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Link Capacity Based Channel Assignment (LCCA) for Cognitive Radio Wireless Mesh Networks

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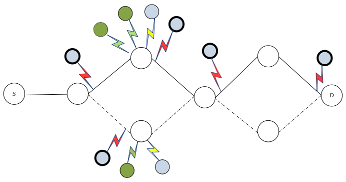
Graphical abstract



Abstract

Cognitive radio wireless mesh network (CRWMN) is expected as an upcoming technology with the potential advantages of both cognitive radio (CR) and the wireless mesh networks (WMN). In CRWMN, co-channel interference is one of the key limiting factors that affect the reception capabilities of the client and reduce the achievable transmission rate. Furthermore, it increases the frame loss rate and results in underutilization of resources. To maximize the performance of such networks, interference related issues need to be considered. Channel assignment (CA) is one of the key techniques to overcome the performance degradation of a network caused by the interferences. To counter the interference issues, we propose a novel CA technique which is based on link capacity, primary user activity and secondary user activity. These three parameters are fed to the proposed weightage decision engine to get the weight for each of the stated parameters. Thus, the link capacity based channel assignment (LCCA) algorithm is based on the weightage decision engine. The end-to-end delay, packet delivery ratio and the throughput is used to estimate the performance of the proposed algorithm. The numerical results demonstrate that the proposed algorithm is closer to the optimum resource utilization.

Keywords: Cognitive radio (CR); interference; channel assignment (CA); wireless mesh networks; primary user (PUs); secondary users (SUs)

Abstrak

Rangkaian jaringan tanpa wayar radio kognitif (CRWMN) adalah satu paradigma baru komunikasi tanpa wayar dengan Kedua-dua potensi kelebihan iaitu radio kognitif (CR) dan rangkaian jaringan tanpa wayar (WMN). Untuk mendapatkan prestasi maksimum dalam rangkaian ini, isu-isu yang berkaitan dengan gangguan perlu ditangani dengan cekap, kerana ia memberi kesan kepada keupayaan penerimaan pelanggan, mengurangkan kadar penghantaran per masa yang dicapai, meningkatkan kadar kehilangan rangka data dan mengurangkan penggunaan sumber. Peruntukan saluran adalah salah satu teknik utama untuk menangani kemerosotan prestasi rangkaian yang disebabkan oleh gangguan. Jurnal ini membentangkan teknik peruntukan saluran yang baru berdasarkan kapasiti pautan, aktiviti pengguna utama dan aktiviti pengguna sekunder bagi menangani isu-isu gangguan dan untuk mencapai kapasiti maksimum sumber. Ketiga-tiga parameter dimaklumbalas kepada mekanisma keputusan berpemberat yang dicadangkan untuk mendapatkan berat bagi setiap parameter yang dinyatakan. Oleh itu, pemilihan saluran adalah berdasarkan pemberat ini. Kelewatan akhir-ke-akhir, kadar penghantaran paket dan pemprosesan per masa digunakan untuk menilai prestasi algoritma yang dicadangkan. Keputusan berangka menunjukkan bahawa algoritma yang dicadangkan itu adalah hampir kepada penggunaan sumber yang optimum.

Kata kunci: Radio kognitif (CR); gangguan, peruntukan saluran (CA); rangkaian jaringan tanpa wayar; pengguna utama (PUs); pengguna sekunder (SUs)

