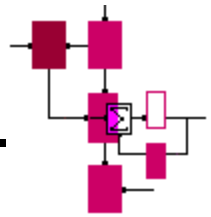

Some perspectives on ultra-wideband

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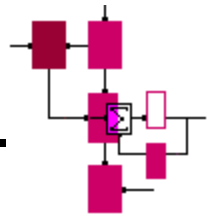
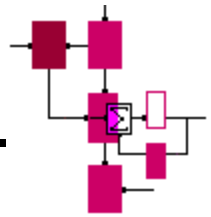
Overview



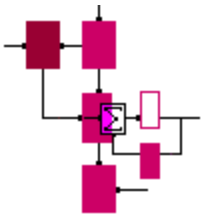
- Wireless communications over broad band have been evolving rapidly
- Quest: uncoordinated, cheap access to large amounts of bandwidth for many users
- What do theoretical limits tell us about how possible this is?
- Topics:
  - Overview of wireless channels and multiple access
  - Effectiveness of different spreading techniques - CDMA, FH, PPM, flash signaling
  - When happens when we are not bandwidth limited?
  - Can we find simple schemes that successfully approximate the infinite bandwidth results?
  - Can we have uncoordinated multiple access?

Wireless channels are challenging

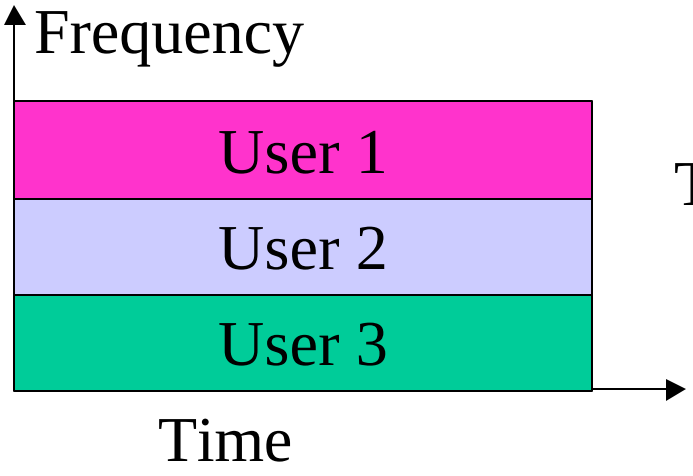


- Additive noise and also distortion through multipath fading, due to interference among different paths
- Rapid effect, with rate of change given by Doppler spread, which is proportional to speed of mobile and to carrier frequency (around 200 Hz) - channel decorrelates in time
- Channel decorrelates also in frequency owing to the delay spread Combat using diversity
  - Diversity in time (traditional coding)
  - Diversity in frequency (spreading in frequency)
  - Diversity of receivers/transmitters (MIMO)
  - Note: coding usually combines these features

