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Routing Strategies in Cognitive Radio Network: A Comprehensive Review

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ABSTRACT

Routing is a very challenging task in a dynamic, large-scale wireless radio network. We have tried to review some of the routing strategies in cognitive radio network. We have studied the different routing technique in cognitive radio network and provide a comprehensive review of broadcasting and channel selection strategies for both wireless and cognitive radio networks.

Key words: Data Dissemination, CRN, Broadcast, Routing and VANET

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INTRODUCTION

Now-a-days advances in communication technologies and the explosion of wireless computing and communication devices make the radio spectrum teeming. In this viewpoint, a lot of work has been conceded to pick up the spectrum utilization over the last several decades. This technology combines the use of different access technologies, e.g., Frequency Division Multiplexing, (FDM), Time Division Multiplexing (TDM), Code Division Multiple Access (CDMA), and Orthogonal Frequency Division Multiple Access (OFDMA). From the technical point of view, the radio spectrum is geographically reutilized to surmount the spectrum deficiency. So the Global System for Mobile Communications (GSM), the radio spectrum is geographically reuse through micro, pico, and femto cells. However, experiments from the Federal communication Commission (FCC) reveals that the spectrum utilization still varies from 15%-85% with frequency, time and geographical location. Thus it necessary to use the radio spectrum opportunistically through Cognitive Radio (CR) technology. Cognitive Radio Technology (CRT) has created new doors to promising applications. This CRT has been widely used in numerous application scenarios including military and public safety networks, post-disaster situations [1], and wireless telemedicine [2]. In disaster situations, with the help of multi-interface this technology can provide as a spur of communications for other devices which may operate in different band and have irreconcilable wireless interfaces. Similarly, this technology can also be used to provide opportunistic access to large parts of the underutilized spectrum in cellular networks [3].The goal of this paper is to provide a comprehensive review of routing of cognitive radio network, broadcasting and channel selection strategies, for both wireless and cognitive radio networks.

The rest of the paper is organized as follows: Cognitive Radio Network discussed in Section 2. In Section 3, we conduct a comparative study of data dissemination. In Section 4 we delineate the application of data dissemination in wireless network. A classification of broadcasting routing protocol is presented in Section 5. Section 6 presents data dissemination in multi channel environment. Challenge of data dissemination in cognitive radio network describes in section 7 and in section 8 describe channel selection in CRN which is followed by conclusions in Section 9.

COGNITIVE RADIO NETWORK

Cognitive radio networks are composed of cognitive radio devices. Ian F. Akyildiz et al. [4] defines cognitive radio as: “A Cognitive Radio is a radio that can change its transmitter parameters based on interaction with the environment in which it operates”. The motivation behind cognitive radio was three that are

i) availability of restricted spectrum,
ii) preset spectrum assignment policy, and
iii) Inadequacy in spectrum usage.

Therefore, cognitive radio networks are designed to opportunistically operate the underutilized spectrum. Moreover, the idea of using the cognitive radio devices to address the spectrum deficiency problem. CR nodes should dodge from harmful interference to primary radio(PR) nodes [5] during their communication. Note that PR nodes are the legacy users and they have higher priority to use the licensed band. Idle channels can be used by CR nodes to distribute non-urgent and advertising messages with low cost and complexity. Cognitive radio technology can help Delay Tolerant Networks (DTNs) to provide reliable, dependable, delay-sensitive opportunities for communication [6]. For instance, DTNs and CR technology could be used in urban scenario, where high density of wireless devices causes delay in communication due to contention over the link. Cognitive radios thus help in finding empty channels for opportunistic use and ensure timely delivery of messages. Wireless Sensor Networks (WSNs) is another domain where cognitive radio technology could be used by either providing Internet connectivity to the drop or help connecting the disjoint parts of the networks. Moreover, the cognitive radio technology can alleviate the problems of contention, collisions, and packet losses to some point over the tremendously congested ISM band.

