

## Resource Coordination Scheme Based on Information Interaction in Distributed Heterogeneous Cognitive Networks

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### Abstract

*Based on the distributed heterogeneous cognitive networks (HCNs) structure from the newest 3GPP release for LTE-A/LTE-B, the resource coordinated allocation scheme is researched to improve the spectrum usage efficiency of the system. Firstly, each network gains the channel conditions by learning scheme; then the information interaction and resource coordination process are carried between neighboring networks periodically to satisfy the QoS of each network and maximize the content of the whole system; lastly the stable resource allocation for each network are achieved. The simulation testifies that the proposed coordination scheme has strong learning ability, fast convergence speed and relatively better throughput performance.*

**Keywords:** *Heterogeneous Cognitive Network, Distributed, Coordination, Resource Allocation*

### 1. Introduction

Heterogeneous networks existing and integrating are the future trend of the next generation of the wireless communication networks. Introducing cognitive radio technology to heterogeneous network, which provides the networks with automatic sensing and dynamic configuration, is the effective method to enhance the frequency usage efficiency. The HCNs can integrate different access networks, such as WPAN, WLAN, WMAN and Ad hoc network, *etc.*, with hierarchical cell structures for macro/micro/pico/femto deployments. In such networks, it is difficult to build concentrated structure to make uniform resource management. Hence we focus on the resource management for distributed HCNs and research the coordinated allocation scheme to realize the highly efficient resource usage in heterogeneous networks.

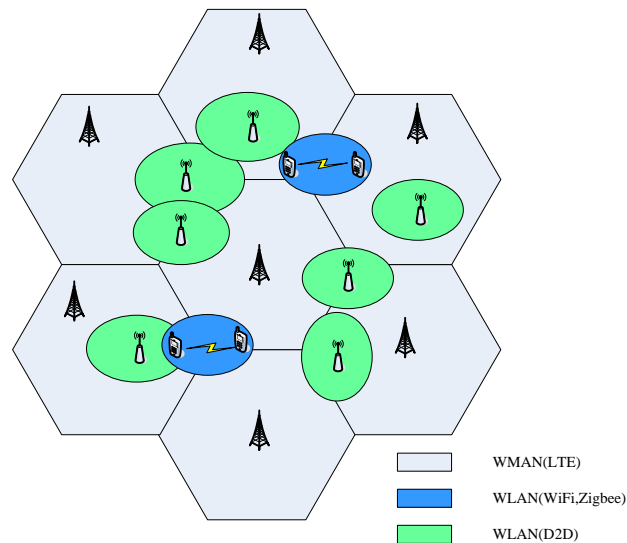
The current research on the resource management of HCNs mainly focuses on the concentrated or simple distributed networks. [1] constructs the macro/micro coexisting network environment and configure the centralized server to realize the dynamic spectrum access management. [2] and [3] analyze the cell selection and resource allocation problem in the condition of single-mode and multi-mode coexisting, but only considers the resource allocation in single cell. [4] researches the power control in the condition of single cell cognitive network and adhoc network coexisting, but not related to the channel access or spectrum allocation problems. In summary, the current literatures only involve the resource allocation in simple distributed HCNs with several same networks or only two different networks

coexisting, without deep research on the complex distributed HCNs with multiple kinds of networks coexisting.

The paper aims at the complex distributed HCNs with multiple kinds of network coexisting and proposes the resource coordinated allocation scheme between neighboring networks to realize the reasonable and efficient spectrum share in different networks. The rest of the paper is organized as followed. Section II constructs the system model of the complex HCNs. Section III introduces the basic thought of resource coordination and designs the detailed information interaction and resource coordinated allocation scheme accordingly. Section IV presents analysis of the simulation results and section V gives the conclusion.

## 2. System Model

According to the newest 3GPP release for LTE-A/LTE-B, [5] proposes a heterogeneous network (HetNet) structure adaptive to the future fifth generation cellular network, which involves LTE, WiFi, Zigbee, Adhoc systems driven by the macro/micro/pico/femto cells coexisting structure. Based on the HetNet structure for reference, we build the HCNs system model including WMAN and WLAN networks for our research in this paper as Figure1. WMAN is conventional LTE network which is formed by evolving NodeBs (eNBs). WLAN include two kinds of networks: WiFi or Zigbee network, which is formed by Micro eNBs, home eNBs or relay nodes, and D2D network constructed by Adhoc network, in which users can communicate with each other directly.



