

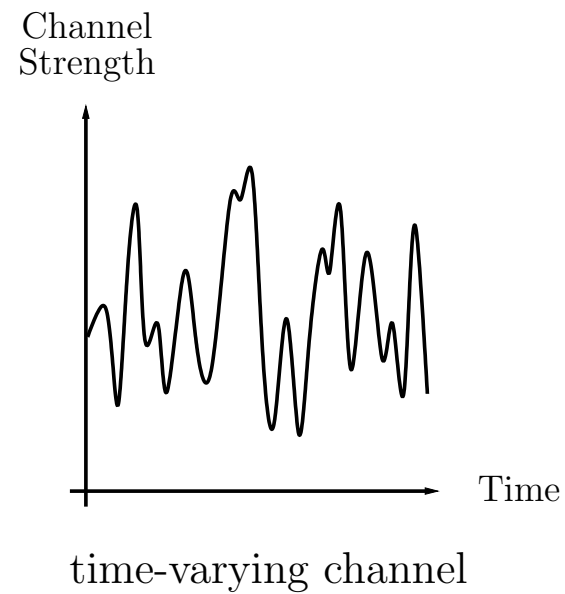
Opportunistic Communication: From Theory to Practice

David Tse
Department of EECS, U.C. Berkeley

March 9, 2005

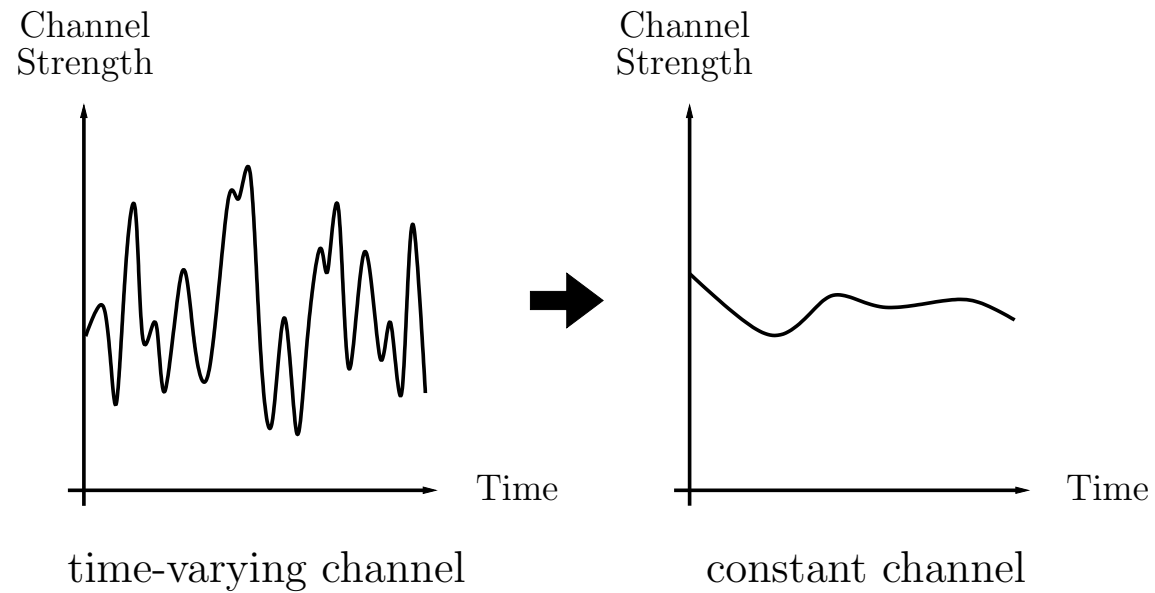
Viterbi Conference

Fundamental Feature of Wireless Channels: Time Variation



- multipath fading
- large-scale channel variations
- time-varying interference

Traditional Approach to Wireless System Design



Compensates for channel fluctuations.

Case Study: CDMA Systems

Two main compensating mechanisms:

1. Channel diversity:

- time diversity via coding and interleaving
- frequency diversity via Rake combining,
- macro-diversity via soft handoff
- transmit/receive antenna diversity

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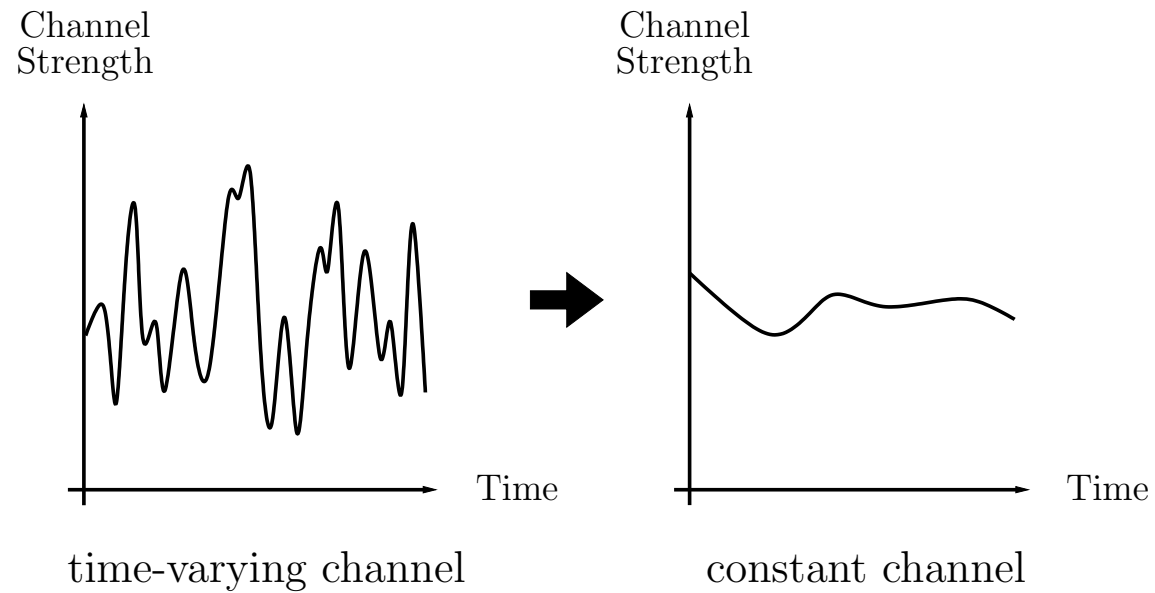
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- time diversity via coding and interleaving
- frequency diversity via Rake combining,
- macro-diversity via soft handoff
- transmit/receive antenna diversity

2. Interference management:

- power control
- interference averaging

What Drives this Approach?



Main application is **voice**, with very tight latency requirements.

Needs a **consistent** channel.

Opportunistic Communication: A Different View

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Exploits fading to achieve higher long-term throughput, but no guarantee that the "channel is always there".

