Smart Scheduling and Dumb Antennas

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September 20, 2002

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Opportunistic Communication

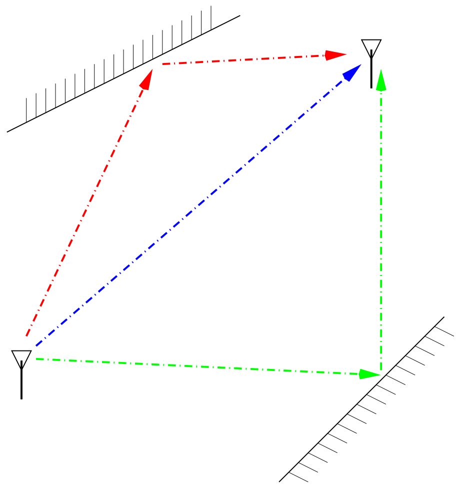
One line summary:

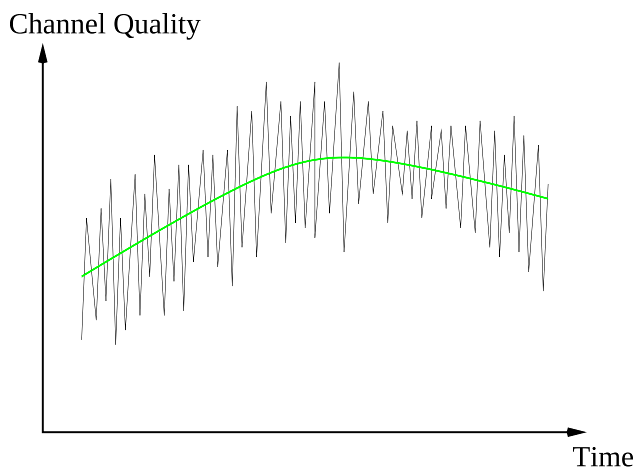
Transmit when and where the channel is good.

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

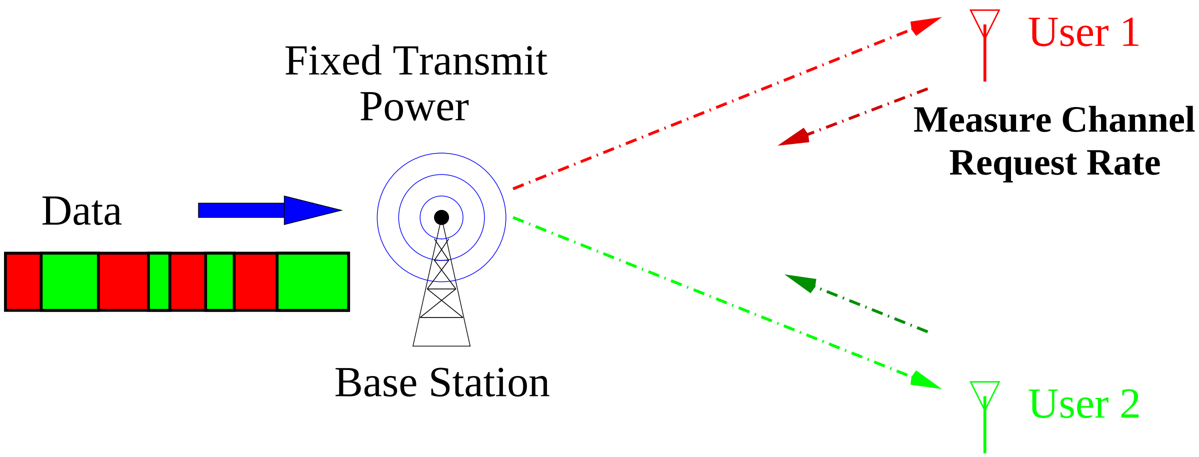




- fading due to constructive and destructive interference between multiple signal paths;
- Rayleigh fading: superposition of many small paths
- Rician fading: many small paths plus one dominant path

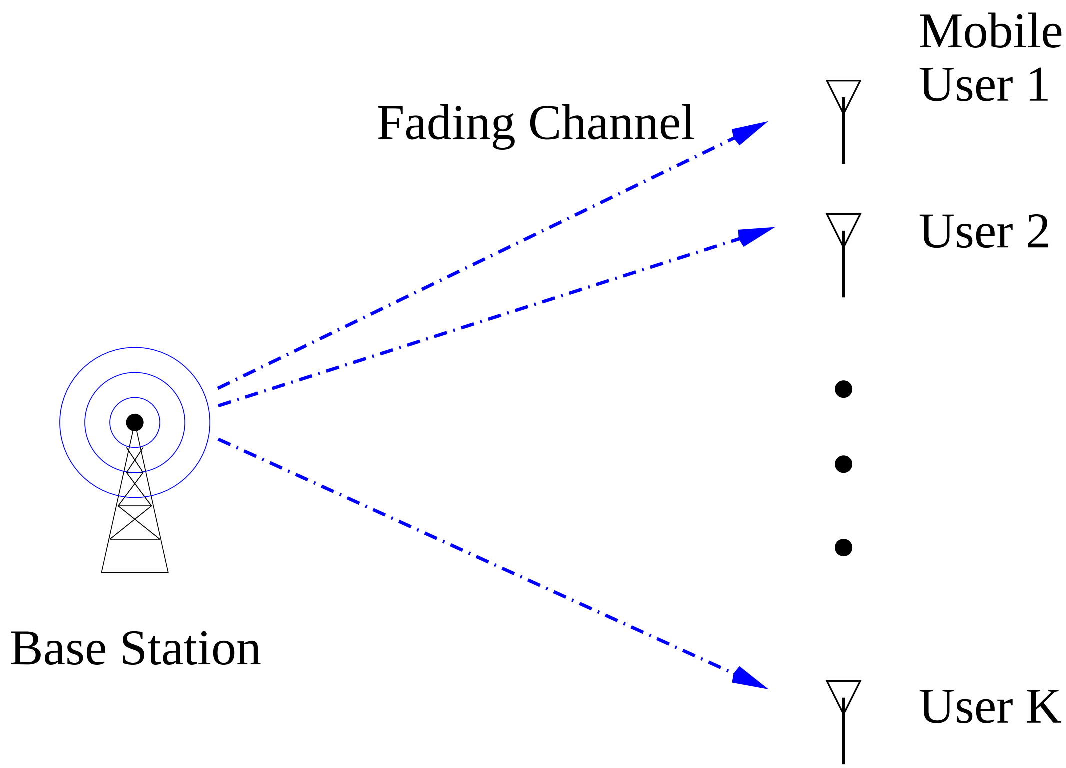
Qualcomm HDR's DownLink

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.

