# A V2V spectral resource allocation scheme in congestion scenarios based on game theory

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## ABSTRACT

With the increasing number of vehicles and the shortage of spectrum resources, the development of the Internet of vehicles is severely limited. Based on game theory, this paper proposes a dynamic allocation scheme of spectrum resources in the congestion scenario. Different from the traditional spectrum resource allocation scheme, the scheme gives users cognitive ability to realize dynamic and intelligent efficient utilization of spectrum resources without relying on the central node and the mutual transmission of channel information between users. In a dense scenario where the number of wireless resources is less than the number of users, the scheme can automatically screen out the users with more advantageous communication conditions to enhance the overall communication capacity of the system. Simulation results show that the algorithm can automatically filter out the channels with relatively better conditions, and can effectively avoid the interference between different users, which is highly efficient.

**Keywords:** IoV, spectrum resource allocation, cognitive radio, game theory

## 1. INTRODUCTION

In the information age of rapid development, cars are not only a means of transportation to expand the radius of human travel, but also an entertainment partner to enrich their daily life. According to the World Automobile Organization (OICA), by the end of 2020, the number of major automobile markets in the world has reached 791 million, and the number is expected to increase by 16% in the next eight years. While cars bring people convenient travel, they also bring great pressure to the social environment, such as traffic congestion, increasingly frequent traffic accidents and other problems. In order to solve the communication problem of vehicles and other transportation facilities, the Internet of Vehicles technology extending to the Internet of Things came into being. Internet of Vehicles (IoV) is a combination of automotive, electronics, communication, the Internet and other fields. It is considered to be the core part of the intelligent transportation system in the future, and one of the most promising practical technologies for 5G vertical application, or one of the most effective intelligent technologies to alleviate existing traffic jams and reduce the probability of car accidents, but also an essential technical support for autonomous driving and even unmanned driving[1]. IoV is also known as V2X (vehicle-to-everything), which mainly includes four types of communication: V2V (vehicle to vehicle), V2P (vehicle to pedestrian), V2I (vehicle to infrastructure), V2N (vehicle-to-network) mode, each communication mode has its own meaning and characteristics[2], as shown in Figure 1.

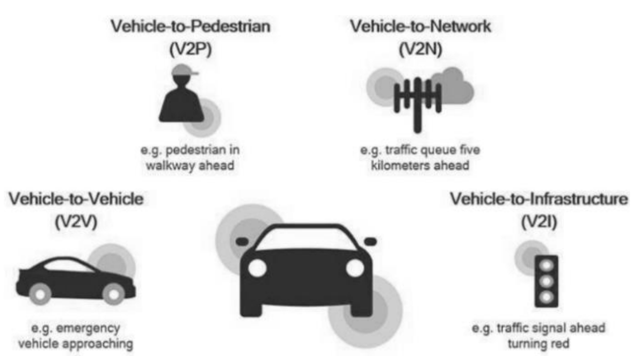


Figure 1. Application scenario for V2X.

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Nowadays, the rapid increase of transportation facilities from number to type has brought a large number of information transmission demand. Its demand for real-time and reliability of communication is growing rapidly, and the requirements of communication demand for service quality are also developing in the direction of diversification and high-speed. The service demand of the Internet of vehicles tends to be heterogeneous, with high requirements for transmission speed and transmission reliability, and a higher demand for spectrum resources. However, nowadays, the available spectrum resources for communication on the Internet of Vehicles scenarios are very limited. Spectrum resources are rare and scarce, and the existing spectrum management schemes cannot effectively adapt to the gradually growing spectrum demand, which seriously restricts the development of the Internet of Vehicles.

3GPP specifies two V2V communication modes based on PC5 interface and Uu interface, which are suitable for sparse scenarios and congestion scenarios, respectively, but both have the disadvantages of large system delay or large channel interference between users. Uu interface based transmission mostly adopts centralized spectrum resource allocation scheme, but the system delay cannot be applicable to V2V communication with rigid requirements; the communication method of distributed spectrum resource distribution based on PC5 interface cannot overcome the disadvantages of large channel interference between users, which for V2V communication with limited spectrum resources in congestion scenarios is a nightmare[3,4].

