Optimized Solutions for Routing Issue in IEEE 802.11 based Wireless Mesh Networks using Cooperative Game Theory and Bargaining Solutions

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ABSTRACT

Routing is a major issue in the Wireless Mesh Networks. Game theory can be one of the solutions to this problem. The outcomes of the game theory can be sometimes not Pareto-optimal for the leader follower approach, so cooperative solution can be used to enhance the optimality of the solution or make them Pareto optimal. In this paper we presented an analytical model to inculcate the concept of bargaining and cooperation. This is done by associating the channel with various levels of QOS, so that the user can negotiate with the manager for different types of applications according to their QOS requirement. This proposed model can increase the throughput of the network also.

General Terms

Optimizing Wireless Mesh Networks using Cooperative games, Bargaining Solutions, Negotiations.

Keywords

Bargaining solutions, cooperative game, Leader-follower game, Pareto-solutions, Quality of service.

1. INTRODUCTION

Wireless Mesh networks are the highly promising techniques in the today's era. The optimization of the Wireless Mesh networks is the main area where the research is confined these days. Ample number of tools can be applied to optimize the WMNs. While looking into the history, game theory is the main tool for various economists for getting the best results from the economic deals. From this inspiration game theory is selected as the tool to optimize routing in the wireless mesh networks.

In [25] we introduced a game theoretic model for a node to find the optimal route from the given set of routes. One important limitation of the work is that we have limited our self to the case in which each node sends the traffic to a single node in the network and only the single flow of the traffic through the channel/route is considered. Since in this case we are evaluating the channel with restriction to single flow then if the link is shared by more than one node then the previous approach is of no use. We now extent the analysis to a more general case in which if the link is shared by more tan one nodes, then the manager provides the channel allocation according to the traffic being sent by the requesting node. So, the manager provides the variable QOS levels to the nodes for different types of traffic. If the node wants to transfer VOIP then high QOS is needed for transmission despite of the factor of cost. If the traffic is video then intermediate QOS level can be used and if its data the user can even opt for low QOS routes with minimal costs. So, in this work, we are implementing IEEE 802.11e to provide better efficiency of the route.

1.1 Related Work

As in [3] Wireless mesh networks (WMNs) consist of mesh routers and mesh clients, where mesh routers have minimal mobility and form the backbone of WMNs. They provide network access for both mesh and conventional clients. The integration of WMNs with other networks such as the Internet, cellular, IEEE 802.11, IEEE 802.15, IEEE 802.16, sensor networks, etc., can be accomplished through the gateway and bridging functions in the mesh routers. Mesh clients can be either stationary or mobile, and can form a client mesh network among themselves and with mesh routers. WMNs are anticipated to resolve the limitations and to significantly improve the performance of ad hoc networks, wireless local area networks (WLANs), wireless personal area networks (WPANs), and wireless metropolitan area networks (WMANs). They are undergoing rapid progress and inspiring numerous deployments. WMNs will deliver wireless services for a large variety of applications in personal, local, campus, and metropolitan areas. Despite recent advances in wireless mesh networking, many research challenges remain in all protocol layers.

Routing in the WMN's deals with the selection of the best optimal routes from an available route set, so the node has to define the route to be selected on the bases of certain criterion. One of the ways is to find out the optimal route using the routing metrics. These route metrics may be hop count, ETX, ETT etc. Hop count is not the fruitful routing metrics due to certain limitations. As the nodes are almost stationary in case of the WMN's with limited mobility, So ETX can be selected. The ETX metric measures the expected number of transmissions, including retransmissions, needed to send a unicast packet across a link. The ETX metric incorporates the effects of link loss ratios, asymmetry in the loss ratios between the two directions of each link, and interference among the successive links of a path. In contrast, the minimum hop-count metric chooses arbitrarily among the different paths of the same minimum length, regardless of the often large differences in throughput among those paths, and ignoring the possibility that a longer path might offer higher throughput. In [9] it is observed that ETX improves the throughput.

