EIGENT TECHNOLOGIES

Adaptive Arrays for Multi-Platform Networks

Presented to:
The Long Island Chapter of the IEEE Antenna and Propagation Society

Jack Winters
CTO
732 208 5568
jwinters@eigent.com

February 16, 2007

ET

Outline

- Introduction/Motivation
- Universal Front-Ends for Multiplatform Devices
- Small Antennas
- Cross-Layer Optimization
- Conclusions

Introduction

Goal: Ubiquitous wireless access: anywhere, anytime, in any form

Wireless Service Limitations

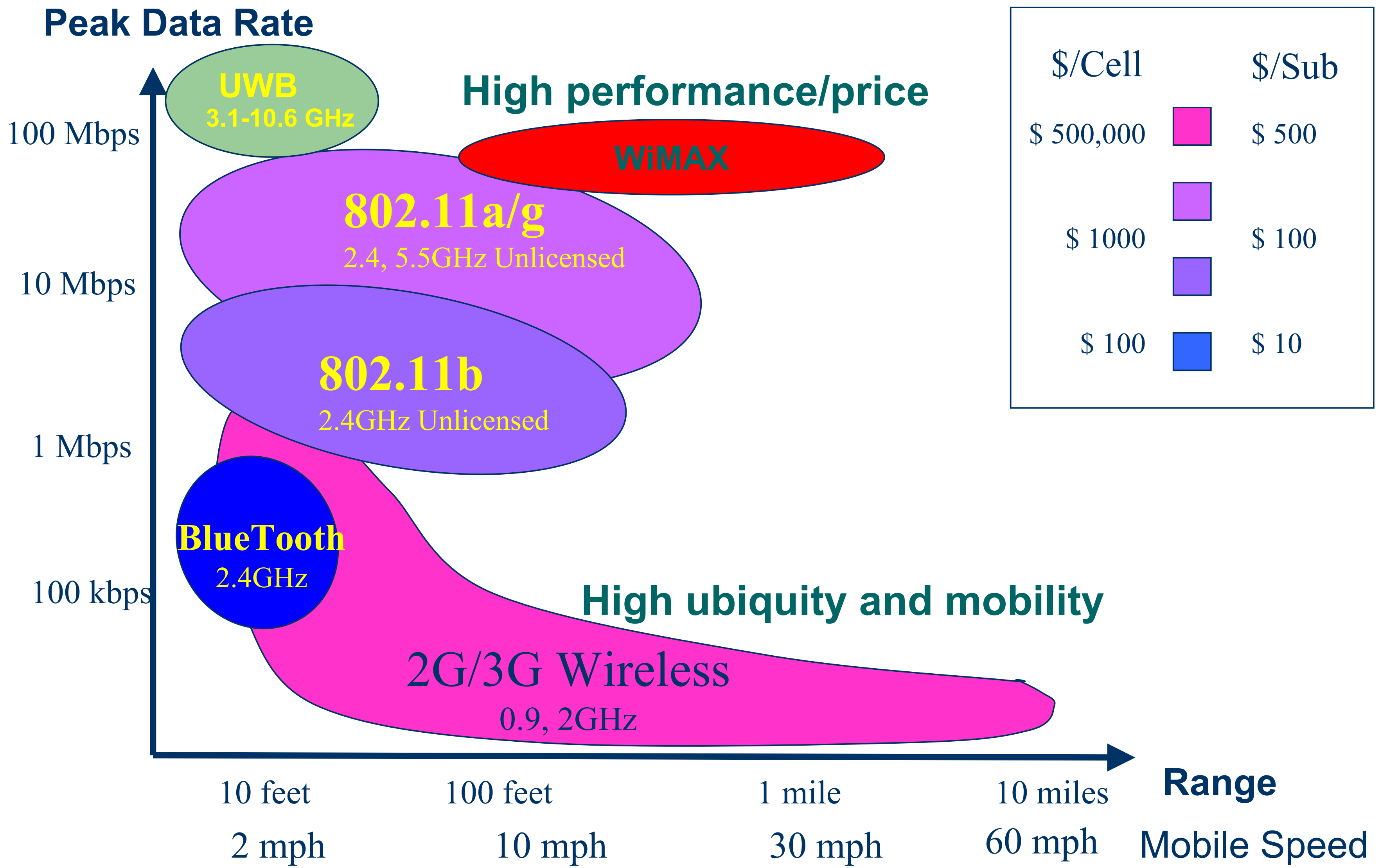
- Quality of service for each user is not consistent:
  - Too far away from the access point/base station
  - Behind a wall
  - In a "dead" spot
  - Working off a battery, as with a laptop
  - Suffering from low bandwidth due to range/interference
- Performance not adequate
  - Higher throughput
  - Ubiquitous coverage

Means

Standard-based heterogeneous networks, since no one wireless network is best in all cases –

- **Centralized networks – cellular, WiMax**
- **Decentralized – WLANs, Bluetooth, sensor networks - RFID**

Wireless Systems



Multiplatform Devices

- No single wireless system is best in all cases.
- Increasingly, multiple systems are being integrated into devices:
  - WiFi/RFID into cellphones
  - WiFi/WiMAX/cellular into laptops
- To improve these systems, multiple antennas (smart antennas) are being considered (in standards) and implemented for each system

