On the Use of Smart Antennas in Multi-Hop Wireless Networks

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Introduction

- Smart Antennas
  - Range from switched beam, adaptive arrays to MIMO systems
  - Well researched at the PHY layer [IEEE-JSAC2003]
  - Single hop network performance obtainable [Infocom2004]
- What about multi-hop networks?
  - Magnitude of improvements
  - Optimal strategy for a network scenario
  - Best performing antenna type
- Study the performance and answer some of the fundamental questions

Outline

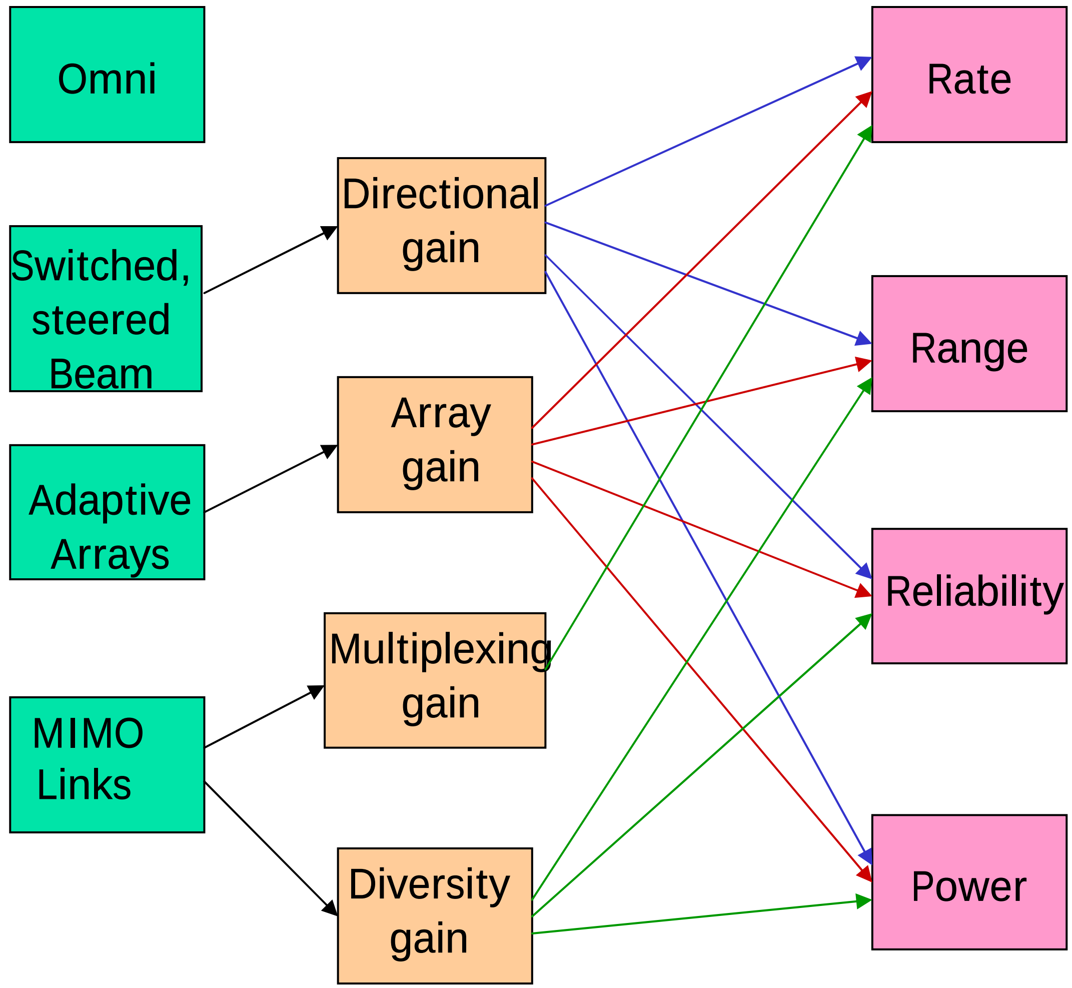
- Background
- Strategies
- Centralized algorithm
- Evaluation of strategies
- Evaluation of Technologies
- Conclusions