DATA DISSEMINATION

Data dissemination is a conventional and a fundamental function in any kind of network. Data dissemination is the distribution of information through broadcasting. The main goal is to reach the maximum number of neighbours with every sent message i.e., no routing is used and no end-to-end path is maintained. Data dissemination has been studied in different wireless networks, such as Wireless Sensor Networks (WSNs), Vehicular Ad-Hoc Networks (VANETs), Wireless Mesh Networks (WMNs), and Mobile Ad-Hoc Networks (MANETs). In wireless networks, the characteristics and problems inherent to the wireless links bring several challenges in data dissemination (broadcasting) in the shape of message losses, collisions, and broadcast storm problem. If broadcasting is done through flooding, i.e., blindly, serious redundancy, contention, and collision could exist [7]. First, many broadcasts are considered to be redundant because the radio propagation is omni-directional and a geographical location may be covered by the transmission ranges of several hosts. Second, after a node broadcast a message, if many of its neighbours decide to rebroadcast, these transmissions may sternly assert with each other. Third, the timing of rebroadcast of the neighbouring nodes may cause collisions. All these three problems associated with flooding, collectively referred as broadcast storm problem. One method to reduce the broadcast storm problem is to inhibit some wireless nodes from rebroadcasting, which results in less contention and collision. It has been proved that if a simple counter-based scheme is used instead of simple flooding, it can eliminate many redundant rebroadcasts. One such method is probabilistic broadcasting, where wireless nodes rebroadcast with certain probability. In cognitive radio networks, broadcasting is expected to be done more frequently due to the higher spatio-temporal availability of channels. The situation is more complex than multi-channel wireless networks, where the availability of multiple channels are static. On the contrary, channels are dynamic in cognitive radio networks due to the primary radio activity. Therefore, the broadcast storm problem is present in cognitive radio networks. In cognitive radio networks, an important step in having efficient data dissemination is to know how to select best channels. In fact, channel selection plays a vital role in robust data dissemination.

APPLICATION OF DATA DISSEMINATION IN WIRELESS NETWORK

In vehicular ad-hoc networks, an interesting application is to broadcast emergency messages to the precise area and guarantees all related vehicles receive the emergency message, such that people can amend their routes to destination in time. In this way, people can avoid getting into a traffic jam. In this context, an analysis of emergency message dissemination in vehicular networks is done. A fast and trustworthy emergency message dissemination method was proposed to disseminate emergency message in VANETs [8]. In addition, to resolve the broadcast storm problem, achieve low dissemination delay, and provides the high reliability in highway scenario. Data dissemination in wireless sensor networks has been widely studied in the literature. In WSNs, data dissemination is generally performed from sensor nodes to a static sink. This data could be an emergency message such as a fire alarm, and it must be transmitted firstly and reliable towards the sink. Note that in emergency situations, the sink could move, e.g., a fire fighter roaming in the area or an Unattended Aerial Vehicle (UAV). Supple effectively distributes and stores monitored data in WSNs such that it can be later sent to or retrieved by a sink. Epidemic dissemination has huge potential, enabling, for instance, a wide range of mobile ad-hoc communication and social networking applications, supported entirely through opportunistic contacts in the physical world.

BROADCAST ROUTING PROTOCOL

For sharing information about traffic, weather and emergency road conditions among vehicles broadcast routing is more suitable. In broadcast routing a node of the network disseminates a message to the vehicle beyond its transmission range through the use of multi hops. Broadcast sends a packet to all nodes in the network, typically using flooding. This ensures that the delivery of such packets consume more bandwidth because of duplicate message reception; also disseminated messages collide due to congestion. It performs better in the sub-urban and highway where a small number of nodes take part in the network. The various Broadcast routing protocols are BROADCOMM, UMB, V-TRADE,DV-CAST, EAEP, SRB, PBSM, PGB, DECA and POCA.