Smart Antennas

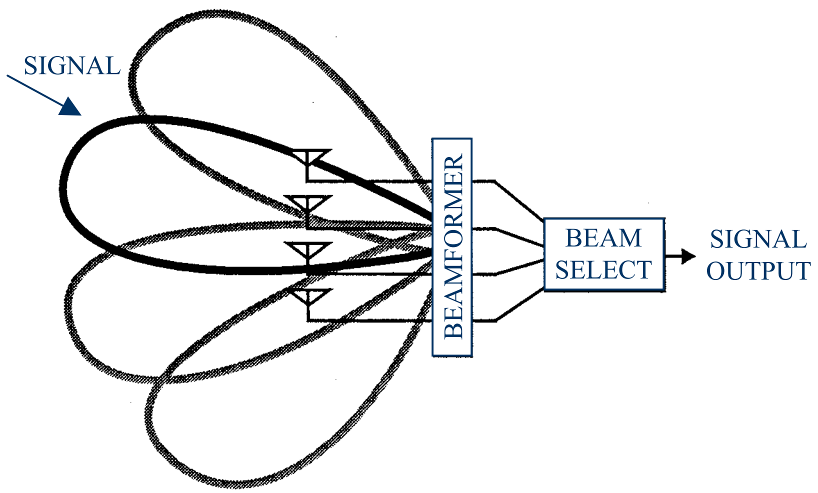
A smart antenna is a multi-element antenna where the signals received at each antenna element are intelligently combined to improve the performance of the wireless system. The reverse is performed on transmit.

Smart antennas can:

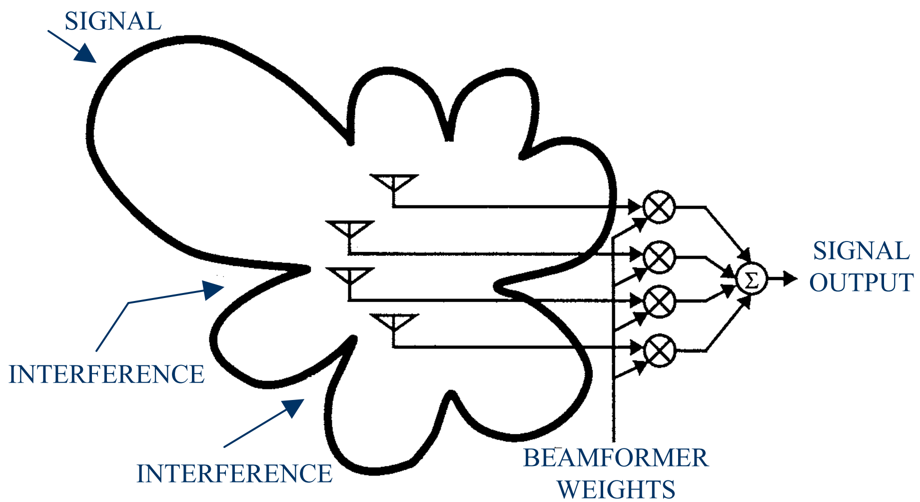
- Increase signal range
- Suppress interfering signals
- Combat signal fading
- Increase the capacity of wireless systems

Smart Antennas

Switched Multibeam Antenna



Adaptive Antenna Array



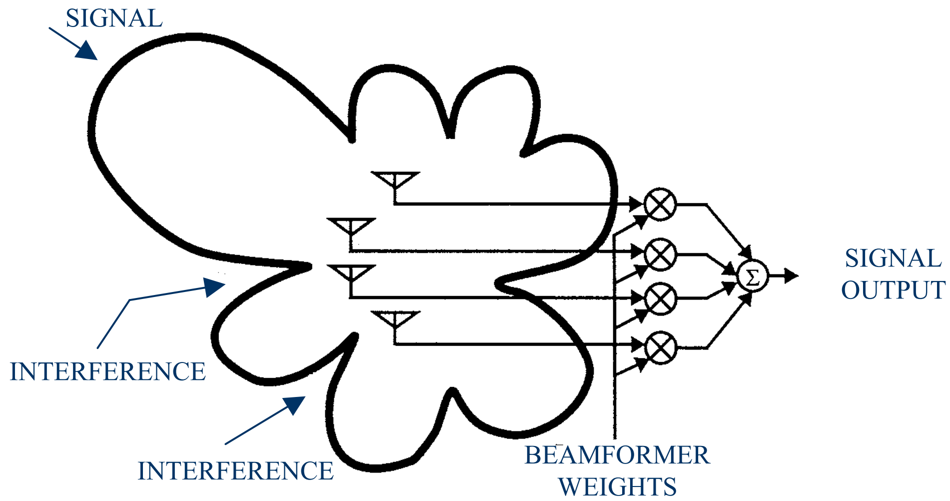
Smart antenna is a multibeam or adaptive antenna array that tracks the wireless environment to significantly improve the performance of wireless systems.