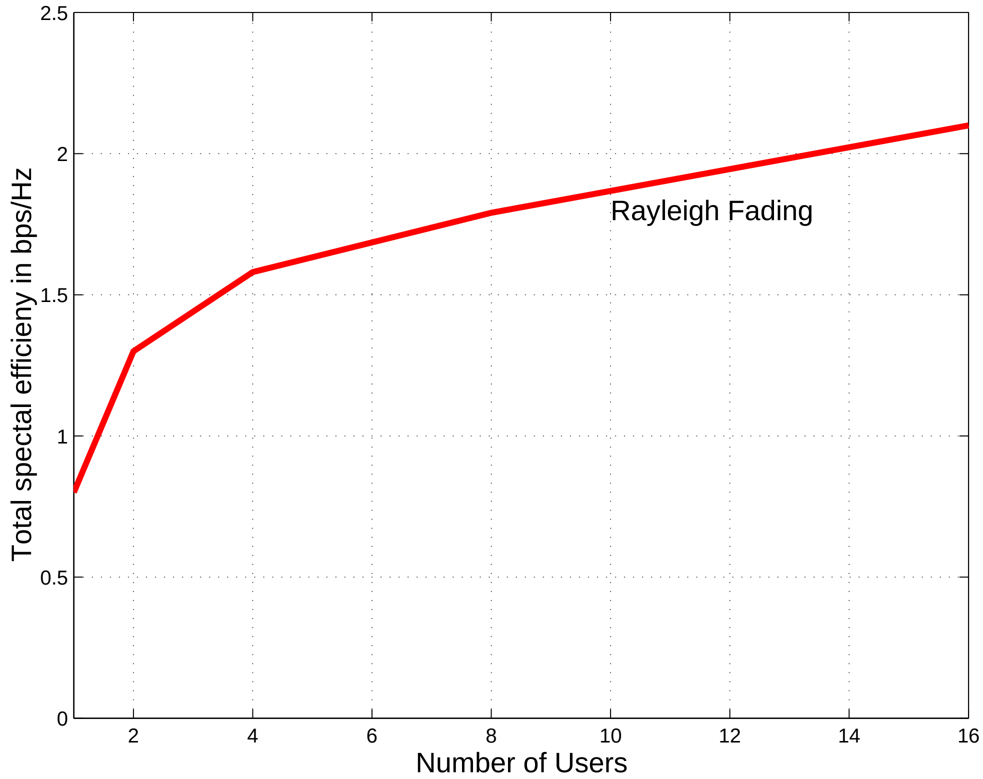
Downlink Multiuser Fading Channel



What is the sum capacity with channel state feedback?

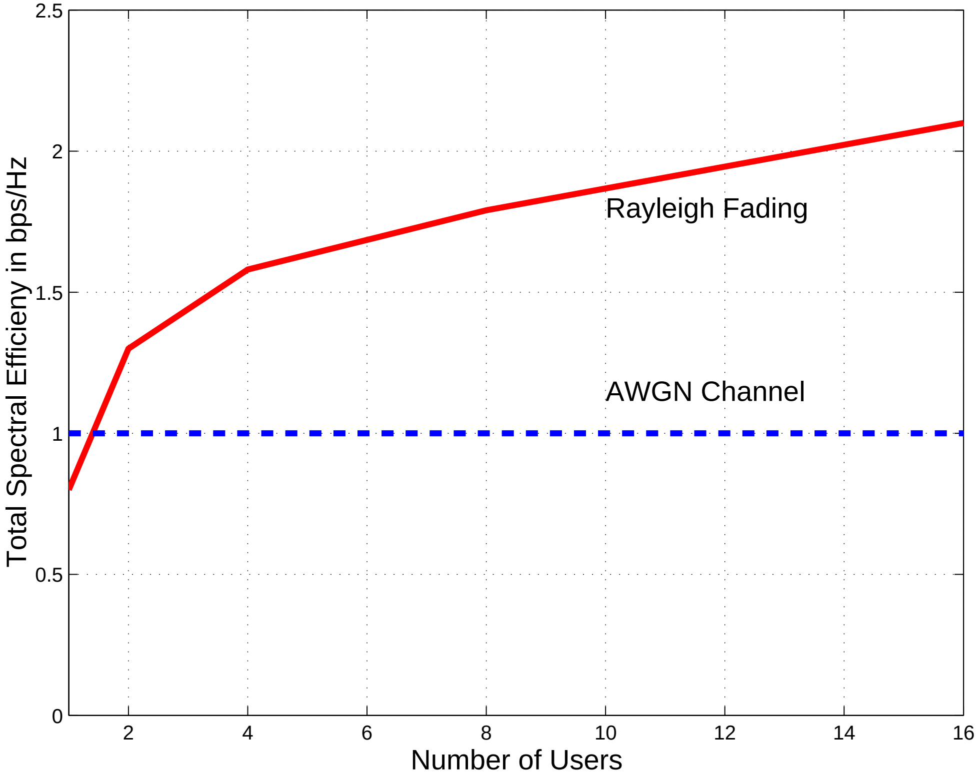
Information Theoretic Capacity of Downlink

(Tse 97)



