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Research paper

A survey for cognitive radio (CR) networks

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Abstract

Fixed spectrum allocation policy in the wireless networks leads to variations in the spectrum utilization of the allocated spectrum. This variation ranges from 15% to 85%, with high variance in time and geographical area in a random manner. However, the spectrum scarcity, the new technologies which provide high data rate but need more bandwidth, the new demand of lower cost per bit, and the inefficiency in the spectrum bands all these problems can be addressed using the Cognitive Radio (CR) technology. In this paper, the CR aspects and functionalities are discussed, a brief discussion about the Medium Access Control (MAC) protocol design for a Cognitive Radio Network (CRN) is introduced, and the main critical CR issues as well (including heterogeneity induced problem, multichannel spectrum sensing, Common Control Channel (CCC) problem, spectrum mobility, and the self organization schemes in the CR functionalities).

Keywords: *Cognitive Radio Network; Dynamic Spectrum Access; Primary Radios.*

1. Introduction

NOWADAYS various technologies provide high data rate but need more spectrum bands, while the spectrum is a limited resource and fixed allocated and can't be used unless from an exclusive users whom have the right Primary Radios (PR), moreover, the new demands require lower cost per bit, which means more spectrum efficiency [3]. Recent studies from the Federal Communications Commission)FCC(indicates that the licensed spectrum bands are heavily allocated but vastly underutilized [1]; therefore, a need for a new technology provides high data-rate with high spectrum efficiency allocated to increase the spectrum utilization have appeared.CR technology is a new technology uses bands from licensed and unlicensed spectrum bands in an opportunistic manner to improve the spectrum efficiency, hence, to solve these problems in four main functionalities; spectrum sensing, spectrum sharing, spectrum management, and spectrum mobility. The CR has the ability to sense the environment's spectrum to detect the opportunity in the spectrum bands, and reconfigurability; in which the CR can reconfigure its own parameters to establish its communication transmission within the available spectrum bands. The spectrum sharing in CRN is Dynamic Spectrum Access (DSA), where the key enabling technology is concluded in the CR which enables sensing and reconfigurability functionalities.
Many papers discussed the CR's technical aspects, functionalities, main challenges and open issues, its enabling technologies, its optimization techniques, and some of the specific design issues (i.e., [1-5]). The typical CRN environment is a CRN coexists with other Primary Radio Networks (PRNs) in the same geographical area. PRNs share orthogonal spectrum bands. PR users can use the spectrum bands of all PRNs in an opportunistic manner, with low transmission power per CR transmission to guarantee no degrade in the Quality of Service (QoS) of the PR users. CR users should operate in transparent from the PR users; no corporation between the PR users and the CR users. The CR user should vacate the spectrum band very fast whenever a PR user appear, and look for new available spectrum band; this is called the spectrum mobility. The spectrum mobility degrades the QoS of the CR users. Usually the CRN environment consists from a heterogeneous distribution of the spectrum bands. The CRN should give guarantees on the PR users' performance. However, these specifications and challenges need new MAC protocols to address these problems as well new network protocols. Theses protocols should maximize the overall network throughput, or minimize the overall transmission power, etc. Thus, the best rout and MAC protocols could be a joint optimization problem. In both centralized algorithm; in which there is centralized Access Point (AP) and CR users, the CR users performs the sensing and send the control packets to the AP, and the AP distribute the available spectrum bands between CR users, and decentralized algorithm (distributed) in which there is no infrastructure (infrastrucureless) as in mobile ad hoc Wireless Sensor Networks (WSNs); in which each CR may performs the sensing and uses a distributed algorithm to achieve the network goal (i.e., highest network throughput). Our work helps understanding the concept of the CR technology and its new demands necessitate the CR technology, including the CR's functionalities, and discuss the MAC design for the CR, as well as the main CR's challenges and open issues.
The rest of the paper is organized as follows; in section II, we introduce the CR functionalities, indicating the four functionalities of CR; spectrum sensing, spectrum management, spectrum sharing, and spectrum mobility. In section III, we introduce the MAC protocol for CRNs. The IEEE 802.22 Wireless Regional Area Network (WRAN), which is the first standard for CRNs. Section IV introduce and discuss some of the CR challenges and open issues. Finally, section V introduces a brief summary of this paper.

2. CR functionalities

The CR communication cycle concludes four main steps, namely; spectrum sensing, spectrum management, spectrum sharing, and spectrum mobility. In this section we will indicates the functionalities of each step.