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

Adaptive arrays are generally needed for devices and when used for MIMO

Smart Antennas

Adaptive Antenna Array



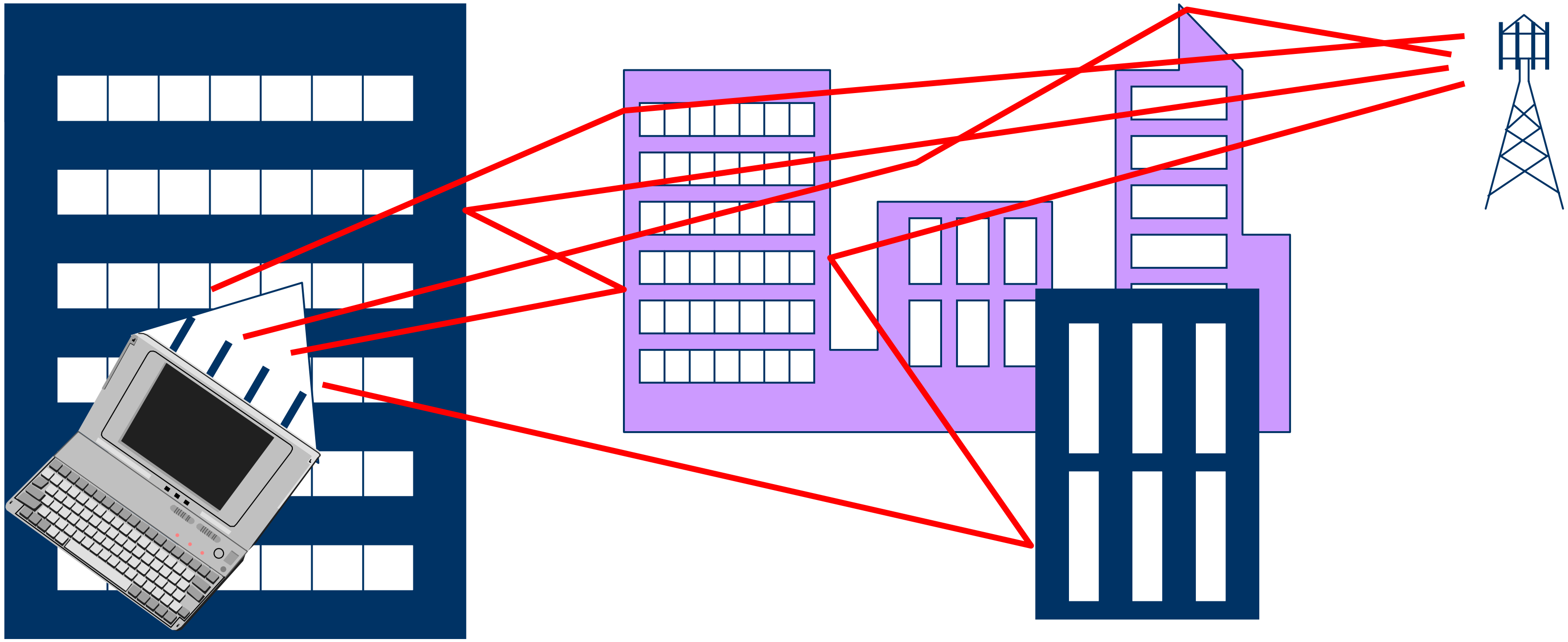
Adaptive arrays in any environment provide:

- 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)

Implementation: Analog (RF) or Digital

Analog Advantages:

- Digital requires M complete RF chains, including M A/D and D/A's, versus 1 A/D and D/A for analog, plus substantial digital signal processing
- The cost is much lower than digital
- An appliqué approach is possible - digital requires a complete baseband

Digital Advantages:

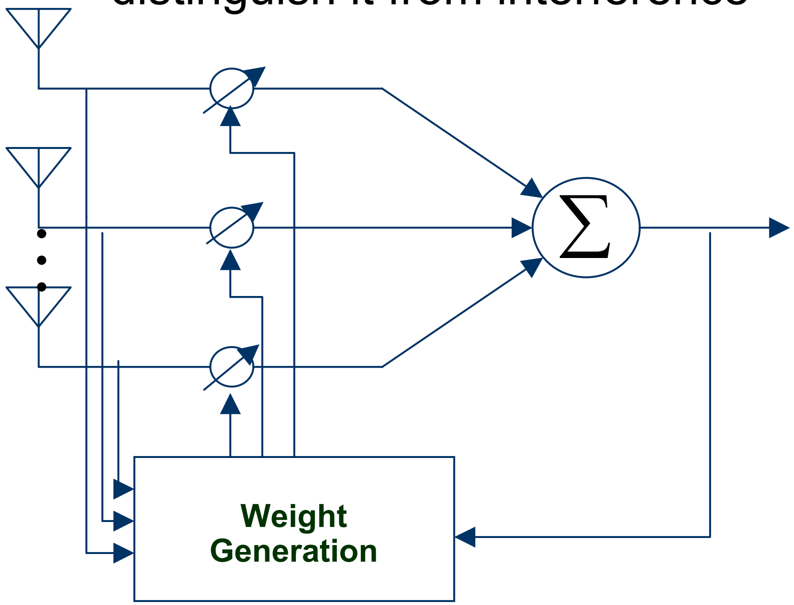
- Slightly higher gain in Rayleigh fading (as more accurate weights can be generated)
- Temporal processing can be added to each antenna branch much easier than with analog, for higher gain with delay spread
- Modification for MIMO (802.11n) possible

=> Use RF combining where possible, minimizing digital combining (limit to number of spatial streams)

IMPLEMENTATION:

WEIGHT GENERATION TECHNIQUES

For Smart Antenna: Need to identify desired signal and distinguish it from interference



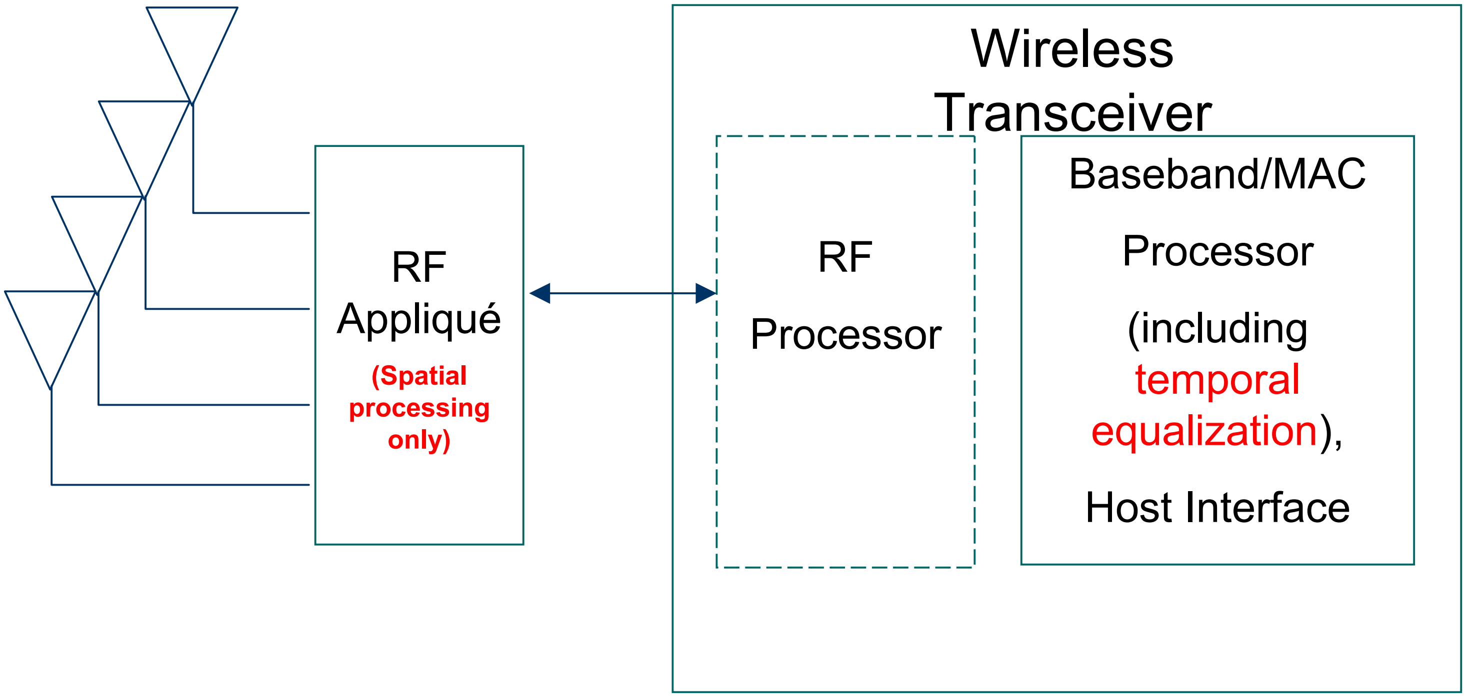
Blind (no demod): MRC – Maximize output power
Interference suppression – CMA, power inversion, power out-of-band

Non-Blind (demod): Training sequence/decision directed reference signal
MIMO needs non-blind, with additional sequences

