Spectrum Resource Management of Cognitive Radio

Liu Qin
(State Key Laboratory of Integrated Services Networks, Xidian University, Xi'an 710071, P. R. China)

Abstract:
As the most important technology of CR, the wireless spectrum resource management technology is the key to CR performance improvement. By introducing the concept of resource space to describe wireless spectrum resource management in the field of CR technology, a data system of wireless resource management is formed that covers wireless spectrum resource space, resource grid and available resource atlas. Besides, the corresponding lamination distributional management structure and the resource management database are constructed. The resources description system and the management structure will become the theoretical concept foundation and reference of the CR spectrum resources management technology.

The rapidly developing wireless communication system and network are facing a bunch of obstacles. One is the inherent conflict between limited spectrum resource and the fast growing bandwidth need, from several megahertz to hundreds megahertz for a single network, and also high-speed service need, from several megabit per second to hundreds megabit per second for a single user. Another is the need for the heterogeneous wireless networks (for example, wireless LAN, mobile communication network and wireless access network) made up of several different systems (for example, 3G, E4G and 4G systems for mobile communication) to function normally in the presence of each other. To fill different service needs and guarantee improved user experience, the spectrum utilization has to be enhanced and varied heterogeneous networks have to work together, which have become the major trends and challenges of wireless communication development.

The concept of Cognitive Radio (CR) was first put forward by Joseph Mitola and his coworkers in 1999. CR is the evolved software radio technology and also the new intelligent wireless communication technology. It is able to cognize the environment features of radio transmission and use radio knowledge descriptive language to make intelligent interactions with the communication system. It analyzes, understands and judges the wireless environment and then adaptively adjusts the system's communication parameters accordingly. On condition that the communication of no authorized user is affected, CR makes intelligent use of the idle spectrums to provide the users with highly possible access anytime and anywhere, hence greatly boosting spectrum utilization.

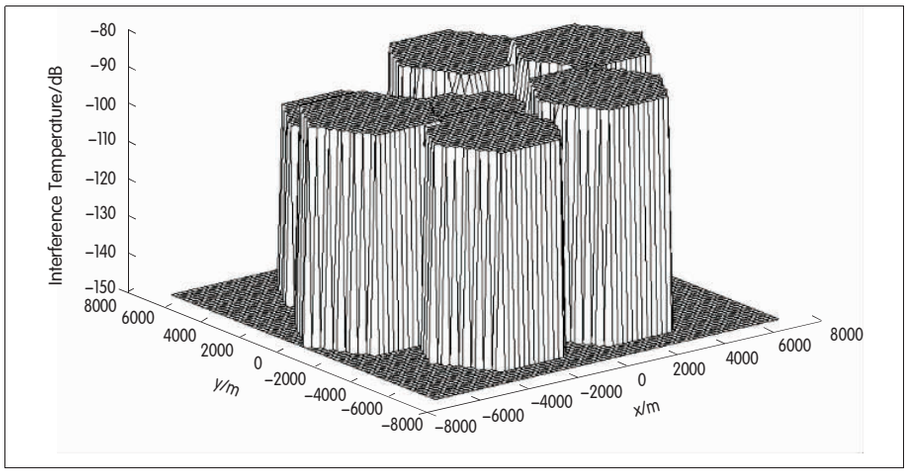
The birth of CR concept has drawn wide concern in the communication circle. The wireless industry has come to a common sense that CR should be the optimal solution to the low utilization of wireless spectrum resource and therefore the next massive surge of new technology. Powered by CR technology, the users without frequency use license are able to, on condition that no service of authorized user is affected, use the already allocated frequency, thus making more efficient use of the wireless spectrum resource. This feature is making CR technology one of the effective ways to ease the increasing pressure on spectrum resource use.

The CR technology is basically an intelligent approach to spectrum resource use. It boasts the sensibility to detect and obtain available spectrum resource, then manage the resource, and next. allocate the resource to wireless users for optimized use, to make higher spectrum utilization. In other words, the process of CR communication is all about high efficient management and use of the spectrum resource. Therefore, the research of wireless spectrum management technology accounts for a key component and important branch of the CR communication study. Resource management and allocation control is a critical part of the Cognitive Circle (CC). The optimal use of spectrum resource depends on perfect guidance of the management system.

