Cognitive Radio using Spectrum Sensing by Cooperative Two Secondary Users

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Abstract. In cognitive radio systems, users that are cognitive (unlicensed) must constantly scan the spectrum for primary (licensed) users to be present. In this article, the researchers display the benefits of cognitive radio collaboration. It is demonstrate that detection times can be reduced by motivating cognitive users to cooperate in the same band, thus increasing overall agility. Next, a cognitive two-user radio network is depicted and a method to exploit the inherent network asymmetry to improve agility. It is shown that our cooperation program improves the efficiency of cognitive users by 35%. The researchers then extend the cooperation scheme to two user-per-carrier multi-carporate networks and calculate the gain in asymptotic agility.

Keywords. Cognitive radio, Spectrum sensing, Radio network.

1. Introduction
The early evolution of software-defined radio and its comparatively recent form of cognitive radio have attracted considerable interest. The SDR [1] improves dramatically on current structures of wireless networks. The embedded software on mobile phone, for example, explains with SDR, as the mobile phone should be operating in a time-bound way. In a comparative analysis, today's frequency band and protocol are set to cell phones' parameters. CR is much stronger than SDR. The climate changes are expected to be sending by CR. CR networks learn from their climate and perform operations that best support users. This is a significant feature of CR networks, which enable users to operate without a license on licensed bands, as in Figure 1.
While the above technologies offer a considerable advantage, practical systems are still in place that allows different users start sharing the spectrum smartly. In [2] the principle of RF implementing model for front-end CR networks is discussed. As cognitive users are using the licensed band, they need to feel that licensed (primary) users would be present in a very short period and leave the primary user band. CR networks have dramatically reduced detection capabilities. They typically coordinate two activities at a very high level [3, 4]:

- Dynamic Unused Spectrum Access (also known as Dynamic Spectrum Access).
- Sensing of the available spectrum before the approved user (also called spectrum sensing) is detected.

As shown in Figure 2, [5, 6] discusses extensively the DSA problem for CR networks. In the version of the Markov chain, the optimized allocation strategies for maximizing the overall efficiency are used. It describes in the use-based assignment method [7, 8] that a spectrum should be minimized based on such cost functions. A decentralized channel assignment game-theoretical approach is implemented in [9]. The inherent trade-off between overhead information and network overhead in CR networks are especially examined in detail in Figure 2, [10].

In [11] the spectrum-sensing topic is discussed. The local oscillator leakage power is used for primary user’s detection and position in sensor node detector RF receivers. The detectors then are transmitted to the cognitive radios of the channel pattern. In [12] the detection of signal in unknown bands in the cyclical spectral analysis is proposed by a neuronal network process. [13, 14] CR networks with
OFDM technology for primary user detection are proposed with power and frequency sensing techniques. This is complicated in itself because the CRs need to find conjoining bands that primary users do not use. In [15, 16] a system is recommended for the mutual spectral detection of the primary user. The sharing of data among cognitive radios is shown to increase the primary user detection possibility. In this paper, techniques are proposed to detect cognitive radio networks in a cooperative spectrum. Collaborative networks benefit from diversity by the motivation to co-operate [17, 18]. It is explained in [18] that a cooperative protocol can be implemented into a CDMA scheme. Cooperation plans on in the latest proposed TDMA orthogonal transmission [19] and [20, 21]. Two types of cooperation protocols are normally:

- Amplify and Forward
- Decode and Forward

It has been demonstrated that there is a lower risk of failure in two one-hop user networks where one user serves as a relay. It demonstrates that the (AF) protocol in which the relay transmits, without any processing, maximum diversity is achieved by the signal obtained from a transmitter as shown in Figure 3.

Concerning the impact of AF Cooperation Protocol on cognitive spectrum ability, the radio network is examined in this paper. For a short version of the findings in this report, see [22]. This is conducted from [23] to the point where cooperation strategy (AF and DF protocols) is not taken into consideration. Each cognitive user has a difficult decision on the presence of the primary user and most factors are used as part of the primary user presence determination. In order to achieve better cognitive networks, the researchers use spatial uncertainty inherent in the multi-user scenario. The scheme analysis is explained. Section 2, a theoretically studied novel cooperative method for the simple model of a fading channel and energy detection, is discussed. Section 3 of cooperative efficiency analytical detection requires a new scheme. Section 4 points out the potential interest in science.

