Opportunistic Communication: From Theory to Practice

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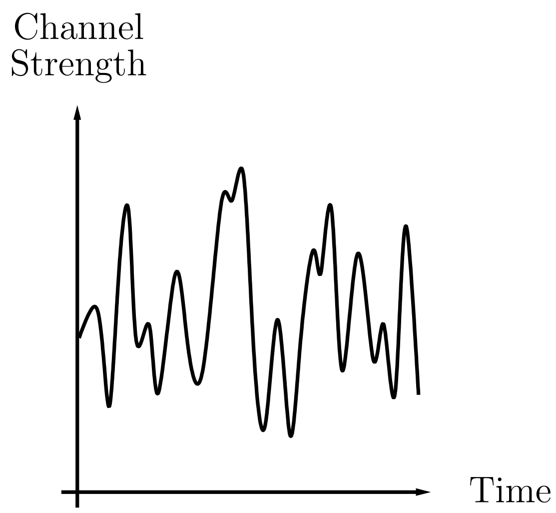
"Deeper understanding of this relationship is found in multiuser information theoretic papers and texts. Though the latter do not illuminate the path towards practical system realization, we firmly believe that, as in the past, the next significant advance will depend heavily on such foundations."

Epilogue, *CDMA: Principles of Spread Spectrum Communication*, A.J. Viterbi, 1995.

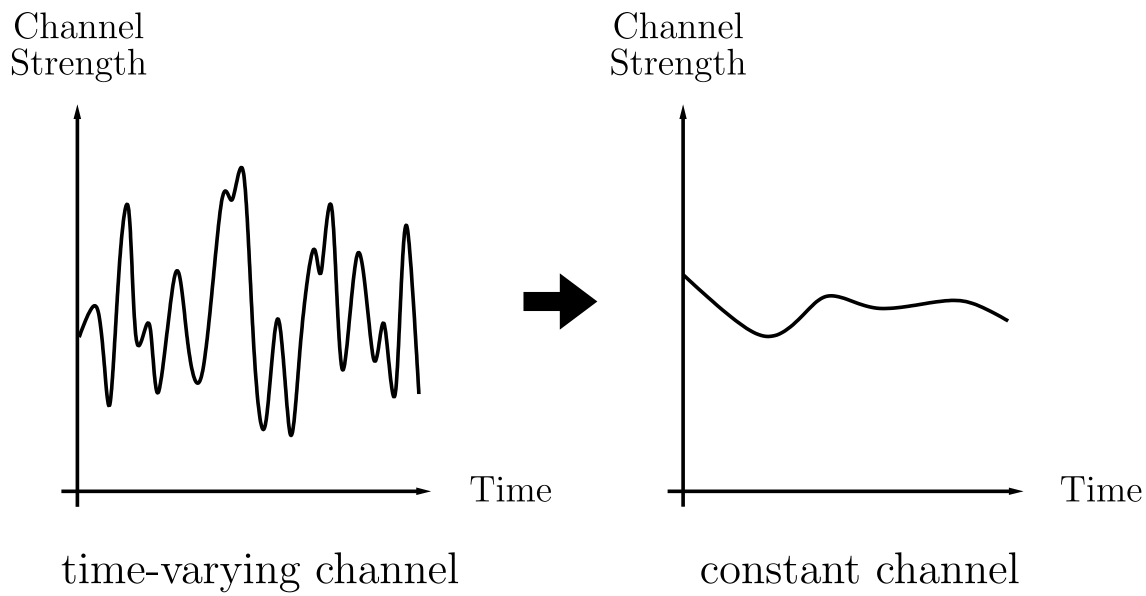
Fundamental Feature of Wireless Channels: Time Variation



time-varying channel

- 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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1. Channel diversity:
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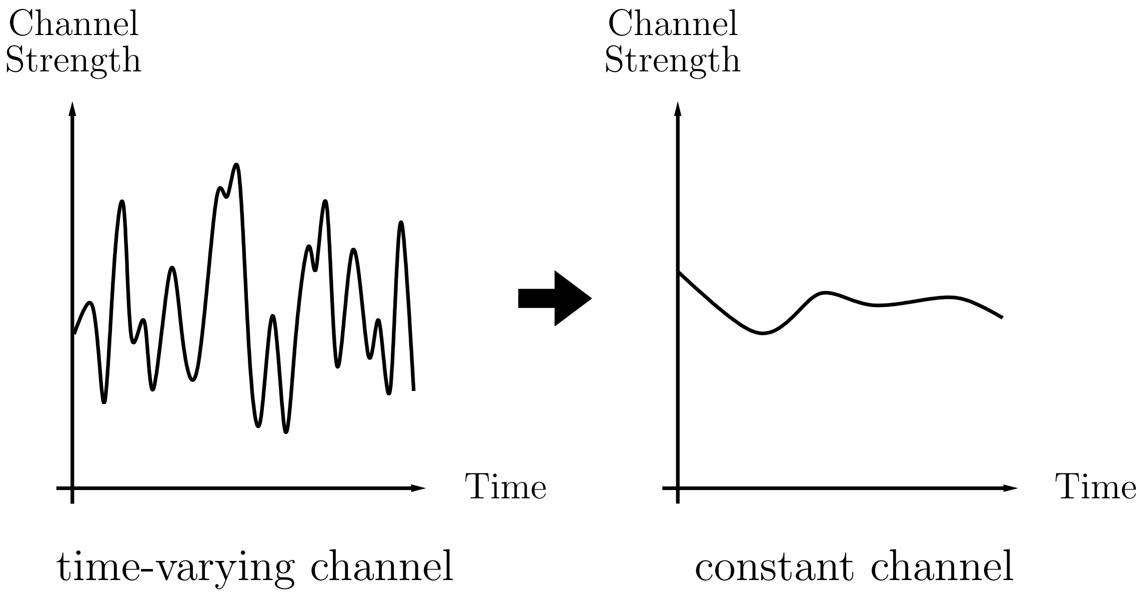
   - transmit/receive antenna diversity
2. Interference management:
   - power control
   - interference averaging

