Proposal: Decentralized Resource Assignment for Dynamic Spectrum Access Networks

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CONTENTS

I. ABSTRACT

II. INTRODUCTION

III. PROJECT CONCEPT

Resource allocation in DSA networks can be modeled by using game theory. In the case of an infrastructureless mobile wireless networks, devices are able to access the spectrum when idle or when the amount of interference caused is not harmful. Therefore, it is important to have strategies that would control the access to idle available spectrum in a fair way. Power, bandwidth size and bandwidth allocation are subject of study in this project to introduce fairness in a non-cooperative game. To achieve fairness and pareto-optimality, the concept of pricing of the spectrum is presented. The modeling presented here, is not constrained to any implementation; on the contrary, it is expected to optimize power, bandwidth and allocation that increase the network throughput. This project is part of a much larger project that approaches the trade off between cooperative versus non-cooperative games.

Different studies considering non-cooperative games for networks have been done. Users enter into a non-cooperative game to maximize their individual utilities by adjusting their transmit power, bandwidth size for each link and bandwidth allocation within the available spectrum. A unique Nash equilibrium have been shown to exist when the utility function is modeled as a function of the capacity achieved given a signal to interference ratio SIR; however, this equilibrium is not unique. A pricing function is then introduced leading to pareto improvements. By introducing a penalty or price function, each node's final utility increases while still allowing others to use the same channels minimizing the amount of harmful interference.

A. Scenario

1) Networks: Two kinds of networks are present in this scenario: primary and DSA enabled networks. Primary networks are composed by incumbent non-cooperative devices part of legacy services. Primary nodes work on previously assigned and fixed portions of the spectrum where they have the right of way. DSA enabled nodes are envisioned to be devices capable of sensing portions of frequency spectrum originally assigned to primary users and opportunistically reuse them without causing destructive interference. Both networks are deployed in the same region overlapping in both frequency and transmission range.

Characterization of spectrum occupancy dynamics is the first step in resource assignment of DSA enabled wireless networks. Three factors that allow for frequency reuse, namely, frequency (band), time and space are needed for a generalized analysis. The next subsections present a model characterizing the discrete division of the RF spectrum.

2) Physical layer: The presence of transceivers that are *"frequency agile"* and *"flexible"* are assumed. *Agilibility* allow transceiver to tune to different frequencies while *flexibility* allow them to change modulation, power and bandwidth size. Nodes can be in transmitting or receiving status but not both.

3) Frequency Diversity: Division of the RF Spectrum: Groups of licensed users occupy only a portion of the RF spectrum. The spectrum is discretized and divided into n_f frequency intervals or bands. Each of the n_f bands are assigned to licensed or primary "users". Channel conditions are independent over all portions of the spectrum and over all geographical regions where primary nodes are located.

4) Temporal Diversity: Frequency Availability: Time is slotted, and in every time slot, the channel conditions of each link randomly change (due to external effects such as the presence of a primary node, fading, user mobility, and/or time varying weather conditions).

5) Spatial Diversity: Interference Regions: An *interference region* is associated with each primary node. Based on the assumption of omnidirectional antennae and a simple two wave ground propagation channel model the signal strength of primary node transmissions decay with a power of 4 proportional to the distance. Consequently, an interference region is modelled as a circular space of radius R, which defines the threshold power loss and SNR.

The mix of the conditions previously described create opportunities with limited power that secondary nodes can use. Then, iterative water filling (IWF) techniques are used so nodes can occupy the available portion of the spectrum. The game of choosing power levels at different frequencies have been presented before as the Gaussian interference Game.

6) The Gaussian Interference Game: The Gaussian Interference Game was presented and defined in **??**. Its first application was in the modeling of power assignment in DSL networks. Although the physical characteristics of the copper wire are different than those of the wireless environment, the power assignment problem along the frequencies can be adapted. Let $f_0 < ..... < f_n$ be an increasing sequence of frequencies. Let I_k be the frequency interval limited by $I_k = [I_{k-1}, I_k]$. We now define the approximate Gaussian interference game denoted by $GI_{I_1,...I_k}$.

The game considers the N DSA nodes in the network as players where they have to allocate power for each of the f_n frequencies on the range $[0,P]$, where P is the maximum amount of power available for transmission. Each channel also presents an maximum power level to make sure that DSA node do not interfere with primary users. Each player can transmit a power vector $p_i = (p_i(1), ..., p_i(K)) \in [0, P_i]^K$ such that $p_i(k)$ is the power transmitted in interval I_K. Therefore, we have $\sum_{k=1}^{K} p_i(k) = P_i$. The equality follows from the fact that in a non-cooperative scenario all users will try to use the maximum power that they can use. To avoid this problem a pricing function is needed. The difference between the utility function (rate) based on the SIR and the price, will limit the amount of power and hence will help create a level of fairness among the players. The utility function to be used is based on the maximum Shannon capacity.

$$r_{ab} \approx \log(1 + \frac{\alpha_{ab} P_{ab}}{N_{ab} \alpha_{ab} \sum_{j \neq b} P_{aj} + \sum_{i \neq a} \alpha_{ib} \sum_j P_{ij}}) \qquad (1)$$

where $r_a b$ is the maximum rate obtained from node a to node b, N_{ab}, α_{ab} and P_{ab} represent noise, fading coefficients and power allocated associated with the particular channel state, between nodes a and b. The summation of all capacities obtained at each frequency will give the total utility function for one player.

By introducing a set of pricing functions, the trade offs on bandwidth and power allocation will be shown . Three main ingredients will penalize the greedy use of the resources: 1)Power, 2)bandwidth size and 3)the continuity of selected bandwidth.

Transmission power have a direct impact on the achieved capacity since the transmission power of one source can be received in all other radios; SIR decreases and hence the utility of other players. Bandwidth size is another element that have to be rationalized among the players; the excessive exploitation from one player will lead to spectrum scarcity and the larger the group of intervals the more the chances of overlapping with other player transmissions and therefore the higher the probability of creating excessive aggregated interference to primary nodes. Finally, it is expected to see that by using frequency intervals that are contiguous creates more interference than using frequency intervals that are uniformly distributed among all available frequency intervals.

The outcome of this project will show how game strategies followed to allocate resources change increase the utility of players. All analytical results can be validated by simulations in OPNET where the strategies are implemented as part of the routing-mac layer for DSA networks. These strategies are expected to have a direct impact on throughput, route selection and QoS applications. This study show that there is a trade off between spectrum usage optimization, QoS and fairness.

IV. SUMMARY OF RESEARCH PLAN

V. PROPOSED BUDGET

VI. CONCLUSIONS AND FUTURE WORK

VII. RESEARCHERS

Daniel Ugarte received his B.S. degree from the Universidad Nacional de Ingenieria in Lima, Peru in 2000, and the M.S. degree in Electrical Engineering from Northeastern University in Boston in 2005.

During the summer of 2003, he worked at BBN Technologies in Cambridge in a project part of the XG program for Dynamic Spectrum Access Networks. At BBN, he received funding to continue his studies at Northeastern University during another year to continue working on the same project. In summer 2005, he worked for Scientific Systems Co. Inc. were he continued working on DSA implementations for Ad-hoc networks. Currently he is a PhD candidate at Northeastern University where he holds a Research assistantship.

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