

Multiple Input / Multiple Output Communication Systems for Indoor Environments

EE 252
Data Transmission II
Prof. Robert Morelos-Zaragoza
Spring 2003

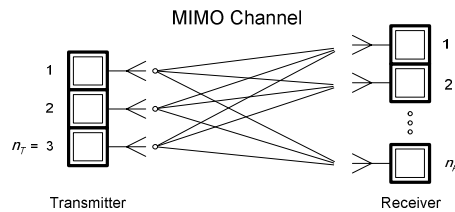
Cang Nguyen adamlivington@yahoo.com
AnhSon Nguyen anhsonn@yahoo.com
Eric Krebs ekreb@ieee.org

Agenda

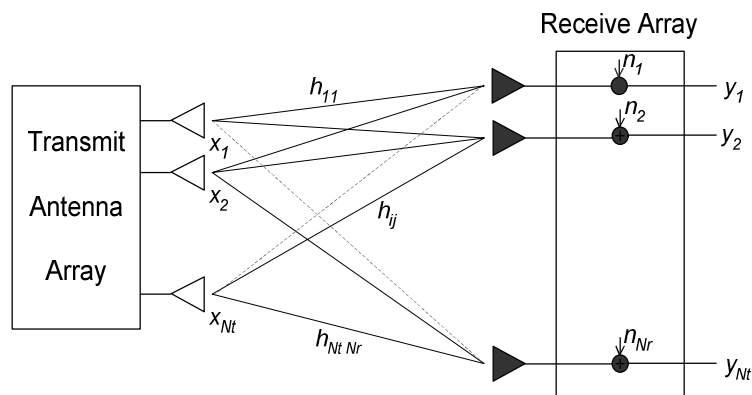
- Definition
- Model
- Technical Approaches
- Measurement Techniques
- Current Technology
- Future Trends
- Conclusion

Definition of MIMO

DEFINITION: Multiple Input / Multiple Output systems consist of several transmission antennas and receiver antennas, the combination of which exploits the spatial and time dimensions of the channel.



MIMO Structure

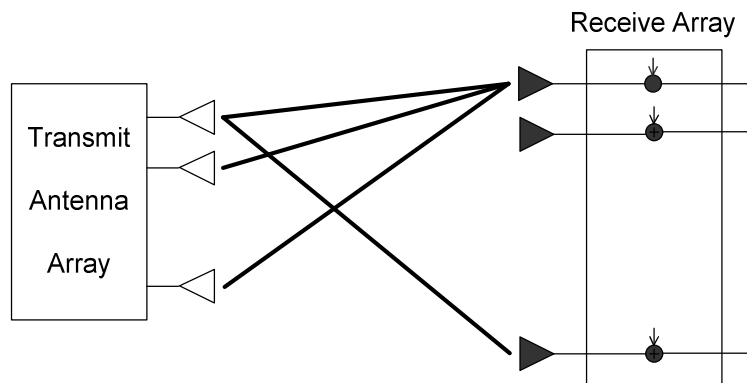


$$y = Hx + n$$

Advantages & Disadvantages

- MAJOR ADVANTAGES:
 - higher capacity
 - lower bit error rate
 - increased coverage
 - improved position estimation
- DISADVANTAGES
 - Computational Complexity
 - Channel Modeling Complexity

Diversity



Channel Capacity

Shannon's Capacity Equation for band-limited channels

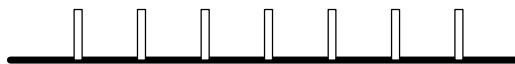
$$C = \log_2 \left(1 + \frac{P}{N_o B} \right)$$

