Project	**IEEE 802 Executive Committee Study Group on Mobile Broadband Wireless Access** <**http://grouper.ieee.org/groups/802/mbwa**>
Title	**Adaptive Antennas for MBWA**
Date Submitted	**2002-09-03**
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Re:	MBWA ECSG Call for Contributions
Abstract	MBWA systems will be faced with limited spectrum availability at operating frequencies below 3 GHz, and with challenging link conditions arising from the combined requirements for mobility support, broadband data rates, and indoor penetration. Adaptive antennas are a potentially valuable component technology for this application; they provide active interference mitigation, fading mitigation and array gain over single conventional antenna systems. This presentation provides an overview of adaptive antenna technology as well as related spectral efficiency considerations.
Purpose	Tutorial on principles of adaptive antenna technology.
Notice	
Release	
Patent Policy	

Adaptive Antennas for MBWA

IEEE 802 MBWA SG

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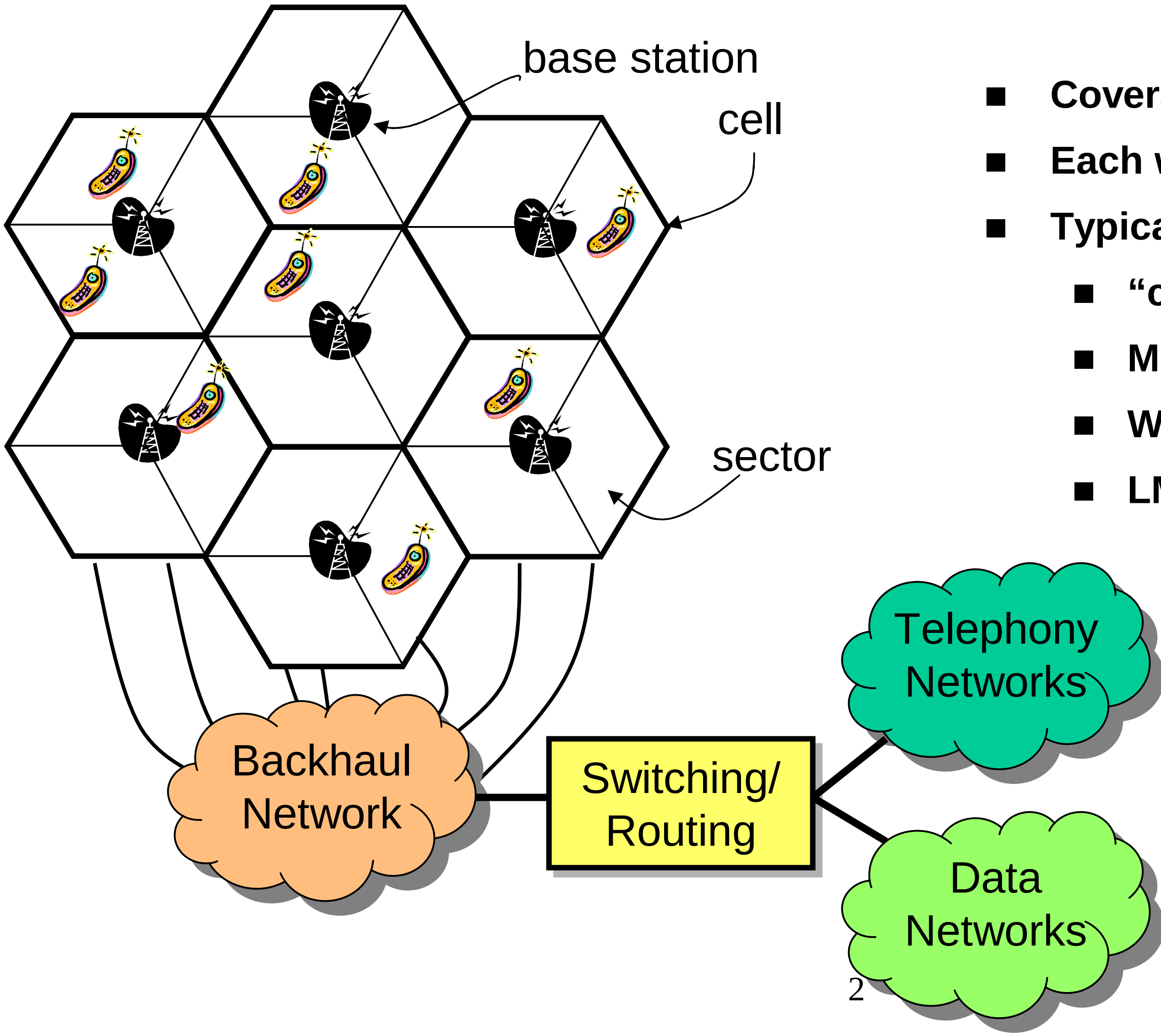
Cellular Technology



