Azimuth®
Wireless Test & Channel Emulation Experts

The Road to Mobile Broadband from a Test Perspective

Graham Celine
Azimuth Systems
Sept '09

What We Will Discuss

- The Trend to MIMO
  - *The migration to OFDM / MIMO, and why*
  - *What does MIMO provide that is better for 4G wireless?*
- Why is MIMO test different to SISO test
  - *The difference between MIMO and SISO and how the effect of channel is critical to the operation of 4G*
- What is Channel Emulation
- The Role of Channel Emulation in Testing MIMO
  - *Requirements for 4G channel emulation*
  - *Emulation capabilities needed to test 4G*

Azimuth at a Glance

- Privately held company, founded in 2002
  - Headquarters in Acton, MA with offices world wide
- Focus on wireless communications test equipment
  - Test solutions in the Wi-Fi, WiMAX, LTE, 2G/3G, FMC markets
- Industry leading position
  - More than 155 customers worldwide
  - > 90% Market Share in Wi-Fi Engineering Test Equipment
  - > 85% Market Share in MIMO channel emulator market
- Recognized product excellence
  - Unique, patented test architecture and test methodology
  - Multiple industry awards for product leadership and excellence
- Multi-Industry group leadership and participation
  - 3GPP, Wi-Fi Alliance, IEEE, WiMAX Forum, GCF, LSTI, IWPC
- Profitable company delivering record revenue growth

