11. PROJECT PRESENTATION

11. 1.1 The motivation of the proposal: In the emerging information society the wireless networks and related services will become as pervasive as cellular telephony is today. Therefore, it is expected that the demand for wireless services will continue to increase in the near and medium term, calling for more capacity and putting more and more pressure on the spectrum availability. Although the use of advanced signal processing techniques may enable a very efficient usage of the spectrum even in the traditional framework of command and control spectrum management, there is a worldwide recognition that *the actual methods of spectrum management have reached their limit and are no longer optimal.* In fact spectrum utilization studies have shown that most of the assigned (licensed) spectrum is under-utilized. *Considerable spectrum could be available when both the dimensions of space and time are considered*, and hence the problem of spectrum scarcity as perceived today, is in most cases one of inefficient spectrum management rather than spectrum shortage**.**

As a consequence of this observation the regulatory bodies decided to investigate radically different and more flexible access paradigms. For example, the EU parliament approved in February 2007 a resolution [EUR1] that endorses spectrum liberalisation embracing technology and service neutrality, flexibility and a secondary market and, in USA, the Federal Communications Commission (FCC) has expressed its interest in permitting unlicensed access to white spaces in the TV bands.

An important role in studying the electromagnetic context and in deciding what frequencies could be used at a given moment comes to the receiver. New concepts and architectures should be used in conceiving the receiver but not only. The **cognitive radio (CR)** [INT1][HXX1][FCC1], built on a **software-defined radio (SDR)** [SDR1][DXX1], is defined as an intelligent wireless communication system that is aware of its environment and uses the methodology of understanding-by-building to learn from the environment and adapt to statistical variations in the input stimuli, with two primary objectives in mind: highly reliable communication whenever and wherever needed and efficient utilization of the radio spectrum. Consequently this technology represents a promising answer to the formulated problem.

As the CR field has a quite short history (less than 10 years) [] and the standardisation activity has a first term about 2010 there exist many aspects to be developed from the CR concept itself to signal processing algorithms for sensing the RF activity, adapting to new geographical environment and policies, deciding and to the specific technologies for RF section of the receiver (analog front end, antennas etc.). We consider that the CR technology offers a good opportunity for some members of the Telecommunications Department and of the Communications and Signal Processing Research Center from UPB to be involved in top research&development activities both to national and international level.

11.1.2 The state of the art in the RF spectrum-based communications: The future of telecommunications is anticipated to be an evolution and convergence of mobile communication systems with IP networks, leading to the availability of a great variety of innovative services over a multitude of Radio Access Technologies (RAT). To achieve this vision, it is mandatory to embrace the requirements for support of heterogeneity in wireless access technologies, comprising different services, mobility patterns, device capabilities, and so on. Furthermore, it is equally important to promote important research in networking technology. Present-day wireless communications, which stand at the forefront of current technological advances, comprise a multiplicity of RAT standards. Of these, the most commonly used are the Global System for Mobile communications (GSM), Generalized Packet Radio Service (GPRS), the Universal Mobile Telecommunications System (UMTS), Broadband Radio Access Networks (BRANs), various types of Wireless Local Area Networks (WLANs) [VXX2], Digital Video Broadcasting (DVB) [DVB1] Worldwide Interoperability for Microwave Access (WiMAX), and so on. Moreover, the complete set of wireless technologies is currently being transformed into one global infrastructure vision, called the *Beyond 3rd Generation* (B3G) wireless access infrastructure. This is aimed at offering innovative services, based on user demands, in a cost-efficient manner. Major contributing concepts towards this convergence are *cooperative networks*[DPS1] and *reconfigurability* [DVK1]. The cooperative networks concept assumes that diverse technologies, such as cellular 2.5G/3G, BRAN/WLAN and DVB systems, can be joint components of a heterogeneous wireless-access infrastructure. This allows a Network Provider (NP) to rely on more than one RAT, dependent on the encountered specific conditions (e.g., hot-spot requirements, traffic demand alterations, etc.) at different times and in different areas. The NP may also cooperate with other NPs in order to make alternative solutions available for maximization of QoS levels offered to users. Advanced management functionality is required to support the cooperative networks concept, and much associated research has been done in the recent past [DPS1][DKK1]. This envisaged functionality deals with the reallocation of traffic to different RATs and networks, as well as the mapping of applications to QoS levels. The move towards the *reconfigurability concept* was initiated as an evolution of *Software Defined Radio* [SDR1]. It aims to provide essential mechanisms to terminals and networks, so as to enable them to adapt dynamically, transparently, and securely to the most appropriate RAT dependent on the current situation. Through reconfigurability, one envisages network segments being able to change RAT in a selforganized manner, allowing them to better handle offered demand. In this context, reconfigurability also allows for the dynamic allocation of resources (such as spectrum) to RATs.