1 Introduction of Wireless Spectrum Environment Resource

Since CR technology is to make use of the wireless spectrum resource, the management object in the field of CR

This work was supported by the National Basic Research Program of China ("973" Program) under Grant No. 2009CB320404.



▲Figure 1. Interference temperature estimation through conventional MTM–SVD approach.

technology is wireless spectrum resource. To make efficient and optimized use of the spectrum resource, CR has to thoroughly analyze the resource and study its feature indexes and status parameters so as to make a reasonable selection.

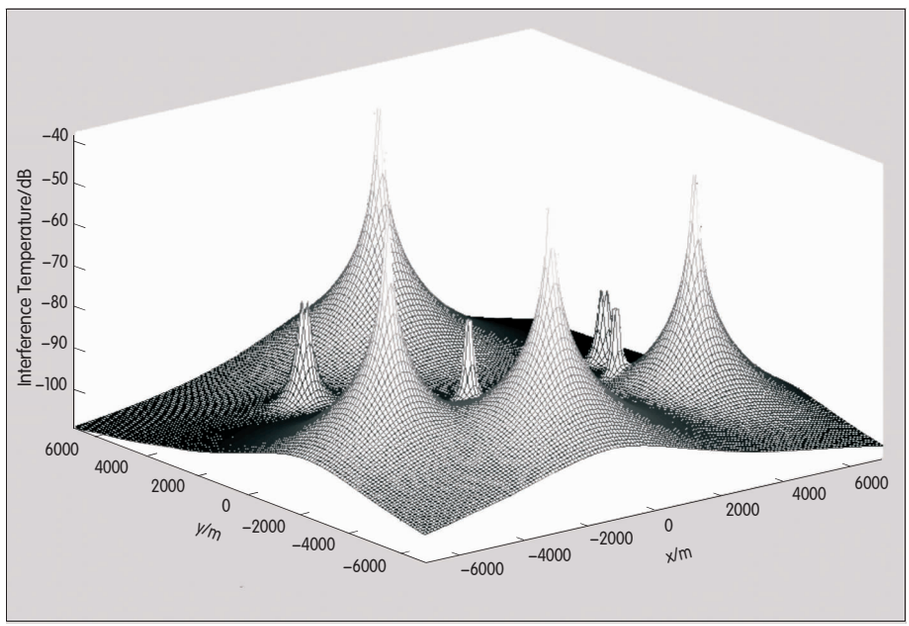
Some descriptive parameters of environment features have been worked out from the past studies on spectrum acquisition and analysis. The measurement standard for resource availability is hence constructed. A typical and conventional approach is to use the interference temperature as the parameter for measuring the spectrum property. Simon Haykin[1] defines interference temperature and gives the way to estimate it. He also takes interference temperature as the index to measure the availability of spectrum hole. There are also other references and researches concerning the similar topic. For example, a method of spectrum capacity estimation[2] is offered and the method takes into consideration the bandwidth, allowed transmission power and the relation between the two. Another example, autoregressive coefficient, dynamic noise and measurement noise are used to analyze state space model and select proper channel tracing policy to obtain the channel's state information[3].

However, these parameters are limited to the description of only a single or very few performance features, rather than the whole picture or all features, of the wireless spectrum resource. Consequently, the CR resource management covers the analysis and management of the wireless spectrum resource in light of part of the features, and only limited performance improvement can be resulted from resource allocation. These are potential risks of resource management and selection.

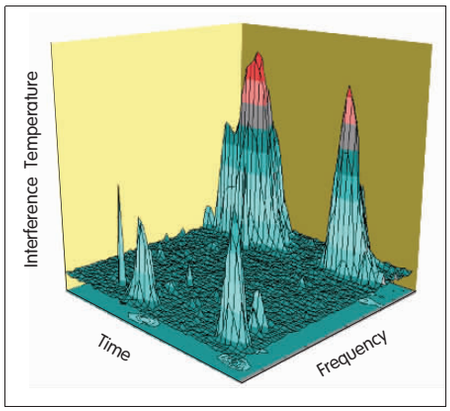
The most widely applied interference temperature is taken here as an example. The management system studies the interference temperature value inside a certain region, which is equivalent to the concept of signal strength or power spectrum density. Since the interference temperature reflects only the changes of the spectrum environment along the time, it can be taken as a representation of time–frequency relation. Also if the Multiple–Taper Method–Singular Value Decomposition (MTM–SVD) approach[1] is applied to examine the interference temperature, the same strength representations within single regions will be obtained. Figure 1 shows the estimation of interference temperature at a certain temporal point. As reuse of spectrum resource is concerned, the result shown in Figure 1 is unified region by region in spatial terms. As a result, resources judged as usable are fragmented in space and opportunities of using many available resources are lost indirectly.

