

# Implementation of Smart Antenna using SDR

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# Outline

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- Smart Antennas for Software Radios
  - Fundamentals
  - Algorithms
- Implementation Issues
  - Hardware
  - Software
- Case Studies
- Future Directions



# Smart Antennas for Software Radio

# What is a Smart Antenna

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- Definition

- Antenna array system aided by some “smart” algorithm to combine the signals, designed to adapt to different signal environments
- The antenna can automatically adjust to a dynamic signal environment

- Mechanisms

- The gain of the antenna for a given direction of arrival is adjustable
- Take advantage of different channels for different antennas

- Some antennas are “smarter” than others

# Smart Antennas in Software Radios

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- Software radios and smart antennas complement each other
- Software radios need to adapt to different protocols, systems and channel environments
  - Smart antennas aid software radios in attaining this flexibility through the use of signal processing algorithms to combine the received signals in an optimum manner
  - Smart antennas provide the benefits that motivate the adoption of software radios
- Implementation of smart antenna algorithms require flexibility in the infrastructure which is provided by software radios

# Motivation

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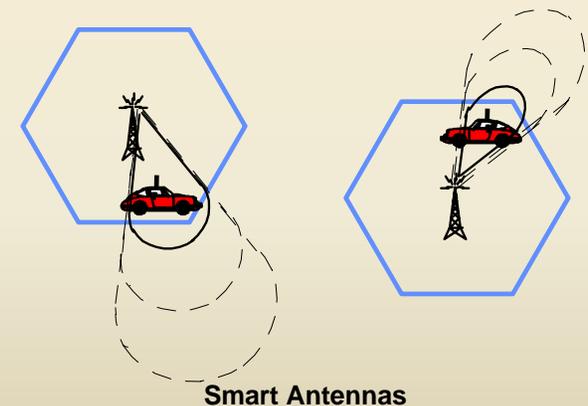
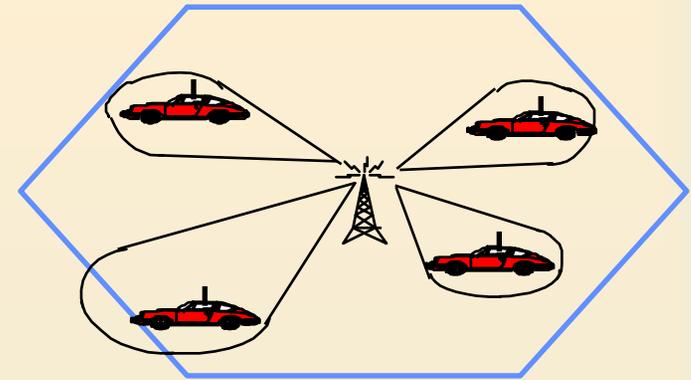
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- Recent years have seen a great proliferation of wireless systems for higher data rates and more capacity
  - PCS: IS-95, GSM, IS-136 (9.6 – 14.4 kbps)
  - WLAN: IEEE 802.11, Bluetooth, HomeRF (30 kbps – 50 Mbps+)
  - 2.5G: GPRS, EDGE (115 – 144 kbps)
  - 3G: WCDMA, CDMA2000, EVDO, EVDV, HSDPA (2-10 Mbps)
- Interference environment becomes increasingly hostile as the number of active devices and standards increases
  - Capacity limitation
  - Advanced methods are necessary to overcome these problems
  - Military-derived techniques useful
  - Interference is a big issue in migration of technology

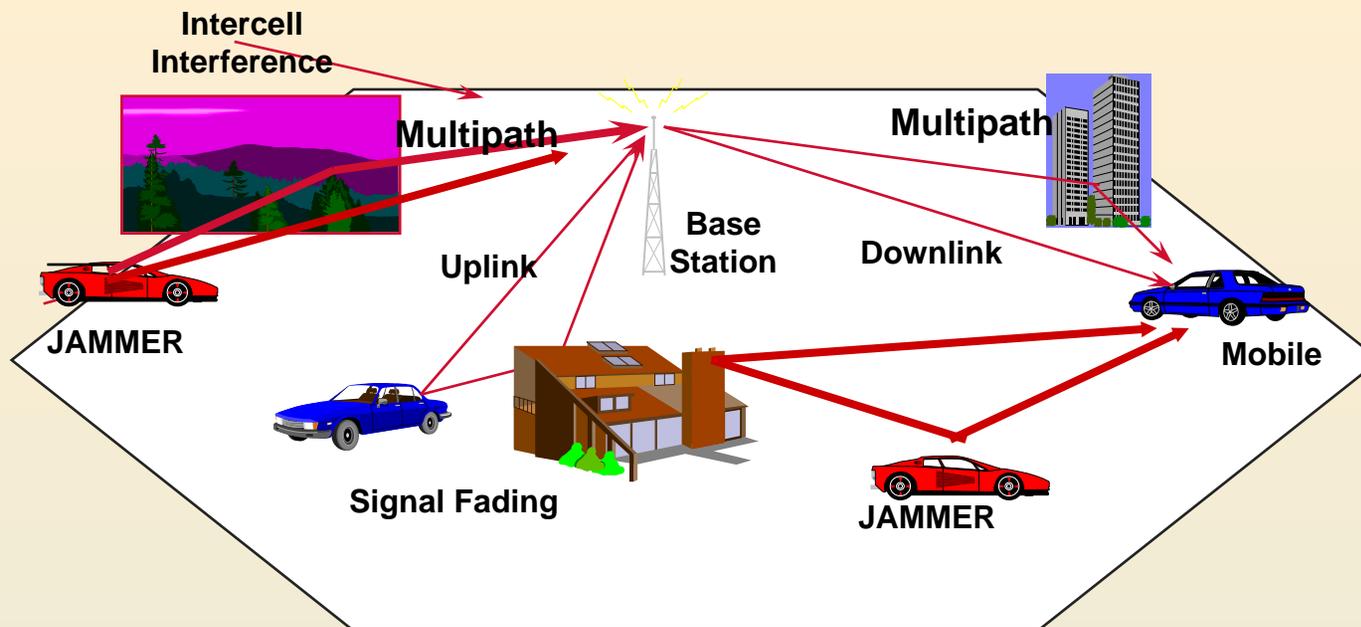
# Benefits of Smart Antennas (1/2)

- Benefits of smart antennas at the base station

- Improved channel re-use
- Co-channel (jamming) and adjacent channel interference reduction
- Multiple access interference reduction for capacity improvement
- Robustness against multipath, fading, and noise to improve coverage and range
- Lower probability of interception and detection
- Enhance location estimates

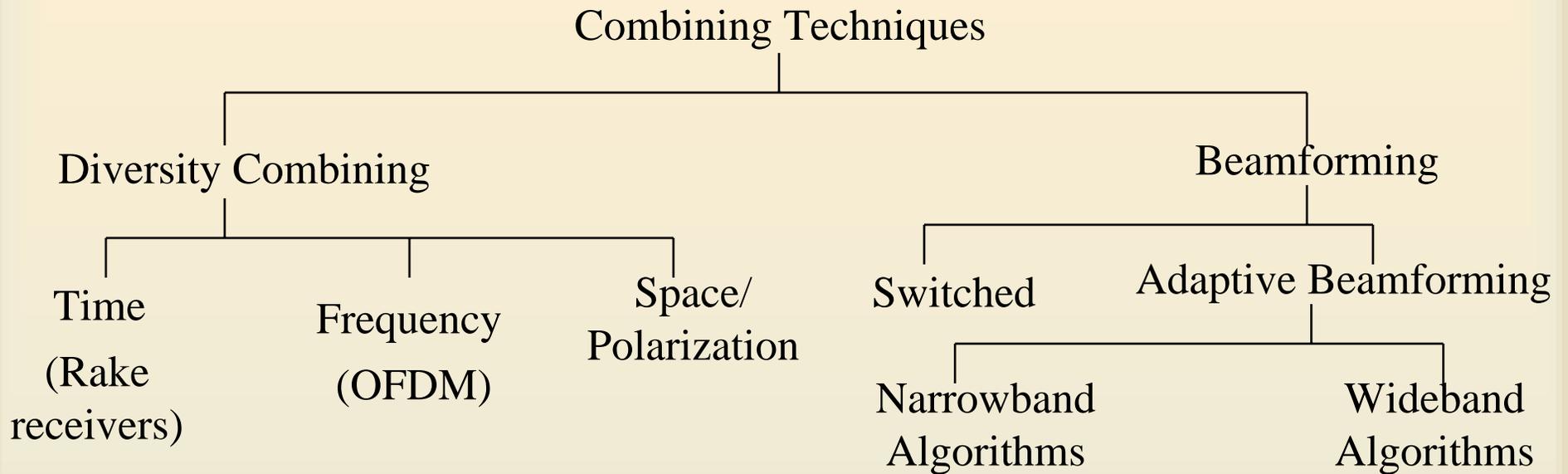


# Benefits of Smart Antennas (2/2)



- Benefits of hand held smart antenna
  - Anti-jam capability
  - Increased capacity
  - Extended range
  - Reduced fading
  - Lower transmit power

# Smart Antenna Combining Techniques



# Diversity vs. Beamforming

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## Diversity Combining

- Combine signals from different antenna elements using various algorithms
- Signal from each element is processed separately
- Signals have to be uncorrelated for maximum performance
- Mitigates fading
- Increases gain
- Can improve polarization match
- No interference rejection capabilities

## Adaptive Beamforming

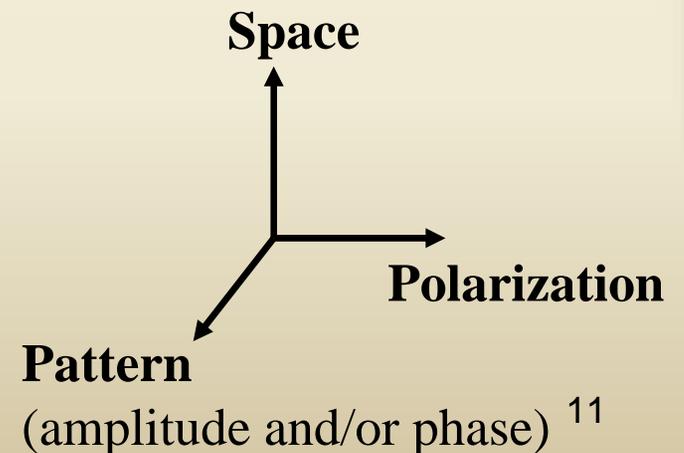
- Focus the antenna's gain in the direction of the desired signal
  - Achieved by manipulating the weights associated with each element
- Antenna elements have to be separated by  $\lambda/2$  to attain a certain phase difference in the signals
  - Signals are correlated
- All advantages of diversity combining
- Has interference rejection capabilities

# Antenna Diversity Principles

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- Multiple antenna sensors provide diversity signals
- Independent copies of the same signal that experience different fading increase the probability of having a usable signal at any instant
- Diversity is effective if the two signals are decorrelated to a level where the correlation coefficient is approximately 0.7 or less
- Possible diversity dimensions:

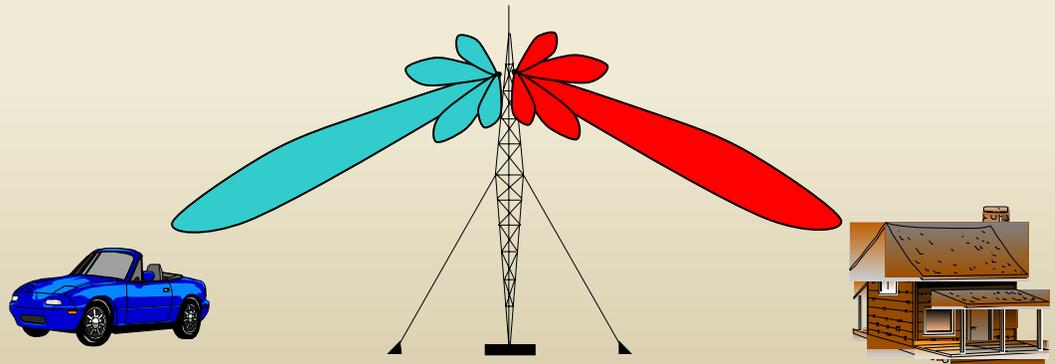


# Transmit Diversity

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- Transmit diversity
  - Closed Loop Techniques: Switched, selection, or optimum combining
  - Open Loop Techniques: Space-time coding
- Benefits
  - Anti-jam capability, Extended range, Low probability of intercept (LPI) may be possible, Reduced fading,
  - Lower transmit power
    - Increased battery life



