Giga-bit WLAN: Areas with Potential for Breakthrough

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Outline

- Spectrum Sharing & More Spectrum Sharing!
  - 1 Gbits/sec in 4 Key Network Configurations:

Uplink = Multiple Access Channel

Down-link = Broadcast Channel

Parallel Links = Interference Channel

Channel with feedback = Two-way Channel

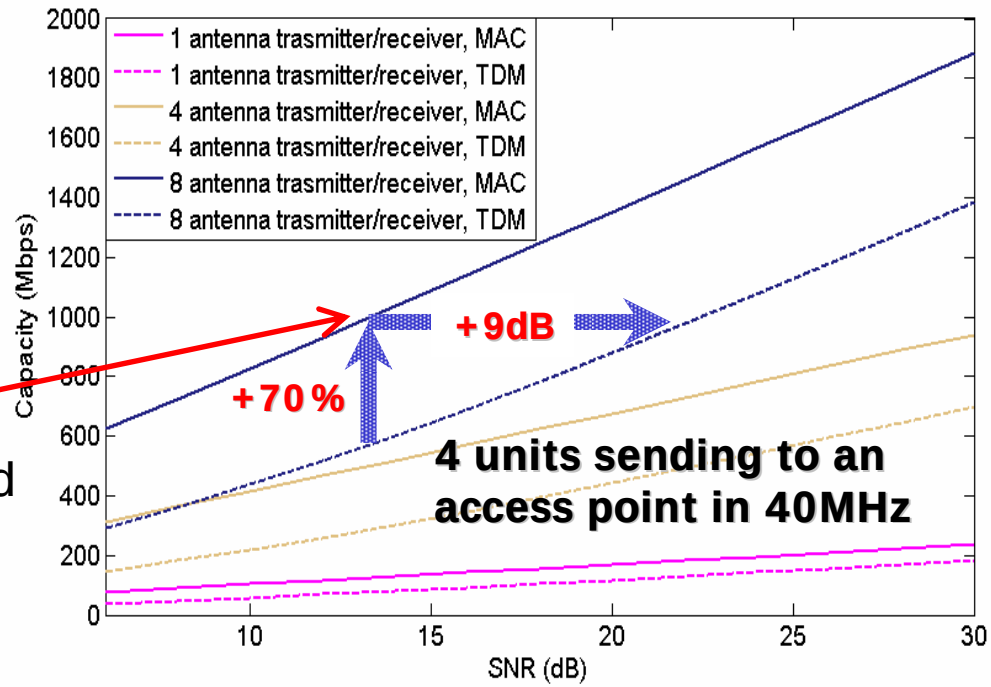
- Is Coding & Modulation Dead? Never!

Main Message

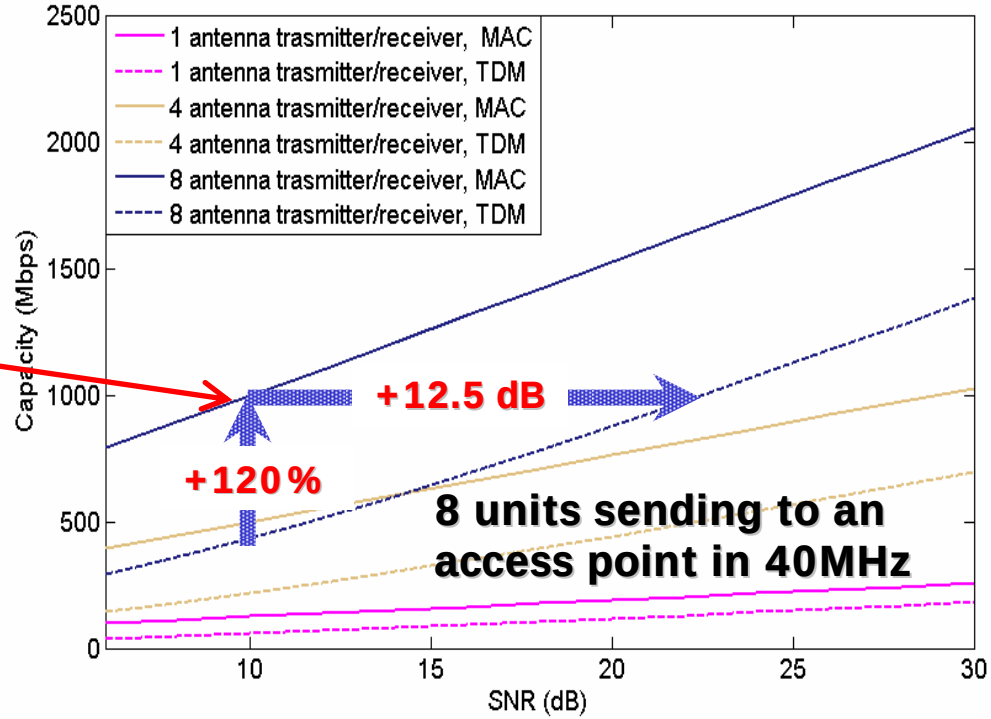
- MIMO with better Frequency Reuse:
  - ***Interference Management*** instead of
  - ***Interference Avoidance***
    - TDM/FDM (orthogonal transmission) is NOT the right choice
- Closer Attention to Fundamentals
  - Cross Layer Design
  - Network Information Theory

Multiple Access Channel:
Interference Cancellation, Joint Detection

1Gb/sec @ **13.5dB** vs. **22.5dB** obtained with 8x8 MIMO and TDM



1Gb/sec @ **10.0dB** vs. **22.5dB** obtained with 8x8 MIMO and TDM



Advantages of MIMO

- Multiplexing Gain (MG): $Rate \sim MG \times W \times \log(SNR)$
  - MG shows an effective increase in bandwidth
- Diversity Gain (DG): $P(error) \sim SNR^{-DG}$
  - DG determines reliability when CSI is not available at the transmitter
- MIMO breakthrough:

$K \times K$ MIMO offers $MG = K$ or $DG = K^2$

and a variety of **tradeoffs** in between

Forgotten Link: Bandwidth

- **People got so excited about MIMO that forgot the effect of bandwidth ($MG \times W$) in the effective rate:**

$$Rate \sim \underline{MG \times W} \times \log(SNR)$$

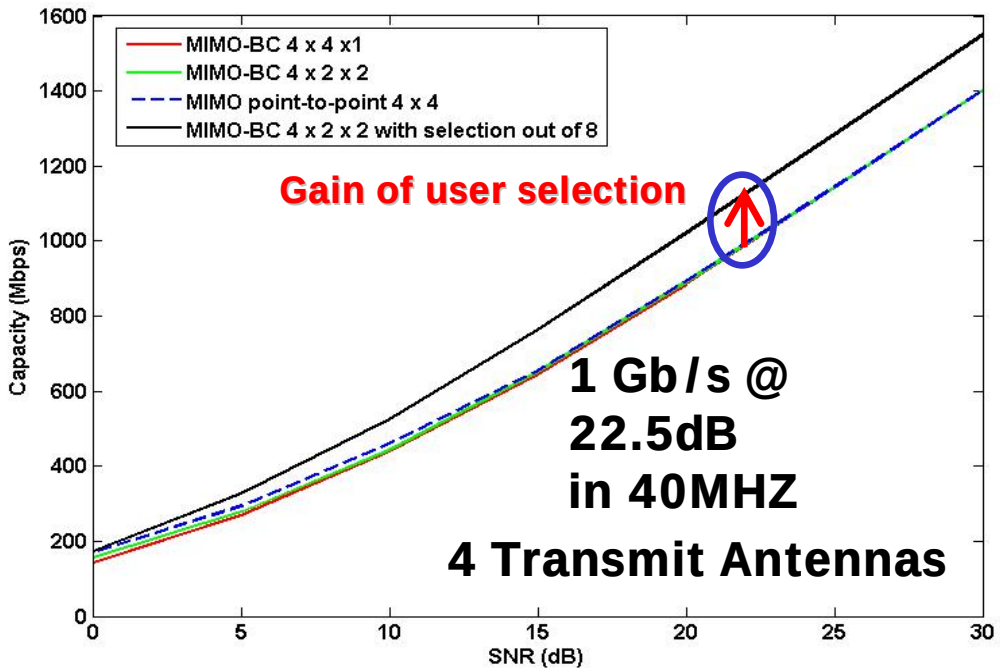
- Traditional view in a point-to-point system:
  - There is a tradeoff between MG and DG for a fixed W
- Correct view in a network of links:
  - In addition to the tradeoff between MG, DG, there is a tradeoff between W and SNR
  - **Bandwidth allocation should be taken into account**

