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RESEARCH REVIEW OF COGNTIVE RADIO

Naiqi Wei[1], Zili Chen[1], Junwei Lv[1] and Honglin Huang[2]
Department of UAV Engineering, Ordnance Engineering College, Shijiazhuang, China
Department Operational and Tactical Intelligence, Army Command College, Shijiazhuang, China
Email: oec_ljw2009@163.com

Abstract: Cognitive radio(CR), which is one of the main development directions of future wireless communication, can effectively solve the problem of frequency spectrum shortage faced by wireless communication development. Several concepts about CR were introduced and analyzed at first. Then the key technology of realizing CR was presented. The paper mainly analyzed the research dynamic of CR. The problems which exist in the study or need further research were also presented. At last, it is pointed out that the research on CR is still in its infancy and we must do more work on studying CR to meet its realization.
Keywords: Cognitive radio, Software radio, Spectrum sensing, Research dynamic.

1. Introduction

With the rapid growth of wireless communication in business demand, the available spectrum resource becomes more and more scarce presently. The efficient usage of spectrum resource becomes an important problem of wireless communication and a new bottleneck which restricts wireless communication development. People make efforts to improve spectrum resource utilization efficiency by adopting advanced wireless communication theory and technologies such as link adaptation technique and multi-antenna technology, etc. However, it is discovered that the spectrum utilization efficiency in the global authorized spectrum band, especially in the low band which has better signal propagation characteristics, is very low. The study shows that the ratio of spectrum resource in use of all available resources is less than 6% in most cases [1]. It shows that the real problem is not in the lack of spectrum resource but the existing static pattern of spectrum management. The existing static pattern of spectrum management has three prominent contradictions: the spectrum usage is dynamic while the spectrum allocation is static; the spectrum is a kind of scarce resource while its utilization efficiency is very low; the spectrum to be allocated is very little while it is in great demand. Cognitive radio provides effective way for solving these contradictions.

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2. Concept of Cognitive Radio

Cognitive radio was firstly put forward by Dr. Joseph Mitola from Sweden's Royal Institute of Technology in 1999. It is further expanded to the Software Defined Radio (SDR) [2]. Mitola defined CR as "a kind of radio applying schema-based reasoning to meet specific wireless relevant requirements" in his dissertation [3]. Dr. Mitola is also the proposer of software radio (SR). He thought CR was further expansion of SR and CR turns SR from a blind performer of the initialized program into intelligent agent in the radio field. According to CR definition from Mitola, CR can improve the flexibility of personal wireless communications business through SR and radio knowledge description language. CR can sense and communicate with radio environment intelligently by adopting schema-based reasoning method, according to its own communication needs. The cognition cycle that makes CR so smart was described in Fig. 1. The outside world provides stimuli. CR parses the stimuli to recognize the context of its task.

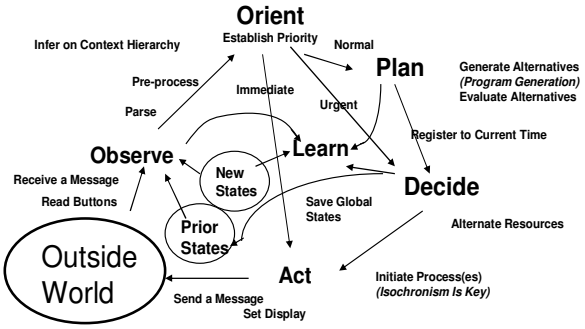

Fig. 1 The Cognition Cycle

In 2003 , the U.S. Federal Communication Commission (FCC) defined CR from the application view as: "CR is a kind of radio that can change its transmitter parameters according to interacting with its working environment" [4]. Professor Simon Haykin thought from the aspect of signal processing and defined CR as: "CR is a kind of intelligent wireless communication system; it can sense the environment outside and study of the environment using artificial intelligence technology; it makes its internal state adapt to the statistical change of receiving wireless signals through changing some operating parameters (such as transmission power, carrier frequency and modulation technology, etc.) in real time, which achieves the purpose like this: realize high reliable communication and make use of spectrum resources effectively at any time and any place" [5].

The CR blueprint sketched by Dr. Joseph Mitola is far from realization under today's technology. The FCC introduced CR only from the point that making full use of the spectrum.

The definition of CR made by prof. Simon Haykin well balances digital signal processing, network, artificial intelligence and computer hardware and software implementation. The cognitive loop based on the definition well reflects the concept of CR. Although the CR definitions above are a little different, the flexibility and intelligence are the two main characteristics.

3. Key Technologies of Cognitive Radio

The key technologies of cognitive radio include several aspects as follows [6-11].

3.1. Spectrum sensing

The spectrum sensing ability is an important premise for CR communication. CR can adapt to the surrounding environment through applying the spectrum detection ability to discover spectrum holes. As the authorized user has no obligation to change their structure to share spectrum resource with CR user, CR user can only implement detecting authorized user through continuous sensing spectrum environment independently and reliably. The spectrum sensing methods are shown and classified in Fig. 2.