# Transmit Diversity Techniques

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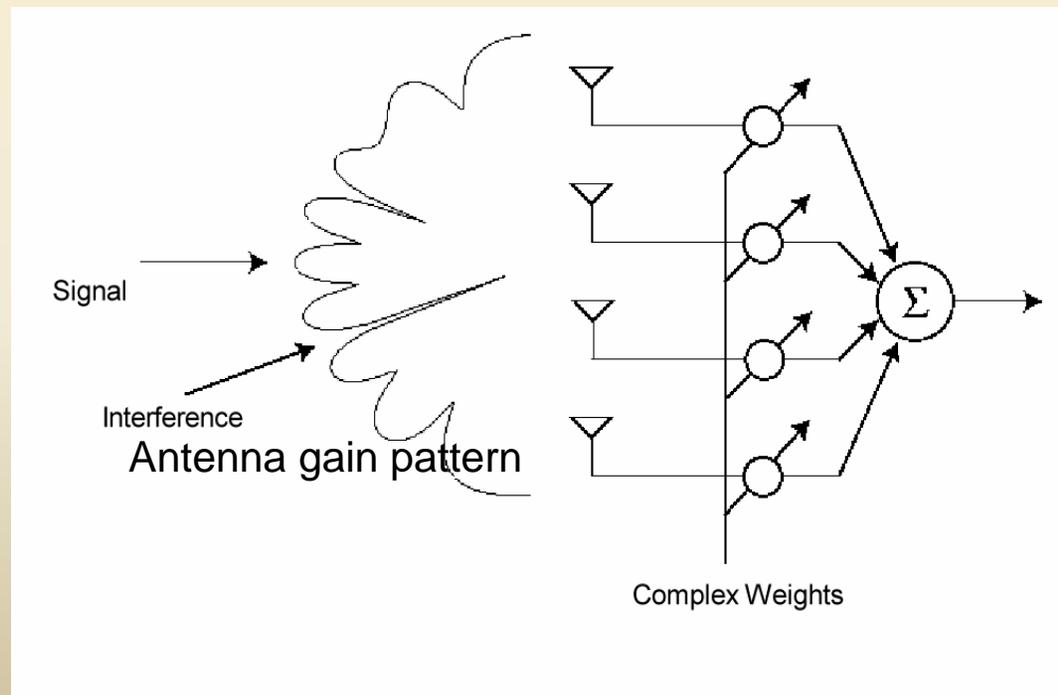
- Weight Reuse Technique (Applicable to TDD systems)
  - Reuse of uplink weight if  $f_c$  is the same in both uplink and downlink
  - Downlink weights are a scaled version of uplink weights
  - Receiver transmits the weights to the base station
- Transmit Diversity Techniques for FDD
  - Probing signal from base station to the mobile
  - Response measured at each mobile and feedback to the base station

Assumption:

- Channel relatively static

# Beamforming

- Discriminate between signals according to their AOA
- Beam pattern controlled by complex weights in each RF chain at the receiver
  - Antenna elements are generally separated by  $\lambda/2$



# Beam Patterns

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- The beamformer output is given by

$$y(n) = \mathbf{w}^H \mathbf{x}(n)$$

- A beampattern describes the gain versus AOA of the beamformer

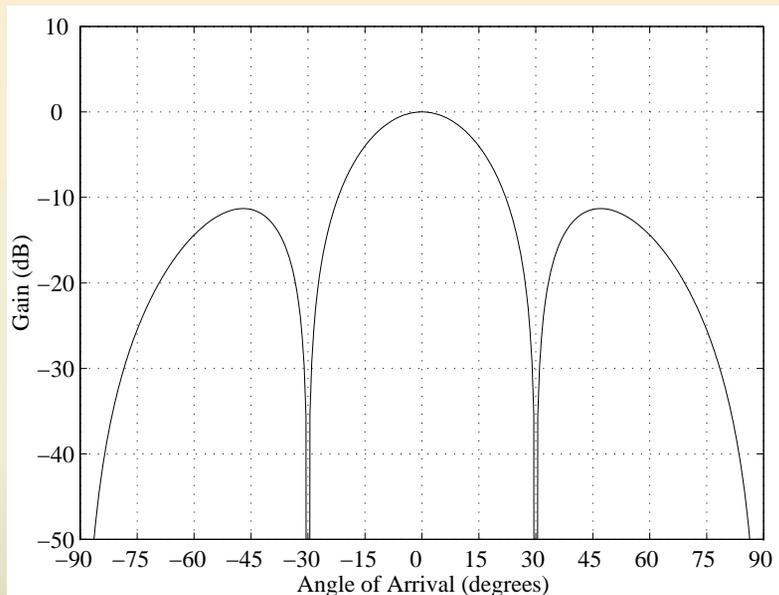
$$S(\phi) = |\mathbf{w}^H \mathbf{a}(\phi)|^2$$

Reflects array geometry

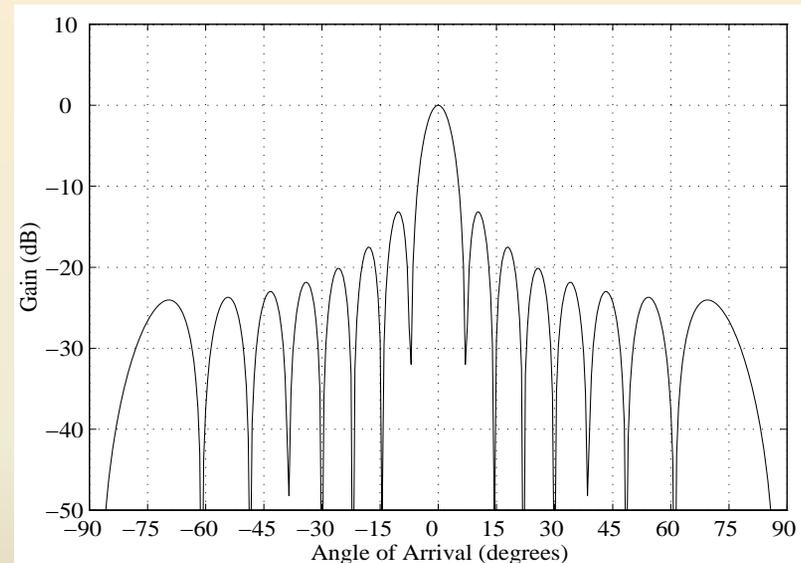
- The beampattern is dependent on
  - array geometry (number of antennas, physical extent of the array)
  - carrier frequency
  - gain pattern of each individual antenna
  - antenna weights

# Example Beam Pattern (1/2)

- Antenna weights equal to unity
- Note the similarity with a rectangular time-domain window function

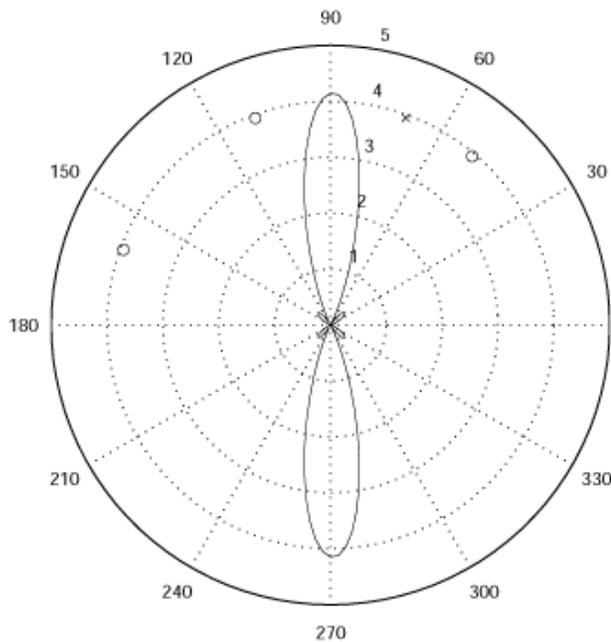


4 element Uniform Linear Array  
(ULA) with 1/2 spacing

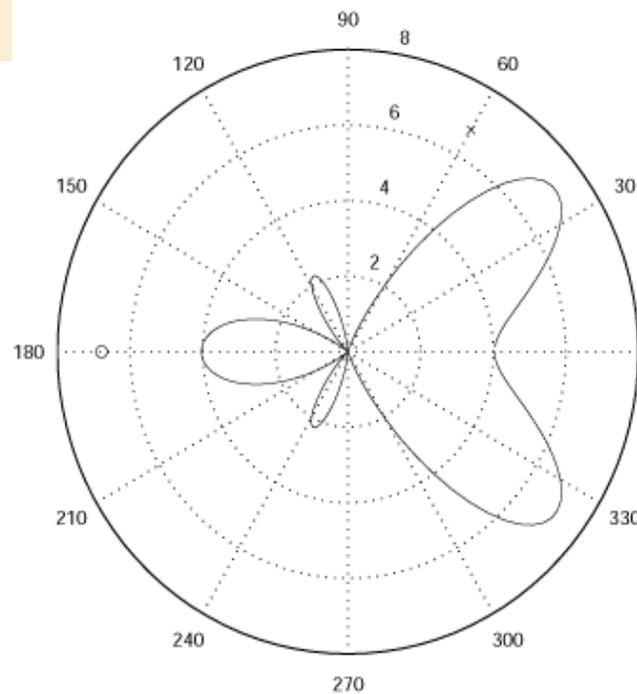


16 element Uniform Linear Array  
(ULA) with 1/2 spacing

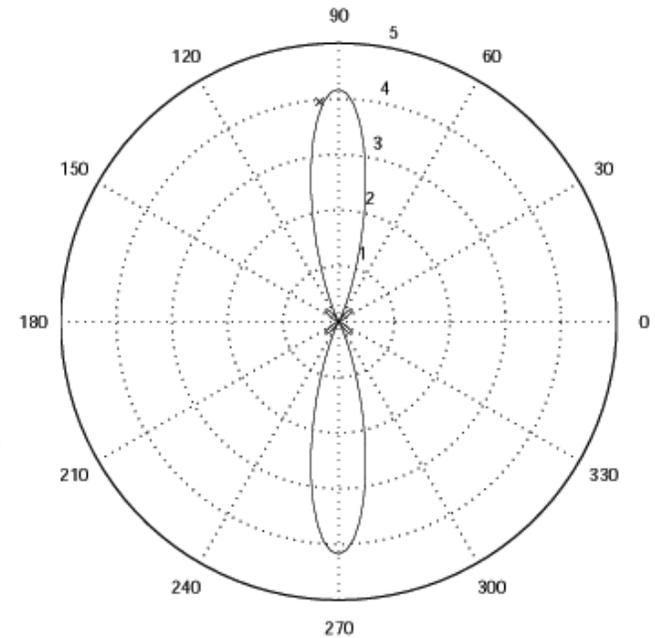
# Example Beam Pattern (2/2)



