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A Brief Overview of the Developments of the Cognitive Radio Technology

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Abstract

Cognitive radio's rising popularity among various engineers, scientists and researchers can be credited to the increasing number of users of wireless technology and the radio spectrum which is limited. In this paper, various advances which have been made so far to improvise cognitive radio technology have been discussed in brief to give the reader an overview of this emerging technology. The basics of cognitive radio networks are introduced first and then various developments on different aspects of this technology are discussed.

Keywords

Cognitive radio, radio spectrum, wireless technology.

1. Introduction

The concept of cognitive radio was first proposed by Joseph Mitola in 1998. Cognitive radio is considered as a goal towards which a software-defined radio platform should evolve: a fully reconfigurable wireless transceiver which automatically adapts its communication parameters to network and user demands. It is a well known fact that day by day the demand for wireless enabled communications is increasing be it point to point communication or broadcasting. But a major constraint which might limit this exponential growth is the medium of all wireless communications i.e. the radio spectrum. The radio spectrum has been divided into various frequency bands for different purposes. There is a different frequency range allotted for television broadcasting and different frequency range for mobile communications. Here arises the main problem. It has been observed over a period of time that while one portion of spectrum may be sparsely used another portion may be over crowded. This problem gave rise to the concept of cognitive radio.
Cognitive radio was thought of as a wireless network with no fixed spectrum allocation that is if all the channels of the spectrum allotted to it are occupied at that time than it can sense the radio environment and search for the vacant channels from the other portions of the spectrum to which it has access. Thus this kind of network after being cognizant about the radio environment reconfigures it's transmission and reception parameters to transmit and to receive using those vacant channels until it's own channels are free or the primary network (the network to which those vacant channels originally belongs) asks them back. The initial analysis has been made on network architecture of dynamic spectrum sharing. This is followed by discussion on "**sensing the radio environment"** that is spectrum sensing. Spectrum sensing has been the main focus of the research conducted so far on cognitive radio. Thus the various advancements made in spectrum sensing are discussed under the section 'SPECTRUM SENSING'. Issues related to spectrum sensing such as returning the borrowed spectrum to the primary network whenever it asks for are discussed here. After the cognitive radio network has sensed the radio environment the next function of cognitive radio is to reconfigure the parameters of its transceiver so that it can transmit and receive over the new channels. After a cognitive radio network has sensed the vacant spectrum and has reconfigured its transceiver's parameters and starts transmitting and receiving then it cannot continue to function smoothly without any interruption primarily because of primary user's activities and competition from other secondary users. Thus the next topic of discussion is the coexistence with primary users and other secondary users and which portion of the spectrum should be accessed when the current one is not available. Since cognitive radio can automatically sense and detect the radio environment without any human intervention thus it is termed as intelligent wireless network and hence it can be said that it is a part of artificial intelligence. It is because of this fact that various models of artificial intelligence like neural networks, fuzzy logic and genetic models are used to add some new dimensions to network configurations.

A. Software Defined Radio

Software defined radio (SDR), as the name suggests, is a radio communication system which is realized using a software on a computer rather than using the hardware components. Advancement in the field of digital electronics has made it possible to implement many processes of SDR's which were earlier not possible. Cognitive radio systems are based primarily on SDR's.

B. Cognitive Tasks: An Overview

As stated by Simon Haykin in his research work [1], cognitive tasks can be viewed as three steps. For reconfigurability, a cognitive radio looks naturally to software defined radio to perform this task. The cognitive process starts with the passive sensing of RF stimuli and reach the final stage with action. Main focus in his paper rest upon three on line cognitive tasks [1], which are summarized in table.1

Table I: Summary of three on-line cognitive tasks

Tasks	Includes /regards	Working site
Radio scene analysis	• Sensing and estimation of interference temperature of the radio environment • Detection of spectrum holes	Receiver
Channel identification	• Helps transmitter to predict channel capacity • Estimates channel state information	Receiver
Transmition	• Transmit-power control • Dynamic spectrum management	Transmitter

This paper is organized in five sections. Section II., introduces network architecture of cognitive radio in brief. It deals with evolution and research work done till the date. Section III., introduces spectrum sensing in cognitive radio which is the most important task in this field.Various different techniques are discussed like interference temperature, energy detector, feature detector, matched filter and coherent detection are discussed. Section IV., deals with the existence of various secondary users along with the primary users on the same licensed band. Several important issues in dynamic spectrum allocation and sharing are discussed in brief. Section V., provide researchers with more concrete understanding of AI to their CR designs, this section reviews several CR implementations based on AI techniques like artificial neural networks (ANN) and metaheuristic processes are discussed.