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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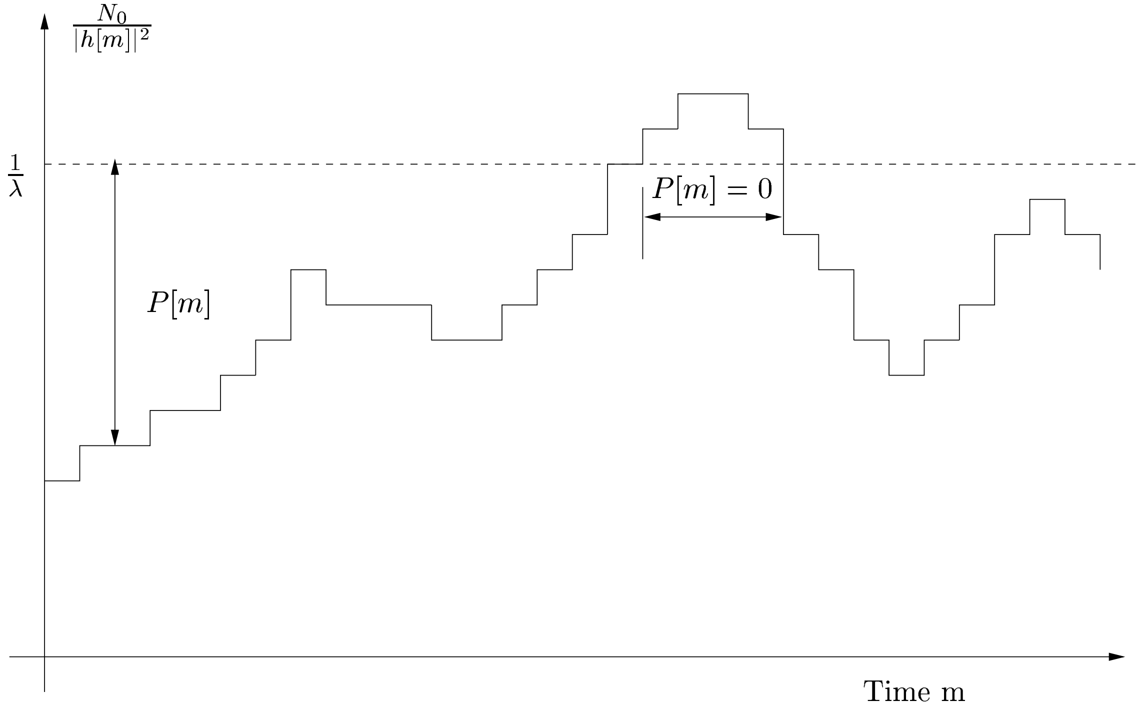
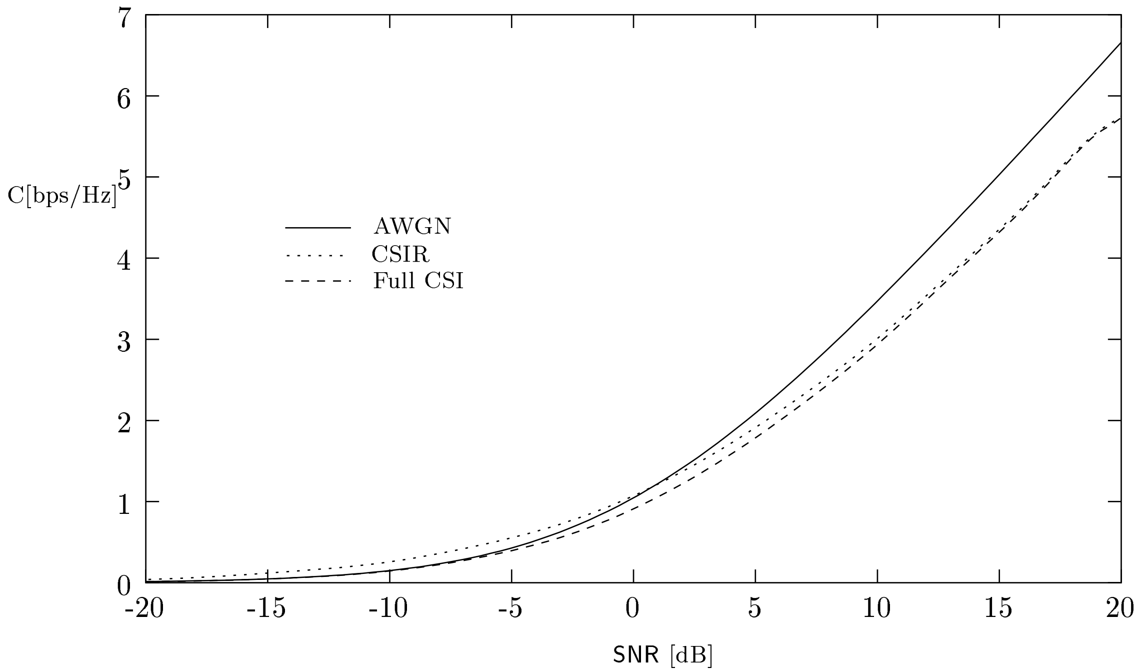
Appropriate for data with laxer latency requirements.

Point-to-Point Fading Channels

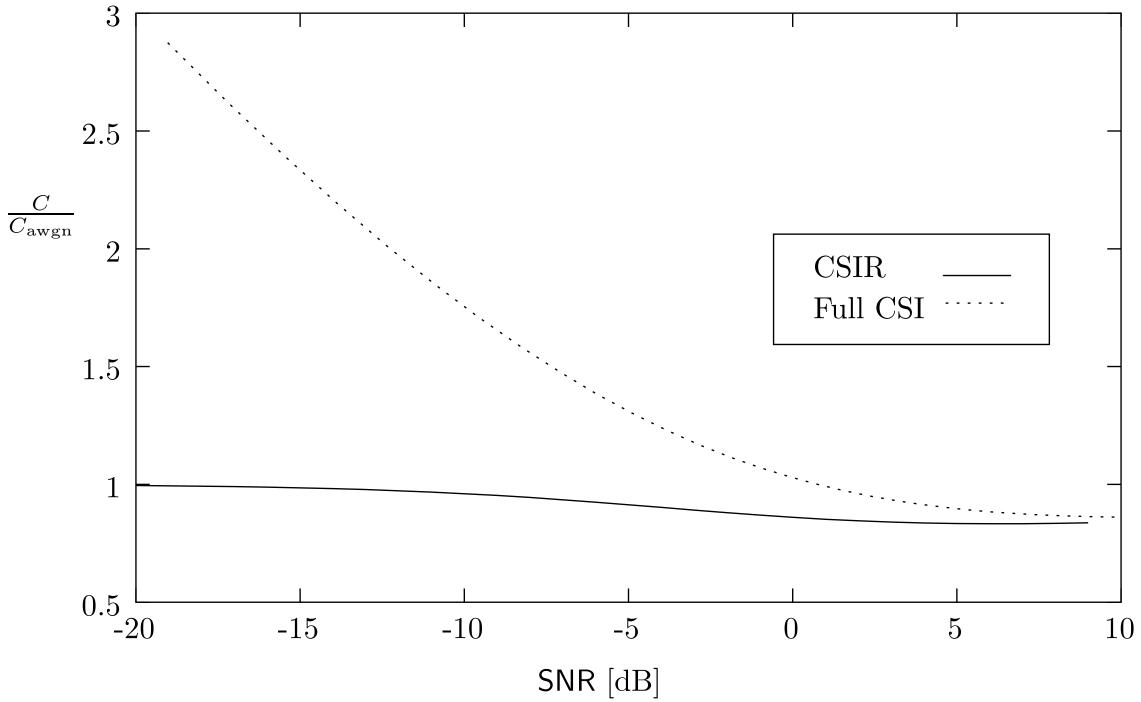


Capacity-achieving strategy is waterfilling over time. (Goldsmith and Varaiya 97)

