Smart Antennas in Realistic Propagation Channels

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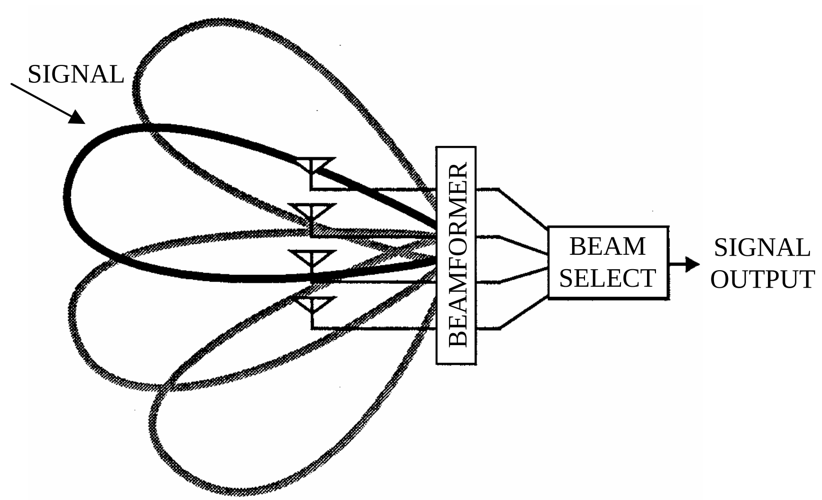
Outline

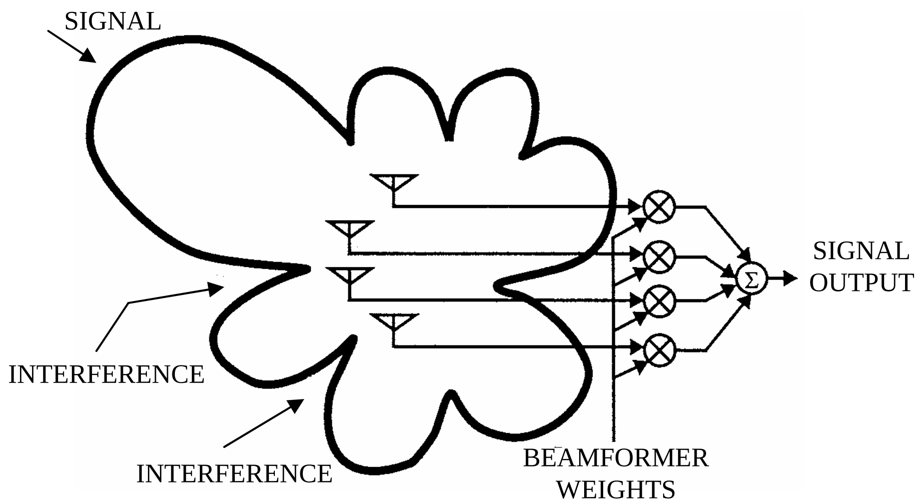
- Types of smart antennas
- MIMO
- Diversity and angular spread
- LOS cases
- Delay spread
- Conclusions

Smart Antennas

Switched Multibeam Antenna



Adaptive Antenna Array



Smart antenna is a multibeam or adaptive antenna array that tracks the wireless environment to significantly improve the performance of wireless systems.

Switched Multibeam versus Adaptive Array Antenna: Simple beam tracking, but limited interference suppression and diversity gain

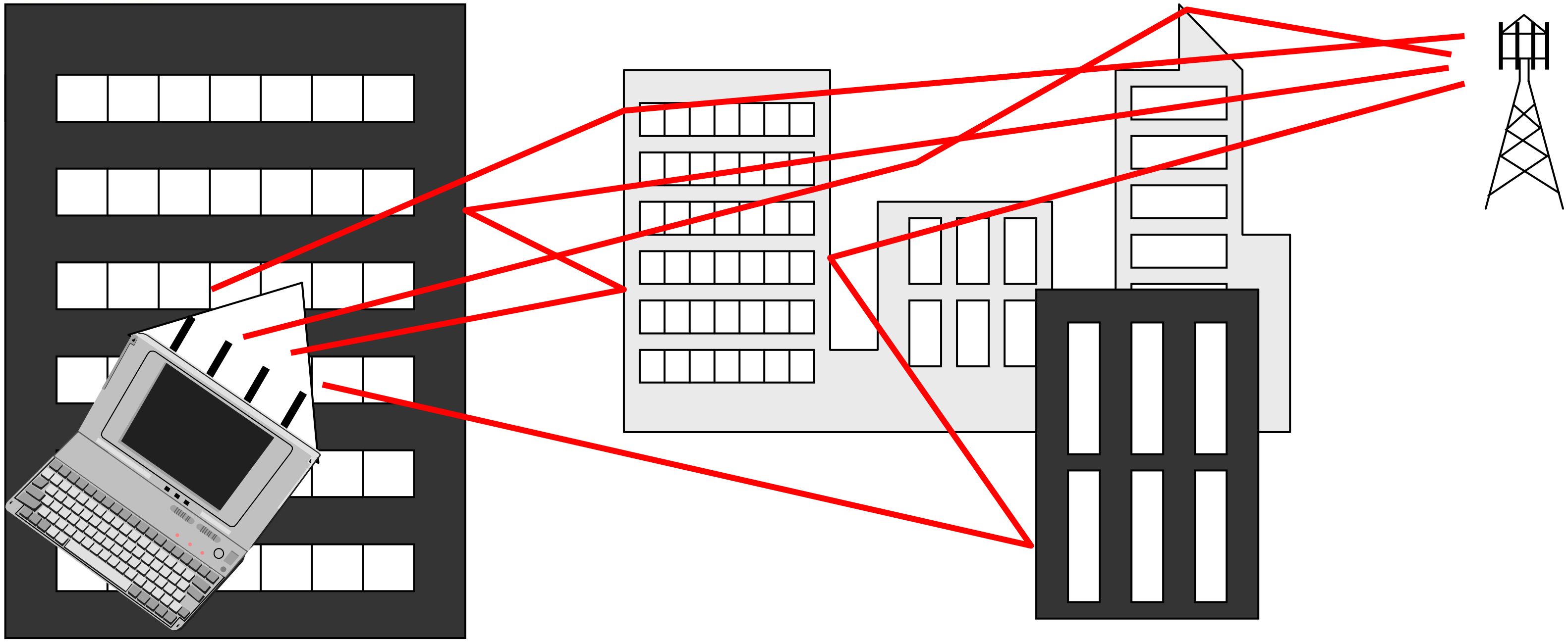
Adaptive arrays in any environment provide:

- Antenna gain of M
- Suppression of M-1 interferers

In a multipath environment, they also provide:

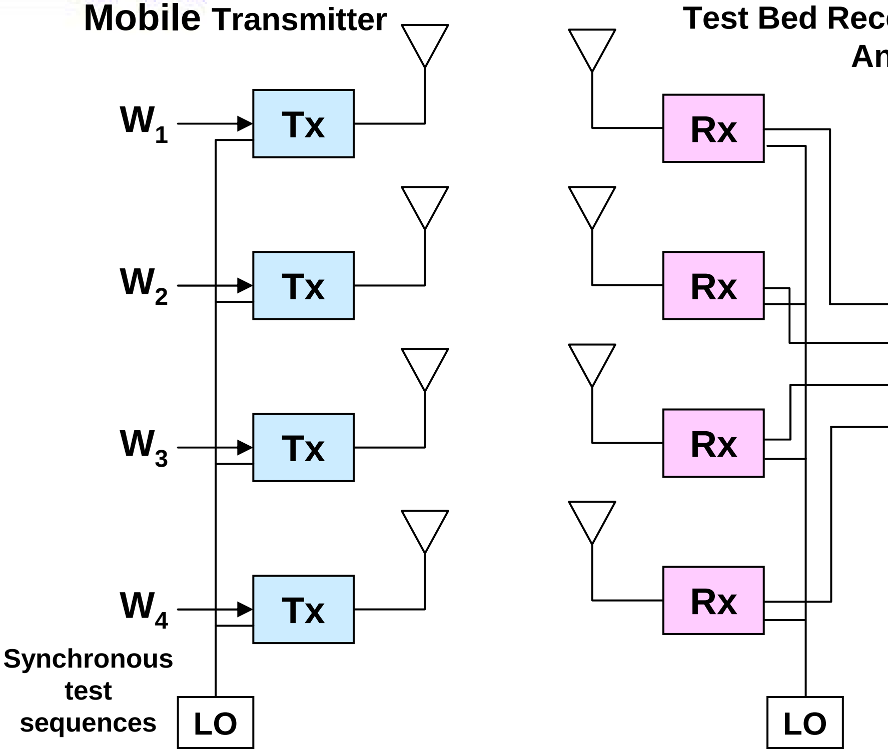
- M-fold multipath diversity gain
- With M Tx antennas (MIMO), M-fold data rate increase in same channel with same total transmit power

