Orchestrating Virtual Wireless Networks from Common Resource Pools

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Agenda and summary
Exploding demand

- Smartphones use 24x more data than regular phones
- Tablets use 122x more data than smartphones
- However, it is not feasible for operators to increase prices proportionally to this demand

How to deal with this?

- More efficient utilization of spectrum and other forms of resource sharing
- New wireless network architectures (small cells, seamless integration of different wireless technologies)
Towards a sharing economy

Towards a sharing economy

An evolution...

Mobile Provider A

Mobile Provider B

Mobile Provider C
An evolution...
An evolution...
Networks without Borders

**Networks without Borders**

- Network is composed on the run from a pool of resources (spectrum, infrastructure, management services, ...)
- Some wireless resources are fungible
- Contributors to this pool range from households to small scale operators to traditional wireless providers
- Network exists, virtually, to provide specific services to a specific subscriber/user population
- Network has a transient nature
- Virtualization is a key component, leading to new entities (the resource aggregator, the virtual architect)
- New business models and lower barriers to entry
interests

fundamental principles that will allow the wireless network of the future to evolve into new architectures characterized by increasing autonomy, resource sharing, and ubiquity of wireless services.

ability to learn  distributed and autonomous decision making  transient ownership of resources
Game theory and cognitive communications

A set of analytical tools from economics and mathematics to predict the outcome of complex interactions among rational entities in the context of cognitive radio...

Models of interactions among adaptations performed by cognitive radios in a network

Design of incentive structures for efficient resource sharing in a cognitive network

Economic models of spectrum markets
Coordination for heterogeneous and multi-hop networks

- Distributed spectrum sharing for multi-hop topologies and HetNets (relays, coexistence between small and large cells)

- Adaptations: channel selection, transmit power

- Goals: network-wide spectrum efficiency, fairness, network connectivity, coverage

- Cooperative game theory, coalition formation


Imperfect monitoring

• Impact of incomplete or erroneous information about channel or network conditions or neighbor activity on effectiveness of radio adaptations

• Framework is games of imperfect public/private monitoring

Utility ftn: imperfect public monitoring

\[ \pi_i(a) = \int_{p \in \Omega} u_i(a_i, p) \cdot dF(p; a) \]

\( \pi \) is the expected utility

\( p \) is the public signal

Need to model the distribution of \( p \), parameterized by the action vector \( a \)

Price of ignorance in topology control adaptations upon departure of one radio

Hierarchical game for vertical spectrum sharing

1. Primary users (PUs) can charge secondary users (SUs) for access to spectrum

2. SUs distributedly select on which sub-bands to operate
   - Multiple SUs can occupy the same sub-band and cooperate in communicating

3. SUs control their transmit power

Hierarchical game for vertical spectrum sharing: the sub-band allocation game

- SUs choose the sub-band that maximizes their payoff (achievable data rate minus price paid)
- Set up as a coalition formation game because multiple SUs may pick the same sub-band, in which case they share the sub-band according to a proportionally fair allocation
Hierarchical game for vertical spectrum sharing: the power control game

- SUs are charged according to the interference they cause
- The choice of transmit power affects both cost and achievable rate, and is affected by all SUs’ choice of sub-band
Hierarchical game for vertical spectrum sharing: the price adjustment game

- PUs set their prices according to the availability of excess capacity
- Access by SUs is restricted based on their aggregate interference

\[
\max_{\beta_{Pj} \geq 0} \pi_{Pj} \left( w_S, \beta_{Pj}, \beta^*_{-Pj} | l_S \right),
\]

s.t.

\[ H w_S \leq q_P. \]
As for the three inter-related games...

We can devise an algorithm with the following properties:

**Thm:** If the algorithm terminates with the prices given in the previously stated result, then:

1. The resulting transmit power levels are the NE for the power control game, given a fixed sub-band allocation and pricing structure
2. The resulting sub-band allocation is a stable point for the coalitional game
3. The resulting prices are a NE for the PU price adjustment game
4. The combination of prices and transmit power levels are the SE for the hierarchical game
How about infrastructure and spectrum sharing?

- Relying on data from mobile operators to assess virtual networks constructed from resources belonging to multiple operators
- Picture above is from Warsaw
Preliminary work

- Assessing what portion of resources is needed if we were to customize a network by combining assets from multiple MNOs, with a certain coverage goal
- Considered a mix of urban (large and medium size cities) and rural areas in Poland
- Starting to model demand for capacity, as well as coverage
• Mapping between physical resources and virtual networks over shared resources

• Economic drivers and incentives/disincentives for infrastructure sharing

• Virtualization techniques and locality of resources

• Regulatory issues in spectrum and in infrastructure sharing

• Development of standard interfaces for combining resources from multiple sources
Current areas of investigation...

• Efficient distributed resource management mechanisms under imperfect information

• Virtualization of networks built on multi-provider infrastructure and heterogeneous access technologies

• Effects of new wireless network architectures on the design of the optical backhaul

• Incentive models for inter-operator cooperation

• Incorporating DSA into LTE-A and beyond
‘The new status symbol isn’t what you own—it’s what you’re smart enough not to own’

Lynn Jurich
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