MIMO Broadcast Channel:

Space Division Multiple Access (SDMA)

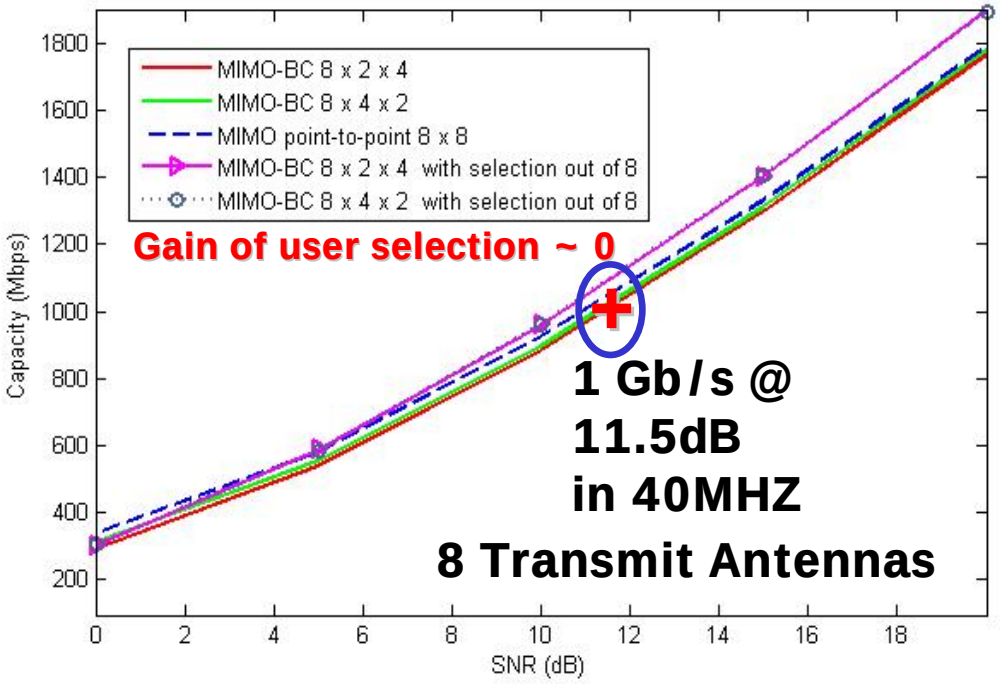
- **Main result:** A system with K transmit antennas support $MG = K$ if the total number of receive antennas is at least K
  - Same MG as a point-to-point MIMO
- Disadvantage vs. point-point MIMO:
  - Transmitter needs to know the channel to all receivers
- Advantages vs. point-point MIMO:
  - Rich scattering as each receiver is at a different location
  - Low complexity receivers
    - Each receiver receives a fraction of the total rate

MIMO-BC=SDMA



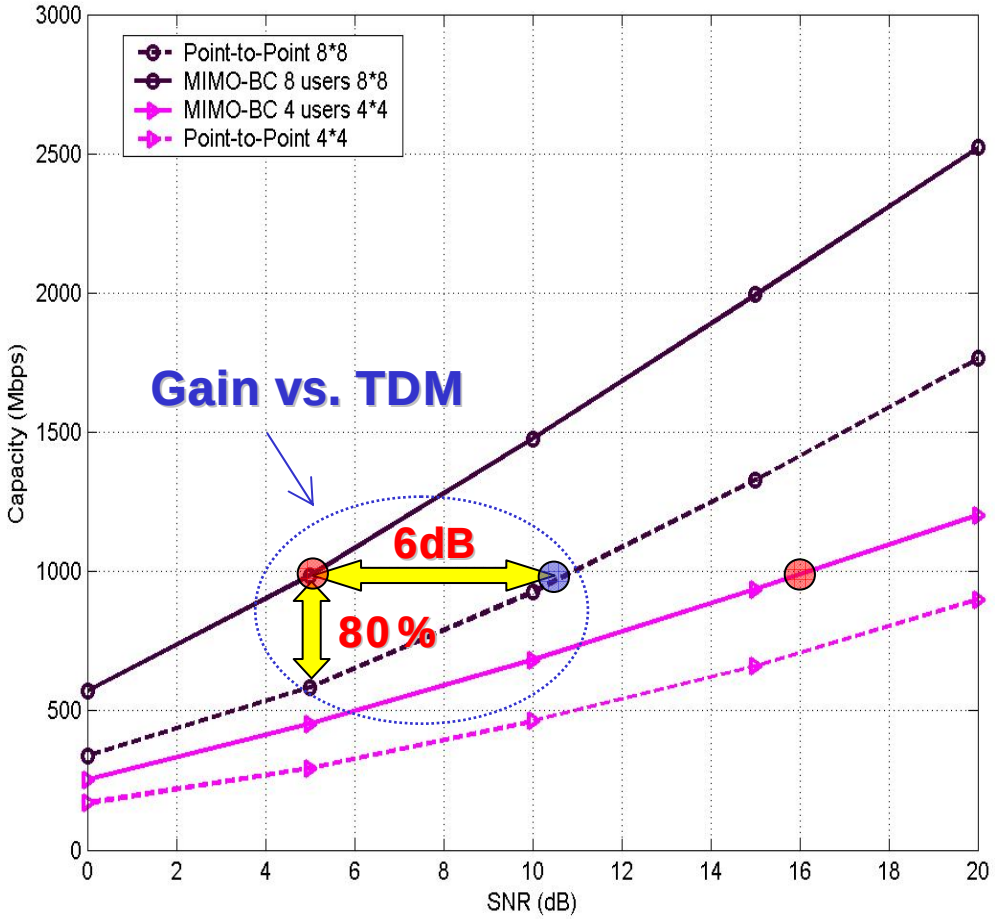
Observations:

- Perform almost the same as point-to-point MIMO
- Various configurations provide almost the same gain as log as the total number of receive and transmit antennas are the same
- User selection (multi-user diversity) does not help much