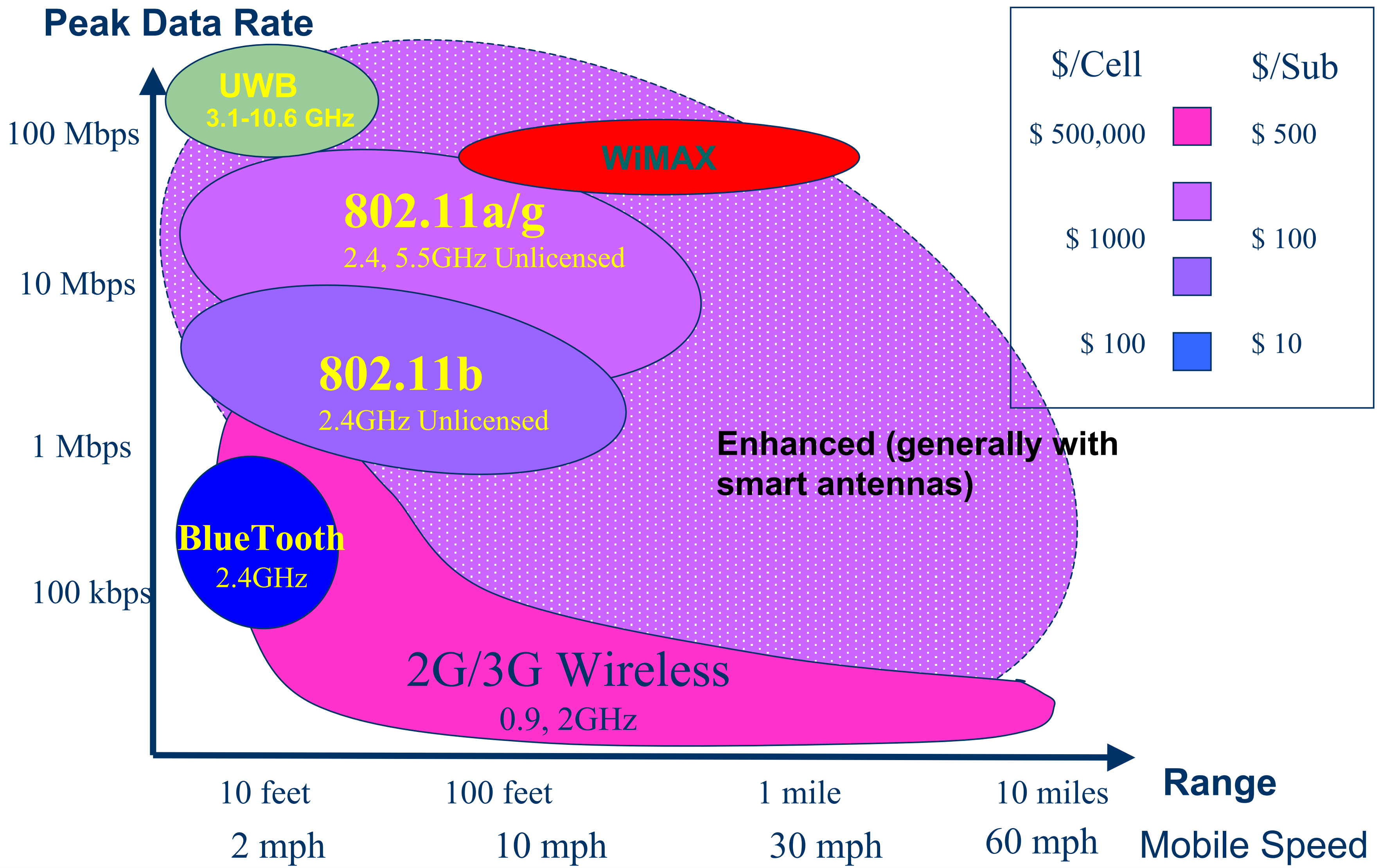
IMPLEMENTATION EXAMPLE:

Blind Beamforming Appliqué

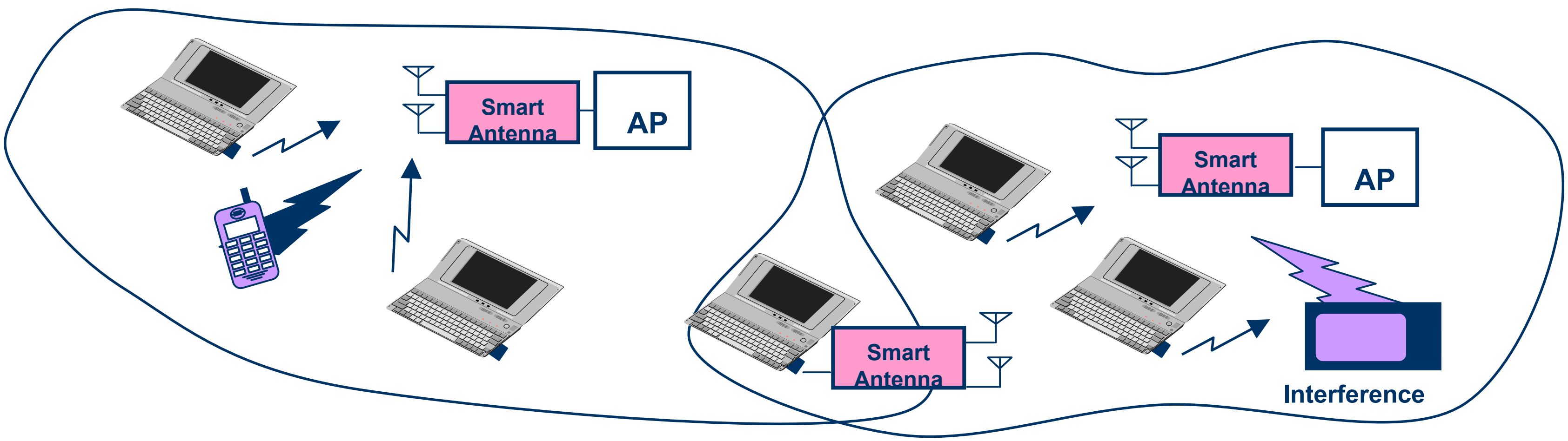
- Cellular
- WLANs – 802.11a/b/g/n (commercially-available)
- WiMAX – 802.16



Wireless System Enhancements



Smart Antennas for WLANs



Smart Antennas can significantly improve the performance of WLANs

- TDD operation (only need smart antenna at access point or terminal for performance improvement in both directions)
- Higher antenna gain ⇒ Extend range/ Increase data rate/ Extend battery life
- Multipath diversity gain ⇒ Improve reliability
- Interference suppression ⇒ Improve system capacity and throughput
  - Supports aggressive frequency re-use for higher spectrum efficiency, robustness in the ISM band (microwave ovens, outdoor lights)
- Data rate increase ⇒ M-fold increase in data rate with M Tx and M Rx antennas (MIMO 802.11n)