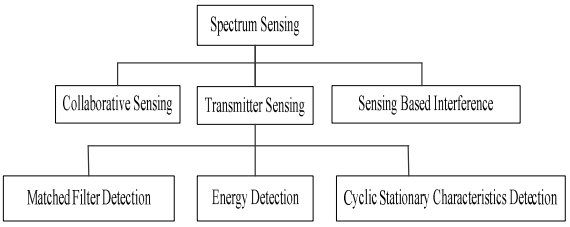

Fig. 2 The classification of spectrum sensing methods

3.2. Channel state estimation

In order to implement relative detection and predict the channel capacity in CR receiver, it's essential to estimate the channel state. The general methods include two types: difference detection method and training sequence transmission method. The information of channel state varies with time, which can be expressed with the state space model. In Gaussian noise environment, the Gaussian state space model can be used and the channel state is tracked by using Kalman filter. In non-Gaussian noise environment, the non-Gaussian state space model can be used and the channel state can be tracked by applying the particle filter.

3.3. Power control

Power control is also one of the important problems that need to be solved in CR network. The premise of being able to utilize authorized spectrum resource for CR is that the communication among authorized users isn't influenced. For this, the unauthorized users with cognitive function have to control its transmission power and ensure not causing harmful interfe-

rence to authorized users nearby who use the same frequency. When multiple CR users coexist, there should be no significant performance decline between each other.

1. Spectrum management

The available frequency bands, detected by the CR spectrum sensing function, may be distributed in broad frequency domains including authorized and unauthorized frequency band. They have dynamic spectrum characteristics including center frequency, channel bandwidth, etc., and the time of being used is changing. As CR needs to select spectrum bands in good condition from all available spectrums to meet the QoS (quality of service) needs, it's necessary to possess the spectrum management function.

3.4. Interference coexistence between CR network and authorized network

Interference is the most sensitive problem when CR network and authorized networks coexist. The control strategy, eliminating method and improvement measures for interference will directly affect the performance of CR network and authorized network. The research on the coexistence between CR network and authorized network is an essential part of CR study.

4. Research Dynamic

Since CR technology has been proposed by Dr. Joseph Mitola in 1999, people study CR from all directions. Professor Simon Hakin published a review about CR in JSAC in Communications in 2005. His iconic article, called "Cognitive radio: brain-empowered wireless communications", opened a curtain for international research on CR technology [5]. Many famous scholars, industrial organizations, universities, research centers and enterprises began to study the theory, realization and actual application of CR. Presently, the research mainly focuses on the physical and MAC layer, including spectrum detection, access control, the dynamic spectrum allocation, security mechanism and cross layer design, etc.

4.1. Overseas Research Status

Sweden, the Great Britain and the United States are the sponsors of CR technology research. The United States has been the powerful country of CR research, whose number of published papers is more than the sum of any other countries. This also means that the United States government pays the attention to new technology. European countries, such as Germany, France, the Netherlands etc., also spend a lot of time and money to the cognitive technology research [12].

The next generation communication plan (xG) was established by the Advanced Research Projects Agency of the United States Department of Defense in 2003, which focused on development of CR practical standard and dynamic spectrum management standard and planed

to develop system methods and key techniques based on CR to realize the dynamic spectrum access and sharing.

The Berkeley wireless center of the university of California at Berkeley mainly focuses on the study on the physical design and implementation of CR. Berkeley cooperated with Technical University of Berlin and developed CORVUS (a Cognitive Radio approach for usage of Virtual Unlicensed Spectrum) system structure and CR test bed BEE2 (Berkeley Emulation Engine 2) [13]. The CORVUS system utilizes virtual unauthorized spectrum based on cognitive radio way, which uses two-level management models to reduce its reliance on the central unit. BEE2 provides a very good experimental platform for cognitive radio research. BEE2 can be used for the development of CR physical and network layer. It can also use Matlab Simulink of Mathwork Company combined with Xilinx system generator for programming development.

Professor F.K.J ondral, from Karlsruhe University, proposed the spectrum pool system and the centralized network structure based on OFDM [14]. The idea of spectrum pool is building up a spectrum pool by concentrating spectrum resource that dose not make full use of by authorized system. Being stand-by resource of dynamic spectrum access system, the spectrum pool's resource is allocated and managed by an entity in a unified manner. For instance, the spectrum pool will be divided into multiple channels and allocated to channel as the basic unit.

In 2006, AdaptLLC Company, in Melbourne, Australia, announced that they had developed the first commercial CR system called XG1 which had obtained the FCC's authentication. XG1 provides 30-180 Kbps data throughput, supports point to more and point-to-point connectivity, supports Ethernet and the serial data communication. Another CR product called XG2 Plus from the company won the best wireless equipment award in the 2008 UTC exhibition.