Telatar Capacity Equation for Gaussian MIMO channels

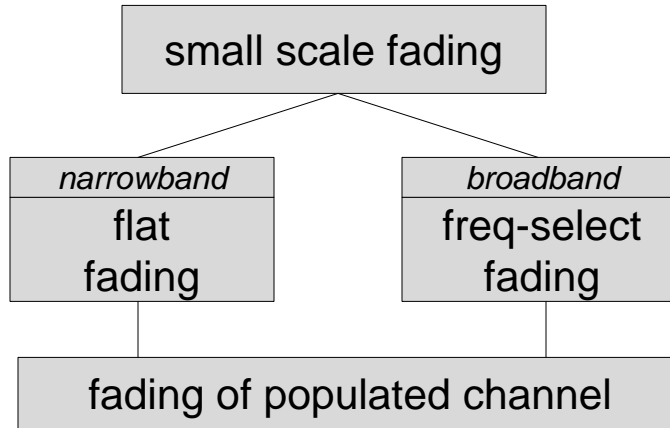
$$C = \log_2 \left[\det \left(I_{n_r} + \frac{P}{n_t N_o B} H H^* \right) \right]$$

Narrowband MIMO Channel

- Each transmit antenna connects to each receive antenna with its own narrowband channel
- Spatial Multiplexing & time space coding optimizes spectral efficiency
- Broadband channels will offer better performance in the future, but with current technology better performance results from narrowband channels



Fading Issues

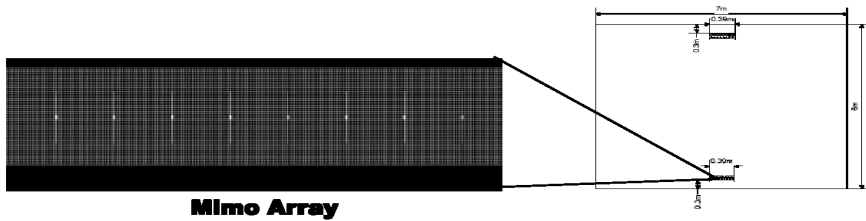


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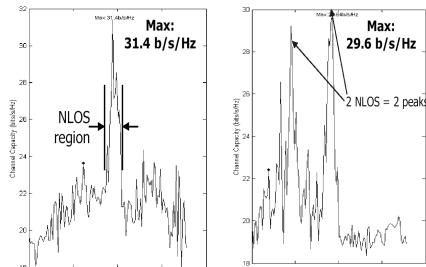
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Populated Channel Model



Exp. by K.Siri-Castro, W.Scanlon, & F.Tofoni



- Capacity increases on channel with a persons along its path
- A Person position can be determined
- Exploitation of populated channel can improve system performance

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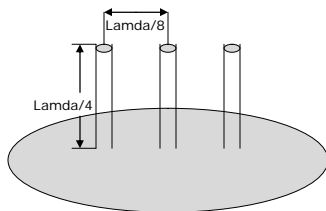
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Technical Approaches

- Switched Parasitic Antenna
- Antenna Array
- Spatial Multiplexing
- Space Time Coding
- Transmit & Receive Diversity
- V-BLAST

Switched Parasitic Antenna Yagi-Uda Array

- SPA offering directional patterns dates back to the early work of YAGI and UDA in the 1930's.
- Provide angle diversity as two parasitic on a mobile phone.
- By use a single active antenna element connect to a transceiver with one or several passive antenna elements.
- The parasitic antenna can be design using Monopoles on a ground plane or as parasitic patch antennas.
- The effect is an increased directivity as their length are shorten than the corresponding resonant length ($\lambda/4$).

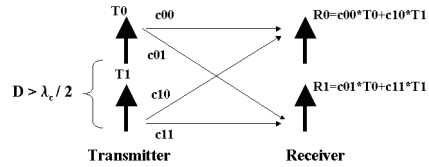


Can achieve a high capacity & large diversity gain in MIMO.

