Visual Cognitive Radio

Tian Liu, Daixiong Ye, Shihai Shao, Youxi Tang, and Juan Zhou

National Key Laboratory of Science and Technology on Communications,
University of Electronic Science and Technology of China, Chengdu, China
{liutian,yedaixiong,ssh,tangyx,zhoujuan06}@uestc.edu.cn

Abstract. Cognitive radio are always based on spectrum sensing to cognize the physical characteristics of the wireless channel and carry out wireless communication resource scheduling. This kind of method has limited predictive ability and cognitive content, which cause it is hard for cognitive radio to response to the change of radio environment in advance. This paper proposes a new system called visual cognitive radio, which use visual information to cognize radio environment. Visual observation has well predictive ability and abundant cognitive information, which enables the visual cognitive radio to deal with the change of radio environment in advance and make optimal configuration to the process of wireless communication. This paper presents a typical communication scene as an example to explain the advantage of visual cognitive radio, and also makes a preliminary analysis of the application and challenge of visual cognitive radio.

Keywords: cognitive radio, visual cognition.

1 Introduction

With the rapid development of radio communication technology, radio spectrum has become a precious resource. Therefore, how to improve spectrum utilization is an important research issue in wireless communication [1]. Over the past decade, the cognitive radio (CR) based on spectrum sensing (monitoring) captured significant interest in academic research. It has been proved that CR is an effective method to improve the spectrum efficiency of wireless communication [2].

1.1 The Features of Conventional Cognitive Radio

The conventional cognitive radio can exchange information intellectively with communication network by sense the spectrum hole of electromagnetic environment, use radio knowledge representation language (RKRL) [3] and combine with software radio technology to adjust the communication parameters, in order to maintain efficient spectrum utilization. Its main features include [4]:

P. Ren et al. (Eds.): WICON 2011, LNICST 98, pp. 265–275, 2012.

Cognitive Ability. It includes three processes [5]: spectrum sensing, spectrum analysis and spectrum decision. Spectrum sensing is to monitor and detect spectrum hole; spectrum analysis is to estimate the feature of the spectrum hole; and spectrum decision is to select appropriate frequency band to transmit data according to the feature of spectrum hole and user demand.

Reconstitution Ability. It can program the parameters of transmitter and receiver dynamically according to radio electromagnetic environment, and have different radio transmission technologies to send and receive data. This reconstitution ability can utilize the idle spectrum and provide a reliable communication service on condition that not disturb the authorized user.

1.2 The Shortages of Conventional Cognitive Radio

The conventional cognitive radio based on spectrum sensing (monitoring) to collect information, monitor radio channel environment passively, and learn an event (such as be shaded by a building) only after it has happened. It has no preventability, and the remedial measure is relatively laggard, which will cost extra consumption. Its main shortages include:

The Poorness of Predictive Ability. It always begins to allocate new frequency band to user and adjust the parameters of radio communication only after the user's geographical position changed (the available frequency band also changed). It can hardly do any prediction to response to the change of radio environment.

The Simpleness of Cognitive Content. It only focus on the feature of radio signal to cognize radio environment. The cognitive content is too simple for cognitive radio to obtain the panoramic and multidimensional radio environment, and make the optimal communication plan.

1.3 The Proposition of Visual Cognitive Radio

This paper will propose an innovative cognitive radio called visual cognitive radio, which uses the visual information to cognize radio environment. It can analyze user's wireless scenario in advance, enable the communication system to have strong adaptability and maintain high spectrum utilization.

2 Visual Cognitive Radio

Visual cognitive radio can "see" user's forthcoming radio environment by analyzing the real time image of user's environment, and do a series of parameter adjustment to deal with the real time change of user's radio environment, guarantee the robustness of communication link. As Fig. 1 shows, the structure of visual cognitive radio consists of the following four modules.

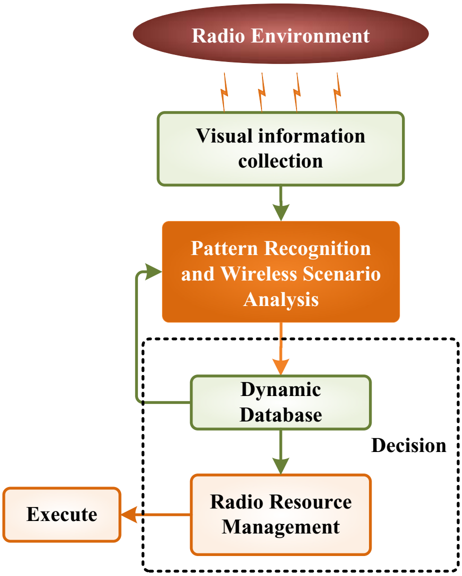

Fig. 1. The structure of visual cognitive radio

2.1 Visual Information Collection Module

This module is an essential step, its purpose is to obtain the real time visual information of the users radio environment by the use of multiple antennas resource of wireless mobile network. Therefore, the visual cognitive radio can "see" the radio environment, not like the conventional cognitive radio to "hear" . The multiple antennas of the next generation mobile wireless communication system provide the behavior of "see" with technical feasibility.