Performance over Rayleigh Channel

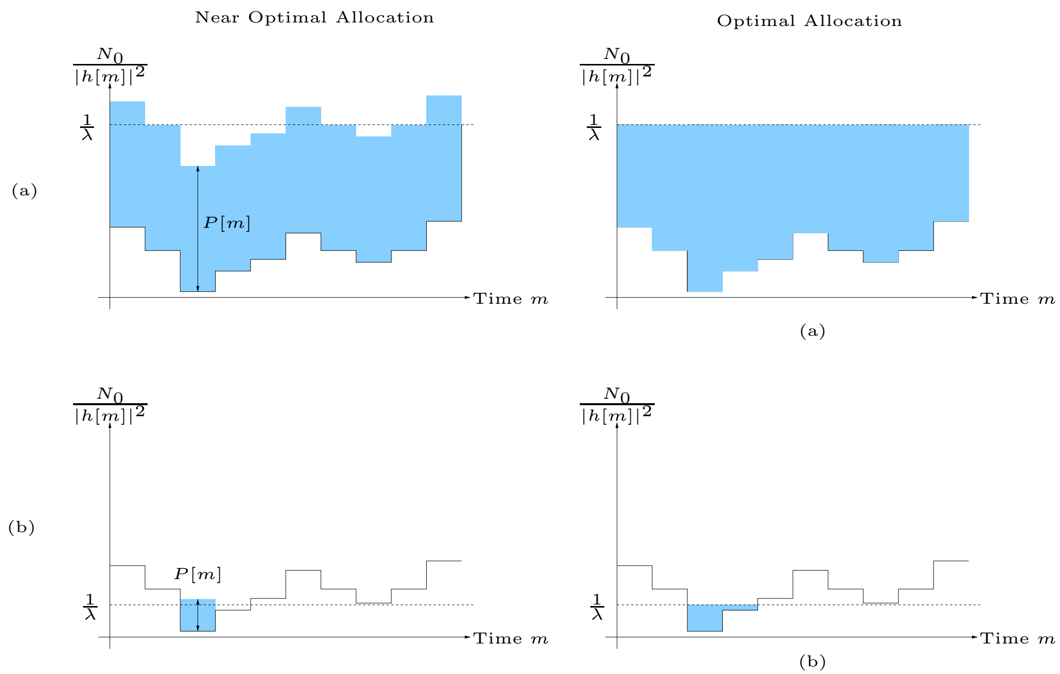


Performance: Low SNR



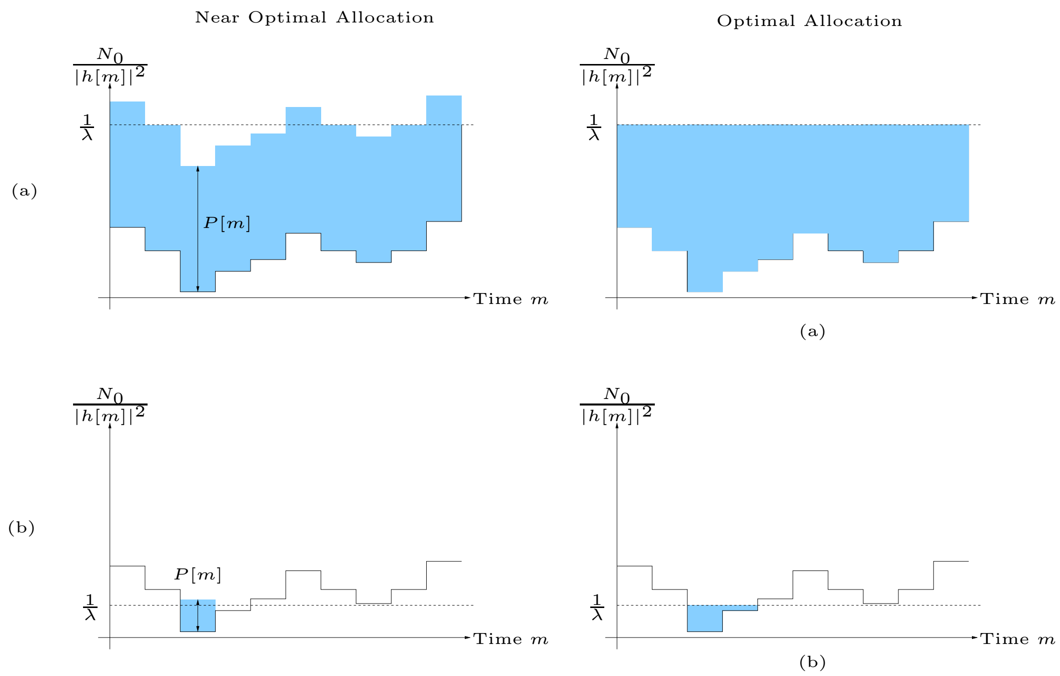
At low SNR, capacity can be greater when there is fading.