2.1. Spectrum sensing

The spectrum sensing aims to find an opportunity in the unused spectrum bands (white holes), to establish CR's transmission. Ideally speaking, we want to identify the presence of the PR receiver, and its interference margin from the CR transmitter. This is too difficult to achieve since the CR should operate transparently from the PR (no corporation between CR and PR), and the passive property of the PR receiver; we can detect the presence of the transmitter since it is an active element, but the receiver is a passive element. So, we will discuss two main sensing approaches and their branches; namely; primary transmitter detection, and interference-based detection.

2.1.1. Primary transmitter detection

In the primary transmitter detection approach, each CR observes the weak signals from the PR by sensing the surrounding environment. This can be done using one of the three schemes;

1) Matched filter: this scheme needs a prior knowledge about the PR's waveform. Sometimes the CR doesn't have knowledge about the PR's waveform.
2) Energy detection: which is a good scheme in case when no information about the PR's waveform. This scheme is prone to error and can be jammed easily.
3) Cyclostationary feature detection: this is based on autocorrelation function of the received signal, by extracting features from the periodicity and cyclostationarity properties of the received signal.

2.1.2. Cooperative detection

multiple CR users are incorporated to detect the PR users, increasing the number of incorporated CR users leads to high accurate sensing, as a result will increase the control overhead. The main problem in spectrum sensing is to design a high accurate devices and robust algorithms to share the sensing information to CR users [2].

2.1.3. Interference based detection

In this scheme a limit on the interference at the PR users caused by the CR user is defined as an interference temperature. Each CR transmit unless reach this limit of interference. However, CR users can't detect the presence of the PR's receiver, on the other side, each interference will be added constructively at the PR's receiver; this yield to drop its transmission. For more accurate detection of the presence of PR user; is done by increasing the number of cooperating sensing CR users [5, 7]. Fig.1. indicates a brief summary of the CR's sensing techniques.

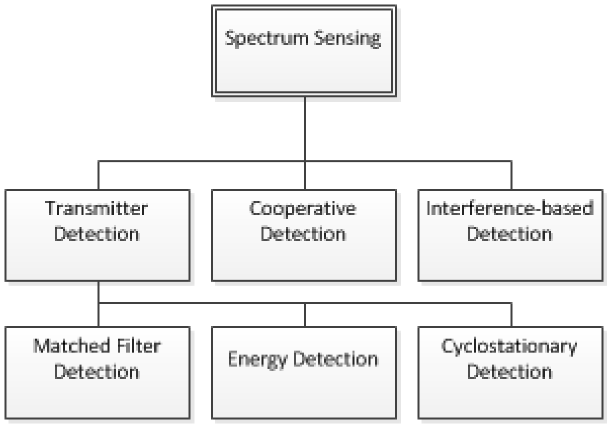

Fig. 1: Spectrum Sensing Techniques.

2.2. Spectrum management

In spectrum management, each CR user chooses the best available channels to meet its requirements. After sensing the surrounding environment's spectrum, the CR estimates the characteristics of the white holes (i.e., this is called spectrum analysis). Then the spectrum decision performs the best channel/s according to their characteristics and CR's requirements.

2.3. Spectrum sharing

CR users share their channels between either the same CRN's users or with different CRNs' users (using spectrum broker which facilitate spectrum sharing among different CRNs) [2], [8], and using a fair schedule algorithm to maximize the spectrum utility. Both of the network architectures are available in the CRNs; centralized spectrum sharing and distributed spectrum sharing. In the centralized architecture a central entity controls entire CR users. The CR users perform sensing and send the control packets to the central entity, where the central entity controls the spectrum allocation among all the controlled CR users. This needs an infrastructure and synchronization. On the other hand there is decentralized spectrum sharing, where each CR user access and allocate spectrum upon its own measurements. Sometimes external devices perform the sensing and broadcast the control packets to the CR users [3]. However, the spectrum sharing among multiple CR users can be performed in cooperative manner or in non-cooperative manner. In the cooperative spectrum sharing each CR performs sensing, shares its sensing report among neighbours CRs, and cooperatively allocate the spectrum to increase the spectrum utilization [3], [9].