The use of multiple antennas to obtain visual information has been successfully applied to microwave and millimeter wave radar imaging [6] and medical imaging [7][8]. A typical technology of radar imaging is synthetic aperture radar (SAR)[9]. Its main idea is to add a number of antenna elements together (the array element space is usually shorter than half wavelength), to constitute a bigger antenna array, and radiate signal by electronic scanning, then obtain high resolution radar image by correlating processing of the received echo from different locations.

A typical technology of medical imaging is phased array ultrasonic imaging [10]. Its main idea is that it firstly processes acoustic beam scanning, and changes the phase relationship when the sound wave arrive at the body, by controlling the time delay of each array element of phased array transducer, in order to realize the change of focus point and acoustic beam, then finish the imaging of need checking organ.

In the above multiple antennas imaging technologies, the antenna array is contract designed, which is to eliminate grating lobe and provide the real image of observed object. In order to observe and obtain the visual information of radio environment in the next generation mobile wireless communication network, the help of multiple antennas resource of mobile communication equipment is needed.

At present, the multiple antennas of mobile communication equipment have two mechanisms: multiple-input multiple-output (MIMO) and smart antenna. In MIMO system, the array element space is usually longer than half wavelength (even can be hundreds of meter in some distributed antenna system)[11], in order to decrease channel correlation and increase system capacity. Smart antenna system uses digital beamforming technology to restrain interference, the array element space usually shorter than half wavelength, but the number of array element is relatively small, usually is eight to sixteen [12].

Therefore, in order to use multiple antennas resource of mobile communication system to obtain the image of radio environment, three aspects research work are still needed: (1) How to use the antenna which array element space is longer than half wavelength to obtain image of radio environment? (2) What is the relationship of the number of array element and the performance of visual cognition? (3) What extent of the image of radio environment visual cognitive radio system needs to obtain?

Fig. 2. Multiple antennas in radar imaging

2.2 Wireless Scenario Analysis Module

This module is to cognize the obtained image of radio environment and use the cognition results to analyze and output wireless communication scenario parameters. This kind of method uses visual information to cognize and analyze wireless scenario, and is different from the conventional cognitive radio which is focus on frequency spectrum. It via cognizing the image of wireless scenario to output wireless communication scenario parameters, and enable the cognitive radio equipment to obtain the real-time and panoramic information of radio environment. Specifically, it can obtain three kinds of information, which are shown in Fig. 3.

Users Location. Cognizing the users visual information obtained by visual information collection module, visual cognitive radio can obtain the precise geographic information of the user, base station and obstruction, and also the relative position information of user and base station between obstruction.

Users Mobile Trend. Analyzing the cognized image of user, visual cognitive radio can obtain the information of the users displacement. And considering the duration of a frame, visual cognitive radio also can know the users speed and direction.

Users Interference. Using the relative position information of user and base station between obstruction, visual cognitive radio can know users current interference. And using users mobile trend, visual cognitive radio can analyze the time when user will be interfered. Detect and cognize the image of obstruction, visual cognitive radio can know the feature of this obstruction, and then obtain the feature of interference.

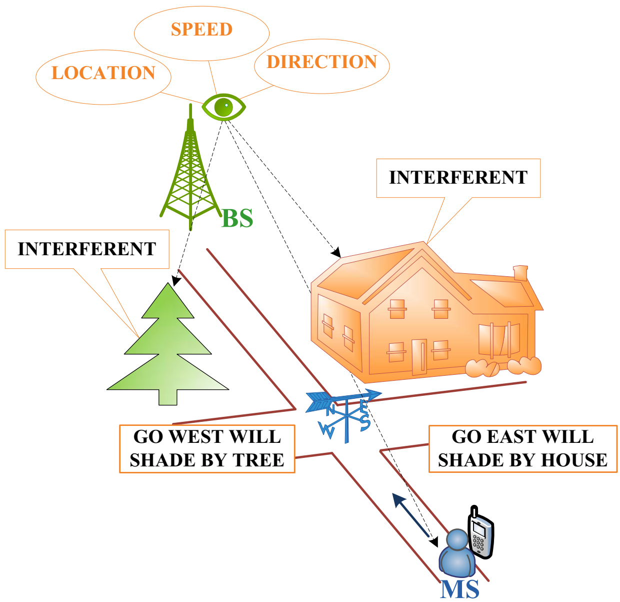

Fig. 3. Visual information

It is worth to mention that the users mobile trend cannot obtain by conventional cognitive radio, and the users interference obtained by visual cognitive radio gives more information of the radio signal feature of the users radio environment.