2. Network Architecture

Secondary users, who are unauthorized users can access authorized spectrum of primary users, temporally. Therefore in a cognitive radio (CR) network architecture both primary users and secondary users coexist, as seen from the figure 1. It is composed of various kinds of communication systems and networks around it. This can be viewed as a sort of heterogeneous networks. The heterogeneity exists in wireless access technologies, networks, user terminals, and service providers as stated by X.Gao et.al. in [2].A comprehensive analysis are presented in [3], by K.C.Chen et. al., which predicts the design of cognitive radio architecture and shows that it is build up with the objective of improving the entire network utilization, rather than just link spectral efficiency. Research shows this can be viewed in two different ways i.e. from users' perspective and operators' perspective [3]. From users' perspective, the network utilization means that they can always fulfill their demands anytime and anywhere through accessing this technique. From the operators' perspective, they can provide users with better services, and allocate radio and network resources to deliver more packets per unit bandwidth in a more efficient way.
Wang and liu's work [4] added to advancement in this field.

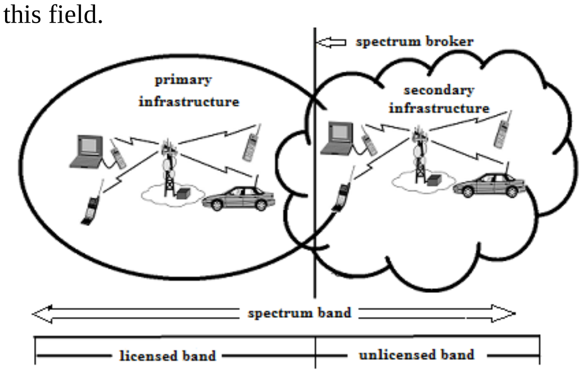

Fig 1: Network architecture of dynamic spectrum sharing

They coined a term called 'spectrum broker':
'if several secondary networks share one common spectrum band, their spectrum usage may be coordinated by a central network entity, called spectrum broker'.[5]

The spectrum broker communicate with secondary user and collects operating information from them to achieve efficient and fair spectrum sharing. Thier work made the network architecture of dynamic spectrum sharing uncomplicated, this is clearly illustrated in the fig 1.

This area was further excogitated and concluded as cognitive radio can be deployed in network –centric, distributed, adhoc, and mesh architectures, and serve the needs of both licensed and unlicensed applications. It was also concluded that possible "uni-directional" links can be established among these network structures, while such links are gifts from the special nature of cognitive radio. This work can pave the way for future research in a taxonomical way.

3. Spectrum Sensing

Spectrum sensing provides the cognitive radio network all the required information so that it can adapt its transmitting and receiving parameters. Early literature used a term, spectrum holes, depicted in following figure.Spectrum hole is beautifully defined by Simon Haykin [1]:

'A spectrum hole is a band of frequencies assigned to a primary user,but, at a particular time and specific geographic location, the band is not being utilized by that user.'

It was apparent that a realiable strategy for the detection of spectrum holes was of paramount importance to the design of cognitive radio systems. Later, the studies concluded that the task of spectrum management was not only impervious to the modulation formats of primary users, but also several other issues like environmental factors (path loss, shadowing) grew as a big obstruction and underestimated the efforts involved in the detection of spectrum holes and their subsequent exploitation in the management of radio spectrum.

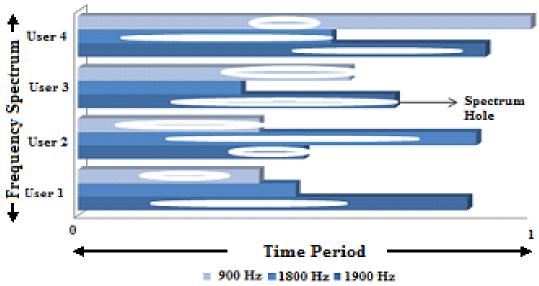

Fig 2. Depiction of Spectrum Holes (white spaces) in licensed frequency band

The various different aspects of spectrum sensing are discussed here namely:

A. Interference Temperature

When various cognitive radio networks are existing along with various primary users then each cognitive radio network should be cognizant about the primary users activities so that it can detect vacant portion of the spectrum. To solve the above mentioned problem it was proposed that that the transmitting power of various transmitting devices should be limited to a certain level but this approach was not pragmatic as transmitters of various secondary networks are mobile and there is a steady increase in the interference level. To find a solution of this problem in [6] the Federal communication copmmission(FCC) proposed the establishment of interference temperature to enhance the available unlicensed operation. In 2006, P.J. Kolodzy has defined [7] the interference temperature as a measure of the RF power which is available at the receiver which is to be transmitted to the receiver end. His work was continued in 2007 by T.C.Clancy who has formalized [8] a model for the interference temperature and has given a mathematical definition for interference temperature as

$$\mathbf{T(f,B)} = \frac{\mathbf{P(f,B)}}{\mathbf{K\,B}}$$

Where P(f,B) is the average power in Watts, B is bandwidth measured in hertz and k is the Boltzmann constant. Thus interference temperature is used to measure the level of interference at the receiver. Receivers should have a reliable method to measure the level of interference. Further Simon Haykin has proposed multitaper method to solve the above problem [1]. This method works well even when there are a large number of sensors. A new technology of a subspace – based method for spectrum sensing has been proposed by A. Wagstaff et. al.in which the value of interference temperature can be calculated [9]. Latest advanaces has been made by M. Sharma et. al. who suggested the use of hidden markov model for the calculation of interference temperature has been proposed [10].

B. *Energy Detector*

In energy detector method analysis are based on energy received at the receiver. It is easy to enforce and the most common type of spectrum sensing. One of it's advantage is that it does not require a prior information about primary signals. But it has several short comings also eg.there is a great chance of detecting a signal when there is no signal present primarily due to the presence of noise, which is very uncertain. Since there is a great chance of uncertainity M.P. Olivieri et.al. propsed a noise level estimation approach where multiple signal classification algorithm to minimize the spectrum sensing error by reducing the false alarm rate [11]. Further advances were made by F.Weildling et. al. on a framework for spectrum measurements and analysis [12]. Sensing- throughput tradeoff has been discussed by Y.C.Liang et. al. for cognitive radio network using the energy detection method[13].The methods for wideband spectrum sensing using energy detector method has also been discussed by Z.Quan, [14]. This technique has many flaws and was not considered satisfactory one. As an improvement to it R.Tandra et. al. has resolved the issue of signal to noise ratio(SNR) walls for signal detection in which the detection of primary user becomes almost impossible [15].

C. *Feature Detector*

In contrast to energy detector method, feature detector method has some of the characteristics of the primary signal already known. These known features of the primary signals are used to match the characteristics of the received samples. Thus it is more immune to noise uncertainity and also performs better where SNR is low. It can also distinguish between primary systems and other transmissions. In 2006, work was done by T.Yucek and proposed spectrum characterization for opportunistic cognitive radio systems which uses the centre frequencies as a feature [16],which was based upon research of W. Gardner who had proposed a theoretical framework for feature detection in which cyclostationary features were mentioned for the first time in 1988 [17]. R .Tandra et. al. have discussed the method of noise calibration as a feature for feature detection [18]. A.Fehske et. al. have proposed a new approach using a combination of spectral correlation and neural networks for feature detection[19]. Whereas, R.Chen et. al. proposed a scheme for trustworthy sensing of the spectrum by verifying the location of the primary user [20].

D. Matched Filter and Coherent Detection

J. Proakis noticed that, in matched filtering and coherent detection, prior information about certain waveform pattern of the primary signals is already available [21]. One of the fundamental benefit of using this technique is that the detection time is greatly reduced. A. Sahai et. al. explained that how in this technique the chances of the miss detection and probability of false alarm is reduced to the maximum possible extent[22]. Because of the fact that matched filtering requires prior information about every signal which in use therefore it is a complex process to implement which is explained by D.Cabric [23]. Further A.Sahai et. al. observed how spectrum sensing can be performed using the method of the matched filtering at a very low SNR in the frequency domain[24]. He have also explained issues related to tradeoff in designing of the cognitive radio networks and how coherent detection can be used in some situations. D. Cabric made advancement in this topic by explaining how spectrum sensing can be performed for pilot signals and for collaborative detection [25].

