Improve Dynamic Spectrum Allocation Scheme in Cognitive Radio Wireless Mesh Network Using Mixed Integer Non Linear Programming

Amaechi Chineke, Aguodo Patrick
Computer Engineering Department Michael Okpara University of Agriculture, Umudike, Abia State, Nigeria

Abstract-- Cognitive radio is a promising technique to increase the efficient utilization of the existing radio spectrum. However one of the key challenges that have to be overcome for optimally harness in power of cognitive radio is dynamic spectrum allocation. This paper tackled the problem using mixed integer nonlinear programming (MINLP). In this paper the MNLP formulation of the spectrum allocation problem is solved using neural network. Results from simulations carried out showed that the proposed solution outperformed the receiver-based channel allocation method in terms of average throughput, average delay of total system utility.

Keywords-- Dynamic Spectrum, Neural Network, Cognitive Radio, Spectrum Mobility, Spectrum Hole, Spectrum Algorithm, Cluster Head

I. INTRODUCTION

The available electromagnetic radio spectrum is a limited natural resource and getting crowded day by day due to increase in wireless devices and applications. It has been also found that the allocated spectrum is underutilized because of the static allocation of the spectrum [1]. Cognitive radio [2] [3] [4] is a promising technology to increase the utilization efficiency of the existing radio spectrum. In a cognitive radio network, users access the existing wireless spectrum opportunistically, without interfering with existing users.

A cognitive radio is a software defined radio that is able to identify idle frequency channel, or so called spectrum holes, through spectrum sensing. Furthermore, a cognitive radio is able to identify the best available spectrum to meet certain quality-of-service requirements through spectrum analysis. Spectrum mobility is another functionality of a cognitive radio which enables it to change its frequency of operation, and therefore enables dynamic spectrum access. In general terms, a cognitive radio is defined as a radio that can change its transceiver parameters based on interaction with the surrounding environment [5]. In this paradigm, wireless users are classified into two categories based on whether they are licensed to use a particular spectrum band or not, and those are primary, i.e, licensed users (PUs) and secondary, i.e unlicensed users (SUs). SUs are allowed to opportunistically use the spectrum as long as they do not cause harmful interference to active PUs. Therefore, for an SU, the term “available (or idle) channel” is used to refer to a frequency channel that can be used by an SU; Such that no harmful interference will affect any nearby PU receiver.

Although the potential of cognitive radio networking appears promising, it entails several challenges that are not present in traditional wireless networks. The key challenges in cognitive radio networks is the design of efficient spectrum algorithm which enable wireless device to opportunistically access portions of the spectrum as they become available [4].

In this paper the cognitive radio spectrum allocation problem is formulated as a mixed integer nonlinear programming problem solved using neural network.

II. COGNITIVE RADIO WIRELESS MESH NETWORK (CR-WMN’S)

A wireless mesh network is a communication network that consists of a number of wireless nodes organized in a mesh topology. These wireless nodes are usually classified into three major categories based on their roles in the network: mesh routers (MRs), mesh clients (MCs), and gateway routers [5]. Gateway routers connect the wireless mesh networks to a backbone network, or the internet. Each mesh router, on the other hand, manages a number of mesh clients in its cell and connects them with the backbone network over multiple hops of mesh routes, and eventually through gateway routers. Lastly, mesh clients are end-user’s equipment, like desktop computers, laptops, cell-phones etc; used to connect the user to the mesh network. Three networks architectures are known for wireless mesh networks (WMNs) [5] [6]. The first one is called infrastructure WMN in which mesh routers form an infrastructure for mesh clients. The second architecture is referred to as clients WMN in which no mesh routers are needed. In this architecture, mesh clients form the actual networks to perform routing and network reconfiguration. Having the two previous architecture combined in the same network forms the third architecture, which is referred to hybrid WMN.