Hitting the Peaks



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

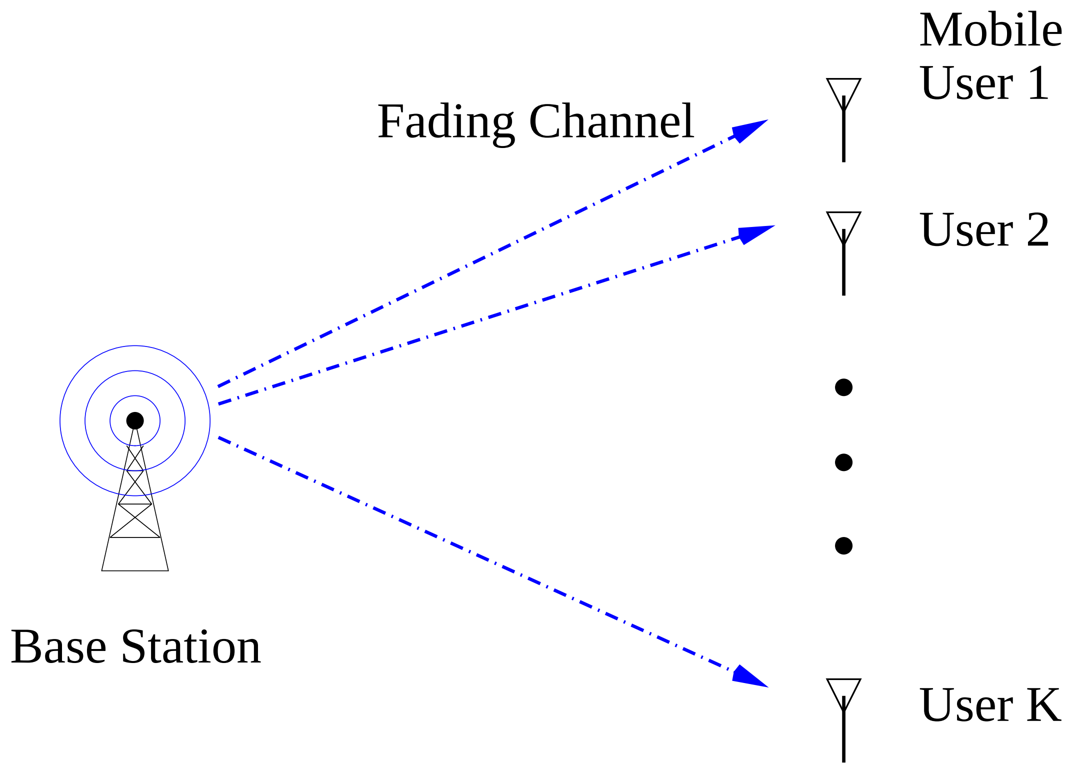
Hitting the Peaks



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

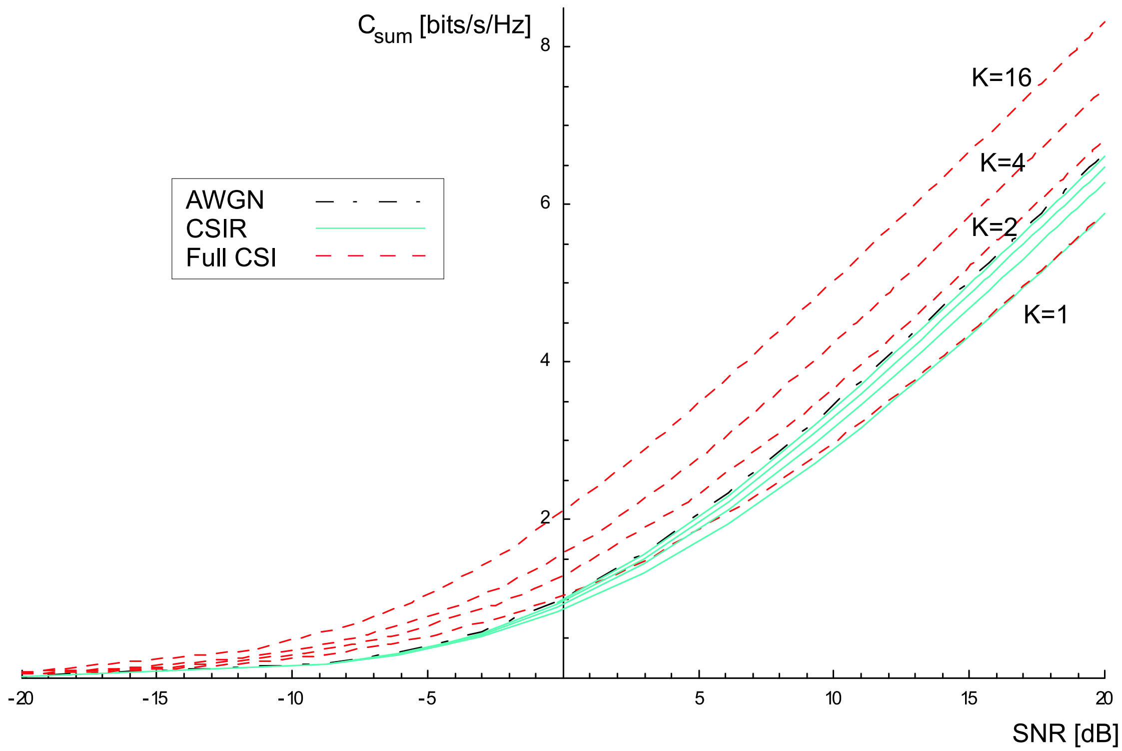
In practice, hard to realize such gains due to difficulty in tracking the channel when transmitting so infrequently.

Multiuser Opportunistic Communication



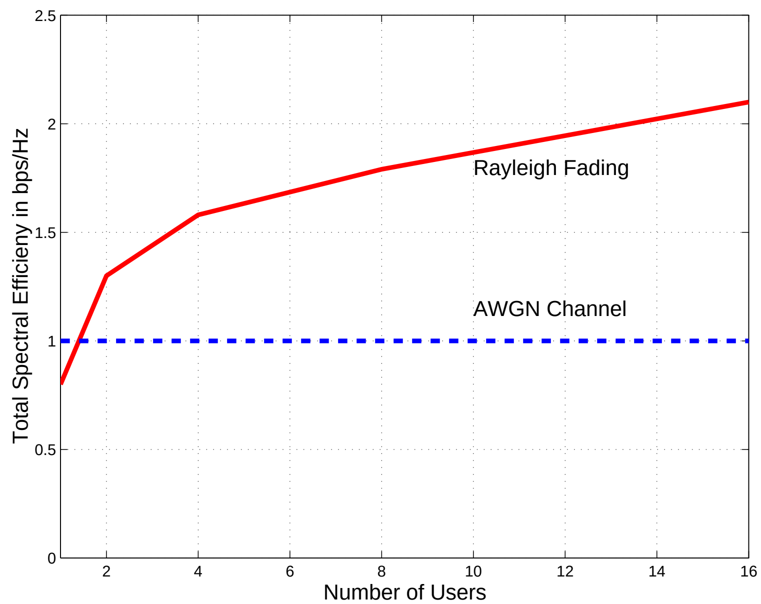
(Knopp and Humblet 95, T 97)

Performance



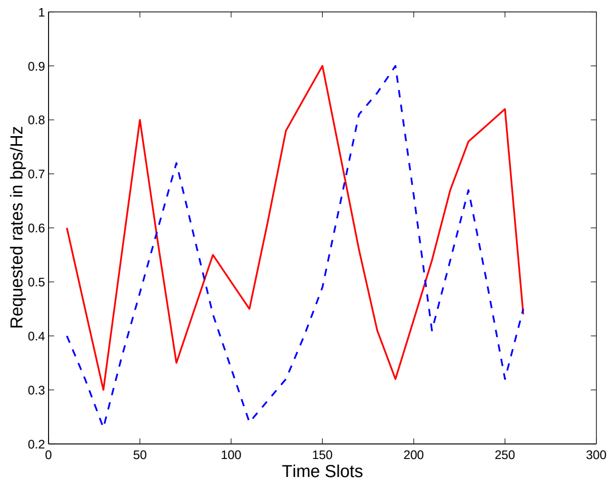
Multiuser Diversity

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



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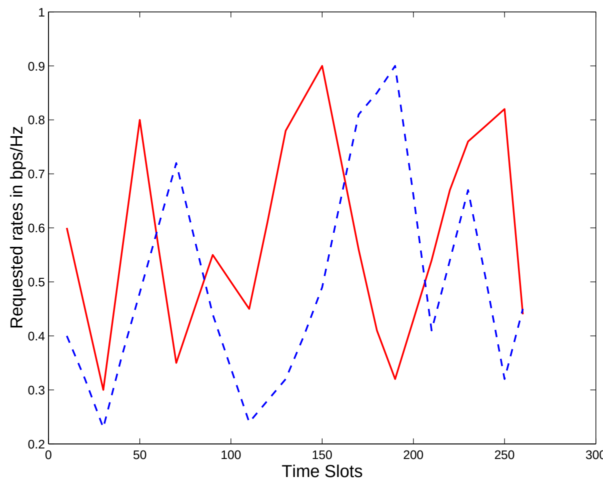

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- In a wideband system with many users, each user operates at low average SNR, effectively accessing the channel only when it is near its peak.

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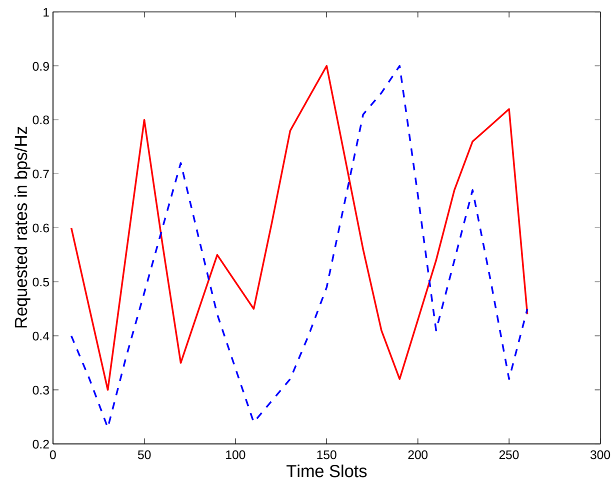
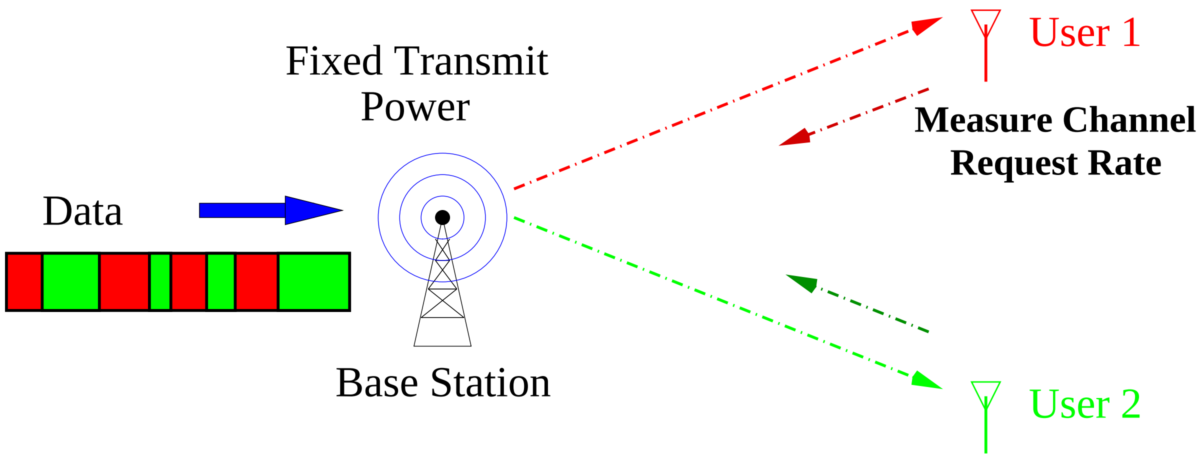