**Three Interferers**



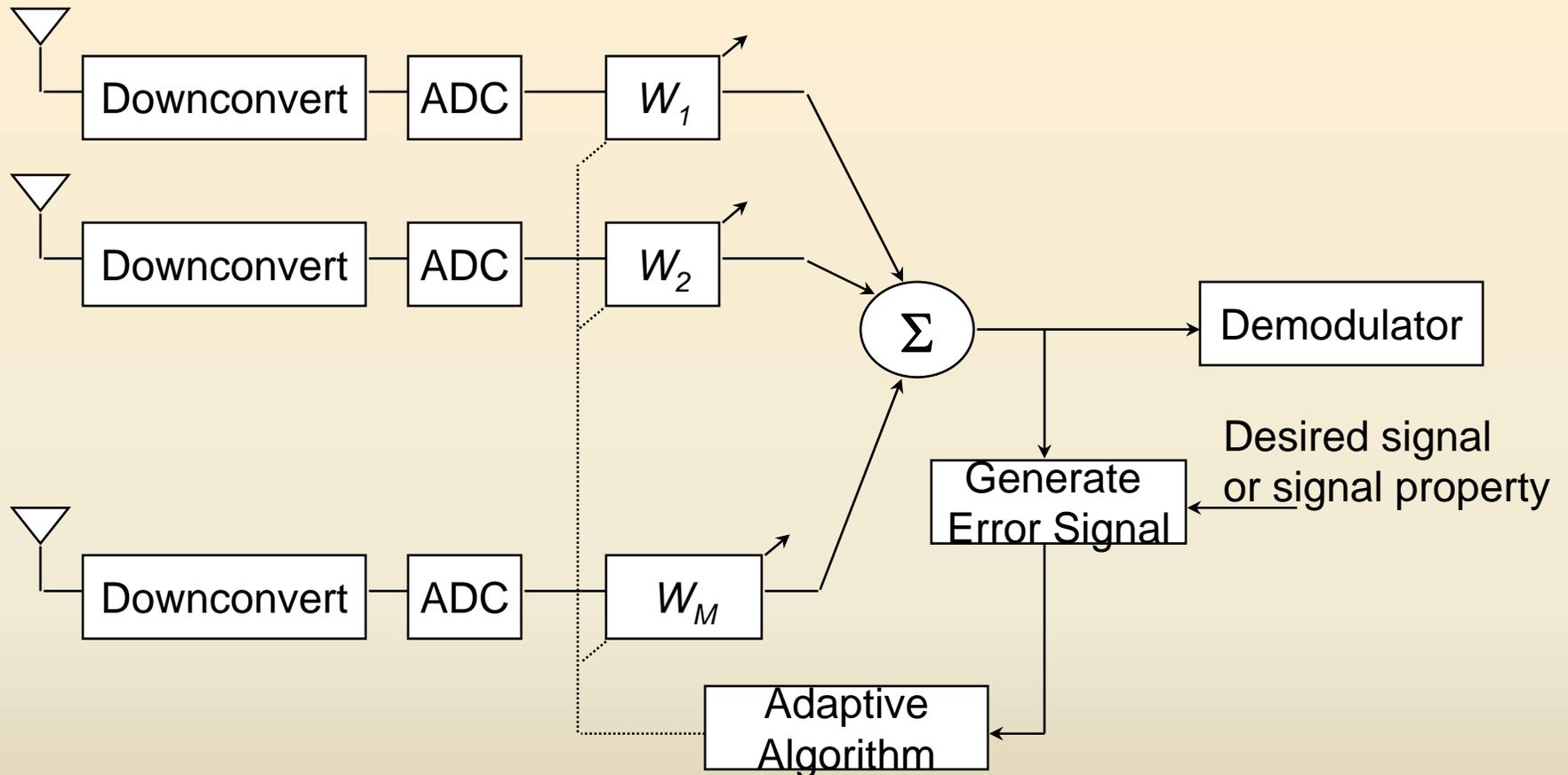
**Moving Interferer**



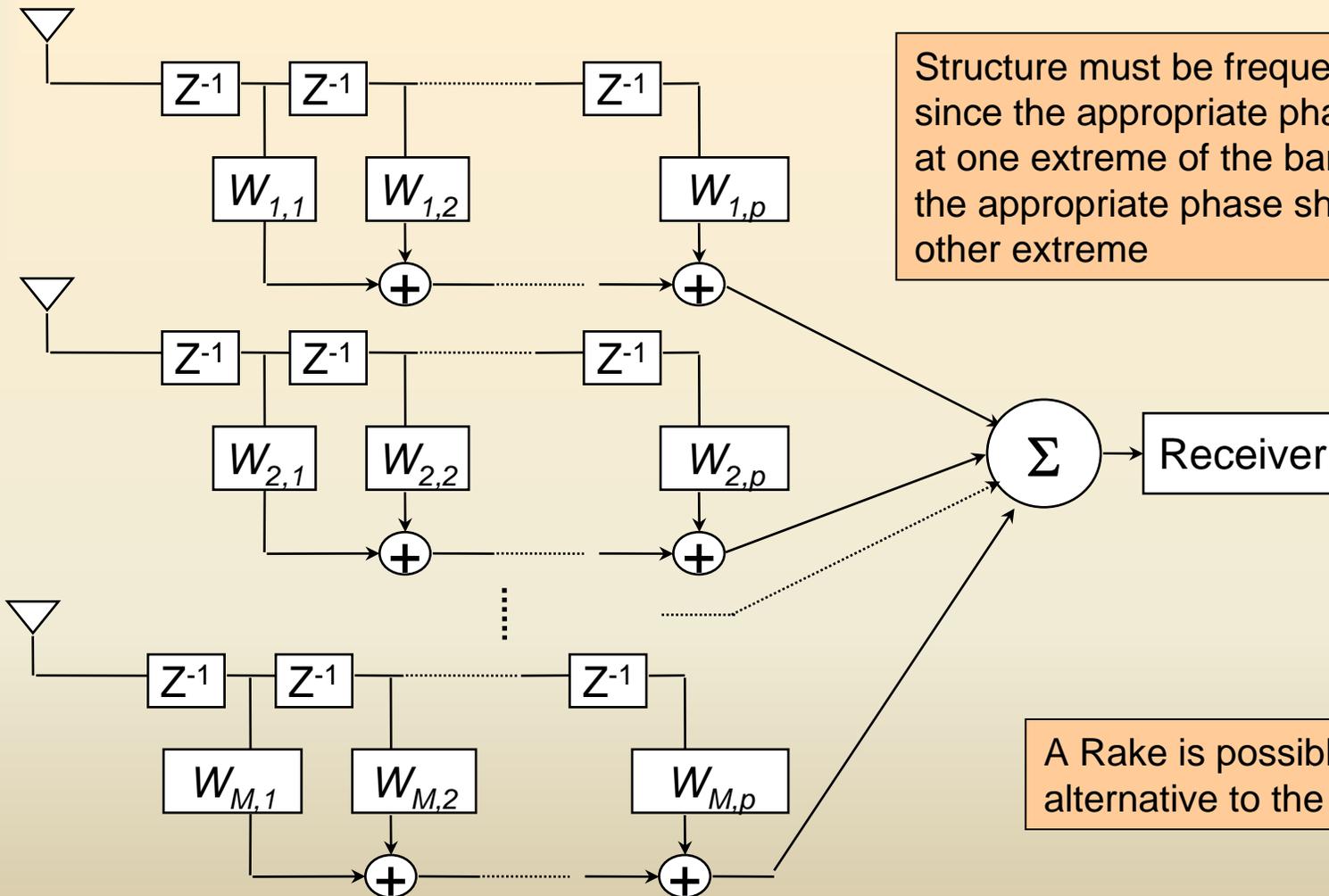
**Moving Target**

**4 element linear array. Constant Modulus Algorithm working in three environments. Note gain changes as a function of angle.**

# Adaptive Beamforming Systems: Narrowband



# Adaptive Beamforming Systems: Wideband



# Analogy Between Adaptive Antennas and Equalizers

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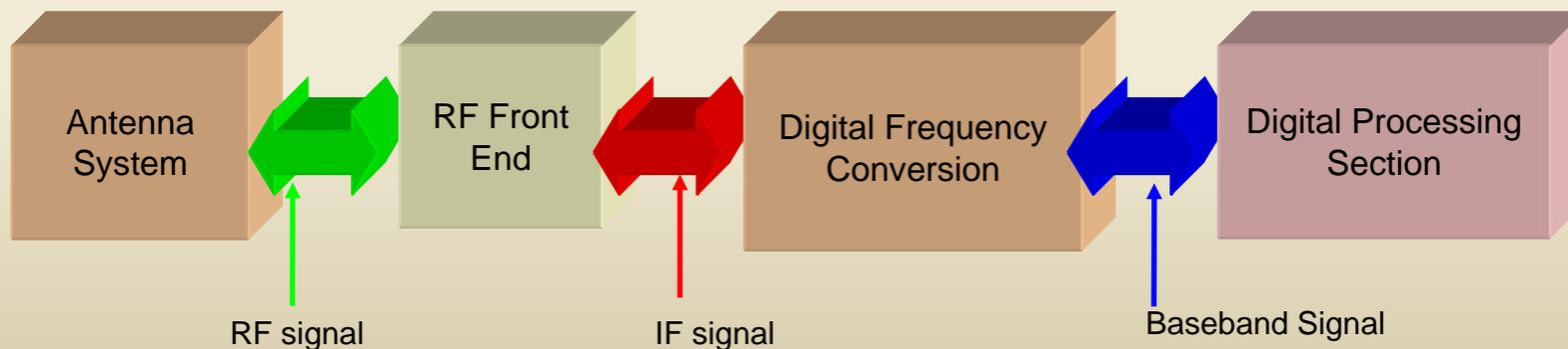
- Antenna arrays are formed by combining the signals from a number of antenna elements (frequently spaced one half wavelength apart)
- Algorithms which weight coefficients form a “spatial filter”
- Goal is usually to minimize MSE in resulting signal
- Adaptive algorithms such as LMS or RLS can be used to steer the resulting antenna beam



# Smart Antenna and SDR: Hardware Issues

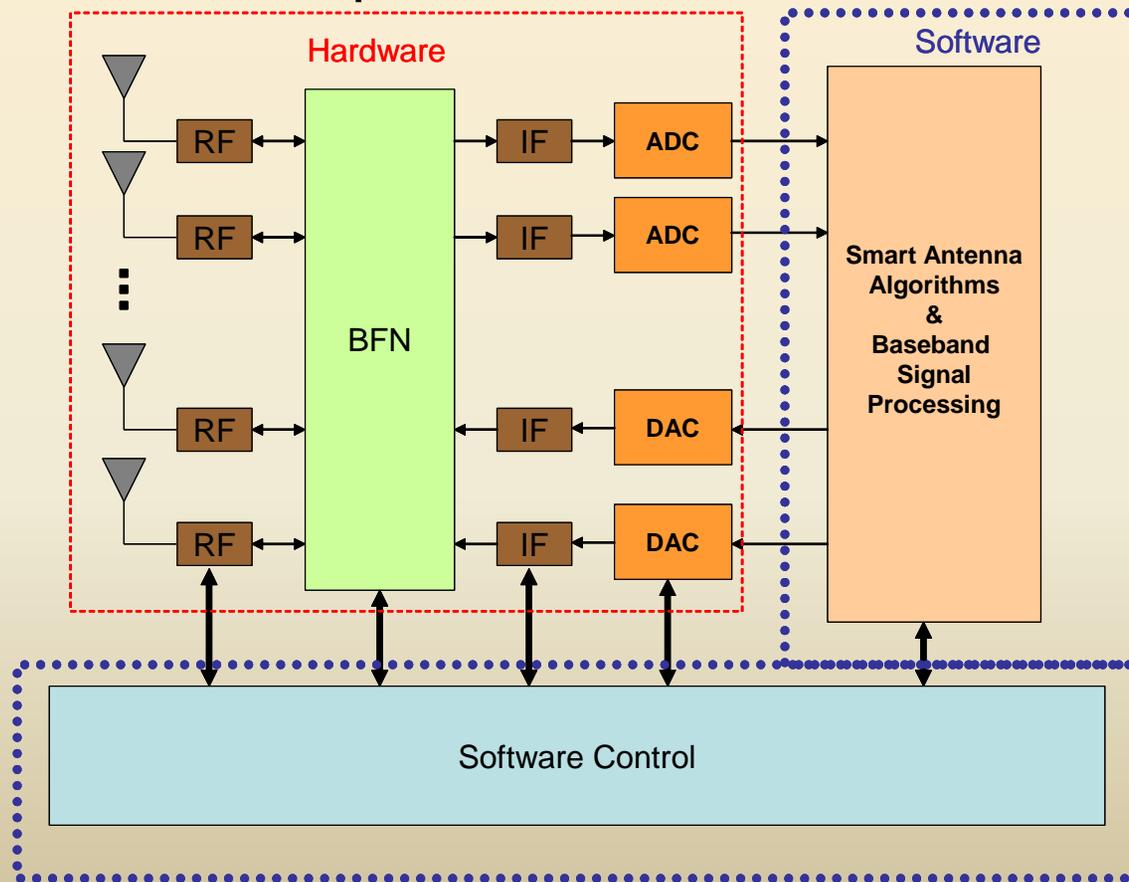
# Generic Smart antenna System

- Smart antenna system components:
  - Antenna array of multiple elements
    - Variations from: element type, geometry and inter-element spacing
  - RF front end of multiple RF chains
  - Array processing section
    - Algorithms: LMS, MMSE, CMA etc.



# Smart Antenna Implementation: A System Level View

- Software and hardware boundaries need to be defined
- Appropriate interfaces required at the boundaries
- Lends itself to SDR implementation



# Implementation: Different Subsystems

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- RF front end
  - RF energy to suitable IF (receive mode)
  - IF energy to RF (transmit mode)
  - Single stage or dual stage
  - Replication of RF chain for each antenna element
- Digital frequency conversion
  - Converts IF signal into complex baseband signal (receive mode)
  - Translates complex baseband signal into IF signal (transmit mode)
- Digital processing section
  - Collection of individual antenna array signal
  - Diversity combining or digital beamforming of the collected signals

# Analog RF Front-End Issues

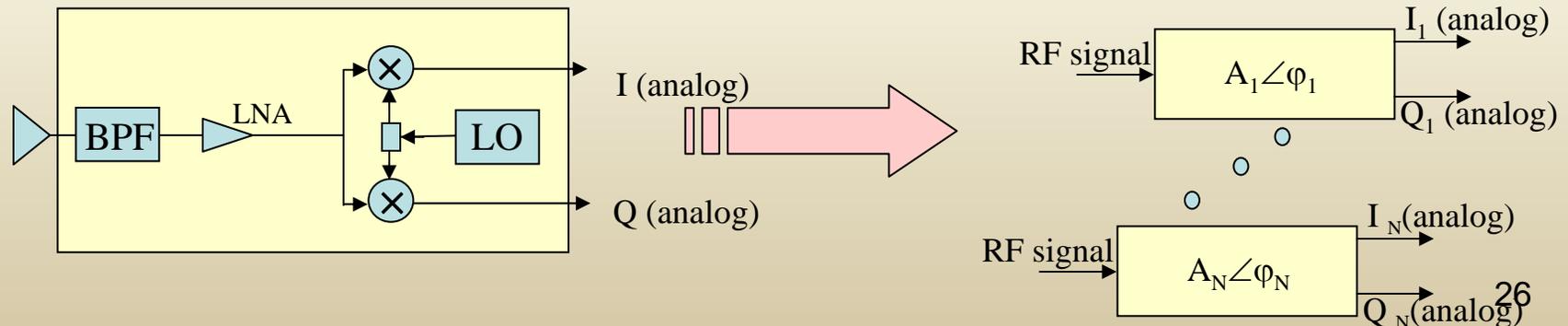
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- Multiple analog RF chains
- Sensitivity - Minimum Input Signal Level Discernable by the Receiver; Determined by NF of Analog Front End
- Channel Matching - Need Nearly Identical Channels
  - Magnitude and Phase Ripple of Filters in each element impacts Accuracy of the Narrowband Model
  - Isolation may be required between the RF chains (in the form of shielding)
- Spur Free Dynamic Range
  - Spurs and Intermods in the ADC Output
  - Typically Want Noise Floor Below the Spur Level Input
- Frequency Range, Power, Weight, Size, etc.

