COGNITIVE RADIO NETWORKS – BASIC APPROACH AND ELEMENTARY TERMS

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Abstract

This paper introduces cognitive radio networks topic. It reveals elementary terms of this field and defines main points of interest that should be presented to show main purpose. There are mentioned network categories from point of view of access to these radio networks in this work. Moreover, this paper deals with fundamental models, which serve as the basement for the frequency spectrum sharing. This chapter draws attention because of three basic types of spectrum sharing models that are well-known and described in the theory. Usage of these models represents standard ways of the spectrum distribution among all the users in cognitive form of radio network. There is discussed spectrum trading in the next chapter. Spectrum pricing principles follow in this article. As its summary section with mathematical formulas describing user's profit and utility serves. The conclusion shows possible future ways of research in this field.

***Keywords*:** *radio network, users, trading*

1 INTRODUCTION

Frequency spectrum is one of the scarcest radio resources in wireless communication networks. The concept of cognitive radio was introduced to improve the frequency spectrum utilization in wireless networks. Accessible radio spectrum is allocated to licensed wireless users. There is common state that some frequency bands in the radio spectrum are unused in one time and one location. Such circumstance is referred to as spectrum hole. In some theses this situation is called spectrum opportunity. Cognitive radio network approach to wireless communication takes advantage of these spectrum opportunities to improve spectrum utilization and thus network performance. Brain of this wireless network is cognitive radio transmitter, which is able to adapt and intelligently change the transmission parameters according

to circumstances in a dynamic environment. Cognitive radio network offers way how to efficiently share frequency spectrum among multiple users to improve its usage.

2 THE NETWORK CATEGORIES

In this complex, there are two network categories on different channels: primary network and secondary network. The first one has highlighted access to the band and the second one uses the channel when the primary network is not transmitting or receiving information. There are algorithms which aims are to solve the access allocation problem and how to maximize the sellers' revenue given via offering the free unused spectrum frequency band. [1]

3 SPECTRUM SHARING AND USAGE

There are three elementary models of spectrum sharing in a cognitive radio network:

- Public commons model;
- Exclusive usage model;
- Private commons model. [3]

Public commons model represents frequency bands that are devoted to free usage and opened to anyone with retention of valid legal rules during its use. The very substantial instances of this model are common wifi network and bluetooth network. Of course, there are also many other radio networks that are invented by private businesses which use them only for their own need. This component of spectrum sharing is not interesting for further economic research because of its free aspect.

Exclusive usage model embodies the radio spectrum partition which is exclusively licensed to the particular user. As the improving factor gaining higher efficiency dynamic allocation of the traded frequency bands can be used by the spectrum partition's owner. This point means entrance for economic approach to the topic.

Private commons model is type of spectrum sharing where many different users in the same cognitive radio network have various priorities to share their spectrum partition. There is obvious tier hierarchy among the users. On the top position primary user sells the frequency bands to the secondary users. It trades the spectrum holes. Secondary user can be in two diverse positions – as final user consuming the frequency band or as seller offering the frequency band further to next tier user – to tertiary user. It is not necessary to be only one situation; the user is able to use and also to sell the assigned frequency bands. Such succession can have more members until all of the users participating in usage of the cognitive radio network fulfil their satisfaction. There are two attitudes of way how to divide the frequency bands among operating users in this model – underlay approach and overlay approach. Underlay method means transmitting information over a large bandwidth using low transmission power.

On the other hand overlay approach presents way of dividing the whole accessible spectrum by frequency or by time.