WINNER
CUSTOMER IMPACT CATEGORY
mi TX 2008 WHAT'S NEXT FORUM & TECHNOLOGY AWARDS
IMPACT AWARD

20 BEST IN TEST 05
TEST & MEASUREMENT WORLD AWARD WINNER

2007 FROST & SULLIVAN
North American Wi-Fi Test & Measurement Product Innovation of the Year Award

WIRELESS NET DesignLine 2006

WiFi PLANET Conference & Expo • Fall 2003 BEST OF SHOW

Standards/Industry Forum Activities

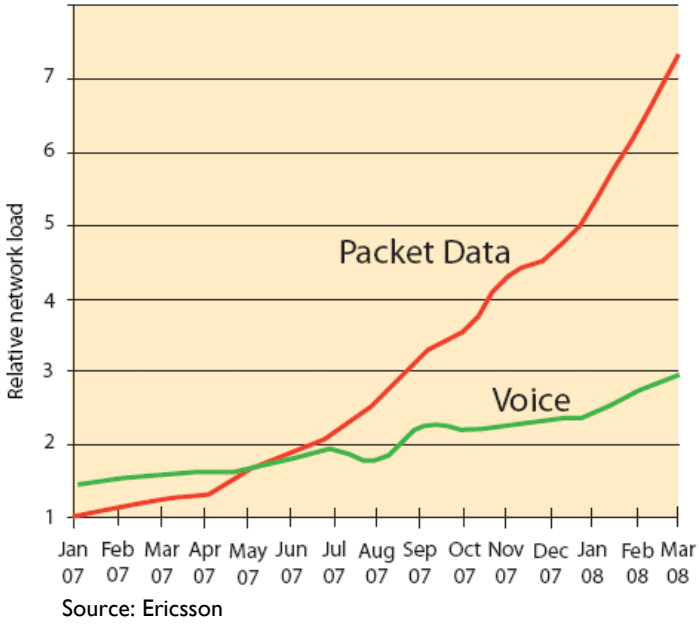
Azimuth®

Wireless Test & Channel Emulation Experts

Wireless Macro Market Overview

DATA, DATA, DATA

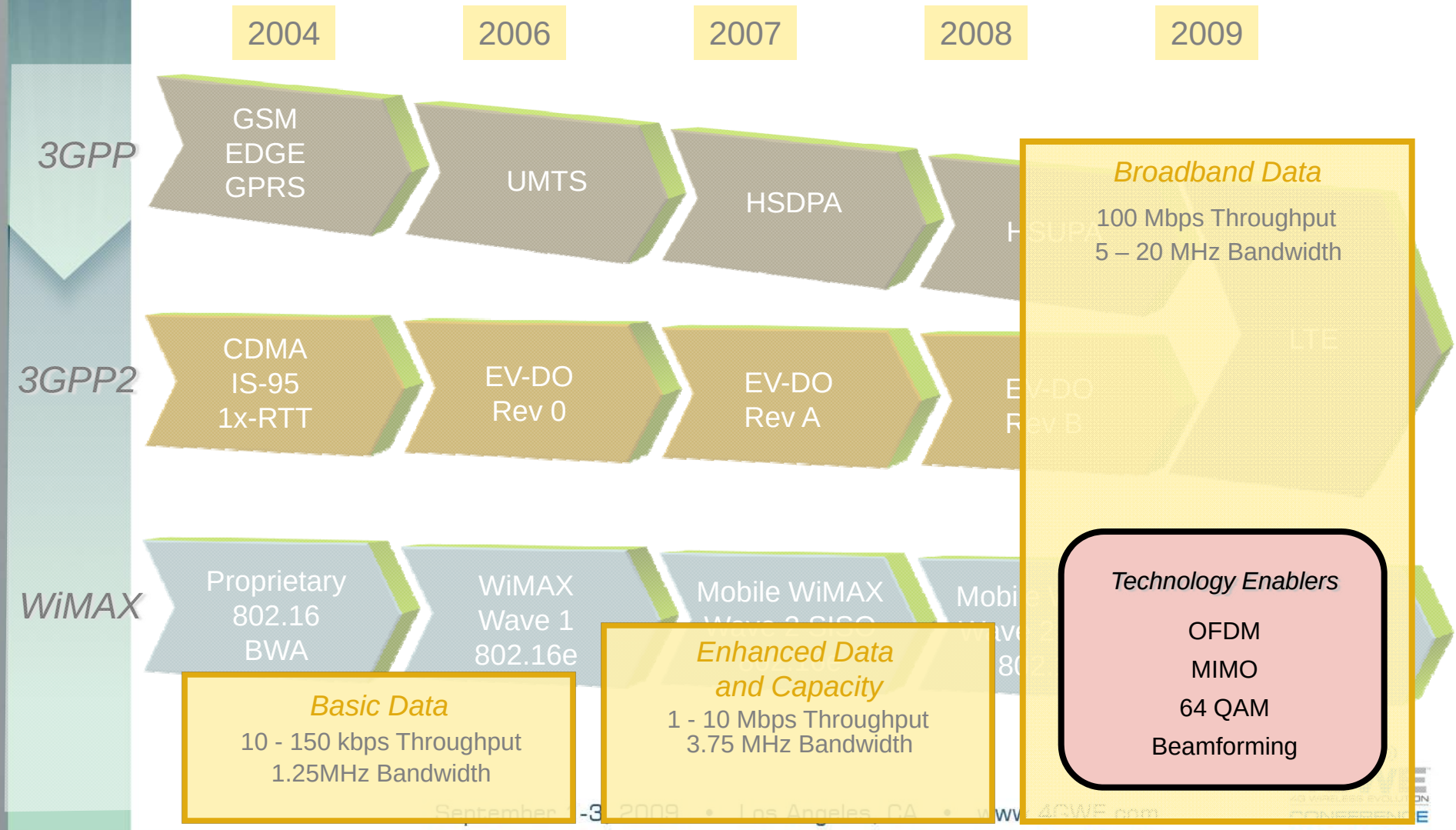
- Wireless data growth being driven by:
  - Flat-rate data tariffs
  - Speeds comparable to fixed broadband
  - Wave of new services (social networking, video)
  - Multi-functional devices (smart phones, data cards)
- More than 320 million wireless users accessing speeds greater than 1 Mbps
- Existing wireless network capacity constrained
  - Requires networks with greater capacity
  - Requires network expansions with lower costs per bit
  - Requires networks with faster connections, lower latencies and video capabilities
  - Requires networks with flat, all-IP architectures



Source: Ericsson

- Driving investment in new technologies/devices/networks/tools to meet these requirements
  - HSPA, HSPA+, WiMAX and LTE
  - Smartphones, Netbooks, Data Devices
  - Associated Test Tools

Radio Access Technology Evolution



Next Generation Mobile Technology Paradigm

- OFDMA and MIMO based technologies are the foundation of next generation mobile broadband technologies
  - WiMAX (802.16e, 802.16m), LTE, 3GPP2
- OFDMA allows for scalability, spectral efficiency and dynamic user bandwidth allocation
- MIMO-enabled products deliver greater wireless throughput and range using multiple antennas
    - Spatial multiplexing
    - Adaptive antenna processing
    - Beam forming

- *Multi-antenna systems **require** realistic propagation conditions to accurately characterize and validate these technologies and systems*
- *Laboratory-based, controlled **channel emulation** is required for controlled, repeatable, reliable testing*

Azimuth®

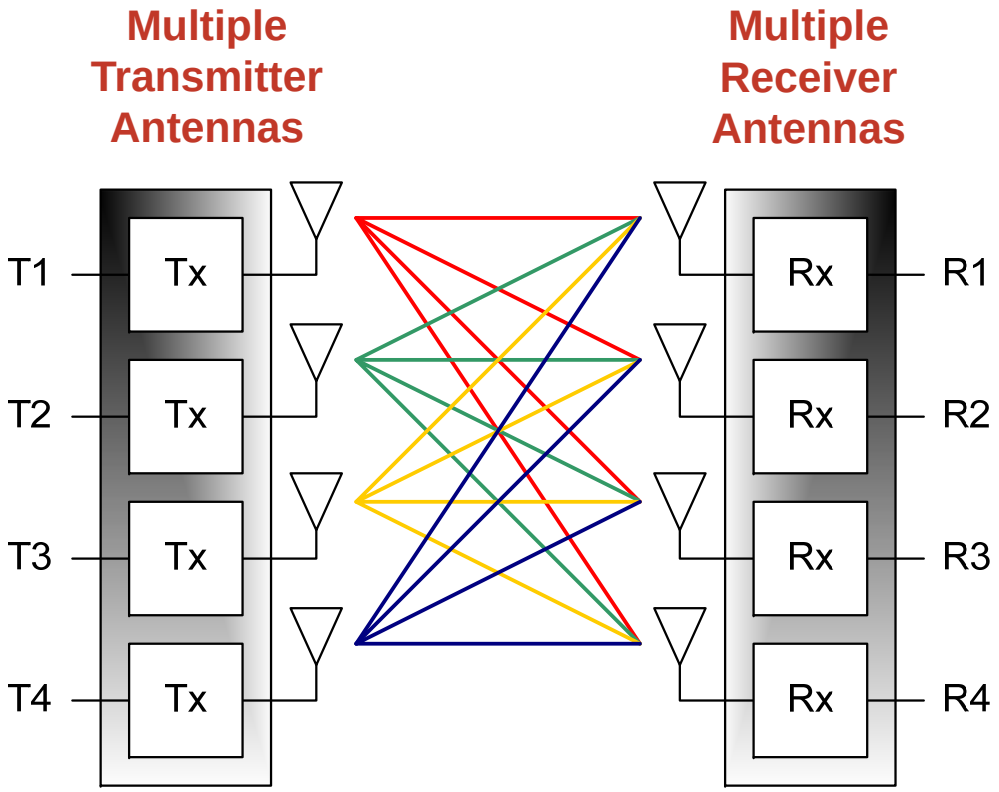
Wireless Test & Channel Emulation Experts