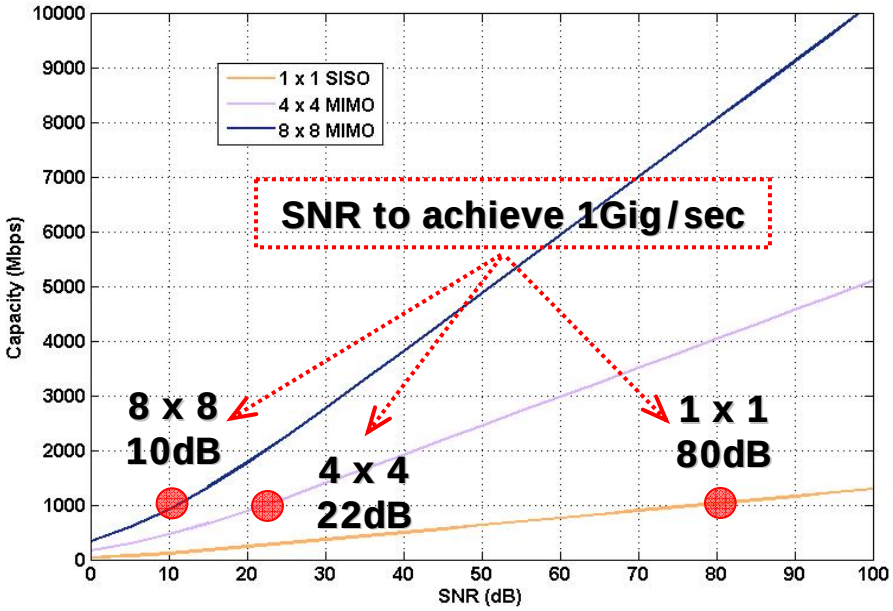
A More Promising Case in MIMO-BC: Transmitters/Receiver units have Equal Number of Antennas

- 1 Gb/sec @ W=40MHZ:
  - ~5dB with 8 antenna units
  - ~16dB with 4 antenna units
- Significant gain vs. TDM
  - ~6dB gain in SNR
  - 80% increase in rate
- Reduced Complexity
  - Low rate receivers



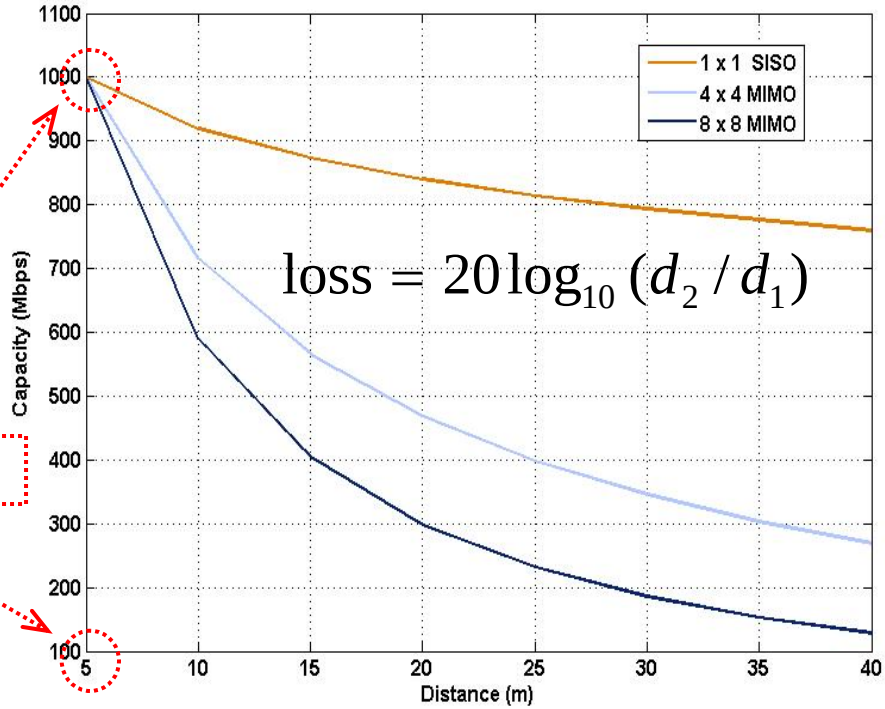
Bad News:

Effect of Distance



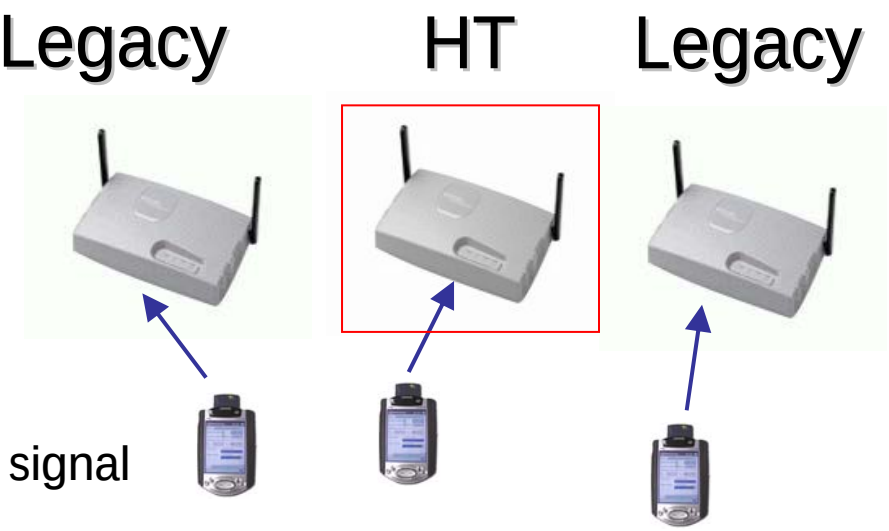
Possible solution:

Relaying



Curves normalized to deliver 1Gig/sec at 5m

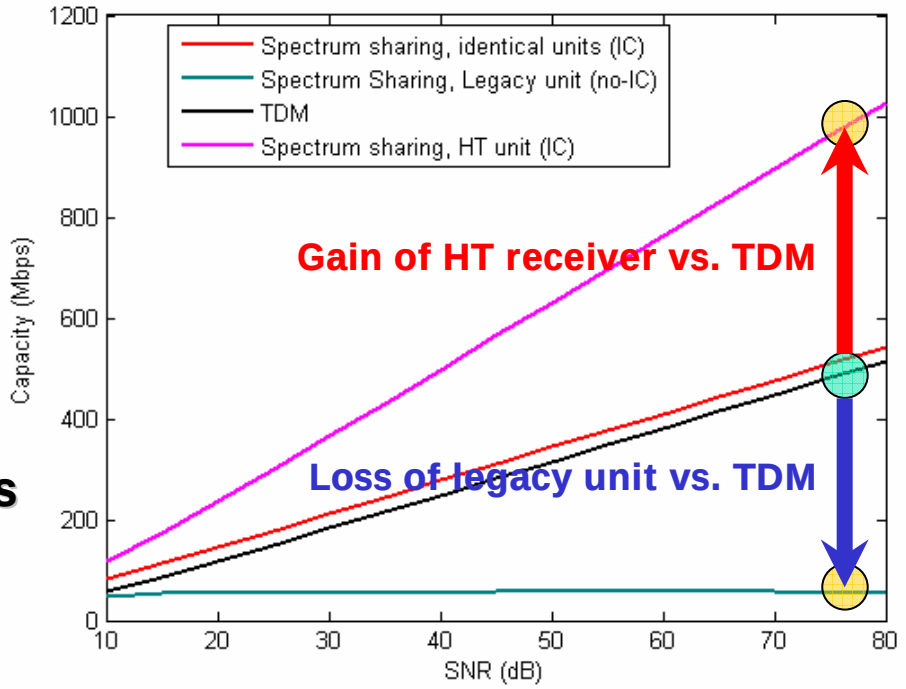
Interference Channel:
Spectrum Sharing

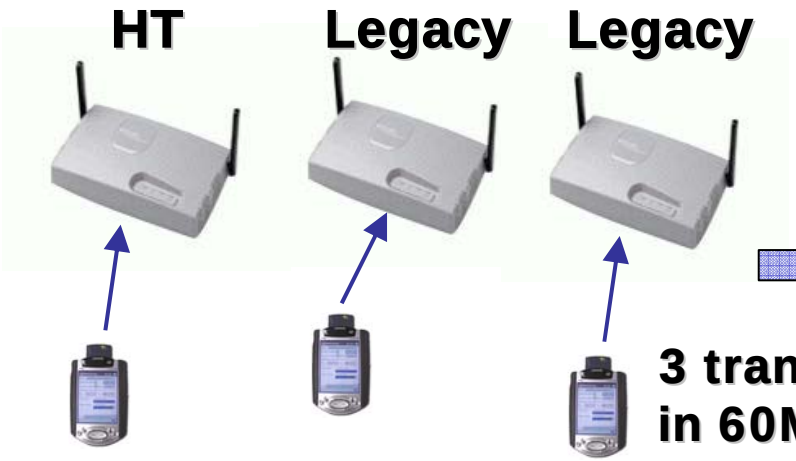


- Receiver's Strategies:
  1) Treat interference as noise
  2) Decode interference jointly with the signal
  3) Decode and cancel interference
- **Key Point:**
  - **<u>Strong interference is good for strategy 3</u>**
- Assume two types of receivers:
  - <u>HT (High Throughput) receivers:</u> Use the best strategy among the 3 options
  - <u>Legacy receivers:</u> Simply treat interference as noise

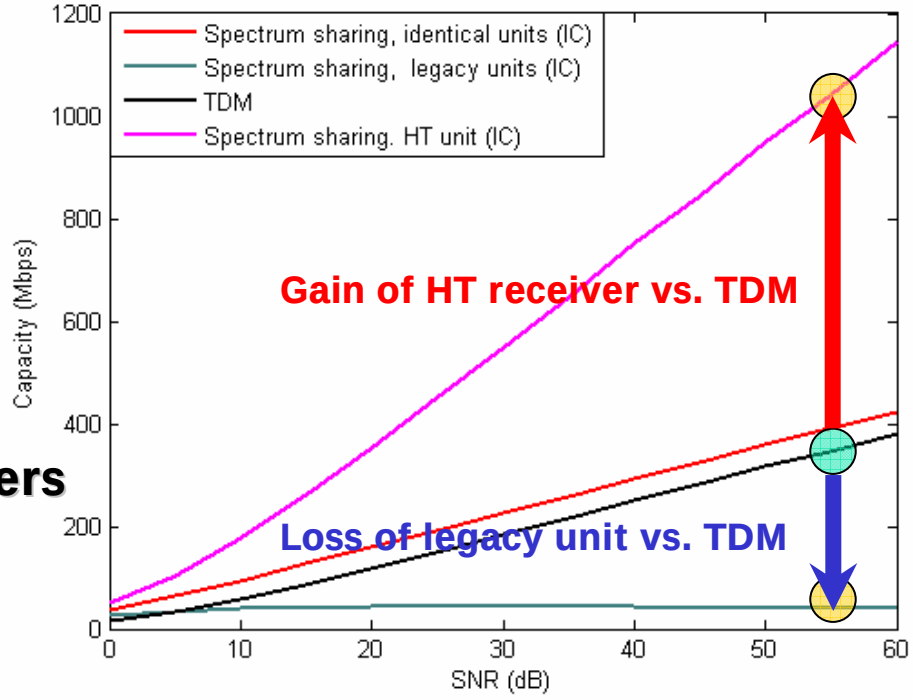
Interference Channel: Single antenna units