**Figure 1. HCNs System Structure**

In the HCNs system model in Figure1, WMAN is licensed network, which uses the licensed spectrum for LTE system, and WLAN network is cognitive network, sensing environment and finding spare spectrum to use. In 2008, FCC has approved TV white spectrum (TVws) for opportunistic secondary use [1, 4]. Therefore we adopt the TVws usage for WLAN users. Then the available spectrum for cognitive network are different with the licensed spectrum of WMAN, so the problem to solve is evolved to how to realize the spectrum sharing in multiple distributed cognitive networks reasonably. Since the spare state of TVws is relatively stable, we assume that the spare time of the available TVws is long enough that the spectrum bands used for

WLAN are always available in the process of spectrum allocation and coordination.

### 3. Coordination Scheme

#### 3.1. Basic Thought

Based on the distributed HCNs structure, we propose a spectrum coordination scheme to realize coordinated allocation between networks so as to reduce the interference and enhance the spectrum usage efficiency. Each network gains the channel conditions through learning scheme, then information interaction and coordinated allocation are carried between neighboring networks until the final stable allocation are achieved.

The detailed process of the coordinated allocation scheme can be divided into three stages as shown in Figure 2.

##### 3.1.1. Initial Stage

The controlling node of each network obtains the channel gain from the accessing users and computes the average gain of each channel in the network. With the users accessing network continuously, the average channel gain are kept to be updated in order to achieve accurate values as far as possible. Each network maintains a table to record the average gain of each channel and the channels allocated to the network and being used in the network.

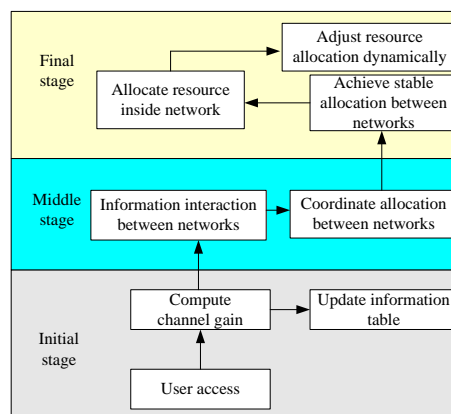


Figure 2. Coordinated Allocation Scheme Process

##### 3.1.2. Middle Stage

Information interaction and resource coordination are carried in this stage. The information including average channel gain and channel allocation condition are interacted between neighboring networks periodically. Base on the channel conditions and Qos requirement of each network the coordinated allocation of the channels are conducted between neighboring networks. For interference avoiding, the neighboring networks can't use the same channel in the same time. To enhance the spectrum usage efficiency, the neighboring networks will coordinate the channel usage according to partial and global optimality principle described in later section.

##### 3.1.3. Final Stage

After coordinated allocation between neighboring networks for multiple times, the allocation results for each network will trend to be stable. Then the controlling centers of each network allocate channels to users according to the channel conditions, power

limitation and service requirements. Since it is possible that the network structure and the Qos requirements of the network change over time, the dynamical adjustment of the channel allocation is operated through periodical coordination between networks.

### 3.2. Optimality Description

The channel allocation inside a network and the coordination between networks are all conducted aimed to some optimal objective under the limit of channel conditions and transmitting power. The optimality problems to solve are summarized into three parts:

#### 3.2.1. Channel Allocation Inside a Network

The problem is resource allocation in single cell, which has been researched maturely [6-7]. Define that  $r_n$  is the actual rate of user  $n$ , then  $r_n$  can be computed as (1)

$$r_n = B \log_2 \left( 1 + \frac{p_n h_n^2}{\sigma^2} \right) \quad n \in \{1, 2, \dots, N\} \quad (1)$$

Assume there are  $N$  users currently and only one channel is allocated to each user for access. In (1),  $B$  indicates the bandwidth of each channel,  $p_n$  is the transmitting power of the base station to user  $n$ ,  $h_n$  denotes the channel gain of user  $n$  and  $\sigma^2$  indicates the variance of the channel noise. Since we assume the spectrums can't be reused in neighboring networks, and furthermore the spectrum reusing in the networks not neighboring is not considered to bring interferences, hence there are no co-channel interferences between networks.

