Interference-aware Routing and Scheduling in WiMAX Backhaul Networks with Smart Antennas

CS 440 — Computer Networks

Montana State University

Fall 2008

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- IEEE 802.16 standards
- Base Station vs Subscriber Station
- Point-to-Multipoint (PMP) mode vs Mesh mode
- Time Division Multiple Access (TDMA)

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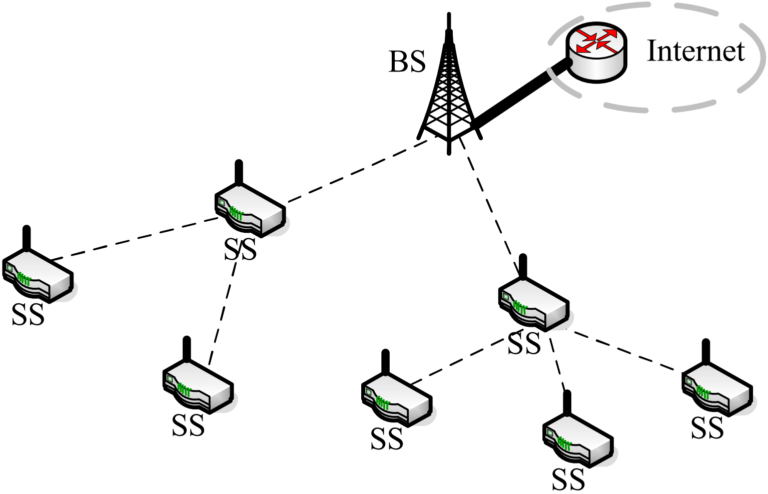
WiMAX	WiFi
802.16	802.11
Licensed/unlicensed spectrum	Unlicensed spectrum
WMAN	WLAN
Longer range	Shorter range
Higher throughput	Lower throughtput
Request/Grant (TDMA)	Contention based (CSMA/CA)


BS
Internet
SS
SS
SS
SS
SS
SS
SS

- Adapt to the environment.
- Longer transmission range.
- Lower power consumption.
- Digital Adaptive Array (DAA) antennas
- Multiple antenna elements (a.k.a, Degree Of Freedom, DOF)
- Beam forming
- Spatial Division Multiple Access (SDMA)

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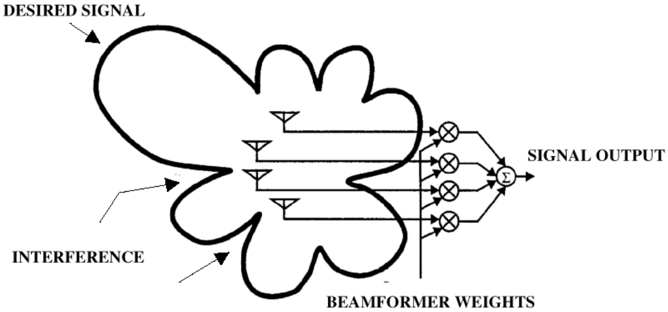
An example of smart antenna beam pattern (from www.wtec.org)



- We consider routing and scheduling in WiMAX backhaul networks with smart antennas.
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- Schedule with smart antennas and spatial reuse is quite different from traditional link scheduling with omni-directional antennas.

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System Model

Antenna Model

- Each node has an antenna with K DOFs. (K is usually a constant. But we do not make this assumption in our work.)
- Each antenna can tune its K DOFs to point at arbitrary directions dynamically.
- In order to activate a link, one DOF needs to be assigned for communication at each end of the link.
- In order to cancel interference from one node to another, only one DOF needs to be assigned to form a null at either node.

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- Bandwidth requests do not change within a scheduling period.
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- A static, single channel, multi-hop WiMAX backhaul network.
- All traffic demands are unicast and between BS and SS. No traffic from SS to another SS.
- Radios are homogeneous, half-duplex, and equipped with DAA antennas.
- Protocol interference model
  - Primary interference
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- Thus, the communication graph G can firstly be layered.
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Interference aware Tree Construction Problem (ITCP)

- Define the secondary interference value of v_i as $I^s(v_i) = |N_i| - 1$, where $|N_i|$ is the set of nodes that can potentially interfere with v_i.
- Define the secondary interference value of link $e = (v_i, v_j)$ as $I^s(e) = \max\{I^s(v_i), I^s(v_j)\}$.

Definition

ITCP seeks a spanning tree rooted at the BS, such that in each layer $h > 1$, the maximum node degree of layer $h - 1$ is minimized subject to the constraint that the maximum secondary interference value of all links picked between layer $h - 1$ and layer h is minimized (or less than K), without causing disconnection of the two layers.