■1.0 INTRODUCTION

In Cognitive Radio Wireless Mesh Networks (CRWMNs) the WMN mesh client (MC) and mesh router (MR) device are equipped with CR features [1-7]. In traditional wireless mesh networks the same set of channels are available to all nodes in the network, which is not the case in CRWMNs. CR users have the ability to access unused portion of the spectrum. The major interference can be caused to CR as well as licensed user. CR enables mesh nodes to sense unused spectrum of PU and use that unused spectrum dynamically. However, in the time-varying radio frequency environment, dynamic spectrum allocation of license spectrum bands is applied opportunistically. So, the system efficiency depends on the overall fairness and complexity. Current research on CRWMNs demonstrates interference controlling is essential to obtain high profile performance in wireless networks as the receiving capabilities of client are directly affected [8, 9]. The interference is the major impeding factor for spectrum reuse caused by the noise generated from the environment or other radio transmitted signal. However, creating a wireless link and the network topology with minimum interference can be achieved by CA scheme of communicating node in the network. Performance degradation due to interference is avoided by CA. Resource utilization and performance can be improved by interference avoidance to maximize the achievable transmission rate and decreases frame loss. Moreover, interference may be in the same network link or may generate from external sources. In wireless networks, interference can be controlled using the basic mechanisms called CA. CA can assign the channels to radio interface of wireless enabled devices in order to obtain proficient frequency utilization and reduce the interference [5]. CRWMNs have the constraints that secondary user must generate no interference or limited interference to the primary/licensed user. Furthermore, to enhance the efficiency, interference with SU must be kept at its minimum value. Thus, for generating proficient cognitive algorithm, interference is one of the most used criteria [5, 9-12].

1.1 Related Work

Many CRWMN CA approaches are depending on the interference temperature limit (ITL) at primary user and allocate channels to Secondary users to keep ITL under a specified limit [12-21]. As suggested by Federal Communications Commission [22], the ITL is the amount of interference sensed by the receiving client. It is calculated as the power obtained by antenna for associated RF bandwidth with Boltzmann's constant. Restricting the interference temperature below the certain level is generally attained through transmission power varying parameter of SU, to have low interference at primary users. Reducing the transmission power of SUs at PUs for minimum interference is availed by reduction in SINR of receiving secondary users. SINR of communicating node must be more than certain threshold for successful reception. Thus, the transmission power of SUs may not be ignored and must maintain under some criteria. For confining the interference with a transmission pair, authors [23, 24] proposed a Dynamic Interference Graph model. In [25] a technique to calculate the interference which depends on the path loss model is used. Many approaches [11, 26, 27] consider the SINR based interference model at every node to carry out an efficient CA. In [28] authors presented an optimization framework that increases the throughput by considering protocol model for interference. However, PU activity on channels is restricted to one channel which limits the CA scalability. A binary interference model based on the protocol model is applied in [29]. Few studies evaluated [5, 30] hierarchy interference model. Generally, interference generated by secondary user to primary user is taken as reference in previous literature. However, the majority of past work only consider SU activity as the only parameter which causes interference in SU network. Therefore, an end-to-end interference model is required to combine all interference issues. In CRWMN is equipped with multi-hoping for fixed nodes and between their link interfaces in which the interference causes severe performance degradation. Hence an effective CA under the new interference model should be deployed. To the best of our knowledge, the end-to-end interference management for CA in CRWMNs has not been fully resolved. Most of the existing CA algorithms based on SINR, interference model and fixed receiver approach [20, 21, 30, 31] partially solve the problem of the overall issue, but raise other problems. These problems include increasing of packet loss ratio, limiting the degree of connectivity, increasing of interference in the system and minimizing the system optimization in CRWMN. Therefore, in this work, we are involving PU activity and neighboring SUs activity on channels and channels' SINR for each link to avoid problem explained above. In the next section, the description of our work is explained.

This paper is organized as follows: We present the network model and layout the assumptions in Section 2.0. The end-to-end interference model is presented in Section 3.0. In Section 4.0, we propose a link capacity based channel assignment (LCCA) algorithm for the resource optimization problem in CRWMNs. The performance of the LCCA algorithm is assessed in Section 5.0 and Conclusion is addressed in Section 6.0.

■2.0 SYSTEM DESCRIPTION

In this work, we show that the end-to-end interference model delivers the ability to achieve the goal of resource optimization in CRWMN. We assume the following scenario: a CRWMN is composed of Mesh Router (MR), Mesh Gateway (MG), Mesh Clint (MC) /Secondary User (SU) and Primary User (PU).