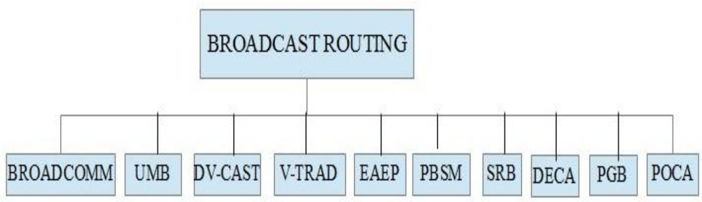

Fig. 1: Classification of Broadcast Routing Protocol

DATA DISSEMINATION IN MULTI CHANNEL ENVIRONMENT

In this section, we briefly discuss some data dissemination protocols for multichannel environment. In [9], the authors proposed two protocols, McSynch and McTorrent, for data dissemination in multi-channel wireless sensor networks. McTorrent achieves end-to-end data dissemination in less time than the single channel protocols, while McSynch can substantially reduce the time required cluster-wide synchronization. The performance limits of data dissemination with multi-channel, single radio sensors under random packet loss. For an arbitrary topology, the problem of minimizing the expected delay of data dissemination can be treated as a stochastic shortest path problem [10]. Broadcasting protocols for multi-channel wireless networks in the presence of adversary attacks are proposed in [11]. Network coding for data dissemination in order to reduce the impact of suck adversary attacks on dissemination performance and derived the optimum number of channels that nodes have to access in order to minimize the reception delay. A power saving data dissemination architecture for mobile clients' units in multi-channel environment is proposed in [12]. A concurrency control technique suitable for the multi-channel dissemination-based architectural model. A data scheduling algorithm over multiple channels in mobile computing environment is proposed in [13]. The average expected delay of multiple channels considering data items' access frequencies, variable length, and different bandwidth of each channel. In cognitive radio networks, very less work has been done on data dissemination. The distribution and limits of information dissemination latency and speed in cognitive radio networks. Hereafter, we discuss the challenges of data dissemination in cognitive radio networks.

CHALLENGE OF DATA DISSEMINATION IN COGNITIVE RADIO NETWORK

Robust data dissemination is a complex task in cognitive radio networks due to its intrinsic properties, such as:

i) The availability of multiple-channels i.e., CR nodes have more than one channel in the available channel set. Available channel set is the set of channels visible to CR node for communication.
ii) The diversity in the number of available channels i.e., CR nodes have diverse set of available channels in the available channel set.
iii) The primary radio activity i.e., channels are occupied by the PR nodes and are only available to CR nodes for transmission when they are idle. In fact, the spatiotemporal utilization of spectrum by PR nodes (i.e. primary radio nodes' activity) adds another challenge to data dissemination. As a consequence, the number of available channels to CR nodes changes with time and location and this leads to the variety in the number of available channel set. Because of PR's activity, the usability of the channels by CR nodes becomes uncertain.

Moreover, without any centralized entity, as in the case of multi-hop ad hoc cognitive radio network, data dissemination is even additional challenging because CR nodes have to rely on locally inferred information for their channel selection decision. If a channel selection is done in an intelligent way, higher data dissemination reachability can be achieved. Furthermore, the consideration of PR activity during channel selection can enhance the effectiveness of data dissemination reachability and can decrease the damaging interference to PR nodes by CR transmissions. Considering the previous described observations, hereafter we describe the key characteristics required by a channel selection strategy for improving data dissemination robustness in infrastructure less multi-hop cognitive radio ad-hoc networks:

i) CR neighbor reception: A good channel selection approach is the one that increases the probability of higher data delivery to the CR neighbors in multi-hop context.
ii) Primary radio constraints: The channel selection strategy should ensure that the transmission on the selected channel does not create damaging interference to primary radio nodes.
iii) Autonomous choice by CR nodes: In decentralized infrastructure less multi-hop cognitive radio networks, CR nodes are required to take autonomous decisions. It means that the channel selection strategy should work well without any centralized authority and channel selection decision should be based on locally inferred information.
iv) Transmission/Reception tuning: The channel selection strategy should guarantee that the CR transmitter and receiver select the same channel with high probability.

In the following section, we provide the classification of channel selection strategies in cognitive radio networks. The heading of the Acknowledgment section and the References section must not be numbered.

CHANNEL SELECTION STRATEGIES IN CRN

Recently, many channel selection strategies have been proposed for cognitive radio networks. These channel selection strategies are designed to achieve different performance goals, for instance, optimization of throughput, delay, etc. Besides achieving these goals, each channel selection strategy has a nature, according to its reaction with the appearance of PR nodes on the CR communicating channel. Therefore, channel selection strategies can be classified into three categories by nature:

i) proactive (predictive),
ii) hybrid, and
iii) Reactive.

From the communication perspective, channel selection strategies can be classified into centralized and distributed. The classification of channel selection strategies in cognitive radio networks is shown in Fig. 2.