MIMO Technology Review

Why MIMO?

(Multiple Input Multiple Output)

- Greater Capacity
  - Spatial multiplexing
  - Scales as min (N_{Tx}, N_{Rx}) antennas
- Greater Reliability
  - Diversity transmission and reception and/or beamforming make possible increased range for better cell-edge coverage

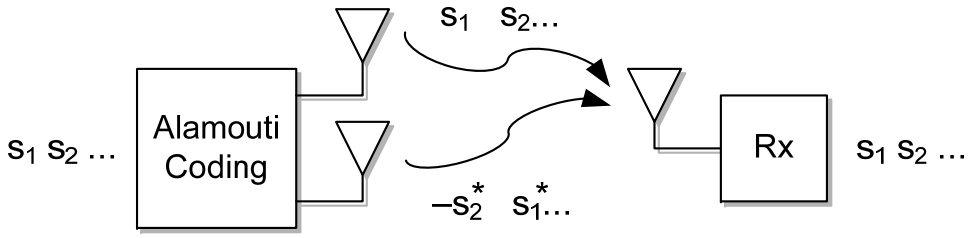


4x4 MIMO Configuration
16 Propagation Paths
Up to 4x Capacity of SISO

MIMO Space Time Coding and Maximal Ratio Combining Combats Fading, Increases Coverage

- Space Time/Freq Block Coding (STBC, SFBC) transmits multiple coded copies of the same data mitigate against fading

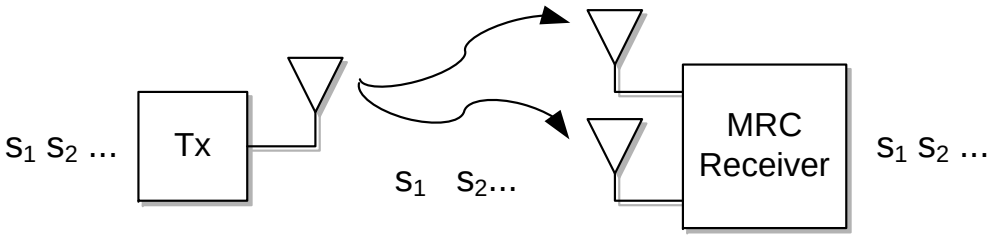
2 x 1 MISO STBC



Improves resistance to fading

- Maximal Ratio Combining (MRC) receives multiple versions of the signal processes it to improve operation in fading channels

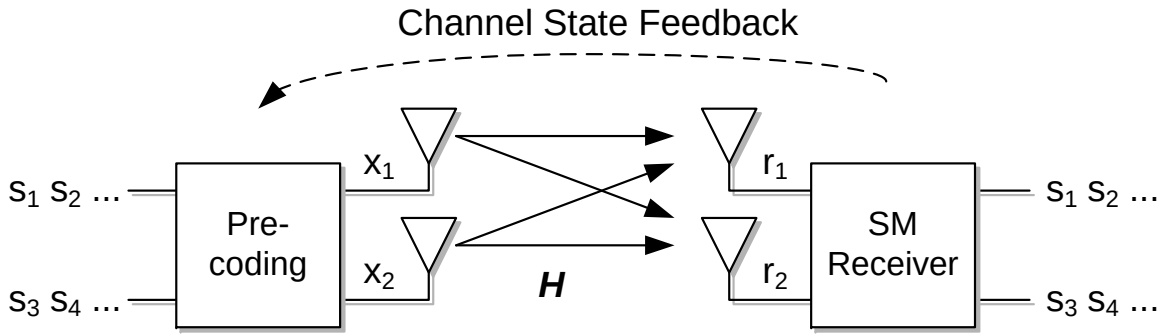
1 x 2 SIMO MRC



Fading resistance + array gain

MIMO Spatial Multiplexing Improves Throughput

- Spatial Multiplexing sends different data on each transmitter to increase the overall system capacity
  - Data is sent on the **same frequency** and at the **same time**
  - Requires high SNR