- Coverage area divided into cells
- Each with infrastructure and users
- Typical of two-way wireless
  - “cellular”
  - MMDS
  - WLAN
  - LMDS

Motivation

- **Mobile broadband services**
  - limited spectrum availability, need for high spectral efficiency
  - mobile channel, broadband esp. sensitive to link impairments
  - economics must permit consumer pricing
- **Adaptive antenna technology addresses requirements**
  - interference management leads to spectral efficiency
  - gain, interference and fading mitigation improve channel
  - >110,000 deployments establish readiness and benefits

Outline

- Spectral efficiency
- Adaptive antenna fundamentals

Spectral Efficiency Defined

- **Information delivered per unit of spectrum**
- **Measured in bits/second/Hertz/cell, includes effects of**
  - multiple access method
  - modulation methods
  - channel organization
  - resource reuse (code, timeslot, carrier, …)
- **“Per-Cell” is critical**
  - primary spectral efficiency limitation generally self-interference
  - isolated base station results not representative of real-world

Why Is Spectral Efficiency Important?

- **Directly affects an operator's cost structure**
- **For given service and grade of service, determines**
  - required amount of spectrum (CapEx)
  - required number of base stations (CapEx, OpEx)
  - required number of sites and associated site maintenance (OpEx)
  - and, ultimately, consumer pricing and affordability
- **Quick calculation (capacity limited system)**

$$\text{number of cells/km}^2 = \frac{\text{offered load (bits/s/km}^2\text{)}}{\text{available spectrum (Hz)} \times \text{spectral efficiency (bits/s/Hz/cell)}}$$

Designing For Spectral Efficiency

- **Spectral/Temporal tools**
  - multiple access method and data compression
    - optimize efficiency based on traffic characteristics
  - modulation, channel coding, equalization
    - optimize efficiency based on link quality
- **Spatial tools (all to minimize interference)**
  - cellularization
    - mitigate co-channel interference by separating co-channel users
  - sectorization
    - mitigate co-channel interference through static directivity
  - power control
    - use minimum power necessary for successful communications

Min-Max Approach to Efficiency

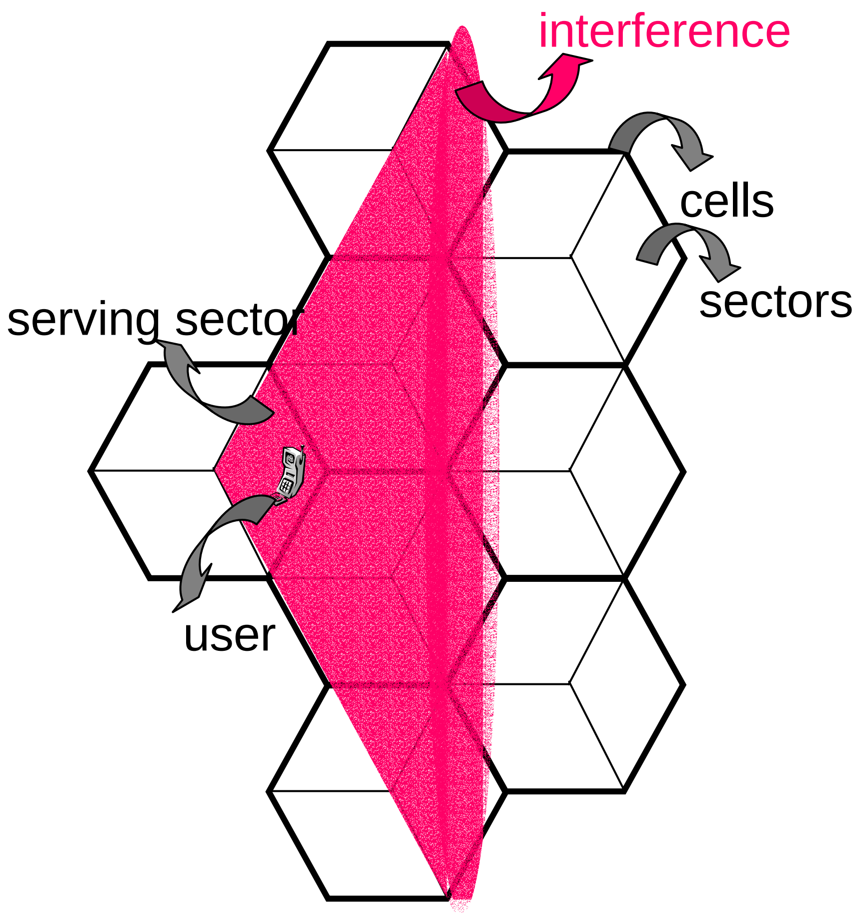
- **What's the greatest inefficiency in current designs?**