2 transceivers in 40MHz



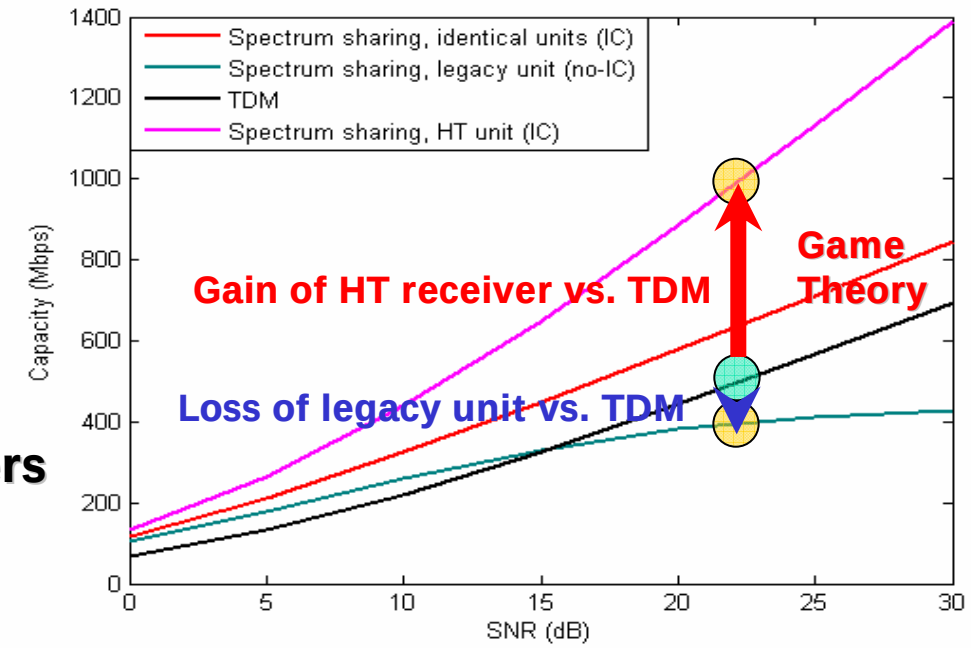


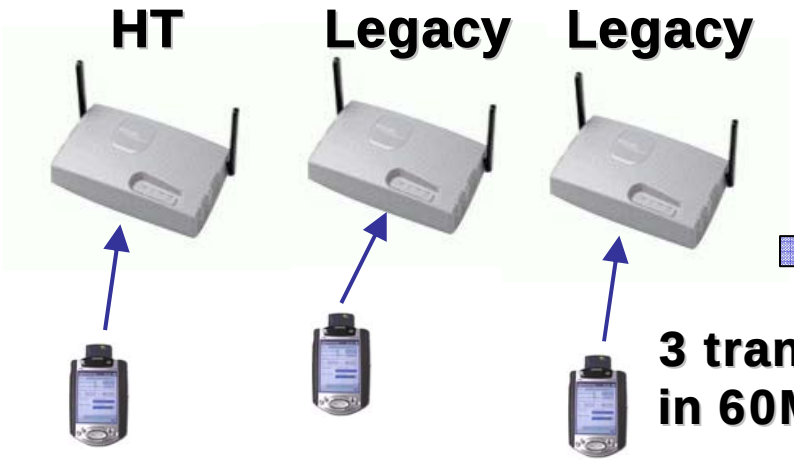
3 transceivers in 60MHz



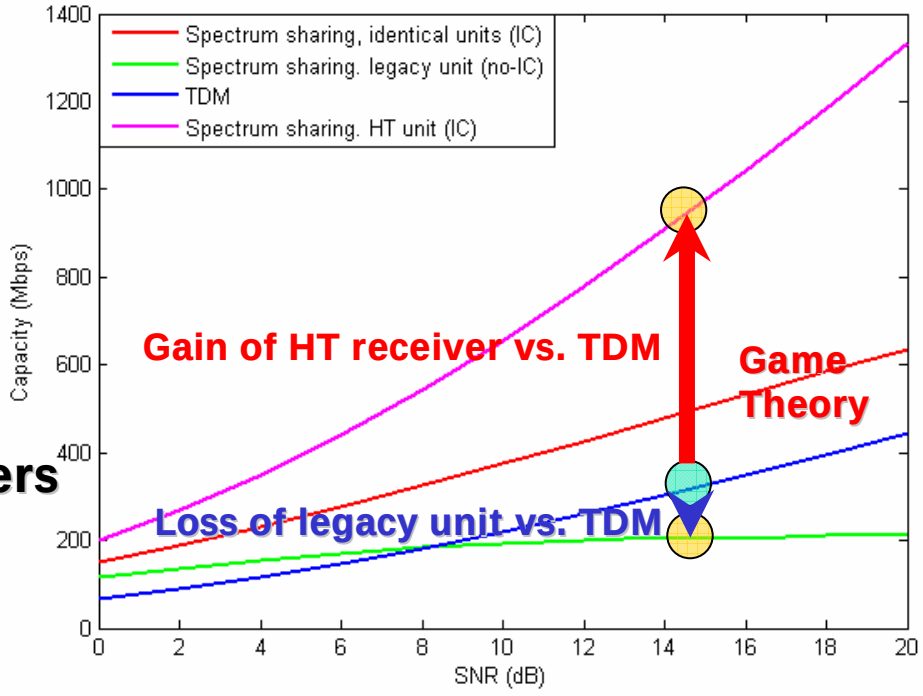
Interference Channel: 4-antenna units

2 transceivers in 40MHz



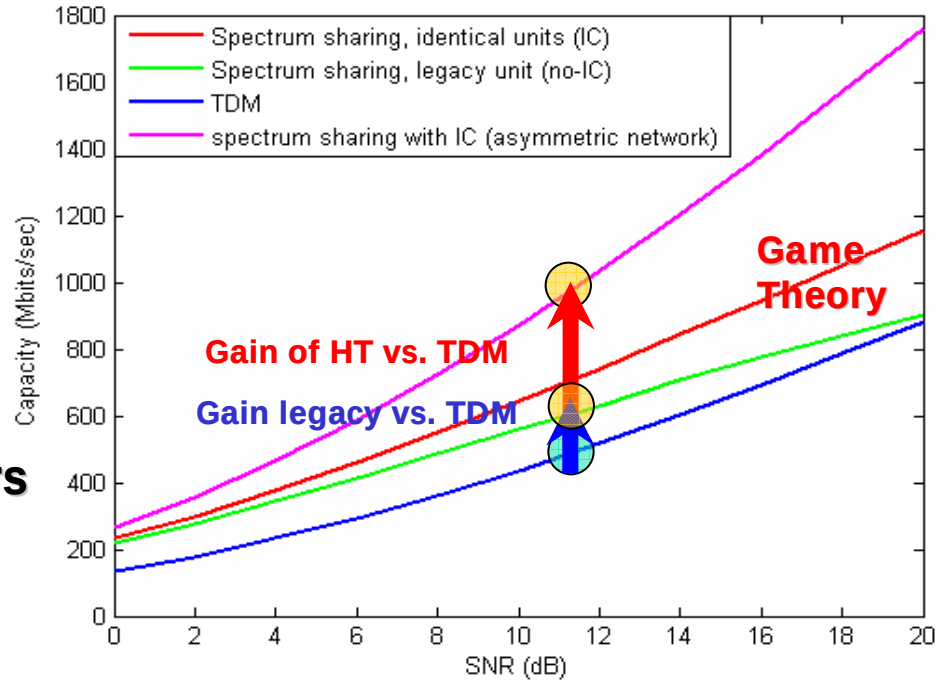


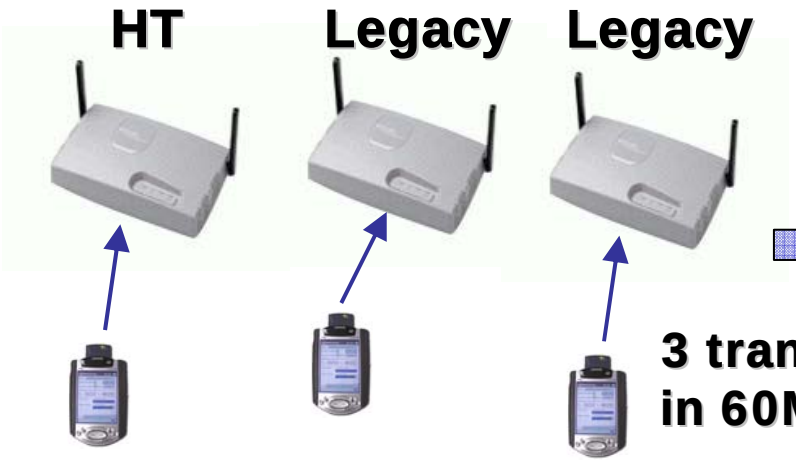
3 transceivers in 60MHz



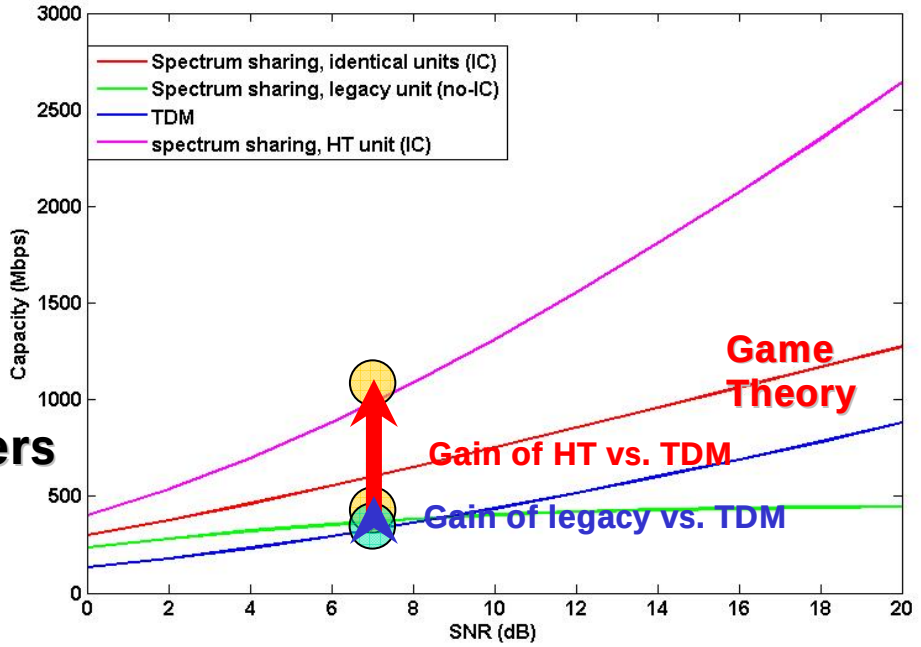
Interference Channel: 8-antenna units

2 transceivers in 40MHz

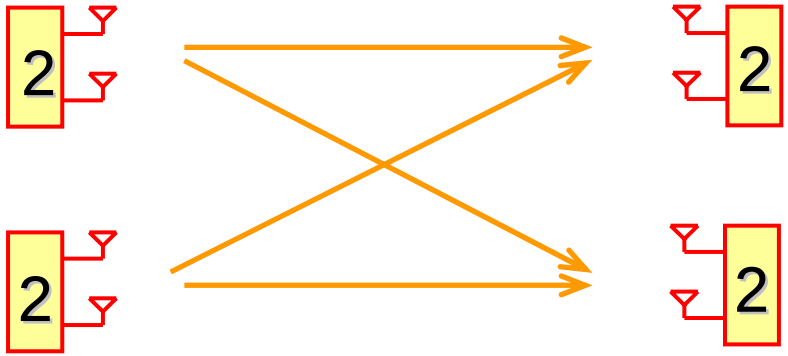




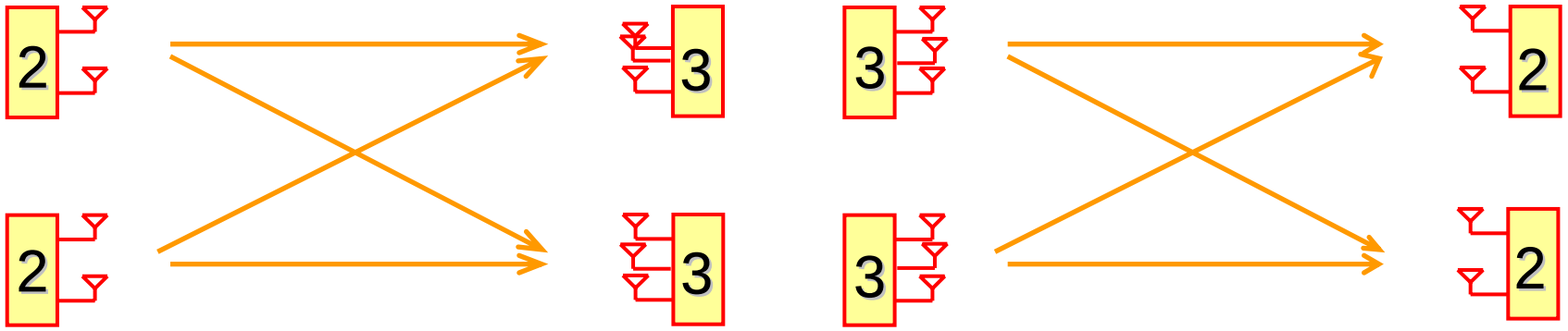
3 transceivers in 60MHz



A Surprising Result: One can achieve full MG without co-operation!