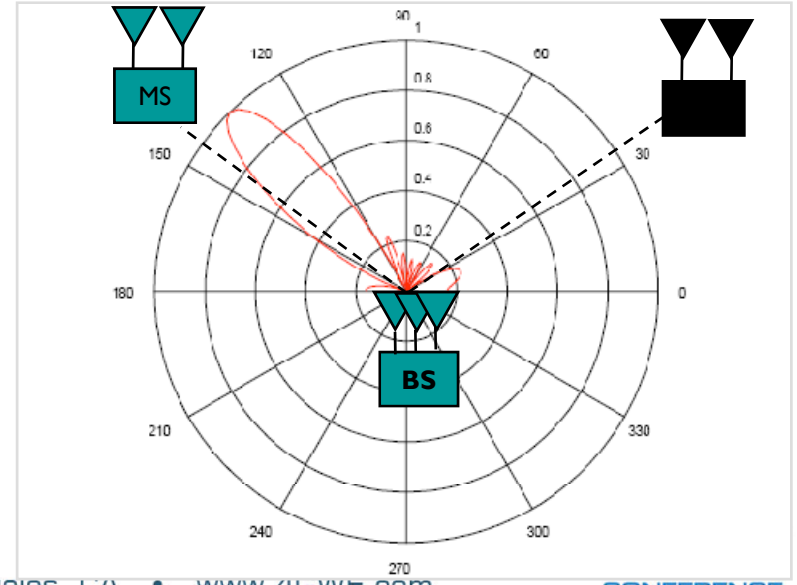
$r_1 = h_{11}*x_1 + h_{12}*x_2$

$r_2 = h_{21}*x_1 + h_{22}*x_2$

- Spatial Multiplexing performance depends on properties of channel matrix ***H***
  - Some techniques feed back information from receiver for better performance

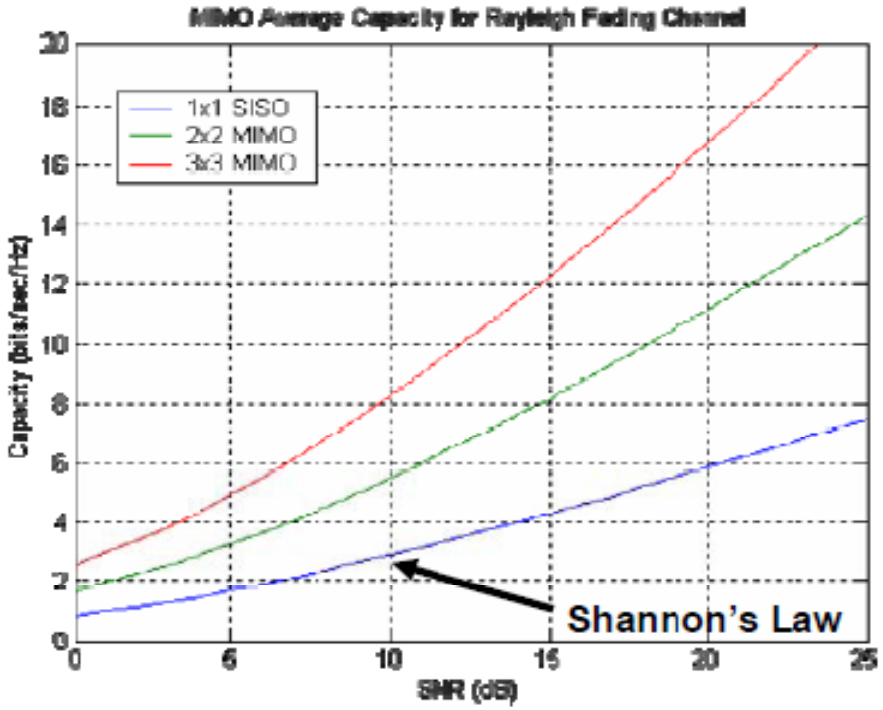
MIMO Beam Forming Improves System Range

- Uses multiple antennas to steer signal power to intended target
- Used for cancelling interference
  - *M* Tx antennas; can cancel *M* – 1 interferers
- Active beam-steering algorithms derive steering parameters from the return link signal
  - Examples 802.11n implicit beamforming
  - TDD: Reciprocal, balanced
  - WiMAX
- Beam forming tests require a bi-directional channel



Why Bother With All This?

MIMO Offers a 2X – 3X and Higher Improvement in Capacity



MIMO Systems and Channel Emulation

MIMO Technique	Benefits	Best When:
Spatial Multiplexing	Increases throughput	Near to the base station (strong signal), best performance at low velocity
Transmit Diversity	Usually at Base Station: Increases range by countering fading (less errors)	Good when beam forming is not appropriate
Receive Diversity	At Mobile Station: Increases Range by countering fading	Advantage over single antenna – under all conditions
Beamforming	Base Station: Increases range	Works best when distance is great (cell edge) and relatively low velocity

- MIMO implementations and techniques vary
- All techniques must operate in real MIMO channels
- Thorough testing requires channel emulation