With the proper space location elements introduced and the estimation method improved, the result of interference temperature estimation will be obtained on the basis of the original interference temperature, as depicted in Figure 2, which shows that the smooth spatial changes take place of the regional step changes in Figure 1, so that the interference temperature used for judging the availability of spectrum resource turns from a time–frequency feature to a space–time frequency feature.

The above example shows that, compared with the primary interference temperature, the new interference temperature added with the space



▲Figure 2. Interference temperature estimation with the help of space concept.



▲Figure 3. Three–dimension resource space.

measurement features comes with more descriptive resource features. Namely, the space coordinate is introduced, which helps make more precise judgment of the spatial region of usable resources and in turn more efficient reuse of resources. This tells us that, if more feature elements are available to jointly describe the wireless spectrum resource, the resource management will be able to obtain a more objective and complete picture of the environment and resource, and hence understand the nature of the wireless spectrum resource, so as to optimize the management and utilization of resource.

2 Space and Concept System of Spectrum Resource

Once the features of spectrum resource are obtained, CR should select the proper working frequency resource for user's communication transmission need as required by the user. On condition that all channels are available with the similar capacity, Reference [4] puts forward five spectrum selection rules based on fairness and communication cost. Reference [5] proposes a channel hopping protocol based on Signal–to–Noise Ratio (SNR) for selecting the best–quality channel. Reference [6] states that the number of spectrum changeovers on a specific frequency band can help make spectrum allocation decisions. All these researches are concerned with resource selection to suit one or more performance requirements of the user. However, it is necessary to design and construct a more complete structure and methodology for measuring the wireless spectrum resource in terms of all the above described feature parameters.

To facilitate the research work, the mathematical space concept can be employed to describe the features of wireless resource, and the multi–dimensional coordinates can be used to build a mathematical space model for the wireless spectrum resource.

Various parameters for describing the resource features can be obtained if the wireless spectrum resource is looked into from different angles and levels. The feature parameters will be taken as individual elements that are then defined in strict mathematical terms and given clear–cut attributes. Next, the mathematically expressed elements are used as measurement parameters and granted with the coordinate concept; hence the spectrum space is represented in multiple dimensions.

Resource space is a scientific concept described in mathematical language to cover numerous feature parameter elements. For example, if only the relation among three feature parameters (time, frequency and interference temperature) of the spectrum resource is to be studied, the three parameters will be taken as the reference coordinate respectively to form a simple three–dimension space model. Figure 3 shows such a model. If n types of feature parameters are to be researched, an n–dimension resource space representation can be shaped up.

To analyze the relation among different feature parameters and use function relation for their mathematical representations, the spectrum resource space can also be deemed as the n–dimensional function or function group. Such function relations are continuous on multiple dimensions. However, for the sake of easy recording and measurement in wireless resource management, the relations have to be fragmented to discrete ones. For example, the time changes will be made discrete according to the sampling interval or time resolution. Consequently, once the described above space is made discrete from varying dimensions, a grid–shaped structure is produced and it is called the spectrum grid. The spectrum grid is to describe the structure and attribute of spectrum resource space after the space is made discrete in multiple dimensions such as space domain, time domain and frequency domain.