# Effect of Variation of Analog Components

- Analog components have finite precision
- Physical fabrication of the devices never guarantees that two similar devices are “exactly the same”
- Random amplitude and phase perturbation by each analog component
- Phase perturbation is more critical
- Cumulative effect from all the components in a single RF chain



# Effect of Variation of Analog Components

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- Component variation due to:
  - Thermal factors
  - Aging
  - Stray capacitance at the terminal from improper connection
- Performance sensitive to temperature (ambient or operating) and age of the components
- Sensitivity depends on the quality of the component
  - Can be solved by using high-precision components
    - More expensive
  - Also solved by “going digital”
    - Replace analog components with digital components as much as possible

# Calibration

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- Uncertainties in the array manifold:
  - Element position error
  - Mutual coupling
  - Element amplitude and phase errors
  - Frequency errors
- Uncertainties in the array manifold limit the performance of direction-finding algorithms or Direction of Arrival (DOA) algorithms
- Direction-finding applications
  - E911 and location services
  - Military surveillance

# DSP/SDR Issues

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- Collect data from multiple DDCs
- Perform a combining technique on these collected sampled data
- Collection scheme involves sampling each board sequentially when data is ready
- Different schemes
  - Design a back-plane interface to DSP
  - High Speed multiprocessor systems and cross-processor communication

# Digital Frequency Converter Issues

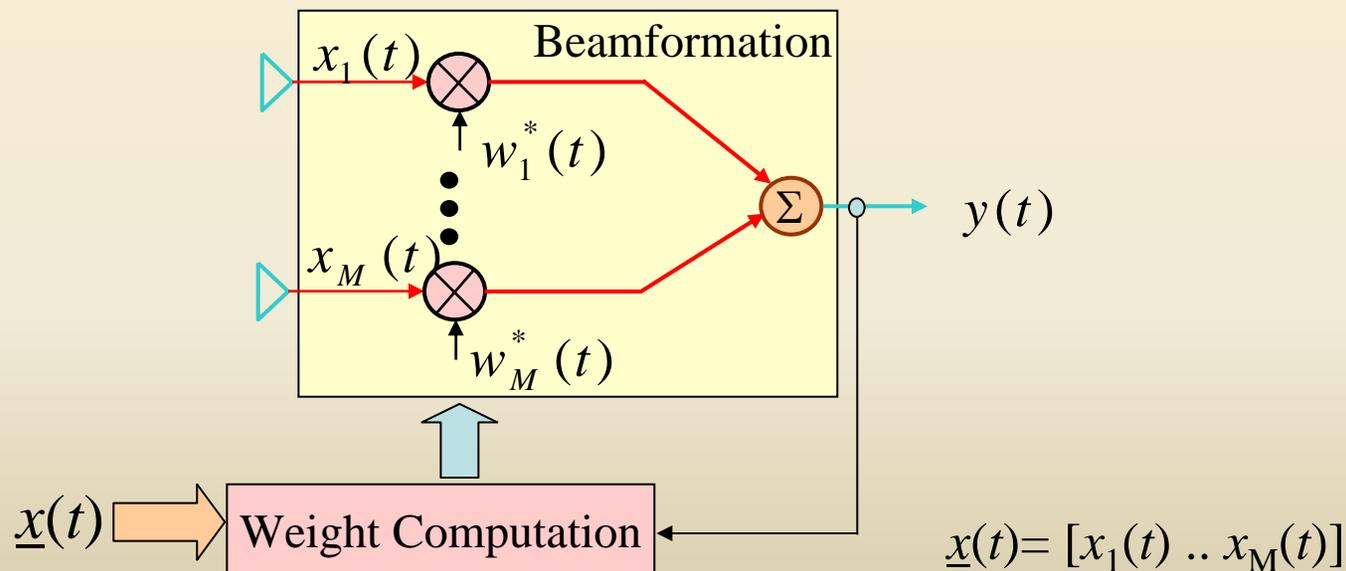
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- Multiple DDCs/DUCs, each following individual analog RF front-end
- Better precision as magnitude/phase uncertainty not present
- Synchronization needed between individual DDCs/DUCs
- Synchronization scheme may be difficult for commercial DDCs/DUCs as they are not designed for array operation
- Space constraint can be a problem for handset structure

# Digital Beamforming

- Process of combining individual array signals
- Implemented by processing the signals digitally
- Basic process involves two steps
  - Weight computation using adaptive algorithms
  - Beam forming



# Digital Beamforming

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- Beam formation
  - Implements inner product between  $\underline{W}$  and  $\underline{x}(t)$
  - Simply multiply and add operation
  - Processing at a high rate of signal bandwidth
- Weight computation
  - Updating of  $\underline{W}$
  - Implemented by adaptive algorithms
    - Performed at a slower rate than beam formation

# Sample Computations for Digital Beamforming(1/2)

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- Let  $N$ = number of antenna elements
  - $f_s$ = sample rate
  - $\mu$ = update rate
- Weight updating:
  - Computations to implement multiplication
  - One complex multiplication= four real multiplication
  - Order of complexity (multiplies/update):
    - $8N$  for LMS
    - $(16N^2 + 16N + 8)$  for RLS
- Total number of calculations:
  - $N_{T,LMS} = \mu * 8N$
  - $N_{T,RLS} = \mu * (16N^2 + 16N + 8)$

# Sample Computations for Digital Beamforming (2/2)

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For two-element smart antenna with updating every msec:

$$N_{T,LMS} = 16 \times 10^3 \text{ /sec.}$$

$$N_{T,RLS} = 10.4 \times 10^4 \text{ /sec.}$$

Beamforming:

Inner product between incoming signal and weight vector

Total number of computations:

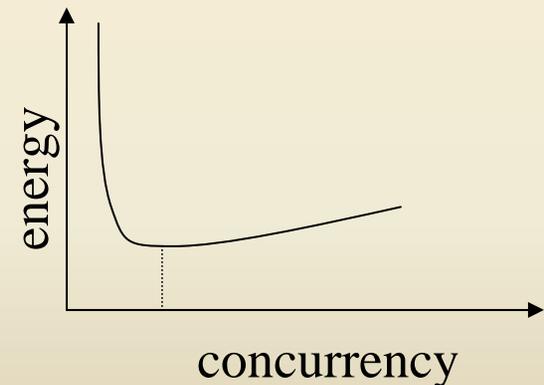
$$N_{T,BF} = 4 * N * f_s$$

For the same smart antenna at  $f_s = 10 \text{ MHz}$

$$N_{T,BF} = 80 \times 10^6 \text{ /sec.}$$

# System Issues: Pipelining and Parallel Processing

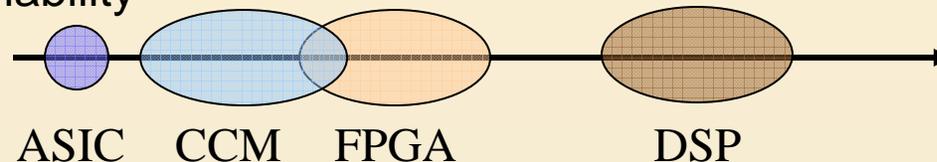
- $m$  stage pipeline can be used to speed up operation by a factor of  $m$
- Compensate for delay incurred in the low power design when the supply voltage drops significantly
- Parallel processing with slower, but lower power devices
- FFT is an example of a possible algorithm
  - Decompose DFT into smaller DFTs, each operating at a reduced rate
  - Overhead in partitioning process causes diminishing returns in power savings



# Tradeoffs in Hardware Platforms

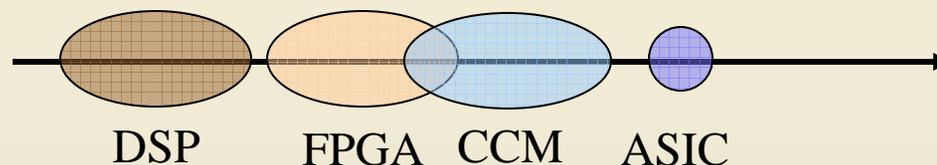
- Commonly used hardware devices
  - DSPs, FPGAs, Configurable Computing Machines (CCMs), ASICs

- Reprogrammability



- FPGAs
  - Not well suited for floating point applications
  - May require 7-10x the power for a particular switching speed for the same gate

- Speed



- FPGAs have high potential for parallel processing
- DSP
  - Performance depends on programmer and compiler
  - Some tasks such as the MAC or bit-reversing for the FFT optimized



# Smart Antenna and SDR: Software Issues

# Smart Antenna API

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- The various SA algorithms must be applicable to SDR-based wireless communication systems such that SA API does not confine to the evolution of communication standards and system hardware.
- Interface between Smart Antenna Base Station (SABS) and SDR network must operate independently of hardware.
- SABS should be partitioned into small modules and each of modules should interface independently of various algorithms and communication standards.
- Functions and capability of each module must be known to the network controller. Thus, Beam-forming module in SABS should be manageable through SDR network.
- Network interface should be independent of system upgrade.

# What makes a Smart Antenna API Difficult to Create?

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- Wide range of smart antenna algorithms
- Significant interdependencies with other radio functions
  - RF: mixer control, power amp, converters, ...
  - Antenna: type, location parameters
  - Demod: error correction, synch, rake, interference rejection algorithms, framing, ...
  - Radio Resource Management: power control, frequency allocation, QoS, ....

# Outstanding Questions To Resolve

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- How general can it be in practice?
- Best approach with working with OMG and JPO?
- What is the border between the smart antenna API and the antenna API?
- Is this API more appropriate for SCA 3.0+?
- How can it be verified?
- Best mode for cooperation in producing API?
- How much synergism is there with the Open Base Station Architecture Initiative (OBSAI) and the Antenna Interface Standards Group (AISG)?

# Example Smart Antenna API Logical Functionality

- Commands** Asynchronous protocols-to-device primitives for performing immediate, typically non-persistent actions.
- Variables** Persistent antenna state or long-term measurement primitives.
- Response** The synchronous device response to a protocol's command or variable operation.
- Signals** Asynchronous device-to-protocols primitives for reporting recent, typically non-persistent events.



< Interface between Network and SABS through Network protocol >

# Recent Activities in Creating the API (1/2)

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- Smart Antenna Working Group of SDR Forum leading efforts to develop the API
- An OMG submission on RFP for Smart Antenna API is now available
- An RFI on Smart Antenna API will be issued soon through SDR Forum
- The API on Single Antenna is available from SCA Specialized Hardware Subsystem (SHS) working group

## Recent Activities in Creating the API (2/2)

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- The first draft on the architecture for the Smart Antenna Base stations (SBS) is available for CDMA
- Some primitives for smart antenna API have been defined
- Completing the smart antenna API based on the proposed architecture and the primitives constitute the next technical step in the development effort
- Need to think of generic SA-APIs which include other classes of smart antenna implementation eg: MIMO and for mobile terminals
- Need to coordinate with OMG and JPO for inclusion into SCA.