A cognitive radio mesh network is a WMN that deploys cognitive radios (for both routers and clients) and relies on opportunistic and dynamic spectrum access for its operation [5] [7] [8] [9]. In addition to the fundamental motivations of increasing spectrum utilization and overcoming spectrum scarcity, cognitive radio mesh networks were motivated by a number of potential applications, like:

1. All evicting congestion in traditional WMNs: exploiting cognitive radios allows mesh routers to search for available channels in the primary band (i.e; the licensed band) so they can reduce the congestion on the operational band of the WMN (usually a sub-band of the 2.4 GHz ISM band) by shifting the mesh clients they serve to those available channels. [8] [10].
2. Increasing network: In some situations, mesh clients may demand some QoS guarantees regarding SINR (signal to interference and noise ratio) and BER (Bit-Error Rate). To achieve such guarantee, mesh routers and clients need to restrict their transmission power levels so that the interference they cause at the location of other mesh clients in neighboring cells stays within a pre-calculated threshold that insures the required SINR.
3. Integration of heterogeneous wireless access networks: Different heterogeneous wireless access network currently exist, like wireless personal area networks (WPAN),

wireless local area network (WLAN), wireless metropolitan area network (WMAN), and wireless repind area network (WRAN). As cognitive radio is becoming a crucial system to increase spectrum utilization and overcome spectrum scarcity. The margin of the aforementioned frequency separated access networks is inevitable. Recent research initiatives suggest that the integration of these heterogeneous access network into one cognitive radio mesh network using the ability of cognitive radio to adapt to different transmission/reception parameters like power, frequency, modulation, and medium access [11] [12].

III. RELATED WORK

Resource allocation (RA) (is also spectrum allocation) has attracted significant attention in [13], an efficient algorithm. It is developed by jointly considering transmission power budget and interference constraints. The algorithm achieves a good tradeoff between sum capacity and complexity.

In [14], the author studied the problem of spectrum allocation in a clustered cognitive radio sensor network (CRSN) in a spectrum overlay settings. Based on the PU activity modeling, cluster head (CH) assigns channels to different member nodes with the aim of minimizing transmit power while eliminating SU-SU interference by assigning each channel to one SU at most. In [14], the author did not consider the power budget, or the minimum rate constraints, which are essential to cognitive radio sensor networks.

Algorithm based on lagranigian dual optimization are presented in [15]; where the formulation of the problem satisfies the frequently-sharing constraints introducer by [16], thus a dual Lagrange to the non-convex heads to zero duality gap.

In [10], the author investigated the spectrum allocation problem for a set of cognitive radio nodes coexisting with a set of PU's in the same band in a spectrum sharing setting. The author formulated a joint channel/power allocation problem that aims to maximize the network sum rate under interference, hardware, and minimum received SINR constraints. Due to the NP- load nature of the mixed integer Nonlinear programming (MINLP) problem, the author transformed the problem into a binary linear programming (BLP) problem that has a uni-modular constraint matrix, and hence can be solved in polynomial time using linear programming (LP) solver.

In this paper the spectrum allocation problem in cognitive radio is formulated as a mixed integer nonlinear programming problem. However unlike in [10] ; in which the MILNP formulated problem is transformed into a binary linear programming problem, the MINLP formulation of the cognitive radio spectrum allocation problem is solved using neural network.

IV. FORMULATION OF THE SPECTRUM ALLOCATION PROBLEM

Consideration is made of a cognitive radio network consisting of M primary users (PU's) and N secondary users (SU's). The wireless mesh network is modeled as a connectivity graph G(V,E) where V = $(V_1 \dots . V_{N+M})$ is a finite set of nodes, with |V| = N+M, and (i,j) ΣƐ represent wireless link from mode V_i to mode V_j. Nodes from the subset PU={V_i……., V_m} are designated as primary users, and nodes from subset SU = {V_{m+1} …., V_{m+N}}are designated as secondary users [K_I].

It is assumed that all secondary users are equipped with cognitive radio that consists of a reconfigurable transceiver and a scanner. The available spectrum is assumed to be organized in two separate channels. A common control channel (CCC) is used by all secondary users for spectrum access negotiation, and is assumed to be time slotted. A data channel (DC) is used for data communication. The data channel consists of a set of discrete minibands {F_{min}, $F_{min\ +1}$,….F_{max-1}, F_{max}}, each of bandwidth w and identified by a discrete index. For example, the interval [F_i, $F_{i+\Delta fi}$] represents the (discrete) set of minibands selected by secondary user (i) between f_i and $f_{i+\Delta fi}$ with bandwidth $w_\Delta f_{i.}$

If wAfb denote the maxiumu bandwidth of the cognitive radio, where Δf_B denotes the maximum number of minibands, then $\Delta f_i \leq \Delta f_B$ represents the constraint of maximum bandwidth of the cognitive radio.