2.1 Mesh Network Model

The Figure 2.1 depicts the network model. Some notations and terminology are defined as follows:

- MCs MRs are CR enable features, and use common control channel (unused licensed) to communicate with each other.
- Here in the abbreviation MR refers to a mesh router regardless of whether it is a gateway or not, and the word node is referring to an SU (MR/MC).
- Source node denoted as S, destination node as D.
- Both S, $D \in A$, A is the set of nodes in the system.
- $Link_{ij} = (i, j)$ exists as link for any pair of nodes $i, j \in A$.
- Set of available channels in system are denoted as L.
- L_i is the set of available channel at node i.
- Moreover, $L_i \subseteq L_j$ because j cannot use a channel that is not available to i node.
- K is set of common channels of nodes. Let $k \in K \in L_i \in L_j$
- M is the set of neighboring SUs from which channel is shared. $M \in A$, and $m_j \in M$.
- Q is the set of neighboring SUs from which node j can hear (or sense) a packet but not sharing channel, $Q \in A, q_j \in Q$
- Transmission distance is R_T and interference range is $R_{i,}$ we assume $R_i = 2R_T$

- PU is randomly active at the location of all nodes in different time slots.
- Each node in this system has more than one neighboring node and they are randomly active in using the same channel.

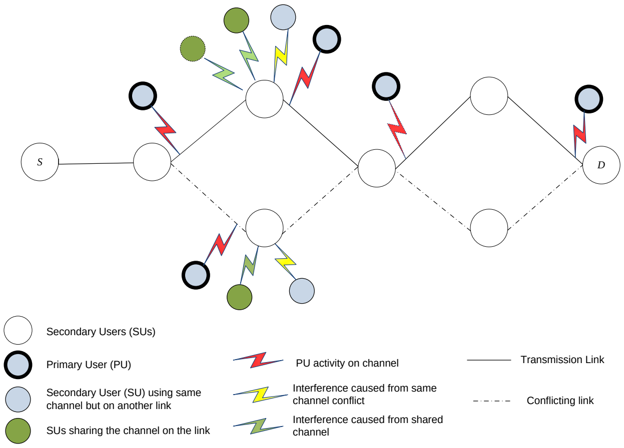


Figure 2.1 Proposed network model

In order to take into account the interference in the proposed end to end model, CRWMN is modeled as a bidirectional graph using graph theory. G = (V, E) where V is the vertices representing a set of nodes and E is edges and represents a set of wireless links. To develop end to end interference model in a system, V_c is the set of the corresponding node in the network.

$$V_c = \{Link_{ij}(i, j) \text{ in a communication link}\} \tag{1}$$

where $Link_{ij}$ is developed if node *i* and node *j* have the one same channel in their channel list.

The connectivity graph shows conflict in which one vertex is linked to the other vertices having same channel availability, where these two vertices are linked to one vertex. In this scenario the corresponding links are interfaced to each other and present the conflict graph to produce interference in wireless links. If the neighboring node is active at that time slot and starts sharing the same channel, then it will create co-channel interference at particular link.

■3.0 END-TO-END INTERFERENCE MODEL

In this section, we start from a physical interference model and then extended it by adding PU activity and SU activity as additional features. As shown, when the interference on the link is minimized then the capacity of the link is maximized. To account this, we are considering three key parameters of CRWMN; Link interference ratio, PU activity and SU activity. Link between node *i* and node *j* is established if the SINR at the receiver node is above the threshold limit. This communication transmission depends on the required communication parameters, which are channel, data rate etc. Furthermore, indicating the transmission strength of a packet from node *j* at node *i* referred as $P_i(j)$ packet on the link. This link is referred as $Link_{ij}$.