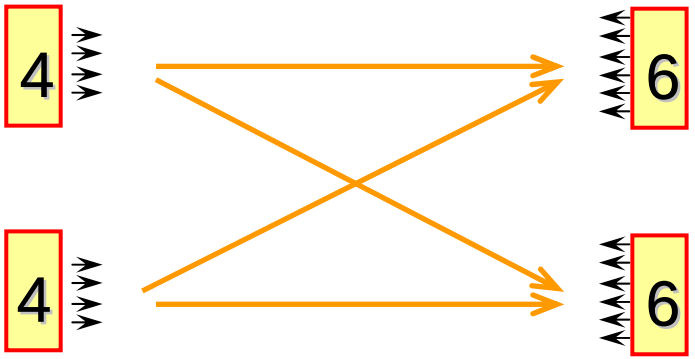
Can transmit 4 streams of data with a multiplexing gain of 2



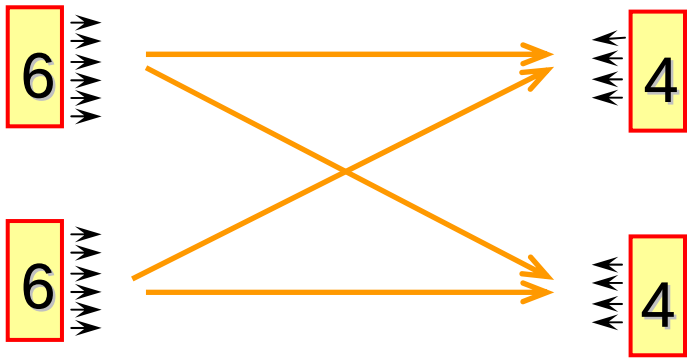
Can transmit 4 streams of data with a multiplexing gain of 4

M. A. Maddah-Ali, S. A. Motahari, and Amir K. Khandani, "Communication over MIMO X Channels: Signaling and Performance Analysis," Submitted to IEEE Transactions on Information Theory: www.cst.uwaterlo.ca

A Surprising Result: One can achieve full MG without co-operation!



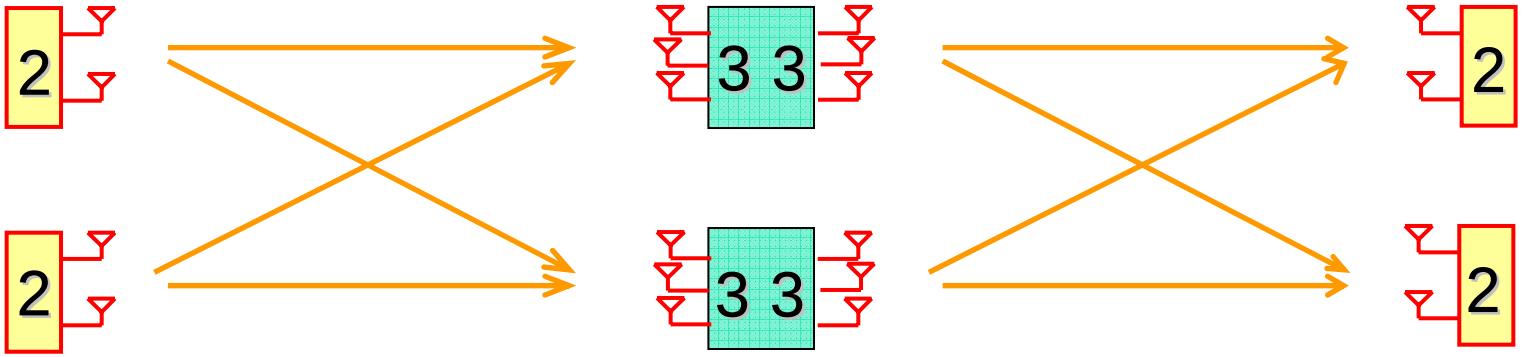
Can transmit 8 streams of data with a multiplexing gain of 8



Can transmit 8 streams of data with a multiplexing gain of 8

An Important Message:

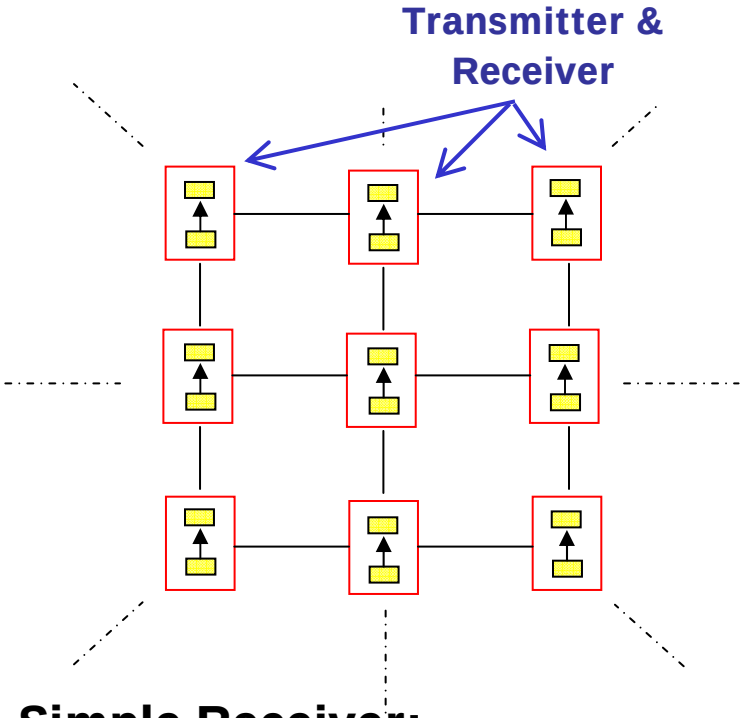
Shared relay is better than dedicated relay



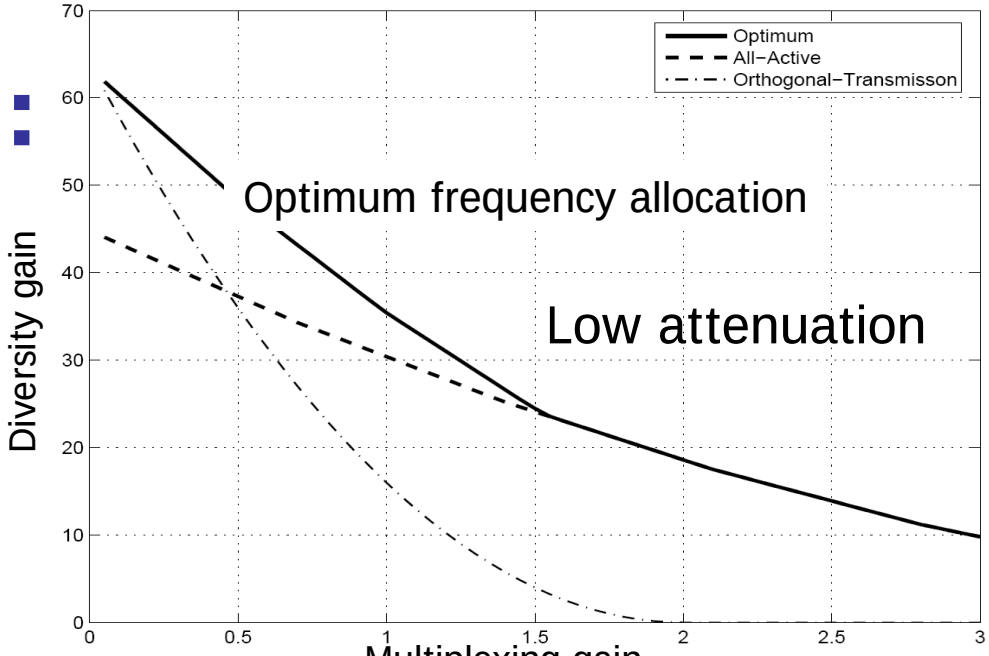
- Transmits 4 streams with a multiplexing gain of 4
- By increasing the number of antennas in the relays from 2 to 3, the effective bandwidth is increased by a factor of two

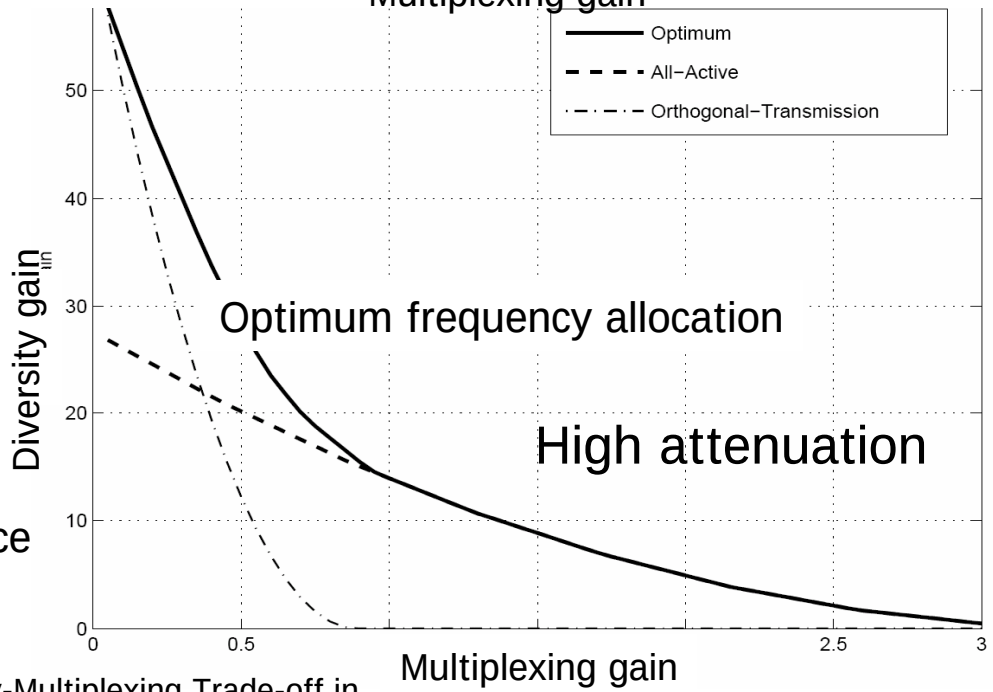
Spectrum Sharing:

- **Network Model:**



- **Simple Receiver:**
  - Treat interference as noise
  - Similar results obtained for more advanced receivers with interference cancellation/joint detection