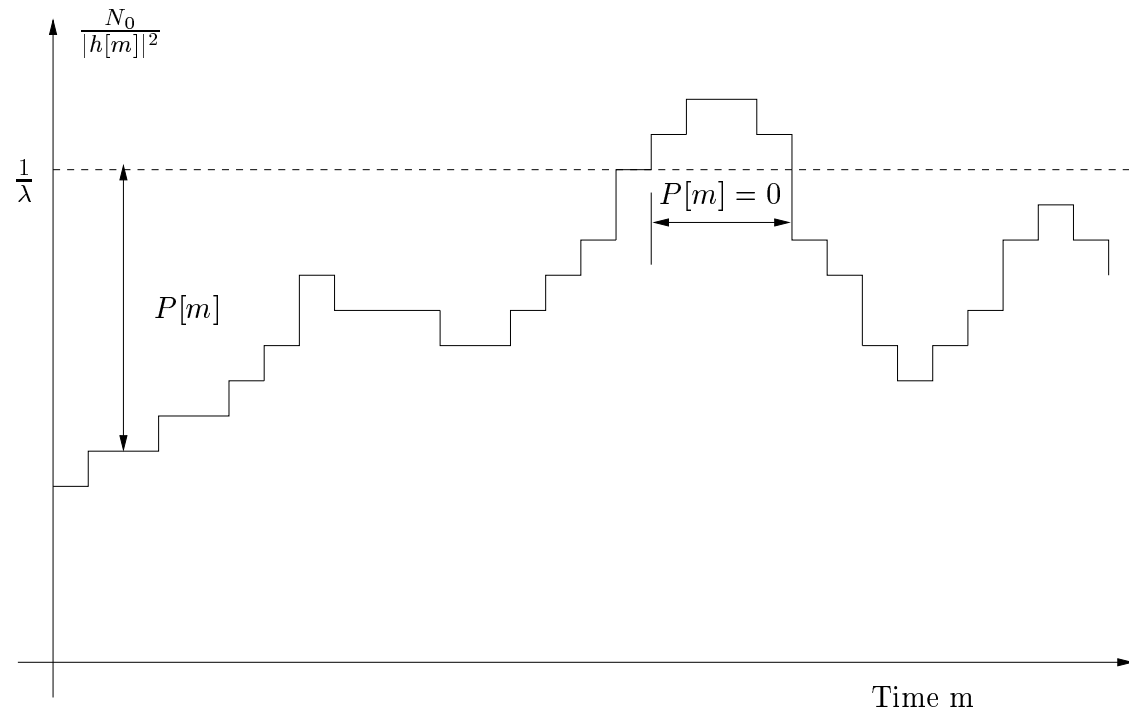
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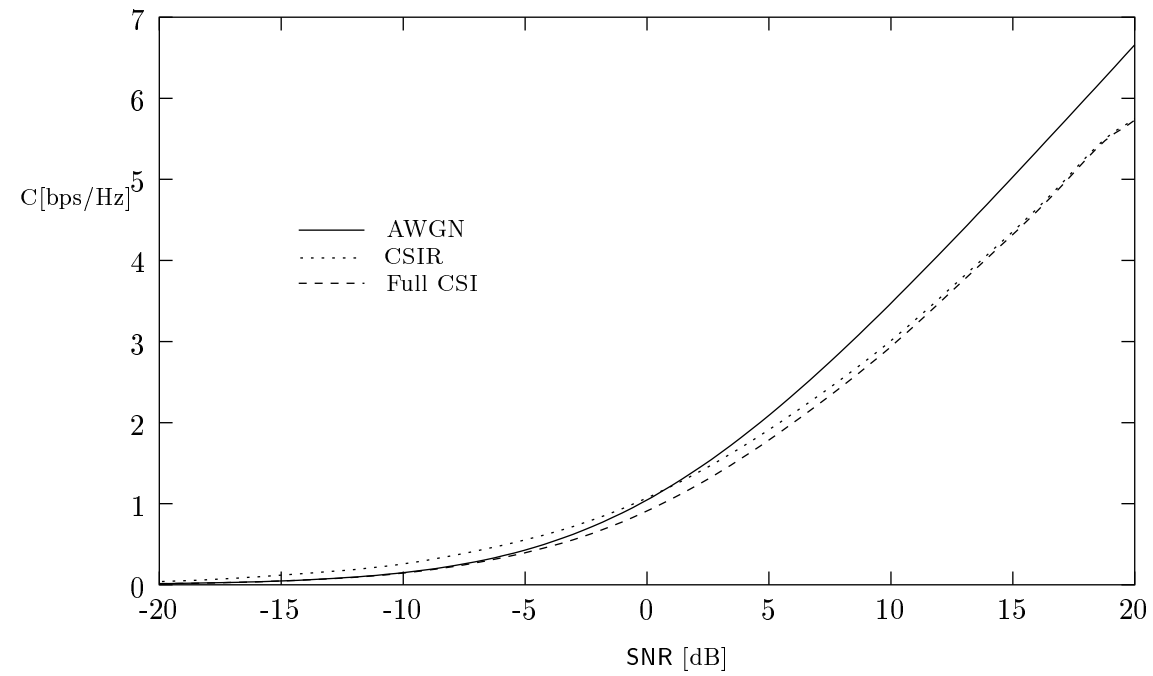
Appropriate for data with laxer latency requirements.

Point-to-Point Fading Channels

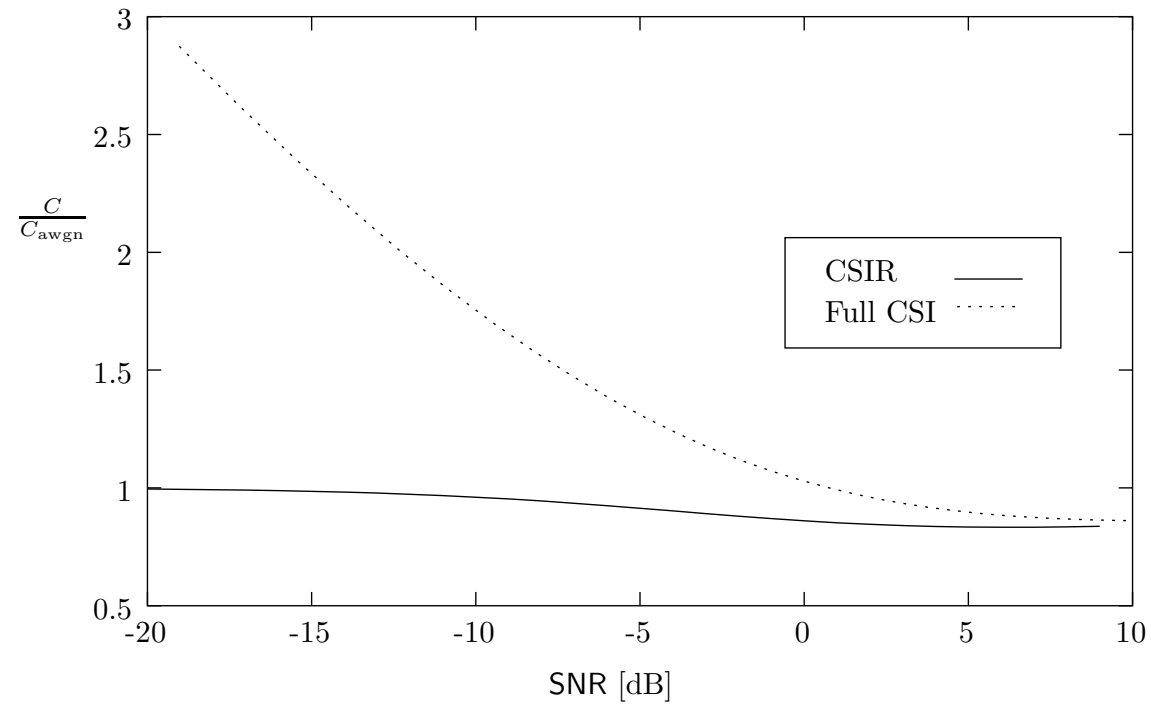


Capacity-achieving strategy is waterfilling over time. (Goldsmith and Varaiya 97)