Three elements Monopole

Antenna Array

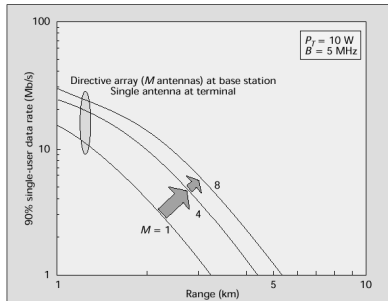
- Multiple antenna were used to provide diversity gain & increase the reliability of wireless link & improve bandwidth efficiency.
- Having both multiple T/R antennas provides additional spatial dimension for communication & yields a degree of freedom gain. These additional degree of freedom can be exploited by spatially multiplexing several data streams onto the MIMO channel.



$$C = B \log_2 \left(1 + \frac{P_T \|h\|^2}{\sigma^2} \right)$$

$$C = B \log_2 \det \left(I_N + \frac{P_T}{M\sigma^2} HH^H \right)$$

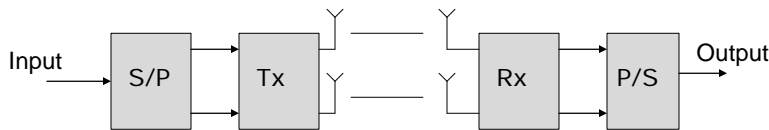
$$C \approx BM \log_2 \left(\frac{\rho}{e} \right)$$



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Spatial Multiplexing

- Incoming data stream is split into data streams which are transmitted independently & simultaneously on the antennas.
- Receiver is able to remove the mixing effect of the MIMO channel.
- Spatial multiplexing is a linear code.
- Achieves a high bit rate by transmitting independent symbol streams on each antenna but suffers from sensitivity of the channel rank.
- Only MIMO systems can use spatial multiplexing.
- Multiplexing gain come at no extra bandwidth or power.
- Orthogonal H maximizes capacity.



System Structure

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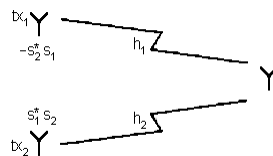
Space Time Coding

- Is a transmit diversity technique that applied to MIMO & MISO.
- Introduces spatial & temporal correlation between the signals transmitted from different antenna in an intelligent manner.
- Require Channel State Information at the receiver which in FDD systems has to be estimated using a training sequence.
- Use trellis or block coding methods over the entire high dimensional signal set.
- Available for small antenna systems.
- Demodulation complexity is too large for big systems.
- Three types of space time codes:
 - *Trellis space time codes*: Complex but best performance in slow fading environment (INDOOR)
 - *Layered space time codes*: Easy to implement but NOT accurate due to the error propagation effect.
 - *Block space time codes*: Best trade off of performance Vs. complexity.

T/R Diversity

- The Alamouti space-time code (STBC)

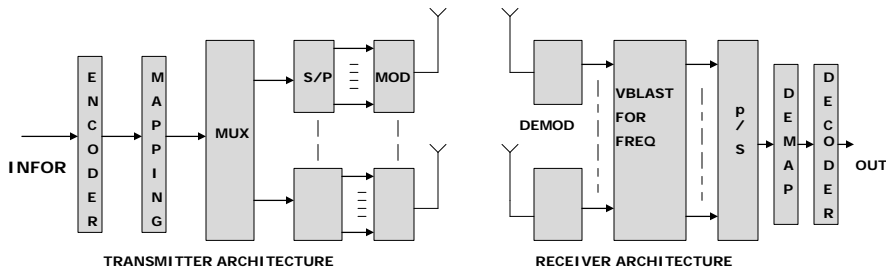
| | T_1 | T_2 |
|--------|-------|----------|
| tx_1 | s_1 | $-s_2^*$ |
| tx_2 | s_2 | s_1^* |



- Orthogonal symbol sequences
- Achieves diversity order $2m$ for any number m receiving antennas

Transmit Diversity & Receive Diversity

- Transmit from independently fading antennas with selection to maximize SNR at receiver.
- Transmit space diversity techniques require flat fading at the channel bandwidth.
- CSI available provides array gain and diversity gain.
- MRC for array gain and diversity.
- Transmit diversity sends redundant information stream to max reliability.