To this point one can remark that a significant role in answering the requirements of an efficient management of the spectrum will be played by the newly emerging **technology cognitive radio (CR).** This can be derived from most used definition [HXX1][MXX1] of the cognitive radio. Built on a software-defined radio, the CR is defined as an intelligent wireless communication system that is aware of its environment and uses the methodology of understanding-by-building to learn from the environment and adapt to statistical variations in the input stimuli, with two primary objectives in mind: a) *highly reliable communication whenever and wherever needed; b) efficient utilization of the radio spectrum.*

In accordance with the above observations the Reconfigurability Group, WG6, from Wireless World Research Forum, has been produced a white paper [DDG1] aiming at providing the basic principle that must be adhered to in order to make cooperating reconfigurable networks commercially successful. These principles lie in the effective management of the available resources, i.e.: more efficient utilization of available spectrum, management of radio resources belonging to different RATs with fixed spectrum allocation, and an intelligent network planning process.

First the WG6 considers the general characteristics of Radio Resource Management (RRM), providing an analysis of RRM and requirements for the effective management of resources, along with associated technical considerations. A summary of some envisaged RRM solutions and Next Spectrum Management is provided. As spectrum today is a scarce resource, it is necessary to use it efficiently; cooperation amongst networks will assist the efficient use of radio spectrum in future communication systems. The group presents Joint Radio Resource Management (JRRM), consisting of a feasibility study for JRRM, a functional overview of the proposed JRRM scheme, and some important JRRM-related research topics, along with a novel scheme for managing resources of different RATs, namely Hierarchical Radio Resource Management (HRRM). Finally Dynamic Network Planning, enabling technologies that can be utilized to facilitate the provision of Flexible Spectrum Management and JRRM, in a reconfigurability context based on Cognitive Radio is treated.

The figure 1 depicts the technological functionalities that are needed to accomplish dynamic frequency selection using cognitive radio that can be referred to as policy-based radio.