Microsoft and Dell jointly developed a project called KNOWS (Kognitive Networking over White Spaces) which is a CR system prototype. The project lets the second users cooperatively detect the blank portion of TV frequency band and make full use of all available bandwidth [15].The goal of KNOWS is to let self-organizing wireless nodes connect to the network without coordination of central controller and achive the goal of maximizing the utilization ratio of spectrum resource. Akyildiz, from Georgia Institute of Technology, developed a cognitive radio platform based on OFDM transmission technology in his wideband wireless network laboratory and put forward the spectrum sharing architecture [16].

4.2. Domestic Research Status

Compared with overseas research status, although the CR research in China started a little later, it also received serious attention. Many research institutions and universities have carried out the research on CR. The national 973 basic research programs, the national 863 high technology plan and the Natural Science Foundation of China have respectively funded some research projects about CR since 2005. The information science department of the National Natural Science Foundation set up major project groups about CR according to the development demands of the communication field, which consists of four projects with intrinsic relation and constitute an organic system. Project 1 explores the environment cognitive technology which provides environmental information and decision-making basis. Project 2 studies cognitive anti-interference technology which does research on the application of CR in anti-jamming communication. Project 3 explores the cognitive cooperative technology which is applied to multi-hop cooperation system in future wireless network. Project 4 studies various CR spectrum management technologies which provide the theoretical foundation for spectrum allocation and coexistence of multi-system.

Beijing University of Posts and Telecommunications is the first institution that does the most research work about CR technology in China. Besides, there are other universities that study CR technology well, such as University Of Electronic Science And Technology Of China, Zhejiang University and Tsinghua University, etc. On May 26, to 30, 2008, China-European cognitive radio working conference was held in Beijing University of Posts and Telecommunications, which is a symbol that CR technology results in China has been recognized. On January 10, 2009, the kick-off meeting of 973 planning project "research on cognitive wireless network theory and key technology", whose chief scientist is professor Zhang Ping, from BUPT(Beijing University of Posts and Telecommunications), was held in BUPT. The project aims to promote the research on basic theory and key technology of cognitive wireless network in China, and provide new ideas and new plans for this area's research, so as to make China's research on the field of cognitive wireless network achieve international top-ranking level. The large international project E3 (End-to-End Efficiency) spent about 19 million Euros to study CR and cognitive network integration technology which faced the next generation mobile communication. The Key Laboratory of Ubiquitous Network in BUPT was the only non-European Union partner who joined the project.

The key project "spectrum resources sharing wireless communication system", which belongs to the information technology field of the 863 plan, will be invested 40 million yuan.

The project will break through the key technology of the spectrum resources sharing system and studies the wideband cognitive wireless communication system that coexists with the existing system. The spectrum resource sharing wireless communication system will be studied and the system will be demonstrated and verified in the 698-806 MHz spectrum band.

The general SR platform based on DSP+FPGA was built at Xidian University to study two key modules of CR: cognitive and communication modules [17]. The software and hardware design and implementation of the modules is done. But there are still some problems as follows: The hardware platform they used is a universal SR hardware platform whose real-time character was not good; In order to improve processing speed, the period gram method was used for spectrum estimation, which had not high performance. The design of RF circuit was basically limited by devices such as amplifier and filter. The cognitive module is difficult to work well in the actual situation as the system RF module is lack of amplification ability; The union debugging of three modules, including cognitive module, communication module and RF module, was not realized, namely having not constitute a complete CR verification system. A CR transmission scheme based on a feasible hardware system structure of the CPCI bus was put forward by UESTC, which was realized by adopting the hardware system framework of CPCI industrial control computer plus double DSP and FPGA [18].

4.3. Existing Problems

Presently, the problems that exist and need more research are mainly as follows:

- The basic theory and its related applications: This will lay a solid foundation for large scale application. The more important research contents include CR basic theory and related technologies about CR network, such as frequency resource management, cross layer joint optimization, etc.
- Cognitive radio can now only recognize the transmitters around but not the receivers. Therefore, it may meet the problem of hidden terminal and how to avoid this problem is one of the important research directions.
- Integration with existing systems: The general theory model of interference from cognitive users to the authorized users under complex electromagnetic environment hasn't been built at present. The application of cognitive radio should not require authorized users to make any change.
- Development of verification system: There are multiple test and validation systems being developed at present. The successful development of these systems will provide test beds for

verification of CR basic theory and key technologies, which will promote extensive applications of CR.

5. Conclusion

Cognitive radio provides an effective solution for solving the contradiction between the growing wireless communication demand and the limited resources of the frequency spectrum. It is expected to become one of the key technologies of the fifth generation mobile communication. Cognitive radio has great application prospects whether in civil areas or military domain, especially has great application potential in aspects of public safety, emergency communication, military jamming communication and anti-jamming communication. Presently, the research points of CR are not a few but scattered and still in the starting stage. There are many key technologies needing to be solved. There is still a long distance from practical application. But it is believed that the rosy prospect depicted by cognitive radio will certainly be realized with the development of science and technology and the increasing research investment.

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