Spectrum Management for Wireless Networks with Hybrid of Controls and Game Theory Approaches

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Abstract

Cognitive radios enable a flexible and dynamic sharing of the radio spectrum. Devices can adopt their channel access strategies to allow higher utilization of the spectrum while maintaining a high quality of service (QoS). However, several challenges exist in enabling fair and distributed sharing of the spectrum. Those include incomplete or incorrect information about the radio spectrum, neighboring devices, and strategies of the neighbors (e.g. is it cooperative, greedy, or malicious?). Hence, a suitable strategy is required to dynamically adopt the channel access strategy for cognitive radios. The proposed approach will utilize game theory based decision-making and context detection to management radio spectrum and enable coexistence of wireless networks. The specific objectives include: (a) coordinated and fair sharing of radio resources in presence of heterogeneous networks and wireless technologies, (b) detection of intruders that intend to disrupt network operations, and (c) selection of best strategies to counter such attacks.

1. Research Objectives

This paper postulates a novel approach to development of adaptive and distributed schemes for spectrum management for multiple wireless networks. Specifically, a novel scheme for channel allocation in a dynamic, multi-channel, multi-network scenario is proposed in this work, as illustrated in Figure 1. This proposed generic approach combines a control based learning mechanism, for example neural networks or an adaptive scheme, with game-theoretic decision-making. The main benefits of the proposed hybrid approach includes relaxation of typical assumptions made when solving a cooperative game, for example availability of complete and accurate information [1][2][3].

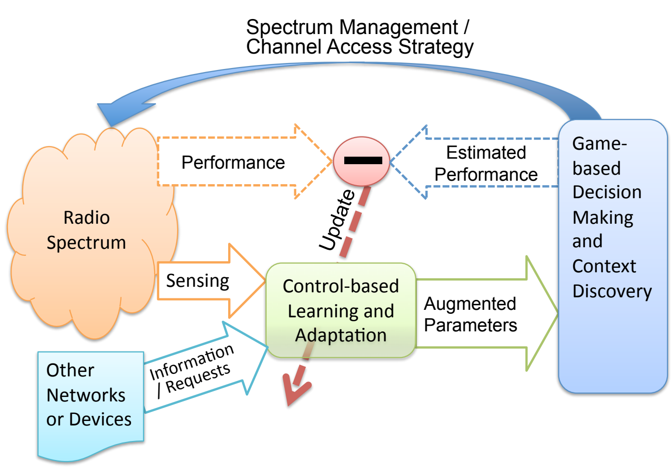

Figure X. Overview of the proposed approach

Simplified game theory problems can be easily solved, for instance using linear dynamic programming [4][3]. Moreover, the cooperative and non-cooperative games are suitable to analyze performance and derive suitable decision rules in environment with multiple players, for instance wireless networks that share radio channels on Industry, Scientific, and

Medical (IMS) band. However, such solutions often rely on strong, simplifying assumptions, for instance a concavity of utility function for market game solution [3][5]. As a result, the performance of such schemes suffers in realistic applications since the existing nonlinear dynamics invalidate the simplifying assumptions. For example, when two 802.11-based networks share the same channel their performance should ideally be proportional to their back-off interval. However, due to a hidden terminal problem, interference, and signal fading the network performance may decrease and vary between networks [6][7][8][9]. Hence, the proposed approach employs a learning methodology to discover the actual relation between channel access parameters and the network performance. Subsequently, this knowledge can be used to simplify the game solution by eliminating such nonlinearities from the input parameters.

2. Game Theoretic Approach with Control-based Adaptation Scheme

At present, the challenges in networks coexistence are emphasized by increased deployment of wireless networks in industrial and personal applications. However, these applications require reliable and uninterrupted communication. Often such applications use the common ISM unlicensed spectrum due to availability of inexpensive and easy-to-use devices and tools. Unfortunately, the rapid and uncontrolled deployment of such networks and devices results in an increased interference [6][7]. Moreover, the lack of standardized mechanism to detect and resolve conflicts with the channel allocation leads to an unacceptable performance of such systems. This requires an altogether new scheme that is introduced.

2.1. Problem Description and Background

Wireless networks equipped with cognitive radios can support inter-network communication. They may exchange basic information about the required quality of service, channel quality measurements, and channel access strategies thus allowing for coordinated spectrum management. In general, the goal is to allocate the limited resources such that the performance of the networks is maximized while ensuring fairness among them.

The challenges are in the optimization of channel allocation strategy and accommodation for errors in the information and models. For example, the achieved throughput may be insufficient if the network underestimates the required bandwidth, or if the nodes experience higher collision rate than expected due to a hidden terminal problem.

In the past, game theory-based channel access schemes [1] [2] have focused on cooperative type of games where the participants intend to find a desirable solution that satisfies performance requirements for everyone. However, these schemes require availability of full and accurate information about the participants and channels in order to succeed. In contrast, participants in a realistic scenario may unintentionally or intentionally provide incorrect or incomplete information. In addition, an intruder may take action contrary to the optimal strategy dictated by the game solution. In such scenarios, it is desired to alter the decision-making strategy that ensures robustness. The non-cooperative game theory, on the other hand, can provide a more suitable tool for analysis of such scenarios in the wireless networks [10][11][12]. However, they also require sufficient information in order to succeed.

2.2. The Proposed Approach

The main challenges in the realistic scenarios are related to hidden and nonlinear dynamics in channel access including:

1) *Varying capacity* – the channel capacity varies with level of interference and noise, number of nodes competing for a channel, radio signal fading, etc. Moreover, each network and each device may experience independent fluctuation of channel capacity since the affects vary spatially and temporary.

2) *Varying spatial overlaps between networks* – the co-located networks have to share the same radio resources thus dividing the channel capacity. However, when some nodes in one network are out of interference range of the other network, the spatial reuse will occur. As a result, the total throughput can exceed the channels' capacity.

Pure game theory based approach would require modifying the game formulation to incorporate those dynamics. However, this can invalidate the solution building assumptions, for example that the utility function is a concave. Consequently, the general solution and analysis would become difficult to calculate [3][5]. Instead, the proposed effort aims at applying control-theory approach to adapt the decision-making strategy. The learning scheme, for example neural networks or adaptive schemes can learn the unknown dynamics of a varying channel capacity and interference. Next, this knowledge can be utilized to minimize errors in input parameters to decision-making stage. Moreover, by carefully analyzing the internal parameters of the control-based adaptation stage we can speculate about the root-cause of the error. For example, we could distinguish between inaccurate measurements and intentional attack thus gaining additional insight before selecting strategy for channel access. Similar approach based on adaptive control scheme has been previously demonstrated by the author for the problems of power and congestion control for a single wireless network [8][13].

3. Conclusions

The proposed approach utilizes game theory approach to make decisions on suitable strategy for the radio channel access thus implementing spectrum management in both cooperative and non-cooperative environments. Additionally, the learning capabilities of control-based scheme will provide necessary adaptation of information utilized in decision-making. The control theory can be used to design scheme that guarantees desired performance, for example by using Lyapunov analysis and design. Furthermore, the learning parameters of the control scheme can be utilized in concert with game theory to identify non-cooperative or hostile networks and devices.

4. References

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