MIMO in Wireless Communication

SP Swedish National Testing and Research Institute
Electronics – EMC
Paul Hallbjörner

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History

1987: Original paper by J. H. Winters.

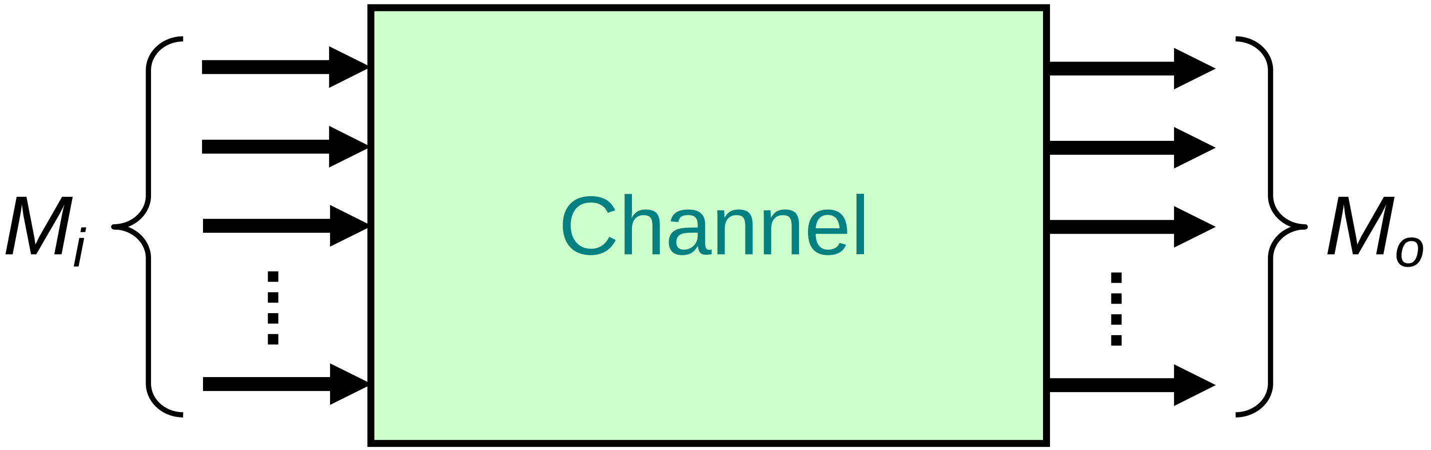
1998: First demonstration of the technique in a lab, by Bell Labs.

1999: First functioning outdoor prototype, by Gigabit Wireless Inc and Stanford Univ.

2002: First commercial product by Iospan Wireless Inc.

What is MIMO?

MIMO = Multiple Input, Multiple Output
(SISO, MISO, and SIMO also exist)



Data, Information, Channel Capacity

Data is measured in the unit bit, but says nothing of the amount of information.

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Information is a measure of the reduction in uncertainty when looking at the data, also with the unit bit.

$$I = -\sum_k p_k \log_2 p_k \quad , \quad \sum_k p_k = 1$$

Mutual information of a channel is the reduction of uncertainty in the input data when looking at the output data.

Channel capacity is the maximum* mutual information per time unit, with unit bit/s.

*Maximum over all possible input data and all possible ways of using the channel.

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Orthogonality

The concept of orthogonality is important in order to understand MIMO.

Signals are orthogonal if they are separated, e.g. in space, angle, time, frequency, polarization, waveform...

$$\int_T E_1 E_2 dt = 0$$

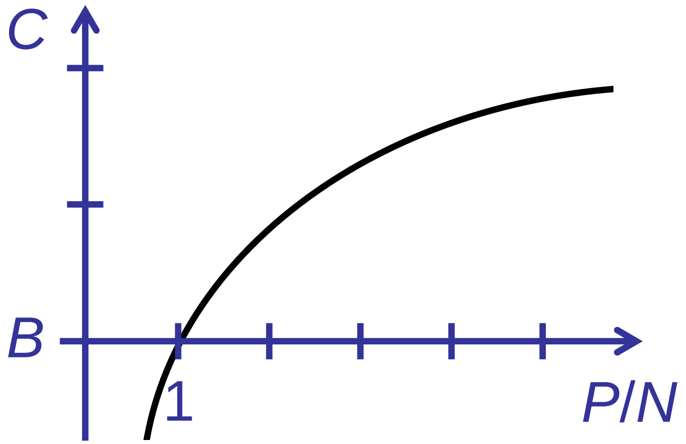
$M \times M$ MIMO can be seen as M orthogonal (separate) signals, i.e. a signal space with M dimensions.

The orthogonality must be maintained along the entire signal path.

