Intelligent Antennas and Blast for cdma2000 Networks

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The Need For Intelligent Antennas

- **Despite improvements in 3G systems over 2G, there is a predicted need for more capacity than will be supported by conventional antenna and processing configurations.**
- **Cell capacity is directly related to receive channel quality and interference level (both at the base station and the mobile).**
- **Intelligent Antenna (IA) technology provides a means to use *multiple antennas* and *extensive signal processing* to achieve significant improvements in channel performance and interference reduction**
  - ***The result is increased capacity***
  - ***Lucent's approach is based on a combination of architecture/cost balances and performance tradeoffs***

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Lucent Intelligent Antenna Strategy

- **Architecture and cost**
  - **Lucent solution is *integrated* into the basestation (not an applique)**
  - **All *IA signal processing* done at baseband in *channel-element ASIC*. No adjunct processing required.**
- **Performance**
  - **Premise: Maintain diversity antennas as integral part of solution**
  - **Benefits**
    - Capitalize on large dB gains worst-case channel environments (single-path flat-fading at low mobile speeds)
    - Facilitates migration of hardware from ***1 -> 2 -> 4*** transmit paths per sector while giving performance gains and incremental costs.
    - Provides ***balanced gains*** in the forward and reverse links.
    - Supports migration to future methods of providing very high speed packet data using ***MIMO / BLAST*** processing

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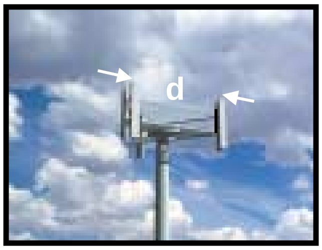
Antenna configurations



Choice of *antenna configuration* determines signal processing techniques available to combat fading effects and reduce interference.

<u>Technology</u>

Diversity: d > wavelength	**Diversity** **(Rx: MRC , MMSE, etc** **Tx: STTD, CLTD)**	**BLAST**
Phased Array: d < wavelength	**Switched beams**	**Steered beams**

Increasing capacity

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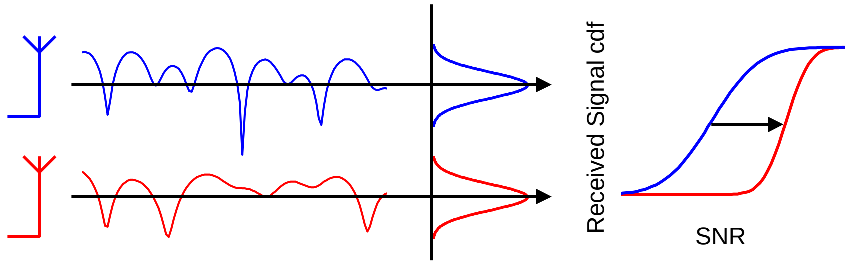
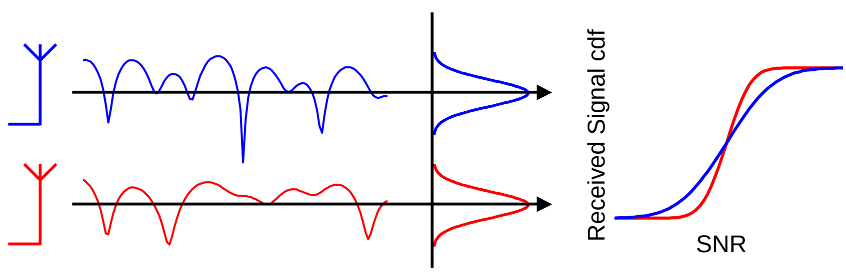
Receive Diversity



- Going from 1 to 2 receive antennas, the receive power is doubled. This produces a *3 dB aperture gain* regardless of the element spacing.
- From 1 to 2 antennas, *add diversity gain (depends on environment and element spacing) ~0 to 6 dB.*
- From 2 to 4 antennas, *additional 3 dB of aperture gain (assuming perfect combining) plus ~0 to 2 dB diversity gain.*

Transmit Diversity



- Because transmit power is split between antennas the average signal strength does not improve (no antenna gain). However, the variance of the signal is reduced.
- From 1 to 2 antennas *diversity gain of ~ 0 to 6 dB (depends on environment)*
- From 2 to 4 antennas *diversity gain of ~ 0 to 2 dB (depends on environment)*
- Closely spaced antennas could form beams providing up to 3 dB of antenna gain *The channel determines whether a narrow beam or diversity would produce a better link.*

Transmit Diversity Methods

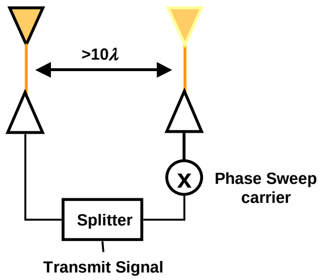
- Need method to resolve two independent transmitted signals leads to these possible solutions.