2.3 Decision Module

This module includes dynamic database and radio resource management module.

Dynamic database includes geographic feature database and radio feature database. Geographic feature database stores the feature of the user's communication environment. Radio feature database stores the radio signal feature of the user's radio environment. Dynamic database's prior information include basic communication model (modulator approach, encoding and decoding method, waveform of physical layer under all kinds of communication system), estimation algorithm (estimate attenuation, multi-path, Doppler shift and user's mobile trend), and initialized geometric data.

Radio resource management module inputs the wireless scenario parameters obtained by wireless scenario analysis module, combines with the prior information of dynamic database to analyze and select the communication mode which user needs and allocates radio resource to user, finally update dynamic database.

2.4 Execute Module

This module executes the concrete communication plan designed by decision module, adjusts relevant communication parameters, allocates radio resource, outputs the response to the cognition of radio environment.

3 Particular Scene

In order to describe the above visual cognitive idea, this section will introduce a particular scene, and show the advantage of visual cognitive radio in the aspect of power control. We will contrast the visual cognitive power control (VCPC) method and conventional fixed step power control (FSPC)[13] method.

3.1 Scene Description

As Fig. 4 shows, mobile station (MS) is moving from point A to point B. When MS comes to point C, it will be shaded by the building. And d_1 denotes the distance from the building to base station (BS) and d_2 denotes the distance from the building to MS, d_3 and d_4 are the building's width and length, respectively, d denotes the distance from point A to point C.

3.2 Method Analysis

Suppose the MS use the code division multiple access (CDMA) system with binary phase shift keyed (BPSK) signaling, the conventional fast closed-loop power control strategy is a fixed-step approach, which is defined by [13]. Due to the loop delay and limited maximum power adjustment in FSPC, the effects of deep shadow fading can hardly be accommodated.

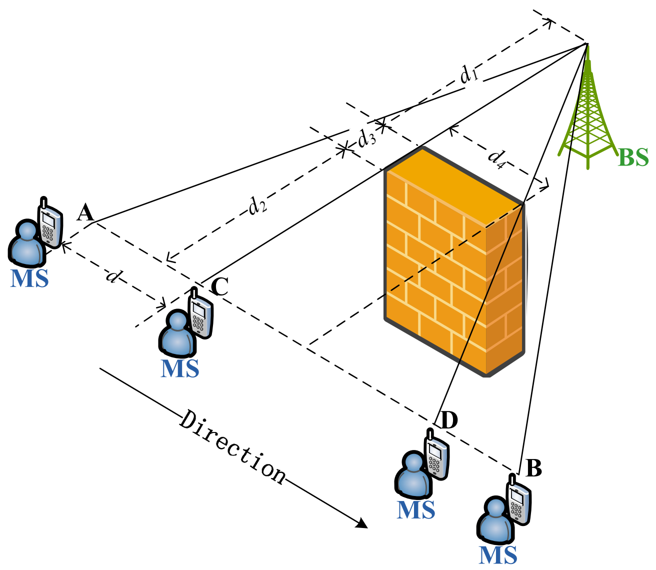

Fig. 4. Particular scene

By the visual cognitive way, according to visual information collection module, the VCPC can know the following visual information: (1) mobile trend and velocity v; (2) distance d from point A to point C; (3) the power loss ΔL at point C; (4) whether MS is shaded by the building or not.

Given the mobile velocity v, the number of power control group (PCG)[14] needed from point A to point C can be expressed as $N_v = \lfloor \frac{d/v}{T} \rfloor$, where $\lfloor \cdot \rfloor$ means the rounds to the nearest integers towards minus infinity and T represents the power control sampling period. Given the instantaneous fading loss ΔL and fixed step size δ, the number of PCG needed to increase enough power is given as $\Delta N = \lfloor \Delta L/\delta \rfloor$.

To accommodate the effects of the deep shadow fading, the transmit power of MS should be increased ahead of the fading. Let N_d denotes the loop delays in samples, then the command to increase power should be sent after N_s PCGs in the BS, which can be described as $N_s = N_v - \Delta N - N_d$.

