Journal of Physics: Conference Series

PAPER • **OPEN ACCESS**

Interference-Avoid Based Spectrum Sharing Approach for Loosely-Coupled Cognitive Radio Networks

To cite this article: Zheng Qiu and Luyong Zhang 2022 *J. Phys.: Conf. Ser.* **2221** 012045

Interference-Avoid Based Spectrum Sharing Approach for Loosely-Coupled Cognitive Radio Networks

Zheng Qiu, Luyong Zhang*

School of Information and Communication Engineering, Beijing University of Posts and Telecommunication, Beijing,100876, China

*Corresponding author's e-mail: lyzhang@bupt.edu.cn

Abstract. Cognitive radio (CR) network is a promising technology to solve the problem of spectrum scarcity arising from the growth of usage of wireless networks and mobile services. CR networks can find idle channels and access them opportunistically with spectrum sensing technology. In this paper, resource allocation with sensing-based interference recording is considered for several loosely-coupled cognitive radio networks, in which the base station controls the end-users' (EUs) transmission by making channel allocation strategies based on recorded interference information. We proposed a method to record this information and an allocation strategy with low computational complexity, to increase the capacity of tasks with fixed data size in the system. Numerical results show the effectiveness of our model for recording the statistical behaviour of the cognitive network interference and allocating channels for higher system capacity.

1. Introduction

With the rapid development of technologies such as the Internet of Things and 5G a large number of terminals are deployed in high-density places, but there are also a great number of spectrum holes in many frequency bands and regions. Therefore, opportunistic spectrum access together with a cognitive radio [1] technology has become a promising solution to resolve this problem.

When end-users access network resources in a hierarchical cognitive network [2], they need to monitor the surrounding channel information within a predetermined time cycle to avoid interference with the primary user. There are three main spectrum access modes for cognitive networks: opportunistic spectrum access [3-4], spectrum sharing [5-6], and perception-based spectrum sharing [7-8]. The system we proposed uses opportunistic spectrum access to allocate channels to EUs. But to take control of the dynamic interference in the area, the system also takes the advantage of perception [7].

As an emerging field, mobile edge computing provides new possibilities for the design of cognitive network systems. For example, the author of [9] has proposed that cognitive network and edge mobile computing can increase the working capacity of the cognitive network, reduce its work requirements, and increase the computing and storage capabilities in the cognitive network. Also, based on the proposed mobile edge computing concept [10], many tasks can be done with computing power at the edge, and in [11] the author jointly allocates computing resources and spectrum resources to increase the utilization rate in the mobile edge computing system and reduce its energy consumption.

In this paper, we proposed a new framework for allocating spectrum resources among multiple loosely coupled cognitive networks, accounting for the perception process, communication methods between networks, and the reuse of spectrum in space. In addition, our framework allows us to model and count the model of the cognitive network interference generated in a limited finite region while considering the influence of inter-network interference on the quality of the channel. Based on this framework, we use two strategies to evaluate and instruct spectrum allocation plans. Then, we proposed a spectrum resource allocation protocol for the cooperation of two methods of active interference-avoiding (AIA) and passive interference-avoiding (PIA) for specific application scenarios. By using heuristic algorithms, we optimize the complexity of the algorithm to a level acceptable to the system in the real world. The numerical results verify the effectiveness of our model in network spectrum allocation in different scenarios.

2. System model and problem descriptions

We consider a CRN consists of several loosely coupled subnetworks located in an adjacent area. Define K as the total number of frequency bands $\boldsymbol{FB} = \{\mathrm{fb_1}, \mathrm{fb_2}, \dots \mathrm{fb_k}, \dots \mathrm{fb_K}\}$ that are available for all base stations (BS) and EUs in this area. We assume that in this area, there are N BSs (BS)$\boldsymbol{BS} = \{\mathrm{bs_1}, \mathrm{bs_2}, \dots \mathrm{bs_i}, \dots \mathrm{bs_N}\}$, and M EU $\boldsymbol{EU_i} = \{\mathrm{eu_1^i}, \mathrm{eu_2^i}, \dots \mathrm{eu_j^i}, \dots \mathrm{eu_M^i}\}$ separately belongs to each BS bs_i. In this area, each BS bs_i and EU set $\boldsymbol{EU_i}$ managed by bs_i form a CRN network $\boldsymbol{RN_i} = \{bs_i \cup \boldsymbol{EU_i}\}$. Additionally, EU eu_j^i can only communicate with its BS $(\boldsymbol{BS_i} | eu_j^i \in \boldsymbol{EU_i})$, and at each time, eu_j^i can only use one frequency band.