The achievable capacity of link (i,j) given the current spectrum condition is defined as [k_i].

$$Cij(F_i, P_i)\ \Delta\ \sum_{f E f_i [f_i, f_{i+\Delta fi}]} w.log_2 \left[1 + \frac{p_{i(f)} L_{ij}(f) G}{N_j(f) + I_j(f)}\right] \quad \text{------(1)}$$

Where I_j (f) represents the interference at j on f. The achievable value of C_{ij} [C_{ij} represents the achievable capacity for link (I,j)] depend on the dynamic spectrum allocation policy ie. Spectrum selection vector $F_i[f_i, f_{i+\Delta fi}]$, and power allocation vector $P_i = [P_i(f)], V_i \epsilon SU, V_f \epsilon F_i, G$

Is the processing gain, e.g length of spreading code. P_i(f) represents the transmit power of i on frequency f, Lij (f) is the transmission loss from node i to j. Maximizing the capacity of link (i,j) means selecting spectrum F_i=[Fi, $F_{i+\Delta fi}$] and corresponding transmit power (P_i(f) on each frequency to maximize the Shannon capacity.

The spectrum allocation problem is to find the spectrum hole with maximal capacity, given spectrum condition and hardware limitations of the cognitive radio. This is stated as a mixed integer nonlinear programming problem.

Given: $(i,j) I_j, N_j, L_{ij}, P_i^{min}, P_i^{max}, P^{Bgt}\, P^{Bgt}$ represents the instantaneous power available at the cognitive radio.

Find: [fi, $f_{i+\Delta fi}$], P_i

Maximize C_{ij} -------------------(2)

Subject to:

$$P_i^{min}(f) \leq P_i(f) \leq P_i^{max}(f), \forall f \epsilon [f_i, f_{i+\Delta fi}] \quad (3)$$

$$\sum_{f \epsilon [f_i, f_{i+\Delta fi}} P_i(f) \leq P^{Bgt}, \forall_i \epsilon \text{SU}; \quad (4)$$

$$0 \leq \Delta f_i \leq \Delta f_b, \forall_i \epsilon SU \quad (5)$$

Where$I_j = [I_j(f_{min}), I_j(f_{min+1}), \dots, I_j(f_{max})]$

$N_j = [N_j(f_{min}), N_j(f_{min+1}), \dots, N_j(f_{max})]$,

$L_{ij} = [L_{ij}(f_{min}), L_{ij}(f_{min+1}), \dots, L_{ij}(f_{max})]$ with $i, j, \epsilon\ SU$

The constraint (3) imposes the presence of a spectrum hole, and constraint (4) and (5) indicate the hardware restrictions.

V. SOLUTION OF THE PROBLEM USING NEURAL NETWORK

The spectrum allocation problem given by (2)-(5) is solved using neural network. The following algorithm lists the structure of the solution.

Algorithm:

INPUT

1. The parameters of the spectrum allocation problem (as given by (2)-(5).
2. Minimum error value

OUTPUT F_i, P_i

TRAINING STAGE

1. Initialize the weight in the neural network.
2. DO

For each example data (e) in the training set

i O = neural-net-output (network, e)

ii T = output for e

iii Calculate error (T-)) at the output units

iv Compute delta-wi for all weights from hidden layer to output layer.

V Backward pass computer delta-wi for all weights from input layer to hidden layer.

Vi Backward pass compute delta-wi for all weights from input layer to hidden layer.

vii Update the weights in the network until data set classified correctly or stopping criterion satisfied.

VI. SIMULATION RESULTS

To evaluate the performance of the proposed spectrum allocation algorithm, a cognitive radio mesh network of NMRs and MCs organized in a grid topology is simulated using Net-simulator. This network simulation program supports algorithm scripting in C++ programming language. A PU is either an MR or an MC assigned a license. There is a total of 60 licensed channels, each has a fixed bandwith (BW) set to 10^5Hz. The transmit power of the PUs is fixed to 20W. For the radio session, channel between two communicating nodes are modeled with a path loss exponent of 2, and a zero mean unity variance Raylight fading. The network operates in rounds (i.e time slots), where in each round, a new selection of "Active" nodes, and channel takes place. Each round is modeled by a duration of 1second.