2. Cooperative detection problems

2.1. Cooperative detection using two secondary users

A significant feature of cognitive radio design is the recognition Primary User Presence as soon as possible. Users of cognitive should also actively feel the spectrum. Consider a network in fixed TDMA mode with two cognitive users S1 and S2 to send data to some common users, as illustrated in Figure 4. Suppose a primary (licensed) user starts using the band. Then both cognitive users have to release the band to make way for the main user as fast as possible.
However, if one user states that S1 is far from the main user, the detection time is critical and the primary user's signal is so weak that a cognitive user S1 will take a long time to be present. It is shown that cognitive cooperation minimizes "weaker" time and increases "agility" in the network. The cognitive users S1 and S2, S2 are required to cooperate as relays for S1. Figure 4 applies to situations in the transmission of data in a particular frequency band to a standard receiver by two cognitive users S1 and S2. Slot transmission is used for transmitting in successive slots S1 and S2 the AF protocol [24] as shown in figure 5.

Figure 4. Cooperation in cognitive radio networks.

T1 transmits S1 and S2 listens in a time slot accordingly. The data received in the previous slot was transmitted in T2, S2 time frame. The primary user has higher priority for the band to be filled according to all these users. It is necessary to immediately recognize the existence of this primary user. The signal received from the T1 time slot S1 by S2 is:

\[ y_2 = \theta h_{p2} + ah_{12} + w_2 \]  

Where; \( h_{pi} \) indicates the instant channel gain between primary user, Si, \( h_{12} \) indicates the instant channel gain between S1 and S2, and \( w_2 \) denotes the Gaussian noise additive. It is assumed that \( h_{p2}, h_{12} \) and \( w_2 \) are zero-medium, independent random Gaussian variables of each other in pairs. It is also presumed that the channels are reciprocal, \( h_{12} = h_{21} \). In (1), \( \alpha \) shows the transmitted signal from S1, and, in \( \alpha \) primary user indicator is denoted; \( \theta = 1 \) implies the primary user's presence and \( \theta = 0 \) implies its absence. If S1’s transmit power limit is P then:

\[ E[|h_{12}|^2] = PG_{12} \]  

Where \( G_{12} = E[|h_{12}|^2] \) relates channel gain between S1 and S2 users. \( h_{p2}, h_{12}, \) and \( w_2 \) are presumed to be independent from (1):

\[ E[|y_2|^2] = \theta^2 P_2 + PG_{12} + 1 \]  

Where \( P_i = E[|h_{pi}|^2] \) corresponds to the primary user's Si signal power. The relay user, S2, transmits S1 to a common cognitive receiver inside time slot T2. The user of the relay has a maximum power constraint. Thus it calculates the average signal power received [25,26] and scales it appropriately in
order to realize its power constraint. S1 also listens to its own message in time slot T2, while S2 is relaying S1’s message to the receiver. The S2 received signal is given by:

\[ y_1 = \sqrt{\beta_1} y_2 h_{12} + \theta h p_1 + w_1 \] (4)

Where \( h p_1 \) constitutes the immediate channel gain between the primary user and S1, \( w_1 \) is a Gaussian noise additive and \( \beta_1 \) is a scaling factor for S2 to transmit data to the popular receiver [14]. \( \beta_1 \) is actually provided by:

\[ \beta_1 = \frac{\bar{p}}{\theta^2 P_2 + P G_{12} + 1} \] (5)

Upon cancelation of the message part, the signal is decided to leave to the user S1:

\[ Y = \theta H + W \] (6)

2.2. Channel model and relation between secondary users

We suggest that Rayleigh fading in this article by all networks. It is further presumed that the networks referring independent of multiple cognitive users. If a signal \( x \) is sent, the signal \( y \) received will be given by [27,28]:

\[ y = f x + w \] (7)

Where there are independent Random Complex Gaussian variables, the additive noise and the fading coefficient \( w \), except otherwise stated, noise is presumed to be a zero mean and unit difference in this article. It is believed that a central control unit exists in the post in which all cognitive users communicate (both receivable and sent). Each user also has access to his or her site's information. The transmitting of pilot symbols at regular intervals makes this easier.

2.3. Energy detection

In this article, the Energy Detector (ED) is used [29,30] to demonstrate gain from the proposed system for collaboration. The reasons behind choosing ED are two-fold:

- The impact of cognitive network cooperation. Therefore, the detector option is not important.
- The signal is modeled as a known-power random variable.