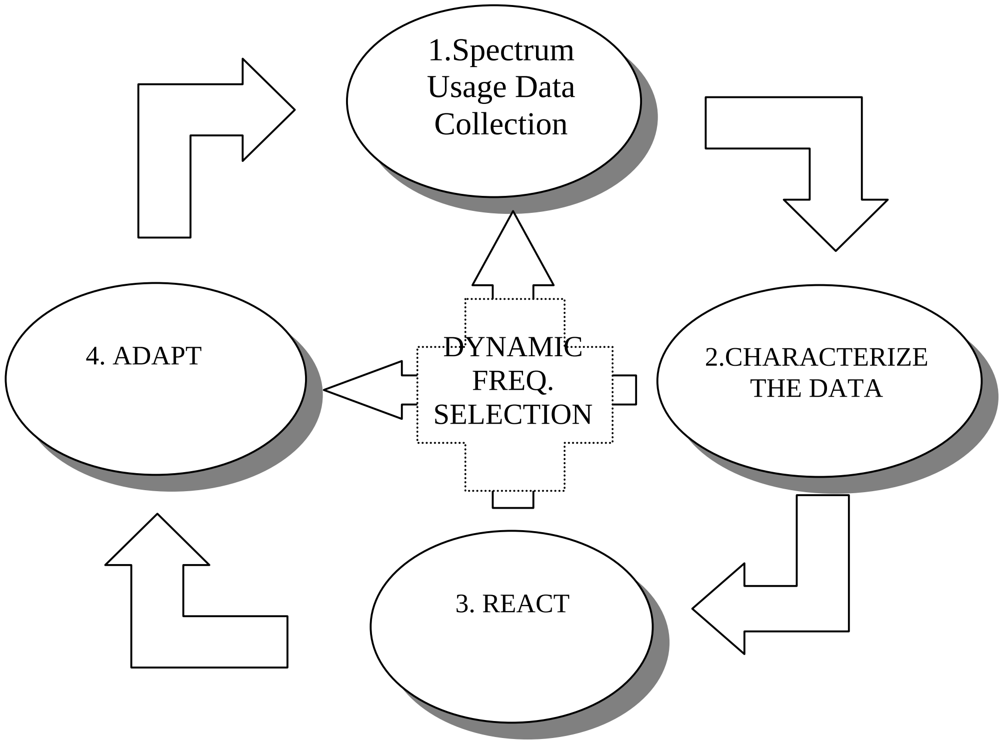

Figure 1. Cognitive radio based Dynamic Frequency Selection

The functionality requirements in Block 1:

- *real-time, wide-band, low-power sensing of the spectrum environment and*
- *downloading machine-readable regulatory policies and spectrum usage information that are both geo-location and time sensitive*,

are critical technology drivers.

Dynamic frequency selection requires the ability for a real-time, wide-band sensing of the spectral environment. This is the process of sampling the channel in order to determine occupancy. It should be noted that there is no agreed definition of when a channel is occupied; several factors are involved including receiver sensitivity, the sampling time and sampling interval, thresholds for discriminating wide-band noise from signals, etc.

One can remark that along with the sensing capability is the need for policy agility which is the ability to change the policies controlling the behavior of the radio to be changed dynamically. Policy agility allows adaptation to policies changing over time and geography. Such policy changes could be downloaded from the internet in a machine-readable format. The functionality requirements in Block 2: *real-time evaluation of the spectrum data and rapid waveform determination i*nclude an analysis of the data to determine if a particular channel is an opportunity for usage. This identification process includes the characterization of the data and uses this information to determine if the channel is used by another communications service or system. The identification process also includes communication with some subset of its neighbors because what may appear to be a clear channel at one end of the link may not be a clear channel at the other end of the link. For some mobile wireless subsystems this communication may require a narrow-band pilot channel. Block 3 of Figure 1 is the synthesis of the specific dynamic waveform and frequency that are appropriate for use at this time and this location. This leads to the need for the network to adapt (Block 4).

11.1.3 Cognitive Radio and the efficient usage of the spectrum: Most of the items cited as references have pointed out that many of the necessary functionalities mentioned above could be implemented by means of the newly emerged technology: **cognitive radio (CR)** [DGA1][CLX1][ALV1][HDH2] . CR has been recently proposed to implement some kind of intelligence to allow a radio terminal to automatically sense, recognize, and make wise use of any available radio frequency, spectrum at a given time. The CR technology coined by Mittola [MXX1] in his doctoral thesis is recognized now as a very promising one. This year a CR conference will be organized in Orlando-Florida (CrownCom2007) and a symposium in Las Vegas in January 2008 (both are at the second edition). Hundreds of papers are devoted to CR development. To understand the role of the CR technology we have to remark that the use of the available frequency spectrum will soon be purely on an opportunistic driven basis many researchers saying that the era of fixed allocation of frequency bands will come to an end. In other words, an user can utilize any idle spectrum sector for the exchange of information and stop using it the instant the primary user of the spectrum sector needs to use it. Thus, cognitive radio is also sometimes called smart radio, frequency agile radio, police radio, or adaptive software radio, and so on. For the same reason, the cognitive radio techniques can, in many cases, exempt licensed use of the spectrum that is otherwise not in use or is lightly used; this is done without infringing upon the rights of licensed users or causing harmful interference to licensed operations. Of course the primary users are not yet convinced that such interference will be avoided and the CR partisans have a lot of work to do in order to implement adequate algorithms and terminals with convincing results.