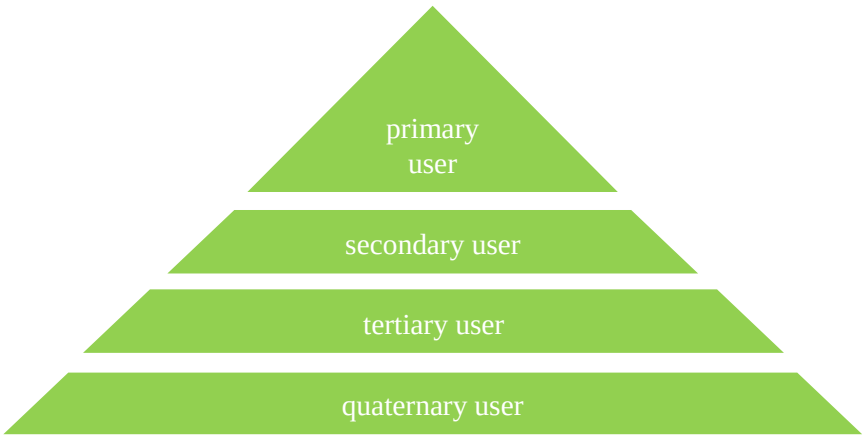


Figure 1 Tier Hierarchy

4 THE SPECTRUM ACCESS CLASSIFICATION

There are two more criteria separating different network architectures and network protocol behaviours: cooperation among users and network administration. Standard sorting out of cooperation is applied – cooperative access and non-cooperative access.

Cooperation among the cognitive radio network units improves efficiency and fairness of network use.

Non-cooperative architecture is constructed in so way that all of the participating cognitive radio network members are satisfied. It means no one is able to reach a better solution by changing its behaviour. One particular practical explanation is Nash equilibrium according to its game theory formulation.

The second aspect is network protocol behaviour – the whole system can be centralized or distributed. Also common definition of these terms is applied.

The centralized spectrum access comprises the centralized point named as controller. The system member gains information about the environment in the cognitive radio network, for instance about spectrum opportunity or spectrum demand. The decision about transmitting data is based on all the gathered information. Principally spectrum owner acts as the centralized controller.

In contrast, the distributed spectrum access architecture involves no centralized point. The decisions are made by each user individually and all the users are equivalent, so they behave like peers to each other.

Based on all above mentioned criteria cognitive radio network architecture comprises four main accesses:

- centralized cooperative dynamic spectrum access;
- distributed cooperative dynamic spectrum access;
- centralized non-cooperative dynamic spectrum access;
- distributed non-cooperative dynamic spectrum access. [3]

Firstly, centralized cooperative dynamic spectrum access is presented by coordinating point that serves as head of the whole cognitive radio network and manages to mediate cooperation among the linked users.

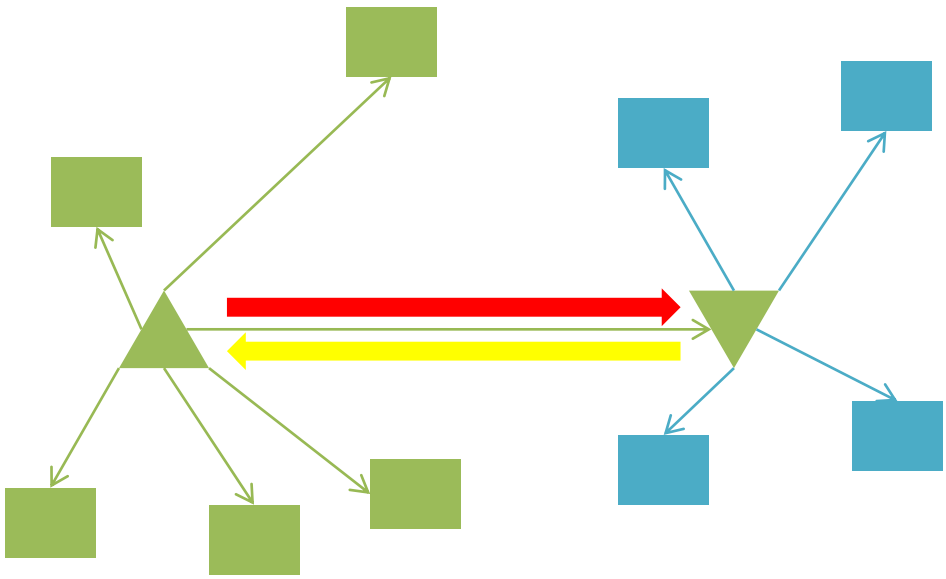
Secondly, distributed cooperative dynamic spectrum access performs with no main node, therefore all the particular users have to make their own decision themselves.

Thirdly, centralized non-cooperative dynamic spectrum access signifies the cognitive radio network with one central unit that determines the state of transmission.

Fourthly, distributed non-cooperative dynamic spectrum access means no preceding information about the network itself is known to the transmitters or the receivers.