- **IS-95A/B:**
  - *Phase-Sweep Transmit Diversity (PSTD)* – no standards modification required. Works with existing terminals.
  - Sweeps second antenna with random phase information.

- **3G1X:**
  - Two options defined by standard *(needs to be supported by terminal)*:
    - *Space-Time Spreading (STS)* - Recommended
    - *Orthogonal Transmit Diversity (OTD)*
  - PSTD can be used for early versions of 3G1X terminals that don't have STS or OTD
  - PSTD can be used concurrently with STS/OTD
    - Proprietary implementation minimizes interaction

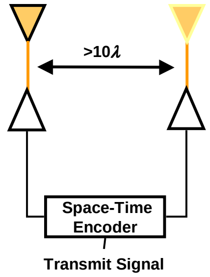
Transmit Diversity Methods

PSTD



- Transmit same signal over two different independent antennas and vary the phase over one of the transmit antennas.
- Equivalently, the link behaves as if the fading rate (but not the fading depth or duration) were increased.
- With this received signal, the decoder recovers the two-path diversity present in the signal and can improve the performance in most scenarios.

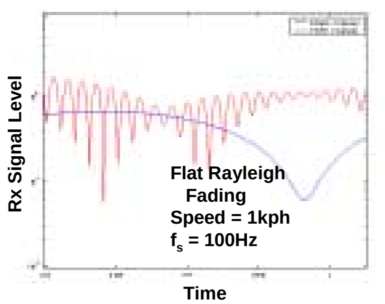
STS



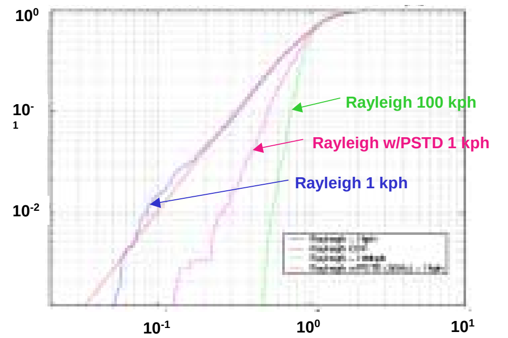
- Transmit two space-time coded versions of the same signal using the same frequency and Walsh code on independent antennas.
- The decoder can separate the interfering signals due to the space-time coding and combine them to achieve diversity

PSTD Fundamentals

Envelope Variation with PSTD



Convolutional Coder performance with PSTD



- Combination of two slowly fading channels coupled with sweeping leads to a single fast fading channel
- Convolutional coder performance is better at high speeds

- Better coder performance is associated with a sharper CDF
- 100 km/hr is better than 1 km/hr
- PSTD makes 1 km/hr performance approximate 100 km/hr performance
- AWGN would be better than all

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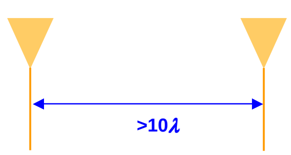
Transmit Diversity and IA Beam Steering Strategy

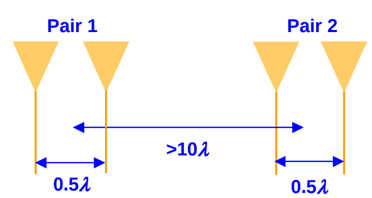
Phase 1

- **Transmit using 2 antennas at the base station**
  - No change to existing (single column) antennas
  - Diversity gain achieved in fading
  - Most effective at low and pedestrian speed



Phase 2

- **Transmit using 2 pairs of antennas at the base station**
  - Install dual-column antennas
  - Diversity gain obtained through wide separation between the pairs (or polarization diversity)
  - Beamforming gain obtained using each pair
  - Beam steering information derived from reverse link signals



