Smart Scheduling and Dumb Antennas

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Opportunistic Communication

One line summary:

Transmit when and where the channel is good.
Outline of Talk

- Downlink scheduling for Qualcomm's HDR (High Data Rate) system. (Tse 99)
- Opportunistic beamforming using dumb antennas (Viswanath, Tse and Laroia 2001)
Wireless Fading Channels

- fading due to constructive and destructive interference between multiple signal paths;
- **Rayleigh** fading: superposition of many small paths
- **Rician** fading: many small paths plus one dominant path
Qualcomm HDR’s DownLink

HDR (1xEV-DO): a wireless data system operating on IS-95 band (1.25 MHz)

- HDR downlink operates on a time-division basis.
- Scheduler decides which user to serve in each time-slot.
Downlink Multiuser Fading Channel

What is the sum capacity with channel state feedback?
Each user undergoes independent Rayleigh fading with average received signal-to-noise ratio $\text{SNR} = 0\text{dB}$.
To Fade or Not to Fade?

Sum Capacity of fading channel much larger than non-faded channel!
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\[
\text{effective SNR at time } t = \max_{1 \leq k \leq K} |h_k(t)|^2.
\]
Multiuser Diversity

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- Multiuser diversity arises from independent fading channels across different users.
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- **Diversity** in wireless systems arises from independent signal paths.
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- Multiuser diversity arises from independent fading channels across different users.
- **Fundamental difference**: Traditional diversity modes pertain to point-to-point links, while multiuser diversity provides network-wide benefit.
Challenge is to exploit multiuser diversity while sharing the benefits fairly and timely to users with asymmetric channel statistics.
Hitting the Peaks

- Want to serve each user when it is near its peak within a latency time-scale $t_c$. 
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• In a large system, at any time there is likely to be a user whose channel is near its peak.
Proportional Fair Scheduler

At time slot $t$, given

1) users’ average throughputs $T_1(t), T_2(t), \ldots, T_K(t)$ in a past window.

2) current requested rates $R_1(t), R_2(t), \ldots, R_K(t)$

transmit to the user $k^*$ with the largest

$$\frac{R_k(t)}{T_k(t)}.$$

Average throughputs $T_k(t)$ can be updated by an exponential filter with time constant $t_c$. 
Throughput of HDR Scheduler: Symmetric Users

Mobile environment: 3 km/hr, Rayleigh fading

Fixed environment: 2Hz Rician fading with $E_{\text{fixed}}/E_{\text{scattered}} = 5$. 
Channel varies faster and has more dynamic range in mobile environments.
Throughput of Scheduler: Asymmetric Users

(Jalali, Padovani and Pankaj 2000)
Inducing Randomness

- Scheduling algorithm exploits the nature-given channel fluctuations by hitting the peaks.
- If there are not enough fluctuations, why not purposely induce them?
Dumb Antennas

Received signal at user $k$: \[ \left[ \sqrt{\alpha(t)} h_{1k}(t) + \sqrt{1 - \alpha(t)} \exp(j\theta(t)) h_{2k}(t) \right] x(t). \]
Slow Fading Environment: Before

![Graph showing supportable rates for two users over time slots. The x-axis represents time slots ranging from 0 to 3000, and the y-axis represents supportable rates ranging from 80 to 220. Two curves are present, one for User 1 (red) and one for User 2 (blue).]
Consider first a slow fading environment when channels of the users are fixed (but random).

Dumb antennas can approach the performance of true beamforming when there are many users in the systems.
Opportunistic versus True Beamforming

- If the gains $h_{1k}$ and $h_{2k}$ are known at the transmitter, then true beamforming can be performed:

\[ \alpha = \frac{|h_{1k}|^2}{|h_{1k}|^2 + |h_{2k}|^2} \]

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Dumb antennas randomly sweep out a beam and opportunistically sends data to the user closest to the beam.

Opportunistic beamforming can approach the performance of true beamforming when there are many users in the systems, but with much less feedback and channel measurements.
Opportunistic Beamforming: Fast Fading

Improves performance in fast fading Rician environments by spreading the fading distribution.
Overall Performance Improvement

![Graph showing overall performance improvement]

- Mobile environment: 3 km/hr, Rayleigh fading
- Fixed environment: 2Hz Rician fading with \( \frac{E_{\text{fixed}}}{E_{\text{scattered}}} = 5 \).
Comparison to Space Time Codes

- Space time codes: intelligent use of transmit diversity to improve reliability of point-to-point links.
- In contrast, opportunistic beamforming requires no special multi-antenna encoder or decoder nor MIMO channel estimation.
- In fact the mobiles are completely oblivious to the existence of multiple transmit antennas.
- Antennas are truly **dumb**, but yet can surpass performance of space time codes.
Cellular System: Opportunistic Nulling

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- Multiuser diversity allows interference avoidance.
- Dumb antennas provides opportunistic nulling for users in other cells.
- Particularly important in interference-limited systems with no soft handoff.
Traditional CDMA Downlink Design

- orthogonalize users (via spreading codes)
- Makes individual point-to-point links reliable by averaging:
  - interleaving
  - multipath combining,
  - soft handoff
  - transmit/receive antenna diversity
- Important for voice with very tight latency requirements.
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Downlink Design: Modern View

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- Wants large and fast fluctuations of both channel and interference so that we can ride the peaks.
- Exploits more relaxed latency requirements of data as well as MAC layer packet scheduling mechanisms.
A Broader Perspective

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- Rely on sophisticated physical layer signal processing techniques: smart antennas, interference suppression, etc.....
- Future progress will come from putting all this in a broader **network** context.