Performance over Rayleigh Channel

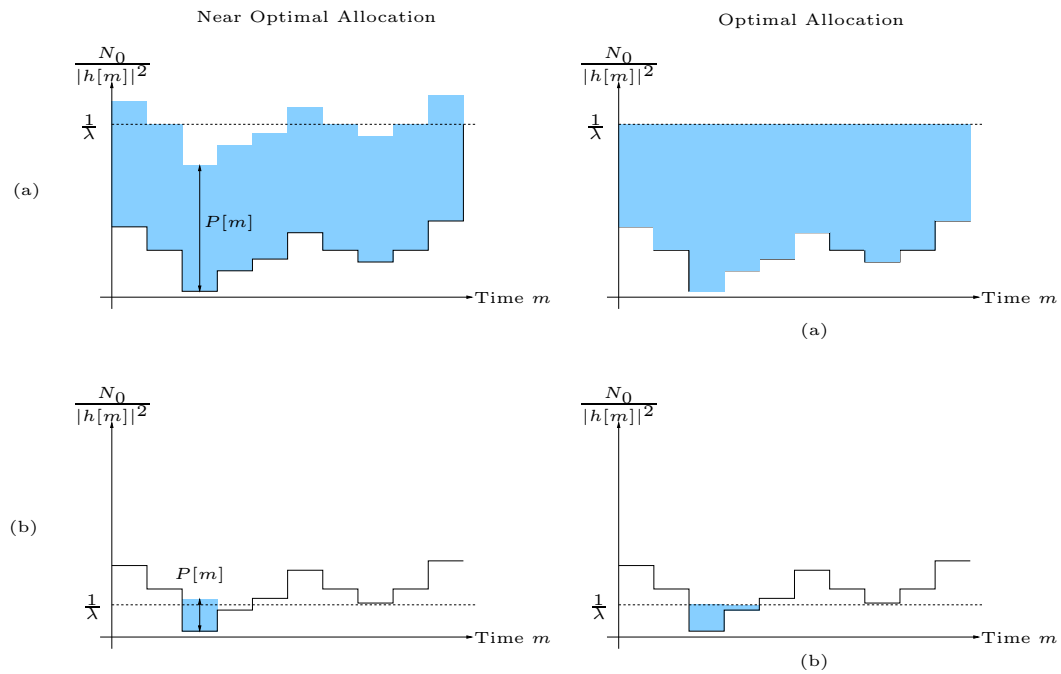


Performance: Low SNR



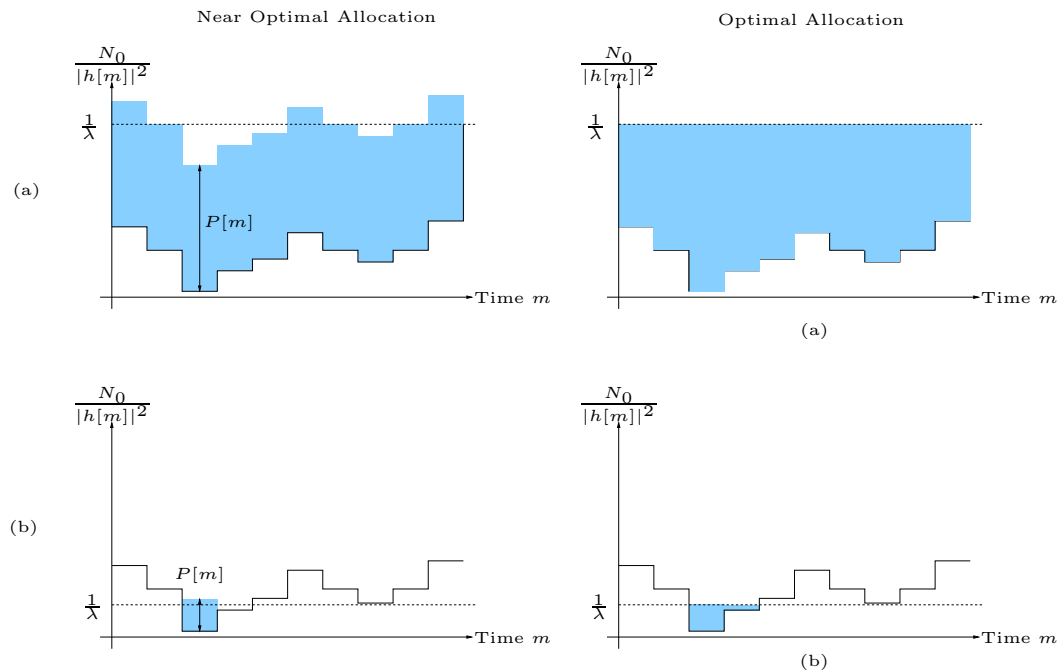
At low SNR, capacity can be **greater** when there is fading.

Hitting the Peaks



At low SNR, one can transmit only when the channel is at its peak. Primarily a power gain.

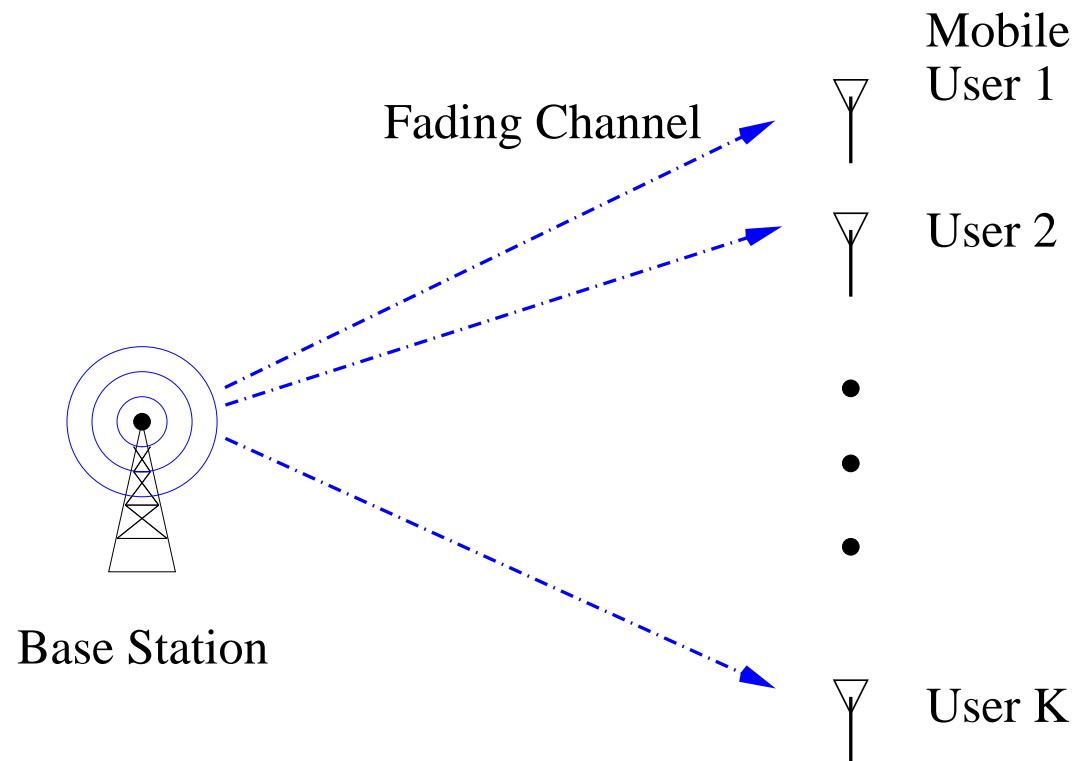
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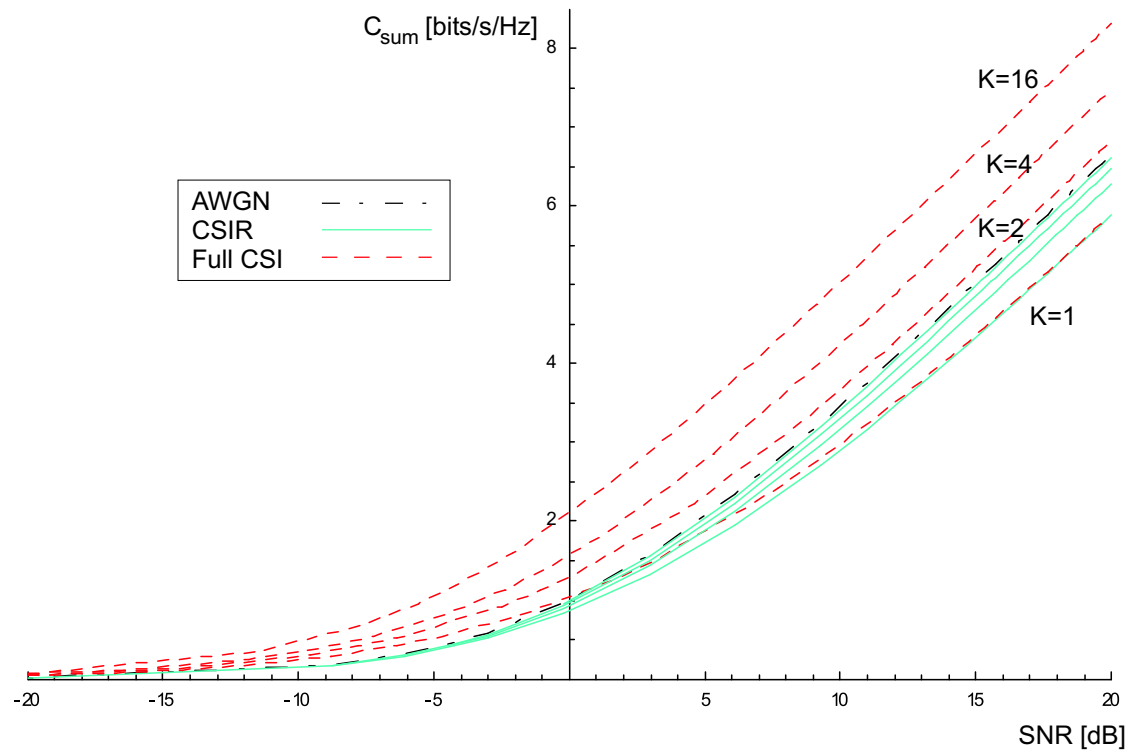
In practice, hard to realize such gains due to difficulty in tracking the channel when transmitting so infrequently.