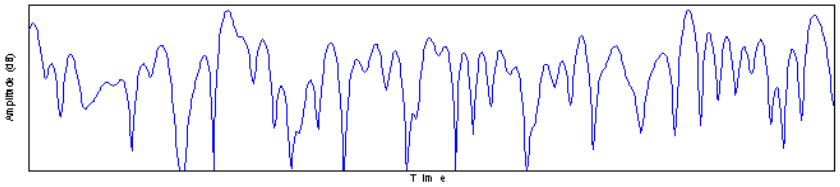
Azimuth®

Wireless Test & Channel Emulation Experts

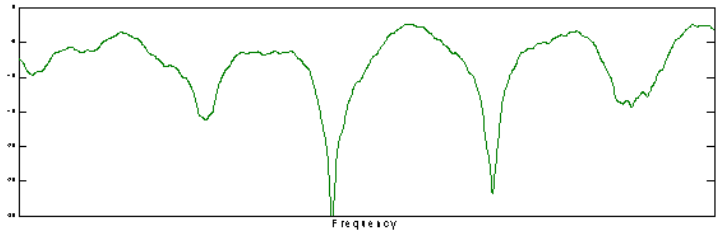
What is the Role of a Channel Emulator

Properties of Radio Channels

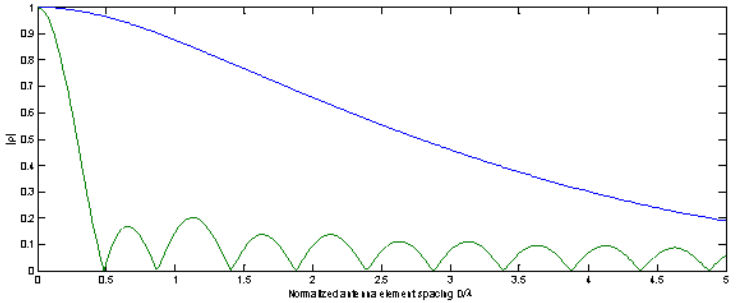
- Fading – time variation of signal
  - Rayleigh fading, shadow fading
  - Rate of variations related to motion in environment



- Multipath – frequency variations
  - Described by Power/Delay Profile, which determines frequency properties
  - RMS delay spread, maximum excess delay



- MIMO – spatial variations
  - Described by angular (AoA, AoD, angular spread…) and antenna array parameters
  - Modeled using ***spatially-correlated fading*** on each MIMO path

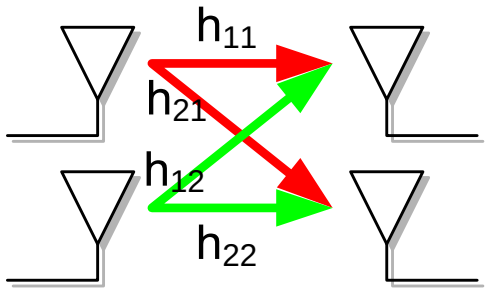


- **It's the MIMO properties that make broadband wireless work and channel emulation allows us to test these conditions**

The MIMO Channel Matrix: H

- The general case:

$$\mathbf{H}(\tau_k, t) = \begin{bmatrix} h_{1,1}(\tau_k, t) & h_{1,2}(\tau_k, t) & \cdots & h_{1,Nt}(\tau_k, t) \\ h_{2,1}(\tau_k, t) & h_{2,2}(\tau_k, t) & \cdots & h_{2,Nt}(\tau_k, t) \\ \vdots & \vdots & \ddots & \vdots \\ h_{Nr,1}(\tau_k, t) & h_{Nr,2}(\tau_k, t) & \cdots & h_{Nr,Nt}(\tau_k, t) \end{bmatrix}$$



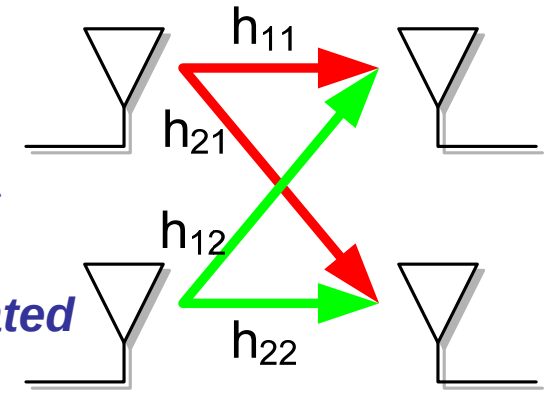
- Each element represents the time-varying fading at a specific excess delay, τ_k
- 802.11n, WiMAX and LTE all use the "non-geometric stochastic" approach to modeling the correlations:

$$\tilde{\mathbf{H}}_k(t) = \mathbf{R}_{Rx}^{1/2} \mathbf{H}_k(t) \mathbf{R}_{Tx}^{1/2}$$

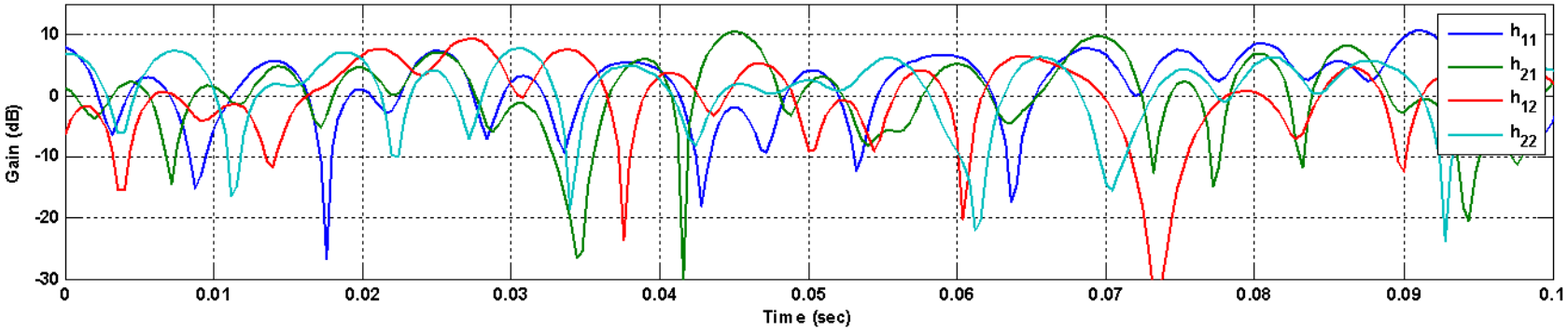
- This is convenient because it separates the effect of the transmitter and receiver arrays