- **Answer:**

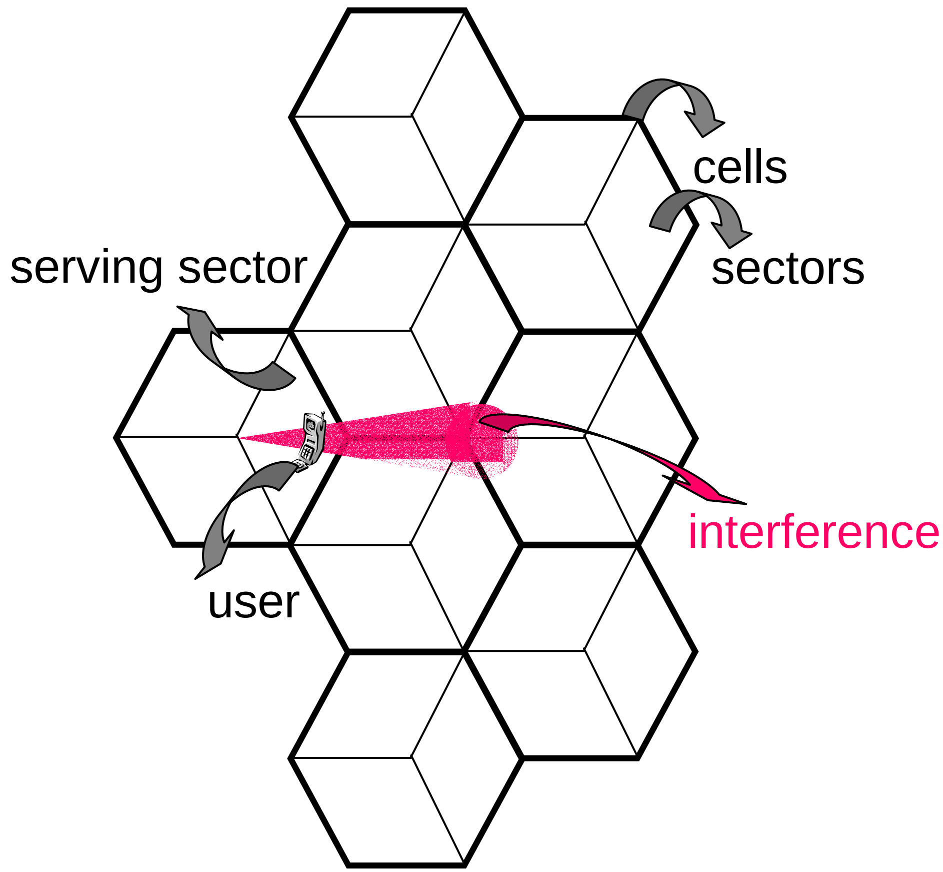
$$\frac{\text{energy transmitted to convey information}}{\text{energy received}}$$