[6] Introduces a novel distance dependent spectrum sharing algorithm called (a.k.a. DDMAC), its exploits the variation of the channel quality to increase the spectrum utility in a cooperative spectrum sharing algorithm. While in non-cooperative spectrum sharing each CR allocate the spectrum upon its own sensing measurements. In general, multiple-CRNs can be located in the same geographical location with other PRNs. These CRNs content for the same spectrum band. This is called internetwork spectrum sharing. Controlling the spectrum sharing among multiple CRNs' users can be done via spectrum broker [2]. The spectrum sharing techniques can be classified into:

1) Overlay spectrum sharing; it is referred to the MAC protocol. In which, the CR user can use only portion of spectrum band that is not used from other CR users [2].
2) Underlay spectrum sharing. This spectrum access technique exploits spread spectrum techniques [2]. The transmission power of the CR is regarded as a noise due to PR users [3]. This technique improves the spectrum utility in compare with overlay technique [2], [10].

2.4. Spectrum mobility

Spectrum mobility is defined as the process of changing the operating (best available) spectrum to a worse available spectrum band [2]. This changing is due to even to appear of the PR user, or due to changes in the channel conditions [2]. The author in [4], refers to the algorithm of choosing the best available channel for a given transmission as the "greedy". However, whenever a PR appears, the CR should vacate the spectrum band and switch rapidly into an empty portion of the spectrum bands [3], [11].

3. MAC design for CRN

In the typical case, there exist multiple PRNs shares orthogonal spectrum bands, and exist with one CRN in the same geographical area [1]. As indicated in Fig.2. CR offers opportunistic capability, as well as cognitive capability [1]. Besides, spectrum sharing and spectrum mobility, give the CR unique characteristics. Many papers discuss the MAC design and challenges for a CR (i.e., [1]). The first worldwide standard MAC protocol for CR technology is the IEEE 802.22, and it is called WRAN [2]. WRAN focuses on utilizing the spectrum in UHF/VHF TV bands (54~862 MHz). WRAN's coverage range can reach up to 100 km (if the power is not an issue) [2]. However, current cell coverage range is 33 km at 4 W CPE Effective Isotropic Radiated Power (EIRP). As denoted the maximum allowable transmit power for a CR is constraints to power mask. This power mask is very small in compare with the PR's transmitted power. Hence, the Inter-Symbol Interference (ISI) from PR to CR is considerable. So, guard-band channels are needed [4], [13]. The author in [4], address the problem of assigning the best channels/powers assignment due to opportunistic transmissions, taking into accounts such constraints for DSA systems. However, a good CR's MAC protocol should:

- Be transparent to PR users; no cooperative between the CR and PR users.
- Provide guarantee about PR's performance.
- Allow cooperation among CR users, allowing improve the spectrum efficiency.
- Be fair for all CR users.
- Allow sharing control packets among neighboring CR users, with no prior CCC.

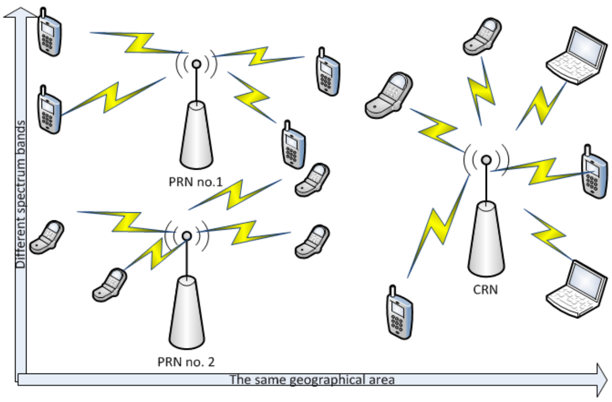

Fig. 2: Typical CRN Architecture Coexists with Multiple PRNS.

4. Challenges and open issues

In spite of CRNs provide high spectrum utility and high data rate to CR users via heterogeneous wireless architectures and DSA techniques, some challenges may still be opened until now; this also referred to the dynamic spectrum environment of CRNs and the diverse QoS requirements of different applications [3].

4.1. Heterogeneity induced problem

The heterogeneity of CRNs is a challenge, since the available channel list at a given user may not be the same at a different CR user. As a result, finding the ideal channel/group of channels becomes an issue in such heterogeneous networks.

4.2. Multichannel spectrum sensing

As the spectrum bands is time varying and may not still idle until the CR's transmission is finished as well. So, non-contiguous spectrum bands can be sensed simultaneously to improve the reliability of the CR's communication [3].

4.3. Common control channel (CCC) problem

For a reliable multihop CR communication via heterogeneous opportunistic spectrum access networks, a reliable mechanism for exchanging control packets is needed [1]. Many MAC protocols assume a dedicated control channel, which is a contradictory for the opportunistic property of the CR, and can cause a single bottle of failure as the bottleneck [1]. Other approaches solve this problem using clustering, despite these approaches solve the CCC problem, they have high control overhead and need reclustering if a CCC is lost.