Multiple-Input Multiple-Output (MIMO) Radio



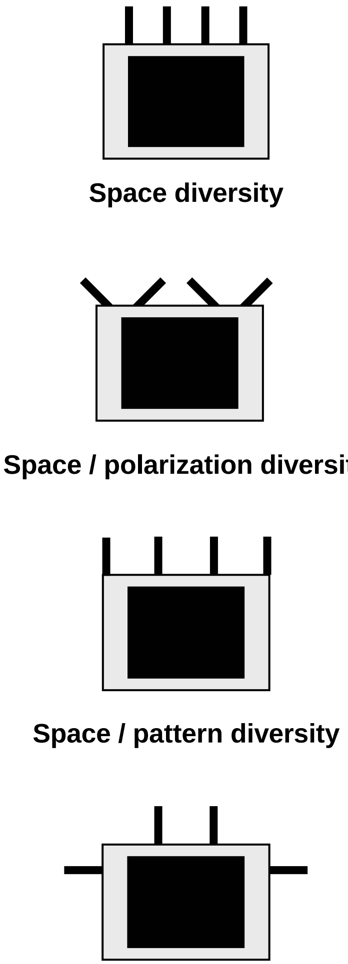
- **With M transmit and M receive antennas, can provide M independent channels, to increase data rate M-fold with no increase in total transmit power (with sufficient multipath) – only an increase in DSP**
  - **Indoors – up to 150-fold increase in theory**
  - **Outdoors – 8-12-fold increase typical**
- **Measurements (e.g., AT&T) show 4x data rate & capacity increase in all mobile & indoor/outdoor environments (4 Tx and 4 Rx antennas)**
  - **216 Mbps 802.11a (4X 54 Mbps) – 802.11n(?)**
  - **1.5 Mbps EDGE**
  - **19 Mbps WCDMA**

MIMO Channel Testing

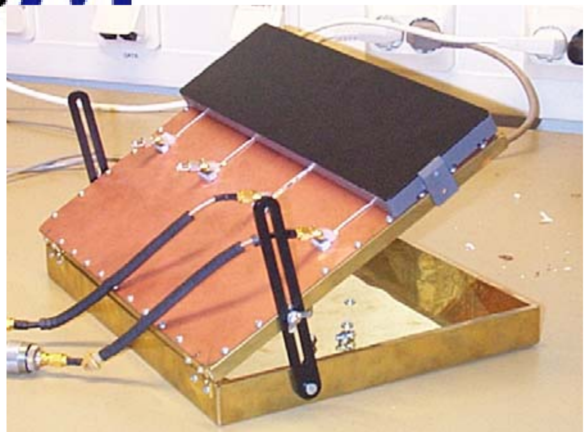


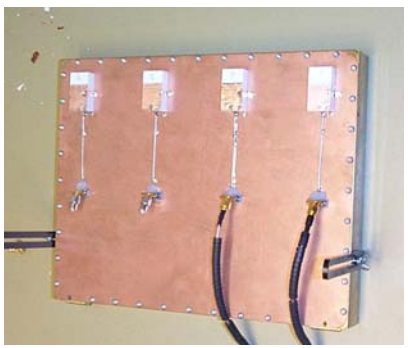
- Record complex correlation of each transmit waveform on each receive antenna, C_{4x4}
- Compute $C^H C$ correlation matrix to determine potential capacity and predict performance
- Compute fading correlation across receive array

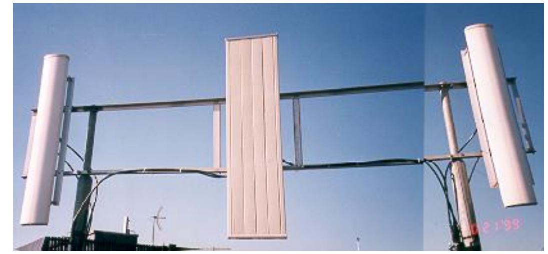
Transmit Antenna Configurations



Diversity Antennas





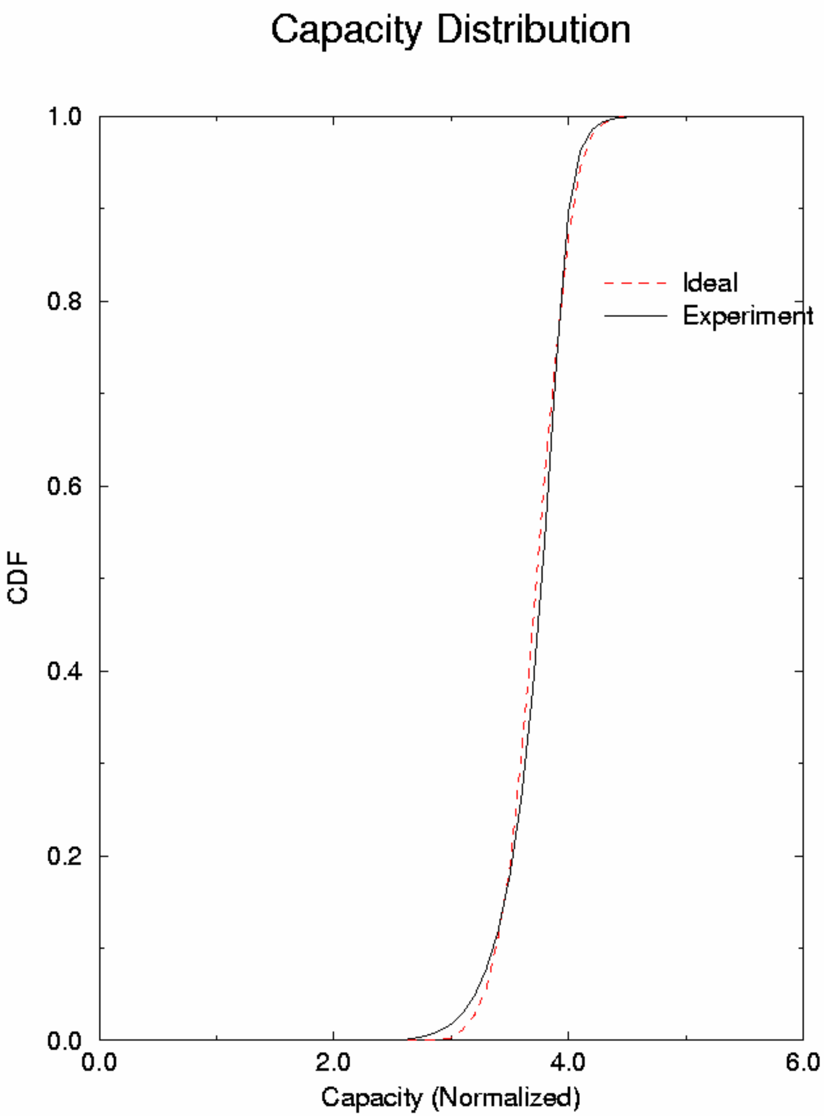


Base Station Antennas

- **Antennas mounted on 60 foot tower on 5 story office building**
- **Dual-polarized slant 45° 1900 MHz sector antennas and fixed multibeam antenna with 4 - 30° beams**

Laptop Prototype

- **4 patch antennas at 1900 MHz separated by 3 inches ($\lambda/2$ wavelengths)**
- **Laptop prototype made of brass with adjustable PCB lid**


Capacity Distribution
1.0
0.8
0.6
0.4
0.2
0.0
CDF
0.0
2.0
4.0
6.0
Capacity (Normalized)
Ideal
Experiment