Here we aim to maximize the throughput of the network under the limit of each user rate and transmitting power, we can summarize the optimality problem as (2)

$$\begin{aligned} \max \quad & C = \sum_{n=1}^N r_n \\ \text{st} \quad & \sum_{n=1}^N p_n \leq P \\ & r_n \geq R_n \quad n \in \{1, 2, \dots, N\} \end{aligned} \quad (2)$$

In (2),  $C$  indicates the total throughput of the network,  $P$  indicates the up threshold of the base station transmitting power and  $R_n$  is the rate requirement for user  $n$ .

#### 3.2.2 Partial Optimality in Coordinated Allocation

The partial optimality is taken by the controlling centers of the neighboring networks to maximize the total throughput of the two networks. The limit conditions are decided according to the Qos requirements and transmitting power of each network. Here we describe the optimality problem under the limitation of the least contents and the largest transmitting power of each network as (3)

$$\begin{aligned} \max \quad & (C_1 + C_2) \\ \text{s.t.} \quad & C_1 \geq C_{LT1} \\ & C_2 \geq C_{LT2} \\ & P_1 \leq P_{LT1} \\ & P_2 \leq P_{LT2} \end{aligned} \quad (3)$$

In (3),  $c_1$ ,  $c_2$  and  $c_{LT1}$ ,  $c_{LT2}$  are the contents and the lowest requirements for the two networks respectively.  $p_1$ ,  $p_2$  and  $p_{LT1}$ ,  $p_{LT2}$  are the transmitting power and the

largest limitation for the two networks respectively.

### 3.2.3. Global Optimality in Coordinated Allocation

The global optimality is also achieved by the optimization between neighboring networks, which maximizes the total content of the HCNs under the limitation of service requirements of each network. After the repeated optimization between networks the convergent allocation of the whole networks are obtained and a result close to the global optimality will be achieved. The optimality problem can be described as (4)

$$\begin{aligned} \max \sum_{m=1}^M C_m \\ \text{s.t. } C_m \geq C_{LTm} \end{aligned} \quad (4)$$

In (4),  $c_m$  and  $c_{LTm}$  are the contents and the lowest requirements for network m respectively.

### 3.3. Proposed Algorithm

Based on the basic thought and optimality description, we consider the detailed process of the resource coordination algorithm for distributed HCNs. To simplify the process, we assume that there are only three cognitive networks shown in Figure3, WLAN2 neighboring with WLAN1 and WLAN3 at the same time. According to the graph theory application in spectrum allocation<sup>[8]</sup>, it can maximize the total system content to multiplex the channels in different networks to the most extent. Hence we follow two principles in the coordination process: the first is that the channels are multiplexed in different networks as many as possible; the second is allocating each channel to the network with largest gain as far as possible. The detailed coordinated allocation steps are summarized in Table1.

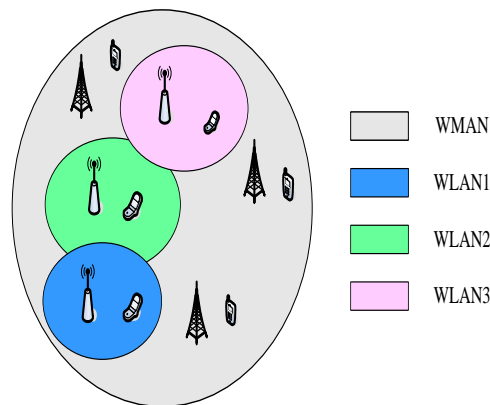


Figure 3. HCNs Network Structure

**Table 1. Steps of the Coordinated Allocation Algorithm**

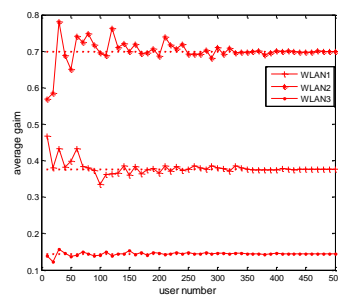
1. WLAN1 and WLAN2 take interaction and coordination. Each channel is allocated to the network with better average gain.
2. WLAN2 and WLAN3 take coordination based on the allocation result of 1. The channels with the largest gain in WLAN2 are left in WLAN2 and the others are allocated to WLAN3.
3. WLAN1 and WLAN2 adjust channels based on the results of 2. The channels removed from WLAN2 in 2 are allocated to WLAN1.
4. With the updating of the channel information in each WLAN, 1, 2, 3 are repeated for multiple times until the allocation become stable.
5. If there are large changes on the network structure or service requirements of users, 1, 2, 3, 4 are repeated to obtain new allocation between networks.