- Independent fading makes it likely that users peak at different times.
- In a wideband system with many users, each user operates at low average SNR, effectively accessing the channel only when it is near its peak.
- In the downlink, channel tracking can be done via a strong pilot amortized between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

1x EV-DO's DownLink



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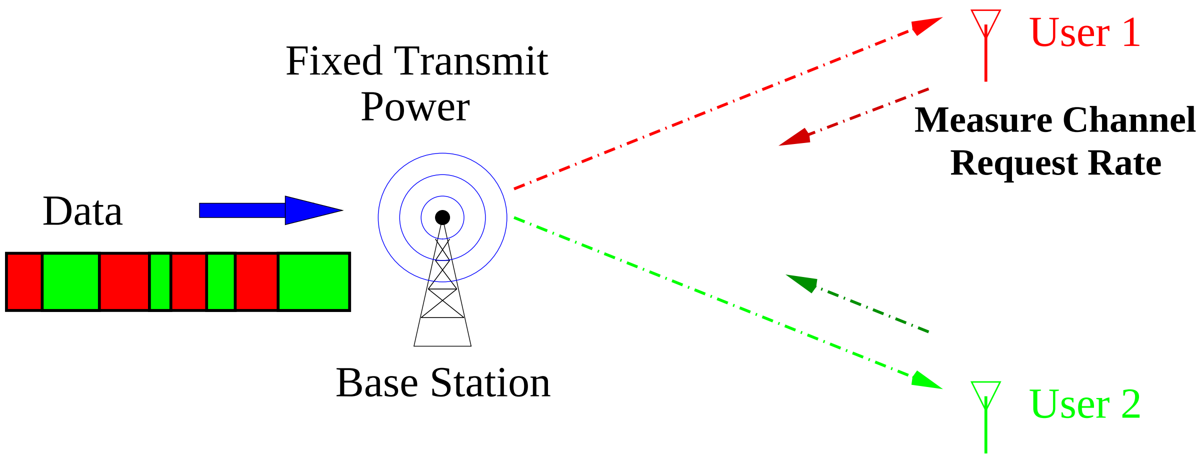
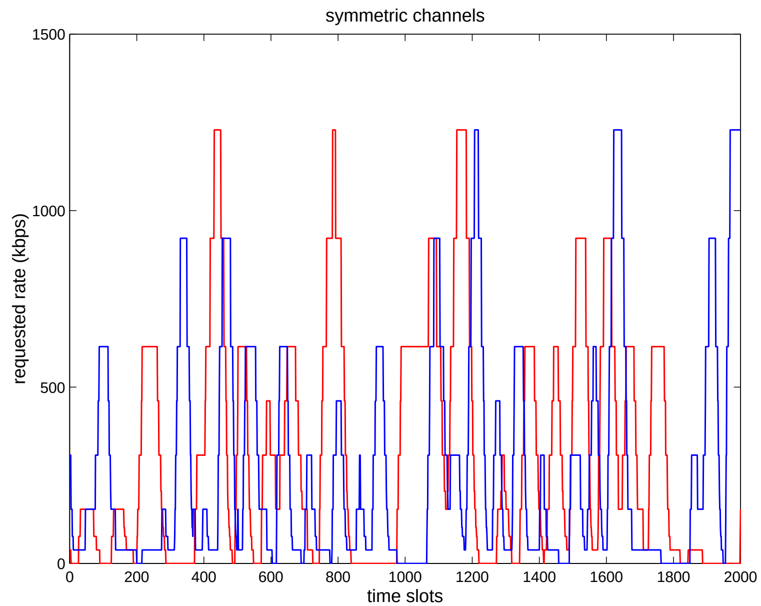


Information theory suggests that resource should be scheduled in a channel-dependent way.

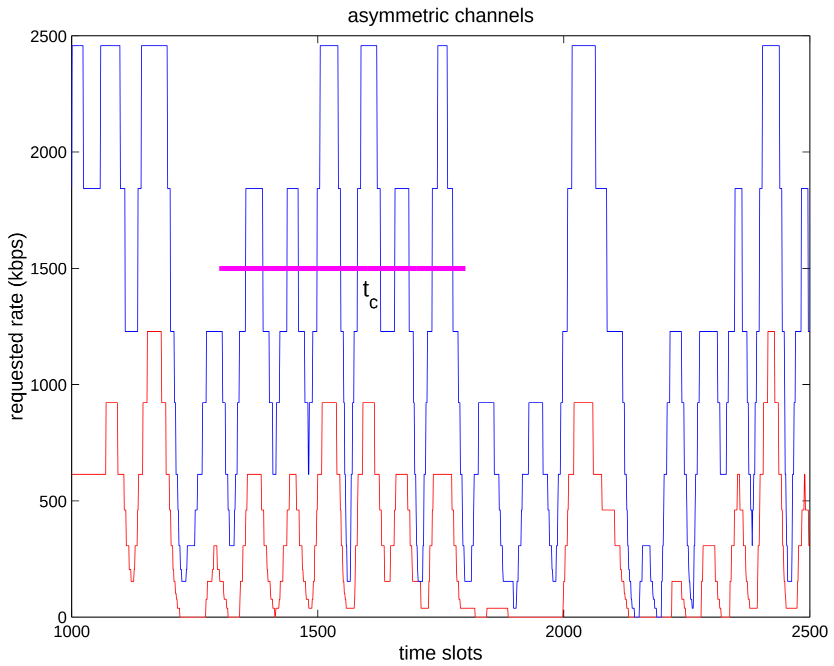
Challenge is to exploit multiuser diversity while sharing the benefits fairly and timely to users.

Symmetric Users



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

Asymmetric Users



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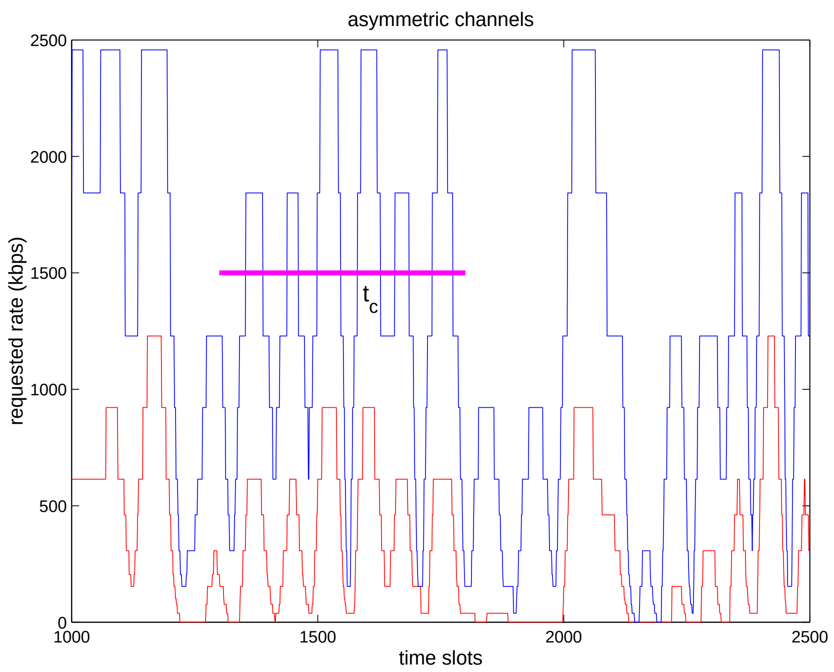

