Multi-radio Multi-channel Network Channel Assignment Model Based On Game Theory *

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Abstract

Channel assignment has been extensively studied in wireless network such as cellular network, with the appearance of the new multi-radio multi-channel network such as wireless mesh network and cognitive radio network, channel assignment in such network has been a hot research topic again. In this paper, we use game theory to study the channel assignment problem, we model channel assignment in multi-radio multi-channel network as a non-cooperative game, we define a utility function that consider the channel load-balance and fairness among players and thus build up the channel assignment game model, based on the model we propose a novel channel assignment algorithm with fairness and load-balance based on the model. Finally we evaluate the proposed model and algorithm, the simulation results show the model can achieve in fairness among the players and load balance of the channel.

Keywords: Channel Assignment; Multi-radio Multi-channel Network; Game Theory

1 Introduction

Frequency division multiple access (FDMA) is one of the widely used technique in most wireless network such as 802.11 WLAN and 802.11 mesh network, FDMA divides the available frequency to different channel. Due to the number of channels available is limited, it needs corresponding channel assignment mechanism to improve the multi-radio and multi-channel wireless network performance, thus the channel assignment in such system becomes a deserved research topic again.

Though there has been a significant amount of work on channel assignment in wireless networks such as cellular networks, there all assumed that the node in the network is cooperate and well-behaved, in reality they can have selfish node in the network. So the wireless network should provide some incentive mechanism to enforce node behave cooperatively. Game theory is
a powerful tool to study situations of conflict and cooperation, which is concerned with finding the best actions for player decision makers in these situations and recognizing stable outcomes. In this paper, we assume the node in the network is rational and selfish, and then present a game-theoretic framework to analyze channel allocation problem of different nodes which use multiple radios. Using non-cooperative game theory, we analyze the scenario of a single collision domain channel assignment, i.e., where each of the nodes can interfere with a transmission of every other device. We model channel assignment in such system using game theory, and then we propose a channel assignment algorithm with fairness and load-balance based on the model. Finally we evaluate the validity of our proposed model.

The paper is organized as follows. In Section two, we present related work on channel allocation in wireless networks and others work on using game theory to analyze wireless network. In Section three, we present the technical Preliminaries. In Section four, we introduce our channel assignment game model, and put forward channel assignment algorithm for computing globally channel assignment with load-balance. In section five we present the numerical evaluation results. Finally, we conclude the paper in Section six.

2 Related Work

There are many work have been done in the wireless network channel assignment, especially in cellular network, according to the existing channel assignment in cellular network they can be divided into fixed channel allocation (FCA), dynamic channel allocation (DCA), and hybrid channel allocation (HCA) [1]. Due to the emergence of new wireless technology, Mishra et al. utilize weighted graph coloring to address channel allocation for WLANs [2]. Mishra et al. use client-driven mechanisms to address the joint problem of channel assignment and load balancing in centrally managed WLANs [3].

Recently, with the more and more multiple radio device was used in wireless network(such as mesh network), multi-radio multi-channel wireless network become a hot research area again. In the multi-radio wireless network, channel allocation became one of the crucial topics. Jinling Wang et al propose a practical Multi-Channel Multi-Radio Wireless Mesh Networks based on the measured traffic demand on the network [4], Minho Shin et al propose distributed channel assignment model for Multi-radio wireless networks which don’t consider routing, it can maintains network connectivity [5]. Kodialam et al. consider channel assignment together with routing or scheduling in order to maximize network throughput [6]. Anjum Naveed et al propose a cluster-based multipath topology control and channel assignment scheme Multi-Radio Multi-Channel Wireless Mesh Networks which ensure basic network connectivity and minimal overheads [7].

All the channel assignment models described in the previous paragraphs are assumed the node is well behaved, but in the reality environment there may exist some selfish nodes in the network, so we can apply game theory to study channel allocation, M. Felegyhazi et al model multi-radio multi-channel allocation as a static game model, and proof the existence of the model Nash Equilibrium[8], but the model don’t consider the fairness among the players and the load balance among the channel.

There are other topic in wireless network which have been studied by using game theory, in cognitive wireless network, game theory was used to analysis spectrum competition, in physical layer, game theory was used to study the power control problem such as in [9], in wireless MAC
protocol [10] and [11] study the protocol fairness even when the network exists selfish node. In wireless network layer, game theory was used to study the data packet forwarding cooperation mechanism such as in [12], [13].

3 Technical Preliminaries

3.1 Game Theory Preliminaries

Game theory is a powerful tool to study situations of conflict and cooperation, which is concerned with finding the best actions for individual decision makers (i.e., players) in these situations and recognizing optimal outcomes. In the game model, there are a finite set of players \( N = \{1, 2, \ldots, N\} \), each player has a strategy set \( S_i \), the set of strategy profile is \( S = \times_{i \in N} S_i \), the game model has a utility function \( u(\cdot) \), which each player according to the utility function to choose strategy to maximize his payoff. The solution of the game model is Nash equilibrium, in a NE none of the player can unilaterally change its strategy to increase its payoff.