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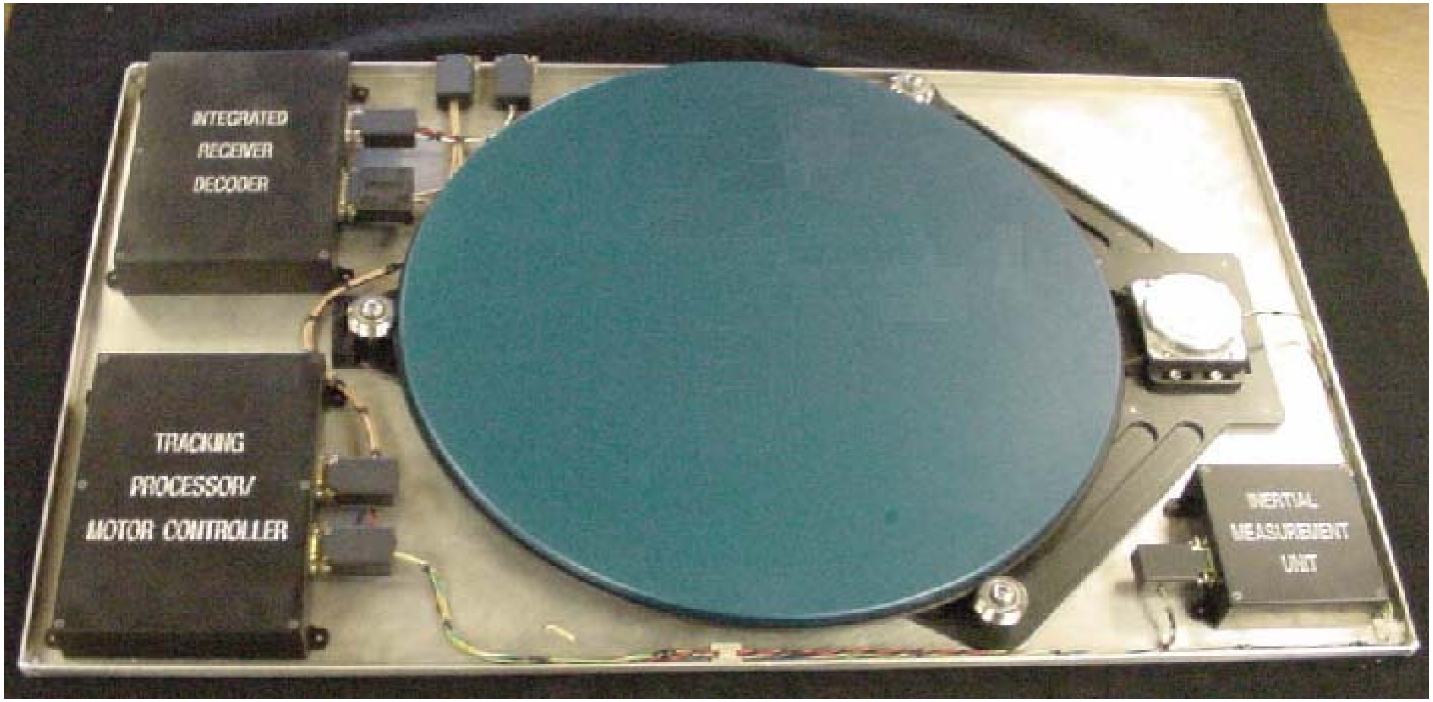
Example of LOS Case with No Diversity: Ultralow Profile Mobile Satellite

Mobile DBS Limitation

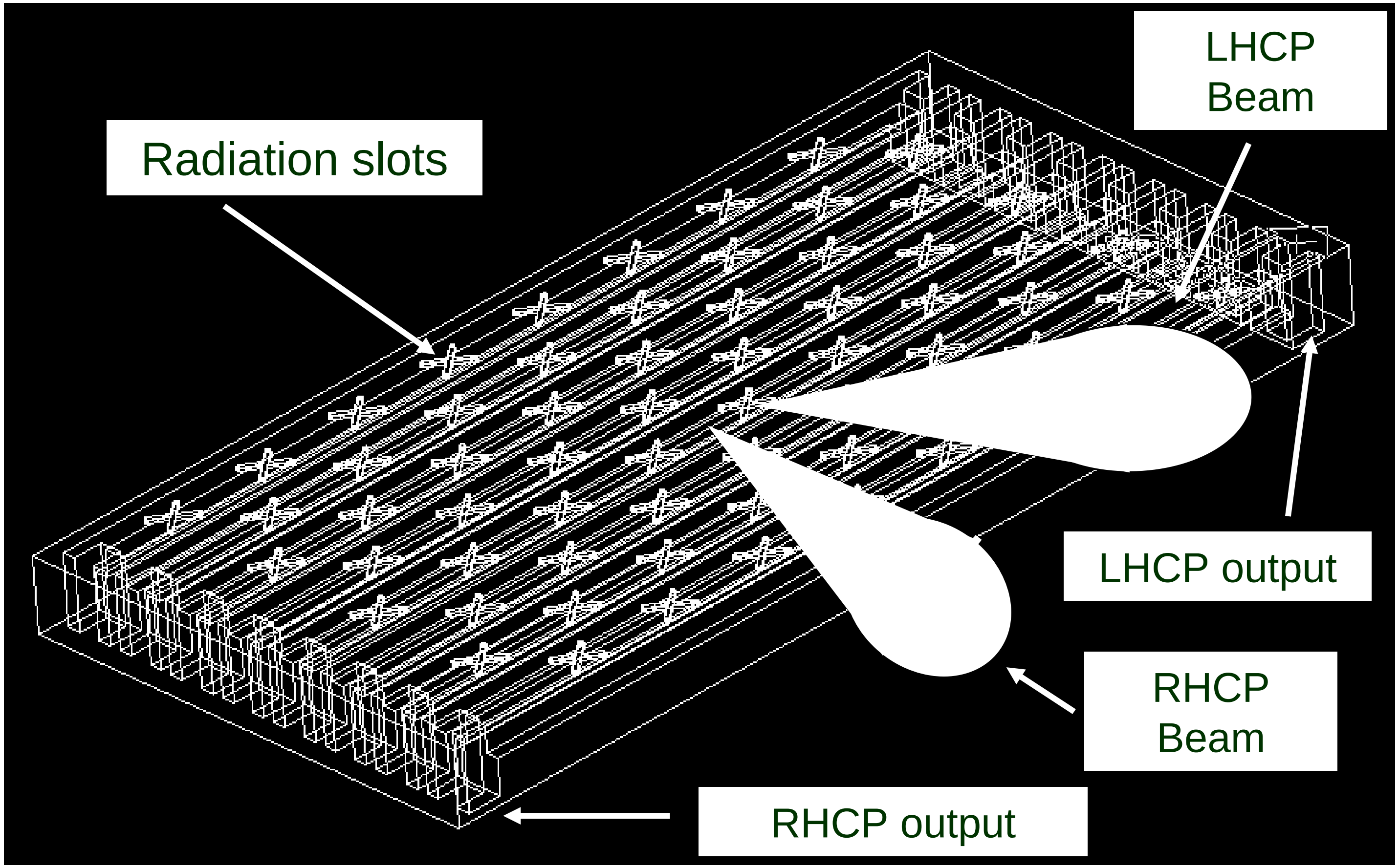
Legacy Products Too Large and Bulky for Minivan/SUV Market

Hybrid Beam Steering Approach

- **Electronic Beam Steering in Elevation Direction**
- **Mechanical Beam Steering in Azimuth Direction**
  - **Most Cost Effective Approach**
  - **Achieve the Lowest Profile**

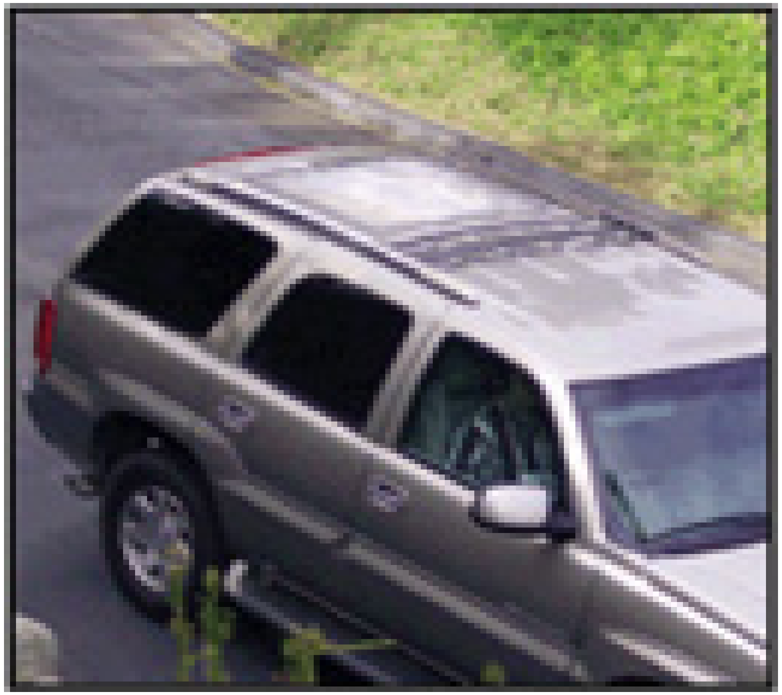


Structure of the Phased Array Antenna



- **Two CPs are Generated by Direction of Wave Traveling within the Waveguide**

Aftermarket



OEM

Incorporation into vehicles

ANTENNA AND DIVERSITY GAIN

Antenna Gain: Increased average output signal-to-noise ratio

- Gain of *M* with *M* antennas
- Narrower beam with λ/2-spaced antenna elements

Diversity Gain: Decreased required receive signal-to-noise ratio for a given BER averaged over fading

- Depends on BER - Gain for *M*=2 vs. 1:
  - •5.2 dB at 10^{-2} BER
  - •14.7 dB at 10^{-4} BER
- Decreasing gain increase with increasing *M* - 10^{-2} BER:
  - •5.2 dB for *M*=2
  - •7.6 dB for *M*=4
  - •9.5 dB for *M*=∞
- Depends on fading correlation

• Antenna diversity gain may be smaller with RAKE receiver in CDMA

DIVERSITY TYPES

Spatial: Horizontal separation

- Correlation depends on angular spread
- Only ¼ wavelength needed at terminal (10 wavelengths on base station)

Polarization: Dual polarization (doubles number of antennas in one location)

- Low correlation
- Horizontal receive 6-10 dB lower than vertical with vertical transmit and LOS

DIVERSITY TYPES (cont.)