The packet from node *j* to node *i* is delivered if

$$\frac{P_i(j)}{N + \sum_{m_j \in M} \tau(m) P_i(m) + \sum_{q_j \in Q} P_j(s)} \geq SINR_T \tag{2}$$

Where *N* represents the background noise, *M* is the set of neighboring SUs $M \notin A$, and $m \in M$. m_j denotes the set of nodes from which node *j* can hear (or sense) a packet. $\tau(m)$ gives the fraction of time node *m* occupies the channel, $P_i(m)$ is used to weight the signal strength of interfering node *m*, *S* is the set neighboring SUs on same channel but not share the channel, s_j is referred as node which is interference range of node *j*. The data rate, channel characteristics and modulation scheme are the main parameters for calculating *SINR*. By using SNR and SINR the Interference ratio (*IR)* is defined in [32]. Link from node *i* to node *j* is denoted. IR_{ij} (*j*) for a node *j* in a $Link_{ij}$ = (*j*, *i*) where $(0 < IR_{ij}(j) \leq 1)$ as follows:

$$IR_{ij}(j) = \frac{SINR_{ij}(j)}{SNR_{ij}(j)} \tag{3}$$

where

$$SNR_{ij}(j) = \frac{P_j(i)}{Noise} \tag{4}$$

$Link_{il}$ = (*i*, *l*) exists as conflict link availability in communicating nodes, where $i, j, l \in A$. In the next section we explain the steps to avoid the conflict in start of initial communication process.

3.1 PUs activity on the $Link_{ij}$

The Bernoulli random variable with binomial distribution is used for each available channel to obtain the preferred channel where PU activity is least.

- Let's assume that attempts of PU are a Bernoulli random variable with **"***e***"** defined as an event when PU is active.
- Let's take assumption that the p_{PU} (probability of active PU) is denoted by *p*.

Total number of attempts is *n*.

$$p_i(e) = \binom{n}{e} p^e (1-p)^{n-e} \tag{5}$$

The event that a PU attempts at a particular node is modeled as a Bernoulli random variable, in which an active PU is defined as a 1, with probability ‘ *p* ’ , and a non-active PU is defined as a ‘ 0 ’, with probability ‘ 1-*p* ’

■4.0 LINK CAPACITY BASED CHANNEL ASSIGNMENT (LCCA) ALGORITHM

The proposed LCCA algorithm consists of three steps. In step one three parameters are obtained from equations 3 and 5. In step two least occupied channels by PUs and SUs and $Link_{ij}$ are compared for each channel, these three parameters are fed into the weightage mechanism, which assigns different weights to each of the parameters. Based on this weightage the channel is selected in the third step. Channel assignment design process is presented in Figure 4.1. We define indicator function *E, F* to define weightage of PU and SU respectively in the channel assignment process.

$$E = \begin{cases} 1 & if \quad p(PU)min \\ 0 & otherwise \end{cases}$$

$$F = \begin{cases} 1 & if \quad p(SU)min \\ 0 & otherwise \end{cases}$$

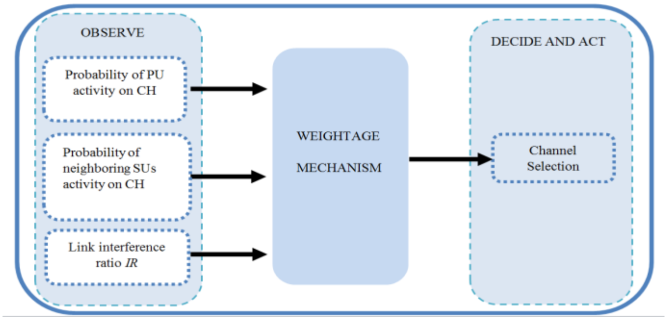


Figure 4.1 Channel assignment decision process

We define $W_{ij}(k)$ as weightage for all available channels at initiating node.

$$W_{ij}(k) = p_{PU}\; i,j(k) + p_{SU}\; i,j(k) + IR_{ij}(k)\,,\ \forall i,j \in A \qquad (6)$$

L_j presents the channels list of node j and each end-to-end path has a corresponding available channel list, denoted as L_1, L_2,….,L_A. Number of nodes in path represented as A. In order for the path to be considered, the minimum one channel has to available at a pair of neighboring nodes on the path. Channel k is selected by node i on the basis of smallest weightage level value form set L, that is,

$$k_1 = argmin\; W_{ij}(k) \qquad (7)$$

4.1 Implementation: Link Capacity Based Channel Assignment (LCCA)

Input: S : source node, D : destination node, L_i : set of available node i, IR_{ij} : interference ratio of $Link_{ij}$, $p(PU)$: activity of PU on channels.

```
1 begin
2 Route Table = Search_Route Table (RREQ)
3 create available channel connectivity graph
4 create a conflict graph
5 make the channel queue list according to $IR_{ij}$
6 If queue is empty then go to 3
    else extract one channel from the head of queue
7 If the channel has the least activity of PU and SU according to Eq.7
    Then compute channel for $Link_{ij}$
    else go to 6
8 end
```

The route request propagation process uses the Route Request (RREQ) same as broadcast in AODV. Figure 4.2 explains the steps.

