Blind Spatial Coexistence in MIMO Cognitive Radios

Project Proposal for the I2C Innovation Challenge

Alexandros Manolakos, Yair Noam and Andrea Goldsmith

ABSTRACT

We present an innovative idea that can allow several wireless communication systems to coexist simultaneously in the same area and on the same frequency bands while causing minimal interference to each other. This work exploits the spatial dimensions of MIMO for coexistence, and is motivated by the scarcity of the electromagnetic spectrum. Our solution is commercially viable and can transform the way today's wireless communication systems share spectrum.

The proposed mechanism is easily implementable in today's systems, does not need any special hardware, and the new radios can actually operate in a "plug-n-play" fashion along with today's cellular networks.

<u>Area of Emphasis of the Proposed Work:</u> Radio signal processing

Introduction

Radio is a broadcast medium where all users coexisting in the same frequency band interfere with each other. As the number of wireless systems and services has grown exponentially over the last two decades, the availability of prime wireless spectrum has become severely limited. This is evident by a glance at the National Telecommunications and Information Administration's frequency allocation chart , which reveals that almost all frequency bands have been assigned, and there is little new bandwidth available for emerging wireless products and services. Out of this spectrum shortage was born the idea for cognitive radios.

The notion of a "cognitive radio", a radio that adapts to the environment and makes intelligent decisions, has emerged as a viable remedy to the spectrum scarcity. Many attempts have been made over the last decade to propose new technologies that use the spectrum more efficiently and in a cooperative manner in order to overcome the spectrum shortage. Most of them have failed either because they demanded too much cooperation from the licensed owner of the spectrum or because the new radios had to operate under too restrictive conditions (e.g. UWB radios).

We exploit the use of Multiple-Input Multiple-Output (MIMO) technologies and propose an innovative mechanism that permits an unlicensed user to quickly and accurately learn where it should NOT transmit in order to not interfere with the licensed user of the spectrum. The proposed technique enables the deployment of more wireless communication networks on the same frequencies and areas. It paves the way for the future of device-to-device communication, of a new type of cellular network paradigm and of a wireless technology which enables new wireless services over existing spectrum and increases competition for the benefit of the public.

Overview

Today's existing techniques for channel learning are not commercially viable since they require a high level of cooperation from the side of the primary users. This cooperation, which includes handshake, synchronization and information exchange, makes the learning process too complex in practice and the whole endeavor too cumbersome for the primary users that have licensed the spectrum. On the other hand, what we propose:

- Requires minimal cooperation from the primary network
- Does not require the primary system to be aware of the presence of the secondary system
- Is based only on energy measurements that are independent of the transmission schemes of the primary and secondary systems
- Allows for simultaneous transmission of information and learning

Area of Emphasis

This project is a clear match to the broad area of radio signal processing since we propose a novel algorithm for fast and blind learning of the null space of a channel through the usage of MIMO and smart antenna capabilities. We envision that this algorithm will become a part of the physical layer of the protocol stack of any cognitive radio equipped with MIMO capabilities.

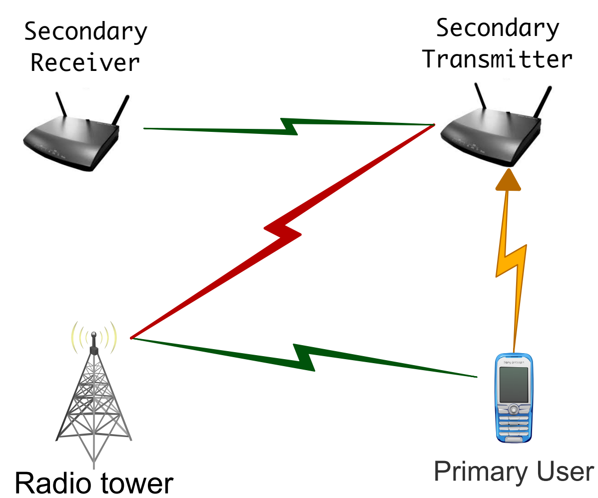
Description of the Project

We now give a high level description of the important ideas of the proposed algorithm.