802.11 Gains with Smart Antennas

- **802.11b/g Beamforming Gains with 4 Antennas:**

Performance Gain over a Single Antenna in a Rayleigh Fading Channel

Adaptive One Side	Adaptive Both Sides
13 dB	18 dB

2X to 3X Range + Uniform Coverage

3X to 4X Range + Uniform Coverage

- **802.11n with 4 antennas: Data rates up to 500 Mbps**

WiMax Smart Antennas

- WiMax operates in unlicensed and licensed bands (more power in licensed bands for up to 70 Mbps over 30 miles)
- WiMax operates with different bandwidths (1.75/3.5/7/14 MHz)

- Smart antennas have been included in IEEE802.16 standards:
  - **Add at client to provide improvements (in both directions with TDD):**
    - **>10 dB increase in SNR (with four antennas)**
      - **Compensates for building penetration loss**
      - **Permits use in buildings (on clients – no truck rolls)**
    - **Increased interference robustness**
    - **Improved QoS**
  - **MIMO techniques for higher capacity, as well as interference suppression**

Cellular Smart Antennas

- 4 antennas provide >6 dB gain on receive
- Transmit weights different:
  - GSM – use receive weights averaged over fading (array gain only)
  - CDMA – use power control bits
  - DVB-H – not an issue as downlink only
- HSDPA/HSUPA, with MIMO proposed in 3GPP

Multiplatform Devices with Smart Antennas

- Smart antennas provide a wide assortment of benefits including:
  - increased range
  - more uniform coverage
  - higher data rates
  - multipath mitigation
  - interference robustness.
- However, these advantages are achieved at the increased cost and complexity of the multiple antennas and RF chains, as well as increased signal processing.
- If multiplatform devices are to get the full benefit of each system, then smart antennas must be incorporated into each of these systems, but in a cost/complexity/power efficient manner.

Multiplatform Devices with Smart Antennas

- Most systems consider only 2 antennas on devices (4 antennas on devices considered by 2010) because of costly A/Ds.

Multiplatform Devices with Smart Antennas

Solution:

Use the same front-end (including antennas) for all systems:

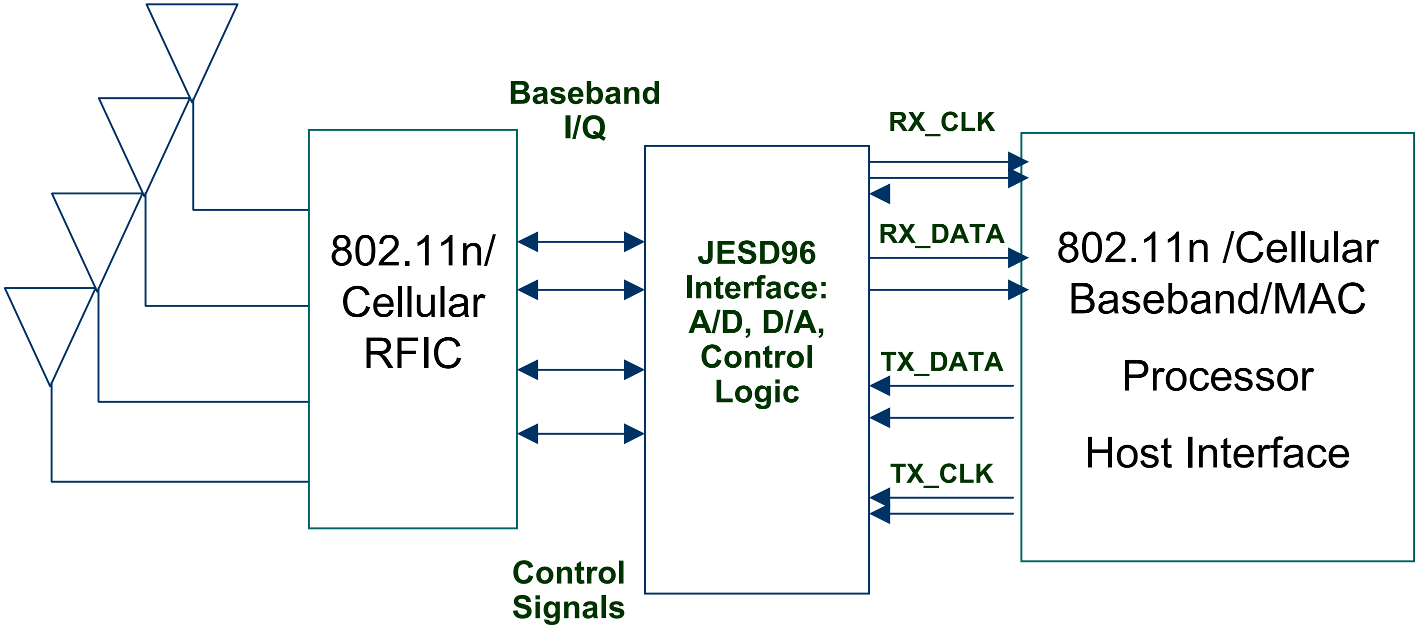
- **RF combining where possible, minimizing digital combining, i.e., A/Ds (limit to number of spatial streams)**
- **Provide standard, modular interface to baseband/MAC for each system**
  - $\Rightarrow$ **Can add more platforms at minimal cost**
  - $\Rightarrow$ **Can add more antennas to each system at minimal cost**