Shannon's Formula

SISO capacity:

$$C_{SISO} = B\log_2\left(1+\frac{P}{N}\right)$$

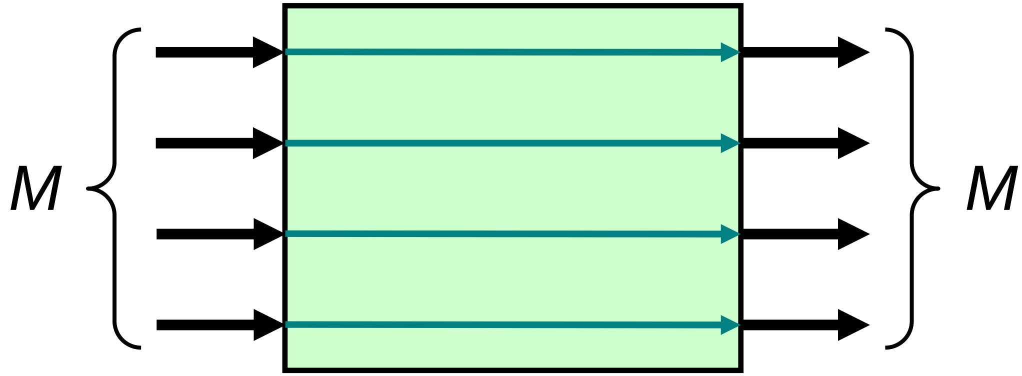


MIMO capacity:

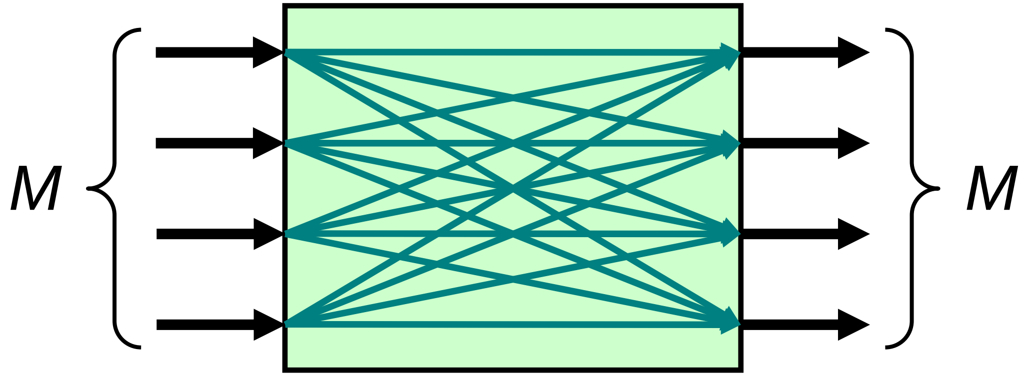
$$C_{MIMO} = B \sup_{\mathbf{P};\mathrm{tr}(\mathbf{P})=P} \log_2\left|\mathbf{I}+\frac{1}{N}\mathbf{HPH}^H\right|$$

Why Use MIMO?

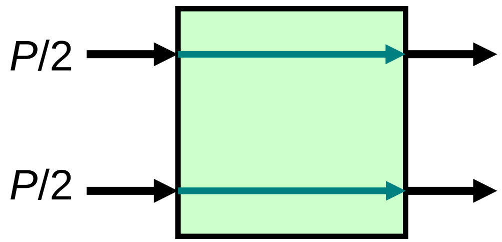
M times higher capacity,
at the cost of *M* times higher transmit power.



Capacity? Transmit power?

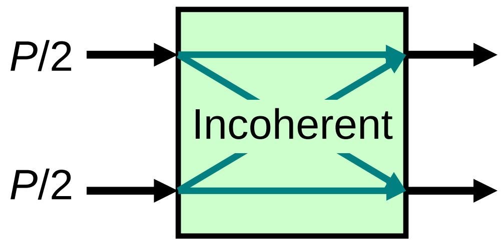


Three Simple Cases of MIMO



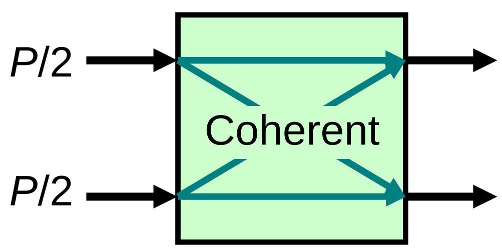
$$C = 2B\log_2\left(1 + \frac{P}{2N}\right)$$