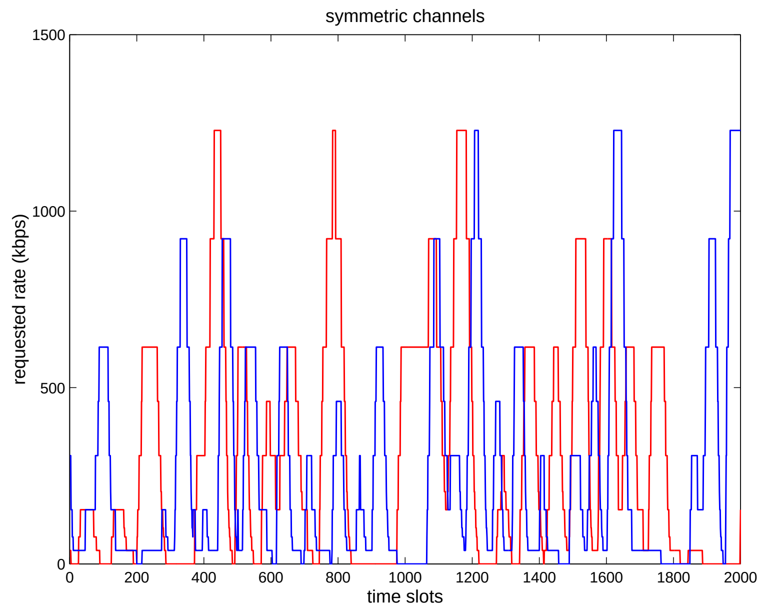
Each user undergoes independent Rayleigh fading with average received signal-to-noise ratio SNR $= 0$dB.

To Fade or Not to Fade?



Sum Capacity of fading channel much larger than non-faded channel!

Multiuser Diversity



- In a large system with users fading independently, there is likely to be a user with a very good channel at any time.
- Long term total throughput can be maximized by always serving the user with the strongest channel.

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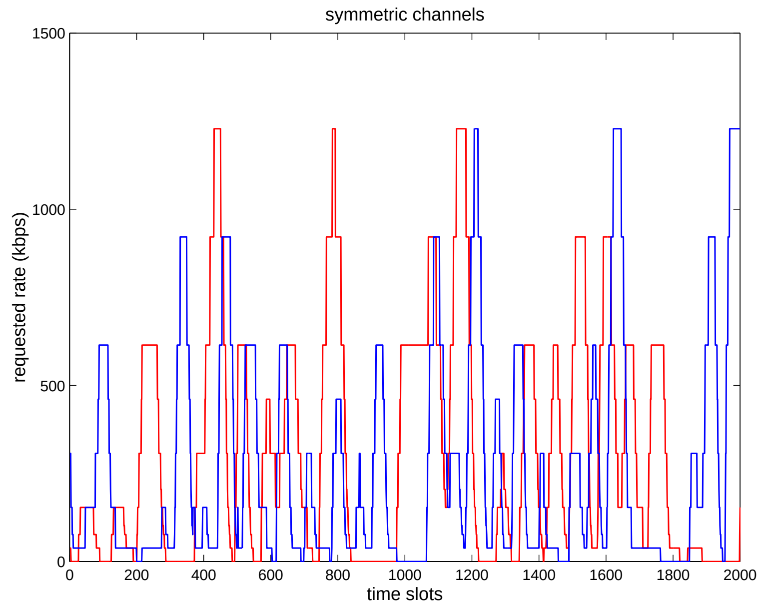

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$$\text{effective SNR at time } t = \max_{1 \le k \le K} |h_k(t)|^2.$$

Multiuser Diversity

- Diversity in wireless systems arises from independent signal paths.
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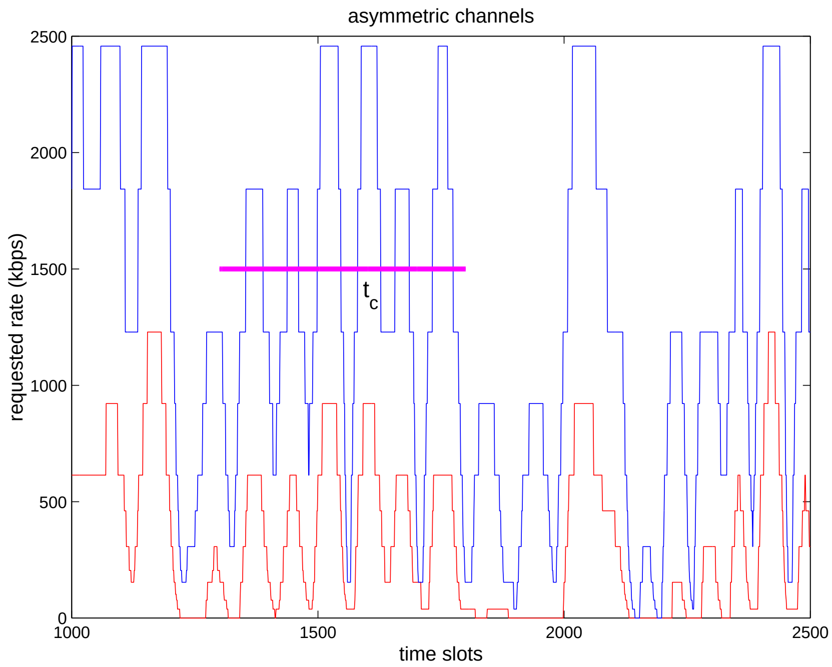
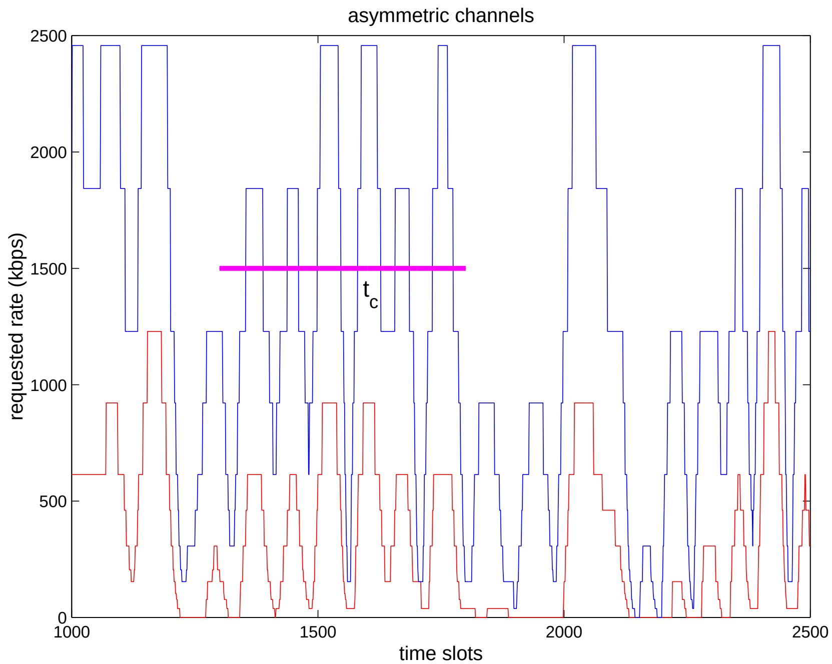
- Diversity in wireless systems arises from independent signal paths.
- Traditional forms of diversity includes time, frequency and antennas.
- Multiuser diversity arises from independent fading channels across different users.
- Fundamental difference: Traditional diversity modes pertain to point-to-point links, while multiuser diversity provides network-wide benefit.