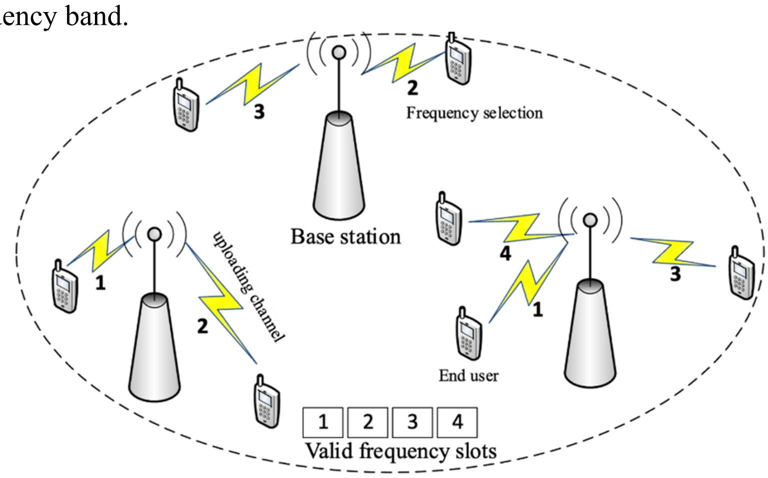

Fig. 1. Model of loosely coupled CR networks

By definition, bs_i and eu_j^i can communicate on a channel $cs_{ij}^k \in \boldsymbol{CS}$. $\boldsymbol{CS}$ means the available channel set determined by timeslot, frequency band, and location information. Leaving out timeslot that is irrelated to the channel allocation, we use bs_i, eu_j^i, fs_k to represent channel cs_{ij}^k, in which location information was indicated by bs_i and eu_j^i.

The system we proposed focuses on one-way transmission tasks from EU to BS. These tasks have strict latency requirements, so only when a pack of data is transferred to a BS in the same timeslot when the data was generated, will we consider it a successful task. The channel capacity matrix we mentioned above indicates the bitrate of the upload channel between an EU and a BS.

Reusing frequency bands in different networks will increase the usage rate of wireless spectrum. Despite that the number of channels used in the system can be multiplied by space-division multiplexing, collisions among different networks will disable many channels and significantly impact the communication process.

At the beginning of each communication time-slot, each BS will allocate a channel to each EU. We use $cc_{ij}^k \in \boldsymbol{CC_i}$ to indicate the allocation choice. When frequency band fb_k will be allocated to EU eu_i^j in network $\boldsymbol{RN_i}$ in next time-slot, $cc_{ij}^k = 1$. And $cc_{ij}^k = 0$ means channel cs_{ij}^k will not be used.

To focus on the time-sensitive uploading problem, we defined an indicator $\mathcal{R}_{valid}$ for these tasks. EUs who choose channels with a higher bitrate than $\mathcal{R}_{valid}$ will finish the task. We define $f(\mathcal{R})$ as the score of a channel in one time-slot.

Journal of Physics: Conference Series **2221** (2022) 012045 doi:10.1088/1742-6596/2221/1/012045

$$f_{assess}(\mathcal{R}) = \begin{cases} 1, & if\ \mathcal{R} \geq \mathcal{R}_{valid} \\ 0, & if\ R < \mathcal{R}_{valid} \end{cases} \tag{1}$$

The signal sent by these EUs to their BS will interfere with other EUs in different networks. We use $\mathcal{R}_{real\,ij}^{k}$ to represent the bitrate of an uploading channel from EU eu_j to BS bs_i.

The interference power and bitrate of each channel can be defined as

$$I_i^k = P_N + P_I^k \tag{2}$$

$$\mathcal{R}_{real\,ij}^{k} = B_k * \log_2(1 + \mathrm{Pr}_{\mathrm{ij}}^{k}/\mathrm{I}_i^{\mathrm{k}}) \tag{3}$$

where $\mathrm{Pr}_{\mathrm{ij}}^{k}$ is the received signal power and P_I^k represents the interference sent by EUs from other networks. So the utilization problem is thus:

Maximize:

$$Score = \sum_{i=1}^{N}\sum_{j}^{M}\sum_{k}^{K} cc_{ij}^{k} * f\left(\mathcal{R}_{real\,ij}^{k}\right) \tag{4}$$

Subject to:

$$\sum_{j}^{M} cc_{ij}^{k} \leq 1, \forall i, k, \sum_{k}^{K} cc_{ij}^{k} = 1, \forall i, j \tag{5}$$

3. Proposed method

We proposed a method that uses historical channel information and active interference-avoiding (AIA) schemes to instruct the BS to make channel allocation decisions. We will illustrate this method in 3 parts below.