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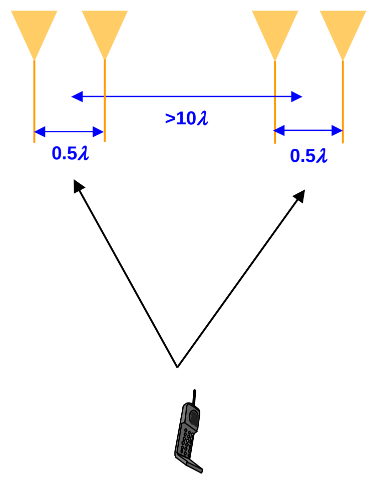
Uplink Approach



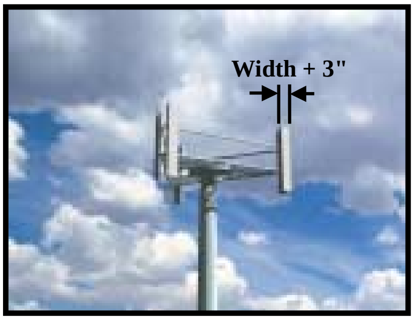
- Spatial filter approach using minimum mean square estimation (MMSE) solution
- Four dimensional covariance matrix is obtained from data from the 4 antennas
- The filter used is an approximation for the well known form:

$$w = (R_{yy}^{-1}\gamma)^{\dagger}y$$

- Further simplification possible using the relationship between the input x and the despread data y.
- Detection fingers assigned and tracked using 4-antenna data to achieve spatial interference reduction.

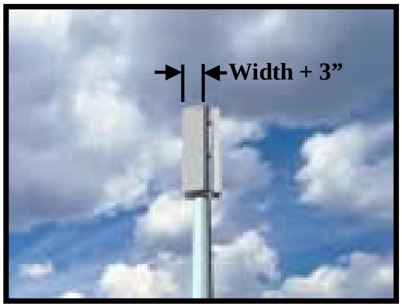
Intelligent Antenna Configurations

Space-Diversity



1.9 GHz 4-Branch Intelligent Antenna
Spatial Diversity Version

Polarization-Diversity



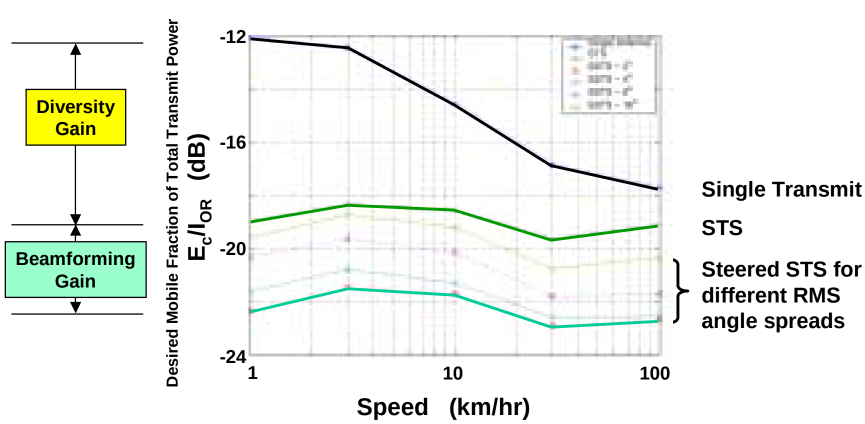
1.9 GHz 4-Branch Intelligent Antenna
Polarization Diversity Version

IA Performance - Link-Level Simulations

- Incorporates all three dimensions:
  - Temporal Fading / Doppler Spread
  - Frequency Fading / Delay Spread
  - Spatial Fading / Angle Spread
- Uses the IMT-2000 model as a foundation
- Is implemented as a collection of individual scattering clusters
- Physically consistent across all three aspects
  - i.e., cannot have arbitrary statistics
- Agrees with known 2-D model for temporal and frequency
- Controlled by a small number of parameter assignments - repeatable!
- Supports both uplink and downlink channel models simultaneously
- Allows both Rayleigh and Ricean fading
- Allows for time evolution (i.e., continuous from frame to frame)
  - Useful in beam steering performance evaluation