- **Not completely attributable to propagation loss …**

Self-Interference and Capacity



sectorized



adaptive antennas

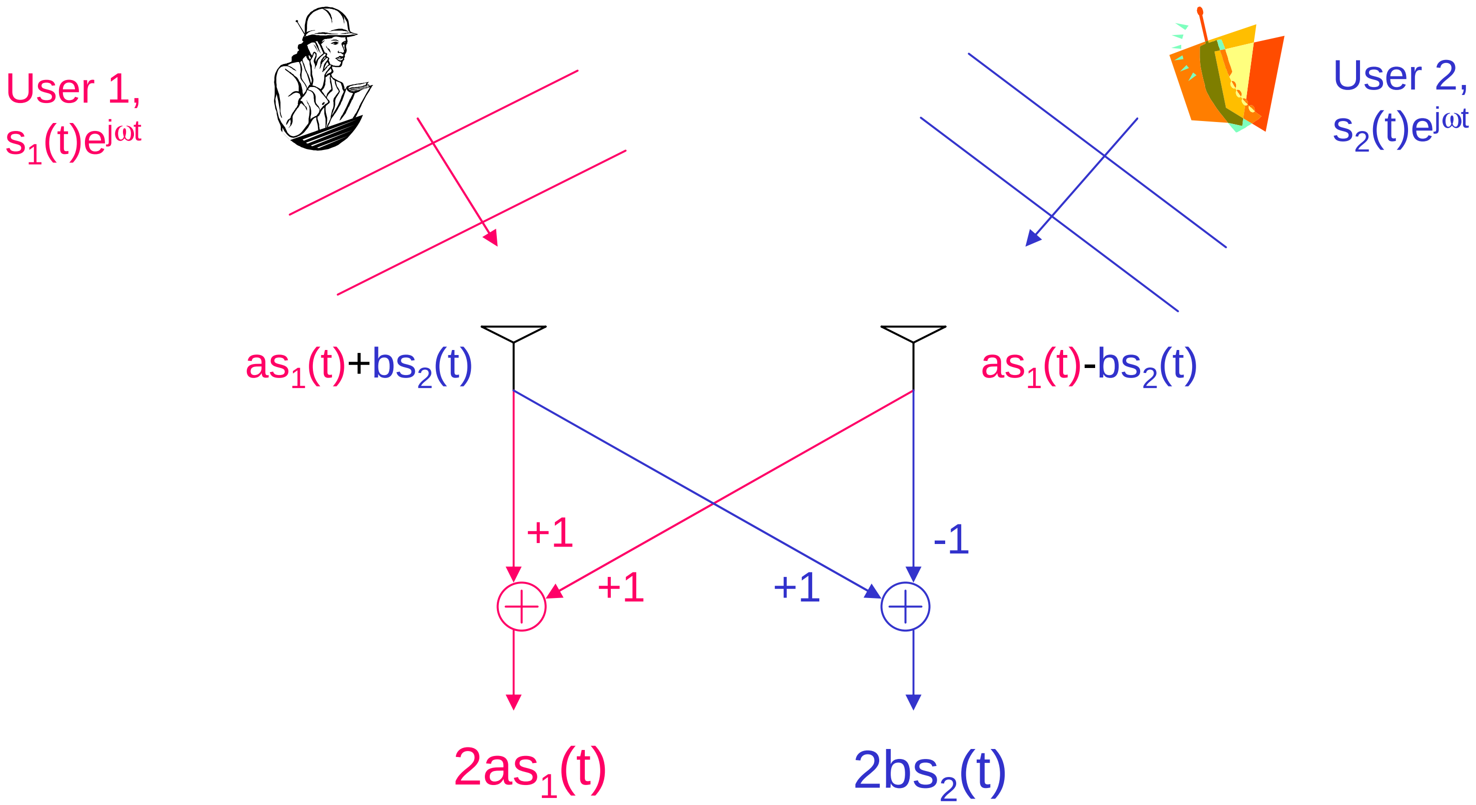
Outline

- **Spectral efficiency**
- **Adaptive antenna fundamentals**

Adaptive Antennas Defined

- **Systems comprising**
  - multiple antenna elements (antenna arrays)
  - coherent processing
  - processing strategies that adapt to environment
- **Providing**
  - gain and interference mitigation
  - improved signal quality and spectral efficiency
  - improved coexistence behavior

