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Channel Allocation Scheme Based on Greedy Algorithm in Cognitive Vehicular Networks

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***Abstract*—With the steep increase in the number of vehicle users, the demand for channel resources is increasing. However, the limited spectrum resources can't meet this huge demands. Using cognitive radio (CR) technology in vehicular networks can effective solve this problem. In this paper, we study the channel allocation in the cognitive vehicular network (CVN), and we established a corresponding network model, channel model, service model and vehicle model for highway scenarios in CVN. In order to solve the problem of channel allocation, we proposed a Channel Allocation Scheme based on Greedy Algorithm (CASGA), which is aimed at maximize the throughput of the CVN. The proposed scheme is compared with a traditional game theory algorithm in the optimization of throughput. Simulation results show that the proposed scheme has a great advantage over traditional game theory algorithm in optimizing the throughput of the CVN.**

Keywords—Cognitive vehicular networks; throughput; channel allocation

I. INTRODUCTION

With the increasing number of various service requests, the demand of bandwidth is growing up.And the problem of spectrum limitation has gradually appeared. It is challenging for RSU to allocate highly dynamic service requests with limited channels [1], [2].The results of spectrum utilization measurements over the years have shown that there are many spectrums of unused or underutilized licensed bands in different spaces and times, which leads to inefficient use of the spectrum, for example, the spectrum band of TV broadcasting, resulting in considerable spectrum wastage [3], [4]. Consequently, regulatory agencies, such as FCC in the USA that are responsible for regulating spectrum allocations, have now opened the licensed band to SUs through the use of CR [5] to enable a more efficient use of the spectrum bands. In view of this, using cognitive radio (CR) technology in vehicular networks will enable more efficient use of spectrum ,which in turn will improve vehicular communication efficiency. CR is an emerging technology that improves spectrum utilization by exploiting underused spectral resources through opportunistic spectrum access (OSA) [6]. Radio cognition (RC) along with dynamic spectrum access (DSA) strategies, provides a promising approach that allows unlicensed/secondary users(SUs) to opportunistically capture and use the spatio-temporally available licensed spectrum holes as long as licensed/primary users (PUs) are undisturbed [7].

There are two major types of vehicular communication in the vehicular ad hoc networks(VANETs): vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I). In V2I communication, the vehicle is able to transmit data both downlink and uplink from roadside unit (RSUs) with minimal latency [8]. Road Side Unit (RSU) and On Board Unit (OBU) are the components of a VANETs. Infrastructure, including RSUs, allows Internet access and provides useful information for vehicles on the road , which is the main driver of the market [9]. Communications among OBUs is classified as V2V [10].

The remainder of the paper is organized as follows. In Section II, we review the related work. The cognitive vehicular network, service model, channel model and user model are introduced in Section III. In Section IV we establish the throughput optimization problem and propose a Channel Allocation Scheme based on Greedy Algorithm (CASGA) to solve this problem. We simulated the system model and analyzed the simulation result in Section V. Finally, we concluded our work in Section VI.

II. RELATED WORKS

In recent years, there have been many works studied the cognitive enabled vehicular networks. The problem of distributed spectrum access in OSA systems has attracted great attention, and has been discussed from the perspective of non-game theoretic and game theoretic.

In [11] the problem of maximizing distributed throughput in OSA system with multiple SUs and multiple primary channels is investigated. To address the challenges of designing efficient solutions in a dynamic and unknown environments, the author describe the optimization problem as a no-cooperative game, further proving that this is an ordinal potential game. In [12] the author proposed a throughput-efficient channel allocation framework for multi-channel cognitive vehicular networks, with the goal of maximizing network-wide throughput and indicating that the problem is an NP-hard non-linear integer programming problem. A channel resource allocation scheme based on semi-Markov decision strategy is proposed in [13] to provide a solution to the shortage of the channel resources in VANETs.

In addition, there exists several research works studying the cognitive radio-enabled VANETs. Based on a heterogeneous

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architecture consisting of a widely covered cellular base stations (BSs) and a roadside infrastructure with cognitive radio-enabled roadside, [14] proposed a semi-Markov decision process (SMDP)-based resource allocation scheme to facilitate the application of video streaming in peak signal-to-noise ratio (PSNR) and smooth playback. In [1], to solve the coexistence problem between the vehicular and an 802.22 network through resource allocation, the coexistence problem is expressed as a mixed integer nonlinear programming (MINLP) problem, to which three algorithms are developed. In [15], to solve channel conflict problem in channel switching in vehicle network, a new dynamic spectrum allocation algorithm is proposed.