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- A schedule is composed of both transmission scheduling and DOF assignment.
- The spanning tree is given as input, together with the bandwidth demands of each SS.
- Nodes need to transmit not only their own demands, but also the aggregated demands from their descendants in the spanning tree.
- We want to promote the throughput of all nodes while maintaining fairness.
- We only discuss uplink scheduling. Downlink is symmetric.

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A schedule and DOF assignment is *feasible* if:

1. For each link scheduled, DOFs have been assigned at both end for communication.
2. There does not exist primary or secondary interference in every minislot.
3. Each node assigns at most K DOFs.

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USP seeks a feasible uplink schedule and DOF assignment such that the bandwidth demand satisfaction ratio of the least satisfied node is maximized.

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A polynomial time optimal algorithm for ITCP
Ideas

- Construct auxiliary graph and use Ford-Fulkerson algorithm to check whether it is possible to bound the node degree of layer $h-1$ while keep layer h and $h-1$ connected.
- Use binary search to find the minimum satisfying node degree.
- The algorithm has been proved to optimally solve ITCP in $O(mnh_{\max}\log\delta_{\max})$ time.

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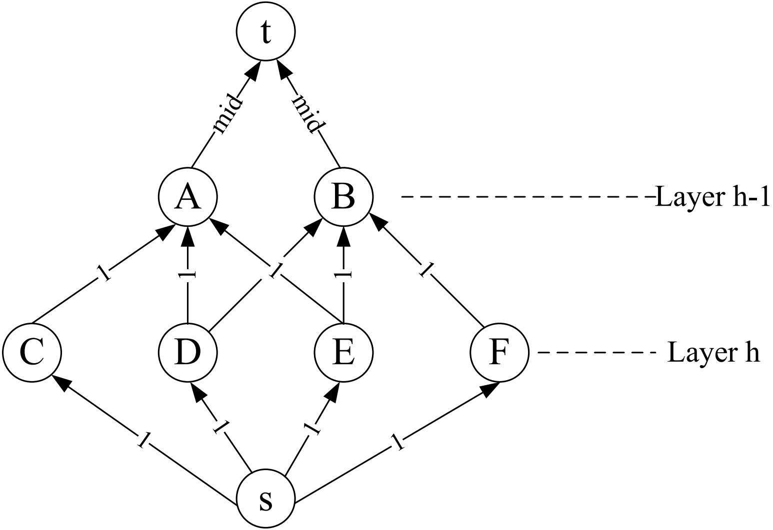
Example Auxiliary Graph



A polynomial time optimal algorithm for a special case of USP

Ideas

- Link scheduling problems in a multihop wireless network have been shown to be NP-hard.
- A special case: when every node has enough DOFs to eiminate all potential secondary interferece.
- Find the bottleneck node in the routing tree.
- Schedule for the bottleneck node and its descendants, then remove them and their demands from the routing tree.
- Repeat until the tree becomes empty, and all nodes scheduled.
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A heuristic algorithm for USP in the general case

Ideas

- Slot-by-slot scheduling.
- Greedily tries to pack as many links as possible in a minislot, consider the least satisfied link first.
- Use auxiliary graph to decide whether a set of links can be active concurrently and compute a feasible DOF assignment.

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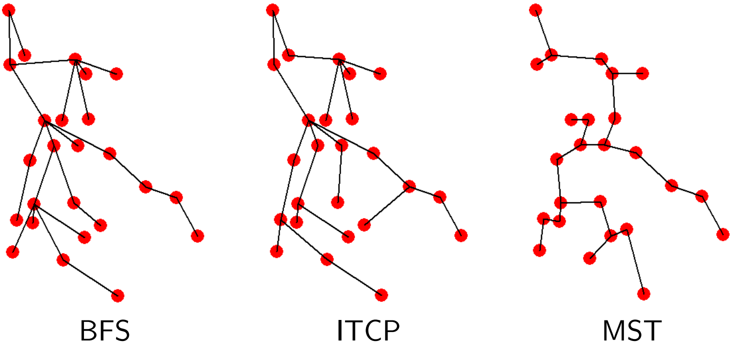
Simulation Scenarios
Scenario Parameters

Parameter	Setting
Scenario Area	$4 \times 8\text{km}^2$
Transmission Range	1km
Interference Range	3km
Number of DOFs per Node	3
BS Placement	Top-left corner
SS Placement	Uniform within the area
Number of SSs	$[25, 50, 75, 100, 125, 150]$
Minislots per Frame	1024
Uplink demand of each SS	Discrete uniform in $[5, 10]$
Downlink demand of each SS	Discrete uniform in $[10, 20]$