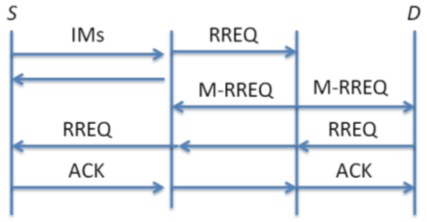


Figure 4.2 Discovery request message

Through all available channels the route discovery request (RREQ) is broadcasted by initiating source node S towards its neighboring nodes. In the initial handshake phase neighbors' operating channels are obtained. S Node receives the channel's parameters from the neighboring nodes that includes channels IR_{ij}, p_{PU} activity and p_{SU} activity. The minimum weighted channel is selected.

5.0 RESULTS AND DISCUSSION

In this section, we compare the performance of the LCCA algorithm to the optimal performance obtained using the formulation in Section 2.0. The probability of PU activities on channels are measured, 20 attempts by PU on different three available channels assessed. In figure 5.1 the channel having least p_{PU} can be identified from the available channel list. Figure 5.2 shows the available channels Interference ratio (IR_{ij}), the minimum IR_{ij} is obtained for LCCA. The performance of the LCCA algorithm leads towards the optimal solution. The simulation is run for three different channels to find the preferred channel where PU and SU activity is least.

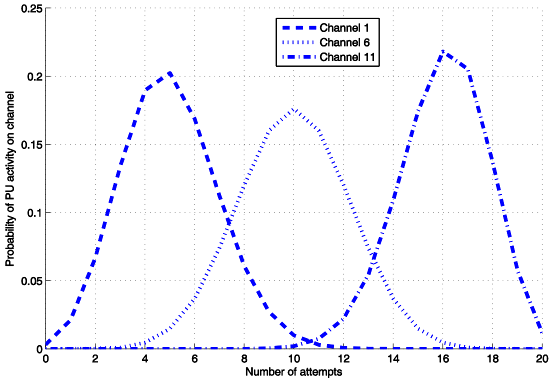


Figure 5.1 PU activity on different channels

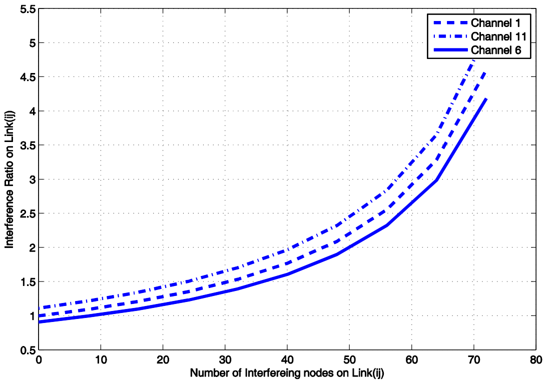


Figure 5.2 End to end Link interference ratio channels

6.0 CONCLUSION

In CR networks the major interference generated between CR users while getting access to unused spectrum of primary users. The PUs activity may cause packet loss ratio and delay ratio increased. Efficient channel assignment scheme for CRWMN has been a main focus of this research. This research probes the features of CR techniques over WMNs to minimize the above mentioned issue. We provide three main contributions in this research field. First, we formulate CRWMNs end-to-end interference issues which causes the reduction in wireless spectrum resources, throughput and maximize the frame loss ratio, and packet delay. Secondly, we propose an interference model by using a collective approach to improve the spectrum utilization. Thirdly, we intend to develop and evaluate LCCA algorithm for CRWMNs.