When the VCPC "see" the MS will be shaded by the building, it begins to read the visual information to get v, d, ΔL, and compute ΔN and N_s, then adjust the power of BS to deal with the forthcoming deep shadow fading.

3.3 Simulation Result

The simulation result is shown in Fig. 5, in the simulation we assume that the visual information provides $v = 50$km/h, $d = 25$m, $\Delta L = 21$dB, and the values of d_1, d_2, d_3, and d_4 are 20m, 10m, 10m, and 25m, respectively. The autocorrelation of the slow shadow fading is $\sigma_A^2 \zeta_D^{(vT/D)|k|}$[14], where $\sigma_A = 4.3$dB, $T = 5$ms,

$D = 10$m, and $\zeta_D = 0.3$. The loop delay is considered as one power control interval T and $\lambda = 0.007$. The fixed step $\delta = 3$dB is used in the deep shadow fading process, and $\delta = 1$dB is used to deal with the slowly varying shadow.

Fig. 5 shows the impact of different power control methods on the BER performance. From Fig. 5, we can observe that the VCPC can accommodate the deep shadow fading and it achieves better performance compared with the FSPC method. When SNR is 10dB, the BER in the FSPC is 1.128×10^{-3} and the BER can be 1.501×10^{-5} in the VCPC method.

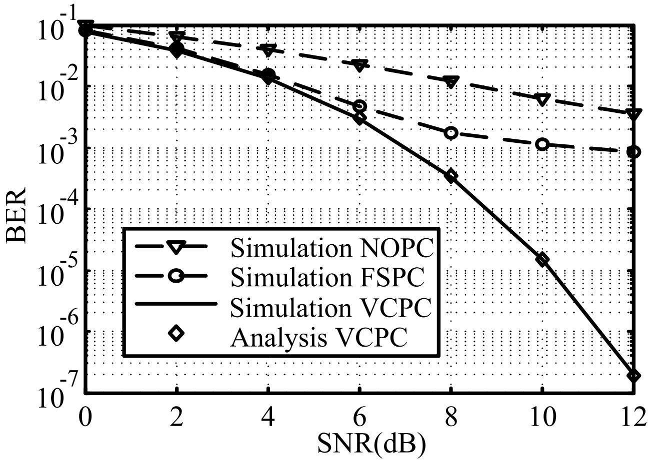

Fig. 5. BER performance comparison of different methods. NOPC, FSPC, and VCPC denote no power control, fixed step power control, and visual cognitive power control, respectively.

4 Application and Challenge

Visual cognitive radio not only has better performance, compared with conventional cognitive radio, in improving spectrum utilization, but also has some special applications and along with challenges as discussed in the following paragraphs.

4.1 Emergency Scenario

Visual cognitive radio can be applied to emergency scenario. In the case of emergency, for example, when a bus had an accident in some remote place, all the passengers need timely rescue. According to [15], the single-antenna mobiles in a multi-user environment can "share" their antennas in a manner that creates a virtual MIMO system. Therefore the single-antenna mobile phones of the passengers can constitute an antenna array, and with the technologies mentioned in visual information collection module, the virtual MIMO system can imaging the real time scene of the accident, which enables the rescue team to response timely and efficiently.

In order to apply visual cognitive radio in emergency scenario, the problems mentioned in the visual information collection module are need to be solved. How to use virtual MIMO technology to get the image of accident scene and what extent of the image of radio environment visual cognitive radio system needs to obtain are still need further research.

4.2 Visual Cooperation

Visual cognitive radio can be applied to cooperative communication [16]. The base station can cooperate with each other to provide the best communication service to mobile station. For example, in Fig. 6, MS is moving from point D to point G. At point D, BS A is serving MS, and "see" MS will come to point E, where the propagation of MS and BS A will be shaded by the house, so BS A asks BS B, which is near MS and have no obstruction, to serve MS. Similarly, when MS comes to point F, BS C begins to serve MS.

In order to apply visual cognitive idea in cooperative communication, there are two main issues need to be solved. One is the synchronization of the visual cooperation, the other is base station switching. The synchronization and switching of the cooperative communication system is a difficult problem, adding the visual cognition, these problems can be even harder.