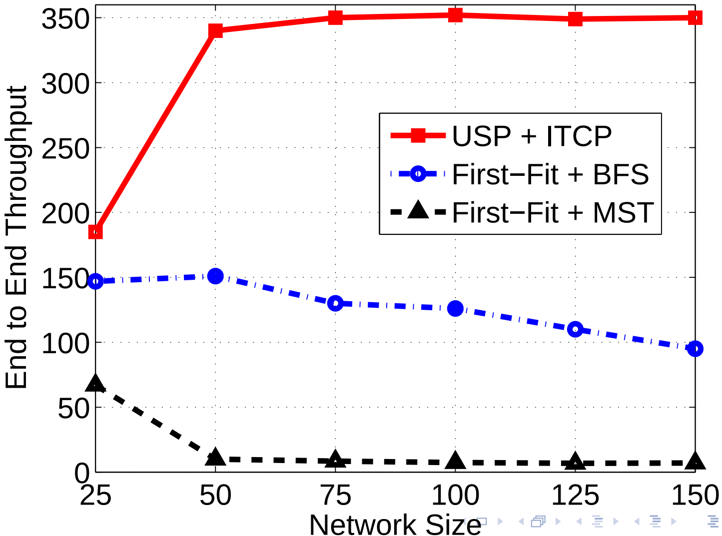
Tree Construction Algorithms

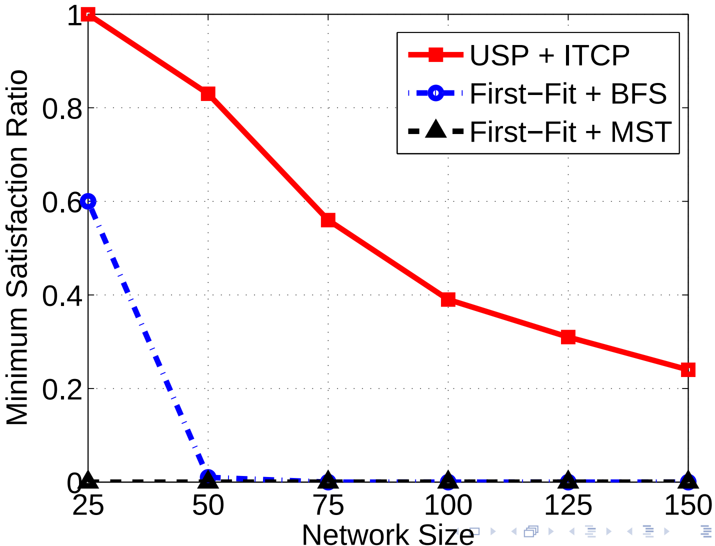
Example Trees



Tree Construction + Scheduling

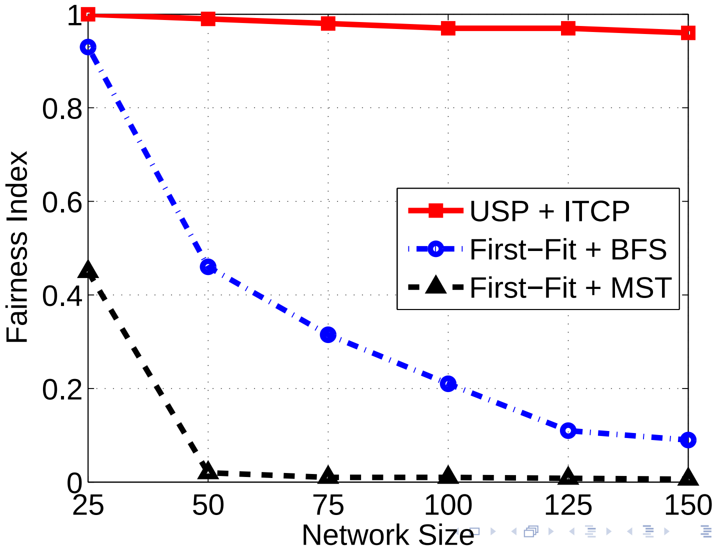
End-to-end throughput




Minimum Satisfaction Ratio
Network Size
0
0.2
0.4
0.6
0.8
1
25
50
75
100
125
150
USP + ITCP
First−Fit + BFS
First−Fit + MST

Tree Construction + Scheduling

Fairness index



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