Transparent Coexistence for Multi-hop Secondary Cognitive Radio Networks: Theoretical Foundation, Algorithms, and Implementation

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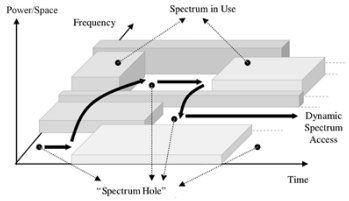
BACKGROUND

- Current prevailing spectrum sharing paradigm is interweave (a.k.a. DSA)
- Follow the classic interference avoidance paradigm
  - Avoid interference by not allowing simultaneous transmission at the same time, in the same channel, at the same location



Existing interweave paradigm (figure from Ref. [1]).

Limitations

- A secondary node cannot transmit if its signal interferes with a nearby active primary receiver.
- Secondary users cannot transmit upon demand.
  - Severe limitation on the quality-of-service that can be offered to the secondary users.
- Waste of spectrum resources in time and frequency

MOTIVATION

- Simultaneous activation of secondary nodes is possible if their interference to the primary nodes are cancelled.
- Exploit effective and powerful interference cancellation (IC) techniques: MIMO interference nulling, successive interference cancellation, etc.
- An example:

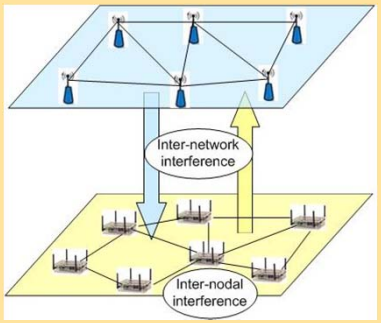
4x4 MIMO Secondary Tx uses 1 DoF for IC and 3 DoFs for SM

4x4 MIMO Secondary Rx uses 1 DoF for IC and 3 DoFs for SM

- Only secondary users employ powerful IC techniques
- Only secondary users responsible for IC to/from primary users
- No change or new requirements on primary users
- All operation transparent or invisible to primary users

Goals and Objectives

- Enable transparent coexistence paradigm for multi-hop primary and secondary networks.
- Preserve the essence of transparent coexistence
  - No change or new requirements on the primary users
  - Secondary users transmission invisible to the primary users
  - All IC burden on the secondary users
- Expect significant performance improvement for the secondary users.



CHALLENGES in MULTI-HOP NETWORKS

At each secondary user:

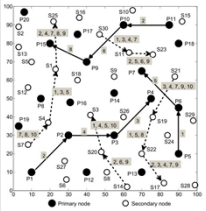
- How to perform IC to & from primary users?
- How to perform IC within the secondary network?
- How to perform scheduling (in time slots or frequency channels)?
- How to collect channel state information (CSI) between secondary and primary users without imposing additional requirements on the primary users?
- How to remain transparent coexistence (invisible) to the primary users?

TECHNICAL APPROACH

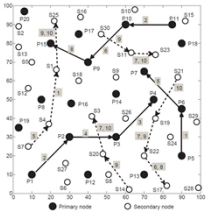
- Employ powerful IC technologies at the secondary nodes
- Configure IC techniques to achieve coexistence as well as transparency
- As a start, focus on MIMO
  - Develop new mathematical models involving multiple layers (cross-layer optimization)
  - Explore performance bounds and theoretical limits
  - Design distributed algorithms for multi-hop secondary networks
- Collection of CSI
  - CSIR: Periodically *overhear* the pilot signal from primary users
  - CSIT: Estimated CSIR can be used for CSIT based on wireless channel *reciprocity*
- Investigate other IC techniques

PRELIMINARY RESULTS

- Have developed a new DoF model for MIMO IC
  - Eliminate potential duplication in IC by Tx and Rx
  - Larger feasible DoF region than any other DoF models
- Based on the MIMO DoF model, developed cross-layer optimization framework for transparent coexistence
- Example results for 20 primary and 30 secondary nodes:



Channel allocation for secondary links under transparent coexistence.



Channel allocation for secondary links under interweave.

- Significant improvement in
  - Spectrum efficiency
  - Secondary user throughput
  - Service experience for secondary users

SCIENTIFIC & BROADER IMPACTS

- Enable simultaneous operation of secondary networks with the primary networks
- Allow much improved service offering to the secondary users, which enables new business models and opportunities for communications service sector
- Expand knowledge frontier for efficient use of spectrum
- Advance inter-disciplinary research across wireless technologies, computer science algorithms, operations research (optimizations), and spectrum policy
- Research opportunities for graduate and undergraduate students
- New teaching materials for graduate and undergraduate courses

REFERENCES

1. I.F. Akyildiz, et al., ``NeXt generation/dynamic spectrum access/cognitive radio wireless networks: A survey,'' Computer Networks, Sept. 2006.