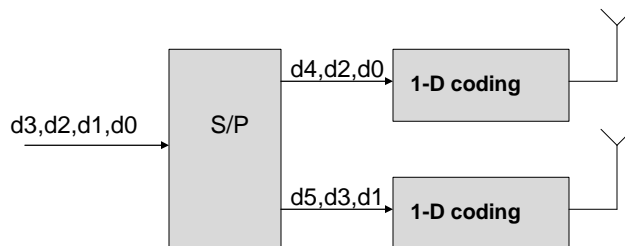
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V-Bell Labs Layered Space Time V-BLAST

- In V-BLAST every transmit antenna radiates an independently encoded stream of data.
- Transmitted uses a simple spatial de-multiplexer followed by a bank of scalar encoders, one per antenna.
- The receiver uses a well know successive detection technique.
- V-BLAST simply allocates equal power & rate to every transmit antenna.
- New scheme called V-BLAST with Per-Antenna Rate Control (PARC) can achieves higher performance.



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Measurement Goals

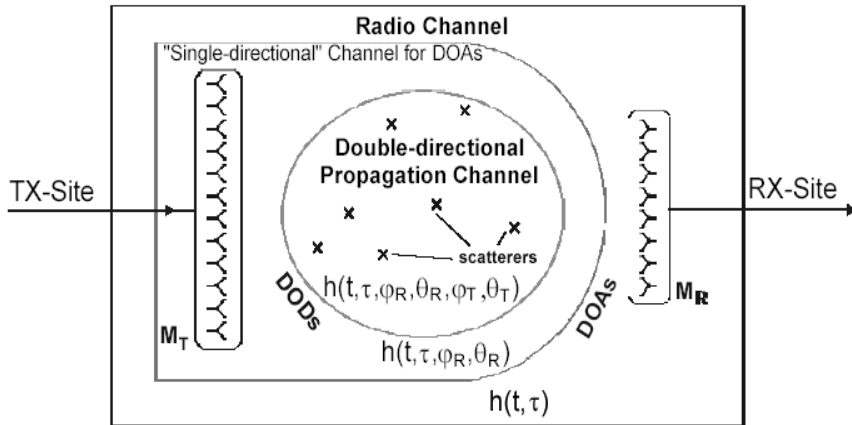
verify the assumptions of

- fading distribution
- signal correlation
- flat fading assumption

Principle

- MIMO holds great promise of huge capacity, if there are parallel, independent between Tx & Rx arrays
- If we can identify & separate individual multipath components, we can set up, in principle, an independent channel on each multipath component
- Since propagation is at the heart of any radio system, it set the ultimate limit for transmission
- So let's characterize the suitability of environments for MIMO installation by propagation measurements.