Fairness and Delay



Challenge is to exploit multiuser diversity while sharing the benefits fairly and timely to users with asymmetric channel statistics.

Hitting the Peaks



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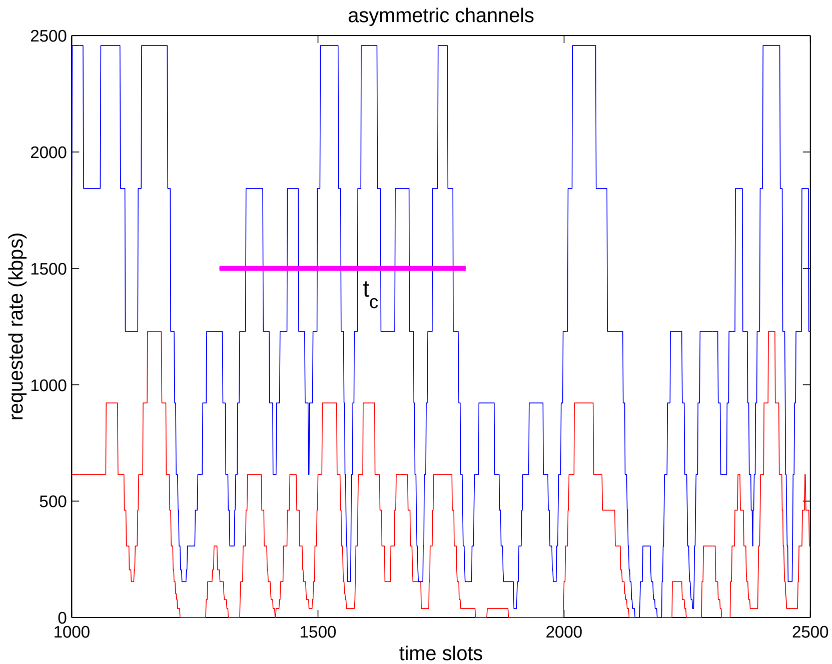


- Want to serve each user when it is near its peak within a latency time-scale t_c.
- In a large system, at any time there is likely to be a user whose channel is near its peak.

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.

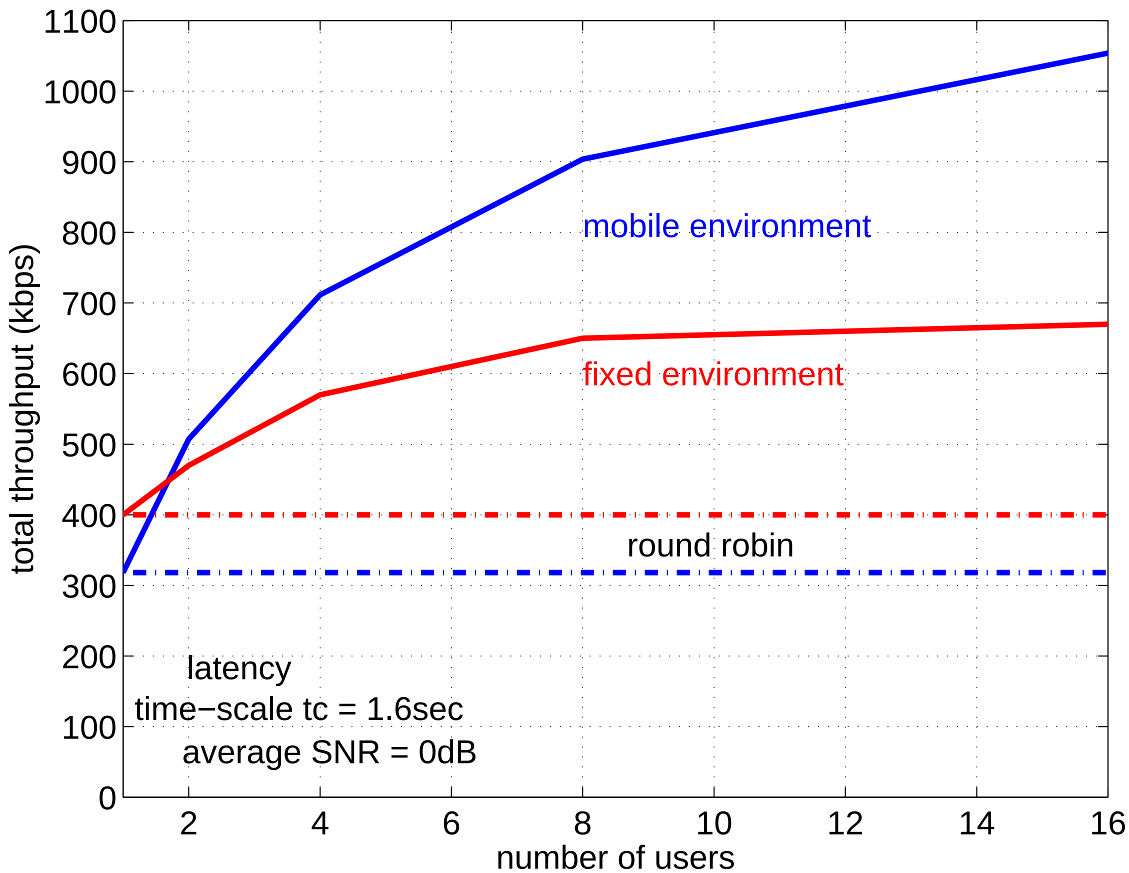
2) current requested rates $R_1(t), R_2(t), \ldots, R_K(t)$

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.