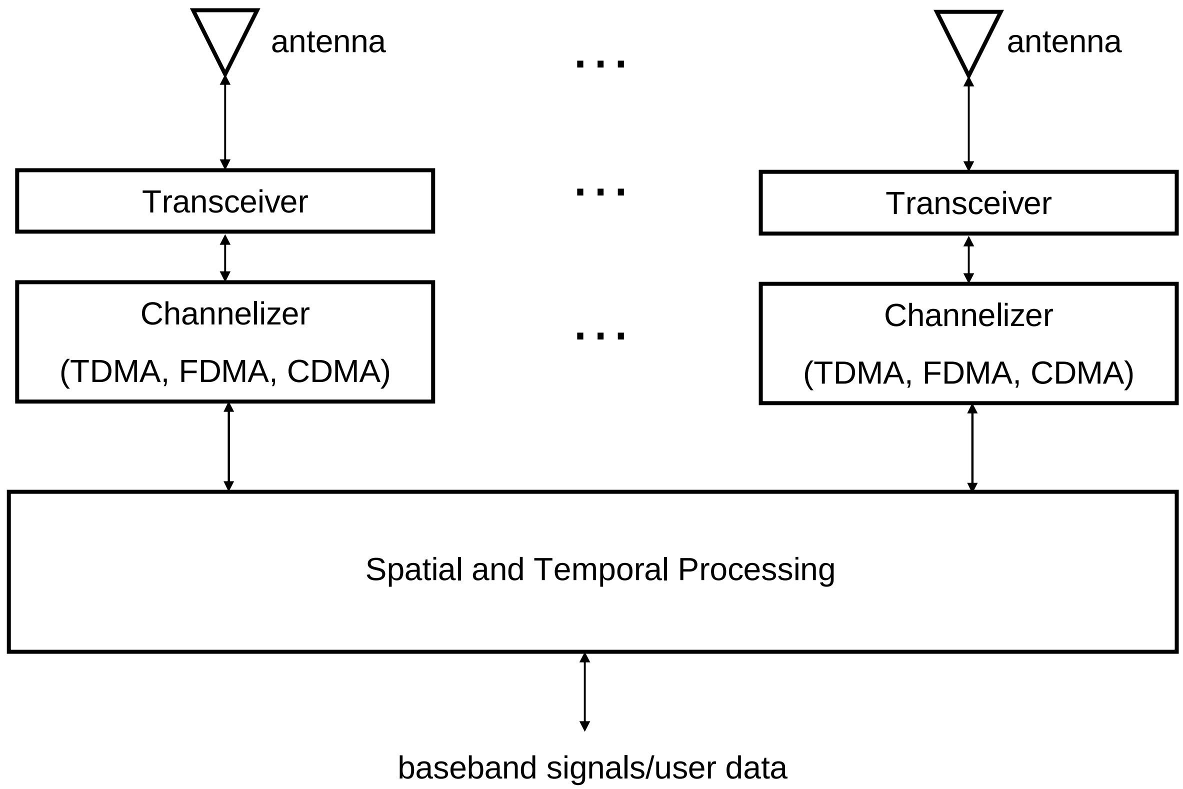
Adaptive Antenna Concept



- **Users' signals arrive with different relative phases and amplitudes**
- **Processing provides gain and interference mitigation**

Protocol Independence

- **Fundamental concepts applicable to all access and modulation methods**



Basic Uplink Gain Calculation

- **Signal s, M antennas, M receivers with i.i.d. noises n_i**

$$\frac{\text{received signal}}{\text{noise}} = \frac{s + ... + s}{n_1 + \ldots + n_M}$$

$$\text{therefore, Uplink SNR} = \frac{(Ms)^2}{M\sigma^2} = M \frac{s^2}{\sigma^2}$$

$$= \text{M x single antenna SNR}$$

- **Adaptive antennas improve uplink SNR by factor of M**
- **M=10, 10x SNR improvement, examples**
  - double data rate if single antenna SNR is 10 dB
  - reduce required subscriber transmit power by 10 dB
  - increase range by 93% with $R^{3.5}$ loss

Basic Downlink Gain Calculation

- **Similar to uplink calculation,**
  - except dominant noise is due to (single) receiver at user terminal
- **With same total radiated power P in both cases**

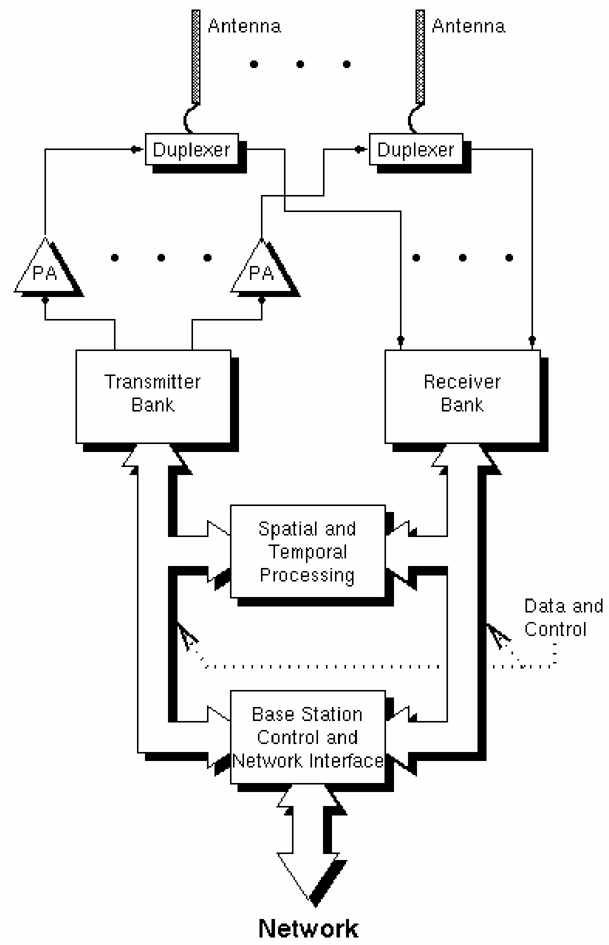
$$\frac{\text{Received Power (Adaptive Antenna)}}{\text{Received Power (Single Antenna)}} = \frac{(\sqrt{P/M}\, s + \dots + \sqrt{P/M}\, s)^2}{(\sqrt{P} s)^2} = M$$