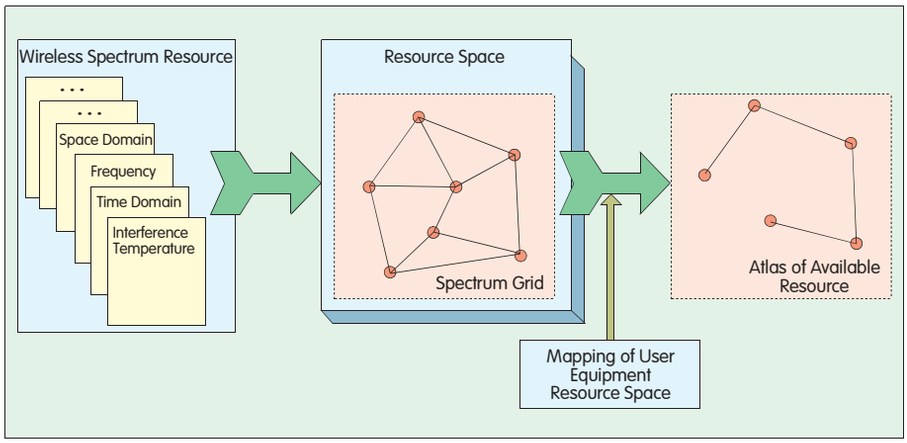
When the CR system is used to manage the wireless spectrum resource and allocate resource to specific cognitive system users, the resource in the resource space suitable for a user varies with user's different needs. For this reason, it is necessary to set up an available resource set in light of different user requirements. Since the wireless spectrum resource is described with the space system, user's actual requirements need to bear the mapping relation with the resource space so as to become the specific measurement indexes used in the resource space. The measurement indexes mapped with the user requirements are used to make judgment on the discrete resource individuals on the resource grid and then measure the availability of resources. The available resource set formed in the resource grid based on the standard mapped to user requirements is called resource atlas.

Figure 4 shows the data architecture and theoretical concept basis for wireless resource management that cover from spectrum resource elements to spectrum resource space, and to spectrum resource grid and spectrum resource atlas.

3 Structure of Wireless Spectrum Resource Management

Two parts of the wireless spectrum resource management system are: representation of wireless resource and structure for implementing resource management. As the former one has been discussed above, this section will focus on the structure issue.

The research of resource management solution is also popular. Reference [7] proposes an approach that uses centralized unit to control the spectrum allocation and access process. The sensed information of every node distributed in the network converges at the centralized control unit, which then



▲Figure 4. Data structure oriented to wireless resource management.

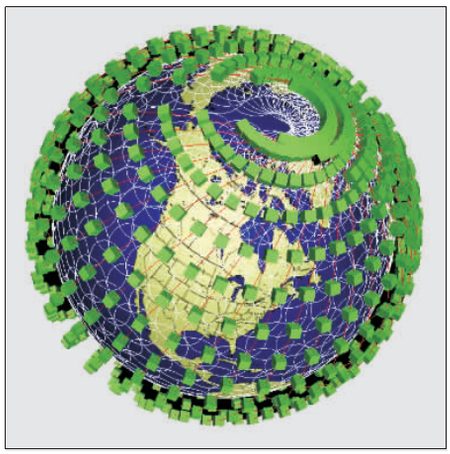
performs spectrum allocate ion. Reference [8] offers a distribution solution in the event that a centralized structure cannot be constructed. With this solution, every distributed node participates in the spectrum allocation and decides for its own spectrum access. The cooperative spectrum sharing strategy considers how the actions of a node can affect other nodes; while the non–cooperative strategy[9] considers actions of its own nodes only. Menon discussed the effects of Overlay spectrum sharing and Underlay spectrum sharing in a cooperative environment[10]. The distribution mode of management is more practical and considers more the overall effects. The following management structure takes shape if the distribution mode of management is combined with the resource space system described above.

In the CR communication system, the devices working with the wireless spectrum resource can be distributed on the ground, in the air or under the ground. When any a user is located anywhere, it senses the use of the spectrum resource differently. That is, it may sense the signal transmitted from a device on the land, from an airborne craft, or from a satellite or deep–space detector. The power, antenna directivity, motion characteristic, and dynamic behavior of transmitting devices at different locations can be different. For the sake of effective management, all wireless spectrum resources that can possibly be used should be fragmented in terms of physical space and network coverage to form the grid of spectrum management. Figure 5 shows the layer of fragmented spectrum resource around the globe.