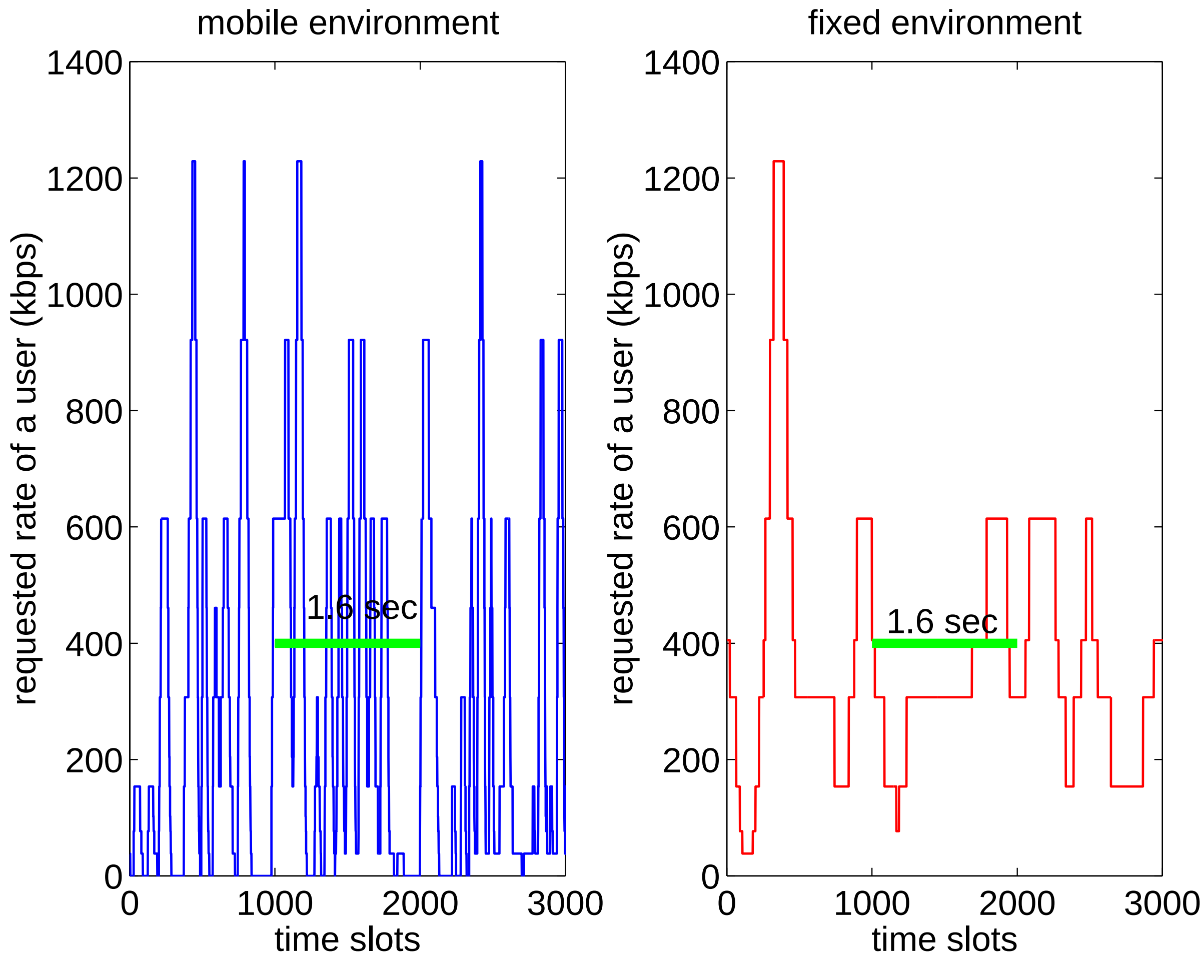
Throughput of HDR Scheduler: Symmetric Users



Mobile environment: 3 km/hr, Rayleigh fading

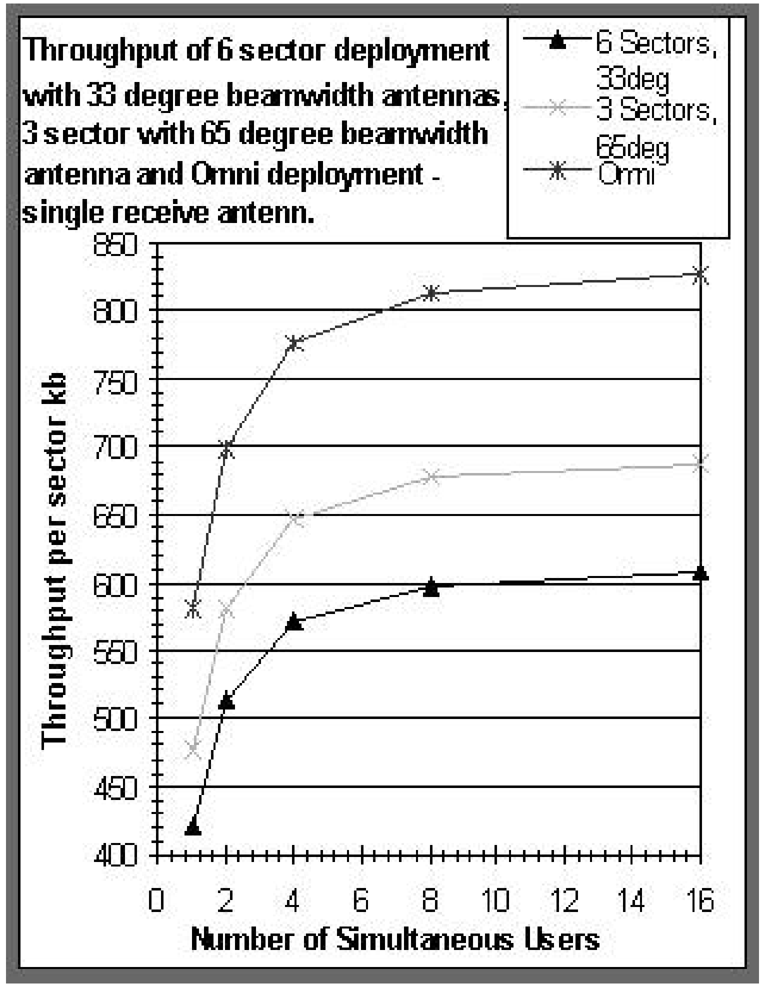
Fixed environment: 2Hz Rician fading with $E_{\text{fixed}}/E_{\text{scattered}} = 5$.