On the basis of Cognitive Radio technology cognitive radio networks can be conceived: intelligent networks that can automatically sense the environment and adapt the communication parameters accordingly. These types of networks have applications in dynamic spectrum access, co-existence of different wireless networks, interference management, etc.

They are conceived to drive the next generation of devices, protocols and applications. Clearly, the cognitive radio network paradigm poses many new technical challenges in protocol design, power efficiency, spectrum management, spectrum detection, environment awareness, new distributed algorithm design, distributed spectrum measurements, QoS guarantees, and security. Overcoming these issues becomes even more challenging due to non-uniform spectrum and other radio resource allocation policies, economic considerations, the inherent transmission impairments of wireless links, and user mobility.

The research on **cognitive radio technology** has a very short history, which spans less than 10 years. We have to get over many technical hurdles before cognitive radios can be deployed on a mass commercial application scale. Many challenges need to be overcome to implement a cognitive radio system for practical applications. From the point of view of cognitive radio used as a methodology for the opportunistic utilization of the rf spectrum one can identify two classes:

- *Unlicensed cognitive radios operating in the unlicensed bands;*
- *Unlicensed cognitive radios operating in the licensed bands.*

Each class has unique challenges to ensure its successful operation. The implementation of the second class of cognitive radios is in particular challenging since there are many parts of the radio spectra that are used by passive receivers such as radio astronomy where very weak distant objects are being observed. A typical signal power in radio astronomy is less than a trillionth of a watt. Detecting and avoiding these passive receivers is an extremely difficult issue and one method of solving this problem is to require any device operating in this band to be able to determine its location and avoid utilizing that part of the spectrum once in the proximity of this sensitive receiver.

It has to be admitted that there exists a huge gap between what we expect a cognitive radio to do and what we can use to implement a prototyping cognitive radio. But without doubt, success with the development of cognitive radio technologies should lead to major improvements in spectrum efficiency, performance, and in the interoperability of different wireless networks as a whole. The wide application of cognitive radio technologies will also bring a fundamental change to the philosophy in global radio spectrum allocation and specification across different frequency bands.

Before having a look in some scenarios of using CR technology in association with different **Radio Access Technologies (RAT)** let’s see some of the problems that have to be solved in the next years and from which we have selecred some of the objectives of the project:

1. New concepts and algorithms for agile radio and spectrum etiquette protocols;
2. Architecture and design of adaptive wireless networks based on cognitive radios;
3. Detailed evaluation of large-scale cognitive radio systems using alternative methods;
4. Spectrum measurement and field validation of proposed methods;
5. Cognitive radio hardware and software platforms.

11.1.4 Cognitive Radio Applications for WLANs: It is widely believed that the technical foundations established by WLANs provide a launching pad for cognitive radios. WLANs already incorporate essential cognitive radio features such as **DFS and TPC [**IEE4][XXX1]. Also, while the RF front ends may require wideband receivers and transmitters, the hardware exists now, and the software only involves the generation of the software engineering to make functions like filtering, band selection, and interference mitigation available as plug-in software modules for the radios. Let have a short look over the Cognitive Radio Tools incorporated in the IEEE 802.11h standard, which is a modified version of IEEE 802.11a standard, as an effort to reduce possible interference to some existing users in the same RF band, such as radar applications, and so on. Mainly the DFS (*Dynamic Frequency Selection*) and TPC (*Transmit Power Control*) used in IEEE 802.11h standard, bear the characteristics of a cognitive radio. The IEEE 802.11a wireless networks operate in the 5-GHz RF band and support as many as 24 nonoverlapping channels, which are less susceptible to interference than their IEEE 802.11b or IEEE 802.11g counterparts. However, regulatory requirements governing the use of the 5-GHz band vary from country to country, hampering 802.11a's rapid deployment in different regions of the world. To overcome the problem, the ITU recommended a harmonized set of rules for IEEE 802.11a WLANs to share the 5-GHz spectrum with primary user devices such as military radar systems, and so on. Issued in 14 October 2003, the IEEE 802.11h standard [IEE4] defines mechanisms that 802.11a WLAN devices can use to comply with the ITU recommendations. These mechanisms are DFS and TPC.