The network throughput, average delay and total system utility obtained for the proposed technique is compared with those not and for the Receiver-based channel allocation (RBCA) technique modeled in [5]. For the simulation N is set to 120.

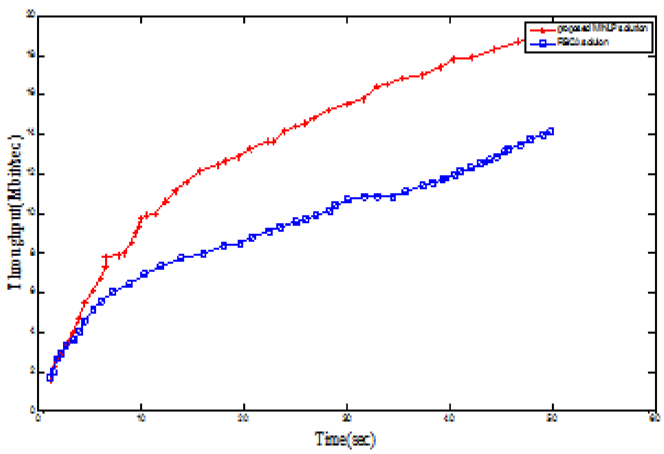

Figure 1: Comparison of the variation of throughput with time

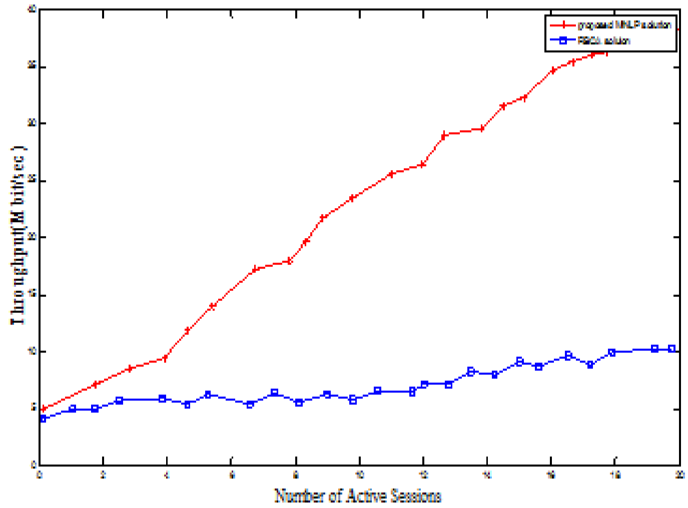

Figure 2: Comparison of variation of throughput with number of active sessions

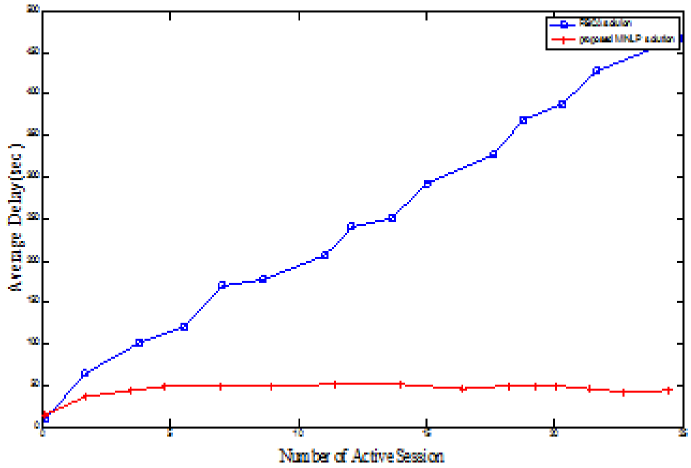

Figure 3: Comparison of average delay with number of active sessions

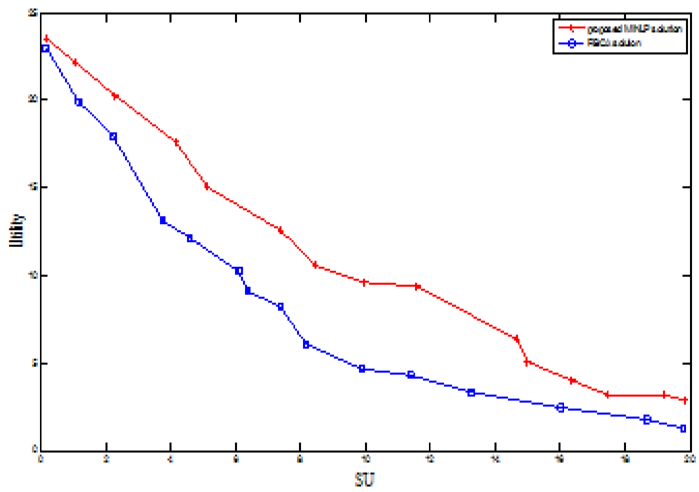

Figure 4: Comparison of performance in terms of total utility with Sus

References

[1] P. Kolodzy and I. Avoidance, "Spectrum policy task force", Federal commun. Washington, DC. Rep. ET Doeket, no. 02-135, 2002.

[2] Lei Ding, Scott Pudlewski, Tommaso Medodva, Stella Butaknu, D. Matyjas, and Michael J. Medley. "Distributed

spectrum sharing for video streaming in cognitive radio and Hoc Network".

[3] I.F. Akyillz, W. T. Lee, M. C. Vuran and S. Moharty "Next Generation/Dynamic Spectrum Access/Computer Networks. Journal (Elsevier), Vol. 50 pp. 21277-2159, Sept. 2016.

[4] A. Attar. O. Holland, M. Nakhai, and A. Aghrami, "Interface-limited resource allocation for cognitive radio in Orthogonal frequency-division multiplexing networks," IET Communications, Vol. 2. Pp. 806 July, 2008.

[5] Hisham Mohammad Almasaeid "Spectrum Allocation Algorithms for cognitive radio mesh network (2011). Graduate thesis and dissertation paper, 10383.

[6] I.F Akyidiz and Xudong Wang. "A survey on wireless mesh networks" IEEE Communications Magazine, 43(9): 523-530 Sept. 2005.