Channel Dynamics



Channel varies faster and has more dynamic range in mobile environments.

Throughput of Scheduler: Asymmetric Users

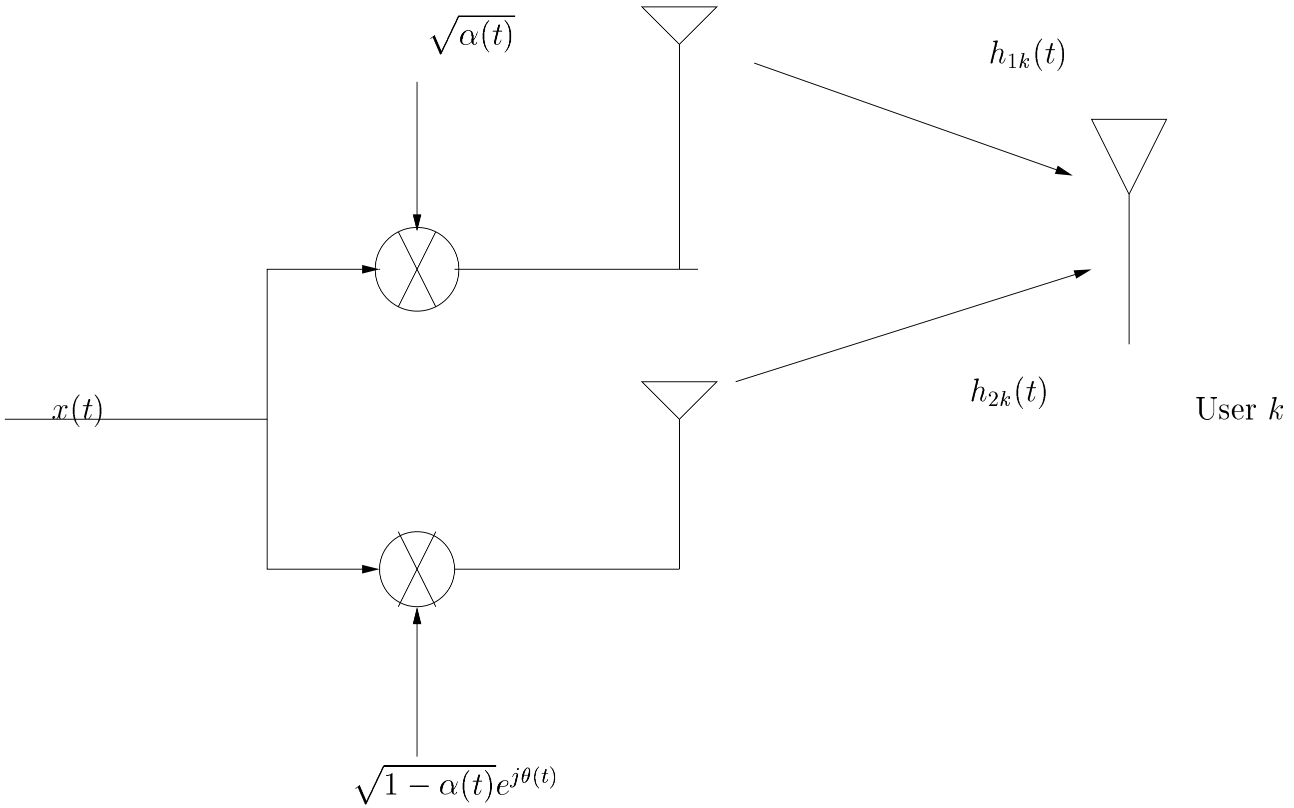


(Jalali, Padovani and Pankaj 2000)

Inducing Randomness

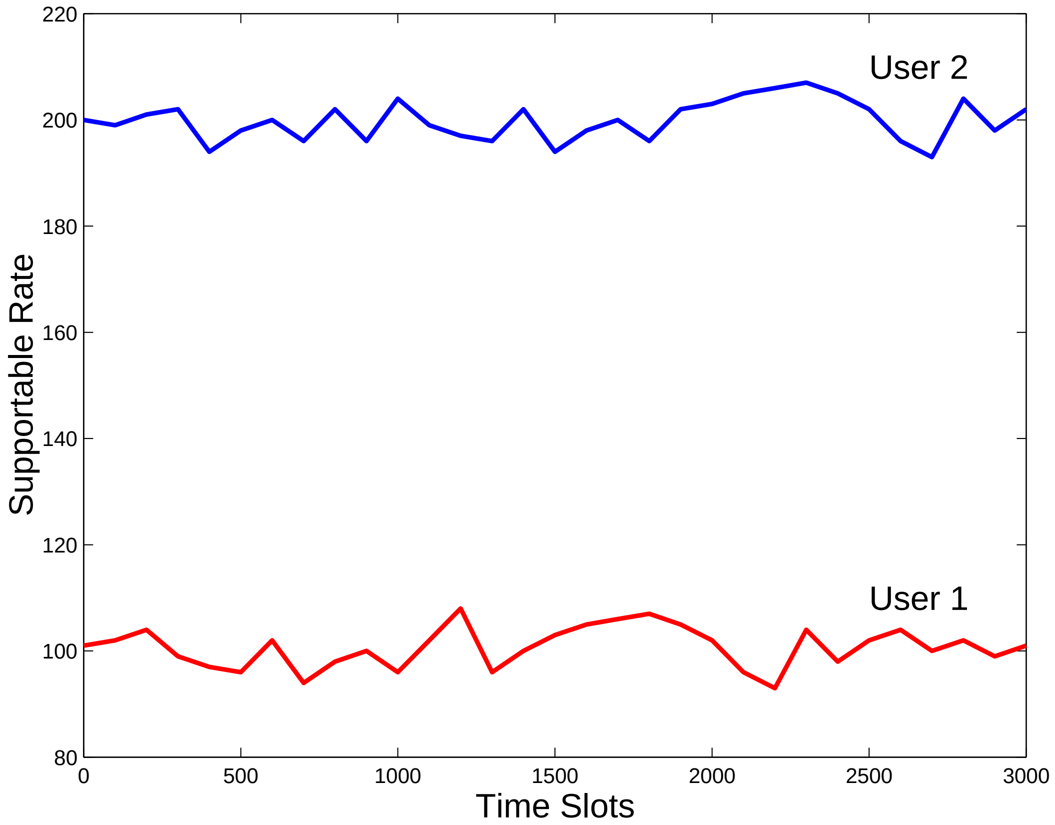
- Scheduling algorithm exploits the nature-given channel fluctuations by hitting the peaks.
- If there are not enough fluctuations, why not purposely induce them?