Examples of Fading Correlation

- Example: low correlation



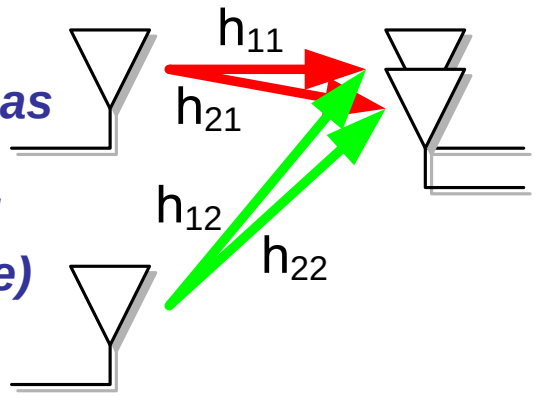
Antennas are uncorrelated

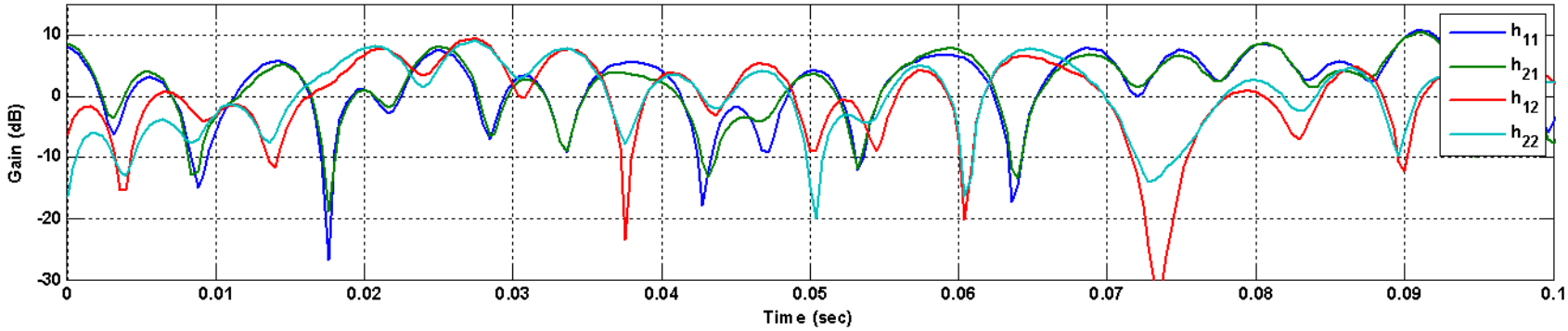


Examples of Fading Correlation

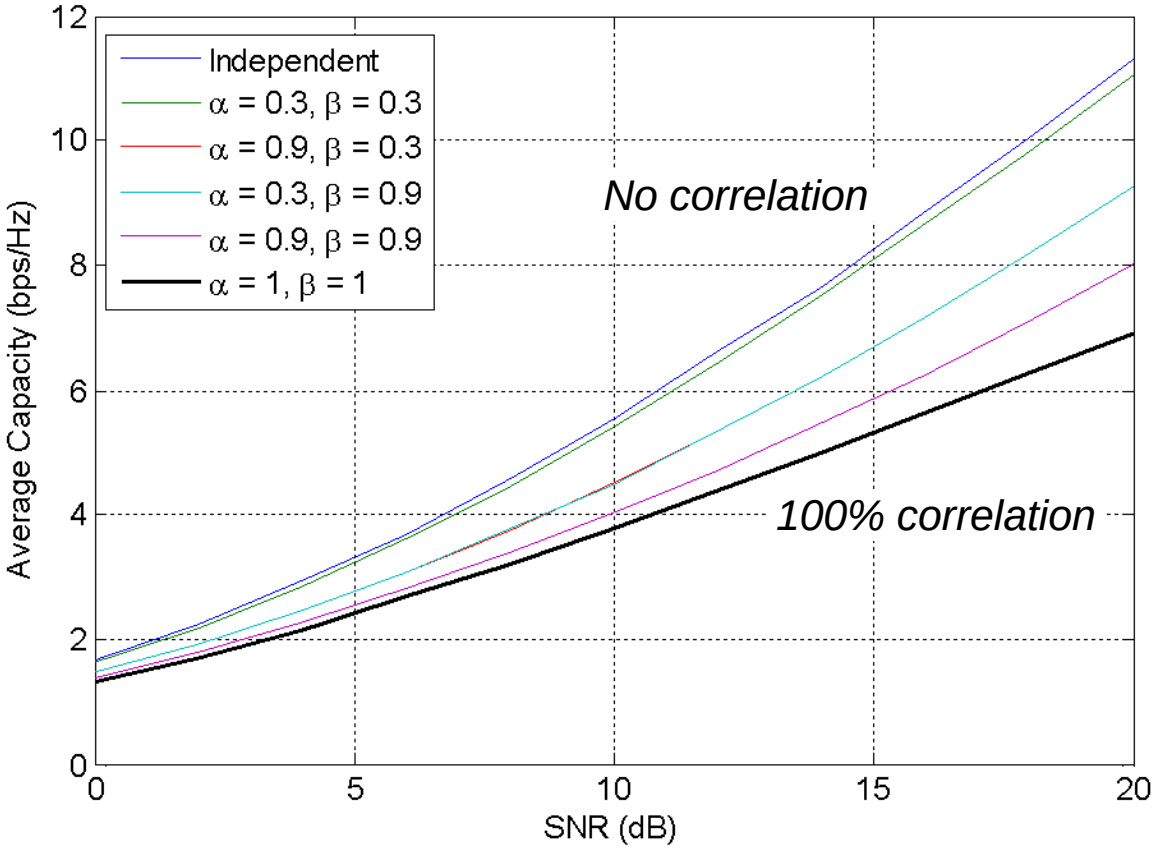
- Example: high correlation

Rx antennas highly correlated (e.g., close)