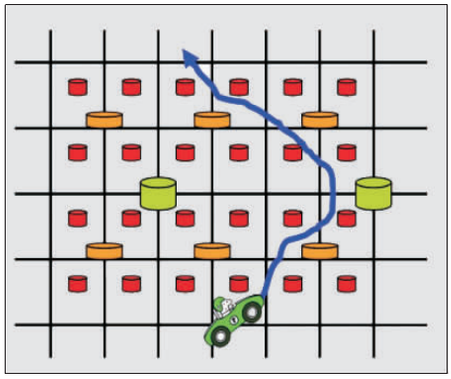
Sensors can be set layer by layer and level by level to manage the spectrum resource space and also keep the management grid updated and maintained. The sensor grid can be set independently or at the same location of the application system. The layer–by–layer distributed database can help with effective resource management. That is, the resource management grid and corresponding available resource atlas are put in different layers and stored at different layers in the database. The bottom layer database manages several resource units, and the Layer N database manages several databases at Layer $N-1$. When a moving or changing user needs to go through the resource management grids at different layers, databases at different layers will all serve the user, as shown in Figure 6.

The database approach is helpful in resource management. The resource management grid and available resource atlas can be stored and managed effectively with sophisticated database management techniques, which may also guide the information update and indexing. The mode of communication with the resource database may vary with the user type. The data service of current public mobile communication network or Internet can be used to access the resource database. The public resource control channel can also be adopted to provide resource service.

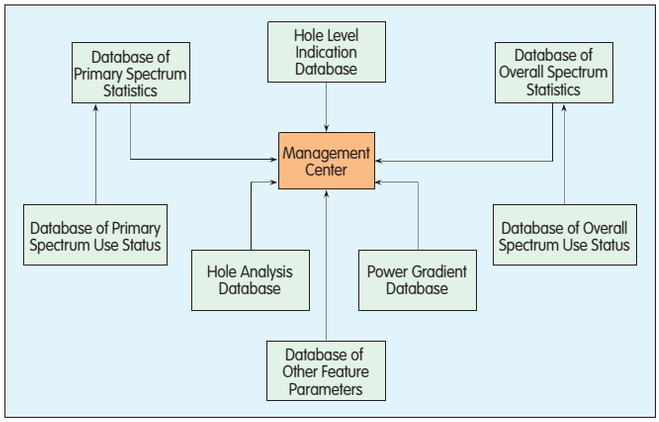
In the information communication of database, the public control channel can be used as a suitable communication approach. Unauthorized users can obtain resource information through this channel. Configuration of the public resource control channel is optimized in view of the type of service user, quantity of service user and service type. In the cognitive environment, the public control channel cannot become one with fixed frequency, instead, it should also be one of the unauthorized users and can change along with the external environment. Consequently, it is necessary to consider how to implement coordinated frequency use by the information communication points on both ends of the public control channel. Possible methods are dynamic channel assignment algorithms including cyclic fixed channel assignment, cyclic unfixed channel assignment and cyclic distributed channel assignment.



▲Figure 5. Stereo–metric fragmentation of spectrum grid.



▲Figure 6. Resource database in layered distribution.



◀Figure 7. Structure of the spectrum resource management database.

The database for spectrum resource management is made up of several small databases as shown in Figure 7. The databases analyze and process the cognized information of the resource space and then describe the spectrum use status in details. The resource atlas will be worked out to adapt to the requirements of the unauthorized users. The small databases can work together in these ways: The database of primary spectrum use status provides service to the database of primary spectrum statistics; the database of overall spectrum use status provides service to the database of overall spectrum statistics. After all, the hole analysis database, hole level indication database, power gradient database, primary spectrum statistics database and overall spectrum statistics database all serve the management center.

4 Conclusion

The CR technology has been proposed to address the problem of scarce spectrum resource. Its primary purpose is to make thorough use of the wireless spectrum resource. Perfect management structure and strategy can help boost performance of the whole system. Resource management technology and its research work are also becoming more important as the CR technology develops for wider application. These are problems found by this paper's author when he studies the CR communication technology. These ideas reflect only one of the aspects of cognitive science and they require more research work.

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Biography

Liu Qin

Liu Qin, PhD, is an associate professor at State Key Laboratory of Integrated Services Networks, the Information Science Institute of Xidian University. His research interests include cognitive radio, software radio and mobile communications. He has presided or participated in seven funded projects. Besides, he has published more than 10 papers, and applied for seven patents.