Relay Selection for Joint Scheduling, Routing and Power Allocation in Multiflow Wireless Networks

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Network-Aware Resource Allocation

The Main Problem

- Slotted system
- Simultaneous transmissions interfere
- Multiple flows

Challenges

- Routing and Scheduling are NP-Hard
- How to represent cooperation to resource allocation algorithms?
- Convexity of Power Allocation
Our Approach
Algorithms and Complexity Management

- Decomposition Technique: *tear apart the problem*
- Complexity-managing data structure: *manage the decomposition*
- Rate control: *capture PHY technology*
- Demonstrate tangible benefits of cooperation in broader networks
Difficulty in Resource Allocation
Mixed-Integer Programming

- Half-duplex system, limited transmission power
- Distance-based pathloss model
- Only sources have traffic, all other terminals have infinite buffers

Goals
- Determine Routes, Schedules and Power Allocations
- Maximize the minimum throughput
- Allow cooperative links
- Do all of this in polynomial time
Cooperative Resource Allocation: Interference Management

Key: Incorporate Rate Control

Performance of cooperative links is best described using physical-layer Information Theory

**Fundamental Approach**

Represent the rate on a link using Shannon-style capacity

For a point-to-point link:

$$\log_2(1 + \text{SINR})$$

For a cooperative link, DF achievable rate:

$$\min \left\{ \log_2 \left( 1 + \text{SINR}_{sr}^{(1)} \right) + \log_2 \left( 1 + \text{SINR}_{sd}^{(2)} \right), \log_2 \left( 1 + \text{SINR}_{sd}^{(1)} \right) + \log_2 \left( 1 + \text{SINR}_{sd}^{(2)} + \text{SINR}_{rd}^{(2)} \right) \right\}$$
Network-Flow Interaction Chart
Decomposition in Space and Time

- Represent terminals as *nodes*
- Expose temporal dimension on $x$ axis
- Edges represent transmissions, weighted with *capacity* of a link

$\log(1 + \text{SINR})$
Network-Flow Interaction Chart
Allocation using Dynamic Programming

- Weight source node with $\infty$, infinite data
- Update edges with $\min$ of nodes and edges
- Update nodes with $\max$ of incoming edges
- Compute throughput at destination node
Network-Flow Interaction Chart

Metanodes: Representing Cooperation

- Metanodes and associated edges capture cooperation
- Edge into $M$: both $X$ and $B$ receive
- Edge out of $M$: both $A$ and $X$ transmit, $B$ does combining
Where to Include Cooperation
Before or After Routing?

Two models:
1. Cooperate to improve chosen route
2. Define many metanodes which may affect routing decision

Insight
Routing decisions may be different when cooperation is available!

Metanode Definition
How many metanodes to define, how to select them?
Complexity Considerations
Where Cooperation Can Hurt

Allocation algorithm runs in $O(N^3)$ time

- Metanodes are elements in the NFIC
- Memory and calculations increase

Complexity
Algorithms remain cubic, but complexity increases:

$$O((N + kN)^3)$$

N(N − 1) edge updates  N node updates  N timeslots
How to Define Metanodes
In the Pathloss Environment

NFIC scheduling algorithms are general, not optimized for particular flow source-destination pairs.

Problem
All flow source-destination pairs should be considered during metanode definition.

Three low complexity metanode definition algorithms:

1. Simplest, just look at the nearest nodes
2. Geographically-equalized for routing
3. Range extension
Nearest-Neighbor Cooperation

Algorithm 1

For each terminal:

- Choose nearest $k$ terminals as relays
- Select terminal nearest to each relay, but not nearer to source, as destination

Cooperation may be available in only one direction
Geographically-Equalized Cooperation

Algorithm 2

For each terminal:

- Divide the region into $k$ sectors
- Within each sector, identify nearest relay and destination as before

Cooperative range may be short
Algorithm 3

For each terminal:

- Partition the region into $k$ sectors
- In each sector, choose the terminal some fraction $\gamma$ of the distance to the furthest terminal in the sector. Assign as destination
- Choose terminal near halfway as relay.
Results
Simulation results

- Geographical metanode definition performs best
- This is because the NFIC algorithms can exploit cooperation to improve bottleneck link regardless of direction of data flow
- Range-extension performs worst, because cooperation over distance doesn’t do better than multihop.
Conclusions and Future Work

Contributions

- Polynomial-time resource allocation algorithm, modeling advanced PHY technologies
- Flow-agnostic cooperative definition algorithms
- Clear performance gains using NFIC allocation with cooperative links

Future Work

- Consideration of *a-posteriori* cooperative definition
- Study of metanode definition in more general channel environments

Thanks!

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