The dynamic programming problem based on spectrum resource allocation can be regarded as the competition problem of resources among users. Game theory was introduced to analyze its mechanism[5,6]. The articles analyzed the behavior of primary users competing to rent spectrum to secondary users based on game theory, and dynamically adjusted their strategies according to the changes of secondary users' frequency spectrum requirements and other primary users' strategies, to maximize its profits[7,8]. But they ignored the spectrum competition among secondary users. The cost function was used to improve the spectrum efficiency, where the article found the best route from the vehicle to the gateway and used licensed shared access (LSA)[9].

This paper proposes a dynamic spectrum resource allocation scheme in congestion scenario based on game theory, which endows users with cognitive ability. They can just make decisions according to their own channel state, which avoids the transmission of channel information between each other, so as to maximize the utilization of system spectrum resources.

## 2. ANALYSIS BASED ON GAME THEORY

As shown in Figure 2, in the congestion scenario, each pair has a receiver and a sender. The solid line represents the user's communication channel, and the dashed line is the interference channel.

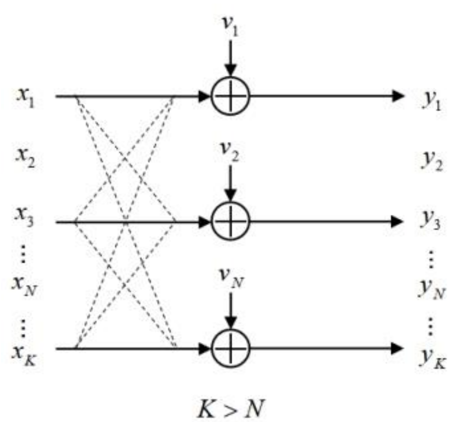


Figure 2. The channel interference model in the congestion scenario.

$h_{kk}$ is the channel gain of user *k*; $h_{ki}$ is the channel interference gain of user ***i*** to user *k*; $x_k$ is the transmission signal; $v_k$ is the noise signal. Then the signal received by user ***k*** is given by:

$$y_k = h_{kk} x_k + \sum_{i=1, i \neq k}^{K} h_{ki} x_i + n_k \tag{1}$$

If the channel is a Rayleigh flat fading channel, the signal and noise are both subject to zero-mean Gaussian distribution. According to Shannon theory, the channel capacity of user *k* is:

$$R_k = \log_2 \left(1 + \frac{h_{kk}^2 p_k}{\sum_{i=1, i \neq k}^{K} h_{ki}^2 p_i + \sigma_k}\right) \tag{2}$$

$p_k$ is the power of $x_k$, and $\sigma_k$ is the power of $v_k$. For a communication system with *N* subcarriers, the system capacity and solution target are:

$$\begin{aligned} \max_{p_k \in S_k} \quad R_k &= \sum_{n=1}^{N} \log_2 \left(1 + \frac{h_{kk}^2[n] p_k[n]}{\sum_{i=1, i \neq k}^{K} h_{ki}^2[n] p_i[n] + \sigma_k[n]}\right) \\ &= \sum_{n=1}^{N} \log_2 \left(1 + \frac{p_k[n]}{c_k[n]}\right) \quad \forall k \in K, \ \forall n \in N \end{aligned} \tag{3}$$

$$c_k[n] = \sum_{i=1, i \neq k}^{K} \frac{h_{ki}^2[n]}{h_{kk}^2[n]} p_i[n] + \frac{\sigma_k[n]}{h_{kk}^2[n]} \quad \forall k \in K, \ \forall n \in N \tag{4}$$

$$S_k = \left\{ p_k \left| \sum_{n=1}^{N} p_k[n] \leq P_k \right. \right\} \quad \forall k \in K, \ \forall n \in N \tag{5}$$

$p_k[n]$ represents the power allocation of user *k* on different channels, and $p_k$ represents the power upper limit of user *k*; $S_k$ represents the policy space of user *k*; $c_k[n]$ represents the normalized sum of noise received by user *k*. It is determined by the electromagnetic environment of the user's location and can be obtained by the user without knowing $h_{ki}[n]$ and $\sigma_k[n]$. Therefore, the channel capacity of the whole system is related to the power of each user, so the allocation of spectrum resources is essentially the allocation of the power $p_k$.