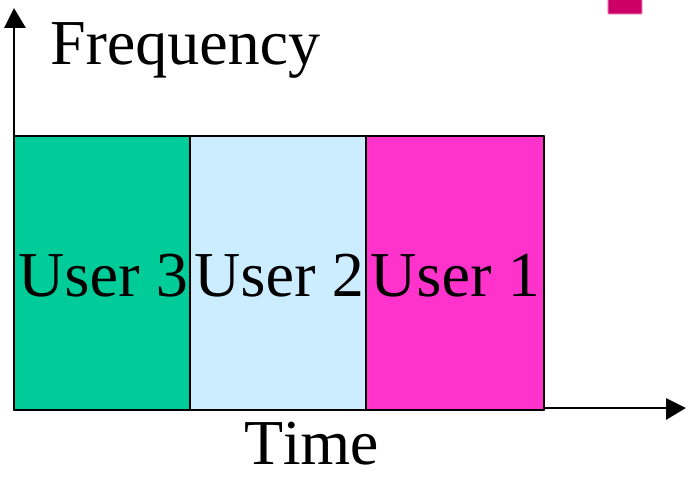
How to perform multiple access



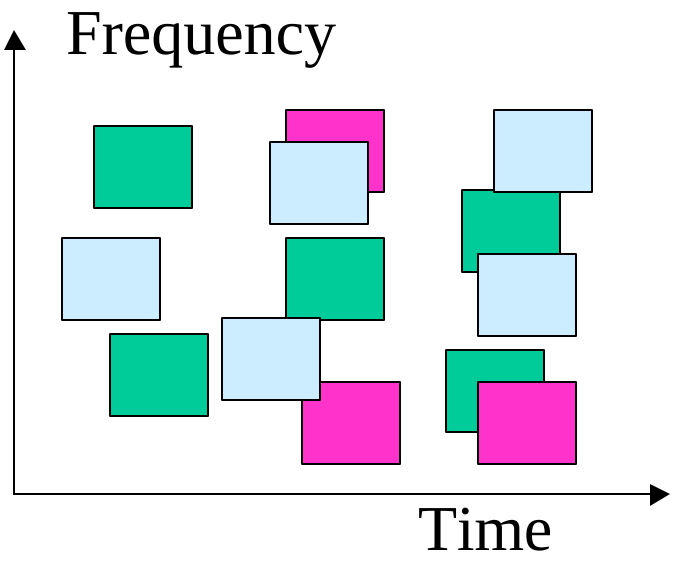
FDMA



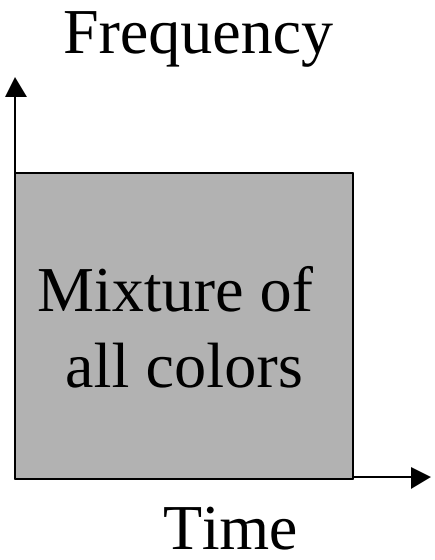
TDMA



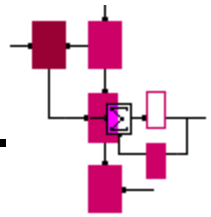
Frequency Hopping Spread spectrum



Direct Sequence Spread spectrum

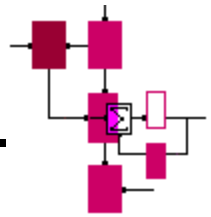


Spreading



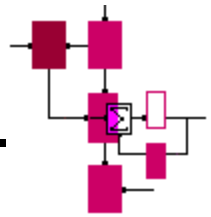
- DS-CDMA (direct sequence code division multiple access) has gained considerable commercial importance
- Spread in frequency by transforming bits into a series of chips
- Every user appears as noise to all other users
- Why not simply extend this to higher bandwidths?
- Does not scale when channel decorrelates in time and frequency (Medard and Gallager, 1997)
- Intuitive justification - cannot track the channel well enough to make reliable decisions because there is not enough energy in any portion of the spectrum

Pulse-position modulation (PPM)



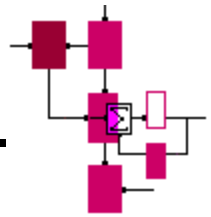
- Spread-spectrum multiple-access wireless system
- Time-hopping baseband signal comprised of very short pulses - occupies frequency band from near-DC to several GHz,
- Low power-spectral density
- Interference to other narrow-band systems should be low (although very poor from the point of view of peak interference)
- Appears to be sub-optimal from the point of view of approaching capacity - it is limited theoretically by the time spread, so may not be useful for very wide bands

Frequency hopping



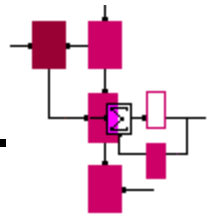
- Robust to fades by changing frequencies
- Does not suffer from channel tracking issues of DS-CDMA because there is enough energy transmitted in a single portion of the spectrum to identify the channel
- Not generally used in commercial systems, except as some extra diversity added onto other systems

What if we had unlimited bandwidth?



