Line of Sight (LOS) MIMO

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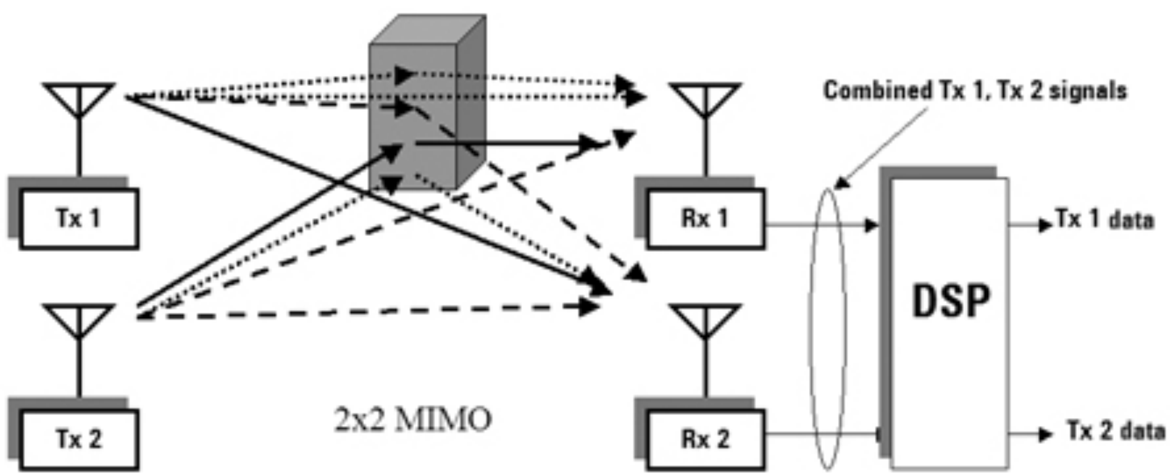
Traditional MIMO Requires A Multipath Environment

- Multiple Input Multiple Output (MIMO) systems are similar to traditional links except that they use multiple antennas and signal processing in a multipath environment
- By exploiting the multipath environment the channel capacity can be increased for the same spectrum and thus enabling multiple independent data streams on the same channel
- A 2x2 MIMO is shown, but others such as 3x3 are also possible



Conventional MIMO Continued

- Digital signal processing is used to de-correlate and remove information in each stream from others creating independence
- As spectrum is a scarce and a limited commodity, this technique permits greater use of this resource to increase capacity
- Acceptance of this technology has resulted in widespread use by LTE (cellular/smart phones), WI-FI hot spots and other network equipment
- But what about environments without multipath to impair propagation – Is there a way to use the same concept
  - For example satellite or aircraft to ground links or mountain top to mountain top line of sight (LOS) repeaters
- This presentation will focus on LOS applications

Line of Sight MIMO

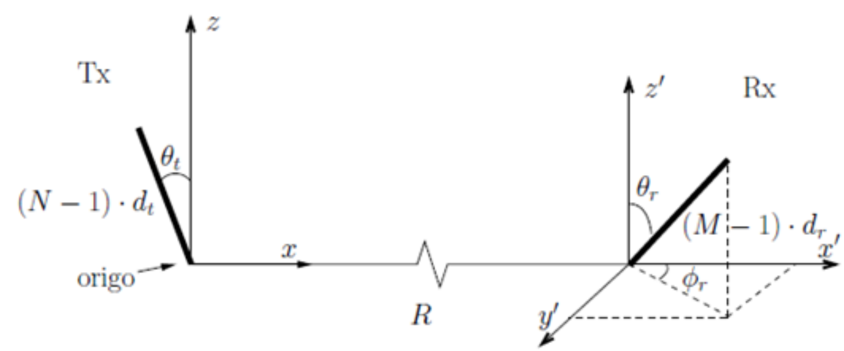
- **There are other scenarios such as mountain top to mountain top where there are no multipath impairments to propagation**
- **If a similar technique could be found to increase channel capacity then the same benefits might be realized, removing mutual interference**
- **In LOS conditions, each receiving antenna collects a full unperturbed sample of each transmitted stream making the application of this method more difficult and limited**
- **We need to find a way to de-correlate the signal (remove mutual interference) and thus permitting the separation of the signals at the receiver**
- **This paper will show how this can be done, what the limitations are and how channel capacity may be multiplied**