Angle: Adjacent narrow beams with switched beam antenna

- Low correlation typical
- 10 dB lower signal in weaker beam, with small angular spread

Pattern: Allows even closer than ¼ wavelength

$\Rightarrow$ 4 or more antennas on a PCMCIA card

$\Rightarrow$ 16 on a handset

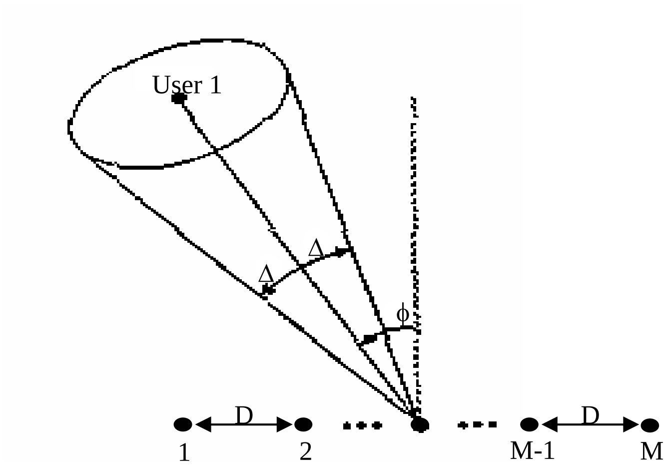
$\Rightarrow$ Even more on a laptop

CORRELATION

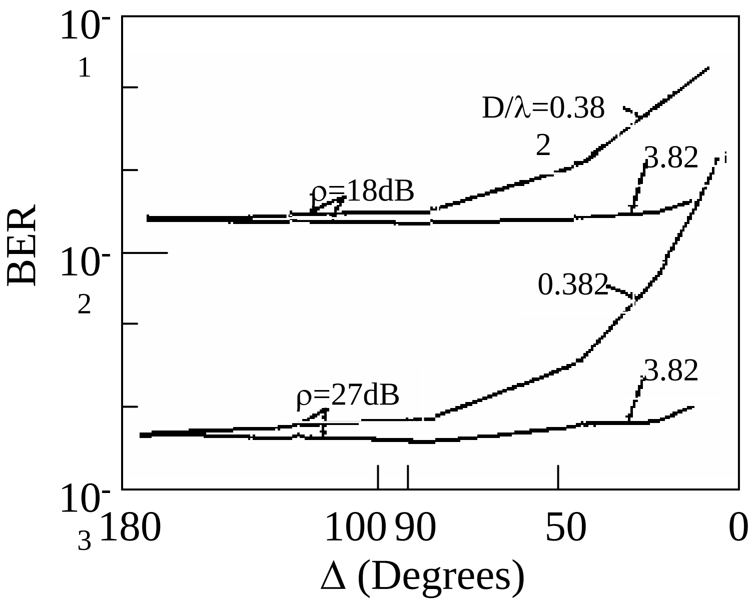
• Degradation due to fading correlation with adaptive array that combats fading, suppresses interference, and equalizes delay spread is only slightly larger than that for combating fading alone:

- Small degradation with correlation less than 0.5

Model

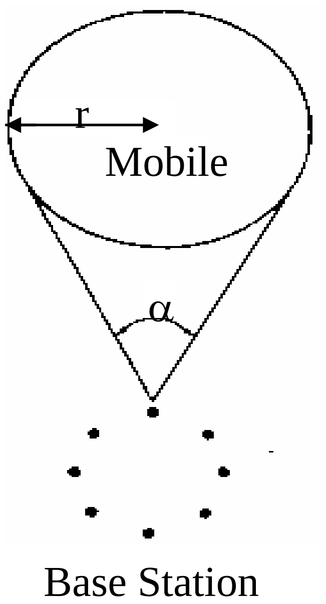


BER with Correlation

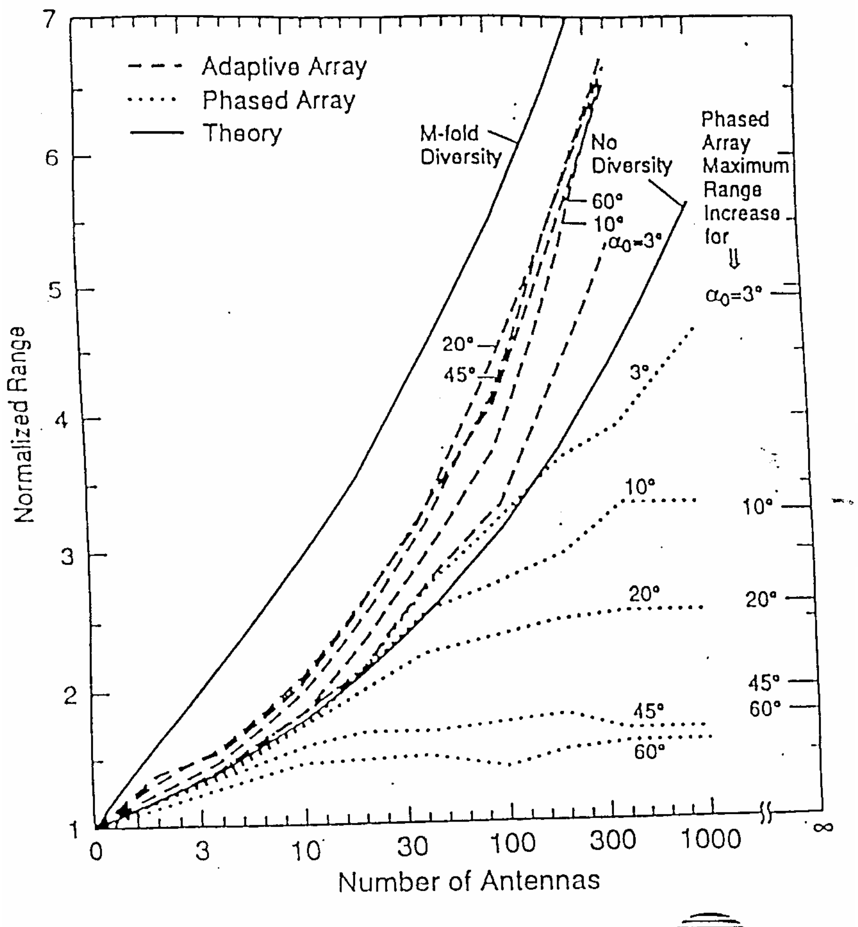


Multibeam Antenna (Phased Array)

- Fixed (or steerable) beams
- Consider cylindrical array with M elements ($\lambda/2$ spacing)
  - Diameter $\approx (M / 4\pi)$ feet at 2 GHz
- With small scattering angle ($\gamma = 4$):
  - Margin = $10\log_{10} M$ (dB)
  - Number of base stations = $M^{-1/2}$
  - Range = $M^{1/4}$
- Disadvantages:
  - No diversity gain (unless use separate antenna)
  - With large scattering angle α, gain is limited for beamwidths $\approx \alpha$