Double-directional Propagation

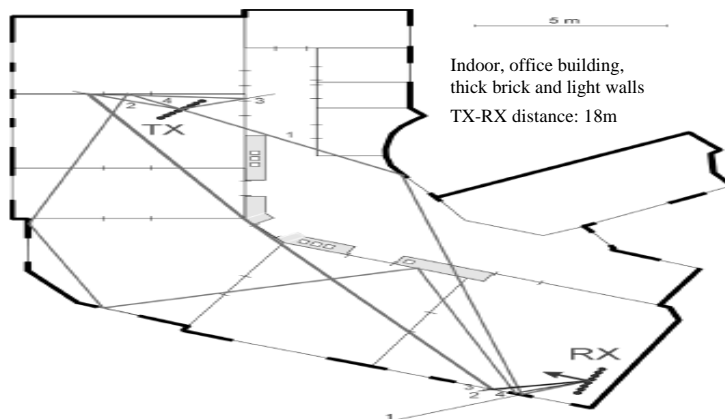


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Multipath Components

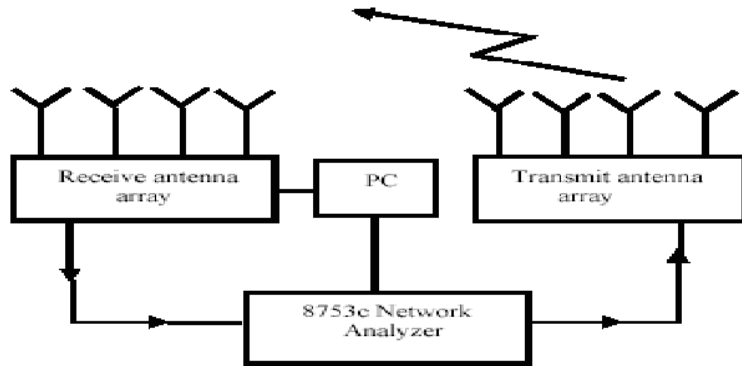


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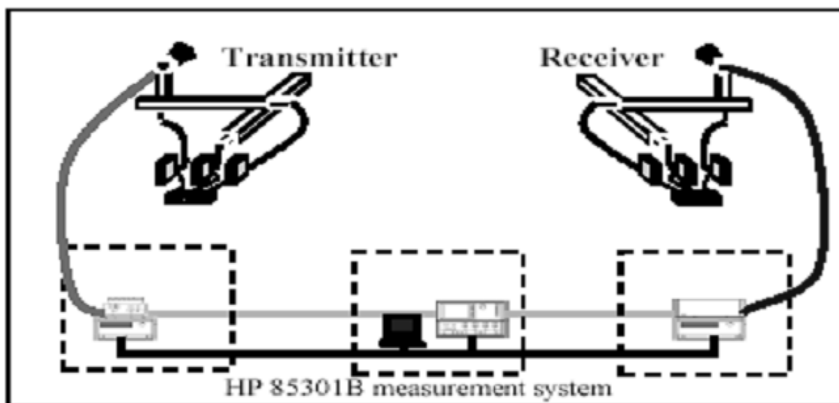
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MIMO Channel Measurement System



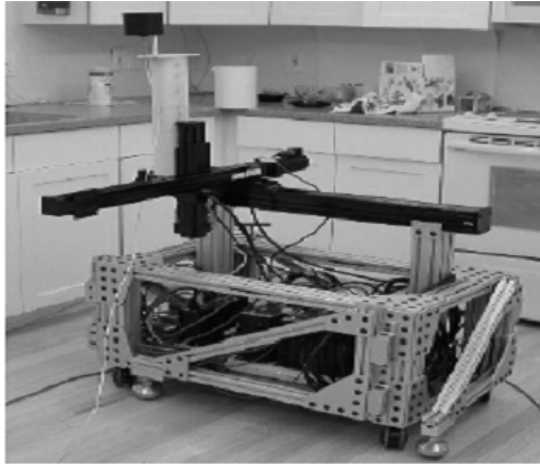
measure paths

MIMO Channel Measurement System



85301B antenna & radar cross section measurement system

MIMO Channel Measurement System



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Current Technologies

- The MIMO principle is independent of frequency bands and modulation schemes
- For 802.11g (2.4GHz), may prove to be even more valuable than at 5GHz
- Be applicable to GSM/GPRS systems
- New 3G chips: Bell Labs Layered Space-Time (BLAST) at 19.2 Mbps
- Lucent Technologies (Bell Labs), Motorola, Iospan, etc

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Future Technologies

- MIMO-OFDM in 3G and 4G wireless
- BLAST

Receive: 4- Branch Diversity
Transmit: 2- 4 Branch Diversity



- ◆ Antenna elements 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. Allows code-reuse for higher spectral efficiency

Benefits:

- Four fold increase in the data throughput.
- High data rates are achieved without increasing the interference or power => more simultaneous users.

Hardware:

- Basestation Antennas: Same appearance as conventional antennas
- Add more antennas to terminal

Signal Processing:

- Performed in BTS and terminal Channel-Element ASICs

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Conclusion

- MIMO systems are very stable
- MIMO Easy to implement using the above techniques.
- MIMO will be use more in the future of wireless communication system.

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