Dumb Antennas

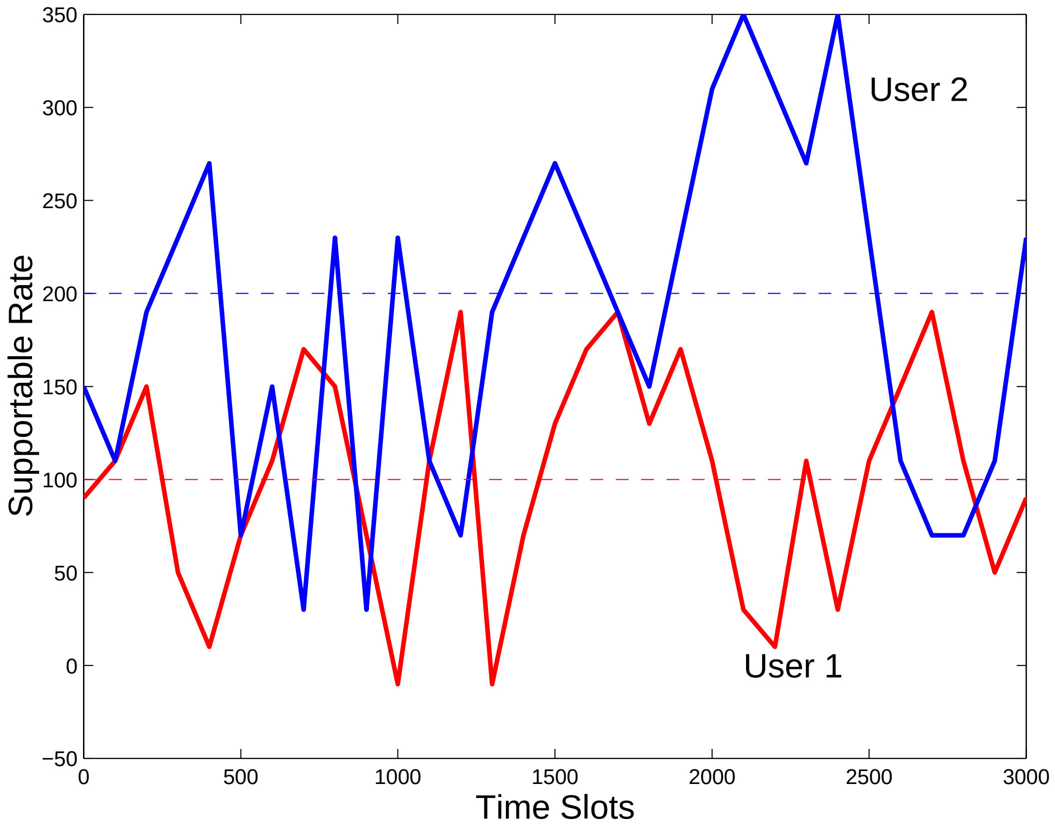


Received signal at user k: $\left[\sqrt{\alpha(t)}h_{1k}(t) + \sqrt{1-\alpha(t)}\exp(j\theta(t))h_{2k}(t)\right]x(t).$

Slow Fading Environment: Before

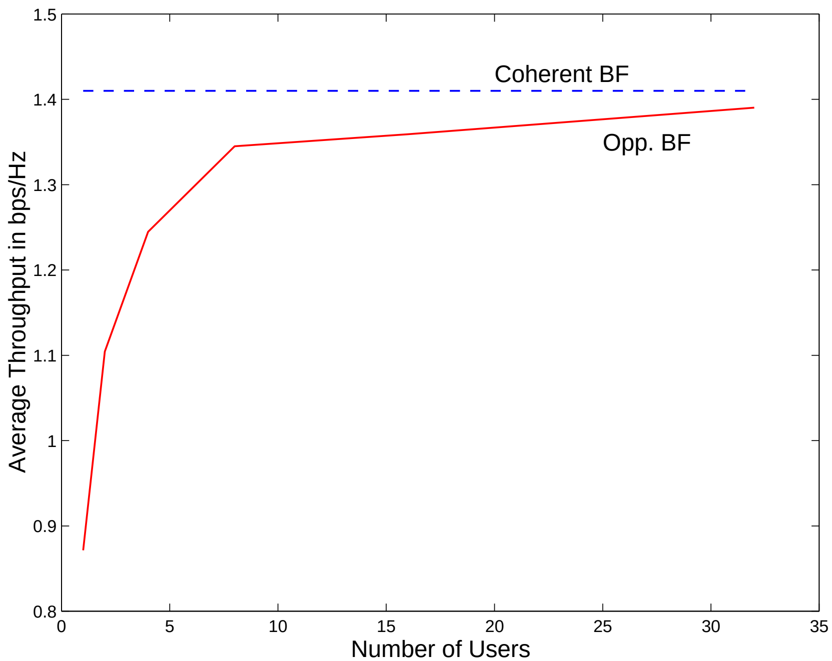


After



User 2
User 1
Supportable Rate
Time Slots
350
300
250
200
150
100
50
0
−50
0
500
1000
1500
2000
2500
3000