Smart Antenna Technologies

- Switched beam antennas
  - Energy focused in specific directions
  - Use pre-determined beam pattern
- Steered beam antennas
  - Beams steered through a range of angles
- Adaptive arrays
  - Adaptive beam pattern in multi-path environments to maximize the SNR on the link (array gain); adaptive nulling of interference
- Multiple Input Multiple Output (MIMO) systems
  - Exploit rich multipath scattering
  - Provide spatial multiplexing and diversity gains

Strategies

- Rate
  - increase capacity
- Range
  - increase communication range
- Reliability
  - increase link reliability (BER & PER)
- Power
  - reduce transmit power consumption



Centralized Algorithm

- Goal: compute Throughput for the technology and strategy
  - Step1: Routing
    - Compute shortest path using the gains and technology
    - Generate flow contention graph
  - Step 2: Scheduling
    - Obtain channel matrix, technology, DOF and strategy of each link
      - DOF – Resources available for use
    - Compute effective DOF based on scattering
    - Schedule link while all scheduled links within contention region can operate
    - Update effective resources
    - Terminate if all possible links are scheduled
  - Step 3: Computation of effective rates based on path loss

Evaluation Methodology

- Ns2 simulator
- MAC protocols for the different technologies implemented as a centralized scheduler
- Max-min fairness model used with shortest path routing
- Network conditions
  - Line of sight (LOS), multipath scattering, multipath fading
- 100 Nodes in a grid of 400m*400m or 1000m*1000m
- Bandwidth of 2 Mbps
- Number of flows from 1 to 50
- Number of Antenna Elements from 1 to 12
- Metrics
  - Throughput,
  - Throughput/Energy

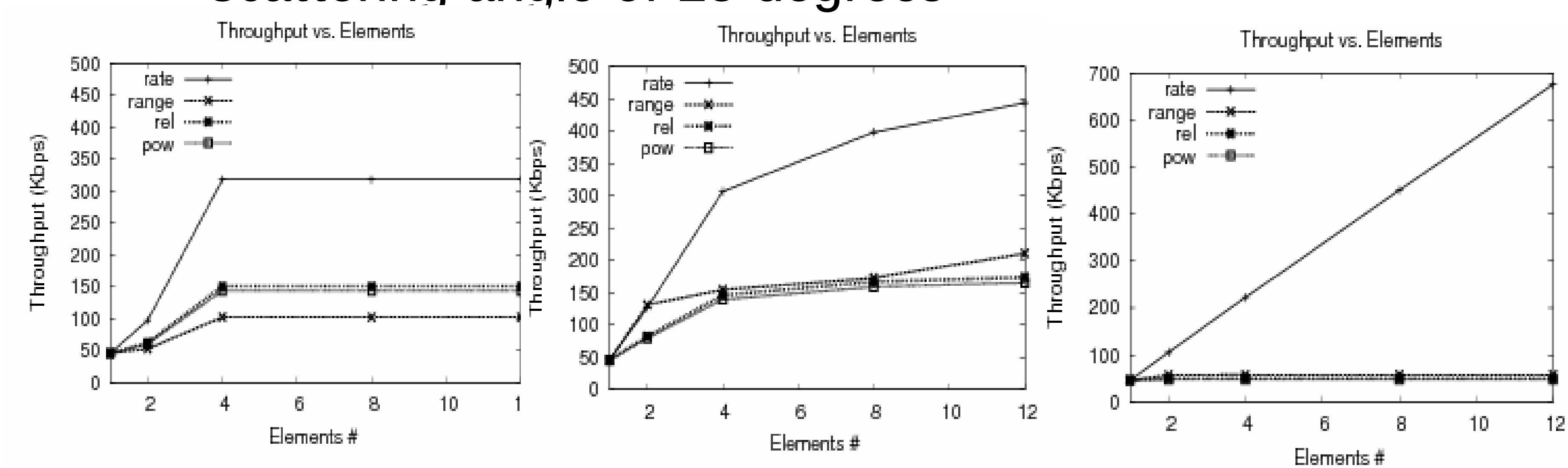
Evaluation Outline

- Strategies
  - Throughput
- Antenna Technology
  - Throughput
    - Scattering and Fading
    - Elements and Density
  - Throughput/Energy
    - Elements and Load