[7] R. Hincapie, Li Zhamp, Jian Tang, Guoliang Xue, R. S Wolf, and R. Busamate "Efficient recovery algorithms for wireless mesh networks with cognitive radios IEE International conference on communication (ICC), page 1-5, June, 2009.

[8] K. R. Chowdury and I. F. Akyildiz "Cognitive wireless mesh networks with dynamic spectrum acess" IEEE journal on selected areas in communications, 26(1): 108-181, Jan. 2008.

[9] Tao Chen, Hongang Zhamp, G. M. Maggro, and I. Chlamtac, "Cogmesh: A cluster-based cognitive radio network". In second IEEE International Symposium on new frontiers in Dynamic Spectrum Access Networks (DYSPAN), pages 168-178, April, 2007.

[10] R. C. Pereira, R. D. Souza, and M. E. Pellenz. "Using cognitive radio for importing the capacity of wireless mesh network". In IEEE vehicular technology conference (VTC), pages 1-5, Sept. 205.

[11] Tao Chen, Honggang Zheng, M. Matinmikko, and M. D. Katz. "Cohmesh: Cognitive wireless mesh networks" In IEEE GLOBECOM workshops, pages 1-6, Dec. 2000.

[12] Open Spectrum: "A path to ubiquitous connectivity" Oueue, 1(3): 60-68, 2003.

[13] L. Tu. C. Liu, and W. Hu, "spectrum allocation algorithm in cognitive ad-hoc networks with high energy efficiency," in 2010 International Conference on green circuits and systems (ICGCS), pp. 349-354, March, June 2010.

[14] X. Li, D. Wang. J. Mcnair, and J. Chen, "Residual energy aware channel assignment in cognitive radio sensor networks," in IEEE wireless communications and Networking Conference (WCNC), 2011, pp.398-403, May 2011.

[15] D. T. Ngo and T. Le-Ngoc "Distributed resource allocation for cognitive radio networks with spectrum-sharing constraints" IEEE transactions on vehicle technology, Vol. 60, pp.3436-3449, Sept. 2011.

[16] W. Tu and F. Lui "Dual methods for nonconvex spectrum optimization of multi carrier systems, "IEEE Transactions on communication, Vol. 54, PP.1310-1322, July, 2006.