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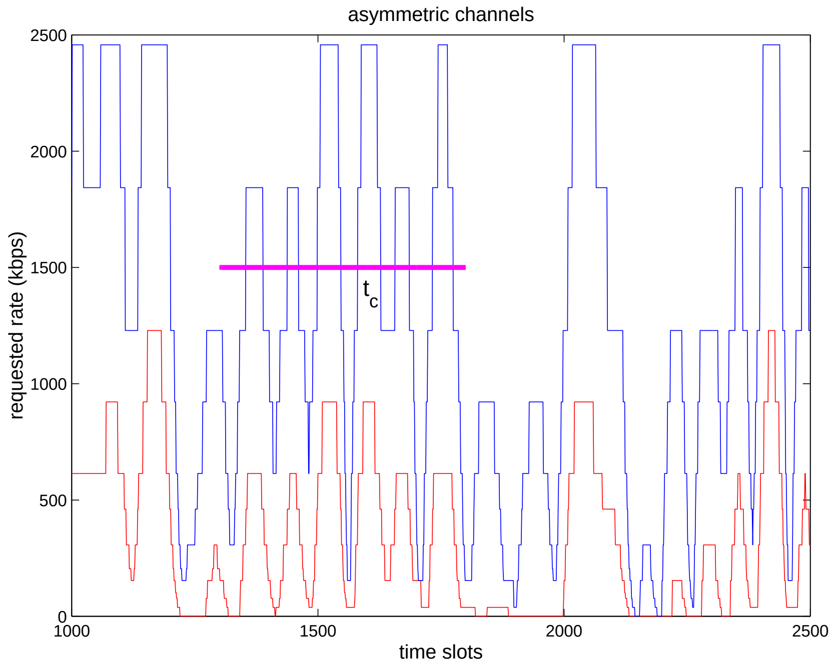


- Want to serve each user when it is near its peak.
- A peak should be defined with respect to a latency time-scale t_c.

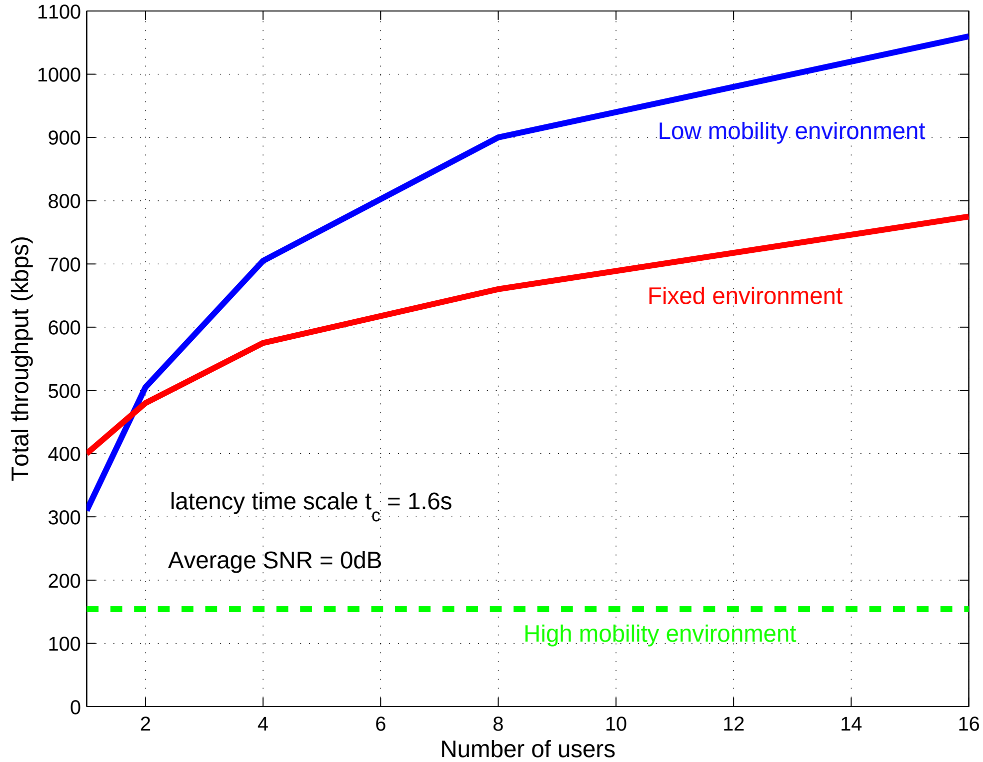
Proportional Fair Scheduling

(T 99)

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

$$\begin{aligned} R_k &= \text{current requested rate of user } k \\ T_k &= \text{average throughput in past } t_c \text{ time slots} \end{aligned}$$