# Technology Needing Development for Smart Antennas

# Technology Needing Development for Smart Antennas (1)

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- Deployment tools
  - System layout
  - Resource allocation and network control algorithms, i.e., handover, channel allocation, admission control, power control, etc.
  - Efficient software evaluation tools
- Metrics and analysis procedures for design
  - Throughput, reliability, capacity
- Low cost hardware
  - RF and consistency / calibration / flexibility
  - High resolution low power A/D and flexible DDC (variable bandwidth)
  - Power amplifiers (key cost for 3G) and synergism with arrays
- Software
  - API
  - SCA 3.0 should help with data throughput problems

# Technology Needing Development for Smart Antennas (2)

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- Variable RF capability: High Quality and Multiple Band Support
- Algorithms
  - Overloaded array capability
  - Balanced up and down links through interference rejection
- Modulation Synergism
  - Packet radio capable
  - Trellis-coded type modulation
- Handset smart antennas with feedback
  - Power consumption and capacity analysis
  - Form factors
  - Trade-offs in space time processing
  - Peer-to-peer capability

# Technology Needing Development for Smart Antennas (3)

- Channel Models

- Smart antenna deployment and benefits depend on the propagation channel conditions
- Vector channel measurements required to measure and characterize propagation channels for smart antenna use

Transmitter: monopole antenna



Receiver: Four-element linear monopole array



# Technology Needing Development for Smart Antennas (4)

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- Regulatory
  - FCC how do you regulate EIRP to reduce amount of interference in the system?
  - How can this technology be mandated to reduce interference?
  - Development of Smart Antenna API for SCA 2.2 (SDR Forum and OMG)



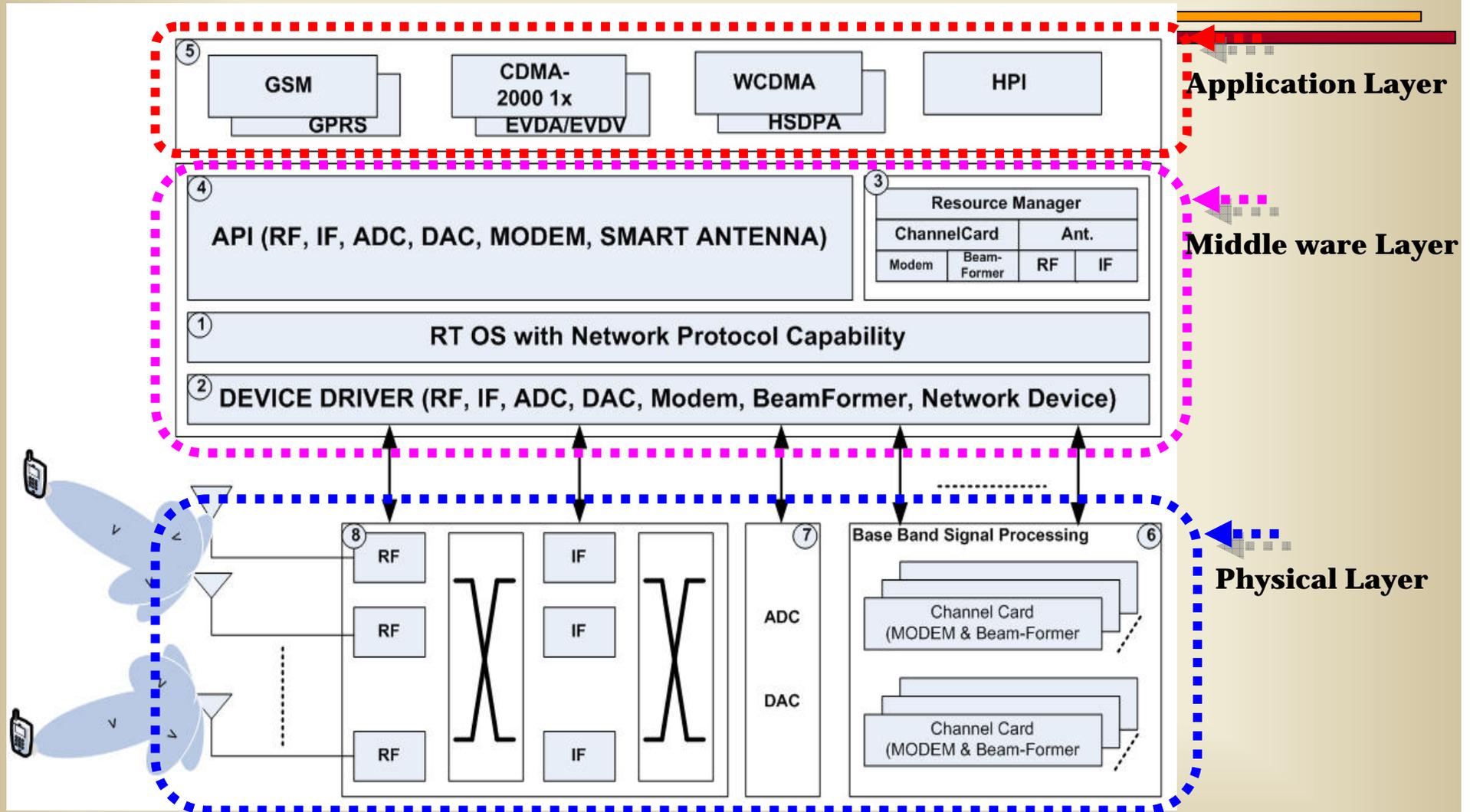
# Case Studies of Smart Antennas

# SDR-based Smart Antenna Base Station Open Architecture:



Courtesy: Professor Choi, HY-SDR Research Center, Hanyang University, S. Korea<sup>50</sup>

# SDR-based Smart Antenna BST: Block Diagram



# SDR-based Smart Antenna BST: Subsystems

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## • **Physical Layer**

### • **Antenna**

- ✓ Broadband, Multi-band / Tunable Antennas

### • **RF/IF**

- ✓ Direct IF sampling SDR structure
  - Required High Speed, High Linear ADC
- ✓ Digital IF SDR structure

### • **AD/DA**

- ✓ Multi-band and Multi-mode operation
- ✓ High resolution, Low noise and Low power consumption

# SDR-based Smart Antenna BST: Subsystems

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- **Base band Signal Processing**

- ✓ RISC CPU, FPGAs, and DSPs Structure

- RISC CPU : Network interface, Call Processing

- FPGAs : Chip Rate Processing

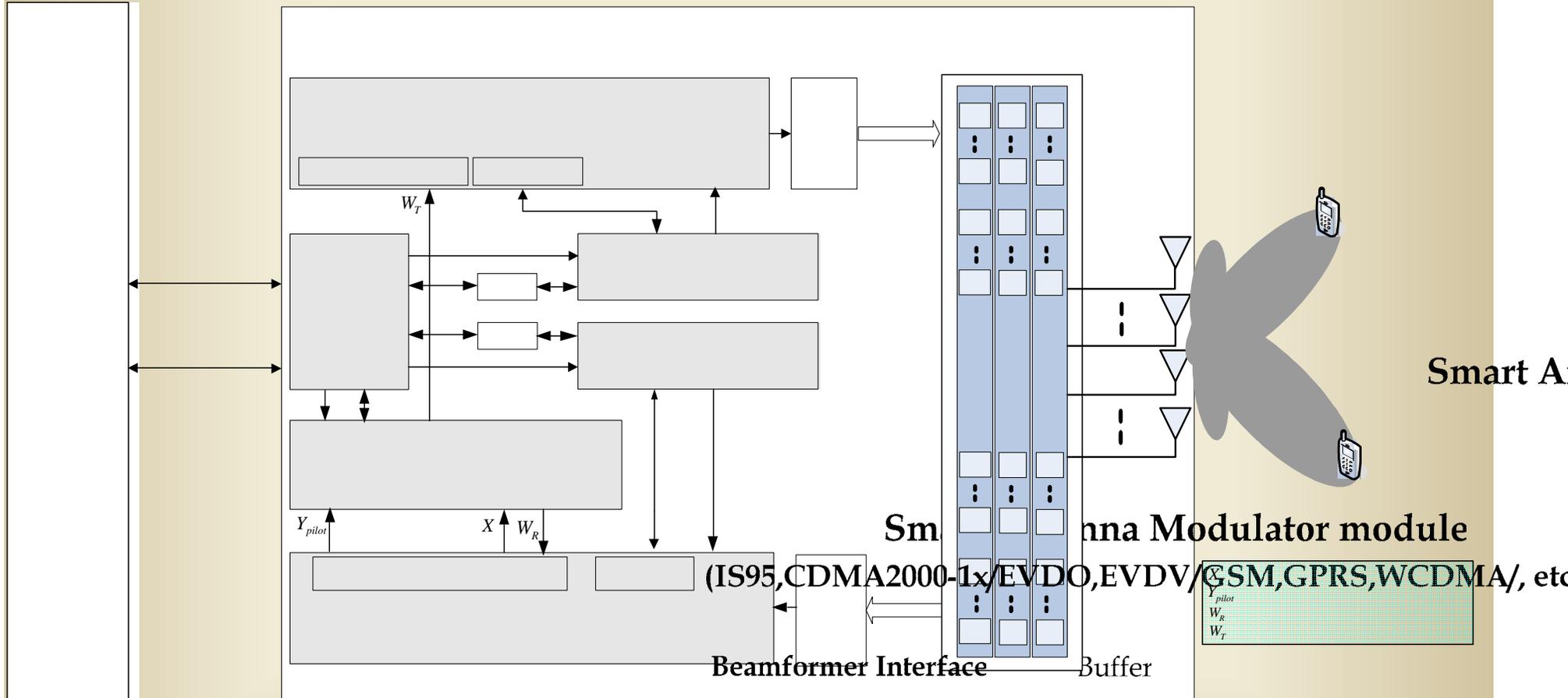
- DSPs : Symbol Rate Processing, Channel decoding, Beamforming Algorithm

- ✓ RISC CPU and Multi DSP Structure

- RISC CPU : Network interface, Call Processing

- DSPs : Chip Rate Processing, Symbol Rate Processing, Channel decoding,  
Beamforming Algorithm

# SDR-based Smart Antenna System Architecture



# Details on Data Signals

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**Data #1: Data to be transmitted to Handsets and channel configuration\* for modulator**

**\* channel configuration for modulator : data rate, channel gain, etc for monitoring of SABS**

**Data #2: Channel configuration , modulation scheme for modulating Tx data and Data #1**

**Data #3: Received data from Handsets and channel configuration \* for demodulator**

**\* channel configuration for demodulator: data rate, channel gain, etc for setting/managing the receiving configuration of SABS**

**Data #4: Channel configuration, demodulation scheme for demodulating Rx data and Data #3**

**Data #5: SABS parameters needed in beam-former, beam-former statements and weight information**

# Details on Command Signals

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- Command #1: Modulator controller operating Commands
  - (modulator controller reset, modulator controller execute, Diagnostic monitoring execute, etc)
- Command #2: Modulator operating Commands
  - (modulator reset, modulator execute, etc)
- Command #3: Demodulator controller operating Commands
  - (demodulator controller reset, demodulator controller execute, diagnostic monitoring execute, etc)
- Command #4: Demodulator operating Commands
  - (demodulator reset, demodulator execute, etc)
- Command #5: Beam-forming module operating commands
  - (beamformer reset, beamformer execute, etc)

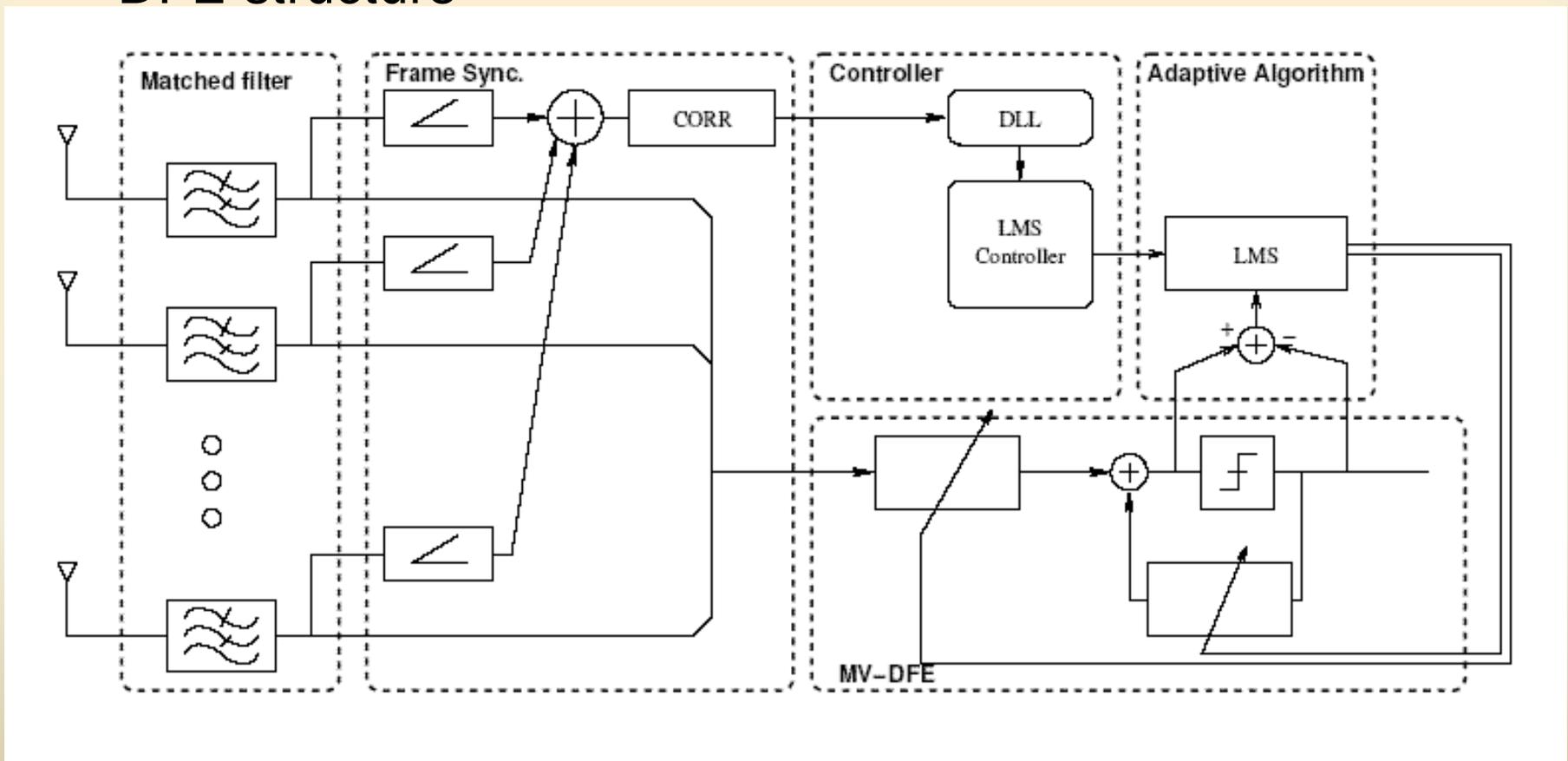
# MIMO Equalizing Receiver Testbed(1/2)