The main contributions of this paper are listed as following.

- First, neither of them consider the different levels of services in the secondary users, whereas the multi-service of secondary user was taken into account as an important factor in our work, and we assume that the services need to be transmitted in SUs subject to Poisson distribution.In view of this, we established a services model. At the same time, we have established channel model and user model for both channel and vehicle.
- Secondly, their optimization objectives are minimizing the regret or optimizing others performance, whereas we consider the total throughput of CVN, and in our work the main objective is to maximize the total throughput of CVN.
- In order to solve the problem of channel allocation, we proposed a channel allocation scheme based on greedy algorithm (CASGA), which is aimed at maximize the throughput of the CVN. And we use the CASGA to solve this optimize problem to compare the traditional game theory.
- The last one is that we simulated the highway scenario in CVN, and get the simulation result by using the CASGA. By comparing and analyzing the simulation results, we draw a conclusion that the CASGA has a great advantage over traditional game theory algorithm in optimizing the throughput of the CVN.

III. SYSTEM MODEL

A. Cognitive Vehicular Networks Model

In this paper, we consider a cognitive enabled vehicular network model in a highway scenario, and we assumed that there are two major type of vehicular communication: V2V and V2I. Fig 1 shows the cognitive enabled vehicular networks model in this one-way highway scenario.

We assumed that the coverage diameter of the RSU denoted as D, then the number of vehicle in the coverage can be detected at a certain moment. Let M be the numbers of vehicles in the network. TV band white space (TVWS) in the vehicular networks also has been used as the access channel here. We assumed that the number of available channels detected at this time denoted as N. The SUs sense the spectrum holes and find an opportunity to access the channel which PUs are not occupied. In this vehicular network, all vehicles act as SUs

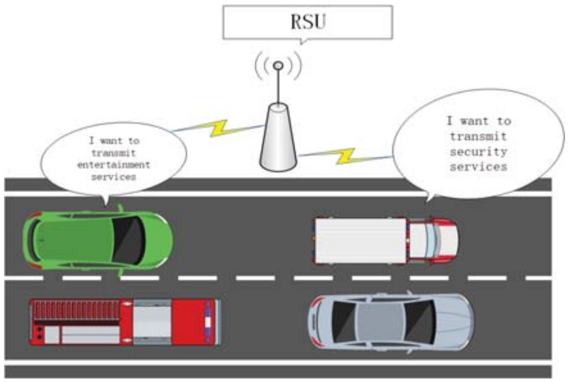

Fig. 1. cognitive enabled vehicular networks model

to access channels, and there are need an access algorithm to allocate these N channels to M vehicles. The RSU acts as a controller center to determine the allocation of channels. The decision scheduling time period of the RSU in this networks defined as $T = D/v$. Where v is denoted as the average speed of vehicles in this vehicular network.

B. Service Model

Each SUsin the vehicular network has different application services (e.g. security services, entertainment services, etc.). There are K different application services at a certain moment in this network. Each services we denoted as $A_k, 0 \leq k < K$ and all transmission sequences are denoted as an ordered pair of sets P , for example $P =< A_0, A_1, \ldots, A_{K-1} >$represents a transmission order of all services. Where the service A_0 will be transmitted preferentially, and the service A_{K-1} is transmitted last.

However, each service A_k has a response delay threshold, we denoted as $Th(A_k)$. Its value can be obtained based on wireless network service indicator statistic. A service is considered non-satisfied if its actual response delay exceeds its response delay threshold. Otherwise, the service is satisfied. We also defined that if the services belong to the same service type, their response delay threshold are the same.

The different services have different transmission rates on different channels. The transmission time of A_k in channel n can be defined as:

$$t_{nk} = min\{\frac{L_k}{R_{nk}}, Th(A_k), T\} \tag{1}$$

Where R_{nk} is the transmission rate of service k in channel n, and the L_k is the amount of data that needs to transmit, T is the decision scheduling time period of the RSU in this networks.

Therefore, if the service transmission order is determined (i.e. P is determined). The transmission time of this service can be defined as:

$$C_P = \begin{cases} 0 & K = 0 \\ \sum_{k=0}^{K} t_{nk} & K > 0 \end{cases} \tag{2}$$

C. Channel Model

The RSU can detect the type of request and decide whether to accept SUs to access to the availability channel. If this request is accepted, the RSU will allocate the available channels to the user. Assume that a RSU detected there are N channels available, and all of channels can be allocated to the vehicles when they are idle. We assume that all channels can meet the minimum service requirements for difference services, and one channel can only be occupied by one user in a period of time. The vehicle needs to utilize the channel when the PU dose not occupy the channel, therefore the SUs transmit data when the channel is idle.