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References

[1] I. F. Akyildiz, W.-Y. Lee, M. C. Vuran, and S. Mohanty. 2006. Next Generation/Dynamic Spectrum Access/Cognitive Radio Wireless Networks: A Survey. Computer Networks. 50: 2127–2159.

[2] Z. Guoan, G. Jinyuan, and B. Zhihua. 2010. Distributed joint Routing and Channel Allocation Algorithm in Cognitive Wireless Mesh Networks. In Broadband Network and Multimedia Technology (IC-BNMT), 2010 3rd IEEE International Conference on. 432–437.

[3] N. Bouabdallah, B. Ishibashi, and R. Boutaba. 2011. Performance of Cognitive Radio-Based Wireless Mesh Networks. Mobile Computing, IEEE Transactions on. 10: 122–135.

[4] B. Ishibashi and R. Boutaba. 2009. The Symbiosis of Cognitive Radio and Wireless Mesh Networks. In Guide to Wireless Mesh Networks, S. Misra, S. Misra, and I. Woungang, Eds., ed: Springer London. 471–496.

[5] L. Dong Heon, J. Wha Sook, and J. Dong Geun. 2010. Joint Channel Assignment and Routing in Cognitive Radio-Based Wireless Mesh Networks. In Vehicular Technology Conference (VTC 2010-Spring), 2010 IEEE 71st. 1–5.

[6] R. C. Pereira, R. Demo Souza, and M. E. Pellenz. 2008. Using Cognitive Radio for Improving the Capacity of Wireless Mesh Networks," in Vehicular Technology Conference, VTC 2008-Fall. IEEE 68th, 2008. 1–5.

[7] R. Pereira, R. Souza, and M. Pellenz. 2010. Overlay Cognitive Radio in Wireless Mesh Networks," Wireless Personal Communications. 55: 237–251, 2010/10/01.

[8] L. Qiu, Y. Zhang, F. Wang, M. K. Han, and R. Mahajan. 2007. A general Model Of Wireless Interference. Presented at the Proceedings of the 13th Annual ACM international Conference on Mobile Computing and Networking, Montréal, Québec, Canada.

[9] L. Jeongkeun, L. Sung-Ju, K. Wonho, J. Daehyung, K. Taekyoung, and C. Yanghee. 2009. Understanding Interference and Carrier Sensing in Wireless Mesh Networks. *Communications Magazine, IEEE*. 47: 102–109.

[10] N. Nie, C. Comaniciu, and P. Agrawal. 2007. A Game Theoretic Approach to Interference Management in Cognitive Networks. In Wireless Communications. vol. 143, P. Agrawal, P. Fleming, L. Zhang, D. Andrews, and G. Yin, Eds., ed. Springer New York. 199–219.

[11] N. Nie and C. Comaniciu. 2006. Adaptive Channel Allocation Spectrum Etiquette for Cognitive Radio Networks. *Mob. Netw. Appl.* 11: 779–797.

[12] S. Haykin. 2005. Cognitive Radio: Brain-empowered Wireless Communications. Selected Areas in Communications. *IEEE Journal on*. 23: 201–220.

[13] G. Alnwaimi, K. Arshad, and K. Moessner. 2011. Dynamic Spectrum Allocation Algorithm with Interference Management in Co-Existing Networks. *Communications Letters, IEEE*. 15: 932–934.

[14] H. Skalli, S. Ghosh, S. K. Das, L. Lenzini, and M. Conti. 2007. Channel Assignment Strategies for Multiradio Wireless Mesh Networks: Issues and Solutions. *Communications Magazine, IEEE*. 45: 86–95.

[15] W. Huahui, R. Jian, and L. Tongtong. 2010. Resource Allocation with Load Balancing for Cognitive Radio Networks. In Global Telecommunications Conference (GLOBECOM 2010), 2010 IEEE. 1–5.

[16] W. Wei, K. G. Shin, and W. Wenbo. 2011. Joint Spectrum Allocation and Power Control for Multihop Cognitive Radio Networks. *Mobile Computing, IEEE Transactions on*. 10: 1042–1055.