Line of Sight MIMO Geometry

- **To enable separation of signals, a specific geometry between transmit and receive paths must be maintained to ensure a fixed phase difference between sets of signals**
- **For this talk, I will focus on the 2x2 MIMO for simplicity**

Assumptions/Definitions:

- **Uniform Linear Arrays at Tx & Rx**
  - **N ≡ Tx Antennas (d_t separation) ≡ 2**
  - **M ≡ Antennas (d_r separation) ≡ 2**
  - **V ≡ Maximum (M and N) ≡ 2**
  - **d_t ≡ Separation of transmit antennas**
  - **d_r ≡ Separation of receive antennas**
- **R = distance between transmit and receive antennas (R >> d_t, d_r)**

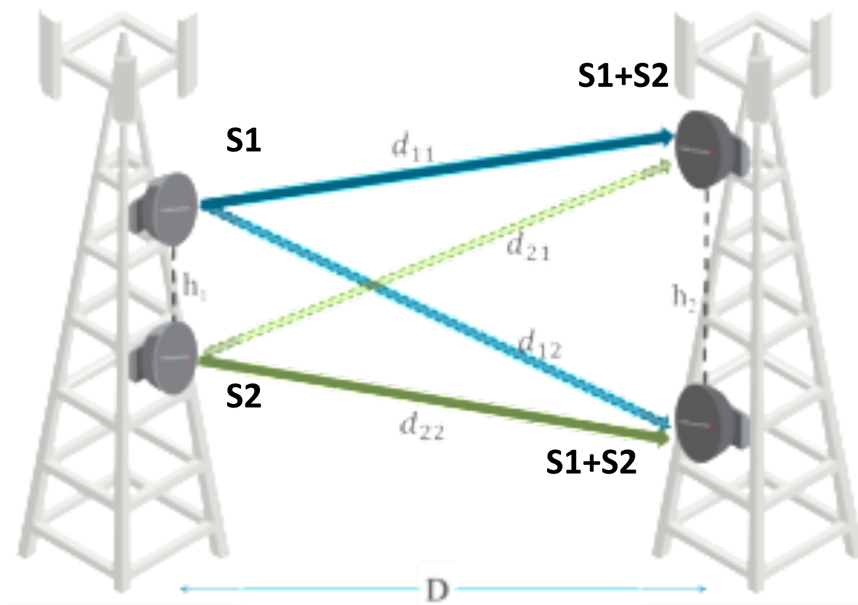


$$d_t d_r = \frac{\lambda R}{V \cos\theta_t \cos\theta_r},$$

For optimal inter-antenna arrays $d{\downarrow}r\ d{\downarrow}t = \lambda R/V$

Geometry Continued

- This geometry creates a 90° phase difference between paths
- This difference will be exploited
- If the left side represents the transmitting stations, then both receivers capture signals from each transmitter
- A transversal filter or space-time equalizer can separate the signals
- This is often called a tapped delay line
- Signal processing is done in the digital domain



Signal Processing Structure

- **Recall that both antennas receive S1 and S2 equally well**
- **Tapped delay line processors are used to enable one output to pass S1 while notching out S2 and vice versa**
- **A digital signal processor is used to set the delays and weights**