The DFS detects other devices working in the same RF channel, and it switches WLAN operation to another channel whenever necessary. DFS is responsible for avoiding interference with other devices, such as radar systems and other WLAN segments, and for uniform utilization of channels. An access point (AP) specifies that it uses DFS in the frames WLAN stations use to find APs. When a WLAN station associates or reassociates with an AP, the station reports a list of channels that it can support.

The TPC is intended to reduce interference from WLANs to satellite services by reducing the radio transmit power that WLAN devices use. The TPC can also be used to manage the power consumption of wireless devices and the range between APs and wireless devices. An AP specifies telephony control protocol (TCP) support in the frames it generates to WLAN stations. These frames also specify the maximum transmit power allowed in the WLAN and the transmit power the AP is currently using. The original motivation for the DFS and TPC mechanisms defined in 802.11h ensure a standard method of operation under the regulatory requirements governing the 5-GHz band, which will spur the deployment of 802.11a wireless networks around the world, especially those places where a strict regulation is imposed. Along with meeting regulatory requirements, the DFS and TPC can be used to improve the management, deployment, and operation of WLANs.

11.1.5 Cognitive Radio Applications for WMANs: As well known a WMAN will cover an area much larger than a WLAN does. The radius of a WMAN can reach several kilometres. The most widely referred standard for WMANs is IEEE802.16,also often called as WiMAX standard, or broadband wireless access (BWA) technology. The last versions of WMAN technologies usually support mobile terminals. For instance, the IEEE 802.16e standard [IEE6][XXX1] can support a terminal moving at a vehicular speed. Like WLANs, a WMAN can use cognitive radio to make it possible to underlay/overlay in those spectra that have been already occupied by other users.

It is to be noted that WiMAX is flexible in its channel sizes and can use the 6 MHz width of the underused TV channels. For a WiMAX system using a bandwidth below 900 MHz, its coverage can be three times larger than that in 2.4 GHz, reducing the number of base stations required, making mobile WiMAX mobile version an even stronger proposition against cellular, both in licensed and unlicensed modes. It is very interesting to note that, many technologies could use TV spectra, though the WiMAX community is keen to claim it for its own. In March 2004, when the IEEE 802.22[IEE2] group was set up, the 802.16 Working Group was angered when its proposal that the cognitive radio work should be under its auspices, rather than in a separate group, was defeated. The story behind the conflict between the IEEE 802.16 and the IEEE 802.22 groups highlights the importance of cognitive radio technology and its applications in either WMANs or WRANs (also called "Wi-TV " technology) [IEE2] operating in underused VHF/UHF TV bands. The IEEE 802.22 working group insisted at the moment the group began its activity that Wi-TV would work with existing IEEE 802 architectures, serving as a "regional area network" complementing both the Wi-Fi LAN and the WiMAX MAN. The IEEE 802.22 group also pointed out that WiMAX is not suitable for TV spectrum because it does not include cognitive radio functions. On the other hand, IEEE 802.16 group denounced that claim, noting that WiMAX does in fact have a provision for cognitive radios (IEEE 802.16h, [IEEE5]) to avoid interference with other WiMAX devices at higher frequencies, and that it could easily be adapted for UHF frequencies.