(Other metrics and dimensions in paper)

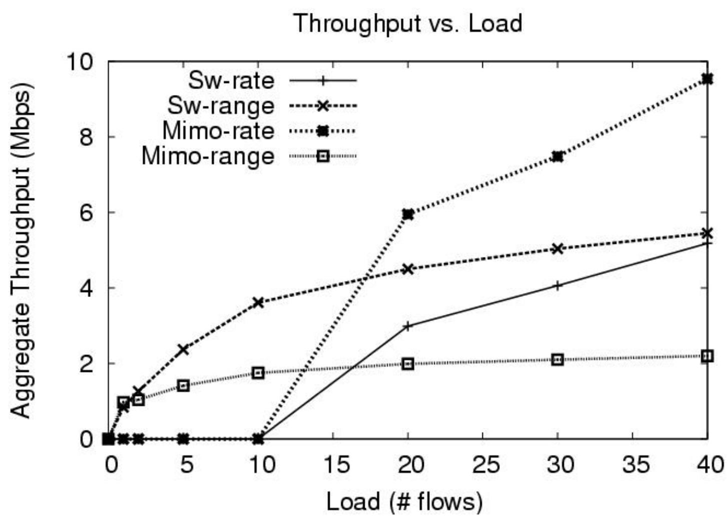
Evaluation of strategies (1/2)

- Default parameters
  - Node degree of 12
  - Fading loss 5%
  - 50 flows and 4 antenna elements per node
  - Scattering angle of 25 degrees



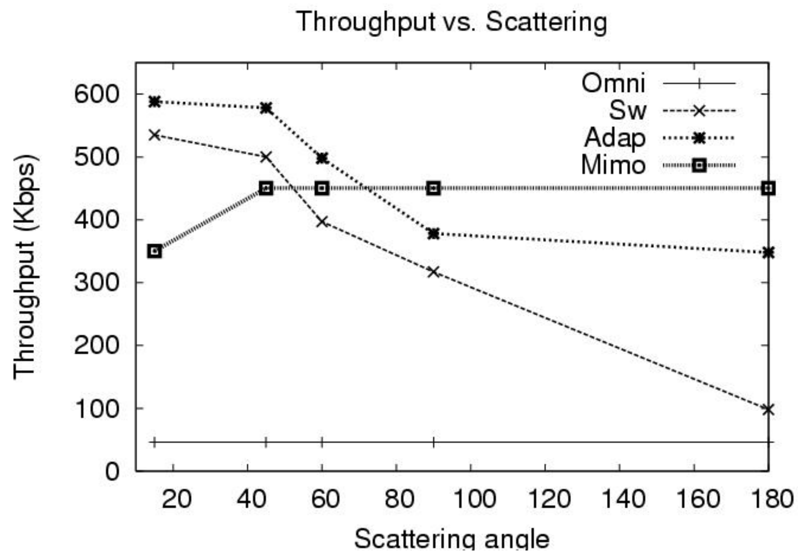
a) Switched beam b) Adaptive c) MIMO

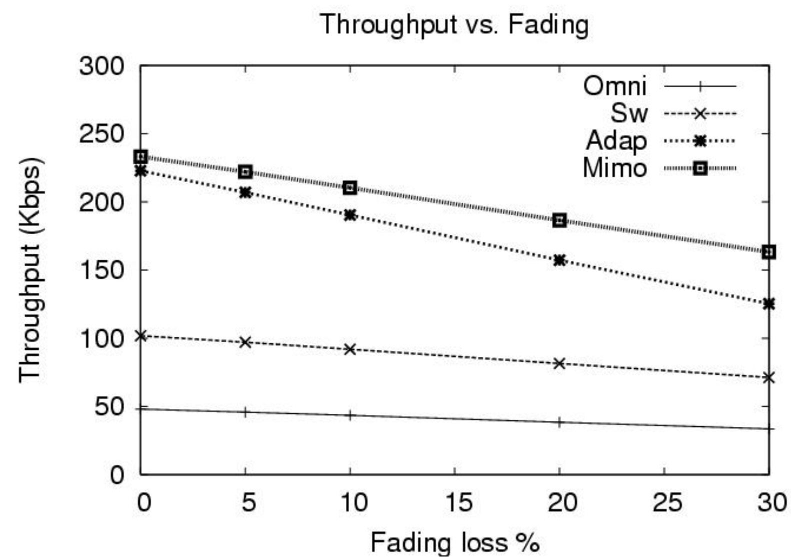
Evaluation of strategies (2/2)