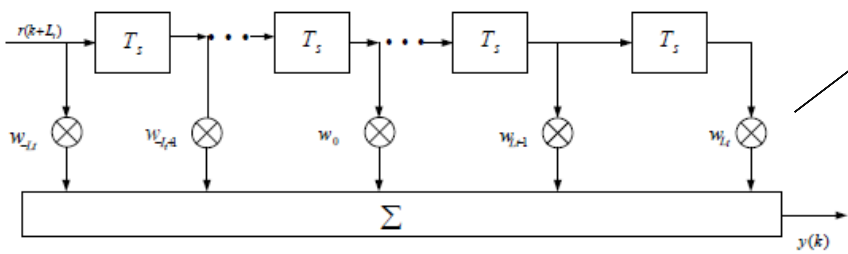


Figure 4.4: Transversal Filter Structure.

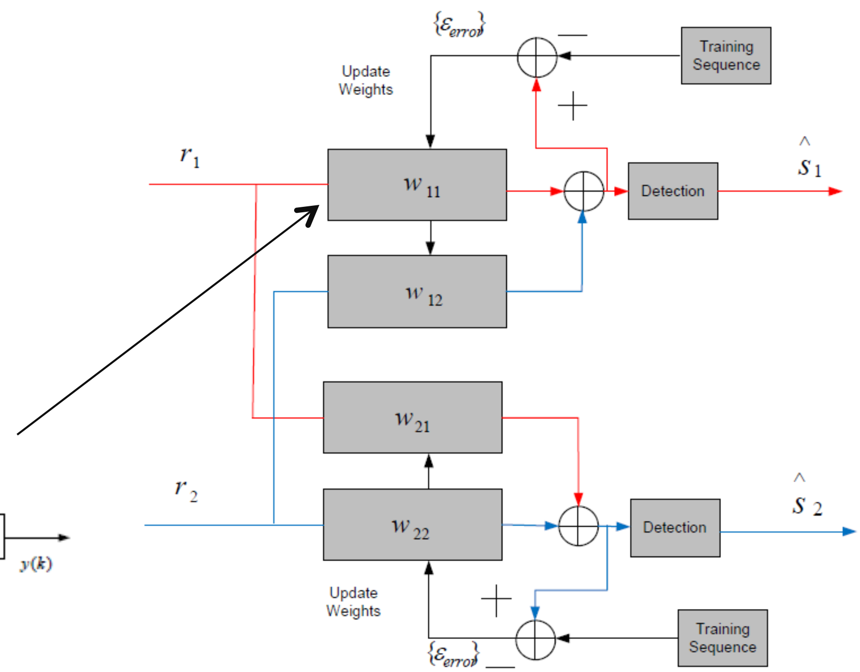
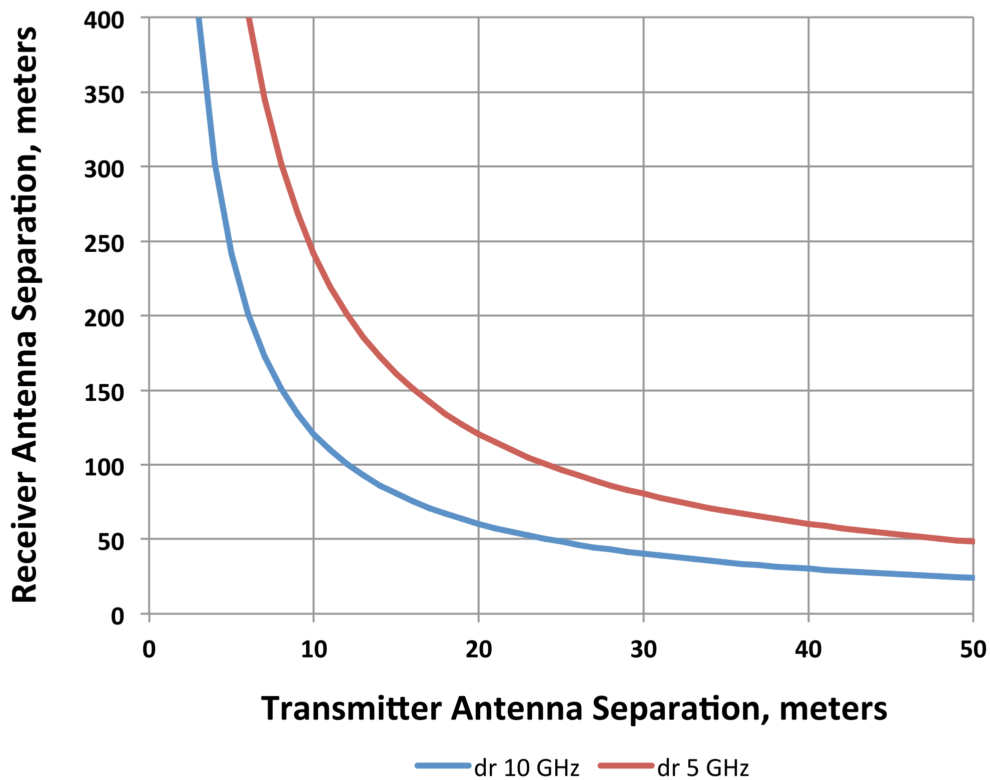