"MIMO"



$$C = 2B\log_2\left(1 + \frac{P}{N}\right)$$

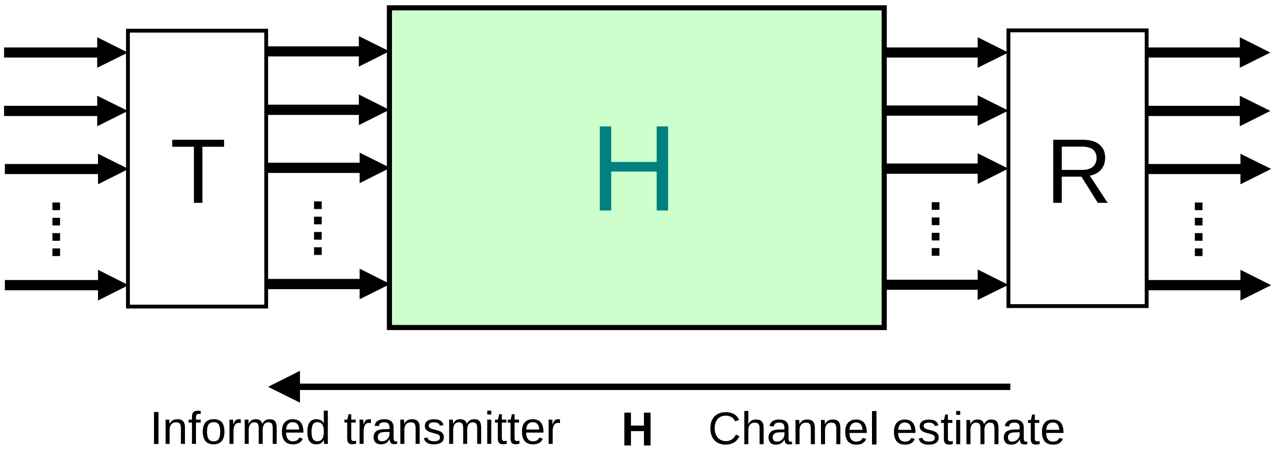
"Beamforming"



$$C = B\log_2\left(1 + \frac{4P}{N}\right)$$

Feedback and Encoding

We need to know the channel and adapt transmission to it. For each channel **H** there is an optimal encoding **T**, and an optimal distribution of the transmit power.



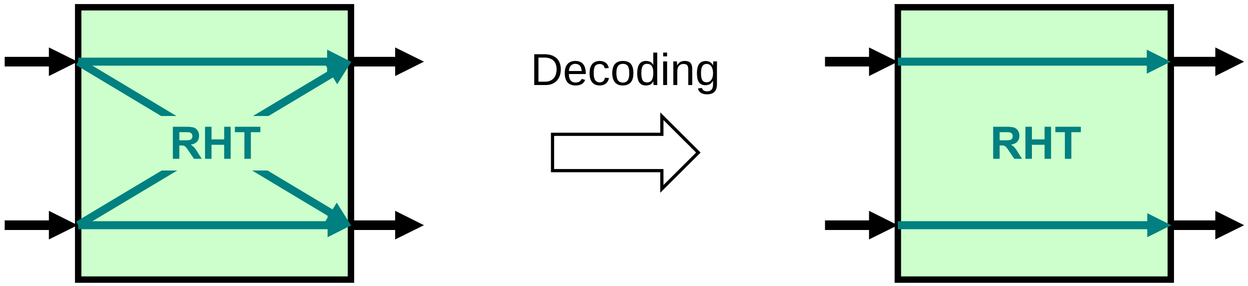
Two cases:

- Informed transmitter (IT)
- Uninformed transmitter (UT)

Decoding

Received signals can be decoded with **R**. MIMO decoding is a complex field, where the optimal decoding depends on many system aspects (including **T** and **H**), as well as the purpose of the decoding.

One simpel example is to use **R** to remove the cross-coupling from the channel including encoding/decoding.