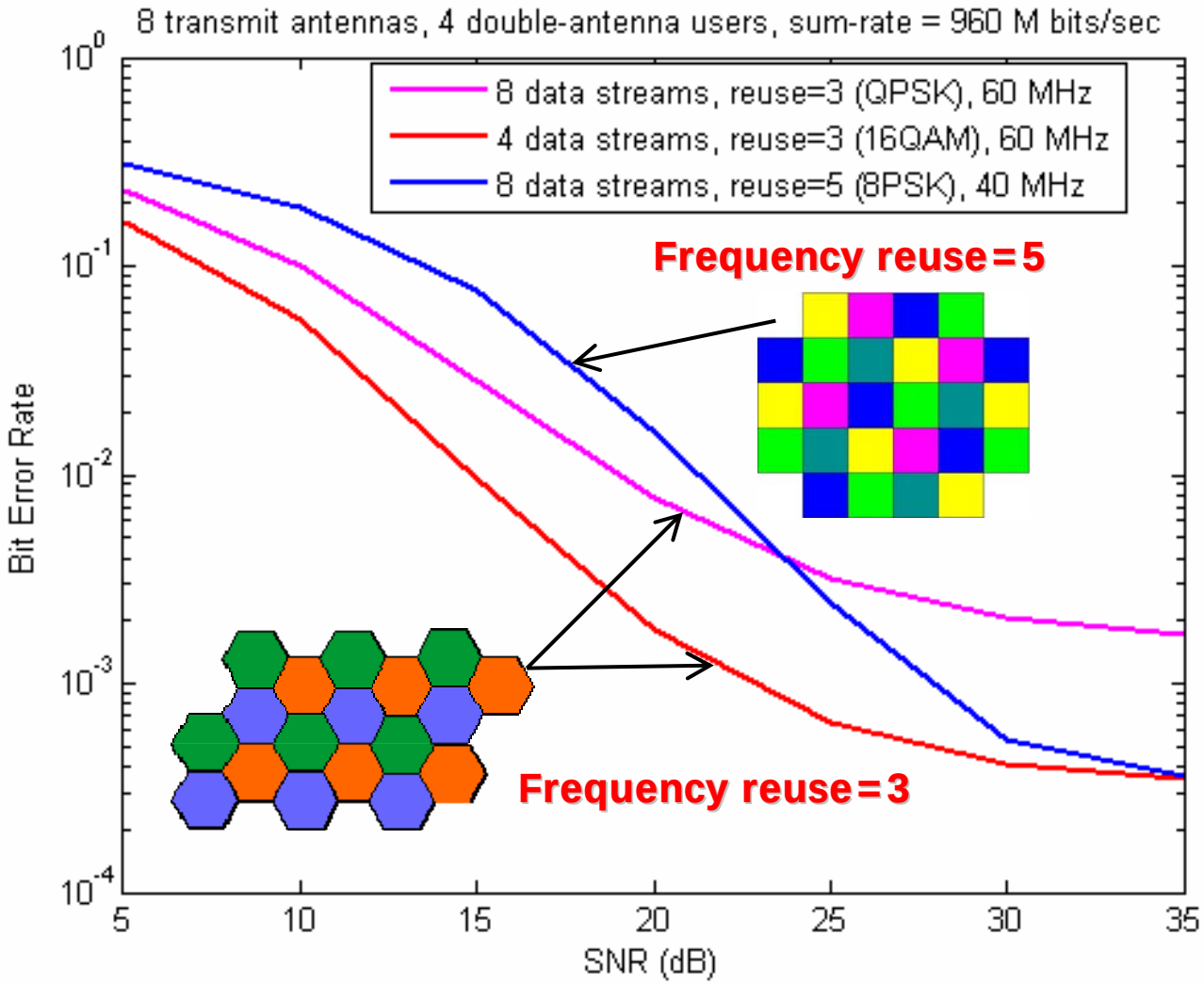


M. Ansari, A. Bayesteh, and Amir K. Khandani, "Diversity-Multiplexing Trade-off in Interference Channels" submitted to IEEE Trans. on Info. Theory: www.cst.uwaterlo.ca

Impact of Interference on MG/DG Tradeoff in Network: An example

Message:

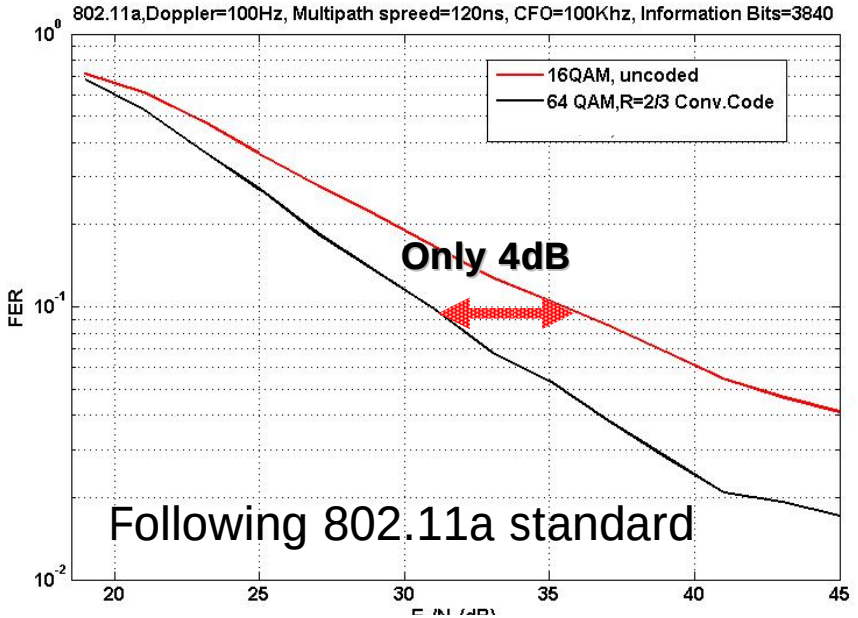
Revisit old design criterion before selecting BLAST vs. Alamouti!

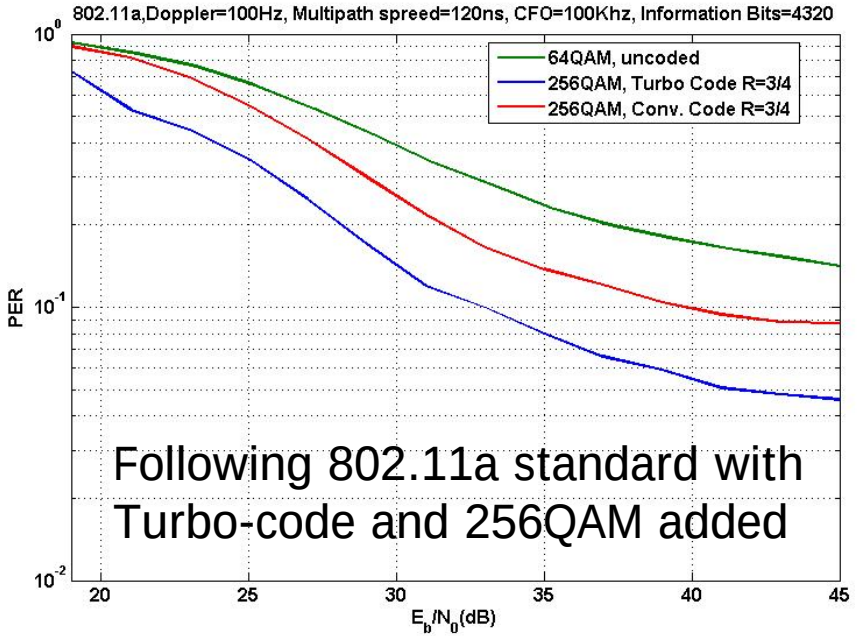


Is Coding & Modulation Dead?

- Higher gains possible using coset coding/shaping*
- Error floor due to imperfections
  - Operate at higher error rates and use continuous feedback
- Coding over packets
  - Erasure Channel

Two-way channel





* A. K. Khandani, W. Tong, Application of Shaping Technique with Turbo Coset Codes, IEEE Transactions on Vehicular Technology, to appear, Sept 07

Network Coding:
A simple example

Packet *X* should be sent from *A* to *B*

Packet *Y* should be sent from *B* to *A*

Half-duplex Relay

- Traditional Way (4 transmissions):
  - Packet X : $A \xrightarrow{T=1} R \xrightarrow{T=2} B$
  - Packet Y : $B \xrightarrow{T=3} R \xrightarrow{T=4} A$
- Network Coding (3 transmissions):
  - Packet X : $A \xrightarrow{T=1} R$
  - Packet Y : $B \xrightarrow{T=2} R$
  - Packet $X \oplus Y$: $A \xleftarrow{T=3} R \xrightarrow{T=3} B$ (relay broadcasts $X \oplus Y$)

As Marconi said,

"It is dangerous to put limits on wireless"