Figure 4.10: The structure for a 2×2 MIMO STE under training mode.

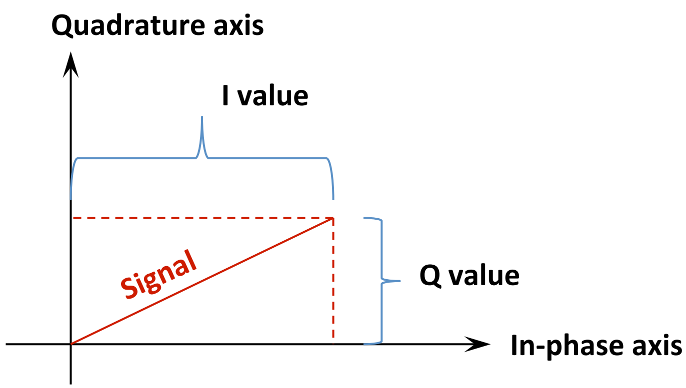
Practical Application of 2x2 MIMO

- **Antenna separation is key to making this work**
- **The example shows the required antenna separation at both ends for 5 and 10 GHz transmission systems over a range of 50 miles**

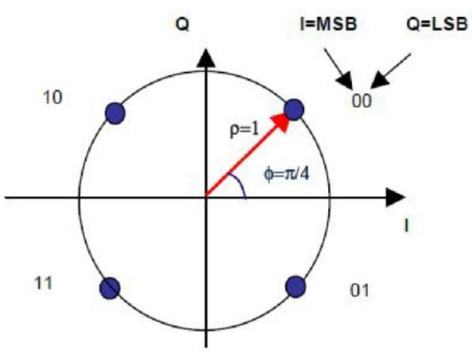


I and Q Signals and Constellation Diagrams

- Digital signal processing often is done with I (in-phase) and Q (quadrature) signal components to form complex signals
- SDR forms I and Q samples early in the modulator to enable arbitrary signal formats to be created such as SSB or PSK63



- The figure to the left shows I and Q components of a signal

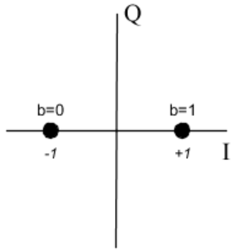


- This figure shows how a 2-bit word is mapped to 4 possible symbol values to be transmitted based on their I and Q components

Transmission Schemes aka Modulation Density

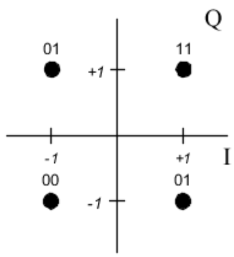
- Data is composed of digital words to be transmitted one symbol at a time
- Each symbol can represent N bits to increase the throughput
- Common schemes range from BPSK to 1024 QAM