The water injection algorithm based on equilibrium Nash game theory (NBF) can well solve the interference collision problem in communication spectrum sharing with different priorities in sparse scenarios[10,11]. In the NBF algorithm, the main user does not participate in the competition of spectrum resources. The cognitive user can effectively identify the occupation of the authorized frequency band through the cognitive ability, so as to avoid interference with the main user. The specific solution algorithm is as follows:

$$p_k^{t+1}[n] = \left( w_k^t - \frac{(c_k^t[n])^2 + (\phi_k^t)_n^{(1)} (p_k^t[n])^2}{c_k^t[n] - (\phi_k^t)_n^{(1)} p_k^t[n]} \right) \quad \forall n \in N, \forall k \in K, t \to \infty \tag{6}$$

where $w_k^t$ is the water injection line, $c_k^t[n]$ is the equivalent noise power of the $n^{\text{th}}$ subchannel. By setting different $(\varphi_k^t)_n^{(1)}$ to get different equilibrium solutions, when the cognitive coefficient $(\phi_k^t)_n^{(1)} = -\left(\frac{c_k^t[n]}{2c_k^t[n] + p_k^t[n]}\right)^{1/2}$, the algorithm achieves very good results.

## 3. SOLUTION ON CONGESTION SCENARIOS

In the congestion scenario, the number of V2V users will be greater than the number of spectral resources. Therefore, the interference between the user and the user will be inevitable, compared with the Nash equilibrium, the cognitive Nash spectrum allocation strategy (NBF) can not effectively improve the channel capacity at this time. How to avoid interference and maximize the channel capacity of the system is key in how to effectively allocate limited wireless resources to many users.

In the Internet of Vehicles, a single vehicle does not need to communicate with all the users in an area, which can be used by the way to connect the vehicle into a network. A single vehicle will only need to communicate its information with a limited number of surrounding vehicles, and exchange information, so that the entire area can be communicated in real time. Reducing inter-user interference can effectively improve the channel capacity.

A virtual channel solution (NBF with Virtual Channel, VNBF) is proposed, as shown in Figure 3. In VNBF model, each communication user needs not to consider the channel information in not only the channel information of each actual channel, but also the channel information of the virtual channel. The communication conditions (channel gain and noise) of the virtual channels should be worse than the real channels. Due to the cognitive capabilities of the cognitive Nash algorithm, users can compete with the good communication conditions to access the wireless resources by comparing the actual and virtual channel conditions. And the real channel Users with poor communication conditions concentrate the transmit power on the virtual channel in the algorithm calculation. In fact, the user stops occupying wireless resources and automatically giving up frequency bands for users with advantages, so as to effectively avoid inter-user interference and improve the system channel capacity.

In VNBF, the number $R$ of virtual channels is supposed to meet $R = K - N$ , to ensure that each pair of users can have a channel communication (including the virtual channel). For parameter settings for a virtual channel, the following:

$$c_k^*[n] = \sum_{i=1, i\neq k}^{K} \left( \lambda \frac{h_{ki}^2[n]}{h_{kk}^2[n]} p_i[n] \right) + \frac{\sigma_k[n]}{h_{kk}^2[n]} \quad \forall n \in R, \forall k \in K \tag{7}$$

$$\lambda \propto \frac{N}{K} \ , \ K > N \tag{8}$$

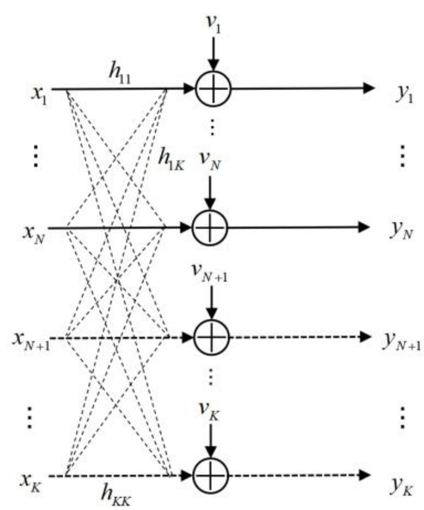


Figure 3. Channel model of VNBF.

When $K \gg N$, the user competition is very fierce, and the value $\lambda$ should be reduced, so the interference noise of the virtual channel is reduced to attract more user competition; when the number of users is close to the number of channels, we need to increase $\lambda$ to avoid the virtual channel attracting too many users to compete.