Therefore, ED [31] is optimum. For a Gaussian noise model, when the secondary user energy detection knows the noise, power can be utilized to monitor the primary signal. The energy of the received signal is stored during this simple method. Period declares that if the energy exceeds a certain threshold, it will occupy the band. It sets the threshold and focuses on optimal PFA. Unlike the other schemes, energy detection requires no primary signal and channel are sensitive to unidentified fading signals. Compared to other techniques, this has standardized implementation, making it less costly. Additional energy detection for spectrum sensing is implemented primarily in the research. It can be seen that given \( h_{12} = h_{21} \), in (6) complex Gaussian variables with zero mean and spread variances [32]:

\[ \sigma_h^2 = P_1 + \beta P_2 h \] (8)

And;

\[ \sigma_w^2 = 1 + \beta h \] (9)

Specifically, where:

\[ h = |h_{12}|^2 / E[|h_{12}|^2] = |h_{12}|^2 / G_{12} \] (10)

\[ \beta = \bar{p} G_{12} / \theta^2 P_2 + P G_{12} + 1 \] (11)
It is assumed here that S1 has channel state $h_{12}$ control. This is facilitated by enabling the user equipment to be transmitted regularly. Since $h_{12}$ is Gaussian complex, it is simple to see that h has the probability density function (PDF) feature [33]:

$$F(h) = \begin{cases} e^{-h} & h > 0 \\ 0 & h \leq 0 \end{cases}$$

The energy detection forms the statistics;

$$T(Y) = |Y|^2$$

and, compares with a threshold $\lambda$ which is determined by a predefined probability of false alarm $\alpha$

$$\varphi(t; \alpha, b) = \int_0^\infty e^{-h\frac{t}{\alpha+b}} dh$$

Let $t$, $a$, and $b$ for positive. $F_1(t)$ denotes the random variable $T(Y)$ cumulative density function (CDF) under hypothesis $H_0$, $I = 0, 1$. So we get from (9), as well,

$$E\{T(Y)|H_0, h\} = E\{|w|^2|h, \theta = 0\}$$

For $H_0(\theta = 0)$,

$$F_0(t) = P(T(Y) > t | H_0)$$

$$\varphi(t; 1, \frac{PG_{12}}{PG_{12}+1})$$

Similarly, it can be shown that,

$$F_1(t) = \varphi(t; P_1 + 1, \beta(P_2 + 1))$$

If $\beta$ is indicated by (11), we need to find the threshold $\beta$ so for a certain (PFA) $\alpha$:

$$\varphi(\lambda; 1, \frac{PG_{12}}{PG_{12}+1})$$

3. Cooperative detection performance analysis

The researchers have concentrated on raising the probabilities of identification by collaboration. The final aim is to reduce the overall detection time. Detection time and probability for complicated networks usually do not follow a simple reverse. A main controller is expected to communicate with all cognitive users to demonstrate the effect of collaboration on the overall detection time which is capable of receiving and transmitting both [34]. We will define a type of protocol that employs different collaborative levels. Totally Cooperative Protocol (TC): the cooperation scheme referred to in Section 2 [35, 36] is applied. Two users who operate in the same carrier coordinate to assess the presence of the primary user when placed as near as possible. The first user to recognize the primary user presence, via the central controller, warns other users. In figure 6, $P_n^{(1)}$ and $P_c^{(1)}$ the researchers have plotted as $P2$ for $P1 = \bar{P} = 0$ dB. $P_n^{(1)}$ and $P_c^{(1)}$ were plotted for the values of $P1$: $P1 = 0$ dB. For value of $P1$, it is noted that constrained cooperation scheme method is beneficial more than non-cooperative ($P_c^{(1)} > P_n^{(1)}$) for a certain range of $P2$. Also, the maximum achievable probability gain is dependent on the received signal power of the cognitive user S1 from the primary user.
In Figure 7 above, the expressions are evaluated and plotted as a function of $P_2$ for $P_1 = 0$ dB assuming $\alpha = 0.1$. As can be seen in Figure 4, the overall probability of detection is logically increased by cooperation among cognitive users. It must be remembered that even a slight improvement in the possibility of detection is important because the cognitive radios are configured to monitor continuously track the spectrum and to detect primary users' presence.

The agility benefit for the network asymmetry $P_2$ is plotted in Figure 8 for $\alpha = 0.1$ and $P_1 = 0$ dB in the context of co-operatives. We note that for this example the average increase in agility is about 11 percent. This endurance upgrade is beneficial for the long term as cognitive radios must constantly track the spectrum to the primary user.
Figure 8. Two user networks have an agility advantage.

Figure 9 also calculates the actual number of slots used for primary user detection. This gives the time saved when the primary user recognizes the signal power via collaboration as can be seen in the figure. The key user in the relay user decides whether it is agility or time-critical to achieve the real savings. We now accept cooperative scheme agility under the cooperative scheme method; we assume flexibility where the relay operator can transmit the received message with sufficient power. We note that the impact of increasing the transmission power leads to an increase in agility of up to 35%.