Multiuser Opportunistic Communication



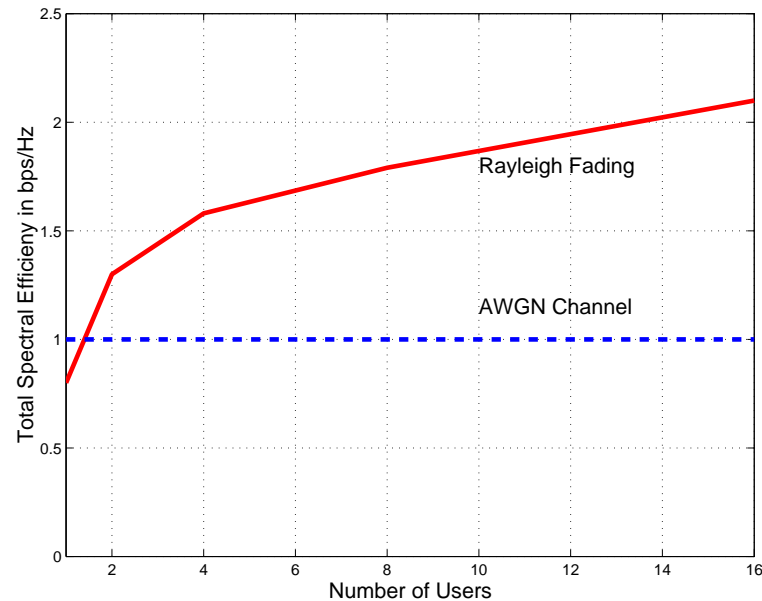
(Knopp and Humblet 95, T 97)

Performance



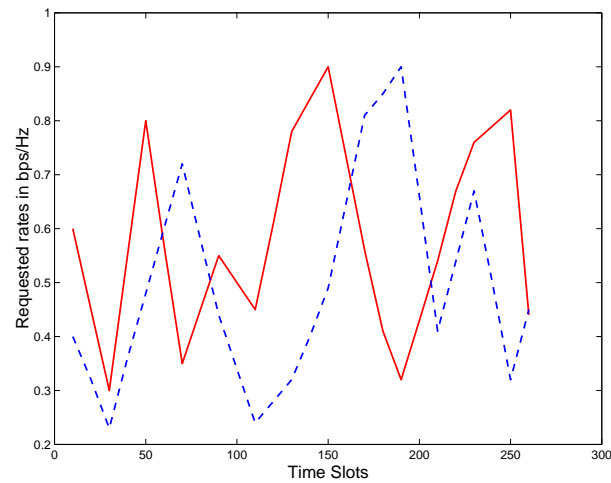
Multiuser Diversity

Total average SNR = 0 dB.



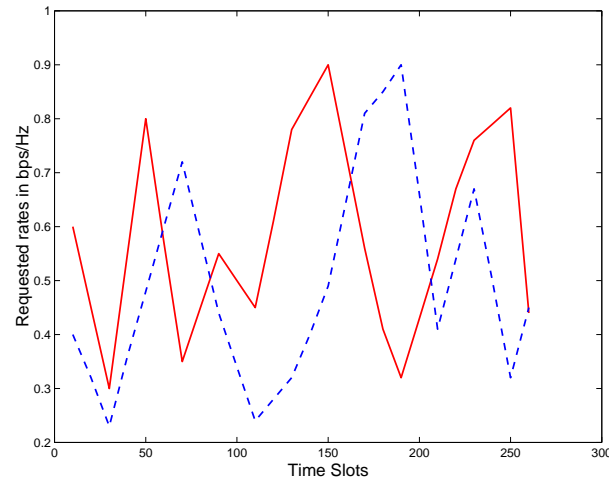
- In a large system with users fading independently, there is likely to be a user with a very good channel at any time.
- Long term total throughput can be maximized by always serving the user with the **strongest** channel.

Multiuser Diversity: A More Insightful Look



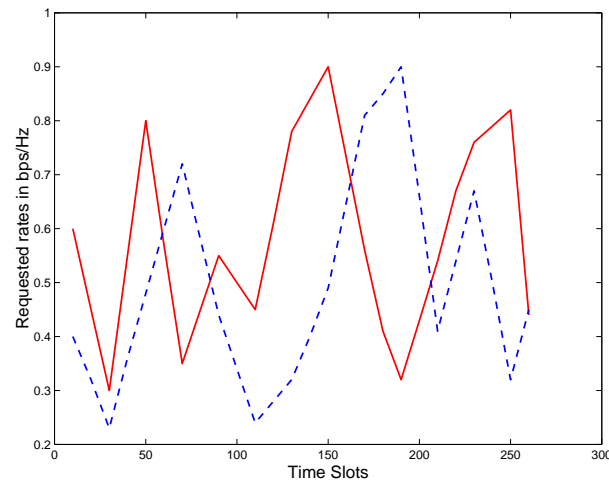
- Independent fading makes it likely that users **peak** at different times.

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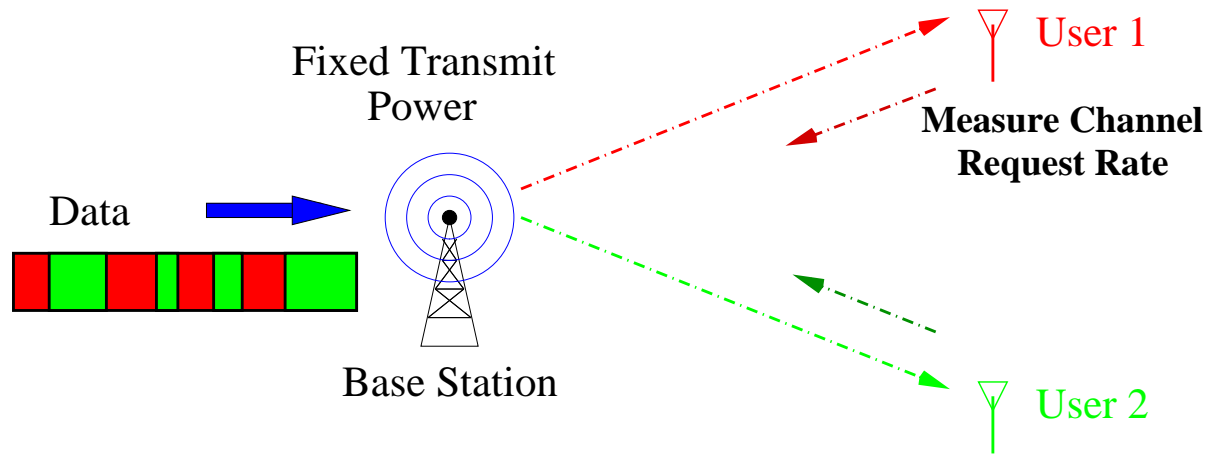
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- In a wideband system with many users, each user operates at low average SNR, effectively accessing the channel only when it is near its peak.