The truth is that the company that controls cognitive radio technology really will have its hand on the rudder of the creation of next-generation communications, and the commercial vendors behind the shadowy IEEE task groups know that. As another development, very recently (according to a report written on February 28, 2005), telecom agencies in India and Canada are working together on a cognitive radio-based broadband wireless technology: The networks will operate in the 5 GHz spectrum (or possibly the licensed Multichannel Multipoint Distribution Service (MMDS) bands) and transmit as far as one to two kilometers. The system would use cognitive radio technology to identify interference and poor links and then change its own signal transmission to improve the weak links.

11.1.6 Cognitive Radio Applications for WPANs: We can identify a very interesting possible application of cognitive radio technology in a WPAN environment, in which a UWB (IEEE 802.15.3) network operates [CLX1][IEE6]. In order to have some information let's see the situation appeared in USA when FCC decided to explore innovative ways to open up new spectra to commercial unlicensed use. One of the examples includes the release of new spectra in the 5 GHz UNII band in 2003, as well as the opening up of 7.5 GHz of bandwidth for UWB signaling in the region between 3.1 and 10.6 GHz. This action marked the first time the FCC had allowed unlicensed use across otherwise licensed bands. In fact, UWB transmits signals that are already below the noise floor. With the help of cognitive radio technology, a UWB terminal can also operate by jumping out really fast from one channel to another if it detects incumbent users. UWB technology has generated a great deal of interest as an attractive means to provide high-speed short-range communications. However, it has also generated a lot of controversy. As UWB signals are flat over a broad range of spectrum at a power level close to the noise floor, some people are concerned that UWB will artificially raise up the noise floor and degrade the performance of the existing primary users located at the same spectrum. After a lot of public debates, the FCC approved the first Report and Order on February 14, 2002, in which the FCC not only gave the definition of the UWB signals, but also defined a spectrum mask that specifies the amount of power that can be sent out by any UWB system working in the band.The spectral mask for UWB signals can help to control the interference to other users of the spectrum, such as GPS, radar, satellite systems and so on. On the other hand, according to the power emission requirements as specified in IEEE 802.15.3a, the UWB signal is generally sent out at or close to the thermal noise floor. Therefore, it is essentially imperceptible in most cases by an incumbent user more than a few tens of meters away. In addition, most UWB devices normally work indoors, and thus the possible interference to those incumbent users (i.e., GPS, radar and satellite systems, and so on.) is very unlikely. However, the outdoor operation of UWB systems will generate the problem of the interference to primary users operating in the same band. A more serious concern of interference is due to the fact that IEEE 802.11 WLANs and IEEE 802.15.1 Bluetooth devices are also operating in the same 2.4 GHz ISM bands. Therefore, there are basically two major interference issues that we need to investigate in the WPAN working environment: one being the UWB's interference to the licensed users allocated in the same band (such as GPS, radar and satellite systems, and so on.), and the other being the mutual interference among unlicensed users (such as WLANs and Bluetooth devices, and so on.).

The cognitive radio technology is well suited for the UWB applications to overcome the above two interference problems. To overcome the first kind of interference problem in UWB applications, it is impossible to mandate a coordination mechanism for spectrum sharing, as non-UWB applications are primary users of the spectrum. Therefore, there will be no collaboration in this scheme and the use of the cognitive radio in the UWB devices will try to avoid using the band if it detects it is in use by some incumbent users, in order not to interfere with their normal operations. Clearly, in this case, the cognitive radio is used by UWB devices on a noncollaborative basis, and only part of cognitive radio functionalities can be used.