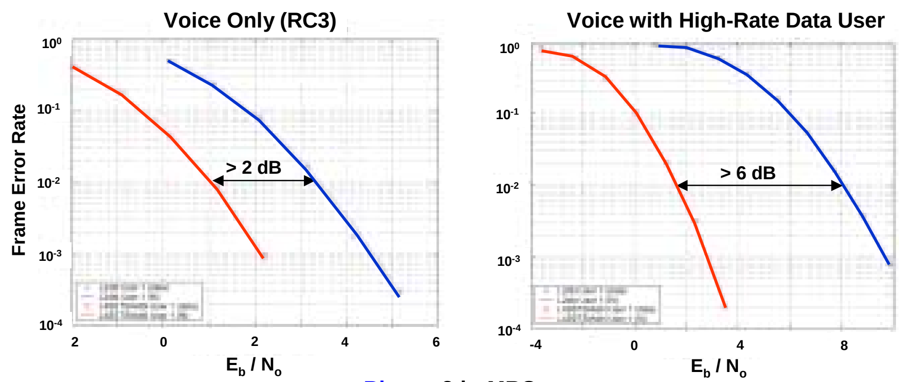
Example IA Forward-Link Performance Gains – Flat Fading

Voice Rate Channel (RC3)



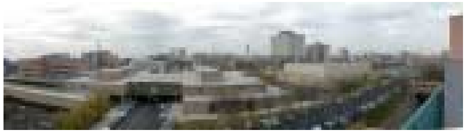
Geometry:
I_{OR} / I_{OC} = 6 dB

Example IA Reverse-Link Performance Gains



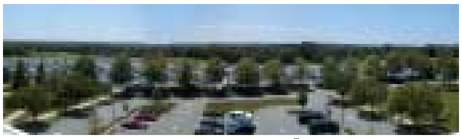
Blue: 2-br MRC
Red: 4-br Adaptive

IA Beamsteering Performance - Experimental Measurement



Urban (Newark, NJ)

- **Urban Results**
  - **>2.3 dB in 90% of locations**
  - **average = 2.50 dB, standard deviation = 0.25 dB.**



Suburban (Whippany, NJ)

- **Suburban Results**
  - **>2.6 dB in 90% of locations**
  - **average = 2.83, standard deviation = 0.17 dB.**

System Capacity Calculations – Channel Parameters

- **Voice**
- 25% AWGN
- 5% 1-path Rayleigh
- 70% 2-path Rayleigh
  - (0dB, - 3dB)

- **Data**
- 25% AWGN
- 25% 1-path Rayleigh
- 50% 2-path Rayleigh
  - (0dB, - 3dB)

	Rural	Suburban	Urban
3km/h	30%	50%	70%
30km/h	40%	30%	30%
100km/h	30%	20%	0%

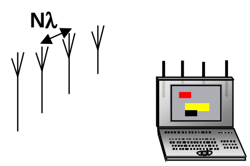
Intelligent Antenna Capacity and Coverage Gains

(Gains relative to system with 1 Tx, 2 Rx)

	Coverage	Capacity/Data Rate
Baseline (1 Tx, 2 Rx)	**1.0x**	**1.0x**
Capacity Increase:		
Tx Diversity (2 Tx, 2 Rx)	**1.0x**	**~1.2x (Ave.)**
IA (4 Tx, 4 Rx)	**1.0x**	**~1.8 to 2.0x (Ave.)** Up to 6x under flat faded, narrow angle spread
Coverage and Capacity Increase		
IA (4 Tx, 4 Rx, w/o TTLNA)	**~1.5x** (30% fewer cell sites)	**~1.4x (Ave.)**
IA (4 Tx, 4 Rx, w/ TTLNA)	**~1.7x** (40% fewer cell sites)	**~1.7x (Ave.)**

Phase 3: MIMO / BLAST

Receive: 4-Branch Diversity
Transmit: 4-Branch Diversity

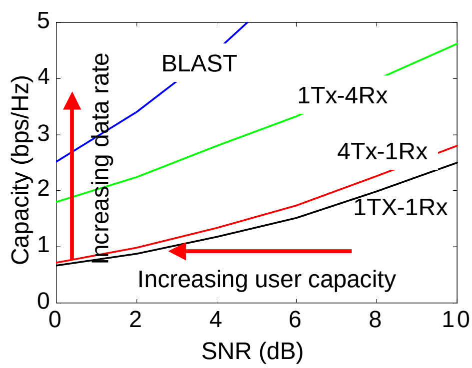


- Antenna elements are configured for four-branch diversity.
- Data is de-multiplexed so that different data streams appear at each antenna.
- Spatial characteristics of the radio link act as additional CDMA codes. This results in a higher data rate.