Multiuser Diversity: A More Insightful Look

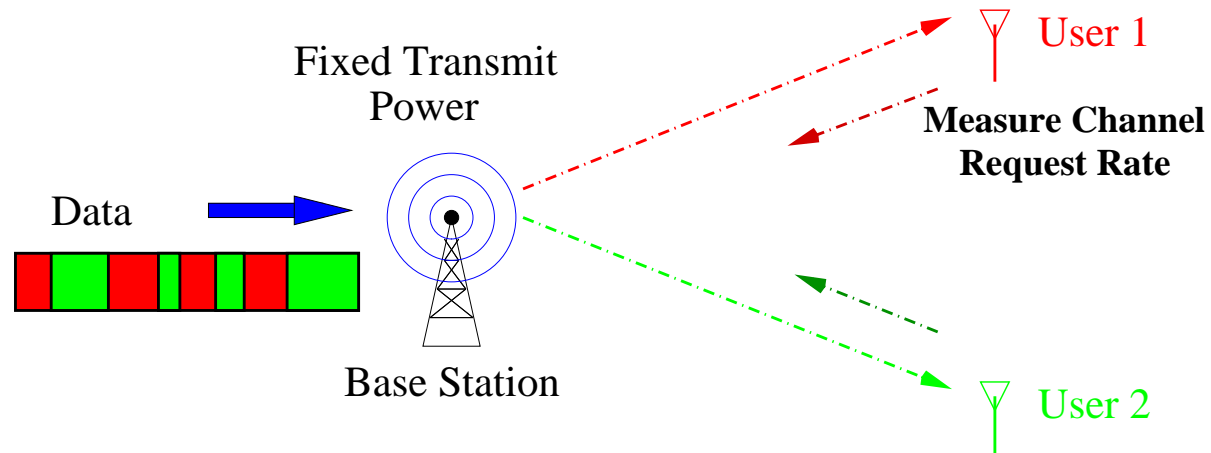


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- In a wideband system with many users, each user operates at low average SNR, effectively accessing the channel only when it is near its peak.
- In the downlink, channel tracking can be done via a strong pilot amortized between all users.

1x EV-DO's DownLink



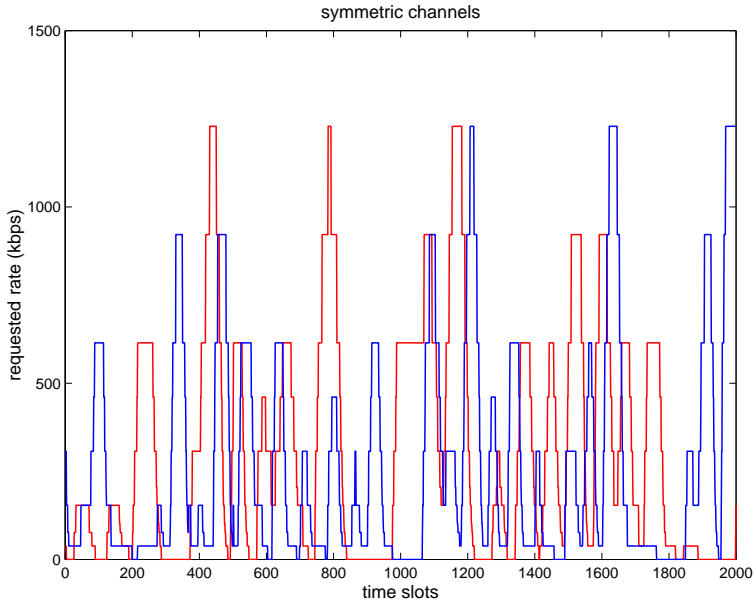
1x EV-DO's DownLink



Information theory suggests that resource should be scheduled in a **channel-dependent** way.

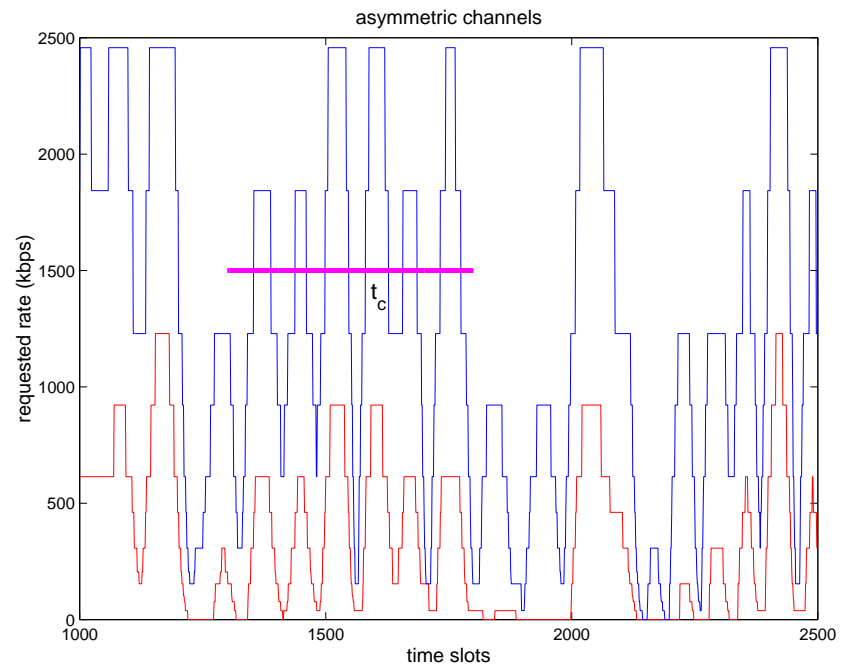
Challenge is to exploit multiuser diversity while sharing the benefits **fairly** and **timely** to users.

Symmetric Users

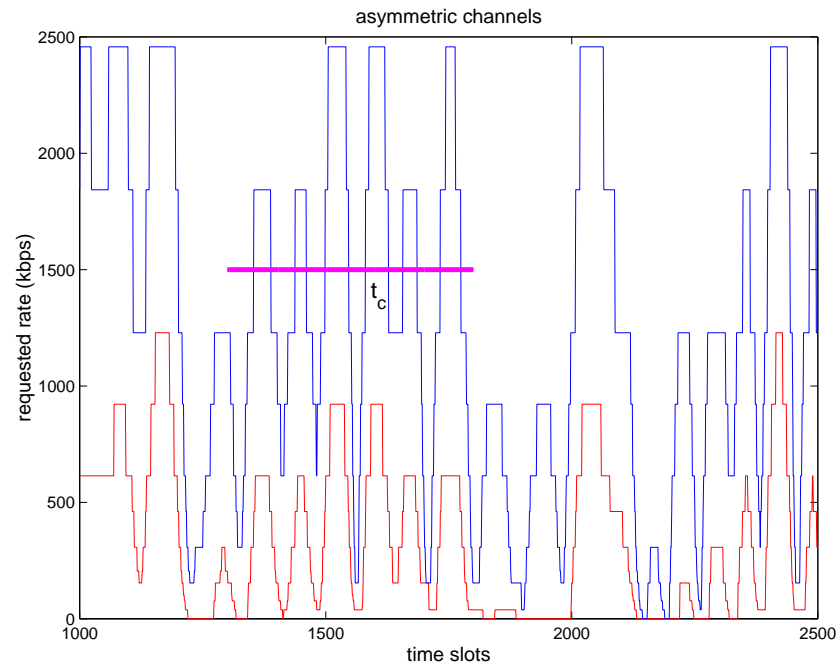


Serving the best user at each time is also fair in terms of long-term throughputs.