Range Increase for IS-136



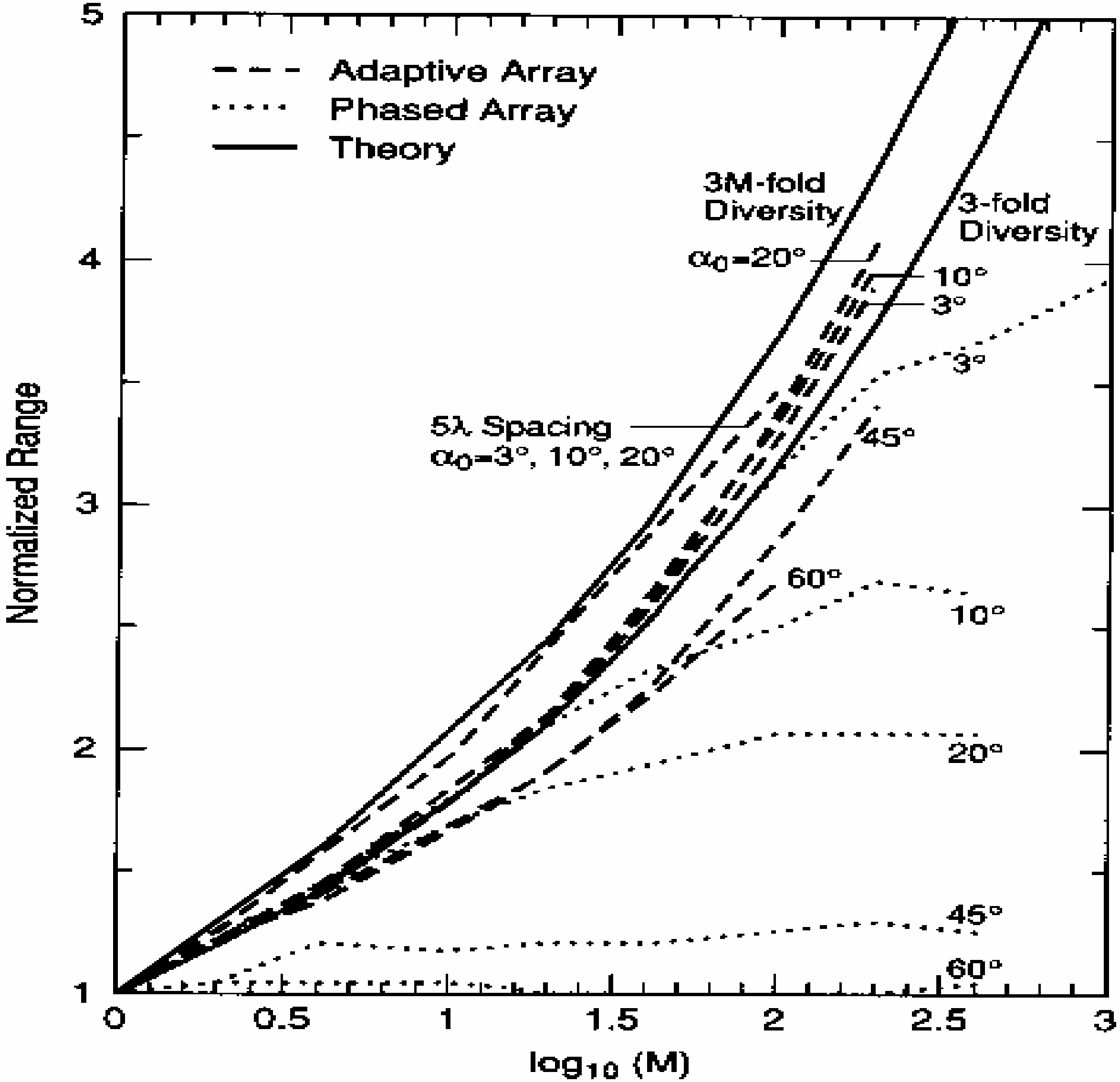
Fixed Multibeam Antenna

- Increases gain for better coverage
- Range increase is limited by angular spread
- No spatial diversity gain
- Can be used on downlink or uplink

Adaptive Array

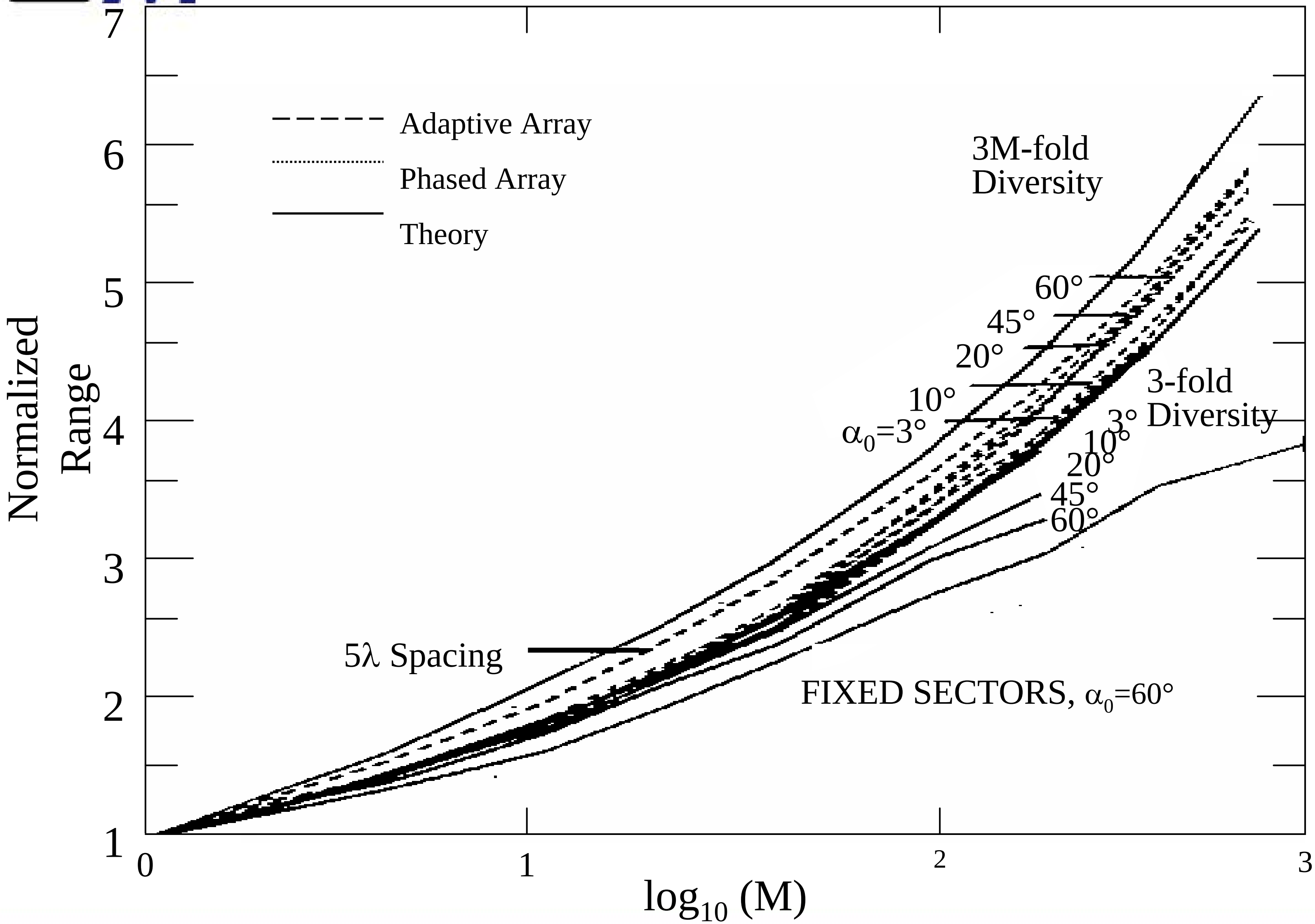
- Range increase independent of angular spread
- Diversity gain increases with antenna spacing
- Can be used on uplink with fixed multibeam downlink

Range Increase with CDMA Signals



Single beam for all RAKE fingers results in range limitation with angular spread for multibeam antenna (phased array)

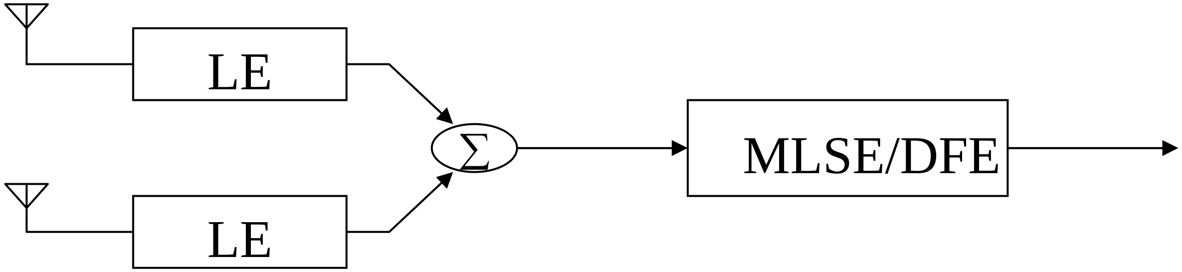
Range Increase with CDMA Signals - Different Beams per Finger



Equalization of Delay Spread

• Delay spread: Delay spread over $[(M\text{-}1) / 2]T$ or M-1 delayed signals (over any delay) can be eliminated