On the other hand, we can also consider a WPAN environment, in which other nonlicensed devices, such as Bluetooth and Wi-Fi networks, may exist. In order to achieve the optimal performance for all nonlicensed devices, cognitive radio technology can be applied to all the terminals which form a cognitive radio network, and can work jointly on a collaborative basis. Only in this case, can the benefit of a cognitive radio network be fully realized. Basically, there are four parameters that a cognitive radio network can try to optimize: transmission data throughput, error rate, quality of service, and cost of connection. The optimization of the aforementioned four parameters can be achieved by leveraging the following seven approaches: power level control, antenna beam steering, carrier frequency, channel-coding adaptation, transmission time slot, MAC protocol adaptation, and using CDMA to manage interference. Obviously, the set of MAC protocols is generally fixed to some extent, but the other parameters can normally be chosen independently from a fairly wide range of values. There is probably some fruitful research into methods for including protocol as part of the optimization; for example, a WLAN user can often choose to modify packet size and data rate, and so does a Bluetooth network. Optimal choices of these parameters in a WPAN using cognitive radio technology are an active research area.

11.1.7 Bibliography

[ALV1]	Ian F. Akyildiz, Won-Yeol Lee, Mehmet C. Vuran, and Shantidev Mohanty, "NeXt
[BRX1]	T. Bates and Y. Rekhter, RFC 2260: Scalable Support for Multi-homed Multi-provider
[CLX1]	Chapin, J.M.; Lehr, W.H., Cognitive Radios for Dynamic Spectrum Access - The Path to Market
[CXX1]	M. Cave, “Review of Radio Spectrum Management,” UK Department of Trade and
[DDG1]	G. Dimitrakopoulos, P. Demestichas, D. Grandblaise, et all, Cognitive Radio, Spectrum and
[DGA1]	M. Dohler, S.A. Ghorashi, M. Ghozzi, M. Arndt, F. Said, A.H. Aghvami, “Opportunistic
[DKK1]	P. Demestichas, N. Koutsouris, G. Koundourakis, K. Tsagkaris, A. Oikonomou, V.
[DMT1]	Devroye, N.; Mitran, P.; Tarokh, V., Achievable rates in cognitive radio channels, *IEEE Trans. on*
[DPS1]	P.Demestichas, L.Papadopoulou, V.Stavroulaki, M.Theologou, G.Vivier, G.Martinez,
[DVB1]	Digital Video Broadcasting (DVB) Web site, www.dvb.org, Jan. 2002
[DVK1]	P. Demestichas, G. Vivier, K.El-Khazen, M. Theologou, “Evolution in wireless systems
[DXX1]	M. Dillinger, etc, Software Defined Radio Architecture, Systems and Functions, ISBN: 0-
[EUR1]	http://www.europarl.europa.eu/sides/getDoc.do?Type=TA&Reference =P6-TA-2007-
[FCC1]	Federal Communications Commission, Cognitive Radio Technologies Proceeding (CRTP),
[HDH1]	M. Haddad, M. Debbah and A.M. Hayar, “Spectral efficiency of Cognitive Radio systems,”
[HFA1]	O. Holland, Q. Fan, A. H. Aghvami, "A Dynamic Hierarchical Radio Resource Allocation
[HKM1]	Harada, H., Kuroda, M., Morikawa, H., Wakana, H., and Adachi, F., (2003). The Overview
[HWA1]	Hu, W.; Willkomm, D.; Abusubaih, M.; Gross, J.; Vlantis, G.; Gerla, M.; Wolisz, A., COGNITIVE
[HXX1]	S. Haykin, Cognitive radio: brain-empowered wireless communications, *IEEE Journal on*
[IEE1]	IEEE 802.22-04/0002r13, “WRAN Reference Model,” *IEEE P802.22* [5] Doc. A/54A,
[IEE2]	IEEE 802.22-05/0007r48, “Functional Requirements for the 802.22 WRAN Standard,”
[IEE3]	IEEE 802.22-06/0252r1, “OFDMA Parameters,” *IEEE P802.22 Wireless RANs*, Nov. 2006.