Asymmetric Users

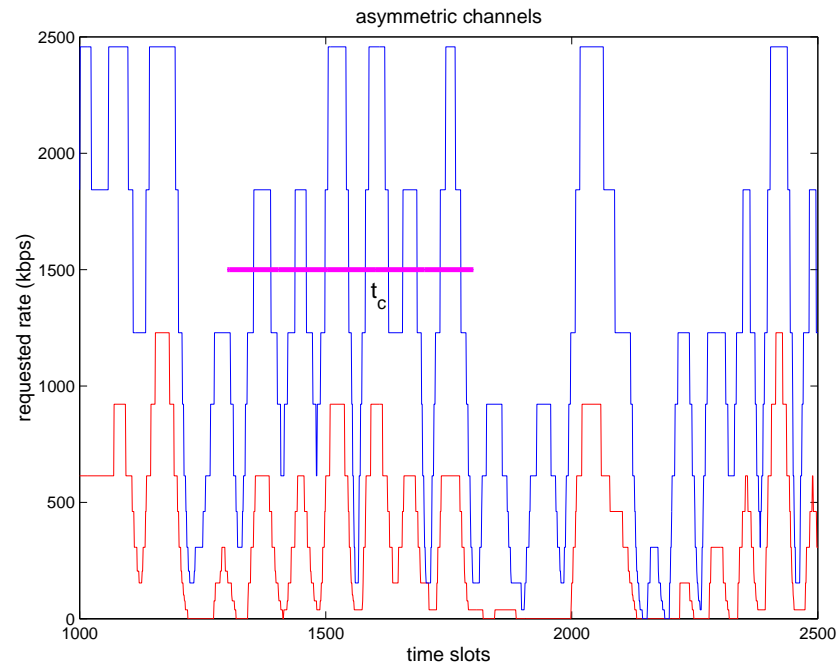


Asymmetric Users



- Want to serve each user when it is near its **peak**.

Asymmetric Users



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- A peak should be defined with respect to a latency time-scale t_c .

Proportional Fair Scheduling

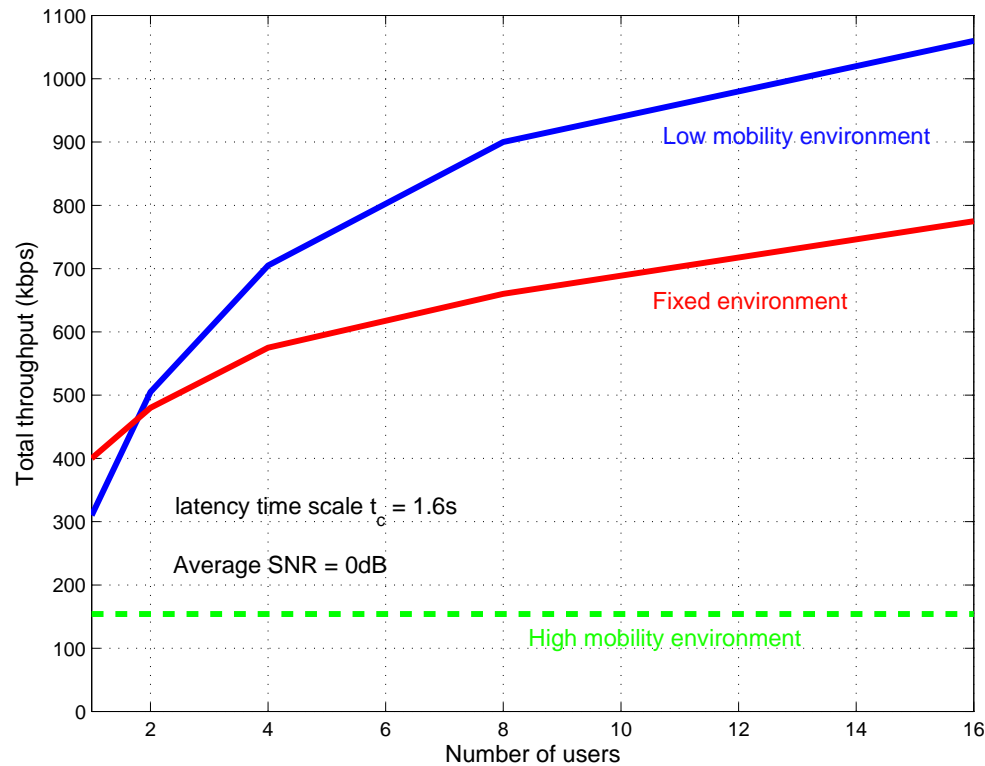
(T 99)

Schedule the user with the highest ratio R_k/T_k , where

R_k = current requested rate of user k

T_k = average throughput in past t_c time slots

Performance

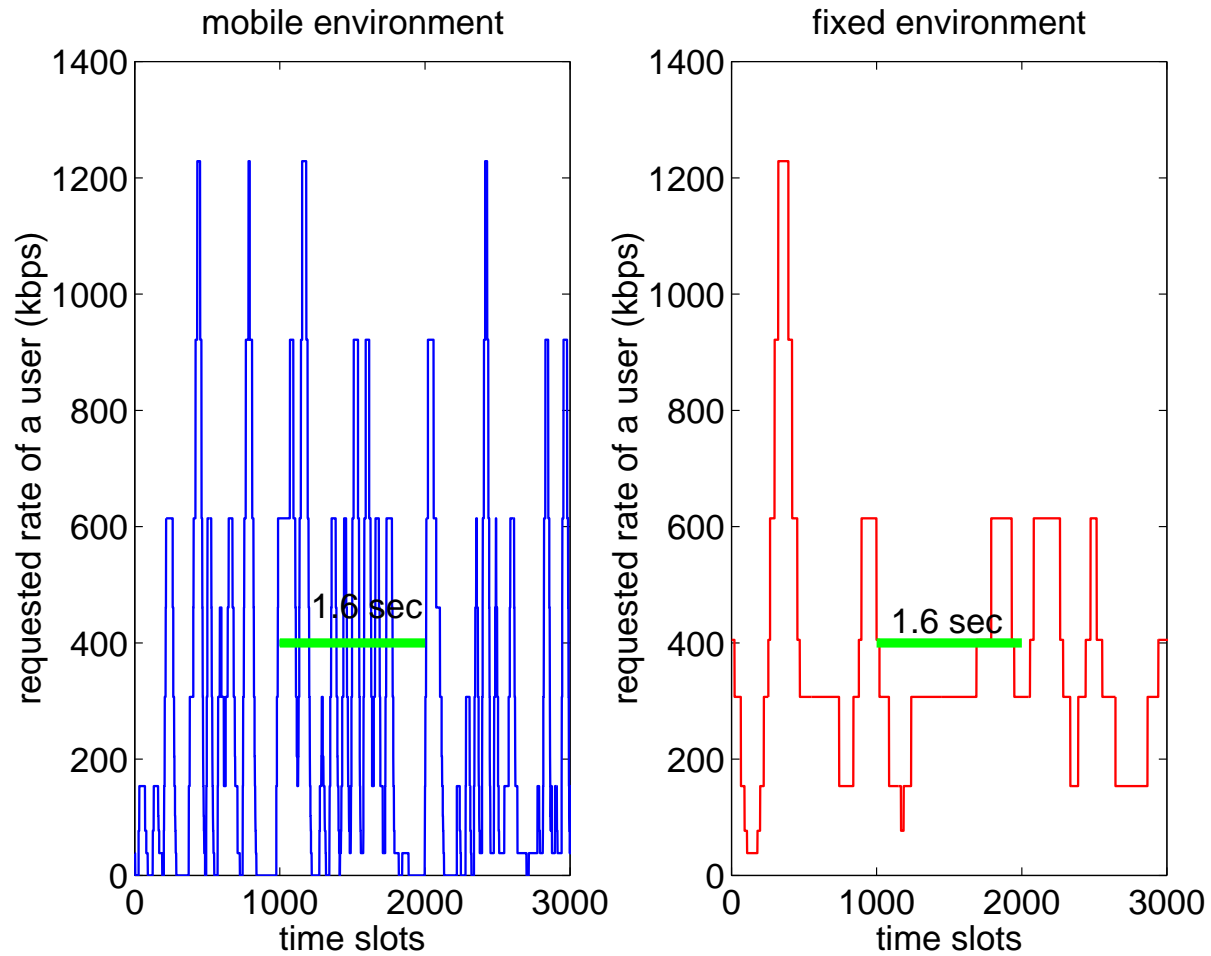


Fixed environment: 2Hz Rician fading with $E_{\text{fixed}}/E_{\text{scattered}} = 5$.