MIMO Channel Capacity is Very Dependent on Channel Correlation



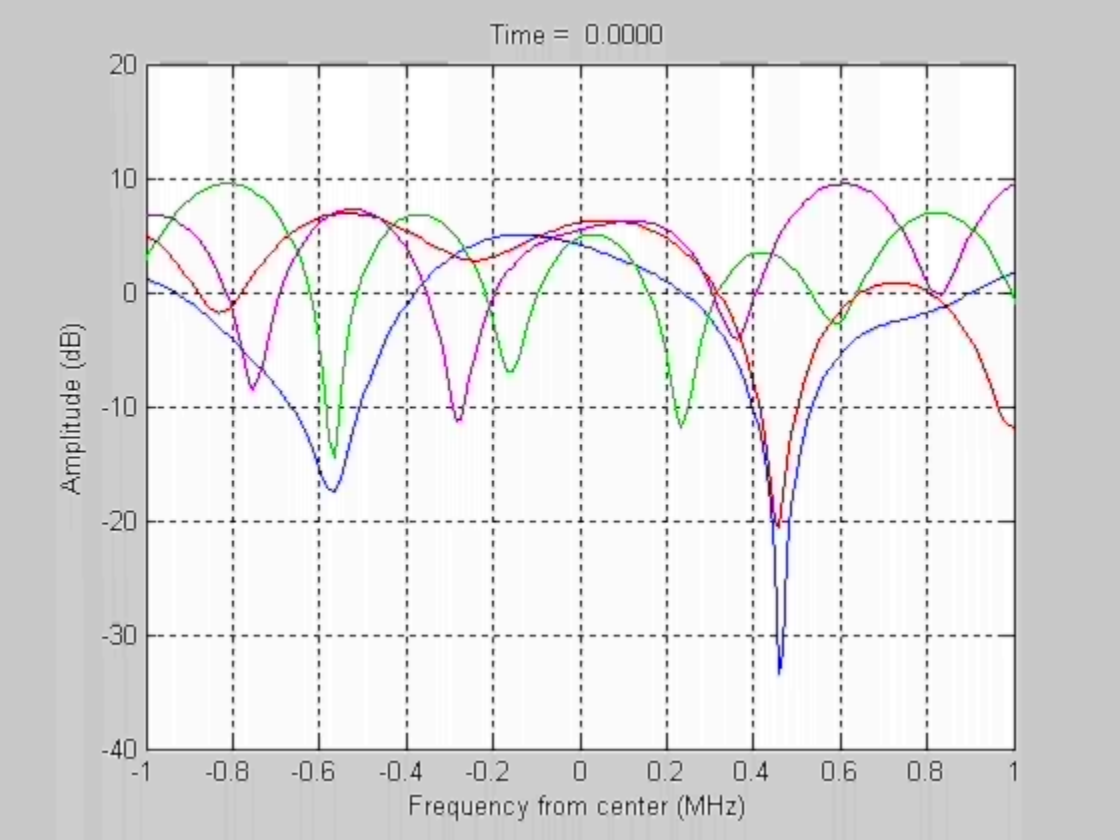
Low Correlation	Widely-spaced antennas Large angular spread	Closely-spaced antennas Small angular spread	***High Correlation***

Industry Propagation Conditions

Technology	Standard	
TGn/IEEE	IEEE 802.11-03/940r4	802.11n recommendations for performance testing
WiMAX Forum	Mobile RCT-Wave 2 Appendix 4 (Based on ITU M.1225)	
CDMA/3GPP2	C.S.0010/C.S.0011 C.S.0032/C.S.0033	Minimum performance standard for CDMA2000 mobile station and base station
GSM/EDGE/3GPP	TS 05.05/TS 45.005	
UMTS/3GPP	TS 25.101/TS 25.102 TS 25.141	User Equipment and Base Station Conformance Testing
3G(HPSA and HSPA+) /3GPP	TS 34.121	User Equipment Conformance Testing
LTE/3GPP	TS 36.101/TS 36.521-1 TS 36.104/TS 36.141	User Equipment and Base Station Conformance Testing
SCM/3GPP	TS 25.996	Spatial channel model for Multiple Input Multiple Output (MIMO) simulations
SCME	Extending the 3GPP Spatial Channel Model (SCM)	Interim Channel Model for Beyond-3G Systems

Role of the Channel Emulator

Channel Emulation in Action



Azimuth®

Wireless Test & Channel Emulation Experts

What to Look For in a Channel Emulator?