Performance

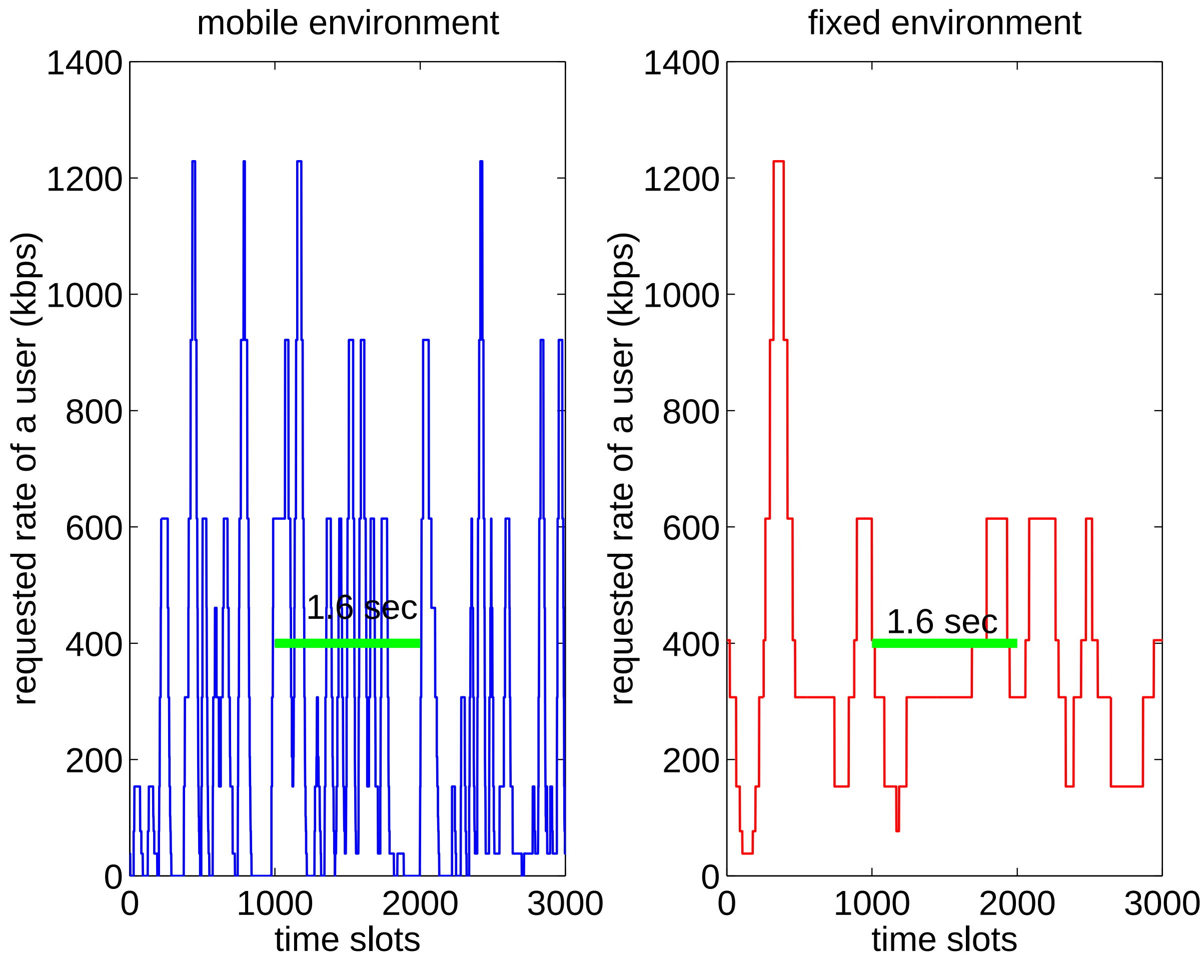


Fixed environment: 2Hz Rician fading with $E_{\text{fixed}}/E_{\text{scattered}} = 5$.

Low Mobility environment: 3 km/hr, Rayleigh fading

High mobility environment: 30 km/hr, Rayleigh fading

Channel Dynamics



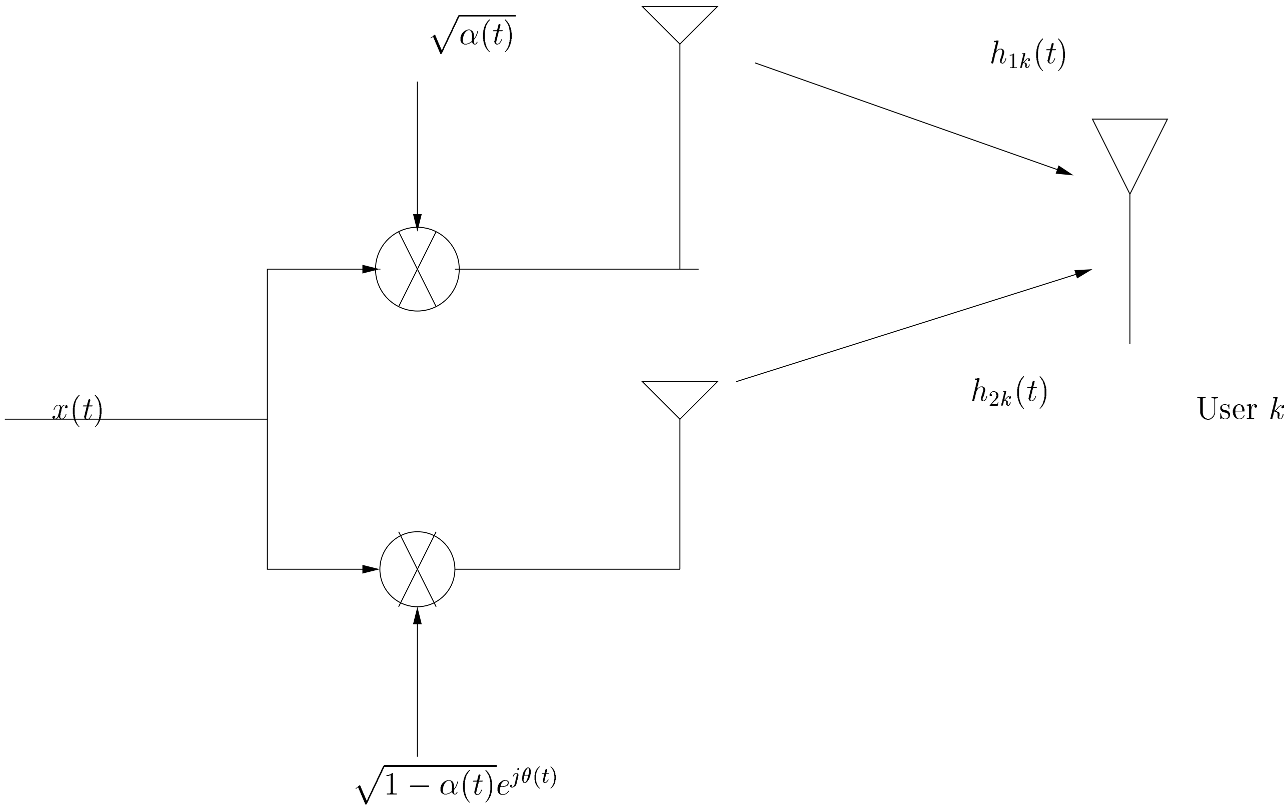
Channel varies faster and has more dynamic range in mobile environments.

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?

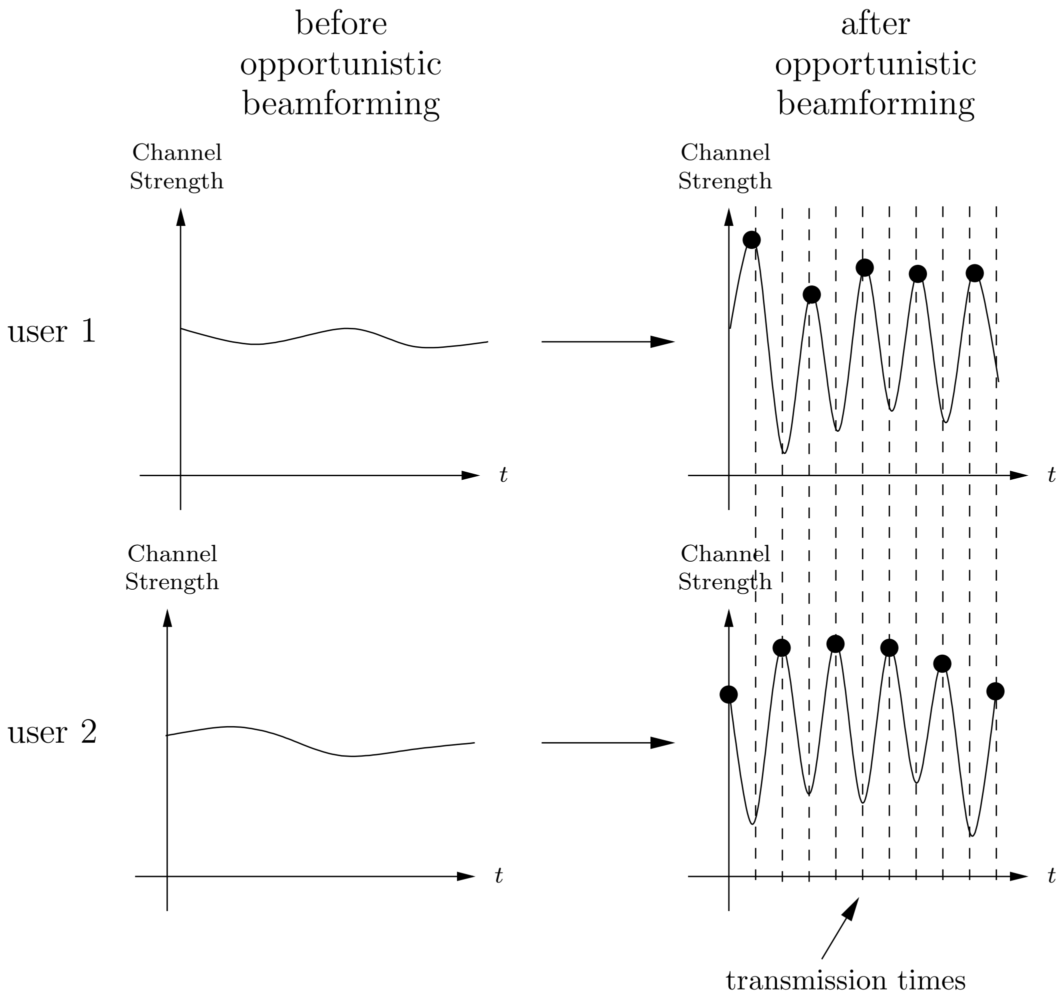
Dumb Antennas

(Viswanath, T and Laroia 02)