- Low Density of users (node degree 3)
  - Range is good at low loads, but rate at higher loads!
- In general, rate is the best strategy
- Throughput per unit Energy has relative orders based on transmit power and circuit power

Evaluation of Technologies (1/3)

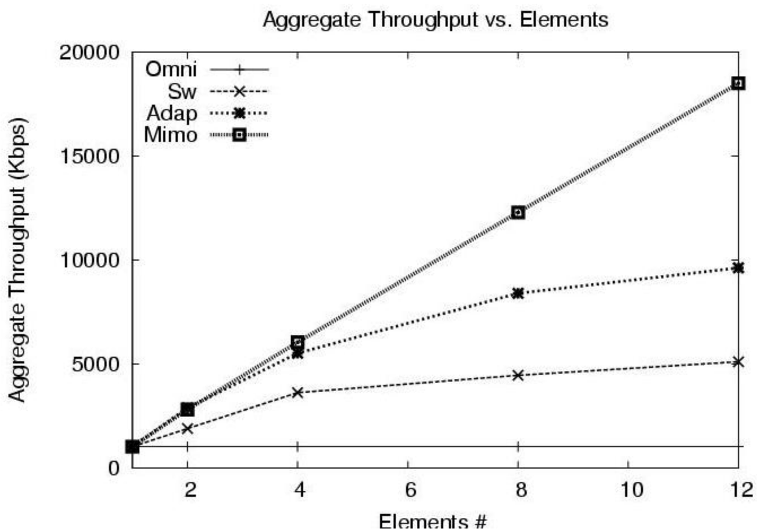


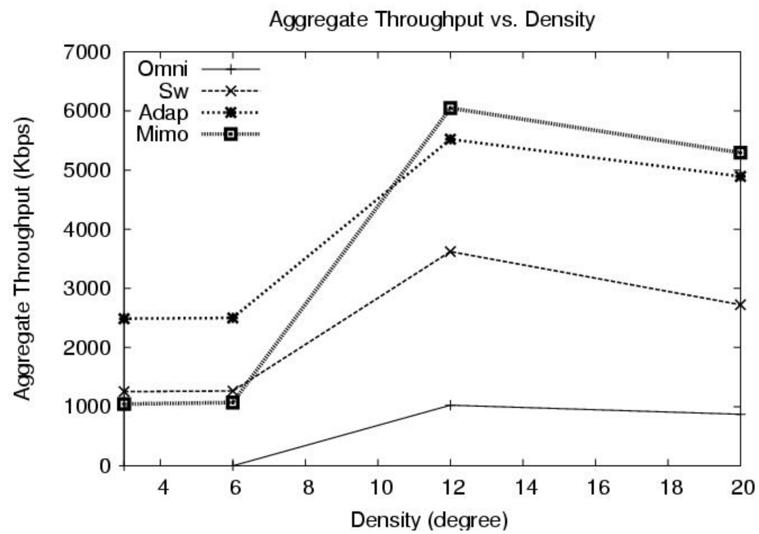


Throughput vs Scattering and Fading

- At large scattering angles, all loads and densities, MIMO performs the best
- At low-moderate scattering angles, high loads and high densities adaptive is the best
- Fading loss impacts all rate strategies alike

Evaluation of Technologies (2/3)