How to Put This Theory to Practice

Key Requirements for Channel Emulators

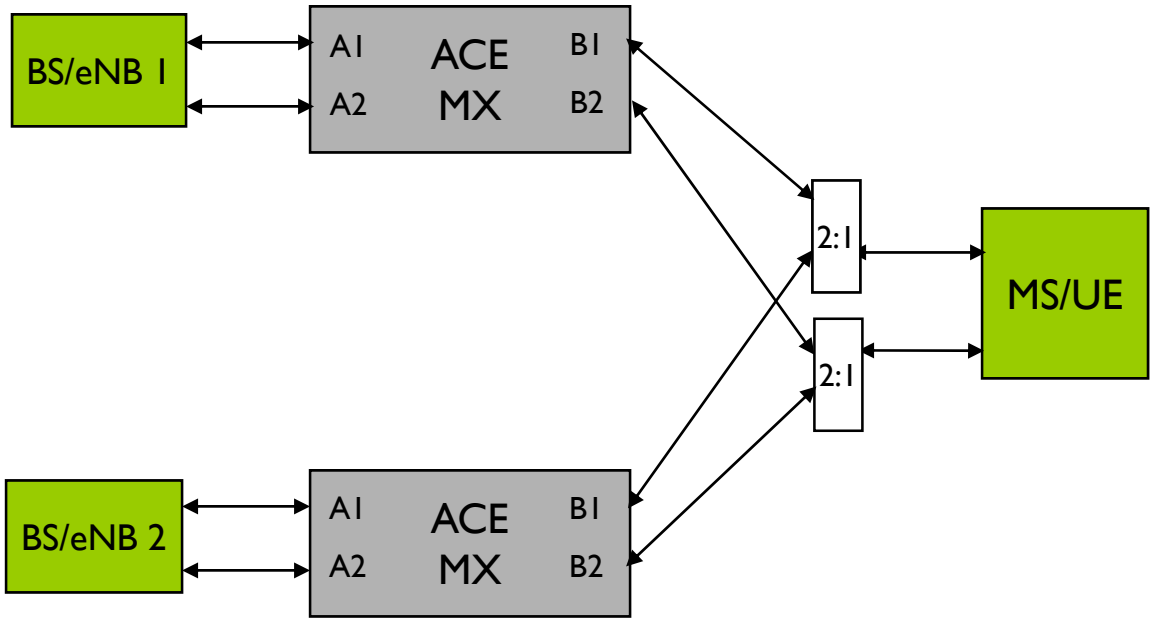
1. Technical specifications for to match the systems under test
   - High Fidelity RF
   - Channel emulator must be better than the equipment under test
     - Very low noise floor, low residual error vector magnitude, wide dynamic power range, precise phase balancing
2. Support for the varied test configurations
   - Multiple Antenna Support
     - Up to 4x4 MIMO infrastructure and mobile devices
     - Independent fading on each path
     - Full Bi-directionality and RF Path Reciprocity
     - Simultaneous rreciprocal channel model application in both downlink and uplink paths
3. Systems test / beamforming
   - Flexible capabilities to test spatial multiplexing, space time coding, maximum ratio combining, beam forming, collaborative uplink, MBSFN, handover and other multi-antenna dependent features
4. Channel emulation flexibility and real time channel emulation
   - Statistically accurate representation of standard, industry-approved channel models including long repeat times
   - Flexible parameters for multipath & fading, correlation, Doppler spectrum, shadow fading, etc.
   - Ability to create new or modify existing channel models
5. Designed for test
   - Automation
   - Ease of use
   - Verification and diagnostic of discoveries

Typical Performance Test Case
Handover Test Configuration Using Channel Emulators

Channel emulators provide full bi-directional operation recreating real world conditions

Independent control of each path attenuation and channel conditions

Supports
- *MIMO correlation*
- *TDD or FDD*
- *Multi-segment handover testing*



Take Home Message

- Channel Emulation is a critical component of testing today and even more so moving forward with emerging technologies
  - MIMO and OFDM based systems introduce new performance requirements and applications for channel emulators
- For full testing, MIMO channel emulation and bi-directional channel emulation is required if you are trying to recreate real world conditions
- Azimuth's ACE is the most scalable and flexible product available with support for 2G, 3G and 4G standards
- Azimuth delivers the industries most flexible and most function rich channel emulator
  - Designed for advanced MIMO testing
  - Designed for ease of use and simplicity of test

Azimuth ACE Benefits

Future-proof design – supports today's needs and software evolvable to meet future needs!

Greater than 85% market share for MIMO channel emulators!

The industry's most scalable channel emulator

- Provides numerous configurations:
  - from 1x1 to 8x4
  - SISO to MIMO
  - uni- and bi-directional
- Supports numerous standard 2G, 3G & 4G industry and custom channel models

Highest RF Fidelity and Performance

- Superior RF performance necessary for error-free conformance and performance testing
- Supports several programmable parameters with wide ranges to enable comprehensive test coverage

Unparalleled ease-of-use

- Fully integrated RF components for simple system configuration
- Simple "player-like" interface enables scan forward, backward and loop
- Extremely easy to use GUI with drop down selection menus and point and click configurations

State-of-the-Art Architecture

- Use of latest DSP/FPGA technologies
- Multi-purpose, multi-functional single enclosure
- Enables leading cost/performance platform on market

Azimuth®

Wireless Test & Channel Emulation Experts

Thank You

Please Feel Free to ask for more information about Azimuth ACE Channel Emulators