- Hardware:
  - Basestation Antennas: Maintain the same appearance as the conventional antenna configuration (i.e. each radome contains dual-column antenna with minimal width increase).
  - Additional antennas required at the UE.
- Signal Processing:
  - Confined to BTS channel-element ASIC and UE modem ASIC
- Benefits:
  - With the same range extension achieved with intelligent antennas we get a four fold increase in the data throughput.
  - High data rates are achieved without increasing the interference so additional uses can be accommodated.

Configuration performance

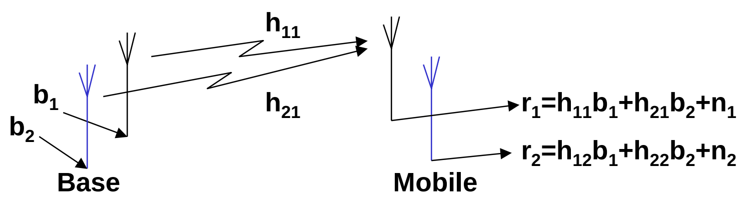
Four transmit antennas at the base, four receive antennas at the mobile



Transmit diversity does not provide as much gain because total transmit power is held constant

The MIMO Concept - Increasing spectral efficiency

multiple antennas at the receiver



If the h_{ij} are independent, then the channel coefficients themselves can provide the data stream labels without using codes or frequencies. We simply solve two equations two unknowns!

In order to decode (separate) the two streams and increase the spectral efficiency, h_{ij} must be known

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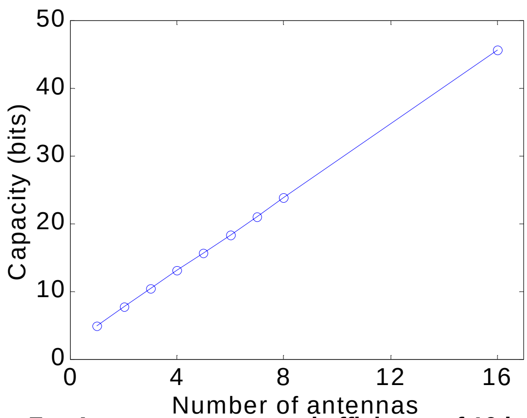
BLAST Capacity



$C/W=\log_2(\det(I+\rho H^H H))$
$\sim N*\log_2(1+SNR)$

Capacity grows as the number of antennas!

- **For 4 antennas a spectral efficiency of 10 bps can be achieved at a reasonable EbNo of 10 dB. As a comparison this would require an EbNo of 50 dB for mpsk!**
- **Requires accurate channel estimation.**
- **Requires at least as many antennas at the mobile than at the base.**

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Peak Rates in High Speed Packet Channel

Ant	Tx technique	Code rate	Mod.	Data rate
(1,x)	Conventional	½	QPSK	2.4 Mbps
(1,x)	Conventional	¾	QPSK	3.6 Mbps
(1,x)	Conventional	½	16 QAM	4.8 Mbps
(1,x)	Conventional	¾	16 QAM	7.2 Mbps
(2,y)	MIMO	¾	8 PSK	10.8 Mbps
(4,4)	MIMO	½	QPSK	10.8 Mbps
(4,4)	MIMO	½	16 QAM	21.6 Mbps

x = 1,2, or 4 receive antennas
y = 2 or 4 receive antennas

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Summary of Intelligent Antenna Approach

- Uses "hybrid" antenna configuration
  - Supports a mixture of diversity and beamforming techniques
- Forward (Transmit) Link
  - Employs transmit diversity for all mobiles
    - Uses STS or OTD coding techniques defined in the standards for mobiles supporting these
    - Uses PSTD for others (including 2G)
  - Employs a combination of per-user beamforming with transmit diversity in full antenna configuration
- Reverse (Receive) Link
  - MMSE adaptive combining provides significant gains for all mobiles and minimizes impact of high data rate mobiles on other mobiles
- Mixture of diversity and beamforming provides significant gains over a wide variety of channel conditions ("robust")
- Large link-level gains support an approximate doubling of capacity when averaged over a variety of channel conditions and mobile speeds
- MIMO/BLAST processing provides a unique way to increase spectral efficiency by taking advantage of vector processing. This vector can originate from a variety of antenna configurations including diversity and polarization.

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