4. Dynamic Spectrum Allocation and sharing

When the communication over a cognitive network is established then it is not possible for the cognitive network to continue that communication very smoothly because the channel over which the communication is occurring might belong to some other primary user and that primary user may demand it back. Such a situation is bound to arise in cognitive network. The secondary network then has no choice but to return the borrowed spectrum and then switch to some other vacant spectrum to avoid the delaying or termination of the communication. Returning the borrowed spectrum and switching over to other channels is termed as 'SPECTRUM HANDOFF [4]'. For a successful spectrum handoff we require efficient mechanisms of spectrum handoff.. Attempts were made by X.Zhu et al., to solve this issue and in 2007 a prudent approach has been proposed which states that some of the channels must be exclusively reserved for this purpose [26]. A location based algorithm has also been proposed, in which the secondary users when cognizant about the handoff switches their frequency depending on the location. Secondary users are equipped with location estimation devices. Some theories are also proposed which states that for a continuous communication the secondary networks should access the spectrum from not only one primary user but other primary sources and other licensed sources also. This approach seems to be more pragmatic than other approaches as in others, there has to be a tradeoff among some important parameters. Another approach, has been proposed by W.Feng et al., in 2009 for handoff in multi-hop multi-radio cognitive networks which is joint optimization [27]. It was declared by D.

Willkomm et al and H. Khushwaha et al., in order to achieve a reliable continuous communication among secondary users, they should select their channels from variety of primary users, from different licensed bands[28],[29].

5. Artificial Intelligence for Cognitive Radio

Artificial intelligence forms the foundation on which the cognitive radio is based. As cognitive radio is primarily about being cognizant about the radio environment and reconfiguring the existing parameters and opportunistically accessing the spectrum. Various artificial intelligence techniques have been proposed so far which can be used for cognitive radio. These techniques are discussed here in brief:

A. Artificial Neural Network

Neural networks is a concept which was introduced for study of the human brain. It comprises of nonlinear functions whose parameters are not fixed i.e. they are adjustable. There are different types of ANN's available which can be differentiated on the basis of their network configurations and training methods like Multilayer-linear perceptron network(MLPN), Multilayer nonlinear percepetron network (NPN) and Radial basis function network (RBFN). The reason because of which ANN's are used in CR networks is that they can be trained and they can adapt at any time. They have an ability to suggest possible soluntions learned during training phase.

A.Fehske et al.has proposed a new method for signal classification using ANN [30]. This method uses the cyclostationeary features and helps in reducing the computational time. A.F.Cattoni et al. introduced the ANN based classification based on frequency distribution and particularly orthogonal frequency division multiplexing signals in 2007, [31]. Using it, X.-L. Zhu developed a channel sensing algorithm particularly for wireless mesh networks based on neural networks in 2008, [32]. Also M.Hasegawa et al. developed an optimization technique based on neural networks particularly for wireless clouds for cognitive radio which contains various heterogeneous parameters [33]. A CR testbed has also been developed and various wireless regional area network (WRAN) cognitive networks algorithms have also been analyzed by J.H. Reed et al. [34] .An attempt has been made to analyze and compute the achievable communication rate in CR using ANN by N.Baldo et al. [35].

B. Metaheuristic Algorithm

Various metaheuristic algorithms are used for describing CR's primarily due to the fact that mathematical techniques and algorithms are sometimes cannot be used for optimization of parameters as no predefined relation between parameters and required performance exist.

Some of the metaheuristic algorithms are Genetic algorithms, Tabu search, simulated annealing and Ant colony optimization. The metaheuristic techniques presented here have been used not only for determination of optimal solutions between various parameters but they have also been used when the training example is present i.e. when the relation between various parameters and performance indices is not well understood.T.W.Rondeau et al. has proposed the intelligent control of SDR's using the genetic algorithm by intelligently adapting the parameters of CR's according to the changing radio environment [36]. The genetic algorithm optimization has been proposed by J.F. Hauris et al., for autonomous vehicle communications using CR [37].K.Moesssner et al has proposed the use of genetic algorithm for improving the spectral efficiency of wireless networks by improving the spectrum handoff [38]. J.M.Kim has implemented a software testbed of cognitive radio utilizing the dual optimization feature of genetic algorithm [39].

It can be observed from above discussion that although various metaheuristic algorithms exist but the most widely applied algorithm for the purpose of improvisation of cognitive radio is genetic algorithm.