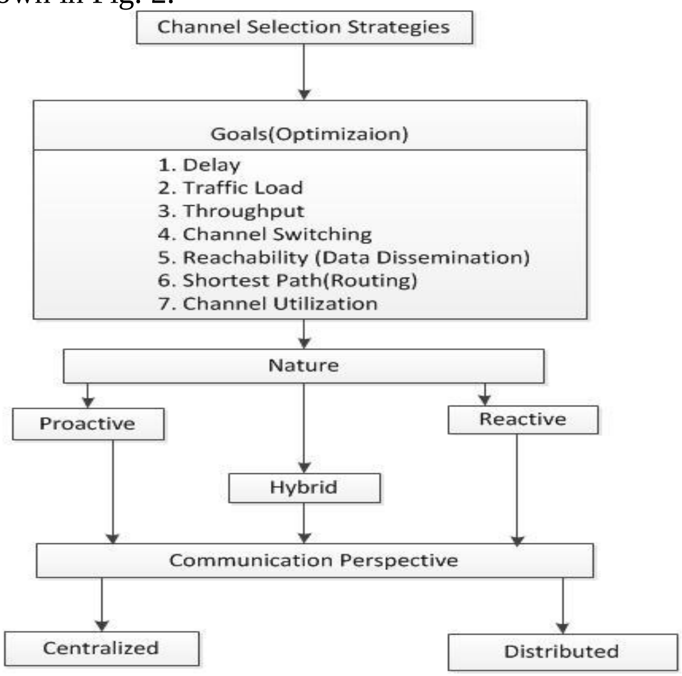

Fig.2. Channel Seelection Stratesgies

GOALS OF CHANNEL SELECTION STRATEGIES

Channel selection strategies have been used to realize different goals, e.g., load balancing, throughput maximization, channel switching delay minimization etc. A channel selection strategy to satisfy the traffic demands of access points. Throughput maximization is another goal and several channel selection strategies have proposed for throughput maximization. The transmission schedule of the CR nodes in order to improve the network throughput. A predictive channel selection scheme to maximize spectrum utilization and minimize disruptions to PR nodes. They considered a single-hop network in which CR nodes coordinates with the TV receiver to collect information regarding PR activity.

Two opportunistic channel selection schemes, CSS-MCRA and CSS-MHRA, are proposed in [14]. In CSS-MCRA, the goal was to maximize the throughput while minimize the collision rate. In CSS-MHRA, the goal was to maximize the throughput while minimize the handoff rate. CSS-MCRA and CSS-MHRA both considered single user and are predictive in nature. Load balancing is another important goal of channel selection strategies [15]. A channel and power allocation scheme for CR networks. The objective was to maximize the sum data rate of all CRs. They considered the availability of a centralized authority, which monitors the PR activity and assign channels to CR nodes. Sensing-based and probability-based spectrum decision schemes are proposed in [16] to distribute the load of CR nodes to multiple channels. The optimal number of candidate channels for sensing-based scheme and the optimal channel selection probability for probability-based spectrum decision scheme. The objective of both schemes was to minimize the overall system time of the CR users. A projecting channel selection scheme to minimize the channel switching delay of a single CR node. Other channel selection strategies focus on optimizing the expected waiting time residual idle time, reducing system overhead and improving CR QoS [17]. A predictive channel selection strategy, Voluntary Spectrum Handoff (VSH) [18] is reducing the communication disruption duration due to handoffs and to select the channel that has maximum remaining idle time. However, VSH requires the presence of Spectrum Server (SS), a centralized entity, to monitor the activities of PR and CR nodes. Channel selection strategies can also be used in conjunction with routing protocols for reliable path selection and good route selection for delay sensitive applications [19].

NATURE OF CHANNEL SELECTION STRATEGIES

According to the response with the appearance of PR nodes on the CR communicating channel, every channel selection strategy has some properties. Therefore, by properties, channel selection strategies in cognitive radio networks can be classified into proactive (predictive), hybrid, and reactive.