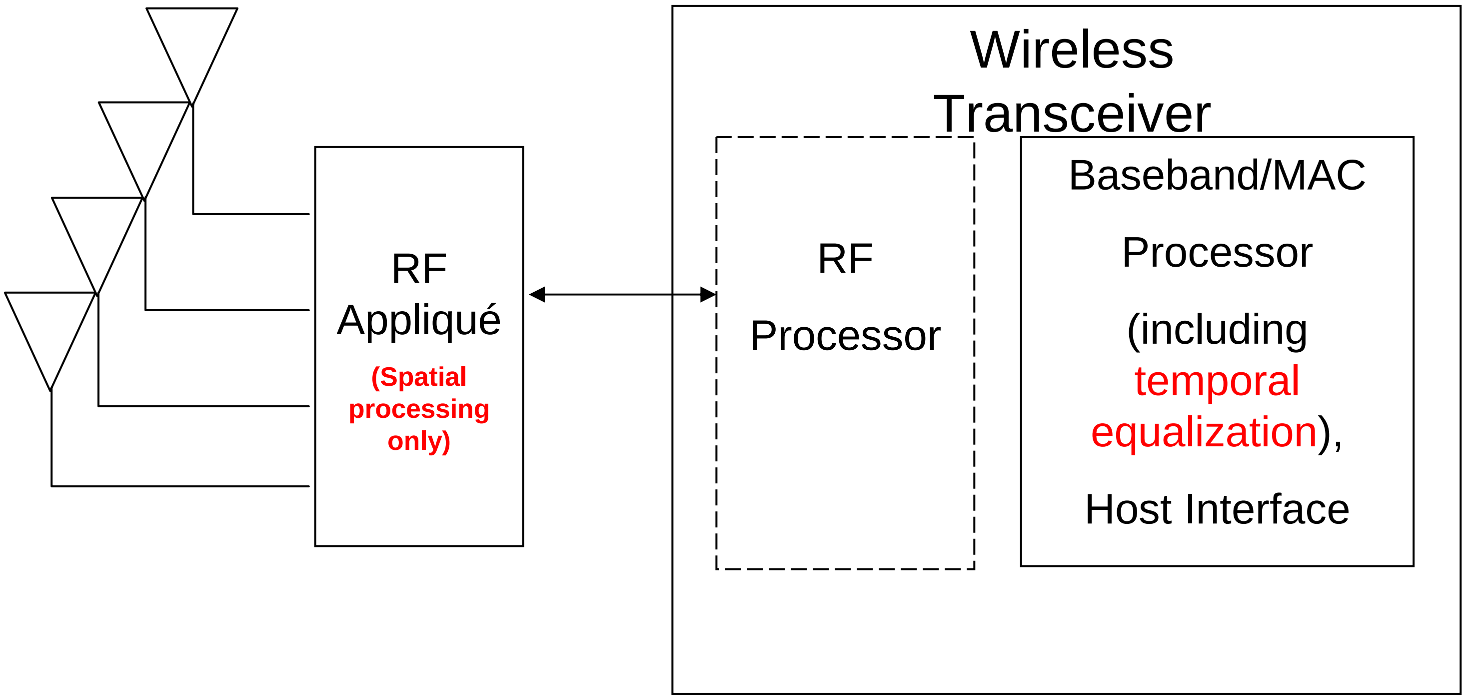
• Typically use temporal processing with spatial processing for equalization:



• Spatial processing followed by temporal processing has degradation, but this degradation can be small in many cases