Definition 1 (Nash equilibrium) The strategy profile is Nash equilibrium when the strategy profile \( S^* \) satisfy the following property for each player \( u(S^*_i, S^-_i) > u(S'_i, S^-_i) \) for all strategy profile in \( S \), where \( S^-_i \) denote all the players expect player \( i \).

3.2 System Model

Considering a Non-cooperative wireless network which nodes equipped with one or more radios, each radio has both a transmitter and a receiver, where the transmitter and the receiver may or may not be able to work simultaneously. We assume that the wireless Non-cooperative network, for example mesh network, ad hoc network and cognitive radio network, whatever its network infrastructure is fixed or dynamic, it has a common signal channel to facilitate the coordination among the nodes as the multi-radio multi-channel wireless network. In the rest of the paper, we always assume the common channel to transmit the coordination signal of the nodes.

In the wireless non-cooperative network, we assume there are many pairs of nodes to want to communicate with each other in one collision domain. We also assume each node in the network only take part in one session at a time, and a pair of node makes use of one or more radio to communicate with each other. So we can consider the scenario in which each node of the pair have multiple radios and each node in the network can allocate multiple radios in one channel.

Considering that communication system, we assume an available frequency of the network band divided into orthogonal channels of the same bandwidth using the FDMA method (e.g. 802.11 protocol and 802.16 protocol), We denote the set of available orthogonal channels by \( C \), the channel \( c \in C \) aggregate throughput as \( T_c(n_c) \), where \( n_c \) denote the number of radio using the channel \( c \). \( T_c(n_c) \) is a constant at the TDMA communication system like 802.16 Wimax, it is also can be a variable which is the decreasing function of \( n_c \), such as 802.11 protocol. We assume the effective throughput is share among the nodes using the channel, so we denote it as \( T_c(n_c)/n_c \).
4 Channel Assignment Game Model on Non-cooperative Game Theory

4.1 Channel Assignment Game model With Load-balance and Fairness

Considering a wireless network with \( N \) nodes, in our model we call it as the player of the game, denote the player set \( N = \{1, 2, \ldots, n\} \), and we identity the node \( N_i \) \( (i \in N) \). Each user \( N_i \) have \( r_i \) radio transmitters to communicate with other user. The radio distribution vector is denoted as \( R = \{r_1, r_2, \ldots, r_n\} \).

We define the strategy of the player in the game is its channel assignment vector \( s_i = \{s_{i,1}, s_{i,2}, \ldots, s_{i,C}\} \), where \( s_{i,C} \) denote the number of radio that player \( i \) assigns to channel \( c \). The strategy profile of all users in the network is a matrix \( S \), where the row of the matrix \( S = \{s_1, s_2, \ldots, s_C\}^T \). The total number of radio employed by user \( i \) is

\[
m_i(s) = \sum_{c \in C} s_{i,c} \tag{1}
\]

The \( m_i(s) \) must obtain the inequality \( m_i(s) \leq r_i \), and the number of radios allocate to channel is

\[
n_c(s) = \sum_{i \in N} s_{i,c} \tag{2}
\]

According to the previous definition, the throughput of player \( i \) from the channel \( C \) is \( T_{i,c} = \frac{s_{i,c}}{n_c} T_c(n_c) \), the total throughput from all the channel is \( T_i = \sum_{c \in C} T_{i,c} \), and the system total throughput is sum throughput of all the user in the system, it can be written as follow:

\[
T(S) = \sum_{c \in C} T_c(n_c) \tag{3}
\]

Denoting \( |C| \) as the number of channel, for every channel we define \( p_c(c \in C) \) as the reputation of the channel, as in the micro economics, the reputation in this paper denote the payoff of the channel load in the game stage, the reputation is decided by the number of radio allocated to it in each stage game. In our model we set the value of \( p_c \) is \([0, 1]\), and the value of \( p_c \) is defined as follow at each round of stage game:

\[
p_c = \begin{cases} 
\alpha p_c^{t-1} + (1 - \alpha) \left( \frac{\sum_{i \in C} \sum_{i \in N} s_{i,c}}{|N|} - \sum_{i \in N} s_{i,c} \right), & 0 \leq p_c \leq 1; \\
0, & p_c < 0
\end{cases} \tag{4}
\]

where \( \alpha \) is a adjust parameter of the reputation, the reputation of the stage game is a function of the past reputation and the previous stage game reputation payoff of the channel.