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- A reconfigurable receiver for rapid development and real-time operation from Tait Electronics Ltd, NZ.
- Current implementations allow up to 12 antenna elements at each end
- Multi-Variate Decision Feedback Equalizer (MV-DFE) implemented to counter delay spread in channels
- Parallel FPGA and DSP modules (Altera Statix)
- IF sampling rate: 60 MHz
- Baseband (input to DFE) sampling rate: 2 MHz
- Processing clock: 300 MHz

# MIMO Equalizing Receiver Testbed(2/2)

- Digital architecture of the FPGA section: Cross-Coupled DFE structure

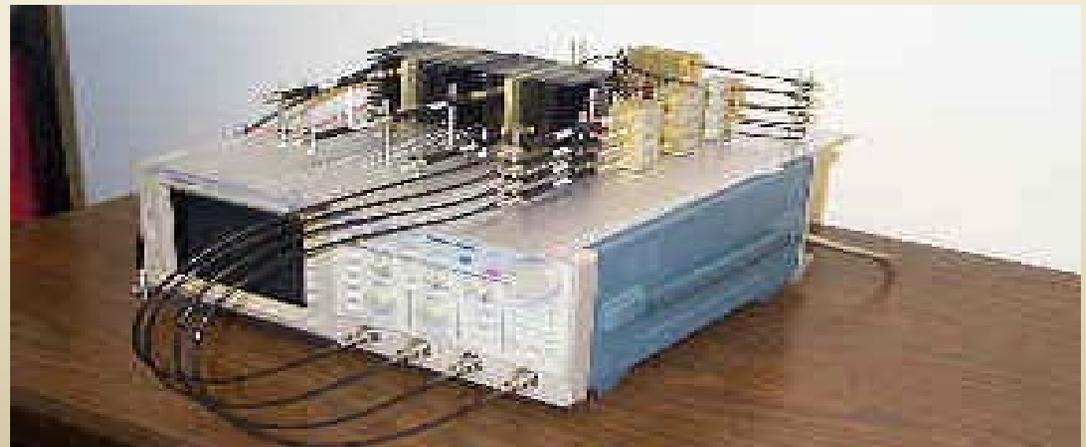


# VIPER Measurement Receiver

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- Vector ImPulse Response Measurement Receiver
- Software radio implemented on a PC platform
  - Direct RF down-conversion and sampling
  - Baseband functionality encased in the PC
- 4-channel (antenna) receiver
- Mobile transmitter
- Variable bandwidths from 100 MHz to 400 MHz





# **Future Directions**

# Smart Antennas for 3G Systems

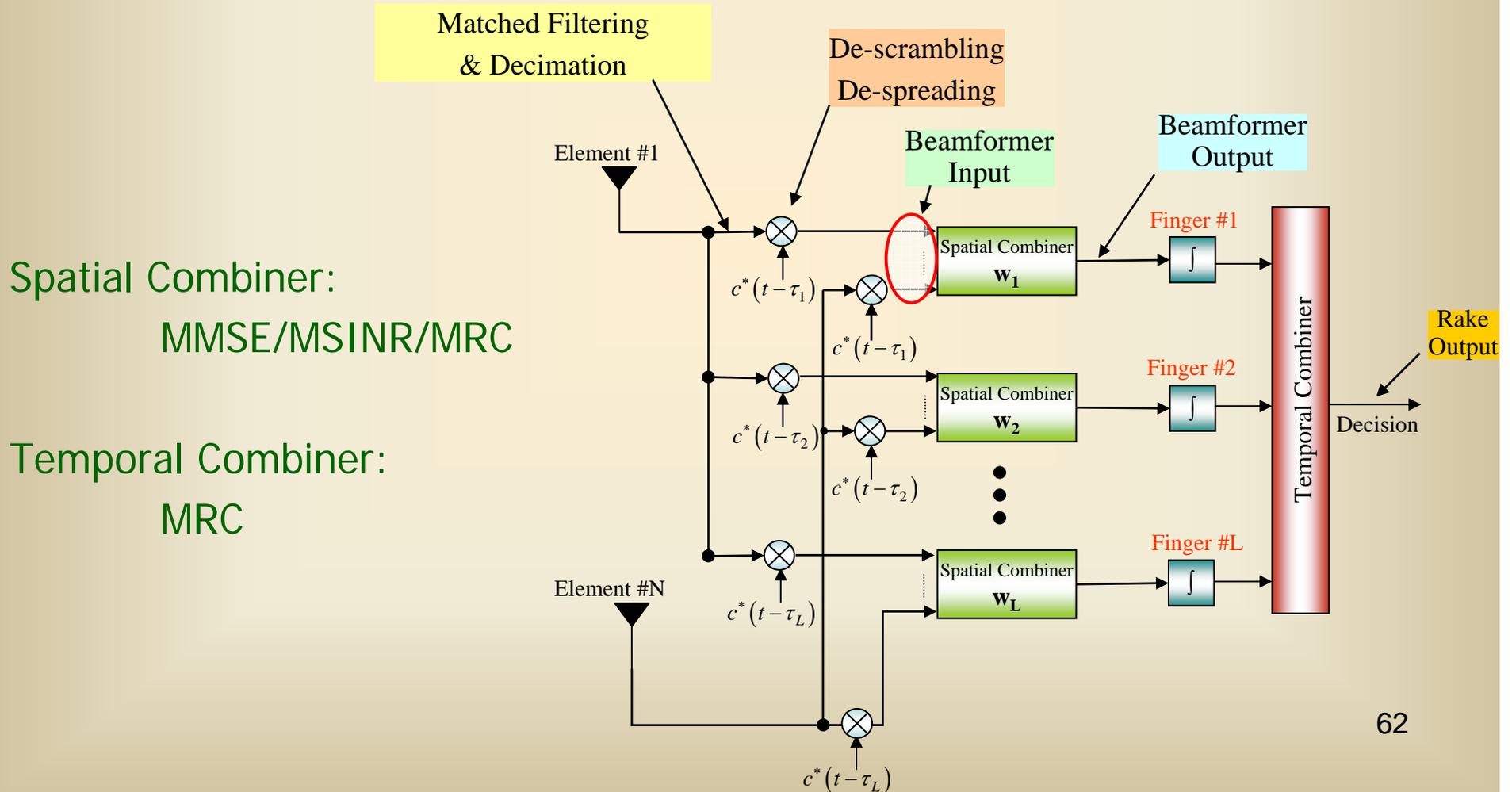
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- 3G cellular systems can benefit from smart antenna applications – Hooks are in the standards to make this feasible.
- Better error rate performance and more capacity for WCDMA or cdma2000 with smart antenna system
- Conventional CDMA receivers coupled with smart antenna system gives rise to 2D Rake receiver.

# WCDMA Downlink Receiver

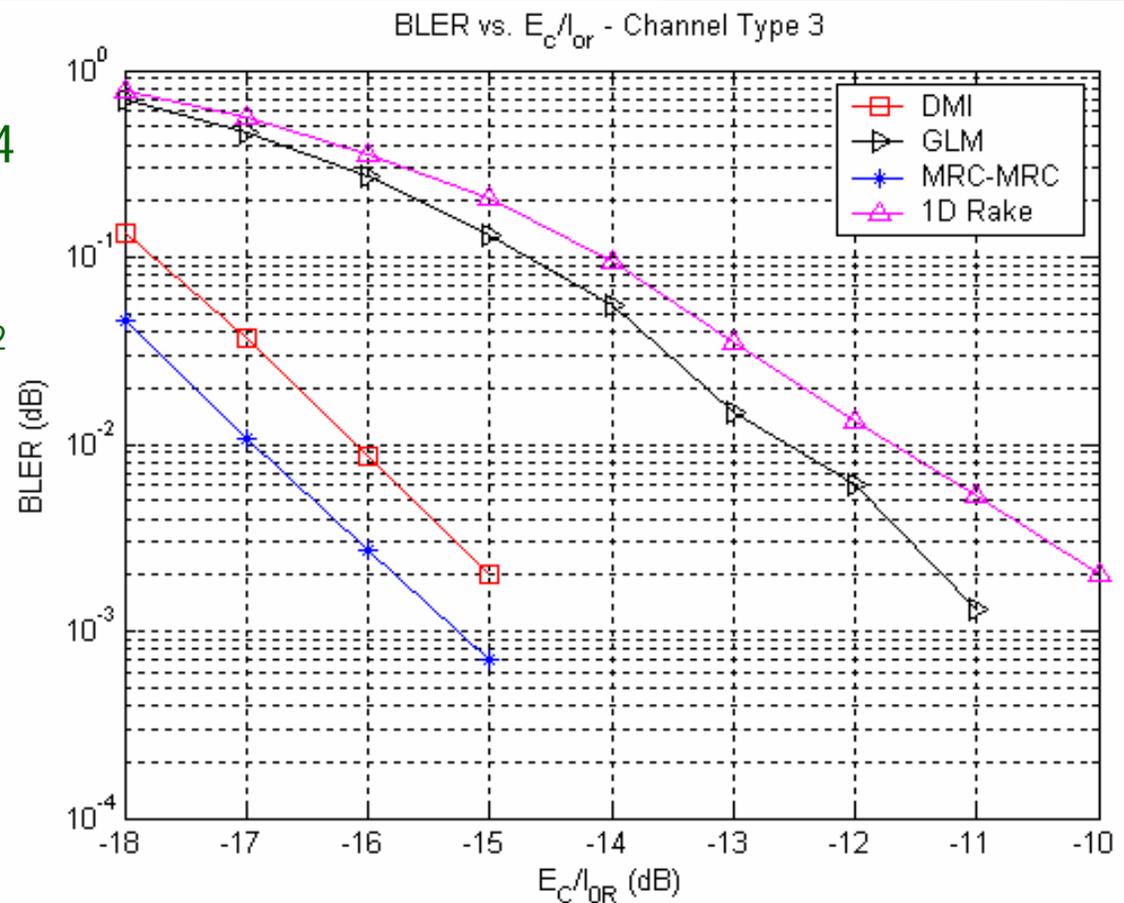
## Concatenated Space Time Processing (CSTP)



# BLER Performance for WCDMA

## Coded BLER - Fading Channel Type 3

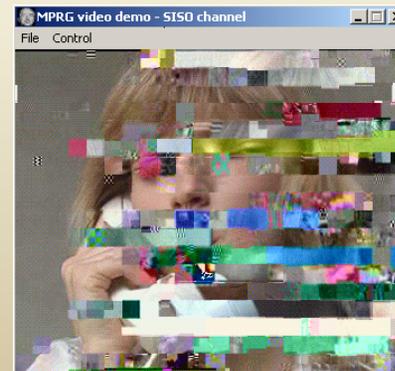
- Convolution coding
- Number of Blocks = 500 (4 frames/block)
- DMI and MRC-MRC better than 1D rake by 5 dB at  $10^{-2}$  BLER
- Performance of 2D Rake - GLM suffers from slow convergence in a high mobility channel



# Introduction to Multiple Input Multiple Output (MIMO) Techniques

- Antenna arrays at both ends of the link
- Goals / Motivation:
  - Improve data rate and reliability of wireless communications with the usage of multiple element arrays in both ends of the link
  - Can overcome the scarcity of spectrum and provide high data rate in a relatively small bandwidth
  - Two basic modes of operation:
    - Narrowband diversity/beamforming at both TX & RX
    - Spatial and temporal processing
  - Diversity advantage
  - Coding gain