Figure 9. Cooperative period of detection $P_1=0 \text{ dB}, \alpha =0.1$.

4. Conclusion

The benefits of cooperative technology in the development of cognitive radio networks have been examined in this paper. First, a simple cognitive network of two users is considered. By utilizing the inherent asymmetry, improvement was demonstrated in agility. The researchers tested scheme using cooperation, in order to keep detection times as low as possible, by implementing the AF cooperation protocol. It is demonstrated that the collaboration between cognitive networks enhances overall network reliability. The researchers also explored the power impact limitations on cooperation schemes and some of the basic properties of these networks. The researchers expanded the cooperation to a further framework to include multi-carrier networks with a maximum of two users per carrier and expressions were derived for the purpose of agility.
5. References

[1] Mitola J 1993 Software Radios: Survey, Critical Evaluation and Future Directions (IEEE Aerospace and Electronic Systems Magazine) vol 8 4 pp 25–36

[2] Cabric D, Mishra S M and Broderson R W 2004 Implementation Issues in Spectrum Sensing for Cognitive Radios (Conference Record of the Thirty-Eighth Asilomar Conference on Signals, Systems and Computers) pp 772–776

[3] Al-Dulaimi A, Al-Dulaimi M and Asevev D 2016 Realization of Resource Blocks Allocation in LTE Downlink in the form of Nonlinear Optimization (13th International Conference on Modern Problems of Radio Engineering, Telecommunications and Computer Science) pp 646–648

[4] Al-Dulaimi A M 2015 Model of Evolution of Scheduling Sub-Channels to Improve Quality of Service in Wimax Network (Восточно-Европейский журнал передовых технологий. Технологический центр, ЧП, Украинский государственный университет) vol 2 no 9 pp25-29

[5] Zhao Q, Tong L and Swami A 2005 Decentralized Cognitive MAC for Dynamic Spectrum Access (First IEEE International Symposium on New Frontiers in Dynamic Spectrum Access Networks) pp 224–232

[6] Etkin R, Parekh A and Tse D 2007 Spectrum Sharing for Unlicensed Bands (IEEE Journal on selected areas in communications) vol 25 no 3 pp 517–528

[7] Zekavat S A and Li X 2005 User-Central Wireless System: Ultimate Dynamic Channel Allocation (First IEEE International Symposium on New Frontiers in Dynamic Spectrum Access Networks) pp 82–87

[8] Raman C, Yates R D and Mandayam N B 2005 Scheduling Variable Rate Links via a Spectrum Server (First IEEE International Symposium on New Frontiers in Dynamic Spectrum Access Networks) pp 110-118

[9] Nie N and Comaniciu C 2006 Adaptive Channel Allocation Spectrum Etiquette for Cognitive Radio Networks (Mobile Networks and Applications, Springer) vol 11 no 6 pp 779–797

[10] Al-Dulaimi A M, Al-Azzawi E M and Al-Anssari A I 2016 Balancing Model of Resource Blocks Allocation in LTE Downlink (International Conference on Electronics and Information Technology, IEEE) pp 1-4

[11] Wild B and Ramachandran K 2005 Detecting Primary Receivers for Cognitive Radio Applications (First IEEE International Symposium on New Frontiers in Dynamic Spectrum Access Networks, IEEE) pp 124–130

[12] Slepian D 1958 Some Comments on the Detection of Gaussian Signals in Gaussian Noise (IRE Transactions on Information Theory, IEEE) vol 4 no 2 pp 65–68

[13] Tang H 2005 Some Physical Layer Issues of Wide-Band Cognitive Radio Systems (IEEE International Symposium on New Frontiers in Dynamic Spectrum Access Networks) pp 151-159

[14] Al-Dulaimi A M K 2015 Linear Model of Bandwidth Allocation in LTE Downlink with RAT 1 (Second International Scientific-Practical Conference Problems of Infocommunications Science and Technology, IEEE) pp 82–85

[15] Ghasemi A and Sousa E S 2005 Collaborative Spectrum Sensing for Opportunistic Access in Fading Environments (First IEEE International Symposium on New Frontiers in Dynamic Spectrum Access Networks) pp 131–136

[16] Al-Dulaimi A M K, Harkusha S V and Al-Dulaimi M K H 2018 Исследование метода распределения частотно-временного ресурса нисходящего канала LTE при использовании RAT 1 (Проблеми телекомунікацій) vol 1 no 22 pp 75–92