## 4. SIMULATION RESULTS

In the simulation experiment design, the upper limit of system throughput is calculated as a comparison of virtual channel schemes. Four-ray Rayleigh fading channel is used as the communication channel. The simulation experiment was completed with MATLAB R2018b.

Figure 4 shows the variation of system capacity with the number of iterations in a simulation experiment. It can be seen that the channel capacity of the virtual channel scheme converges quickly and finally approaches the theoretical limit.

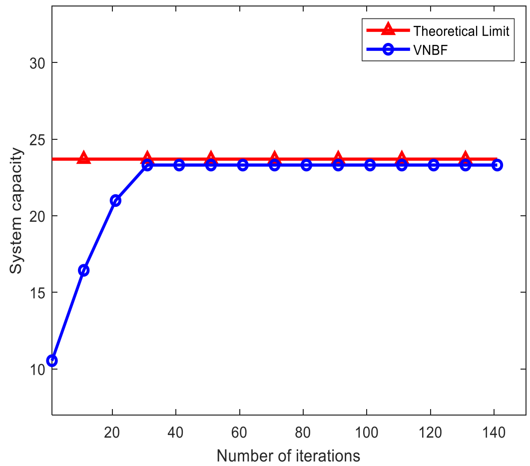


Figure 4. comparison of channel capacity.

In Figure 5, it verifies the reliability of the algorithm. Assuming that the number of neutron channels in the system remains unchanged and the number of users increases, the competition among users increases. At this time, the total system capacity obtained by VNBF algorithm is basically equal to the theoretical value.

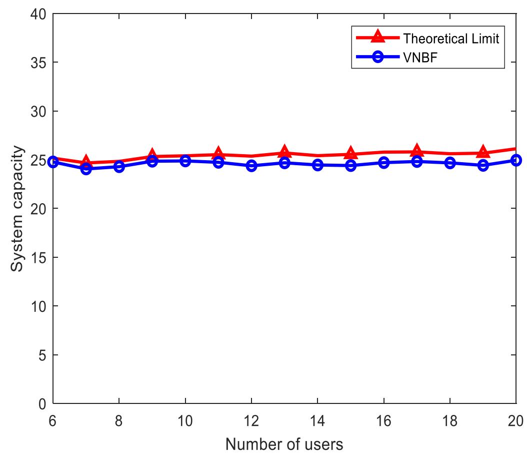


Figure 5. The change of system capacity with increasing number of users at $N$=3.

As shown in Figure 6, when the number of channels and the number of users in the system increase, assuming that the number of users is twice the number of channels, the resource allocation problem of the algorithm in the large-scale congestion scenario is verified. The simulation results show that with the increasing of the number of users, the total system capacity obtained by VNBF algorithm is similar to the theoretical value, and the average error is about 2.3%.

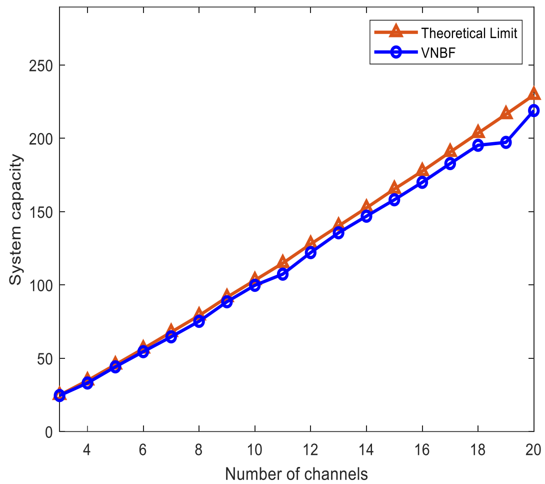


Figure 6. System capacity change when $K=2N$.

## 5. CONCLUSION

In order to solve the problem that the number of communication users is much larger than the number of spectrum resources, this paper proposes a dynamic spectrum resource allocation scheme in congestion scenario based on cognitive Nash game theory. By introducing virtual channel, users compete with each other. Users with good channel gain occupy the real channel, while users with weak channel gain concentrate their power on the virtual channel so that the communication system avoids the interference between users and improves the throughput of it. Simulation results show that VNBF algorithm can solve the problem of lack of spectrum resources in multi-user scenario, and its convergence speed is very fast, and the final result is very close to the theoretical maximum.

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