Standard BB/MAC Interface

JEDEC Standard JESD96 (from JC-61 subcommittee):

- **Flexible interface usable for multiple standards**
- **Low power duty cycle data and clock sub-modes**
- **Low analog complexity**
- **Low latency data transfer configurable down to 20 ns**
- **Raw link bandwidth of up to 2.3 Gbps depending on clocking speed**
- **Supports 0-50 cm line lengths**

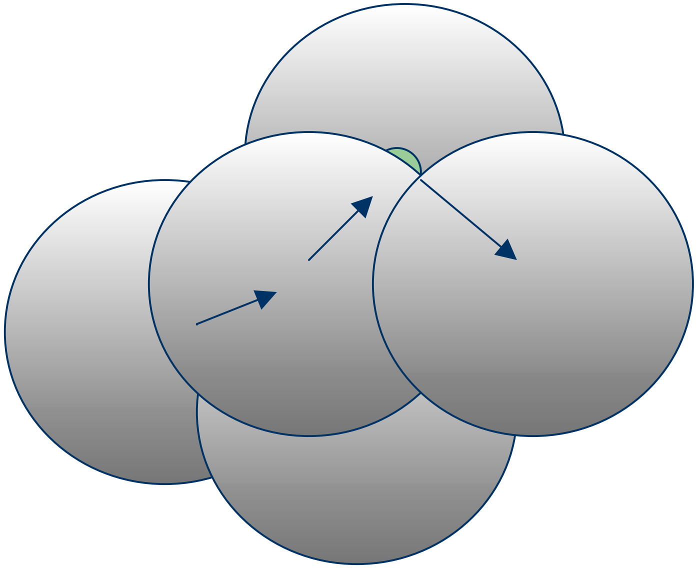
Example: 802.11n/Cellular RFIC with JESD96 Interface



Smart Antennas and Ad Hoc Networks

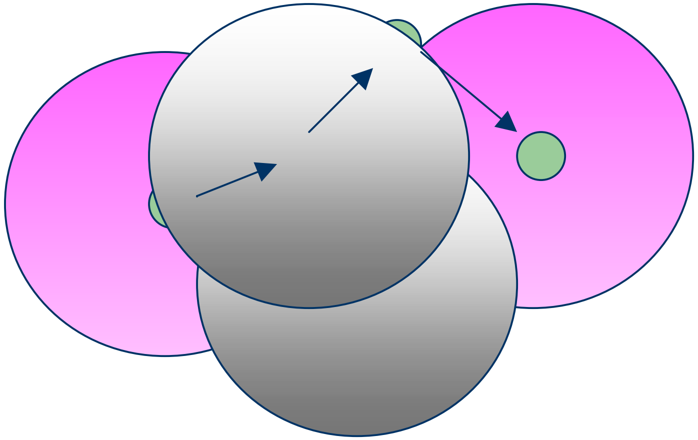
Mobile Ad Hoc Networks

- **Network of wireless hosts which may be mobile**
- **No pre-existing infrastructure**
- **Multiple hops for routing**
- **Neighbors and routing changes with time (mobility, environment)**



Advantages

- Less transmit power needed (longer battery life)
- Easy/fast to deploy
- Infrastructure is not important
- Possible reuse of frequency for higher capacity
- Applications:
  - Home networking
  - Military/emergency environments
  - Meetings/conventions



Impact of Smart Antennas

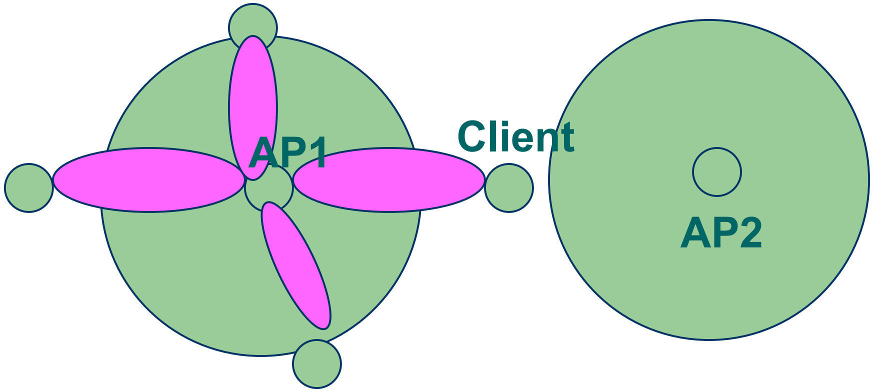
- Most systems today use omni-directional antennas
  - Since this reserves the spectrum over a large area, network capacity is wasted
- Consider smart antenna advantages:
  - Directional antennas (multi-beam and scanning beam)
    - Main emphasis of literature
    - Considered easier/less costly to implement
    - Easier to study/analyze
  - Adaptive arrays

Impact of Smart Antennas

- **Since smart antennas are a physical layer technique, existing approaches for MAC/routing in ad hoc networks will work with smart antennas, but these MAC/routing techniques need to be modified to achieve the full benefit (e.g., the 802.11 MAC has inefficiencies with directional antennas)**
- **Need to add provision to obtain performance data based on smart antenna for coordination:**
  - **Whether or not other access point has smart antenna is information that needs to be exchanged**
  - **The type of smart antenna (switched beam, adaptive array), number of beams/antennas, and type of combining (MRC, MMSE) need to be exchanged**