Opportunistic Beamforming: Slow Fading



- 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:

$$
\begin{aligned}
\alpha &= \frac{|\, h_{1k} \,|^2}{|\, h_{1k} \,|^2 + |\, h_{2k} \,|^2} \\
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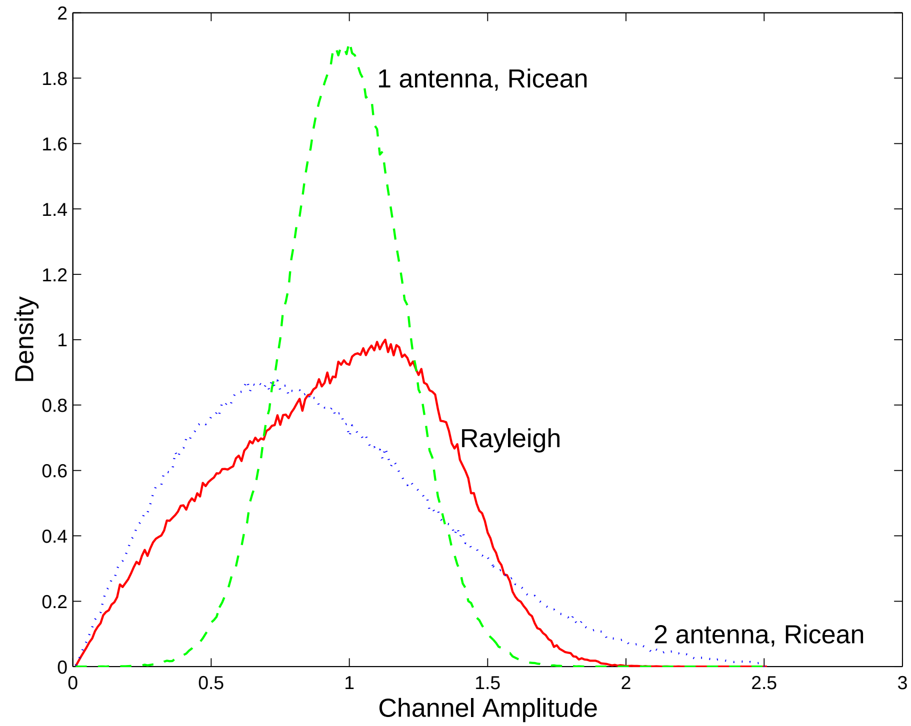
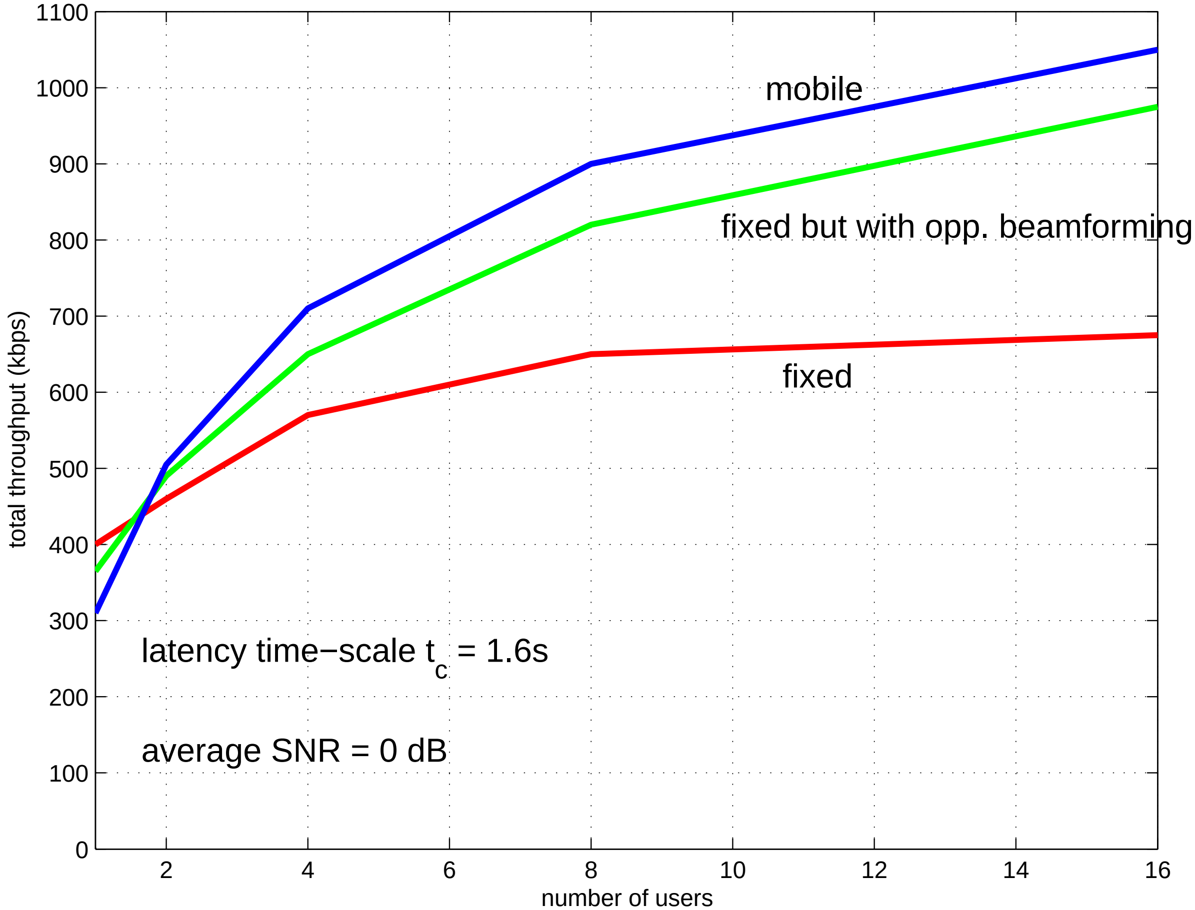
- Dumb antennas randomly sweep out a beam and opportunistically sends data to the user closest to the beam.
- Opportunistic beamforming can approach the performance of true beamforming when there are many users in the systems, but with much less feedback and channel measurements.

Opportunistic Beamforming: Fast Fading



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

Overall Performance Improvement



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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

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- Makes individual point-to-point links reliable by averaging:
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- orthogonalize users (via spreading codes)
- Makes individual point-to-point links reliable by averaging:
    - interleaving
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    - transmit/receive antenna diversity
- Important for voice with very tight latency requirements.

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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.

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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.