3.1. Record and update historical information

As mentioned above, in the system, there are N*M*K potential available channels. For cognitive network $\boldsymbol{RN_i}$, we use a channel capacity matrix $\boldsymbol{\mathcal{R}_i}$ to indicate the capacity of each channel and more precisely, $\mathcal{R}_{ij}^{k} \in \boldsymbol{\mathcal{R}_i}$ indicates the potential transmit rate of channel cs_{ij}^{k}. Each matrix $\boldsymbol{\mathcal{R}_i}$ is individually maintained and used by network $\boldsymbol{RN_i}$ to make channel allocation decisions.

After each communication time-slot, BSs calculate the bitrate of each working channel based on observed signal and interference information. Using these newly generated channel statuses, we update the channel capacity matrix $\boldsymbol{\mathcal{R}_i}$ with rate α_{update}. Pseudocode is given below.

Algorithm 1: update $\boldsymbol{\mathcal{R}_i}$

Input: last channel decision matrix $\boldsymbol{CC_i}$
Input: historical and current channel capacity matrix $\boldsymbol{\mathcal{R}_i}$, $\widetilde{\boldsymbol{\mathcal{R}_i}}$
Output: historical channel capacity matrix $\boldsymbol{\mathcal{R}_i}$
for $j = 1$ to length ($\boldsymbol{\mathcal{R}_i}$) **do**
  for $k = 1$ to length ($\boldsymbol{\mathcal{R}_i^j}$) **do**
    if $cc_{ij}^{k} = 1$ **then**
      $\boldsymbol{\mathcal{R}_{ij}^{k}} = \mathcal{R}_{ij}^{k} * \alpha_{update} + \widetilde{\mathcal{R}_{ij}^{k}} * (1 - \alpha_{update})$
    end if
  end for
end for
return $\boldsymbol{\mathcal{R}_i}$

3.2. Allocate channel based on historical information

By monitoring and collecting channel connecting status, we have obtained the interference information between these networks. Next, we use this information to make the best channel allocation decision. We can use $Score$ as we proposed above to evaluate our decision, but matrix $\boldsymbol{\mathcal{R}_i}$ is just a prediction of channel status. To find best channels, we choose

$$f_p(\mathcal{R}) = \begin{cases} (\mathcal{R}/\mathcal{R}_{valid})^2, & if\ \mathcal{R}/\mathcal{R}_{valid} \leq 1 \\ 2 - \mathcal{R}/\mathcal{R}_{valid}, & if\ \mathcal{R}/\mathcal{R}_{valid} > 1 \end{cases} \tag{6}$$

as the criterion of single-channel allocation quality and

$$f_{sum}(\boldsymbol{CC_i}, \boldsymbol{\mathcal{R}_i}) = \sum_{i=1}^{N} \sum_{j}^{M} \sum_{k}^{K} cc_{ij}^{k} * f_p\left(\mathcal{R}_{ij}^{k}\right) \tag{7}$$

as the criterion of the total system. We choose this criterion to focus on choosing channels that can finish our proposed task, instead of increasing the overall signal rate of the system. Then we can get the most valid channels out of N*M*K potential available channels. This is a Non-deterministic Polynomial (NP)-hard problem, so we use simulated annealing (SA) algorithm to solve this problem:

Algorithm 2: channel allocation using SA algorithm

Input: historical channel capacity matrix $\boldsymbol{\mathcal{R}_i}$
Input: initial temperature $T_{initial}$ and cooling rate α_{cool}
Output: channel decision matrix $\boldsymbol{CC_i}$
initialize a valid channel decision matrix $\boldsymbol{CC_i}$
while $T \geq 2$ **do**
  $\boldsymbol{CC_{copy}} \leftarrow shuffle(\boldsymbol{CC_{copy}}, T)$
  $Score_{old} \leftarrow f_{sum}(\boldsymbol{CC_i}, \boldsymbol{\mathcal{R}_i})$
  $Score_{new} \leftarrow f_{sum}(\boldsymbol{CC_{copy}}, \boldsymbol{\mathcal{R}_i})$
  if $Score_{new} \geq Score_{old}$ **then**
    $\boldsymbol{CC_i} \leftarrow \boldsymbol{CC_{copy}}$
  else if $1 - Score_{new}/Score_{old} > random(0,1) * \alpha_{accept\ rate} * T$ **then**
    $\boldsymbol{CC_i} \leftarrow \boldsymbol{CC_{copy}}$
  end if
  $T_{initial} \leftarrow T_{initial} * \alpha_{cool}$
end while
return $\boldsymbol{CC_i}$