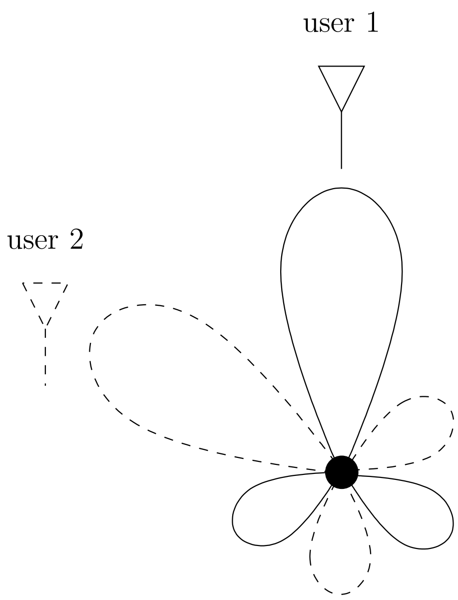


The information-bearing signal at each of the transmit antennas are multiplied by a random complex gain.

Inducing Randomness

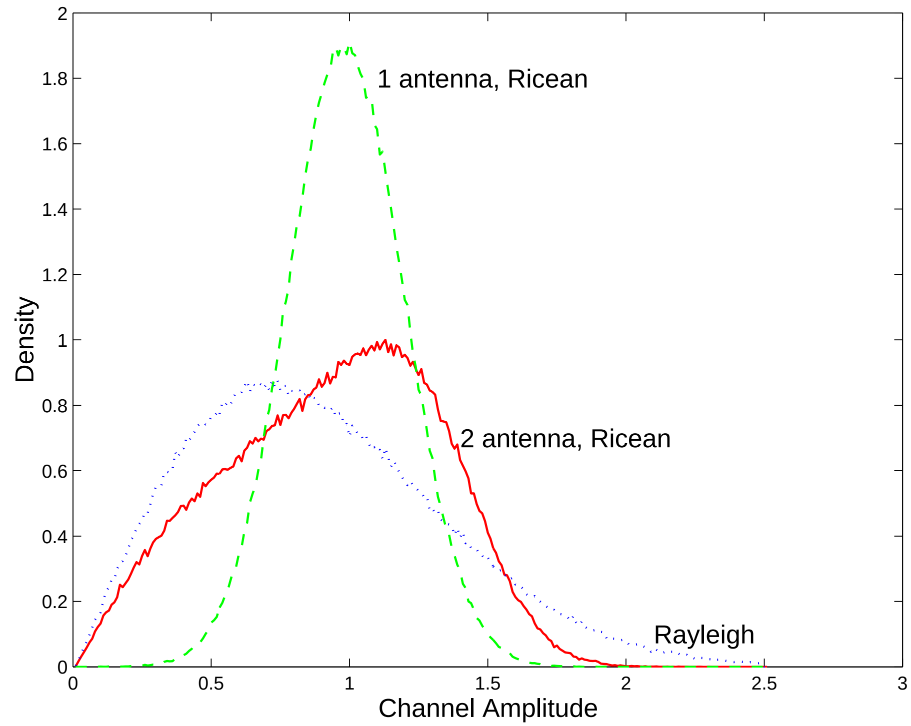


Slow Fading: Opportunistic Beamforming



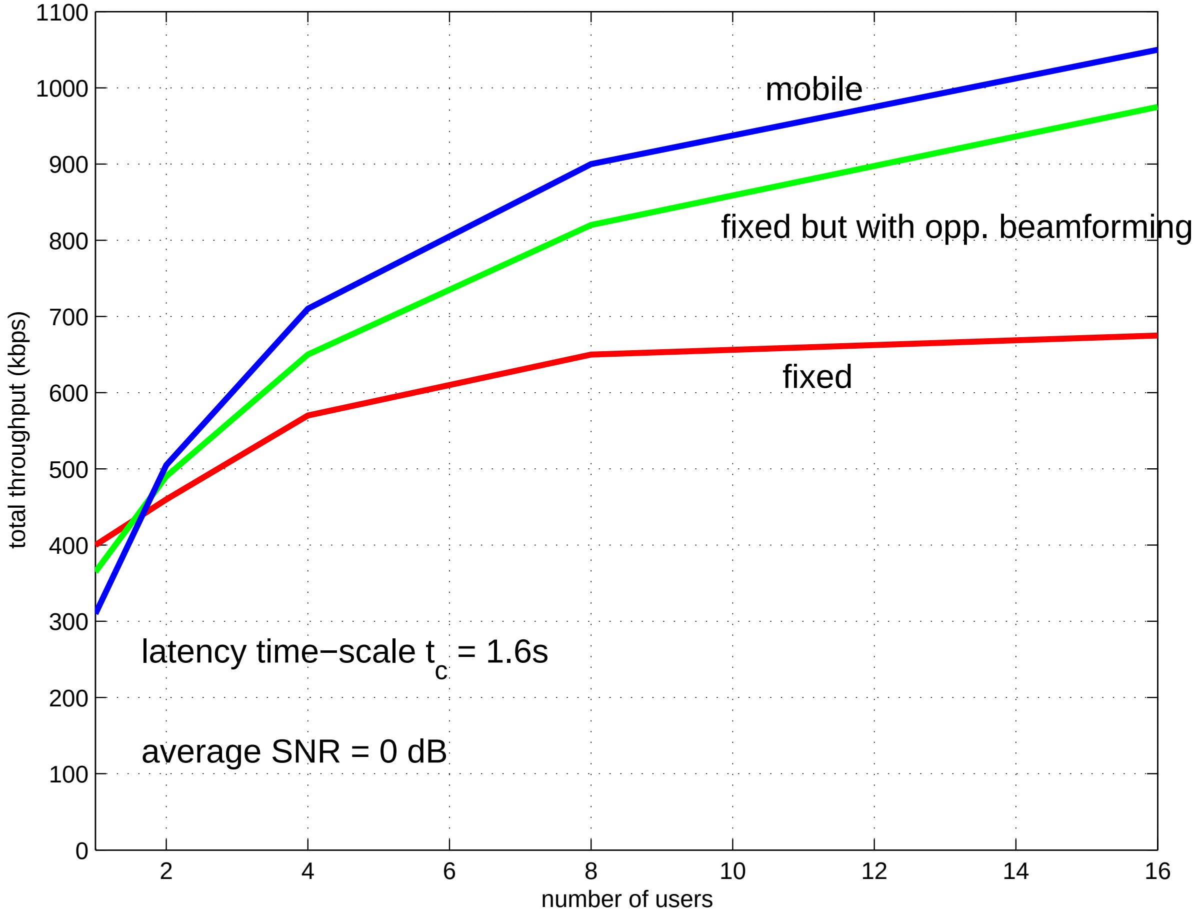
- Dumb antennas create a beam in random time-varying direction.
- In a large system, there is likely to be a user near the beam at any one time.
- By transmitting to that user, close to true beamforming performance is achieved.

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

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