In our model, whether the channel is busy or idle follows a stationary Bernoulli random process over t. Let $X_n(t)$ denote the availability status of channel n at time slot t. $X_n(t) = 1$ means channel n is idle, and $X_n(t) = 0$ means channel n is busy.

Assuming that the probability of channel n being busy isP_{n-coll}. Therefore at time slot t, the mean of occupy time is :

$$T_{n-coll} = t \cdot P_{n-coll} \tag{3}$$

D. User Model

In our CVN, the number of vehicles in the RSU coverage at a certain moment is M, and the service that vehicle m needs to transmit at this moment can be denoted as P, which is the model we introduced in service model. We assume that each secondary user transmits its own services independently. Therefore, the time required for the vehicle m to transmit this service P is C_P (The C_P has given a calculation formula when introducing the service model).

Let x_{mn} be our channel assignment variable(i.e. $x_{mn} = 1$) if vehicle m is scheduled to channel n ,and $x_{mn} = 0$ otherwise. Therefore we can build a $M \times N$ channel allocation matrix to represent of our allocate decision.

We use U_{mn} to denote the expected weighted throughput achieved by scheduling vehicle$m$ to transmit on channel n. Thus

$$U_{mn} = \frac{R_n}{T}(C_{mn} - T_{_{n-coll}}) \tag{4}$$

Where R_n is the data transmission rate in channel n, and T_{n-coll} represents the time when channel n busy during the C_{mn} period. During this period, the channel is occupied and the service of the secondary user cannot be transmitted.

IV. PROBLEM FORMULATION AND SOLUTION

A. Network Performance and problem formulation

The throughput performance in the network includes the sum of the throughput of all vehicles in this cognitive enabled vehicular network. In user model, we introduced a $M \times N$ channel allocation matrix to represent of our allocate decision. A channel allocation scheme can be denoted as:

$$\boldsymbol{A} = \begin{bmatrix} x_{00} & \cdots & x_{0(N-1)} \\ \vdots & \ddots & \vdots \\ x_{(M-1)0} & \cdots & x_{(M-1)(N-1)} \end{bmatrix}$$

We also defined a $M \times N$ matrix $\mathbf{B}$ to represent the throughput of the network.$\mathbf{B}$ can be calculated by the following equation:

$$B_{mn} = U_{mn} \cdot x_{mn}, \forall m \in [0, M), n \in [0, N) \tag{5}$$

Where U_{mn} is the expected weighted throughput achieved by scheduling vehicle m$to transmit on channel n, and x_{mn}$ is our channel assignment variable. Therefore, the matrix $\mathbf{B}$ can be denoted as:

$$\boldsymbol{B} = \begin{bmatrix} x_{00}U_{00} & \cdots & x_{0(N-1)}U_{0(N-1)} \\ \vdots & \ddots & \vdots \\ x_{(M-1)0}U_{(M-1)0} & \cdots & x_{(M-1)(N-1)}U_{(M-1)(N-1)} \end{bmatrix}$$

We consider the sum of the throughput of all the vehicles in the network. Under this channel allocation scheme, the total throughput in the network is:

$$U = \sum_{n=0}^{N-1} \sum_{m=0}^{M-1} B_{mn} \; \forall m \in [0, M), n \in [0, N) \tag{6}$$

We also consider another network performance, spectrum utilization efficiency. The transmission rate is R_n in the channel n. Therefore, the maximum transmission amount of channel n during the T period is:

$$Tran_{n-max} = R_n \cdot T \tag{7}$$

The amount of data transferred of vehicle$m$ in channel n can be denoted as:

$$Tran_{mn} = \int_0^{C_{mn}} t \cdot p_{n-coll} \cdot R_n \, \mathrm{d}\, t \tag{8}$$

Given the above definitions, our objective is to maximize the sum of the throughput of all the vehicles in the network, and the problem can be formulated as:

$$\begin{aligned} & maxU = max \sum_{n=0}^{N-1} \sum_{m=0}^{M-1} B_{mn} \;\; \forall m \in [0, M), n \in [0, N) \\ & s.t. \;\; \sum_{m=0}^{M-1} x_{mn} \leq 1 \;\; \forall n \in \{1, 2, \ldots, N\} \end{aligned} \tag{9}$$

B. Solution

In this paper we have established a formula to maximize the sum of the throughput of all the vehicles in the network. To solve this problem, the general solution is to use game theory. In game theory, each SU will be treated as a player, and all channels as strategies. The throughput of this channel by the vehicle user is the utility. A vehicle user can only choose one free channel. But it does not guarantee optimal results when the channel is insufficient. Therefore, we proposed channel allocation scheme based on greedy algorithm(CASGA) to solve this problem. The CASGA is shown in the Fig. 2.