Low Mobility environment: 3 km/hr, Rayleigh fading

High mobility environment: 30 km/hr, Rayleigh fading

Channel Dynamics



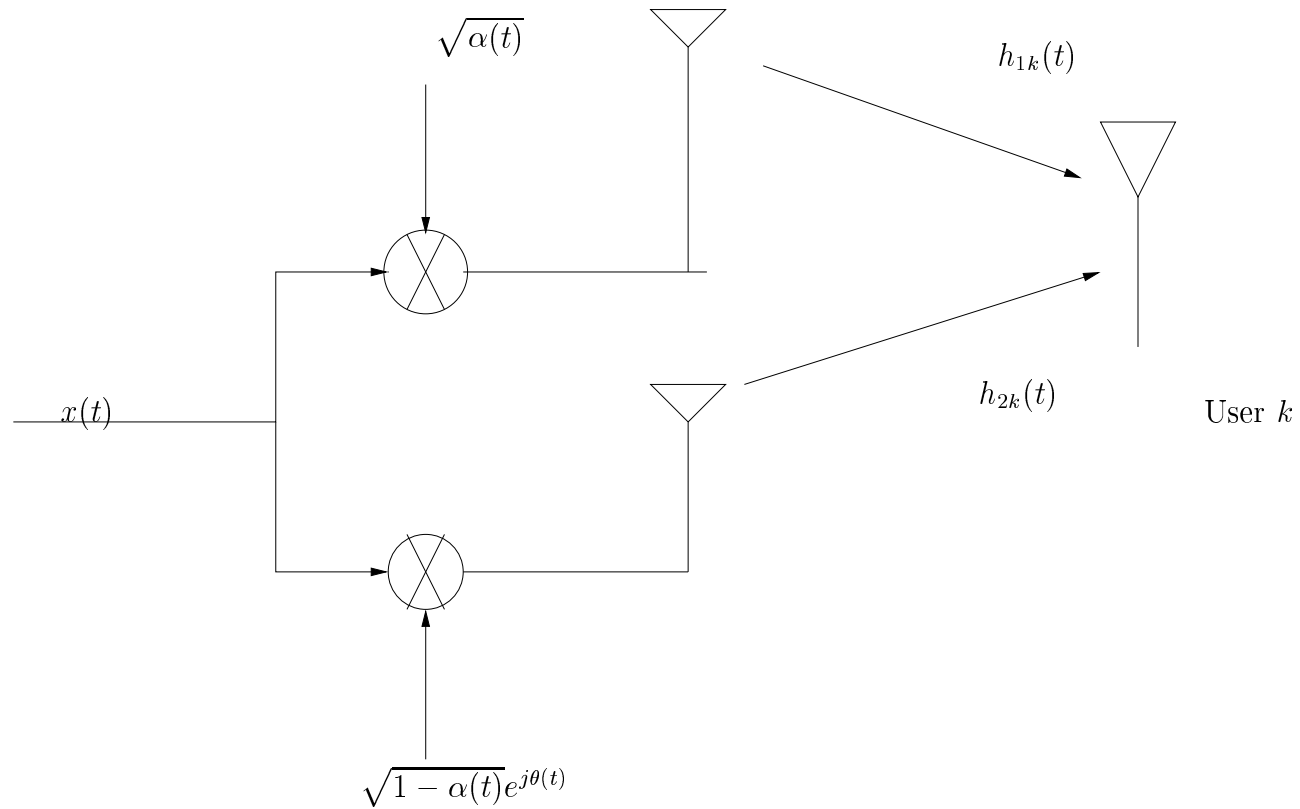
Channel varies faster and has more dynamic range in mobile environments.

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?

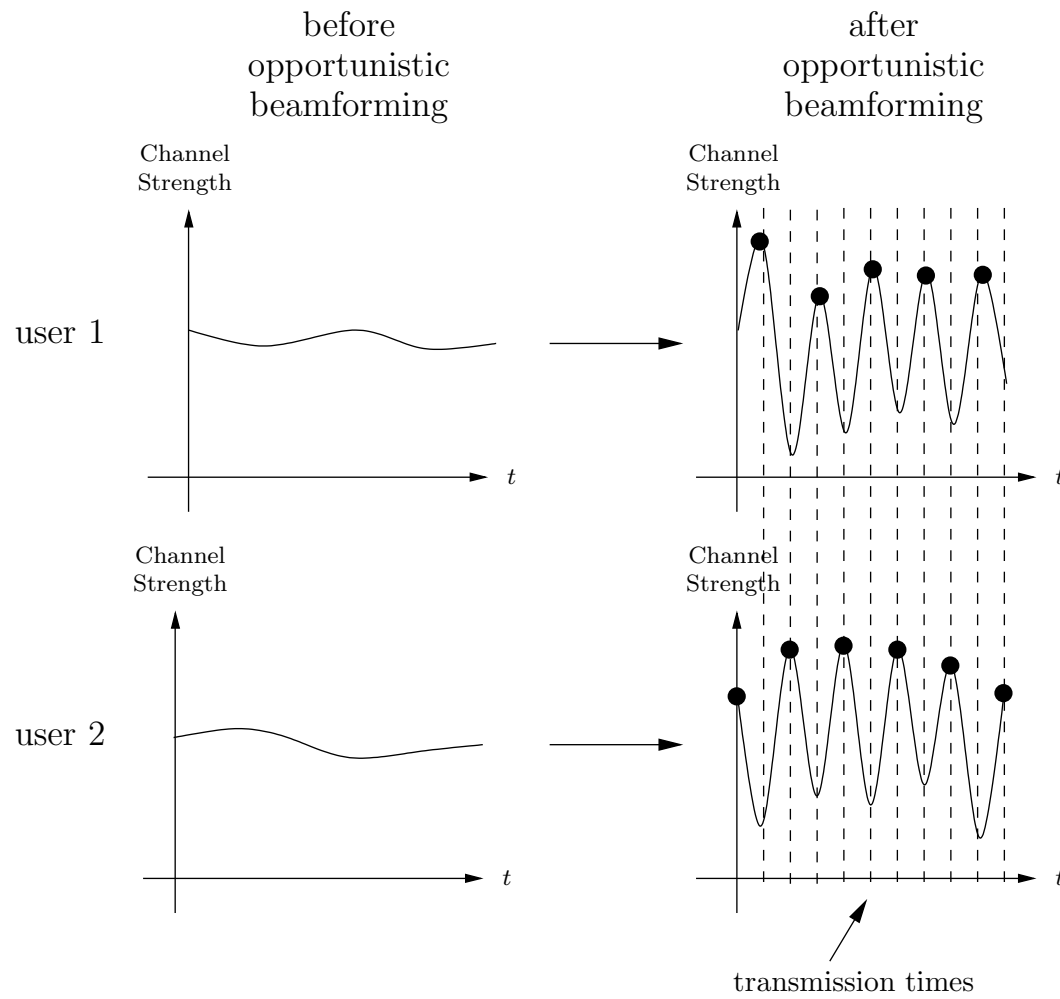
Dumb Antennas

(Viswanath, T and Laroia 02)