[17] Sendonaris A, Erkip E and Aazhang B 2003a User Cooperation Diversity. Part I. System Description (IEEE Transactions on Communications, IEEE) vol 51 no 11 pp 1927–1938
[18] Sendonaris A, Erkip E and Aazhang B 2003b User Cooperation Diversity. Part II. Implementation Aspects and Performance Analysis (IEEE Transactions on Communications, IEEE) vol 51 no 11 pp 1939-1948
[19] Garg J, Mehta P and Gupta K 2013 A Review on Cooperative Communication Protocols in Wireless World (International Journal of Wireless & Mobile Networks. Academy & Industry Research Collaboration Center) vol 5 no 2
[20] Laneman J N and Wornell G W 2003 Distributed Space-Time-Coded Protocols for Exploiting Cooperative Diversity in Wireless Networks (IEEE Transactions on Information Theory, IEEE) vol 49 no 10 pp 2415–2425
[21] Garkusha S, Al-Dualaimi A M K and Al-Janabi H D 2015 Model of Resource Allocation Type 1 for LTE Downlink (International Conference on Antenna Theory and Techniques)
[22] Akyildiz I F, Lo B F and Balakrishnan R 2011 Cooperative Spectrum Sensing in Cognitive Radio Networks: A Survey (Physical Communication, Elsevier) vol 4 no 1 pp 40–62
[23] Garkusha S, Al-Janabi H and Al-Dualaimi A 2014 Results of Development of Sub-Channels Scalable Scheduling Model in WiMAX Network (1st International Scientific-Practical Conference Problems of Infocommunications Science and Technology)
[24] Garkusha S V, Al-Janabi H D K and Al-Dualaimi A M K 2014 Method of Ensuring the Required Transmission Rate for WiMAX Subscriber Station (24th International Crimean Conference Microwave and Telecommunication Technology, Conference Proceedings)
[25] Hammerstrom I, Kuhn M and Wittneben A 2004 Cooperative Diversity by Relay Phase Rotations in Block Fading Environments (5th Workshop on Signal Processing Advances in Wireless Communications, IEEE) pp 293–297
[26] Lebedenko T, Kholodkova A and Al-Dualaimi A 2018 Linear-Quadratic Model of Optimal Queue Management on Interface of Telecommunication Network Router (2018 International Conference on Information and Telecommunication Technologies and Radio Electronics) pp 1-4
[27] Lemeshko A V, Al-Janabi H D and Al-Dualaimi A M K 2015 Model Progress of Subchannel Distribution in WiMAX Antenna System (International Conference on Antenna Theory and Techniques)
[28] Lemeshko O and Al-Dualaimi A M K 2018 Comparative Analysis of Solutions for Management of Time-Frequency Resource in LTE Downlink (IEEE 4th International Symposium on Wireless Systems within the International Conferences on Intelligent Data Acquisition and Advanced Computing Systems, IEEE) pp 108–111
[29] Poor H V 2013 An Introduction to Signal Detection and Estimation (Springer Science & Business Media)
[30] Lemeshko O and Yeremenko O 2018 Comparative Analysis of the Resource Blocks Allocation Balancing Model in the LTE Downlink Using RAT 1 with Existing Solutions (International Scientific-Practical Conference Problems of Infocommunications. Science and Technology, IEEE) pp 701-704
[31] Lemeshko O 2019 Development of the Balanced Queue Management Scheme with Optimal Aggregation of Flows and Bandwidth Allocation (IEEE 15th International Conference on the Experience of Designing and Application of CAD Systems) pp 1–4
[32] Lemeshko O, Lebedenko T and Al-Dualaimi A 2019 Improvement of Method of Balanced Queue Management on Routers Interfaces of Telecommunication Networks (3rd International Conference on Advanced Information and Communications Technologies, IEEE) pp 170–175
[33] Mohammed M 2020 Maximization of User’s Power in D2D Communication Based on Geometric Assumption and Transient Cloud Conception (Technology Reports of Kansai University) vol 62 no 4 pp 1481–1492
[34] Garkusha Sergey, Al-Janabi H and Al-Dulaimi A 2014 *Model of Distribution of Frequency Resource in the WiMAX Mesh-Network* (TCSET)

[35] Sergiy G, Khodayer A D A M and Dheyaa A J H 2015 *Results of Development of Model for Bandwidth Management in LTE Downlink with Resource Allocation Type 1* (13th International Conference: The Experience of Designing and Application of CAD Systems in Microelectronics)

[36] Ahmad Abdulsadda, Ruaa Shallal Abbas Anooz and A M K Al-Dulaimi 2020 *Acoustics Recognition with Expert Intelligent System* (Journal of Green Engineering) vol 10 3 pp 972–985