[17] N. Duy Trong and T. Le-Ngoc. 2011. Distributed Resource Allocation for Cognitive Radio Networks With Spectrum-Sharing Constraints. *Vehicular Technology, IEEE Transactions on*. 60: 3436–3449.

[18] D. R. Joshi, D. C. Popescu, and O. A. Dobre. 2012. Joint Spectral Shaping and Power Control in Spectrum Overlay Cognitive Radio Systems. *Communications, IEEE Transactions on*. 60: 2396–2401.

[19] W. Weiwei, B. Kasiri, C. Jun, and A. S. Alfa. 2011. Channel Assignment of Cooperative Spectrum Sensing in Multi-Channel Cognitive Radio Networks. In Communications (ICC), 2011 IEEE International Conference on. 1–5.

[20] H. M. Almasaeid and A. E. Kamal. 2010. Receiver-Based Channel Allocation for Wireless Cognitive Radio Mesh Networks. In New Frontiers in Dynamic Spectrum, 2010 IEEE Symposium on. 1–10.

[21] H. Anh Tuan, L. Ying-Chang, and M. H. Islam, 2010. Power Control and Channel Allocation in Cognitive Radio Networks with Primary Users' Cooperation. *Mobile Computing, IEEE Transactions on*. 9: 348–360.

[22] F. C. C. S. P. T. Force. 2002. Report of the Interference Protection Working Group.

[23] H. Anh Tuan and L. Ying-Chang. 2008. Downlink Channel Assignment and Power Control for Cognitive Radio Networks. *Wireless Communications, IEEE Transactions on*. 7: 3106–3117.

[24] H. Anh Tuan and L. Ying-Chang. 2006. Maximizing Spectrum Utilization of Cognitive Radio Networks Using Channel Allocation and Power Control. In Vehicular Technology Conference, 2006. VTC-2006 Fall. 2006 IEEE 64th. 1–5.

[25] W. Jiao and H. Yuqing. 2010. A Cross-layer Design of Channel Assignment and Routing in Cognitive Radio Networks. In Computer Science and Information Technology (ICCSIT), 2010 3rd IEEE International Conference on. 542–547.

[26] D. C. Popescu, D. R. Joshi, and O. A. Dobre. 2010. Spectrum Allocation and Power Control in OFDM-Based Cognitive Radios with Target SINR Constraints. In Signals, Systems and Computers (ASILOMAR), 2010 Conference Record of the Forty Fourth Asilomar Conference on. 1891–1895.

[27] H. Anh Tuan, L. Ying-Chang, and M. H. Islam. 2007. Maximizing Throughput of Cognitive Radio Networks with Limited Primary Users' Cooperation. In Communications, 2007. ICC '07. IEEE International Conference on. 5177–5182.

[28] Masrub, A.; Al-Raweshidy, H. S. 2012. Priority-based Cooperative Access for Cognitive Wireless Mesh Networks, Future Generation Communication Technology (FGCT), 2012 International Conference, 12-14 Dec.

[29] M. Ahmadi and P. Jianping. 2011. Cognitive Wireless Mesh Networks: A Connectivity Preserving and Interference Minimizing Channel Assignment Scheme. In Communications, Computers and Signal Processing (PacRim), 2011 IEEE Pacific Rim Conference on. 458–463.

[30] G.-a. Zhang, J.-y. Gu, Z.-h. Bao, C. Xu, and S.-b. Zhang. 2012. Joint Routing and Channel Assignment Algorithms in Cognitive Wireless Mesh Networks. *Transactions on Emerging Telecommunications Technologies*.

[31] H. A. Bany Salameh. 2011. Throughput-oriented Channel Assignment for Opportunistic Spectrum Access Networks. *Mathematical and Computer Modelling*. 53: 2108–2118.

[32] A. P. Subramanian, M. M. Buddhikot, and S. Miller. 2006. Interference Aware Routing In Multi-Radio Wireless Mesh Networks. In Wireless Mesh Networks, 2006. WiMesh 2006. 2nd IEEE Workshop. 55–63.