In realistic environment, any solution of channel assignment is easy to lead to channel starvation and unfair social efficiency. So we should influence on the player selecting strategy to take part in the game, the method of our model is to make use of reputation to build up fair and efficient channel assignment model. We assume that use the one unit reputation should gain \( D \) unit virtual
currency bonus, and the channel enhance the reputation for providing more user service as define as (4). Assuming each user is rational and wants to maximize its own utility function, we define the user utility function as follow:

$$u(s_i) = \sum_{c \in C} \frac{s_{i,c}}{n_c} T_c(n_c) p_c D$$

(5)

where $p_c D$ denote one unit throughput at the channel $c$ gain, $D$ is a constant which have been defined in system. $\sum_{c \in C} \frac{s_{i,c}}{n_c} T_c(n_c)$ is the total throughput of player $i$, the player throughput multiple the one unit throughput gain at all channel is the player utility function.

Though the player maximize utility function can result in Nash equilibrium, it also can lead to some of the player select his own strategy and its utility is very large, but the other player utility is very small, to resolve the fairness among the players utility and the load balance among the channel, through the reputation of the channel we make the efficient channel use and load balance among the channel, we minimize $\max_p \sum_{c \in C} \frac{s_{i,c}}{n_c} T_c(n_c) p_c D$ with respect to vector $S_i$ to avoid the significant difference between the players, so the channel assignment model can get by performing the following optimization model:

$$\min_{S_i} \max_p \sum_{c \in C} \frac{s_{i,c}}{n_c} T_c(n_c) p_c D$$

(6)

### 4.2 Channel Assignment Algorithm With Fairness and Load-balance

To achieve the fairness and load balance channel assignment, we put forward a channel assignment algorithm to compute the channel assignment vector, the input of the algorithm is the channel set $C$, the player set $N$ and the radio vector $R$, the output of the algorithm is the channel assignment vector $S^*$. Each player in the game should implement the channel assignment algorithm.

**Algorithm 1** Channel assignment algorithm with fair and load-balance

1. Initialize $S^*$
2. $i = 1$
3. $c = 1$
4. Reputation = 0
5. for $i = 1$ to $|C|$ do
6.   $p_c = $ Reputation
7. for $i$ do
8.   while $i \leq |N|$ and $c \leq |C|$ do
9.     $s_{i,c} = 1$
10.    $r_i = r_i - 1$
11.   $i = i + 1$
12.  $c = c + 1$
13. end while
14. if $n > |C|$ then
15.   while $i \leq |N|$ do
16.     $c = \min_c \left( T_c \sum_j s_{j,c}^* - T_c \left( \sum_j s_{j,c}^* + 1 \right) \right) p_c D$
According the pseudo-code of channel assignment algorithm with fairness and load-balance, we can achieve the globe optimal channel assignment. The algorithm initiates the output vector and assigns a const to all the channels as his reputation when the game starts. Then algorithm assigns a radio to one channel, if the number of radio equal to the number of the channel, and the algorithm terminates. If the number of radio is less than the number of the channel, the algorithm tries to find the minimal reputation channel, and if the channel hasn’t occupied with other players, then assigns a radio to the channel, until all the channel are occupied or all the radio of radio are used. If the number of radio is more than the number of the channel, it finds a channel to each unassigned player, which the channel will cause less utility reduction when adding a radio on it. Through the algorithm we get the fairness and load-balance channel assignment in the multi-radio and multi-channel competitive wireless network.

5 Numerical Evaluation

In this section, we use Matlab to evaluate the model and implement the channel assignment algorithm. We assume that the available frequency band is divided into 8 orthogonal channels, and we also assume that the channel rate is a fixed value, we can assume the total data rate of per channel is 10m/s, each node in the network equipped with 5 radio. We also assume that there are 10 players in the game and the duration of one stage game is 10ms. The duration of one stage game is roughly equal to the time of all the player transmit one unit data. We run the
simulation for 100 times. Besides, we set $D = 1$, $\alpha = 5$.

We first consider the system throughput when using our proposed channel assignment model. Fig. 1 shows the result of the simulation, from the result we can get the system throughput is equal to the 80m/s after the game repeat 20 times. As the game time is longer and longer, the system throughput is stable at the max point of the system, it shows the channel assignment of the system is efficient and stable.

Secondly we consider the load of the channel. Fig. 2 shows the comparison of the different of the channel at the different game stage, the max channel reputation at each different stage is equal to 1, and the channel reputation is very similar to 1, so we get that the min channel reputation is very similar to the max channel reputation at each different stage. Thus we can conclude that the channel assignment converges to channel load balance.

Thirdly we consider the fairness among the players. Fig. 3 shows the comparison of the player utility at different game stage, the figure illustrate that the min player throughput is very similar to the max player throughput of all player at each game stage. So we can conclude that the channel assignment converge to fairness among players.

**Fig. 1: System Throughput achieved by the Game Model**

**Fig. 2: The Channel Reputation Comparison of Different Game Stage**

**Fig. 3: The Player Utility Comparison at Different Game Stage**
6 Conclusion

In this paper, we use game theory to analyze the channel assignment in multi-radio multi-channel wireless network, we model the channel assignment as a non-cooperative game model with channel load-balance and fairness among nodes, based on the model we propose a channel assignment algorithm with fairness and load-balance. Finally we evaluate the model, the simulation shows the validity of our proposed model.

References