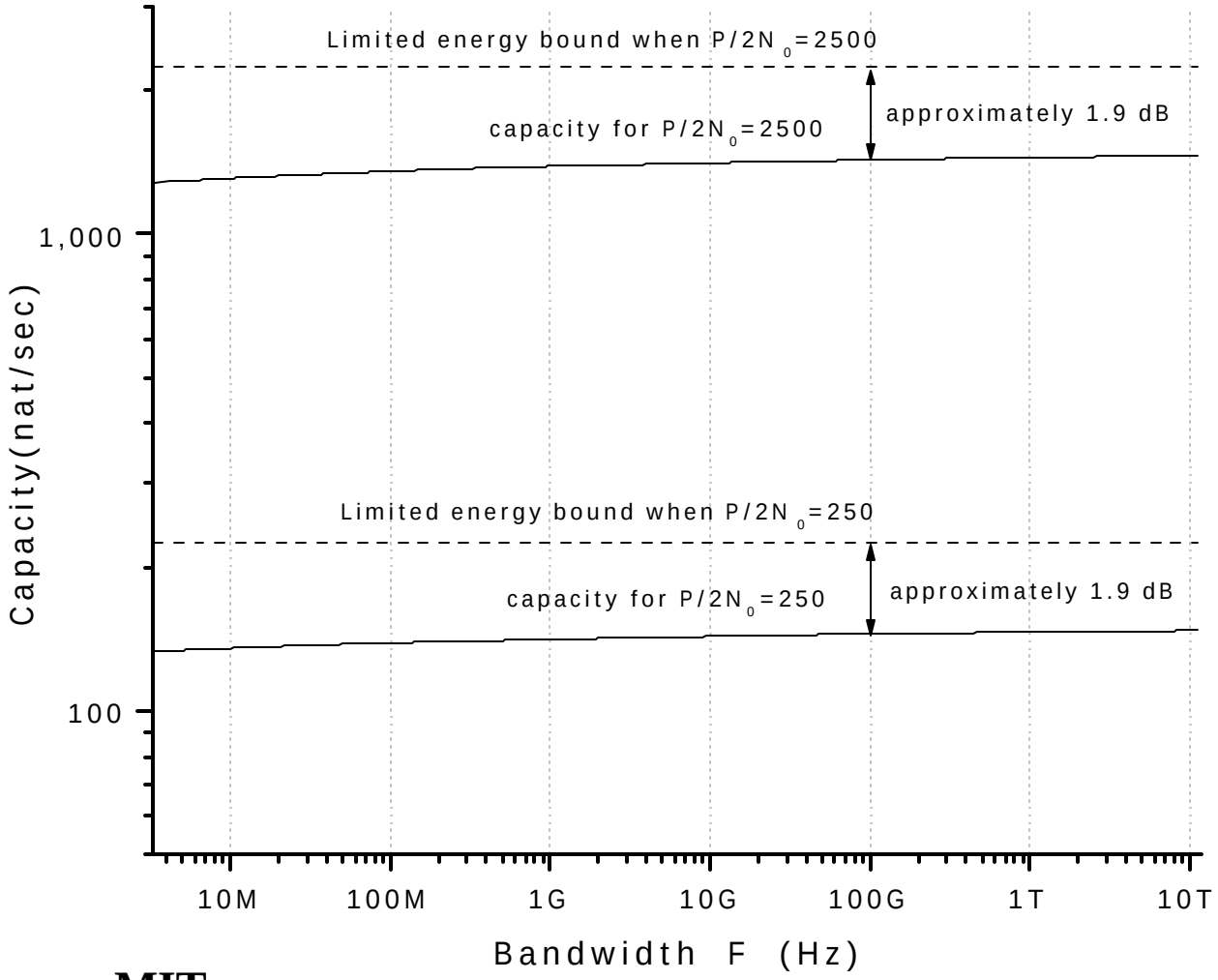
- Capacity of infinite-bandwidth multipath fading channel is equal to the capacity of the infinite-bandwidth channel with noise only
- Capacity can be achieved using frequency-shift keying with non-coherent detection by transmitting at a low duty cycle - ``peaky'' or flash signaling (looks similar to FH)
- How does the probability of error decay to zero as bandwidth approaches infinity for rates under capacity?
- Very slowly if we want to approach capacity (bandwidth must grow rapidly to achieve low probability of error if we are close to capacity)
- Other drawback- huge peak energy

Can we approach the infinite bandwidth limit with finite bandwidth?