i) Proactive Channel Selection Strategies: In proactive channel selection strategies the activity of PR nodes is predicted and the CR nodes move to the channel according to the prediction. A predictive channel selection strategy to reduce delay and channel switching, while maximizing the throughput. These predictions were then used in the predictive channel selection scheme to find the channels with the longest idle times for CR use. T.C. Clancy et al. explored two approaches of predictive dynamic spectrum access (PDSA). The first approach uses cyclostationary detection on the primary users' channel access pattern to determine expected channel idle times. The second approach briefly examines the use of Hidden Markov Models (HMMs) for use in PDSA. Their basic goal was to predict when the channels will be idle, based on observations of the primary radio nodes channel usage. They determined the expected channel idle times for CR usage. Two proactive channel selection strategies, PRO-I and PRO-II are proposed in [20]. The goals of these schemes were to reduce disruptions to PRs and throughput maximization of CR nodes. J. Vartiainen et al. use a single pair of CR nodes and they ignored the impact of other CR nodes contending for the channel. Through their scheme, tried to optimizes the delay in finding the channels using the history. Their scheme is based on two steps: the database step and the signal detection step. In the database step, the database collects information about the channels. The CR node, when required a channel for transmission, sends a query to the database. The database then provides the most probable unoccupied channels, which are the best candidates for searching the channels. These channels are then submitted to the CR node. CR node then selects the channels according to the priority which is based on the signal detection history.

ii) Hybrid Channel Selection Strategies: Threshold based schemes are those channel selection schemes in which the PR nodes active all the time i.e., occupy the channel 100% and no idle channel is available to CR nodes. In these schemes, CR nodes are allowed to share the channel as long as the interference caused by the CR nodes to the PR nodes is below a certain threshold. Threshold-based schemes are also known as schemes that uses grey spaces. For instance, [21] is a threshold based channel selection scheme, in which the authors determined the transmission schedule for the CR nodes to maximize their throughput.

iii) Reactive Channel Selection Strategies: In reactive channel selection strategies, channel switching occurs after the PR node appears. In fact, in reactive channel selection schemes, CR nodes monitor local spectrum through individual or collaborative sensing. A lot of work has been done on individual or collaborative sensing. After detecting a change in the spectrum, e.g., channel is occupied by PR node, CR node stop the transmission, return back the channel to the PR node and search for other channel to resume the transmission. A reactive multi-channel mac protocol, RMC-MAC, for opportunistic spectrum access is proposed in [22]. Their objective was to increase the bandwidth utilization and to reduce the forced termination probability. However, they considered a single-hop CR network. Dynamic frequency hopping communities (DFHC) [23] is also a reactive approach, which is designed for IEEE 802.22 networks and requires the presence of base station. G. Salami et al. compared two types of spectrum handoff schemes: proactive and reactive spectrum handoff schemes. In reactive-sensing handoff scheme, the target channel is selected after the spectrum handoff request is made. While in proactive spectrum handoff scheme, the target channel is predetermined. The authors mentioned that the advantage of reactive spectrum handoff scheme resides in the accuracy of the selected target channel, but incurs the cost of sensing time. On the contrary, the proactive spectrum handoff scheme avoids the sensing time, but the pre-determined channel may not be available.

CHANNEL SELECTION STRATEGIES FROM THE COMMUNICATION PERSPECTIVE

From the communication point of view, channel selection strategies can be classified into centralized and distributed.

i) Centralized Channel Selection Strategies: In centralized channel selection strategies, a centralized entity is present, which helps CR nodes in their channel selection decision, e.g. Different steps for the development of centralized algorithms for different radio networks are investigated in [24]. They discussed the current interests of regulators, technical requirements, and the possible schemes for dynamic spectrum allocation. An efficient spectrum allocation architecture that adapts to dynamic traffic demands but they considered a single-hop scenario of Access Points (APs) in Wi-Fi networks is proposed [25]. An approach that use non-continuous unoccupied band to create a high throughput link. A threshold-based channel sharing scheme between CR nodes is proposed in [26]. Their algorithm is designed for source-destination pairs and is specially designed for single-hop communication. Here assumed that all the PRs are active all the time and no idle channel is available to CR nodes for their communication. A centralized channel allocation scheme for IEEE 802.22 standard is proposed in [27]. The proposed channel allocation scheme allocates the channel based upon three rules:

a) maximum throughput rule,
b) utility fairness rule, and
c) time fairness rule.