5 THE SPECTRUM TRADING

Spectrum trading is the process of exchanging spectrum partitions. There are two sides as usually in each transaction in this trade. Company holding and selling the certain frequency band is the spectrum seller. This is also called the primary user. On the next side the spectrum buyer stands – it purchases spectrum partition to handle it for its own usage. This is the secondary user. In some cases it is entitled renting user. Source of this name comes from the fact that the secondary user pays amount of money as rent for usage of the purchased frequency bands to their owner.



Legend:

– primary user – seller;

– secondary user – buyer as reseller;

– secondary user – buyer as consumer;

– further user – not applicable in this case;

– sold frequency band;

– resold frequency band;

– price;

– demand.

Figure 2 Spectrum Trading from Seller's Point of View

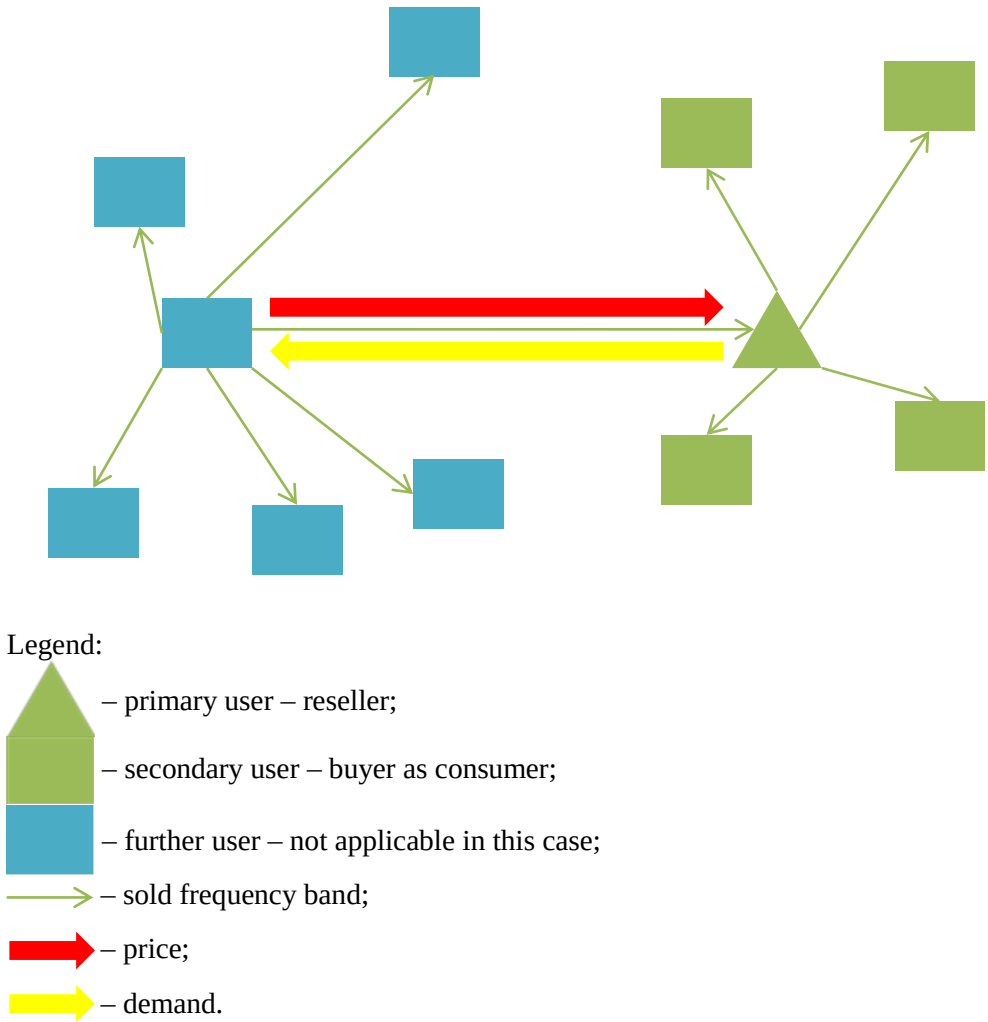


Figure 3 Spectrum Trading from Reseller's Point of View

6 THE SPECTRUM PRICING

On the one hand the primary user's aim is to maximize its profit through selling the frequency spectrum to the secondary user, whilst on the other hand the secondary user's aim is to maximize the satisfaction from the fulfilled connections. The primary service charges price which reflects in contentment of the secondary service. If the price gets higher, satisfaction decreases, because for the same size of spectrum buyer

has to pay more or has to settle for the smaller size of spectrum that it can use for its transmission.

