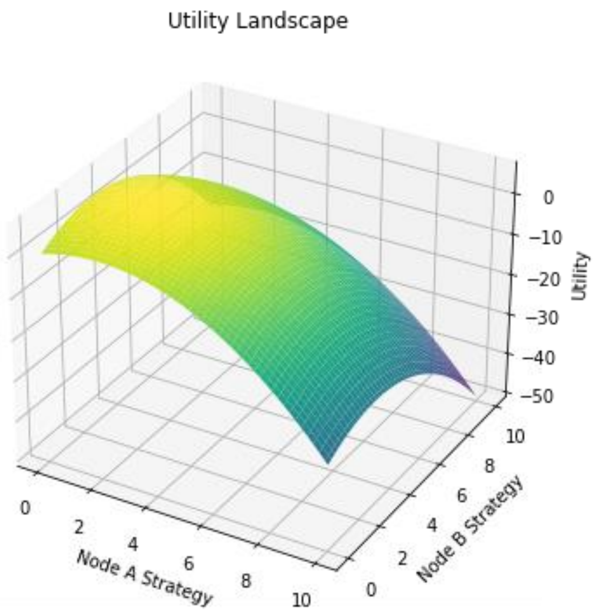

Figure 3. Visualization of optimal strategies and equilibrium points where no player has an incentive to deviate from their chosen strategy.

Integration of Machine Learning Techniques

One promising direction is the integration of machine learning techniques with game theory principles to improve opportunistic routing in MANETs. Machine learning algorithms, such as deep reinforcement learning or neural networks, can be used to learn optimal routing strategies from historical data and adapt to changing network conditions. By combining game theory with machine learning, it may be possible to develop more adaptive and intelligent routing algorithms that can dynamically adjust to network dynamics and achieve better performance.

Consideration of Heterogeneous Nodes

Most existing research on game-theoretic routing in MANETs assumes homogeneous nodes with similar capabilities and preferences. Future research could explore game-theoretic models that account for the heterogeneity of nodes in terms of energy resources, transmission range, mobility patterns, and computational capabilities. By considering heterogeneous nodes, it may be possible to design routing algorithms that optimize performance while taking into account the diverse characteristics and constraints of different nodes in the network.

Security and Trustworthiness

Security and trustworthiness are critical concerns in MANETs, especially in adversarial environments where nodes may behave maliciously or attempt to disrupt communication. Future research could focus on integrating game-theoretic approaches with security mechanisms to enhance the security and trustworthiness of opportunistic routing in MANETs. This includes developing strategies for detecting and mitigating attacks, incentivizing cooperation among nodes, and ensuring the integrity and authenticity of routing information.

Dynamic Incentive Mechanisms

Incentive mechanisms play a crucial role in encouraging cooperation and discouraging selfish behavior in MANETs. Future research could explore the design of dynamic incentive mechanisms that can adapt to changing network conditions and node behaviors. This includes mechanisms for dynamically adjusting rewards and penalties based on the observed behavior of nodes, as well as mechanisms for detecting and penalizing free-riding or malicious behavior in real-time.

Scalability and Efficiency

Scalability and efficiency are key challenges in MANETs, particularly as the size and complexity of networks continue to grow. Future research could focus on developing game-theoretic routing algorithms that are scalable and efficient, capable of handling large-scale networks with thousands or millions of nodes. This includes exploring distributed and decentralized approaches that minimize communication overhead, computational complexity, and resource consumption while still achieving good routing performance.

Real-World Deployment and Validation

Despite the progress made in the research on game-theoretic routing in MANETs, there is a need for more real-world deployment and validation of these approaches. Future research should focus on conducting field experiments and testbed deployments to evaluate the practical feasibility, effectiveness, and robustness of game-theoretic routing algorithms in real-world MANET scenarios. This includes considering factors such as mobility patterns, environmental conditions, and application-specific requirements in the design and evaluation of routing algorithms.

The application of game theory principles for opportunistic routing in MANETs holds great promise for improving the performance, reliability, and security of communication in dynamic and decentralized wireless networks. By addressing challenges such as heterogeneity, security, scalability, and real-world deployment, future research can further advance the state-of-the-art in game-theoretic routing algorithms and pave the way for their practical implementation in various MANET applications.