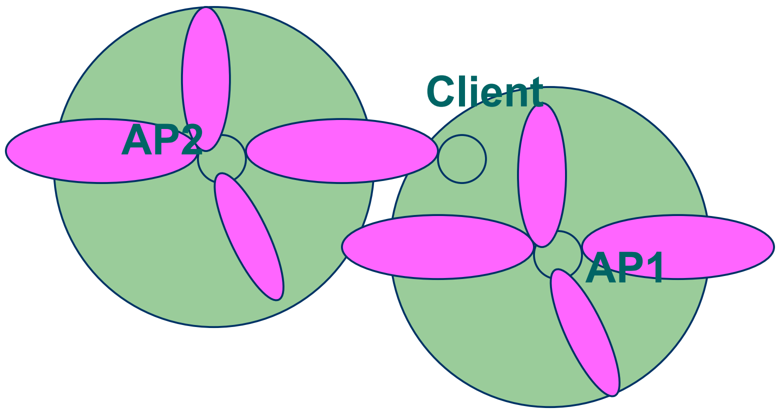
Issues for Smart Antennas

- **Association problems with mixed mode Access Points**



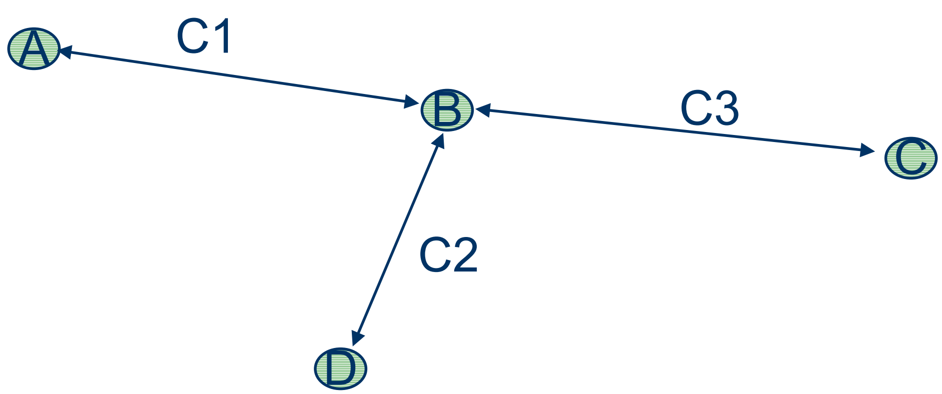
Issues for Smart Antennas

- **Association issue:**
  - **If beacon (for association) from base station is omnidirectional, but adaptive array used by base station for traffic, then may associate with wrong base station**



Example of Degradation Due to Smart Antenna

2.4 GHz ISM band with 3 channels



- **Without smart antenna:**
    - **AB, BD, and BC can communicate using different channels (up to 54 Mbps per link)**
- **With smart antenna using spatial multiplexing (802.11n):**
    - **If AB uses spatial multiplexing (to double its data rate) adjacent channel interference tolerance can be much lower, such that BC and BD cannot use adjacent channel, resulting in substantial loss in overall system capacity**

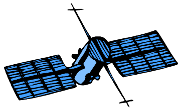
Summary

- Both smart antennas and ad hoc networks can provide increased capabilities/performance to wireless networks (range, robustness, battery life, capacity)
- Combination of smart antennas and ad hoc networks can provide gains that are greater than the sum of the gains, but only if used properly
- Further research is needed (with standards development), but the potential is substantial

RFID – Adaptive Arrays for Readers and Tags

- Active and passive tags
- Read ranges with omni-directional antennas:
    - Active tags (433 MHz) - 300 feet
    - Passive tags (900 MHz) - 9 feet
- Reader can use scanning beam to transmit, adaptive array to receive
- Tag can use adaptive array to receive, then use same weights to transmit

Read Ranges with Adaptive Array Readers and Active RFID Tags (DoD)



@433 MHz, power at 5 miles to activate beacon with a 3 m aperture antenna (14 dB) = 0.185 W

@433 MHz, power at 100 miles to activate beacon with a 3 m aperture antenna (14 dB) = 75 W

5 year battery life at 2 reads/day or 3,650 reads total

@433 MHz, receive antenna gain at 5 miles = 39 dB or 18 m aperture to continuously read beacon

Adaptive Arrays for RFID Tags

- Tags can be very small devices (single chip), making multiple antenna placement an issue
  - At 900 MHz, half-wavelength spacing is 6 inches.

- Solution: Carbon nanotube antennas
  - Wave velocity is 1% of free space

  $\Rightarrow$ 1.7 mm half-wavelength spacing

  $\Rightarrow$ 10,000 antennas in same area as standard antenna (antenna efficiency is an issue, though)

Conclusions

- Ubiquitous wireless access requires heterogeneous networks with multiplatform devices using adaptive arrays.
- The substantial gains of smart antennas can be provided to multiplatform devices through the use of a universal smart antenna front-end.
- Optimization of adaptive array technology jointly with these networks is required to achieve the full benefits of adaptive arrays.