An opportunistic channel selection scheme for IEEE 802.11-based wireless mesh networks is proposed in [28]. In this channel selection scheme, an Access Point (AP) is required to connect the nodes to the Internet via mesh router.

ii) Distributed Channel Selection Strategies: In distributed channel selection strategies, there is no centralized entity that helps CR nodes in their channel selection decision. CR nodes need to take channel selection decision on their locally available information. Very few works has been done on distributed channel selection strategies in the context of cognitive radio networks. A dynamic resource management scheme for multi-hop cognitive radio networks, in which routes are maintained for delay sensitive applications, such a multimedia streaming. Based on the available information exchange, a multi agent learning approach which allows the various nodes to optimize their transmission strategies autonomously, in a distributed manner, in multi-hop cognitive radio networks. In addition, the channel selection scheme proposed in [19] is designed to work with routing protocols, and thus cannot be used for broadcasting. Selective broadcasting (SB) is a distributed channel selection strategy. In SB, each cognitive node selects a minimum set of channels (ECS) covering all of its geographic neighbours to disseminate messages in multi-hop cognitive radio networks. There are however, several challenges in the practicality of SB. Indeed, from the communication perspective, simultaneous transmission over a ECS requires more than one transceiver, which means having bigger and more complex devices, as it is done for military applications. On the contrary, using a single transceiver to transmit over minimum set of channels requires determining the correct channel to overhearing a transmission, increases delay, and brings frequent channel switching. Secondly, from the perspective of overhearing, either neighbour nodes need to simultaneously overhear over multiple channels or synchronization is required among neighbours, which incurs scheduling overhead.

CONCLUSION

Routing has been extensively studied in several wireless networks including wireless sensor networks, vehicular ad-hoc networks, and mobile ad-hoc networks. In this paper, we try to give a prologue on data routing in these types of networks. We then discussed the related works and the challenges associated with routing in cognitive radio networks. Additionally, we highlighted that channel selection plays a vital role in efficient and robust data dissemination. We provided an in-depth study of channel selection strategies in cognitive radio networks. Furthermore, classification of channel selection strategies according to their goals, nature, and communication perspective were provided.

REFERENCE

[1] S. Majid and K. Ahmed, "Post-disaster communications: A cognitive agent approach," in *Seventh International Conference on Networking*, 2008.

[2] P. Phunchongharn, E. Hosssain, D. Niyato, and S. Camorlinga, "A cognitive radio system for e-health appli- cations in a hospital environment," *IEEE Wireless Communications Magazine*, pp. 20–28, Feburary 2010.

[3] M. Buddhikot, P. Kolodzy, S. Miller, K. Ryan, and J. Evans, "Dimsumnet: New directions in wireless net- working using coordinated dynamic spectrum access," in *Sixth IEEE International Symposium on World of Wireless Mobile and Multimedia Network (WoWMoM)*, 2005, pp. 78 – 85.

[4] I. F. Akyildiz, W.-Y. Lee, M. C. Vuran, and S. Mohanty, "Next generation/dynamic spectrum access/cognitive radio wireless networks: a survey," *Computer Networks: The International Journal of Computer and Telecom- munications Networking*, vol. 50 , Issue 13, pp. 2127 – 2159, 2006.

[5] H. Khalife, S. Ahuja, N. Malouch, and M. Krunz, "Probabilistic path selection in opportunistic cognitive radio networks," in *proceedings of the IEEE globecom conference*, 30 Nov - 4 Dec 2008, pp. 1–5.

[5] M. V. D. Schaar and F. Fu, "Spectrum access games and strategic learning in cognitive radio networks for delay-critical applications," *Proceedings of the IEEE*, vol. 97, No. 4, pp. 720–740, 2009.

[7] S.-Y. Ni, Y.-C. Tseng, Y.-S. Chen, and J.-P. Sheu, "The broadcast storm problem in a mobile ad hoc network," in *Proceedings of the 5th Annual ACM/IEEE International Conference on Mobile Computing and Networking(MOBICOM '99)*, 1999.

[8] K. Rostamzadeh and S. Gopalakrishnan, "Analysis of emergency message dissemination in vehicular networks," in *IEEE Wireless Communications and Networking Conference (WCNC)*, march 2011, pp. 575 –580.

[9] R. Simon, L. Huang, E. Farrugia, and S. Setia, "Using multiple communication channels for efficient data dissemination in wireless sensor networks," in *IEEE International Conference on Mobile Adhoc and Sensor Systems Conference.*, nov. 2005, pp. 10 pp. –439.