As in [6] routing metrics and protocols are evolving by designing algorithms that consider link quality to choose the best routes. In this work, the state of the art in WMN metrics and taxonomy for WMN routing protocols is analyzed.

[11] reveals that metric unaware of the link quality cannot guarantee reasonable stability and acceptable loss rates . Routing in wireless mesh networks has evolved by designing algorithm that takes wireless medium conditions into account. Thus, the recently proposed metrics reflect various physical–layer characteristics, such as loss probability and transmission rate.

In [2] Non-cooperative game theory is proposed to get better routing method by heuristic method based on simulated annealing.

In [31] the author presents the concept of incompletely cooperative game theory and used it to improve the performance of MAC protocols in WMN's and finally concluded that the incompletely cooperative game theory helps to increase the system throughput, decrease delay, jitter and packet loss rate and supports the game effectively. Each node estimates the current state of the game and then adjusts its equilibrium strategy by tuning its local contention parameters to the estimated game state. A hybrid CSMA/CA protocol is developed and studied for WMNs.

After the review of [16] it is found that game theory can be implemented in the WMN's for routing. For routing the policy of source routing is followed, where the complete route for each packet is determined by the packet source. In this problem, the players in the game could be viewed as the source nodes in the network, but it is slightly more convenient to view a player as a source/destination pair. (In reality, the decision making will be carried out by the source, but making the source/destination pair the player allows for the existence of multiple flows from a single source.) The action set available to each player is the set of all possible paths from the source to the destination. Preferences in this game can take several forms, but we will assume that the preferences are determined by the end-to-end delay for a packet to traverse the chosen route. A short delay is preferred to a longer delay. If a network contains only a single source and destination pair, or if the available routes were completely disjoint, this problem would represent a simple optimization problem. In the realistic scenario, though, many of the links in the network may potentially be shared by multiple routes. Presumably, the more flows use a given link, the higher the delay will be on that link. It is this dependency that is the source of the game theoretic routing problem. One of the most interesting results to come from consideration of this type of problem is the Braess paradox. Suppose that a given network has reached equilibrium. One might assume that if you add additional links to the network, then performance will improve, at least, on average. Such an assumption would be incorrect, though, as one can readily generate examples where the addition of new links to the network actually degrades network performance for all users. This phenomenon, where more resources lead to worse performance, is known as the Braess paradox.

In[12], Mark Felegyhazi, et. al. Specifies the behavior of nodes as the payers of the game because the radio communication channel is usually shared in wireless networks. In this tutorial author has discussed various types of games modeled for the wireless networks. According to the author(s) In Joint packet forwarding game the players has to establish the packet forwarding service. In static games or single stage games i.e. pure strategy , the players have only one move as the strategy. It means the player have only one move as the strategy but this does not correspond to the time slot of the networking protocol. The mixed strategy is a probability distribution over his pure strategies. In the dynamic game, the player might have a sequential interaction; meaning that the move of one player is conditioned by the move of the other player i.e., the second mover knows the move of the first mover before making his decision.

In [7], Xi-Ren Cao, et.al. in his work specifies that the basic concept of leader-follower, cooperative, and two-person nonzero sum games, and applied to internet pricing issue. The leader-follower game may lead to a solution that is not Pareto optimal and in some cases may be "unfair" and that the cooperative game may provide a better solution for both the Internet Service Provider(ISP) and the user.

In [18], Mohammad Naserian et.al. introduces a game theoretic method, called forwarding dilemma game (FDG),which controls routing overhead in dense multi-hop wireless ad hoc networks. The players of the game are the wireless nodes with set of strategies {Forward, Not forward}. The game is played whenever an arbitrary node in the network receives a flooding packet. In FDG, every player needs to know the number of players of the game. That is why a neighbor discovery protocol (NDP) is introduced. In order for NDP to function, a field is attached to the flooding packets (routing overhead packets). The mixed strategy Nash equilibrium is used as a solution for the FDG. This provides the probability that the flooding packet would be forwarded by the receiver node. FDG with NDP is implemented in AODV protocol in Network Simulator NS-2 to verify its performance with simulations. FDG with NDP improves performance of the AODV compared to the same network with only AODV protocol in moderate and high node densities. FDG can be applied to any routing protocol that uses flooding in the route discovery phase.