[IEE3]	IEEE 802.22-06/0252r1, "OFDMA Parameters," *IEEE P802.22 Wireless RANs*, Nov. 2006.
[IEE4]	IEEE 802.11h standard, http:// www.ieee 802.org
[IEE5]	Detailed scope of IEEE 802.16h standard, http://www.wirelessman.org
[IEE6]	www.ieee802.org
[INT1]	Cognitive Radio, *www.Radio-Electronics.com*
[ITU1]	ITU-R Report BS.1203-1, *Digital Sound Broadcasting to Vehicular, Portable, and Fixed Receivers Using Terrestrial Transmitter in the UHF/VHF Bands*, 1994.
[ITU2]	ITU-R Recommendation BT.1368-1, *Planning Criteria for Digital Terrestrial Television Services in the VHF/UHF Bands*, 1998.
[KLK1]	H.N. Kim, Y.T. Lee, and S.W. Kim, "Mathematical Modeling of VSBBased Digital Television System," *ETRI J.*, vol. 25, no. 1, Feb. 2003, pp. 9-18.
[KWD1]	Krenik, W.; Wyglinski, A.M.; Doyle, L.E.; Guest Editorial - Cognitive Radios for Dynamic Spectrum Access, *IEEE Comm. Magazine*, Volume 45, Issue 5, May 2007 Page(s):64 – 65
[KXX1]	Rajesh Krishnan "Towards Policy Defined Cognitive Radios,", *NSF Workshop on Programmable Wireless Networking Information Meeting*, 5 February 2004; available at: www.cra.org/Activities/workshops/ sf.wireless/BBN_Krishnan2.pdf
[MES1]	Minden, G.J.; Evans, J.B.; Searl, L.S.; Depardo, D.; Rajbanshi, R.; Guffey, J.; Chen, Q.; Newman, T.R.; Petty, V.R.; Weidling, F.; Peck, M.; Cordill, B.; Datla, D.; Barker, B.; Agah, A.;Cognitive Radios for Dynamic Spectrum Access - An Agile Radio for Wireless Innovation, *IEEE Comm. Magazine,* Volume 45, Issue 5, May 2007 pp. :113 – 121
[MXX1]	J. Mitola, "*Cognitive radio: An integrated agent architecture for software defined radio*", Doctor of Technology, Royal Inst. Technol. (KTH), Stockholm, Sweden, 2000.
[MXX2]	J. Mitola, Software Radio Architecture–Object Oriented Approaches to Wireless Systems Engineering, Wiley, 2000
[PXX1]	Poole, I, ;**What exactly is... cognitive radio?,** *Communications Engineer***,** Volume 3, Issue 5, Oct.-Nov. 2005 Pp.42 - 43
[SDR1]	Software Defined Radio forum: www.sdrforum.org
[SXX1]	Suzuki, Y. (2002). Interoperability and Regulatory Issues around Software Defined Radio (SDR) Implementation, *IEICE Trans. Commun*., Vol. E85-B, No. 12, pp. 2564-2572, December
[VXX1]	S. Verdu, " Spectral Efficiency in the Wideband Regime", *IEEE Trans. Information Theory, Special Issue on Shannon Theory:Perspectives, Trends and Applications*, vol. 48, pp. 1319–1343, June 2002.
[VXX2]	U.Varshney, "The status and future of 802.11-based WLANs", *IEEE Computer*, Vol. 36, No. 6, June 2003
[WXX1]	Walko, J.;Cognitive radio, *IEE Review*, Volume 51, Issue 5, May 2005 Page(s):34 - 37
[XXX1]	*Wireless Center*, All Wireless Artcles, posted on the 10'th of January 2007, available at http://www.wireless-center.net.
[YHC1]	Young-Keun Yoon, Heon-Jin Hong, and Ik-Guen Choi Young-Keun Yoon et al. Protection of Digital TV from Cognitive Radio Interference, *ETRI Journal,* Volume 29, Number 3, pp.394..397, June 2007
[ZSP1]	Xiaorong Zhu; Lianfeng Shen; Tak-Shing Peter Yum, Analysis of Cognitive Radio Spectrum Access with Optimal Channel Reservation, *Comm. Letters***,** Volume 11, Issue 4, April 2007 Pp:304 – 306