4.4. Spectrum mobility challenges

For each QoS requirement a limited packet loss and delay are required in spectrum mobility process. These requirements arise new challenges in terms of seamless data transmission, priority-based channel management, and QoS guarantee [3, 12].

4.5. Self-organization schemes in CR functionalities

Since the self-organization schemes are totally based on local sensing measurements and behavior of individuals, the decentralized control may raise new challenges [3]:

- The optimum is not always achieved in self-organization.
- A need for new theory of decentralized control and decentralized management; to pave the way toward the reliable CR's communications with a high scalability and accurate spectrum sensing report

5. Conclusion

Recent researches indicate that the spectrum bands are heavily allocated but vastly underutilized; hence the CR technology arises as a promising technology to increase the spectrum utility in an opportunistic manner. As a result lower cost for the spectrum band per bit is achieved to meet the new demands. The CR technology addressed all the aforementioned problems. The main DSA's enabling technology is concluding in the sensing and re-configurability functionalities in the CR. In this paper we introduce the concept of the CR technology, discuss the new demands necessitate the CR technology. Also, we discuss the CR's functionalities, and discuss the MAC design for the CR, as well as the main CR's challenges and open issues.

References

[1] H. Salameh, M. Krunz, "Channel access protocols for multihop opportunistic networks: challenges and recent developments", Network, IEEE 23 (4), 14-19, 2007. https://doi.org/10.1109/MNET.2009.5191141.

[2] Akyildiz, W. Lee, M. Vuran, "NeXt generation/dynamic spectrum access/cognitive radio wireless networks: A survey", Comp. Net., vol. 50, no. 13, Sept. 2006.

[3] Z. Zhang, K. Long, J. Wang, "Self-organization paradigms and optimization approaches for cognitive radio technologies: a survey," Wireless Communications, IEEE, vol.20, no.2, pp.36, 42, April 2013.

[4] H. Salameh, M. Krunz, D Manzi, "Spectrum Bonding and Aggregation with Guard-band Awareness in Cognitive Radio Networks", IEEE Transactions on Mobile Computing, 2013.

[5] P. Soni, P. Singh, "Cognitive Radio Systems: Realization and Technical Aspects", International Journal of Engineering Technology & Management Research, Volume 1, Issue.

[6] H. Salameh, M. Krunz, O. Younis, "Cooperative adaptive spectrum sharing in cognitive radio networks", IEEE/ACM Transactions on Networking (TON) 18 (4), 1181-1194, 2010.

[7] Feng Hu, Bing Chen, Kun Zhu, "Full Spectrum Sharing in Cognitive Radio Networks Toward 5G: A Survey", IEEE Access (6), 15754 – 15776, 05 February 2018.

[8] Ioanna Kakalou , Danai Papadopoulou , Theofanis Xifilidis , Kostas E. Psannis , K. Siakavara , Yutaka Ishibashi, "A survey on spectrum sensing algorithms for cognitive radio networks", 2018 7th International Conference on Modern Circuits and Systems Technologies (MOCAST), 7-9 May 2018, IEEE *Explore*.

[9] Athar Ali Khan, Mubashir Husain Rehmani, Martin Reisslein , "Cognitive Radio for Smart Grids: Survey of Architectures, Spectrum Sensing Mechanisms, and Networking Protocols", IEEE 860 – 898, 24 September 2015 .

[10] Jia Zhu , Liuqing Yang , Ying-chang Liang , Yu-dong Yao, "Securing physical-layer communications for cognitive radio networks",

IEEE Communications Magazine, (53) , Issue: 9 , 48 – 54, September 2015.

[11] Syed Hashim Raza Bukhari , Mubashir Husain Rehmani , Sajid Siraj, " A Survey of Channel Bonding for Wireless Networks and Guidelines of Channel Bonding for Futuristic Cognitive Radio Sensor Networks", IEEE, (18) , Issue: 2, 924 – 948, 2015.

[12] Rajesh K. Sharma, Danda B. Rawat, "Advances on Security Threats and Countermeasures for Cognitive Radio Networks: A Survey", IEEE (17), 2 , 1023 – 1043, 2015.

[13] Yasir Saleem, Mubashir Husain Rehmani , "Primary radio user activity models for Cognitive radio networks: A survey", Journal of Network and Computer Applications, Volume 43, 1-16, August 2014. https://doi.org/10.1016/j.jnca.2014.04.001.