We use a function *shuffle* to indicate a random channel-reallocating process. It makes a copy of matrix $\boldsymbol{\mathcal{R}_i}$ and randomly swap between the allocation decision of T channels. If the new allocation decision is a better choice according to criterion $f_{sum}(.)$, we simply accept the new selection. And to avoid the system from being trapped by local optimizations, when we get a worse score out of the new allocation decision, we randomly accept the choice by chance. Thus, as temperature $T_{initial}$ goes down, the stride of *shuffle* and the chance of accepting worse allocation decisions will decrease and lead the system to a convergent solution.

3.3. AIA and PIA schemes

By using the A and B part of the proposed method, these networks can avoid certain interference from other networks by recording interference information and adjusting the channel allocation decisions based on this information. We call it a passive interference-avoiding (PIA) scheme.

Based on this, we proposed an active interference-avoiding (AIA) scheme. In a communication timeslot, when a BS senses interference and the corresponding channels have a lower signal rate than needed. A BS will actively emit signals in these frequency slots of specified power.

Based on the above model, the system flow and algorithm proposed in this paper are composed of the following steps:

1. According to the information of the historical channel matrix, the BS allocates channels to EUs in the network. Then the network enters the actual task data transmission stage 2. Each EU transmits tasks to the BS on the allocated frequency band. At this time, the BS will monitor the signal and interference of each channel and update the capacity matrix. 3. The BS starts active interference-avoiding measures for the channels with serious interference. 4. Each BS updates its channel interference status again and updates the capacity matrix.

4. Result and discussion

Our scenario deployed 3 networks in an area, where there are 100 available frequency slots for all BSs and EUs. This simulation does not consider power allocation, and each EU has the same transmission power. The result is represented by the number of valid channels in the CR network system. When we randomly allocated channels, there were about 160 channels available in each round of communication. By using the PIA algorithm, after 400 communication rounds, this number went up to 200 by choosing channels with less interference, increasing the utilization rate by 24%. When we applied the PIA algorithm on the system based on the AIA, we got another 13% improvement.

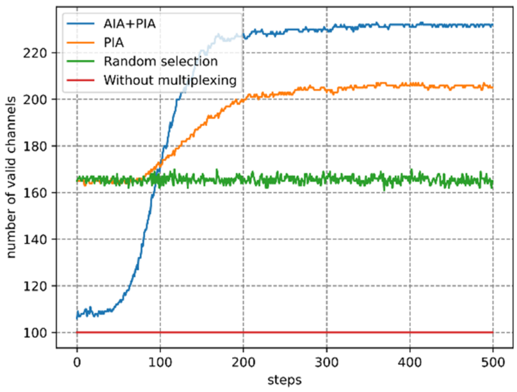

Fig. 2. Channel Allocation by AIA and PIA Algorithm

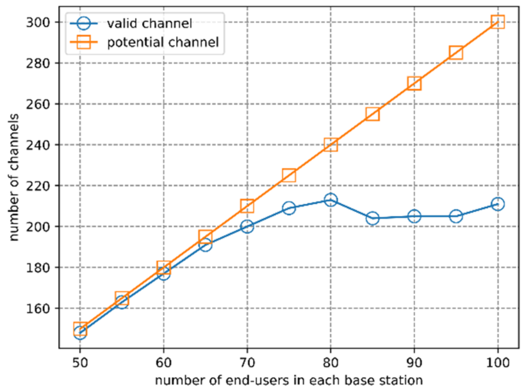

Fig. 3. Comparison of achieved under different number of EUs

As shown in figure 2 above, at the beginning of the simulation, because of the intended interference emitted by networks on interfered channels, the system started with low capacity. But after that, it converged to a higher capacity.

As shown in figure 3 above, in this simulation scenario, before we allocate more than 65 EUs for each network. After the system converged to a plateau, there was basically no interference happening in the system (the number of valid channels in the system are close to potential channels). As we increase EUs, after the system had found all available channels, the capacity of these networks was no longer related to the number of EUs.