BPSK



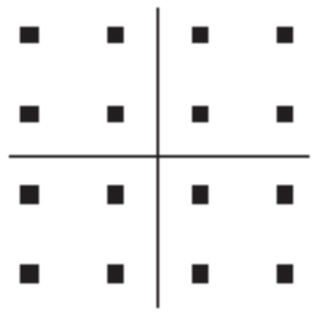
1 bits/sym

QPSK



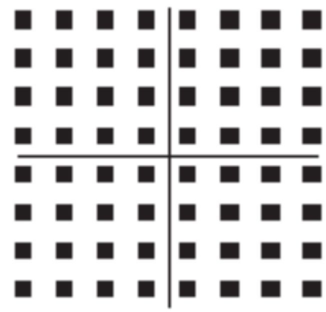
2 bits/sym

16QAM



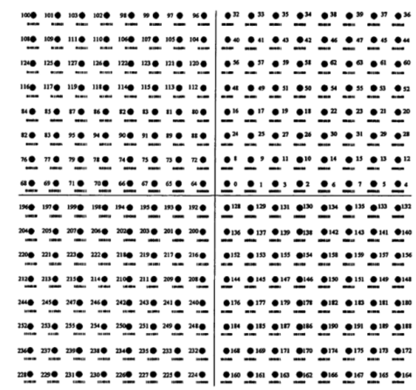
4 bits/sym

64QAM



6 bits/symbol

256 QAM

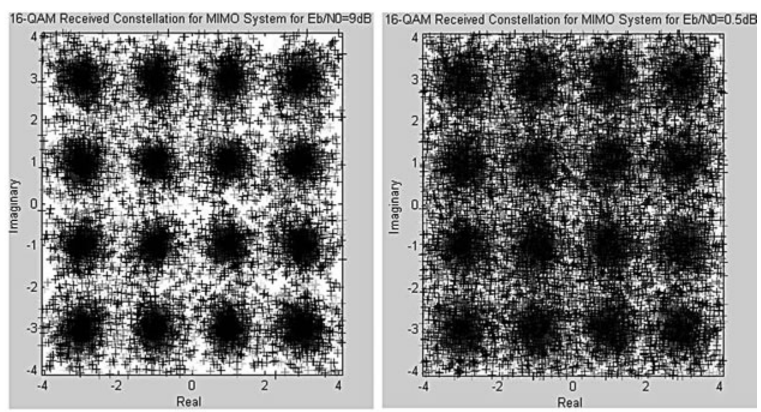


8 bits/symbol

- Increasing the modulation density requires increasing energy per bit and becomes more susceptible to noise in the demodulation process but communicates more information per unit time

Demodulation Issues

- The figure shows the effect noise has at different signal to noise levels for 16 QAM (similar to histogram of each data value)
- In addition, since the points get closer together with increasing modulation density, more good bits are required in the ADC and demodulation process, and this often limits what can be done
- 256 QAM is really efficient to get lots of data across (8 times BPSK) but requires about 7 good bits vs. 4
- A cleaver way to increase capacity while reducing modulation complexity uses dual polarization