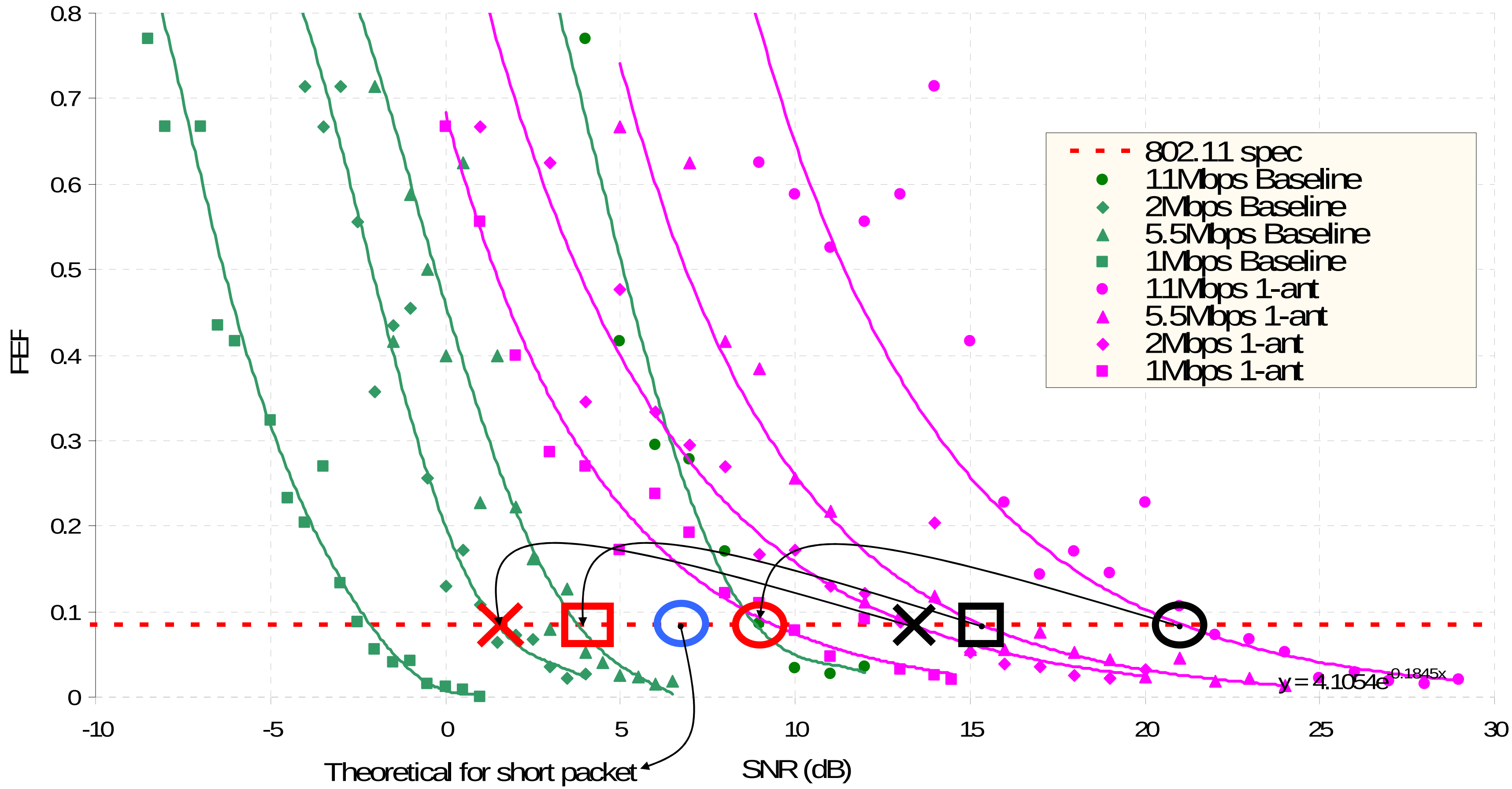
Appliqué

- Cellular – IS-136
- WLANs – 802.11a/b/g
- WiMAX – 802.16



802.11b Performance with Fading

4-antennas (baseline) achieves a 12 to 14 dB gain over a single antenna



Performance Gain over a Single Antenna in a Rayleigh Fading Channel

2 Antenna Selection	Adaptive One Side	Adaptive Both Sides	Theoretical Bound Both Sides
6.1 dB	12.8 dB	18.0 dB	22.2 dB

2X to 3X Range + Uniform Coverage

3X to 4X Range + Uniform Coverage

Channel Model D – 802.11n

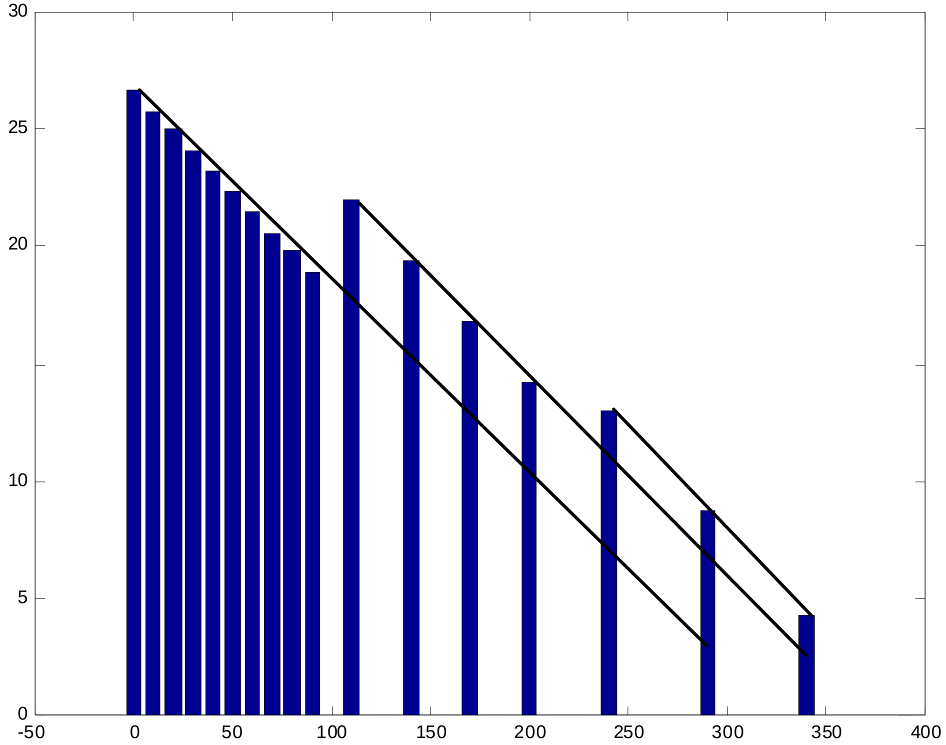
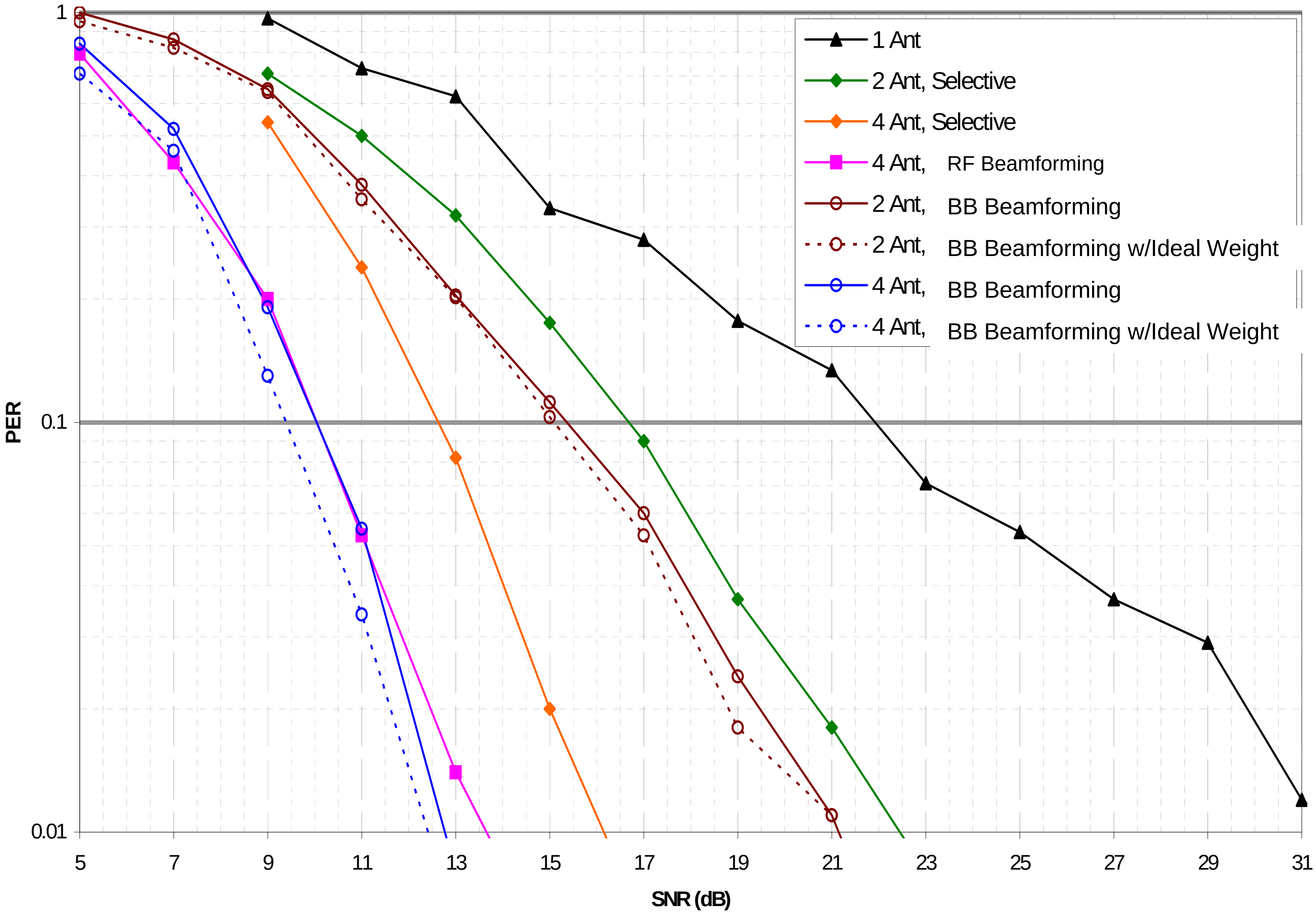


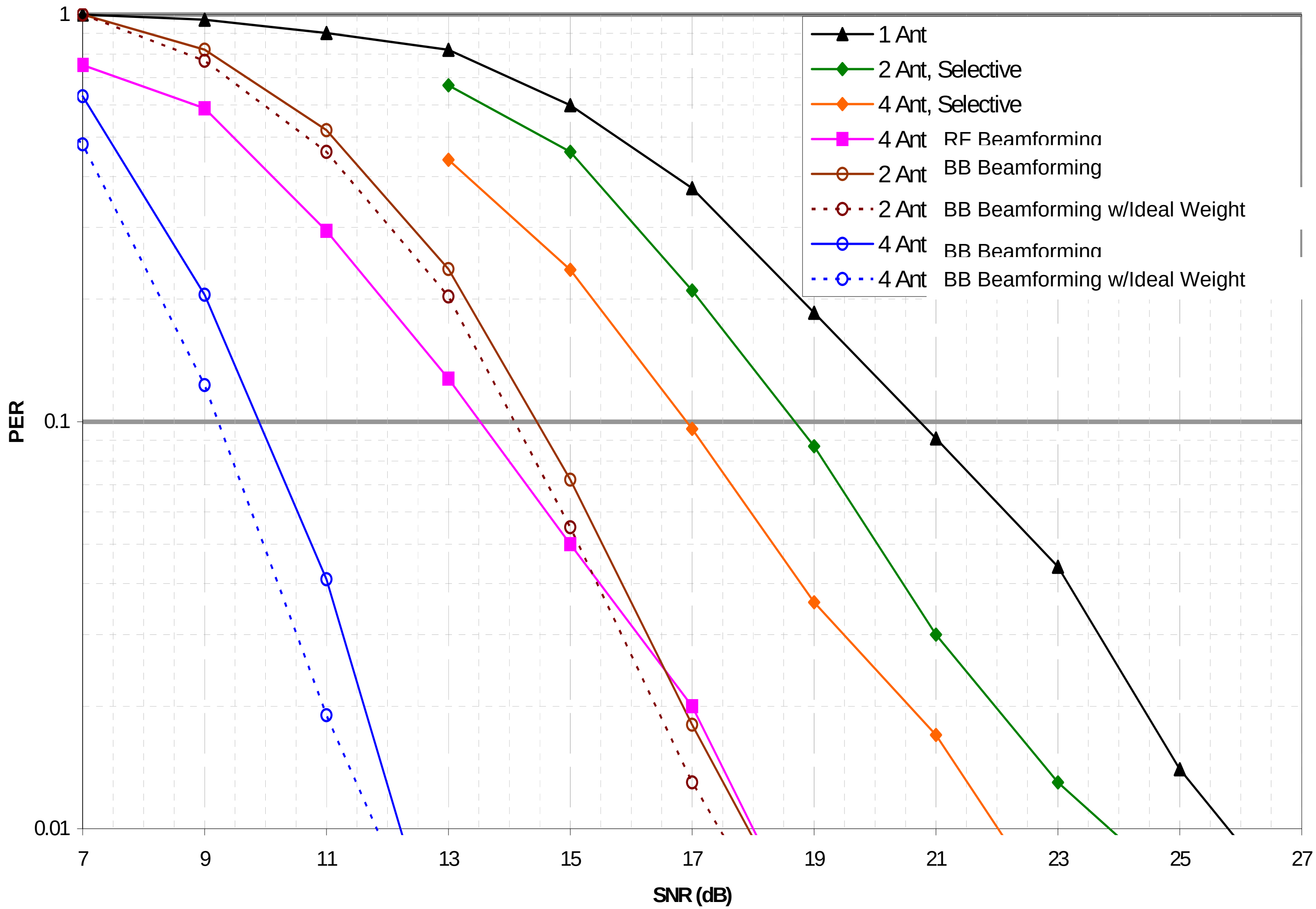
Figure 1. Model D delay profile with cluster extension (overlapping clusters).