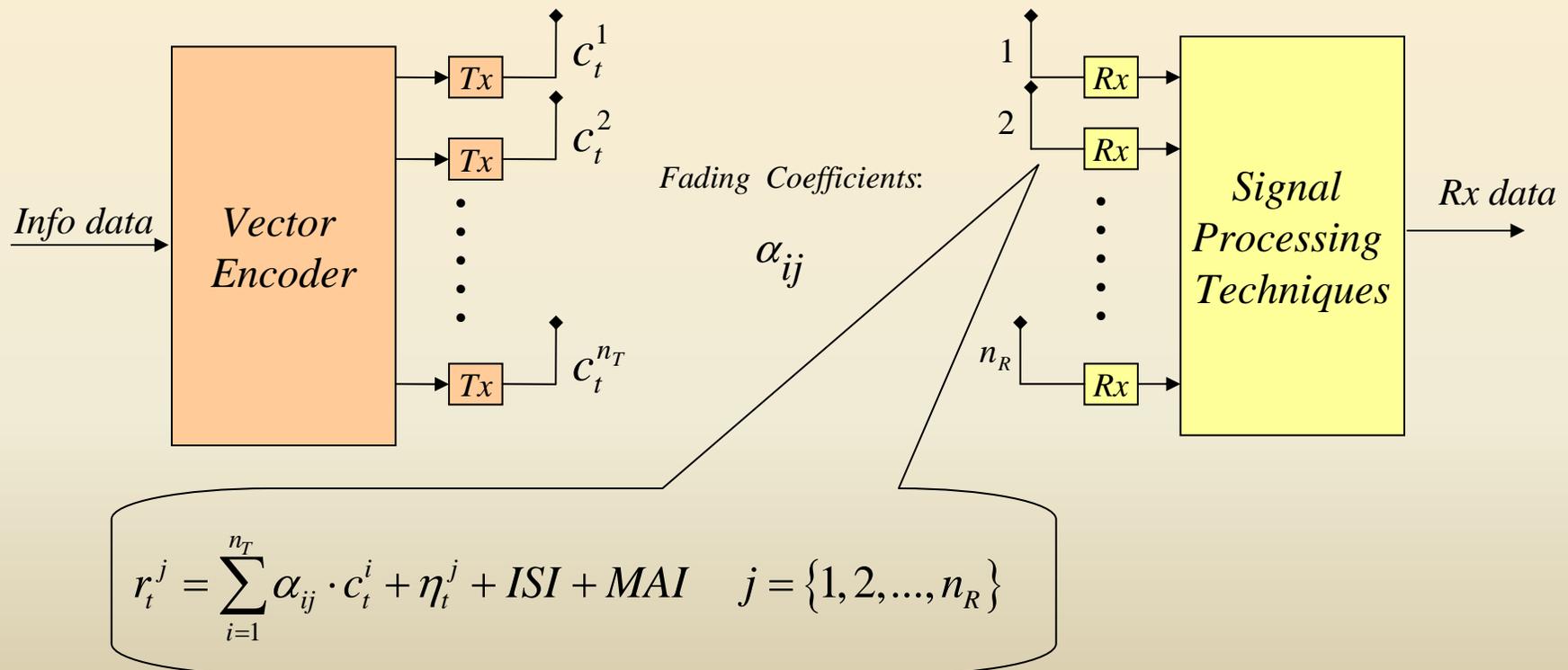
MIMO  
Channel



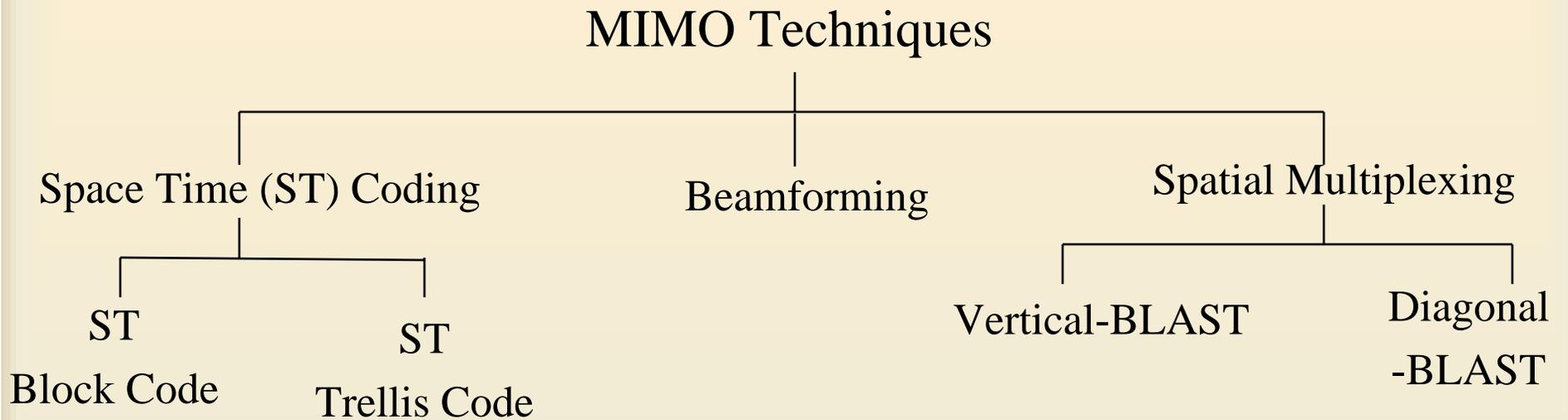
SISO  
Channel

# Block diagram

- $(n_T, n_R)$  - (# of Tx. Ant., # of Rx. Ant.)

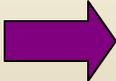


# MIMO Classification



# Spatial Multiplexing Vs Diversity Gain

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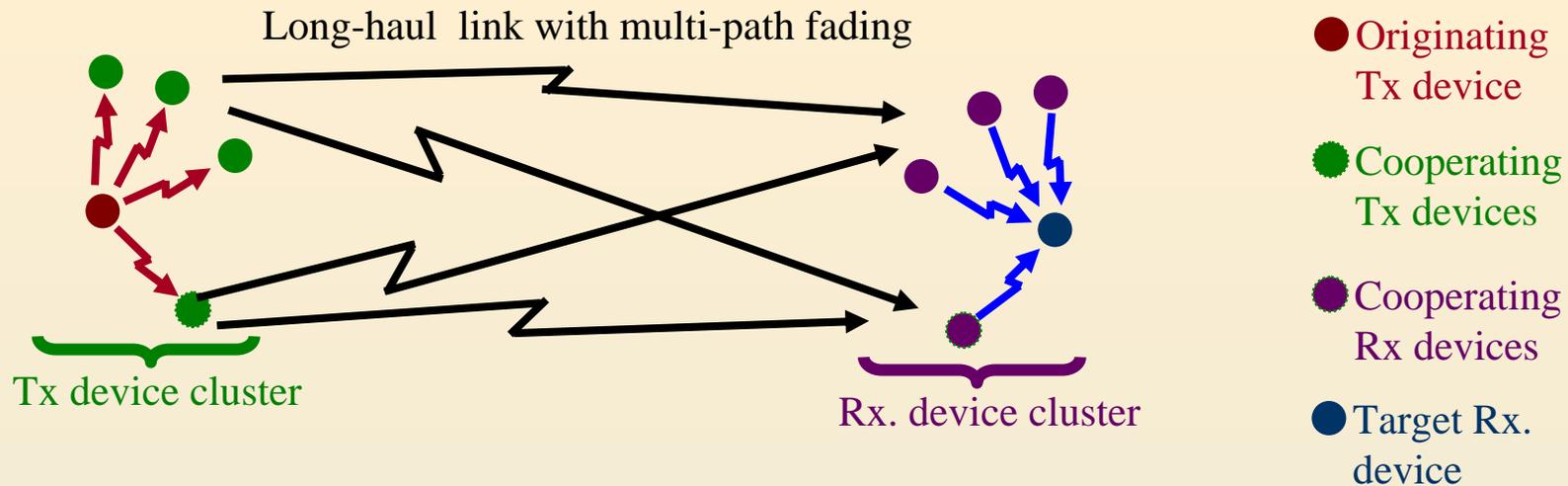
- Spatial Multiplexing
  - Multiplex input bit streams over multiple transmit-receive antennas pairs
  - *Exploits fading* to increase degrees of freedom
  - Independent fading results in multiple parallel spatial channels
  - $C(\text{SNR}) = \min\{n_T, n_R\} \log \text{SNR}$  (Foschini)
  - Multiplexing Gain:  $\min\{n_T, n_R\}$
  - Examples:
    - V-BLAST and D-BLAST (Foschini et. al 1996)
- Spatial Multiplexing  High Data Rate

# Spatial Multiplexing Vs Diversity Gain

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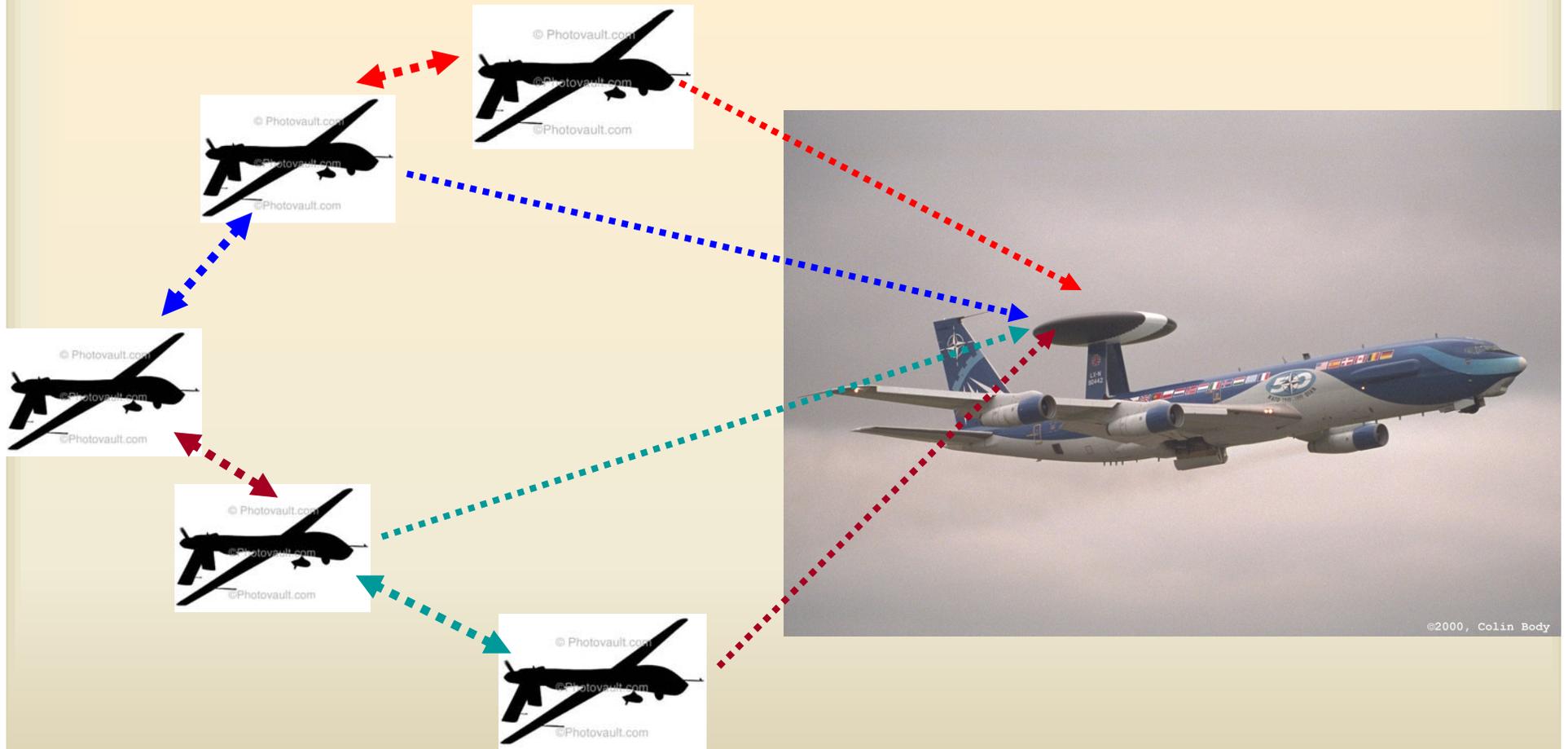
- Diversity Gain
  - Same information – multiple paths
  - Multiple independent faded replicas of data Symbol at receiver
  - *Combats fading*
  - Average error probability decays as  $\text{SNR}^{-d}$
  - Diversity gain:  $d = n_T n_R$  for i.i.d. Rayleigh faded gains
  - Examples:
    - Space-Time Trellis Coding (Tarokh, Seshadri 98)
    - Orthogonal Designs - Space-Time Block Coding (Alamouti 98)
- Diversity  improves reliability

# Distributed MIMO



- Alternatively, can have multiple Tx and Rx nodes.
- Multiple Rx. nodes requires a multi-access channel.
  - This makes sense if the cluster has much more spectrum available than for the long-haul.
    - Example 60GHz communications.
    - WLAN in a building or forest.