From the above literature it is clear that Game Theory is a very suitable tool to model and study systems where the parties involved are competing for resources and are aware that their decision has a direct impact on the other parties of the system. Admission control has been a research area where game theory has been extensively used in Wireless Mesh Networks[27].

2. ANALYTIC MODEL

2.1 Modeling the Problem

The game starts when there is a request from the node to transmit data to some destination. Using game theory the node finds the route which is highly optimized i.e. the route with low ETX and high throughput [25]. Now, in this paper we extended the implementation of the game theory in routing from admission control to the route decision. This approach can be presented as follows:-

According to our previous paper [25] we considered two players: User and Network Manager. Here 'user' is the node which wants to transmit the data over the route and manager is the gateway node which will implement cost on the route to break the selfish behavior of the node. In this paper we are implementing the cooperative game theory to the result so derived from the Leader-follower approach in[25], in order to make the solution more optimal. In case of the Leader-follower approach, when the utility of the network increases, the utility of the user decreases. So, the user has to shift again and again to various routes to send the traffic. This will lead to the increased power and battery loss for the nodes. In the previous solution when the node is reached at the Nash point then the utility of the user decreases exponential and ultimately becoming negative. So at that point the user has to switch the route. The current work is dealt with the cooperation among the user and the network and the problem is extended to the cross layer issue(i.e. Data link layer and Network layer).

In this we will be establishing more than one routes through one link and they are being controlled by the manager. This is done by considering various levels of QOS i.e. QOS level1 (High QOS or low ETX path), QOS level2 (Intermediate QOS or ETX ranging from 50 to 100), QOS level3 (Low QOS or ETX beyond 100). So, each path /route is associated with 3 levels of QOS which means that the user can have three types of paths on a channel.

Let us explain with an example, suppose a node (n) wants to send the traffic to a node (d). It selects the optimized path by using game theory. Now if that path is having the link which is being used by some other route then the applicant node has to either wait or check for the channel which is free on that link. At this stage the node checks the QOS level of the channel and if it find the channel suitable for its application it establishes the route and start sending the data. Once the route is established the manger start imposing the cost on it and the game is started between the user and the ISP.

2.2 Implementation of Game Theory for the current problem

Following table shows the scenario for the players in the game of routing packets from source to destination:

Player	**Move**
New Node	a) Except the route with existing QOS level
	b) Wait for the availability of the optimal route.
Existing Node	a) Send traffic on the existing route
	b) Does not opt for bargaining and starts searching for the new route.
Manager	a) Accept the route with current QOS and the apply cost to the route.
	b) Rejects the route with current QOS

When the Leader-follower solution has reached then cooperation among the nodes can be implemented. Here in this case we are considering leader follower solution point as the start point for the cooperative solution. As cooperation needs the binding of the players with certain coalitions, we are proposing the agreement that when the utility of any of the player starts decreasing it may bargain or it may leave the route. So we implemented the Egalitarian bargaining solution, when the nodes want to bargain without rationality and implemented Nash Bargaining solution when the nodes want to behave rationally.

The equations for the user and Manager before cooperation are:-

Utility of User,

$$U = \lambda_{eff} P_T g(etx) - \lambda_{eff} x$$

And utility of manager,

$$V = \lambda_{eff} x$$

In case of the Egalitarian bargaining solution(EGS), the overall payoff (V_N) is divided equally among the players according to the following equations:

So $V_s = V_N / 2$

After the cooperation, according to EGS the utility of user becomes :

$$U = \lambda_{eff} P_T g(etx) - \lambda_{eff} x + V_s$$

And that of the Manager becomes:

$$V = \lambda_{eff} x + V_s$$

Here V_s and $V_N \subset S$

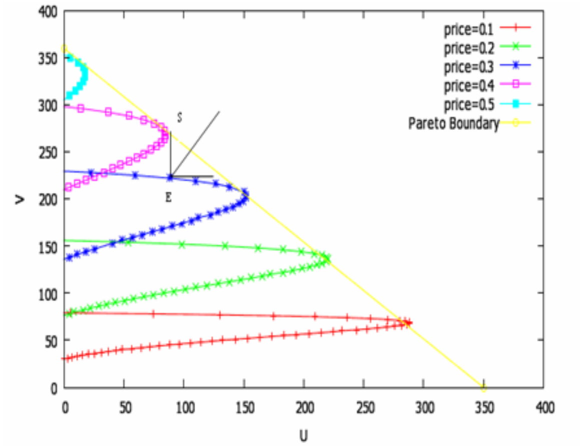

Fig 1: Outcome of Leader follower game for VOIP Traffic

Where S is the set of possible outcomes/utilities derived from the game. Fig below is the outcome of the leader follower game[25], in this we consider a point E from the solution space. In order to optimize the solution at this point, we divide the payoff equally among the Manager and the user. The resultant of this intersects the Pareto boundary at the point S.

On the other hand , if the player wants to bargain only for a limited set of solutions then they will adopt the Nash bargaining solution(NBS).

In case of NBS, the solution for cooperation is :

$$U(x) - U(d) * V(y) - V(d)$$

Where $U(d)$ and $V(d)$ are the utilities obtained if one decides not to bargain with the other player and here 'd' is the element of S corresponding to the disagreement outcome.

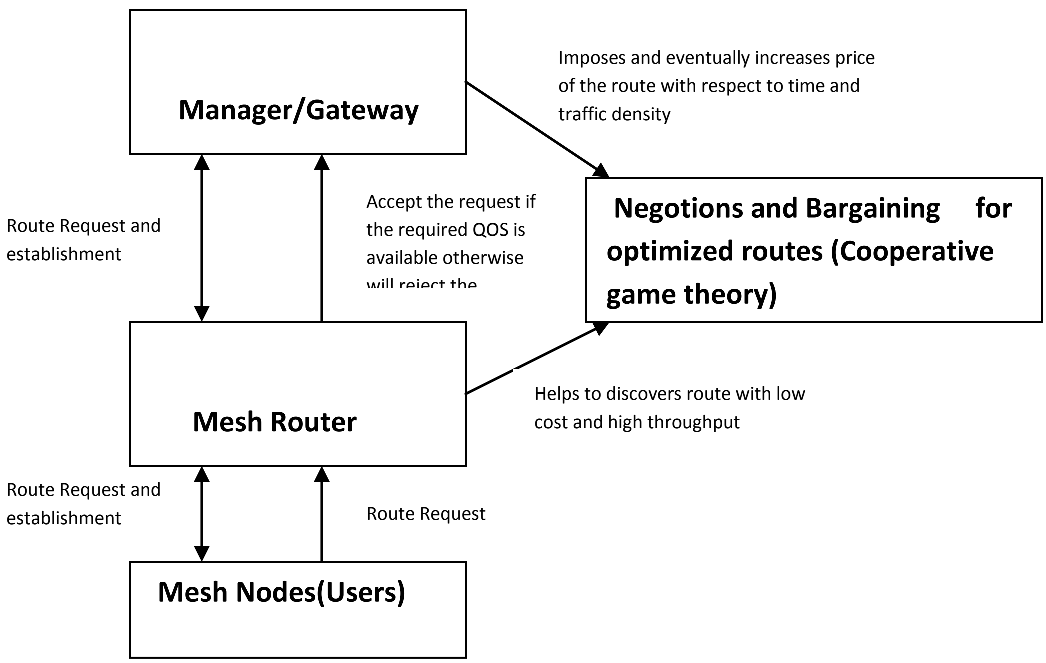

Fig 2: Proposed Model

3. CONCLUSIONS

At this stage we have concluded that the solution with leader-follower approach is not the optimized one, cooperative solution can be the approach which can lead to more optimized route selection for the routing issue. User can have more than one options for negotiation and they can negotiate according to their willingness.

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