6. Conclusion

In this paper an attempt has been made to introduce in brief the various aspects of cognitive radio . An introduction to network architecture has been made, various spectrum sensing techniques have been discussed and spectrum handoff has also been discussed along with the application of artificial intelligence to cognitive radio. It is concluded that cognitive radio is a novel approach for efficient utilization of sparsely used spectrum and it is receiving and will continue to receive attention from various researchers and scientists who will try to improvise various parameters of cognitive radio for it's efficient utilization.

References

[1] S. Haykin, "Cognitive radio: Brain-empowered wireless communications," IEEE J. Sel. Areas Commun,vol. 23, Feb 2005.

[2] X. Gao, G. Wu and T. Miki. End-to-end QoS provisioning in mobile heterogeneous networks. IEEE Wireless Communications, vol.11, no.3, pp. 24-34, June 2004.

[3] K.-C. Chen, Y.-J. Peng, N.Prasad and Y.-C. Liang,S.Sun, Cognitive Radio Network Architecture: Part I –General Structure. Published by ACM 2008 Article. Bibliometrics Data Bibliometrics.

[4] Beibei Wang and K. J. Ray Liu, Advances in Cognitive Radio Networks: A Survey, IEEE JOURNAL OF SELECTED TOPICS IN SIGNAL PROCESSING,VOL. 5, NO. 1, FEBRUARY 2011.

[5] C. Raman, R. D. Yates, and N. B. Mandayam, "Scheduling variable rate links via a spectrum server," in *Proc. IEEE Symp. New Frontiers in Dynamic Spectrum Access Networks (DySPAN)*, Baltimore, MD, Nov. 2005, pp. 110–118.

[6] " Establishment of interference temperature metric to quantify and manage interference and to expand available unlicensed operation in certain fixed mobile and satellite frequency bands," FCC 2003.

[7] P.J. Kolodzy, " Interference temperature: A metric for dynamic spectrum utilization," Int. J. Netw. Manage, vol 16 Mar 2006.

[8] T. Clancy, " Achievable capacity under the interference temperature model," in Proc. 26th IEEE Int. Conf. Comput. Commun.(INFOCOM), Anchorage, AK, May 2007.

[9] A. Wagstaff and N. Merricks, " A subspace-based method for spectrum sensing," in Proc. SDR Forum Technical Conf., 2007.

[10] M. Sharma, A. Sahoo, and K.D. Nayak, " Channel modeling based on interference temperature in underlay cognitive wireless networks", in Proc ISWCS, Iceland, Oct 2008.

[11] M. P. Olivieri , G. Barnett, A Lackpour, and A Davis, "A scalable dynamic spectrum allocation system with interference mitigation for teams of spectrally agile software defined radios," in Proc. IEEE DySPAN, Baltimore, MD, Nov 2005.

[12] F. Weidling, D. Datla, V. Petty, P. Krishnan and G. Minden, "A framework for RF spectrum measurement and analysis," in IEEE Int. Symp New Frontiers in Dynamic Spectrum access networks(DySPAN),Baltimore, MD ,Nov.2005.

[13] Y.C Liang , E.P.Y Zeng, and A.T. Zeng and A.T. Hoang , " Sensing- throughput tradeoff for cognitive radio networks," in Proc. IEEE ICC, Glasgow, U.K Jun 2007.

[14] Z. Quan, S. Cui, H. Sayed and H.V. Poor, "Wideband spectrum sensing in cognitive radio networks," in Proc. IEEE ICC, Beijing, China, May 2008.

[15] R. Tandra and A. Sahai, " SNR walls for signal detection," IEEE J. Sel. Topics Signal Process, vol. 2.

[16] T. Yuecek and H. Arslan, " Spectrum characterization for opportunistic cognitive radio systems," in Proc IEEE military commun. Conf., 2006.

[17] W. Gardner , " Signal interception: A unifying theoretical framework for feature detection, " IEEE trans Comm. , Aug 1988.

[18] R. Tandra and A. Sahai, " Noise calibration, delay coherence and SNR walls for signal detection," in Proc. 3rd IEEE Int. Symp. New Frontiers in dynamic spectrum access, 2008.

[19] A. Fehske, J.D. Gaeddert, and J.H. Reed, " A new approach to signal classification using spectral correlation and neural networks ," in Proc. IEEE Symp. DySPAN, Baltimore, MD, Nov. 2005.