Mode 1: Null-Space Acquisition - BNSL Algorithm

The Blind Null Space Learning Algorithm is at the heart of the proposed mechanism and is used for the initial phase of the algorithm, the null-space acquisition. We assume that the primary system uses a power control mechanism, which actually exist in all current cellular systems.

Consider the paradigm that appears in Figure 1. The ST consists of two antennas whereas the primary user (PU) consists of one antenna. We assume that the ST wants to transmit in the same frequency band as the PU transmits to the radio tower. In order to do so, it first transmits with low power. This transmission inflicts interference to the radio tower and the PU will be informed of this change through the power control mechanism. Then, the PU is going to increase the transmit power in order to mitigate the induced interference. The ST senses the reaction from the PT (yellow row in the Figure) and gradually adapts the interference to the radio tower by iteratively modifying the spatial orientation of its signal and measuring the effect of this modification on the PU's transmit power. Note that the entire process is only based on energy measurements and on detecting energy variations.



In theory, the algorithm, after a sufficiently large number of iterations, can approximate the null space to any desired accuracy. In a practical implementation, the algorithm can lead to a 20 dB reduction of interference from the ST to the PR after a small number of iterations. For instance, for the above example the algorithm needs around 16 transmission cycles in order to reduce the interference by more than 19 dB. If each transmission cycle is 2msec, (current power control mechanisms update their transmit power every 1 ms), then the ST learns where not to transmit in around 32 msec. For a system where the ST has 3 antennas and the PR has 1 antenna, the algorithm can decrease the interference by more than 17 dB in 40 only transmission cycles.

Mode 2: Null Space Tracking while Transmitting Simultaneously

Obtaining the null space via the blind null space learning is not sufficient in practice since the channel might be time varying. For example, consider the case of a smart tablet pc (ST) inside a house that uses the spectrum intended for a cell phone while the tablet moves from room to room. Due to time variations, after the ST has acquired the knowledge of the null space, it needs to update it regularly, a process known as tracking. We enhance our system by introducing a tracking algorithm to learn the channel and send information at the same to the SR. That is, after the ST executes the channel acquisition algorithm, he then tracks the null space of the channel and transmits at the same time. This work is in progress.

Market

Nowadays, it is a well-established fact that a viable solution to the scarcity of the spectrum is going to harness a huge market. The proposed product is the perfect fit for a variety of real world wireless communication scenarios. For instance, the licensed spectrum of a cellular provider can be efficiently exploited by wi-fi in-house access points or by a competing provider. Another example is the paradigm of a secondary device-to-device communication system, which uses the spectrum of the primary cellular network. By enabling more and more devices and services to spatially coexist, this product will transform the spectrum marketplace dynamics. The spectrum will evolve from a scarce and expensive resource allocated by the government into an easily accessible commodity available to the broader public. Both the technology and market have had sufficient time to mature. On one hand, MIMO radios are already commercially available and in widespread use, and on the other hand, the proposed radio will be well accepted by existing cellular providers since it will work in a ``plug-n-play'' fashion, with minimal cooperation required from them.

Milestones

Tasks	*Current Status*	*Estimated Completion Date*
Performance Analysis: Phase 1 & 2	Phase 1 completed [1]	July 2012
Simulations	Partially completed [1], [2]	July 2012

Bibliography

[1] Yair Noam, Andrea Goldsmith. "Blind Null-Space Learning for MIMO Underlay Cognitive Radio Networks". Stanford: http://arxiv.org/abs/1202.0366, 2012

[2] Alexandros Manolakos, Yair Noam, Andrea Goldsmith. "Blind Null-space Tracking for MIMO Underlay Cognitive Radio Networks". Stanford, 2012, Submitted to IEEE Globecom 2012.