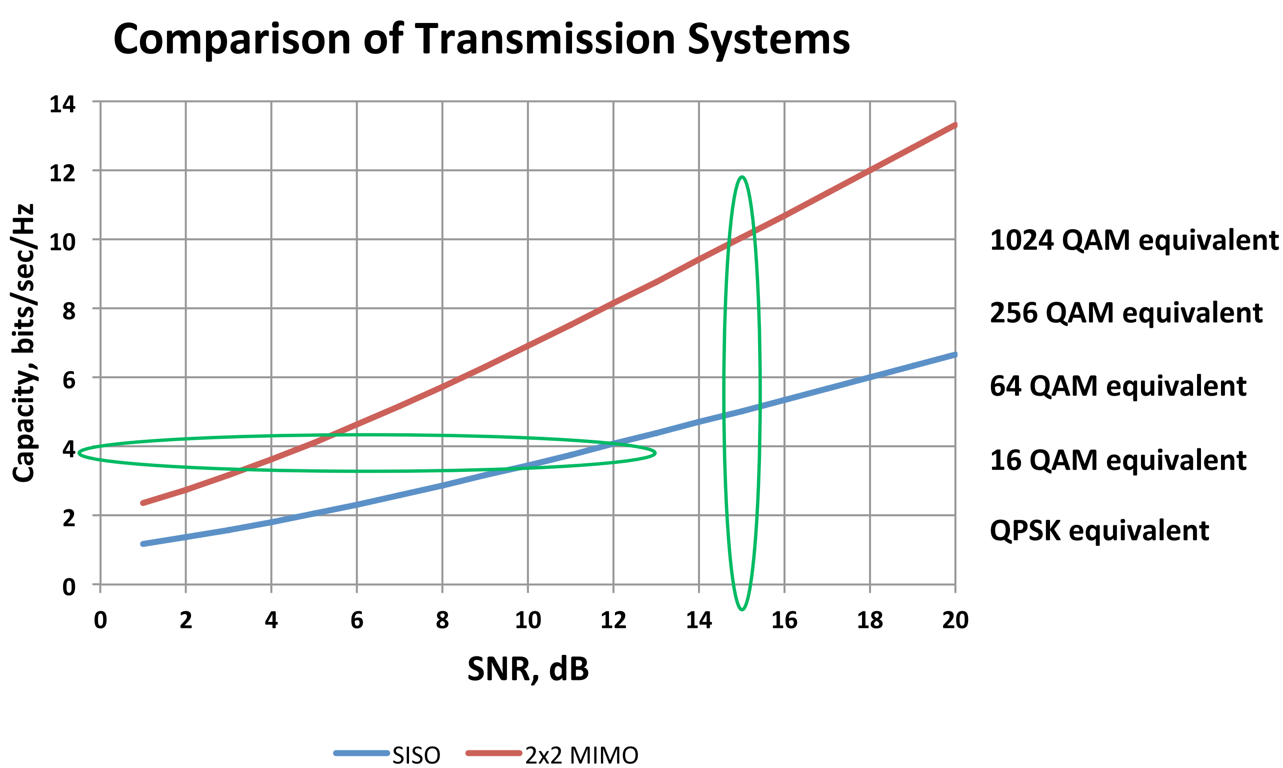


Polarization Improvement

- Each antenna may transmit either a single or dual polarized signal
- If dual polarized signals are used with sufficient polarization isolation, the channel capacity is possible for the same bandwidth
- A cleaver trick is to start with data words of twice the length and transmit half on each polarization
- This permits a simpler modulation constellation to be used on each while still achieving the throughput of the larger constellation
- For example a 256-QAM 8-bit word per symbol can be transmitted as 2-dual polarized 16-QAM signals
- We still achieve the net throughput of 8 bits per symbol using only 2 streams of 4 bits per symbol
- Applying this scheme to 2x2 MIMO has great utility in data throughput

Putting It All Together

- **Let's compare a 2x2 MIMO vs. SISO (Single Input Single Output)**
- **For each comparison, the same total transmitter power is used**



At a 15dB SNR a SISO system can achieve 5 bits per second per Hz of bandwidth compared to MIMO that achieves 10

Using dual polarization allows each to operate with simpler processing

This effectively allows us to transmit 10 Mbps in a 1 MHz channel

I want to thank John Petrich, W7FU for his comments on this presentation

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QUESTIONS?

- **Practical considerations?**
- **Viable frequency ranges?**
- **Signal processing hardware?**
- **Bandwidth limitations?**
- **Constellation limitations?**
- **Polarization imperfections?**
- **Others?**