## 4. Simulation

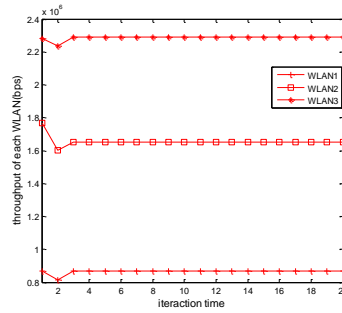
We build the HCNs platform and simulate the proposed algorithm by MATLAB. Assume there are 10 channels in the system totally shared by three WLANs distributing as Figure3. The bandwidth of each channel in the system is 1/64MHz and the power spectral density of AWGN is -80dBW/Hz. The channel environment is chosen to be Rayleigh fading channel and the channel gain of each channel for each user is generated randomly under the Rayleigh distribution. Suppose the period time of information interaction between neighboring WLANs is 1s. And the arrival and leaving rate of users in each WLAN are  $100s^{-1}$ .

### 4.1. Learning Process and Convergence Analysis

We choose one channel randomly and simulate the study process for the average gain in every WLAN. From the results shown in Figure4, it can be seen that after about 250 users have accessed one WLAN the statistical results become stable. In another word the central node in WLAN can acquire relatively accurate channel gain in 2 or 3 interaction periods.



**Figure 4. Convergence Performance in Learning Process**



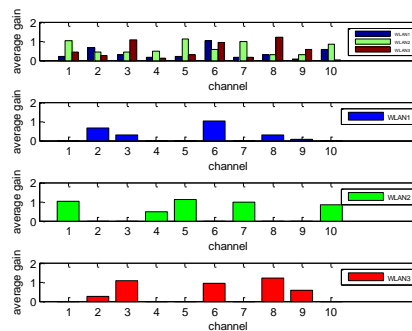
**Figure 5. Throughput Comparison of Different Iteration Times**

According to the algorithm in Table1, we simulate the interaction process between neighboring WLANs and compare the system throughputs after different interaction times in Figure5. As is indicated in Figure4 that from the first period the statistical results of WLANs achieve correct value relationship, the channel adjustments between neighboring WLANs are ended after only 3 periods and then the throughput in every WLAN becomes stable.

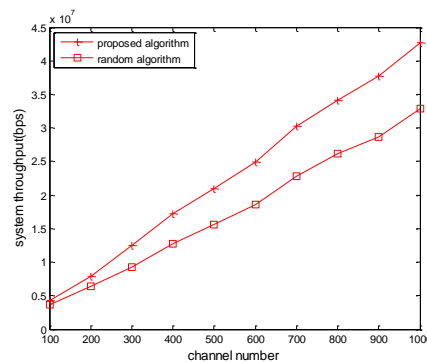
**4.2. Analysis of Allocation Results**

Figure 6 shows the average gain for one channel in each WLAN and allocation result for each WLAN. The topmost figure of Figure6 shows the average gain of each channel in WLAN1, WLAN2 and WLAN3. The lower three figures indicate the allocated channels for each WLAN. From the allocation result, it can be judged that the channels with the largest gain in WLAN2 are allocated to WLAN2 and the others are allocated to WLAN1 and WLAN3 to realize the channel multiplexing to enhance the system content.

We compare the proposed allocation algorithm with the random spectrum sharing algorithm, which allows the users of each WLAN access the channels randomly based on some collision avoidance scheme. Figure 7 indicates the difference in the system throughput between two algorithms. It can be seen that with the channel number increasing the total system throughput has more obvious gain since we realize the channel multiplexing to the most extent in the condition of satisfy the service requirement of WLAN2.



**Figure 6. Channel Allocation in different WLANs**



**Figure 7. System through Put Performance Comparison**

## 5. Conclusion

In this paper, we research the information interaction and resource coordination scheme in distributed HCNs. The scheme adjusts channels between neighboring networks based on the average channel gain to satisfy the QoS of each network and maximize the content of the whole system. The simulation results verify that the proposed scheme has fast learning and convergence speed, and also enhances the system content for a great degree comparable to the existing algorithm. The future research will include the resource coordination scheme for the HCNs with many more WLANs existing and dynamic change of network structure.

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