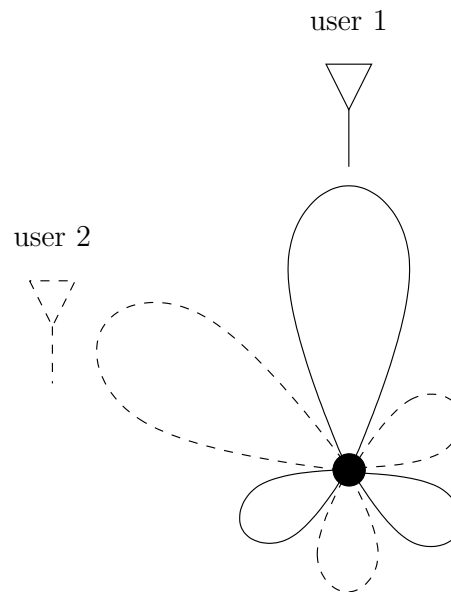


The information-bearing signal at each of the transmit antennas are multiplied by a random complex gain.

Inducing Randomness

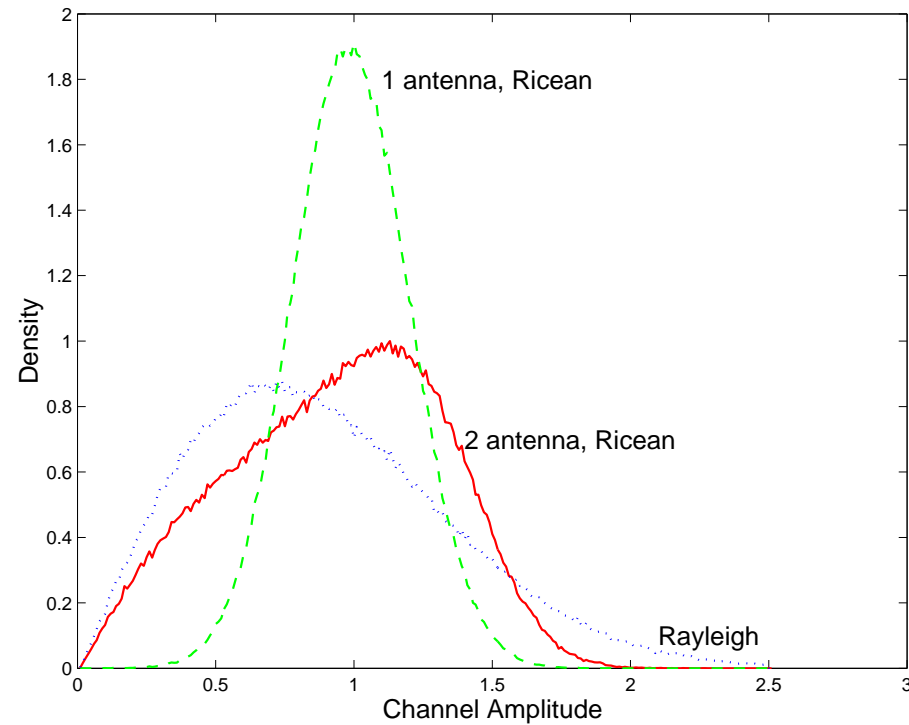


Slow Fading: Opportunistic Beamforming



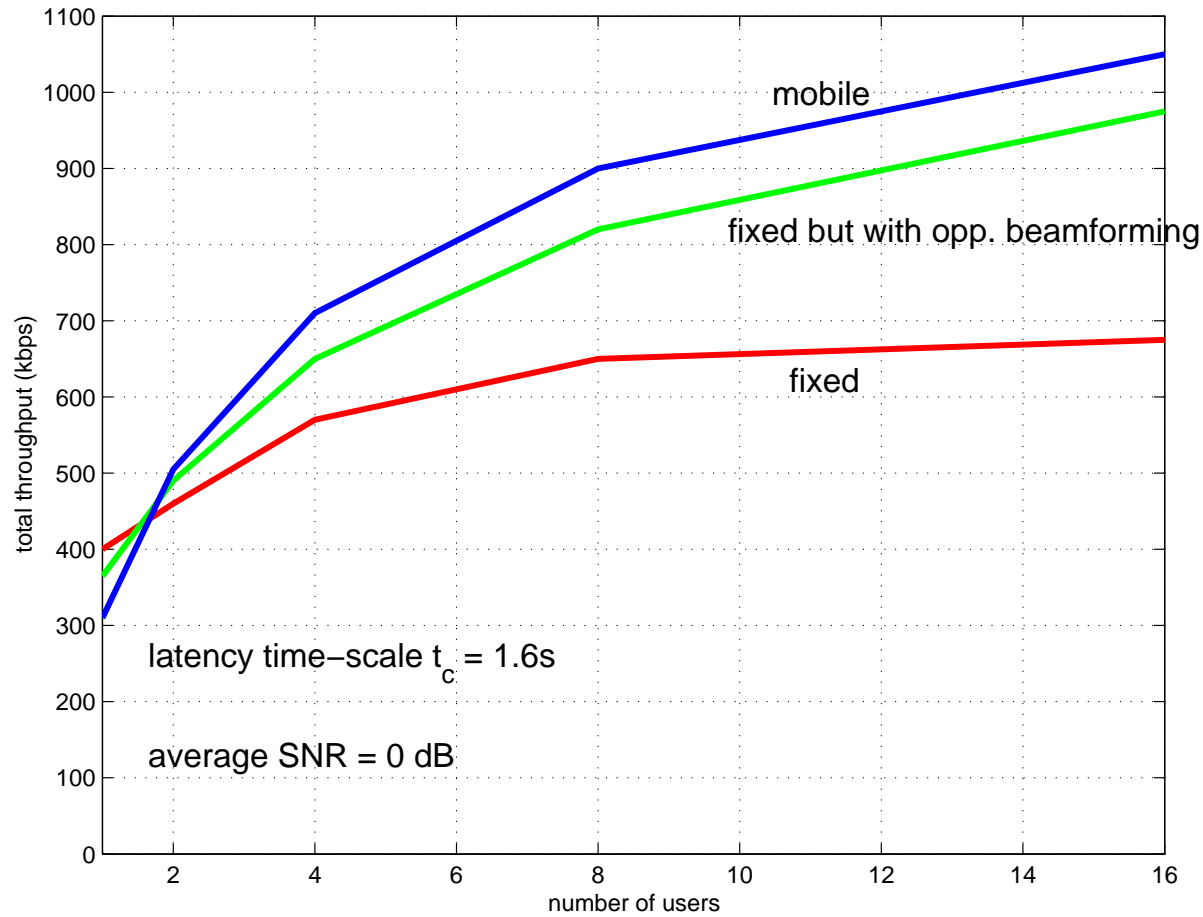
- Dumb antennas create a beam in random time-varying direction.
- In a large system, there is likely to be a user near the beam at any one time.
- By transmitting to that user, close to true beamforming performance is achieved.

Fast Fading



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

Overall Performance Improvement



Mobile environment: 3 km/hr, Rayleigh fading

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

Smart vs Dumb Antennas

- Space-time codes **increase** reliability of point-to-point links but **decreases** multiuser diversity gains.

Smart vs Dumb Antennas

- Space-time codes **increase** reliability of point-to-point links but **decreases** multiuser diversity gains.
- Dumb antennas **add** fluctuations to point-to-point links but **increases** multiuser diversity gains.

Conclusions

- Implementation of a new point of view has to obey system constraints.

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- The new point of view impacts rest of the system design and suggests new research problems.
- Interplay between theory and system is what makes communications research so fun!