[20] R. Chen and J. Park, " Ensuring trustworthy spectrum sensing in cognitive radio networks ," in Proc . 1st IEEE Workshop Newt. Technol. Software Defined Radio Newt. 2006.

[21] J. Prokias in Digital Communications New York: Mc- Graw Hill , 2001.

[22] A. Sahai and D. Cabric, " A tutorial on spectrum sensing : Fundamental limits and practical challenges," in Proc. IEEE Symp. DySPAN, Baltimore , MD, Nov 2005.

[23] D. Cabric, S. Mishra and R. Broderson, " Implementation issues in spectrum sensing for cognitive radios," in Proc. 38th Asilomar Conf. signals, Syst., Comput 2004.

[24] A. Sahai , R. Tandra , S. Mishra and N. Oven , " Fundamental design. tradeoffs in cognitive radio systems," in Proc. 1st Int. Workshop Technol. 2006.

[25] D. Cabric, A. Tkachenko and R. Broderson, " Spectrum sensing measurements of pilot, energy and collaborative detection." In Proc. MILCOM, 2006.

[26] X.Zhu, L. Shen, and T. Yum, "Analysis of cognitive radio spectrum access with optimal channel reservation' ' IEEE Commun., let., vol. 11, no.4,pp. 304-306, Apr.2007.

[27] W. Feng, J. Cao, C. Zhang, and C. Liu, "Joint optimization of spectrum handoff scheduling and routing in multi-hop multi-radio cognitive networks," in Proc. 29th IEEE Int. Conf. Distributed Comput. Syst., Washington, DC, 2009, pp. 85–92.

[28] D. Willkomm, J. Gross, and A. Wolisz, "Reliable link maintenance in cognitive radio systems," in Proc. 1st IEEE Int. Symp. New Frontiers in Dynamic Spectrum Access Netw. (DySPAN), 2005, pp. 371–378.

[29] H. Kushwaha, Y. Xing, R. Chandramouli, and H. Heffes, “Reliable Multimedia transmission over cognitive radio networks using fountain codes,” Proc. IEEE, vol. 96, no. 1, pp. 155–165, Jan. 2008.

[30] A. Fehske , J. Gaeddert and J. H. Reed "A new approach to signal classification using spectral correlation and neural networks", *Proc. 1st IEEE Int. Symp. New Frontiers DySPAN*, pp.144 2005.

[31] A. F. Cattoni , M. Ottonello , M. Raffetto and C. S. Regazzoni "Neural networks mode classification based on frequency distribution features", *Proc. 2nd Int. Conf. CrownCom*, pp.251 2007.

[32] X.-L. Zhu , Y.-A. Liu , W.-W. Weng and D.-M. Yuan "Channel sensing algorithm based on neural networks for cognitive wireless mesh networks", *Proc. 4th Int. Conf. WiCOM*, pp.1 2008.

[33] M. Hasegawa , T. Ha Nguyen , G. Miyamoto , Y. Murata and S. Kato "Distributed optimization based on neurodynamics for cognitive wireless clouds", *Proc. IEEE 18th Int. Symp. PIMRC*, pp.1 2007.

[34] J. H. Reed *Development of a Cognitive Engine and Analysis of WRAN Cognitive Radio AlgorithmsPhase I*, 2005.

[35] N. Baldo and M. Zorzi "Learning and adaptation in cognitive radios using neural networks", *Proc. 5th IEEE CCNC*, pp.998 2008.

[36] T. W. Rondeau , C. J. Rieser , T. M. Gallagher and C. W. Bostian "Online modeling of wireless channels with hidden Markov models and channel impulse responses for cognitive radios", *Proc. IEEE MTT-S Int. Microw. Symp. Dig.*, pp.739 2004.

[37] J. F. Hauris "Genetic algorithm optimization in a cognitive radio for autonomous vehicle communications", *Proc. Int. Symp. CIRA*, pp.427 2007.

[38] D. Thilakawardana and K. Moessner "A genetic approach to cell-by-cell dynamic spectrum allocation for optimising spectral efficiency in wireless mobile systems", *Proc. 2nd Int. Conf. CrownCom*, pp.367 2007.

[39] J. M. Kim , S. H. Sohn , N. Han , G. Zheng , Y. M. Kim and J. K. Lee "Cognitive radio software testbed using dual optimization in genetic algorithm", *Proc. 3rd Int. Conf. CrownCom*, pp.1 2008.