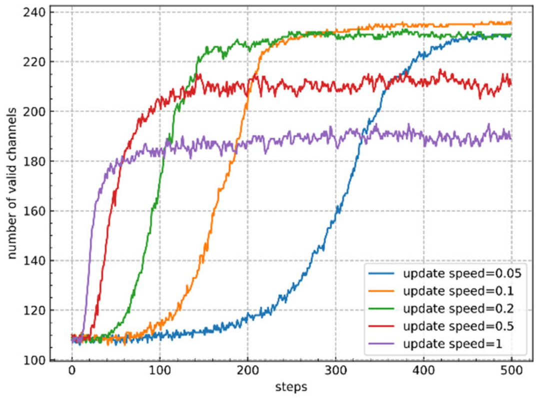

Fig. 4. Comparison of achieved capacity under different update speed

As we mentioned in algorithm 1, we use α_{update} to control the speed of updating the information in historical capacity matrix.

As shown in figure 4 above, when we set update speed as 1, we didn't record any historical information, and the system fluctuated greatly and ended with an unsatisfactory result. When we decreased the update speed, the system exchanged their information more slowly, so the processes of their convergence took more iterations. But they converged more smoothly and had better results. Better overall capacity between a period can be obtained by selecting update rate according to system transformation situations like the movement and status changes of EUs.

5. Conclusion

In this paper, we proposed two methods to reduce interference between several loosely-coupled CR networks. Without communicating about allocation strategies directly, BSs with proposed methods can share interference information using spectrum-sensing and actively emitting signals on disrupted channels. We used a capacity matrix to record historical interference information about channels and represent the future status of these channels. With historical information and simulated annealing algorithm, we managed to reduce the complexity of the channel allocation algorithm from NP to an acceptable standard and effectively increased the system capacity. Simulation results show that the proposed channel allocation algorithm improves about 30% in the achieved capacity over tasks with a fixed amount of data than the baseline algorithm with random allocation. Ideally, a system with proposed methods can find most of the valid channels in the system and maintain the performance when more EUs join the network after the system reaches its performance limit.

References

[1] Wang B, Liu K J R. (2010) Advances in cognitive radio networks: A survey. IEEE Journal of selected topics in signal processing, 5(1): 5-23.

[2] Ghosh G, Das P, Chatterjee S. (2014) Cognitive radio and dynamic spectrum access-A study. International Journal of Next-Generation Networks, 6(1): 43.

[3] Sharma M, Sahoo A. (2013) Stochastic model based opportunistic channel access in dynamic spectrum access networks. IEEE Transactions on Mobile Computing, 13(7): 1625-1639.

[4] Rawat D B, Bajracharya C, Grant S. (2017) nroar: Near real-time opportunistic spectrum access and management in cloud-based database-driven cognitive radio networks[J]. IEEE Transactions on Network and Service Management, 14(3): 745-755.

[5] Yan Z, Zhang X, Liu H L, et al. (2018) An efficient transmit power control strategy for underlay spectrum sharing networks with spatially random primary users. IEEE Transactions on Wireless Communications, 17(7): 4341-4351.

[6] Ahmad W S H M W, Radzi N A M, Samidi F S, et al. (2020) 5G technology: Towards dynamic spectrum sharing using cognitive radio networks. IEEE Access, 8: 14460-14488.

[7] Chen Z, Gao F. (2015) Cooperative-generalized-sensing-based spectrum sharing approach for centralized cognitive radio networks. IEEE Transactions on Vehicular Technology, 65(5): 3760-3764.
[8] Gao X, Feng S, Niyato D, et al. (2019) Dynamic access point and service selection in backscatter-assisted RF-powered cognitive networks. IEEE Internet of Things Journal, 6(5): 8270-8283.
[9] Kakalou I, Psannis K E, Krawiec P, et al. (2017) Cognitive radio network and network service chaining toward 5G: Challenges and requirements. IEEE communications Magazine, 55(11): 145-151.
[10] Mach P, Becvar Z. (2017) Mobile edge computing: A survey on architecture and computation offloading. IEEE Communications Surveys & Tutorials, 19(3): 1628-1656.
[11] Zhang, X., Mao, Y., Zhang, J., & Letaief, K. B. (2017). Multi-objective resource allocation for mobile edge computing systems. In: 2017 IEEE 28th Annual International Symposium on Personal, Indoor, and Mobile Radio Communications pp. 1-5.