# Example Application



Coordinated transmission can lead to longer range, more reliability, and  $\mathbb{ZPD}$

# Benefit of MIMO for Range-Extension

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- Example:
  - 2 x 2 MIMO system.
  - Digital Voice transmission.
  - Urban, environment (Tx/Rxs on ground)
    - Independent Rayleigh Fading
    - Path loss exponent:  $n= 3$ .
- Compare two STC systems
  - 1: uncoded SISO system.
  - 2: STTC MIMO system.
- Noise and transmit power are the same for both systems.
- Define:
  - $d_1$ : Tx/Rx range for uncoded SISO system.
  - $d_2$ : Tx/Rx range for coded MIMO system.
- Range Extension  $d_2/d_1$  is a function of coding gain.

# Benefit of MIMO (contd.)

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- Range Extension 2 x 2 system:

$$\frac{d_2}{d_1} = \left( \frac{SNR_1}{SNR_2} \right)^{1/n} = \left( 10^{15/10} \right)^{1/3} \approx 3$$

- If only one receive node (2 x 1 system)

$$\frac{d_2}{d_1} = \left( \frac{SNR_1}{SNR_2} \right)^{1/n} = \left( 10^{10/10} \right)^{1/3} \approx 2$$

- Benefit improves as:
  - Number of Tx and/or Rx antennas increases
  - QoS requirements become more challenging (e.g. data instead of voice)

# Research Issues

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- What Distributed MIMO applications help the war-fighter?
  - Answer is environment specific.
  - STC techniques only applicable in spatially rich multi-path fading environments.
- Can Tx/Rx timing requirements be improved through more clever signaling at the transmitter and signal processing at the receiver?
- Which STCs best slacken requirements on carrier frequency accuracy?

# Smart Antenna in WLAN

- Smart antenna are being deployed in commercial WLAN products
- Existing techniques employ dual diversity system mostly with selection diversity
- Vivato uses phased array on each packet of data (packet steering)
- 802.11n is being standardized and likely to use MIMO, effective throughput at least 100Mbps, triple 802.11a. Due 2005-2006.

- Example prototype:



# Commercial WLAN Products with Smart Antenna Technology

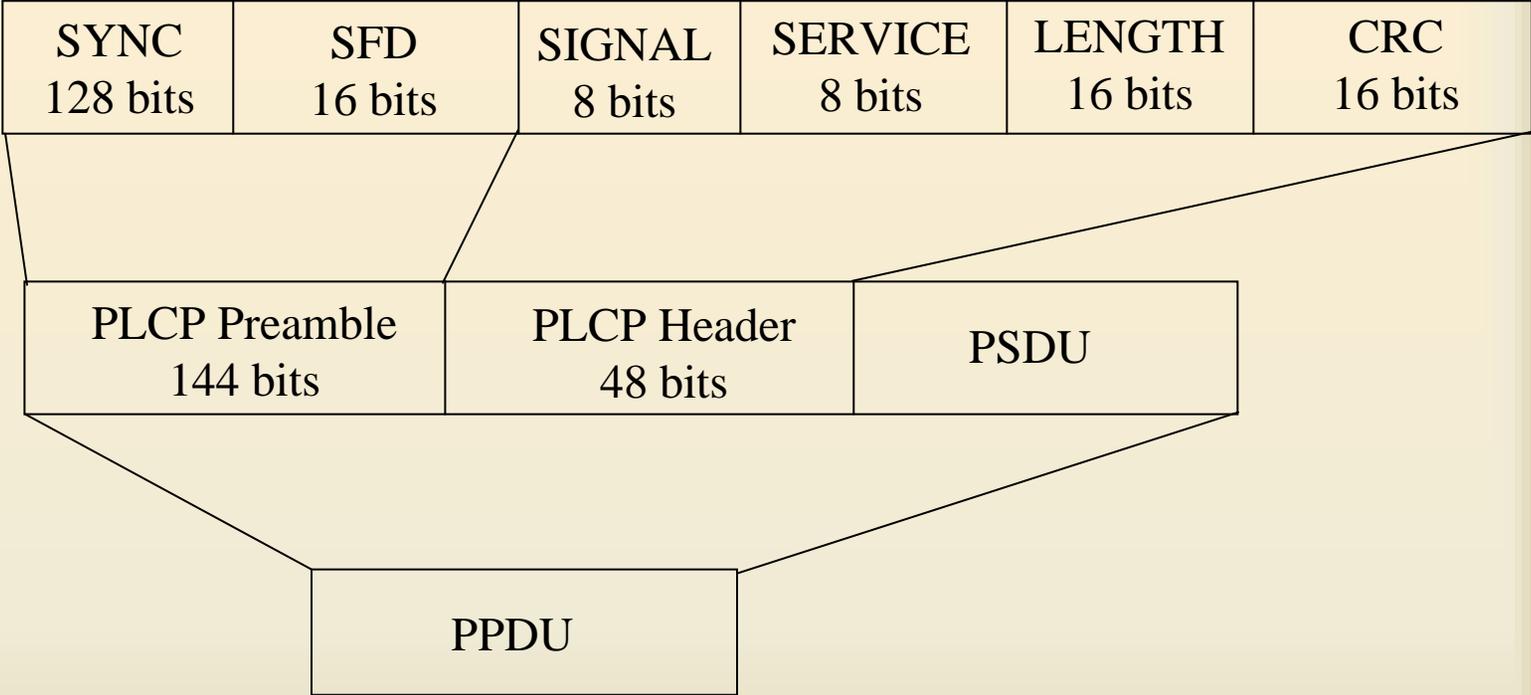
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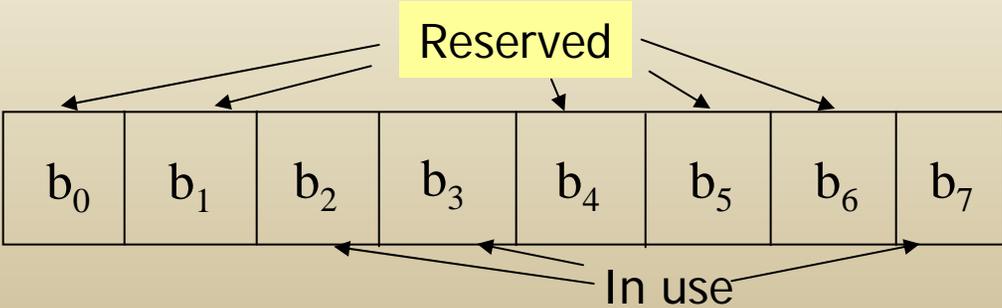
- AGN1000 chipset from AIRGO includes MIMO capability
  - Composed of AGN100BB broadband/MAC chip and AGN100RF radio chip
  - MIMO system from using multiple AGN100RF chips
  - Range of 300 feet with a minimum throughput of about 34Mbps for 802.11a system
  - More capacity: coverage for 100-person office with just two AP vs. nine using existing technology
  
- VP2200: Indoor Wi-Fi base station from VIVATO
  - 802.11g PHY and MAC
  - PacketSteering™ technology
  - Integrated 21dBi high-gain phased array antenna
  - Coverage:
    - Indoor Mixed Office: 295ft/90m at 36Mbps
    - Warehouse: 623ft/190m at 36Mbps

# IEEE 802.11b Air-Interface supports Smart Antenna

- IEEE 802.11b Frame structure
- Pilot bits from the SYNC bits in the PLCP frame
- Feedback in the SERVICE field



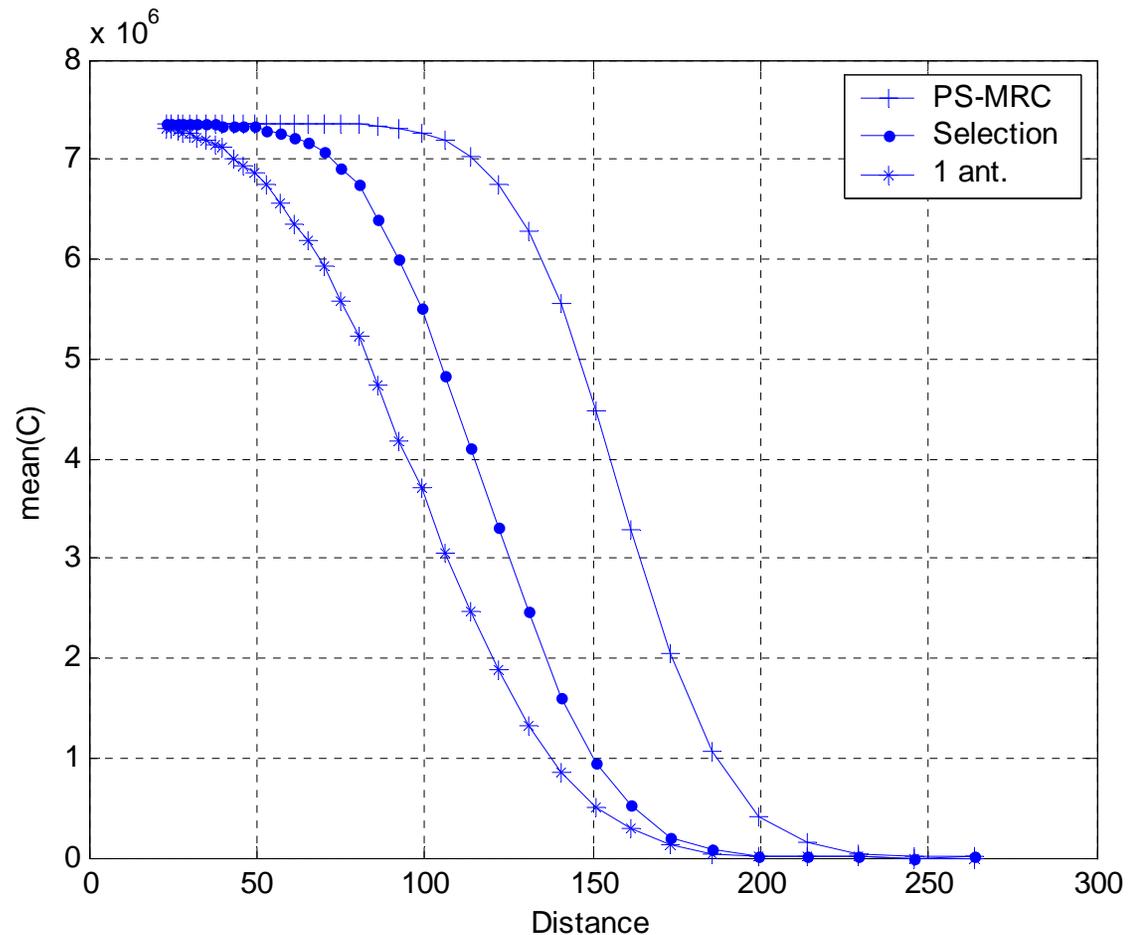
SERVICE field:  
Use the reserved bits for feedback payload



# Example Results on Range Extension

## Range Extension

- 2x2 phase scanning MIMO algorithm developed at VA Tech with MRC at RX
- Considerable range extension from smart antenna technique
- At 6 MBPS rate, range is extended from 70 ft to about 140 ft.
- Selection diversity operation at the receiver provides about an extra 25 ft.



# IEEE802.11n: High Throughput System

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- IEEE802.11 Task Group N (TGn) to develop high throughput wireless systems
- Actual throughput > 100 MBPS
- Operating spectrum: 5 GHz with BW of 20 or 40 MHz
- Main enabling technology: MIMO and OFDM
- Proposals are still being solicited, many in already
- First draft of 802.11n Specification scheduled at mid-2005
- Official proposal due by late 2006

# Competing Proposals for 802.11n (1/2)

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- Two major competitors:
  - TGn Sync
  - World Wide Spectrum Efficiency (WWISE)
- TGn Sync (not nSynch the music group!)
  - Consortium of Agere, Atheros, Philips, Intel, Nortel, Cisco, Sony, Nokia, Samsung, Matsushita and Toshiba
  - MIMO: 2×2 (mandatory) or 4×4 (optional)
  - PHY data rate: 243~250 MBPS expandable to 500~600 MBPS
  - Spectrum: 5 GHz (mandatory) 2.4 GHz (optional)
  - BW: 10, 20 or 40 MHz

# Competing Proposals for 802.11n (2/2)

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- WWISE:
  - Consortium of Airgo, Broadcom, TI, Conexant, STMicro, Mitsubishi and Motorola
  - MIMO: 4x4
  - PHY data rate: probably 216 MBPS
  - Spectrum: 5 GHz
  - BW: 20 and 40 MHz
- Two groups have claims and counterclaims about their technologies
- For recent updates, follow [wi-fiplanet](#) or [unstrung web sites](#)

# Conclusion

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- Many benefits of Smart Antennas motivate SDR
- Smart antennas pose many challenges to implementation:
  - Hardware: Computation, Data Movement
  - Software: Lots of different configurations and hard to break into distinct components
  - System Level: Network planning and performance evaluation
- Development efforts on a complete smart antenna API underway sponsored by OMG and SDR Forum
- Military as well civilian communication systems benefiting from MIMO
- Commercial products already show promise of using smart antenna technology for cellular and WLAN systems
- IEEE802.11n will provide ideal test scenario for the feasibility of commercial applications of MIMO
- Still many research issues needing to be addressed