Dynamic spectrum access incorporates network functionalities including spectrum identifying at the physical layer of the network protocol and medium access control layer, whereas spectrum trading itself can be considered as one of its components which deals with the economic aspects of dynamic spectrum access. The process of trading determines the structure of radio resource selling and buying – way, which is the particular deal made in. Pricing or determination of price level is a very important issue in spectrum trading. It is the value responsible for the worth of the frequency bands. Usually it comes into existence after mutual agreement between the seller and the buyer.

As it is common in almost each fragment of trade in general, competition among the cognitive radio network entities participates in spectrum trading. Contrariwise, it is not possible to fully avoid cooperation among these frequency band sellers.

7 NUMERICAL POINT OF VIEW

Because the majority of the cognitive radio network scheme is involved in the technical aspect of spectrum sharing, economic research should focus on the financial aspect of this topic. There is main characteristic that is contributed to this subject – spectrum trading. It comprises selling and buying radio resource – that is frequency bands – in a cognitive radio environment.

There are several dimensions we can quantify from the mathematical aspect of the cognitive radio network topic and the main points are:

- the profit function;
- the utility function.

7.1 The Profit Function

Initially, there are numerous mathematical formulas how to express profit function. One of them is expressed as follows:

$$\pi_p = c_1 n_p + b_s p - c_2 n_p \left(B_{req} - \frac{W - b_s}{n_p} \right)^2 \qquad (1)$$

where the single parts are:

- π_p – the primary service provider profit, whilst p reaches integer value;
- c_1 – the weight for the revenue from the primary connections and the cost due to performance degradation;
- n_p – the number of connections at the primary service;
- b_s – the vacant spectrum supply;
- p – the given price charged to the secondary service provider;
- c_2 – the weight for the revenue from the secondary connections and the cost due to performance degradation;

- B_{req} – the bandwidth requirement for the primary connection;
- W – the total spectrum. [3]

7.2 The Utility Function

The concept of utility is applied to quantify the satisfaction generally. The utility function is important besides the profit function too by the fact it denotes the user's preferences to choose the product that preferably suits for it.

One of more expressions of the utility function appears in this way:

$$U(b) = \ln b + c_3 \qquad (2)$$

where the variables are:

- U(b) – the utility value;
- b – the vacant spectrum;
- c_3 – the constant value. [3]

8 CONCLUSION

The cognitive radio network approach to the field of transmitting data represents bright future of wireless communication networks. It predicts and indicates higher efficiency of the frequency spectrum usage. The broader usage of wireless communication will be in the future, the more difficult will be transfer as process itself. This is one of the main points why it is important to pay attention to this topic. Further research can be aimed on agent based modeling and it would be instructive to reveal noise and fade issues in this topic.

REFERENCES

[1] HOSSAIN, Ekram – NIYATO, Dusit – HAN, Zhu: *Dynamic Spectrum Access and Management in Cognitive Radio Networks*. Cambridge: Cambridge University Press; 2009. 505 p. ISBN 13 978-0-511-58032-1.

[2] KASBEKAR, Gaurav S. – SARKAR, Saswati: Spectrum Auction Framework for Access Allocation in Cognitive Radio Networks. In *MobiHoc '09: proceedings of the 10th ACM International Symposium on Mobile Ad Hoc Networking and Computing & co-located workshops, FOWANC'09, MobiHoc S3'09, and WiMD'09: New Orleans, Louisiana, May 18-21, 2009*. ISBN 9781605585642.

[3] HOSSAIN, Ekram – NIYATO, Dusit: Spectrum Trading in Cognitive Radio Networks – A market-Equilibrium-Based Approach. In *IEEE Wireless Communications*. ISSN 1536-1284. December 2008; vol. 15, no. 6, p. 71-80.

[4] QIAN, Liang – YE, Feng – GAO, Lin – CHU, Tian – TIAN, Xiaohua – WANG, Xinbing – GUIZANI, Mohsen: Spectrum Trading in Cognitive Radio Networks – An Agent-Based Model under Demand Uncertainty. In *IEEE Transactions on Communications*. ISSN 0090-6778. November 2011; vol. 59, no. 11, p. 3192-3203.