802.11a/g
Flat Rayleigh Fading
24Mbps, Short Packet



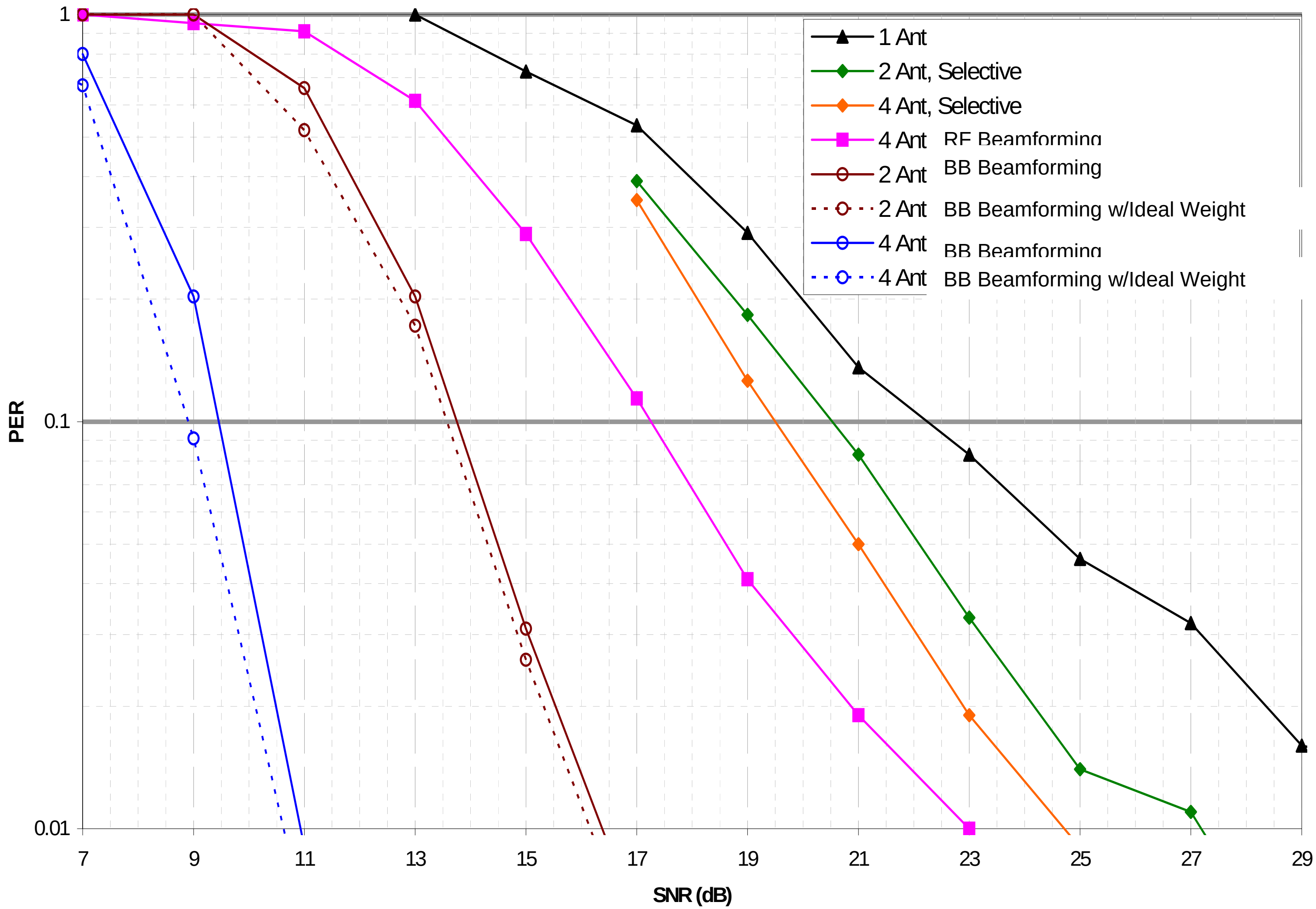
8 symbols/packet

802.11a/g
50ns Exp Decay Rayleigh Fading
24Mbps, Short Packet



8 symbols/packet

802.11a/g
200ns Exp Decay Rayleigh Fading
24Mbps, Short Packet

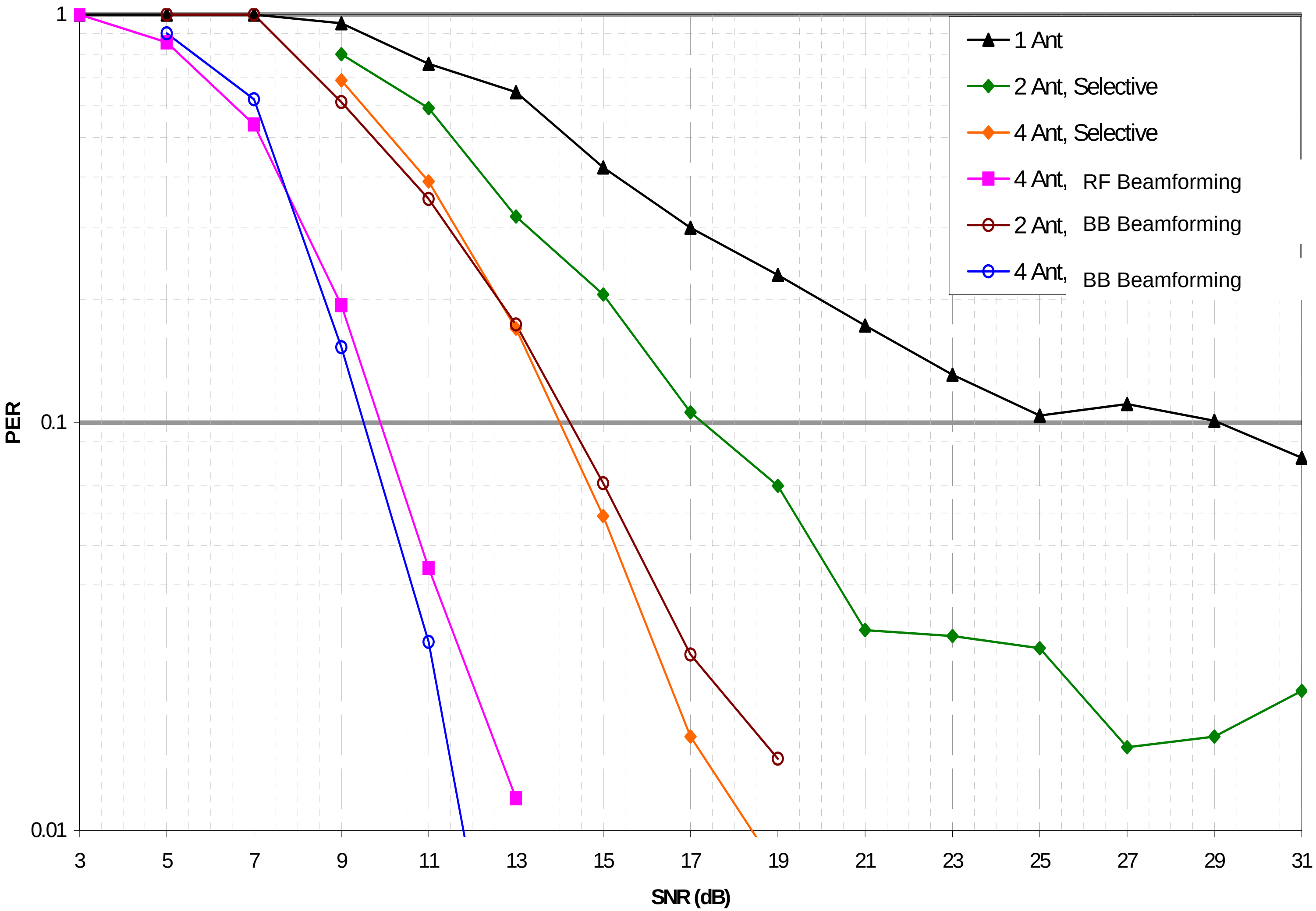


8 symbols/packet

802.11a/g

SUI-2 – WiMax (Outdoor) Channel Model

24Mbps, Short Packet



8 symbols/packet

Conclusions

- Discussed relationship between channel models and communication theory
- Impact on base station and mobile station design
  - LOS versus angular spread systems
  - Delay spread model