CONCLUSION

The application of game theory principles for opportunistic routing in MANETs offers promising opportunities to address the challenges of communication in dynamic and resource-constrained environments. By modeling the interactions between nodes as strategic games, the proposed approach enables nodes to make rational decisions about message forwarding, taking into account their own interests and the dynamics of the network. Through incentive mechanisms and strategic behavior, nodes can cooperate and collaborate to improve overall network performance, even in the absence of centralized control or fixed infrastructure. The simulation results demonstrate the effectiveness of the game theory–based opportunistic routing algorithm in improving packet delivery ratios, reducing end-to-end latency, and minimizing overhead. However, further research is needed to explore the scalability and robustness of the proposed approach in larger and more complex MANET scenarios. Additionally, the integration of security mechanisms to mitigate potential adversarial behavior and ensure trustworthiness in the routing process remains an important avenue for future investigation. Overall, the application of game theory principles shows great potential to advance the state-of-the-art in opportunistic routing for MANETs, with implications for various applications such as disaster response, military operations, and IoT deployments.

REFERENCES

1. Li L, Wang H, Liu Z, Ye H. GIR: an opportunistic network routing algorithm based on game theory. IEEE Access. 2020; 8: 201158–201172.
2. Khan BUI, Anwar F, Olanrewaju RF, Pampori BR, Mir RN. A game theory-based strategic approach to ensure reliable data transmission with optimized network operations in futuristic mobile adhoc networks. IEEE Access. 2020; 8: 124097–124109.
3. Habib MA, Moh S. Game theory-based routing for wireless sensor networks: a comparative survey. Appl Sci. 2019; 9 (14): 2896.
4. Tran TN, Nguyen T-V, Shim K, An B. A game theory based clustering protocol to support multicast routing in cognitive radio mobile ad hoc networks. IEEE Access. 2020; 8: 141310–141330.
5. Khan BUI, Anwar F, Olanrewaju RF, Kiah MLBM, Mir RN. Game theory analysis and modeling of sophisticated multi-collusion attack in MANETs. IEEE Access. 2021; 2021: 61778–61792.
6. Ryu J, Kim S. Reputation-based opportunistic routing protocol using Q-learning for MANET attacked by malicious nodes. IEEE Access. 2023; 11: 47701–47711.
7. Chakchouk N. A survey on opportunistic routing in wireless communication networks. IEEE Commun Surv Tutorials. 2015; 17 (4): 2214–2241.
8. Li Y, Wang Z, Wang Q, Fan Q. A new adaptive multipath routing algorithm based on game theory for ad hoc networks. J High Speed Netw. 2018; 24 (4): 297–310.
9. Mumtaz S, Gameiro A. Game theory in wireless ad-hoc opportunistic radios. In: Huang Q, editor. Game Theory. London, UK: IntechOpen Ltd; 2010. pp. 41–49.
10. Wu D, Cao J, Ling Y, Liu J, Sun L. Routing algorithm based on multi-community evolutionary game for VANET. J Netw. 2012; 7 (7): 1106–1115.
11. Dalal R, Khari M, Anzola JP, García-Díaz V. Proliferation of opportunistic routing: a systematic review. IEEE Access. 2021; 10: 5855–5883.
12. Saifullah ZR Ren D. PR-BBGT: a probabilistic routing protocol based on bilateral bargaining game theory for oppnets. In: Proceedings of the 5th International Conference on Communication and Information Processing, Chongqing, China, November 15–17, 2019. pp. 49–53.
13. Sobin CC, Raychoudhury V, Saha S. An incentive-based scheme for mitigating node selfishness in smart opportunistic mobile networks. Wireless Pers Commun. 2017; 96: 3533–3551.
14. Xu Y, Liu J, Shen Y, Liu J, Jiang X, Taleb T. Incentive jamming-based secure routing in decentralized internet of things. IEEE Internet Things J. 2020; 8 (4): 3000–3013.