First of all, we should initialize the number of vehicles and channels in the CVN to be$M$ and N. For each channel, we need to initialize its data transmission rate and the occupancy

Algorithm 1 Channel Allocation Scheme based on Greedy Algorithm (CASGA)

Require: The type of services an their threshold the vehicle list ***M*** ={0,1…,M-1}, the channel list ***N*** = {0,1,…,N-1}
and transmit matrix **Tran**,the initial a M*N matrix ***arr*** = ***U***

1. Initial the channel list ***N*** = {0,1,…,N-1} and initial their data transmit rate
2. Initial the vehicle list ***M*** ={0,1…,M-1}, and each vehicle transmit different services
3. calculation the throughput matrix according to the following formula:
$$U_{mn} = \frac{R_n}{T}(C_{mn} - T_{n-coll})$$
C_{mn} and T_{n-coll} can be calculated based on the initialization results of step1 and step 2. Therefore we can calculated all $U_{mn}(m \in [0, M), n \in [0, N))$, we can get this Throughput matrix ***U***
4. we set M*N matrix ***arr*** , and all of the element of ***arr*** is 0.
5. **Repeat:**
6. **While** ***U*** is empty or the row or column equal 0
7. Find the max element $\boldsymbol{U}_{ij}$ in ***U***
8. $\boldsymbol{arr}_{i,j}$=1, that means vehicle i is scheduled to channel j
9. Remove the row ***i*** and column *j* in ***U***
10. Update ***U*** and ***arr***
11. **end While**
12. We also defined a $M \times N$ matrix ***B*** to represent the throughput of the network.
13. We can calculated ***B*** according to the following formula:
$$B_{mn} = U_{mn} \cdot x_{mn} \qquad \forall m \in [0, M), n \in [0, N)$$
the total throughput in the network is:
$$U = \sum_{n=0}^{N-1}\sum_{m=0}^{M-1} B_{mn} \qquad \forall m \in [0, M), n \in [0, N)$$
14. Return U and ***arr***, ***arr*** is matrix of channel allocation.

Fig. 2. channel allocation scheme based on greedy algorith(CASGA)

probability. And for each vehicle, we need to initialize the service that this vehicle needs to transmit, since there will may exist different services in the vehicle, we will use the Poisson distribution to simulate the type of service in the vehicle. In this way, our CVN is set up.

In CASGA, We can calculate the throughput matrix $\mathbf{U}$. The throughput corresponding to different channels is different, so we find the largest throughput and assign this channel to the vehicle. And then find the position of the largest number in the throughput matrix, so that we can get the channel we need to allocate, the user can achieve the maximum throughput, and at the same time, we will remove the largest number in the matrix. The number outside the largest number is assigned a value of 0.In order to ensure that a channel can only be assigned to one vehicle user at this time ,this position will be assigned a value of 1. In this way we can continue to look for the next largest value, which will ensure maximum throughput in the CVN.

V. NUMERICAL RESULTS

We consider the cognitive vehicular network controlled by an RSU, which cover diameter is $D = 500m$. The average speed of vehicles in this network is$v = 10m/s$. The scheduling period of this RSU is $T = D/v = 50s$ We proposed scheme by simulating a cognitive vehicular network with M vehicles and N channels. We run the two channel allocation algorithms for 100 iterations. For convenience, we use p to represent the channel occupancy probability in the CVN, M is the number of vehicles in the CVN, N is the number of channels in the CVN, and GT is the Game Theory scheme. By comparing the throughput and spectrum utilization in the CVN, we analyzed the pros and cons of the two schemes. Here, the throughput we calculate is the total throughput of the secondary users.The figure results show the variation of the performance of the CVN under different M,N and p.