[10] D. Starobinski and W. Xiao, "Asymptotically optimal data dissemination in multichannel wireless sensor networks: Single radios suffice," *Networking, IEEE/ACM Transactions on*, vol. 18, no. 3, pp. 695 –707, june 2010.

[11] A. Asterjadhi, R. Kumar, T. La Porta, and M. Zorzi, "Broadcasting in multi channel wireless networks in the presence of adversaries," in *8th Annual IEEE Communications Society Conference on Sensor, Mesh and Ad Hoc Communications and Networks (SECON)*, june 2011, pp. 377 –385.

[12] A. Al-Mogren, "Energy adaptive approach in a multi-channel dissemination-based network," in *New Technolo- gies, Mobility and Security, NTMS '08.*, nov. 2008, pp.

[13] W. feng Lv, F. liang Wang, and T. yu Zhu, "A greedy strategy of data dissemination over multi-channel in mobile computing environments," in *3rd International Conference on Advanced Computer Theory and Engineering (ICACTE)*, vol. 5, aug. 2010, pp. V5–322 –V5–326.

[14] Q. Xiao, Y. Li, M. Zhao, S. Zhou, and J. Wang, "Opportunistic channel selection approach under collision probability constraint in cognitive radio systems," *Computer Communications*, vol. 32 (18), pp. 1914–1922, 2009.

[15] H. Wang, J. Ren, and T. Li, "Resource allocation with load balancing for cogntive radio networks," in *IEEE GlobeCom*, 2010.

[16] L.-C. Wang, C.-W. Wang, and F. Adachi, "Load-balancing spectrum decision for cognitive radio networks *IEEE Journal on Selected Areas I Communications*, vol. 29 (4), pp. 757–769, April 2011.

[17] P. Zhu, J. Li, and X. Wang, "A new channel parameter for cognitive radio," in *CrownCom*, 2007.

[18] S.-U. Yoon and E. Ekici, "Voluntary spectrum handoff: A novel approach to spectrum management in crns, in *ICC*, 2010.

[19] H. P. Shiang and M. V. D. Schaar, "Delay-sensitive resource management in multi-hop cognitive radio net- works," in *IEEE DySpan*, 2008.

[20] L. Yang, L. Cao, and H. Zheng, "Proactive channel access in dynamic spectrum networks," *Elsevier Physical Communications Journal*, vol. vol (1), pp. 103–111, 2008.

[21] G. D. Nguyen and S. Kompella, "Channel sharing in cognitive radio networks," in *MILCOM*, 2010.

[22] S. Fourati, S. Hamouda, and S. Tabbane, "Rmc-mac: A reactive multi-channel mac protocol for opportunistic spectrum access," in *4th IFIP International Conference on New Technologies, Mobility and Security (NTMS)*, feb. 2011, pp. 1 –5.

[23] W. Hu, D. Willkomm, M. Abusubaih, J. Gross, G. Vlantis, M. Gerla, and A. Wolisz, "Cognitive radios for dynamic spectrum access - dynamic frequency hopping communities for efficient ieee 802.22 operation," *IEEE Communications Magazine*, vol. 45, no. 5, pp. 80 –87, may 2007.

[24] L.-C. Wang and C.-W. Wang, "Spectrum handoff for cognitive radio networks: Reactive-sensing or proactive- sensins?" in *IEEE International Performance, Computing and Communications Conference (IPCCC 2008)*, 2008.

[25] L. Yang, L. Cao, H. Zheng, and E. Belding, "Traffic-aware dynamic spectrum access," in *Proceedings of The Fourth International Wireless Internet Conference (WICON 2008)*, Hawaii, USA, 17-19, November 2008.

[26] G. D. Nguyen and S. Kompella, "Channel sharing in cognitive radio networks," in *MILCOM*, 2010.

[27] J. Zhu and S. Li, "Channel allocation mechanisms for cognitive radio networks via repeated multi-bid auction," in *ICWMMN 2006*, 2006.

[28] D. Niyato and E. Hossain, "Cognitive radio for next-generation wireless networks: an approach to opportunistic channel selection in ieee 802.11-based wireless mesh," *IEEE Wireless Communications*, vol. 16, no. 1, pp. 46 –54, february 2009.