- Use FSK that is somewhat impulsive and also use it over more than a single tone at a time
- Code over the tones that are used, rather than a single tone - thus allowing a reduction in peak energy
- Gets close to capacity for large bandwidths where DS-CDMA or PPM may no longer be effective
- Gracefully goes from energy-limited to bandwidth-limited regime
- Joint work with Cheng Luo and Lizhong Zhang

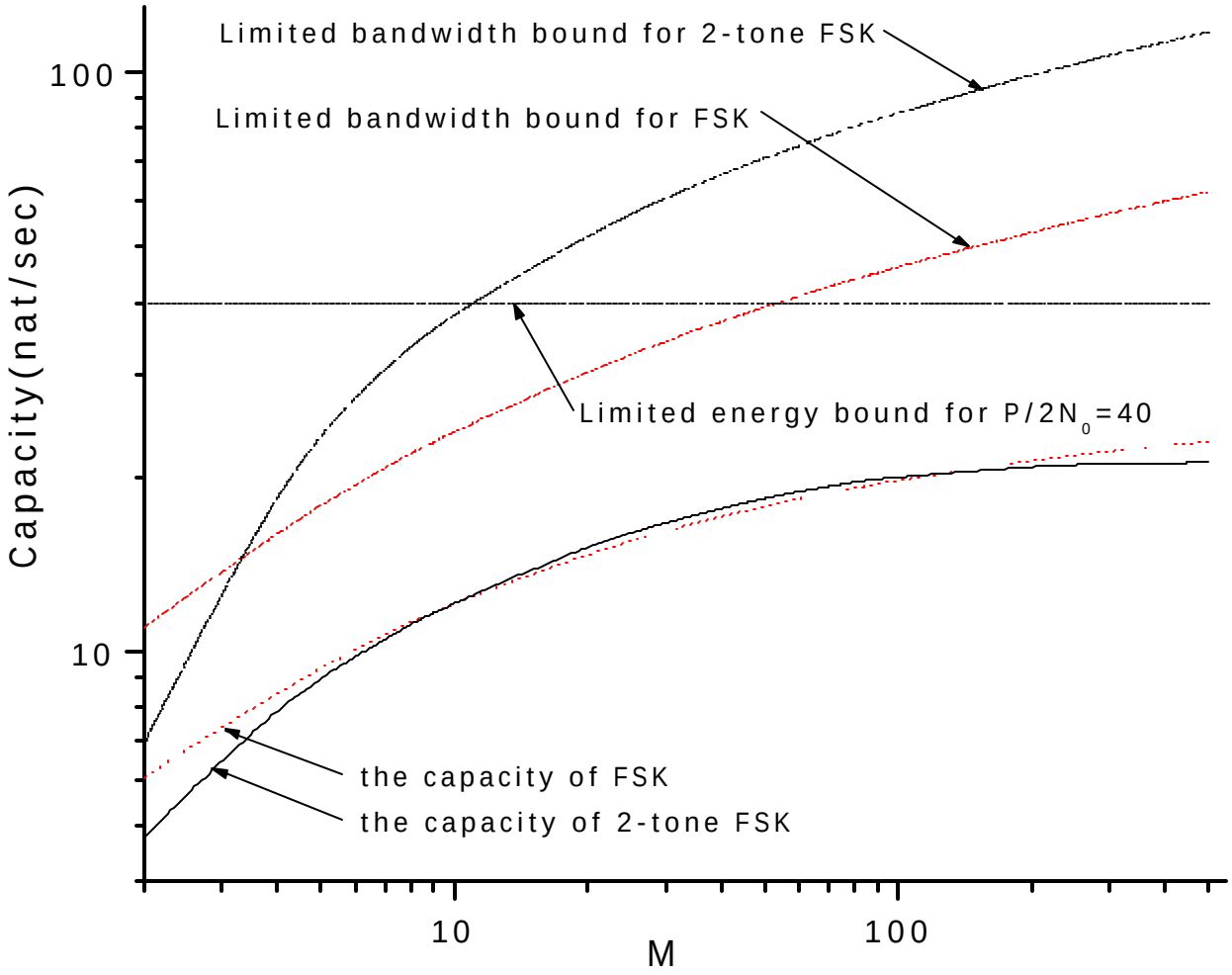
Capacity vs. bandwidth



$T_s = 10\ \mu s$

$T_d = 1\ \text{ì}\ s$

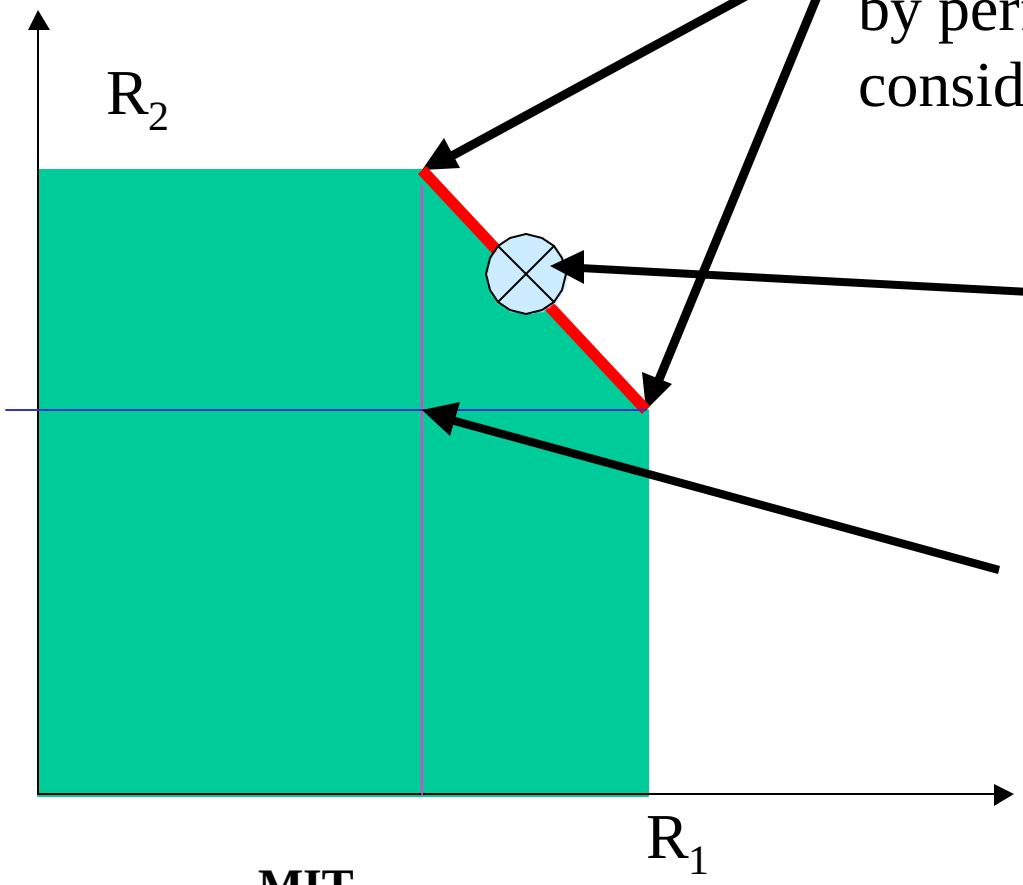
Capacity vs. M = number of coherence bands



T_s= 0.1 s
T_d= 1 ì s
$P/2N_0$= 40

Uncoordinated multiple access

The Cover-Wyner rate region

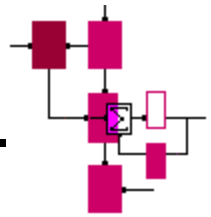


Points are achieved
by performing successive cancellation:
considering one user as noise to the other

Achievable by TDMA
or FDMA

Interference region

Conclusions



- Using wide bandwidths in wireless communications depends greatly on the setting and the attendant channel variations
- Channel variations are significant components of system performance
- New techniques promise to approach theoretical limits in practical ways
- Multiple access limits are unavoidable