- **Again, factor of M or $10\log_{10}$M dB**
- **M=10, 10 dB gain examples**
  - 10 elements with 1 W PA's, same EIRP as single element with 100 W PA
  - 90% reduction in total radiated power for same EIRP

Interference Mitigation

- **Directive gain results in passive interference mitigation**
- **Active interference mitigation independent of and in addition (dB) to gain**
- **Gain and interference mitigation performance are actually statistical quantities**
  - Theoretical gain performance closely approached (within 1 dB) in practice
  - Theoretical interference mitigation, ∞, harder to achieve
    - limited by calibration, environment, number of interferers
    - active mitigation in excess of 20 dB can be reliably achieved for significant interferers

Base Station Architecture



Generic Features

- antenna array
- phase coherent transceiver chains
- automated adaptive techniques to combine (distribute) energy from (to) transceiver chains
- natural application for wideband radios

Architectural Variants

- conventional downlink processing
- analog spatial processing
- narrowband radios
- masthead electronics
- appliqué to conventional system

Antenna Arrays

- **Wide variety of geometries and element types**
  - arrangements of off-the-shelf single elements
  - custom arrays
- **Array size**
  - vertical extent determined by element gain/pattern as usual
  - horizontal extent, typically 3-5 lambda
- **2 GHz, eight 10 dBi element array is 0.5 x 0.75 m**
  - small!
  - conformal arrays for aesthetics

Comments

- **Fundamental concept is coherent processing**
- **Generally applicable to all air interfaces**
- **Parallel, independent processing on all traffic resources**
- **Many important issues that are not addressed here**
  - estimation/prediction of radio environment (will comment later)
  - processing requirements & architectures (easily > 1Gbps array data rate)
  - performance validation
  - equipment calibration
  - effects of air interface specifics (will comment later)
  - broadcast channel support
  - reliability benefits of redundant radio chains
  - intrinsic diversity of an array (fading immunity)
  - multipath processing

Adaptive Antenna Benefits

Processing Gain	Operational Significance
Selective Uplink Gain	Increased Range & Coverage Increased Data Rates Reduced System – Wide Uplink Noise Improved Uplink Multipath Immunity
Uplink Interference Mitigation	Improved Signal Quality Maintained Quality with Tightened Reuse
Selective Downlink Gain	Increased Range & Coverage Increased Data Rates Reduced System–Wide Downlink Interference Improved Co–existence Behavior Reduced Downlink Multipath
Downlink Interference Mitigation	Maintained Quality with Tightened Reuse

- **Actual level of benefits depends on implementation details**

Adaptive Antenna Performance

- **Primary determinants**
  - environmental complexity, nonstationary channels
  - air interface support for adaptive antennas ("hooks")
  - duplexing: frequency-division or time-division (FDD vs. TDD)
    - issue is correlation of uplink and downlink propagation environments
- **Capacity increases in operational systems**

Application	Capacity Increase	Deployments
FWA, TDD, hooks	20x	1996-present
Low Mobility PHS, TDD, no hooks	9x	1996-present
High Mobility AMPS & GSM (900, 1800, 1900), FDD, no hooks	2-6 x	1993-present

Summary

- **Spectral efficiency critical to MBWA**
  - limited spectrum availability and high $/MHz-pop likely
  - economics and end-user pricing linked to spectral efficiency
- **Robust links critical to MBWA**
  - broadband mobile services require high SINR
  - diversity is key tool for combatting fading
- **AA's provide robustness, spectral efficiency**
  - proven in more than 110,000 deployments today
  - highest benefits with TDD and tight protocol integration