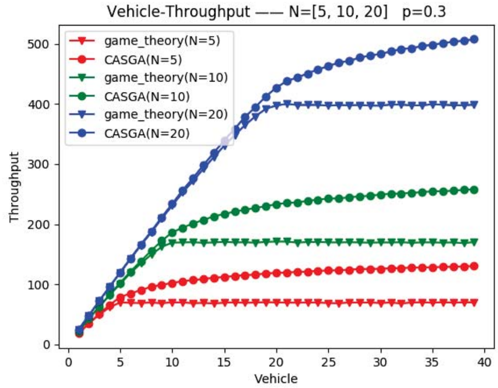

Fig. 3. throughput varies with the number of vehicles

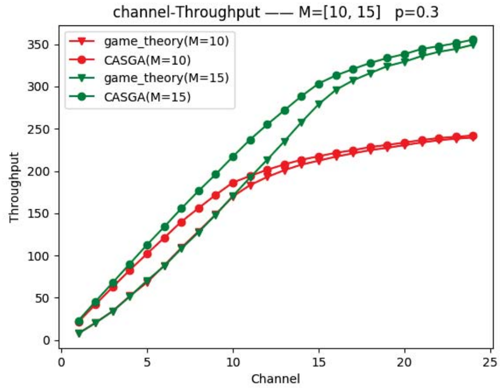

Fig. 4. Throughput varies with the number of channels

Fig 3 shows that throughput varies with M. We set $p = 0.3$, and compared the throughput with different $N(N = [5, 10, 20])$. We can see that both CASGA and GT can achieve higher throughput with the larger M, since we calculate the total throughput in the CVN by the throughput of all the vehicle users. Therefore, the throughput will increase with the increase of M. When $M \le N$, the total throughput is linearly increase with the increase of M. When $M \ge N$, this growth trend gradually becomes flat, eventually reached a saturated state, which is a steady state under the limitation of the N. Comparing the two schemes in the figure, the maximized throughput results in the CVN using the CASGA are significantly better than GT. This shows that the use of CASCA has a great advantage over GT in optimizing the throughput of the CVN.

Fig 4 shows that throughput varies with N. We set $p = 0.3$, and compared the throughput with different $M(M = [10, 15])$.We can see that CASGA achieves higher throughput than GT, since the CASGA compared all the elements in

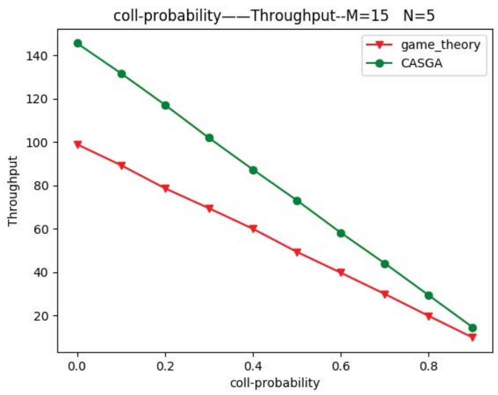

Fig. 5. throughput varies with channel occupancy probability

the entire throughput matrix $\mathbf{U}$, while the GT only compared the elements of a certain row in the $\mathbf{U}$. Therefore the CASGA always can find the maximum elements in the $\mathbf{U}$ in every iteration. It can be see form the curve in the figure that the throughput in the CVN gradually increases with the increase of N. When $N \leq M$ (i.e. the channel resources are insufficient), the throughput in the CVN linearly increases with N, and this growth trend tends to be flat when $N \geq M$. Comparing the two schemes, it can be found that when the channel resources are insufficient (i.e. $N \leq M$), the GACA has obvious advantages over GT for optimizing the total throughput performance in the CVN. However, when the channel resources are sufficient (i.e. $N \geq M$), the CASGA also has a slight advantage in optimizing the total throughput performance in the CVN.

Fig 5 shows that throughput varies with p. We set $M = 15, N = 5$, and compared the throughput with different schemes. We can see that the throughput of both schemes linearly decreases with the increase of the p. Since when the p increases, the using time of vehicle users will reduce. Therefore, the throughput in the CVN will decrease. We can also see that the throughput calculated by the CASGA is significantly higher than GT, and the reason of this result we have explained.

VI. Conclusion

In this paper, we study the problem of channel allocation in cognitive vehicular network(CVN). First, we built a cognitive vehicular network model based on actual conditions, including network model, vehicle model, service model, and channel model. Then we formulate a mathematical optimization problem based on the model of the actual problem to maximize the throughput in CVN. To solve this problem, we proposed a channel allocation scheme based on greedy algorithm(CASGA), and compared with the traditional game theory algorithm. Finally, based on the experimental results, we analyzed the variation of throughput in terms of the number of channels, the number of vehicles, and the probability of channel occupancy probability. Comparing our proposed scheme with traditional game theory through experimental results, we can see that the CASGA has obvious advantages in optimizing throughput compared with game theory.

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