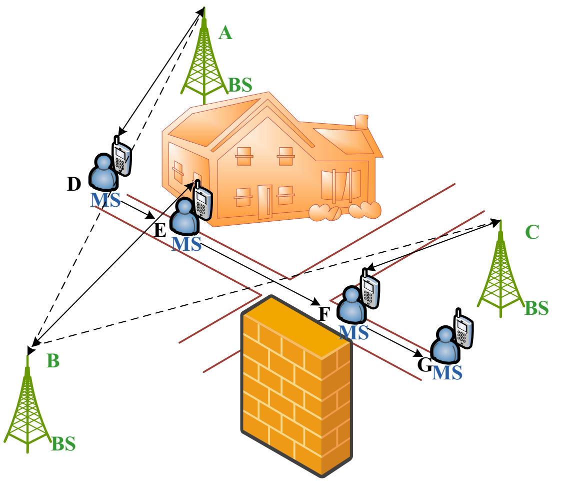

Fig. 6. Visual cognitive radio applied in cooperative communication

5 Conclusion

Analyzing the feature of conventional cognitive radio based on spectrum sensing, this paper summarizes its bottleneck problem in poor predictive ability and simple cognitive content. A new system called visual cognitive radio which use visual information to cognize radio environment is proposed. The visual cognitive information can be obtained by the multiple antennas of the next generation mobile wireless communication system. The visual cognitive radio can response to the change of radio environment in advance and guarantee the robustness of communication link. The process of visual cognitive power control is presented as an example to explain the advantage of visual cognition. In sum, the visual cognitive radio can be widely used in many fields and also the technical challenge coexist.

References

1. Mitola, J.: Cognitive radio architecture evolution. Proceedings of the IEEE 97(4), 626–641 (2009)
2. Matinmikko, M., Mustonen, M., Sarvanko, H., et al.: A Motivating Overview of Cognitive Radio: Foundations, Regulatory Issues and Key Concepts. VTT Technical Research Centre of Finland, Oulu (February 2008)
3. Yarkan, S., Arslan, H.: Exploiting Location Awareness toward Improved Wireless System Design in Cognitive Radio. IEEE Communications Magazine 46(1), 128–136 (2008)
4. Niyato, D., Hossain, E.: Cognitive radio for next-generation wireless networks: an approach to opportunistic channel selection in IEEE 802.11-based wireless mesh. IEEE Wireless Communications 16(1), 46–54 (2009)
5. MacKenzie, A.B., Reed, J.H., Athanas, P.: Cognitive Radio and Networking Research at Virginia Tech. Proceedings of the IEEE 97(4), 660–688 (2009)
6. Sharma, R.: Application of MIMO to IFSAR. In: IEEE Radar Conference, Washington, DC, pp. 81–84 (May 2010)
7. Topsakal, E.: Antennas for medical applications: Ongoing research and future challenges. In: ICEAA Electromagnetics in Advanced Applications, Torino, Italy, pp. 890–893 (September 2009)
8. Ito, K.: Recent Small Antennas for Medical Applications. In: International Workshop on Antenna Technology: Small Antennas and Novel Metamaterials, Chiba, Japan, pp. 1–4 (March 2008)
9. Guida, R., Iodice, A., Riccio, D.: Height Retrieval of Isolated Buildings From Single High-Resolution SAR Images. IEEE Transactions on Geoscience and Remote Sensing 48(7), 2967–2979 (2010)
10. Hungliu, J., Shijeng, G., Kewu, T., Chili, P.: ECG triggering and gating for ultrasonic small animal imaging. IEEE Ultrasonics, Ferroelectrics and Frequency Control 53(9), 1590–1596 (2006)
11. Mohajer, M., Rafi, G.Z., Safavi-Naeini, S.: MIMO antenna design and optimization for mobile applications. In: IEEE Antennas and Propagation Society International Symposium, Charleston, USA, pp. 1–4 (June 2009)
12. Das, S.: Smart antenna design for wireless communication using adaptive beam-forming approach. In: TENCON 2008-2008 IEEE Region 10 Conference, Hyderabad, India, pp. 1–5 (November 2008)

13. Ariyavisitakul, S.: SIR based power control in a CDMA system. In: Proc. IEEE GLOBECOM, Orlando, USA, pp. 868–873 (December 1992)
14. Song, L., Mandayam, N., Gajic, Z.: Analysis of an up/down power control algorithm for the CDMA reverse link under fading. IEEE Journal on Selected Areas in Communications 19(2), 277–286 (2001)
15. Jayaweera, S.K.: Energy efficient virtual MIMO-based cooperative communications for wireless sensor networks. In: International Conference on Intelligent Sensing and Information Processing, Bangalore, India, pp. 1–6 (January 2005)
16. Nosratinia, A., Hunter, T.E., Hedayat, A.: Cooperative Communication in Wireless Networks. IEEE Communications Magazine 42(10), 74–80 (2004)