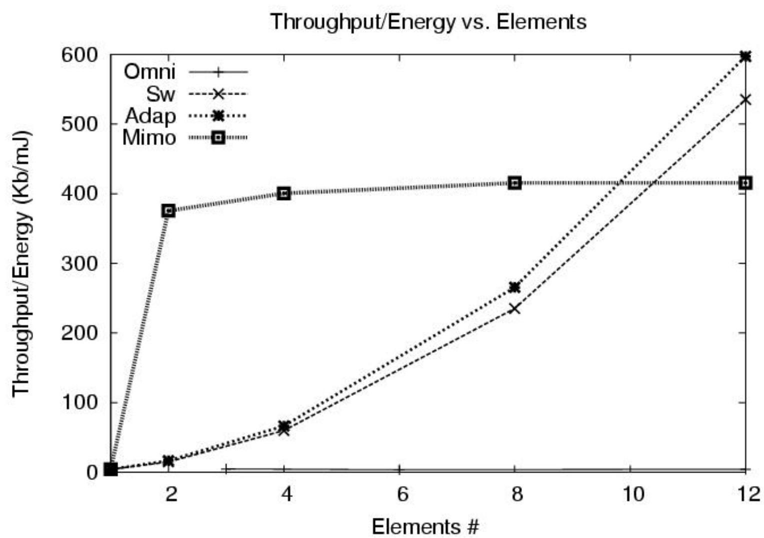


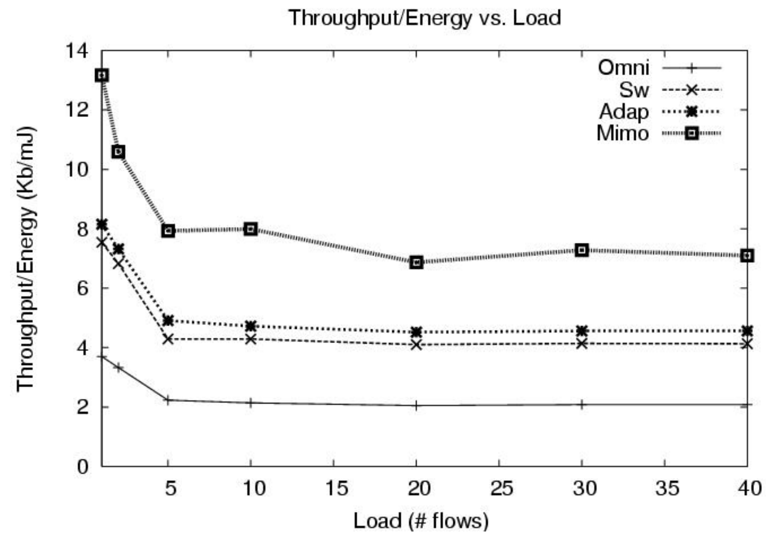


Throughput vs Elements and Density

- MIMO gives linear throughput increase with elements
- At low scatterings and low densities adaptive performs the best, with MIMO's range performing the worst

Evaluation of Technologies (3/3)





- Throughput/Energy vs Elements and Load
  - When Pt >> Pc , pow strategy is used
    - MIMO Performs best due to diversity gain
    - But at large number of elements, the diversity gain benefit is not significant compared to array gain
  - When Pt ~> Pc, rate strategy
    - MIMO performs best due to spatial multiplexing gain

Key Inferences

- MIMO with spatial multiplexing provides most scalability(ability to use all resources)
- Most DOFs to be used for rate and not too many for diversity or range
- Optimal strategy depends on the network parameters and objectives
  - Range reduces spatial reuse and MIMO suffers even with sufficient scattering
  - For low densities range is the best strategy
- Adaptive arrays perform better than switched beams only with large number of elements and scattering

Conclusions

- Comprehensive evaluation of different antenna technologies and strategies
- Design rules for the optimal strategy and technology of operation for different network conditions and different performance objectives
- Applications
  - Design rules can be used by network designers in the appropriate choice of antenna technology and strategy of operation in their networks
  - Help deployment decisions based on cost to benefit ratio

Thank You !

Please refer

http://www.ece.gatech.edu/research/GNAN