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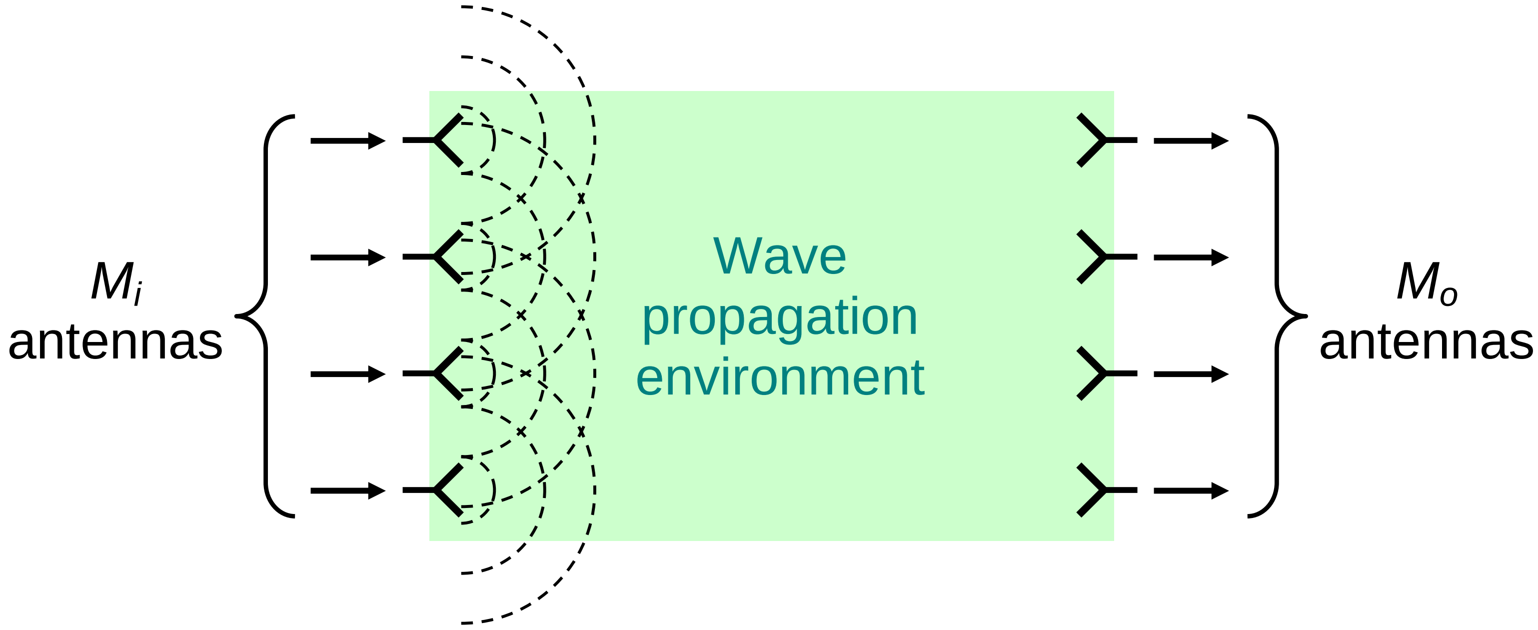
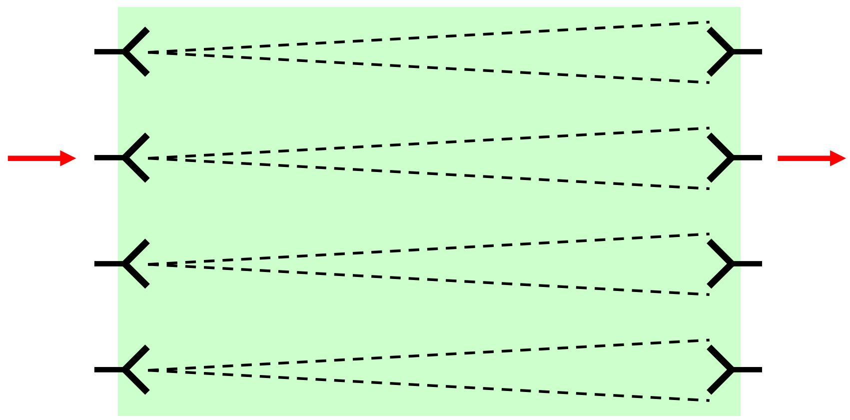
Wireless MIMO

Transmit antennas, wave propagation environment, and receive antennas together constitute the channel.

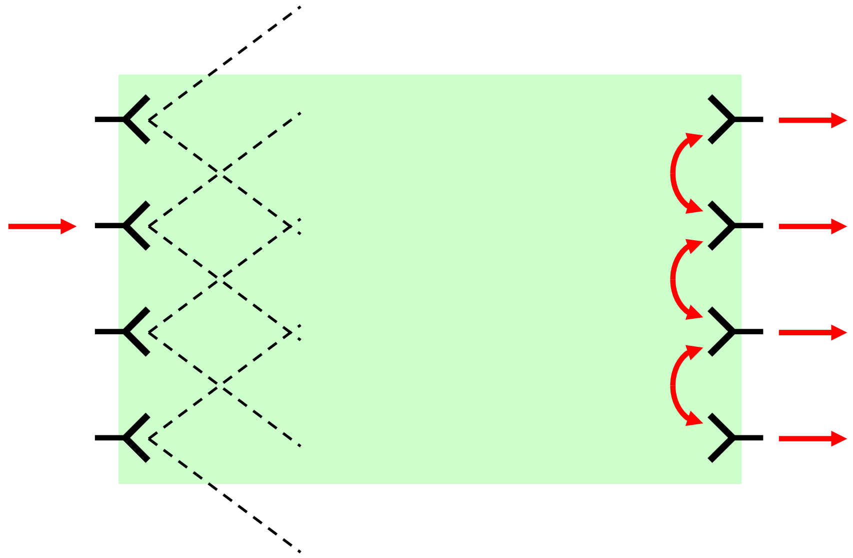


Antenna Properties

Isolated signal paths can in general not be achieved.



Beamwidths and coupling complicates the channel.

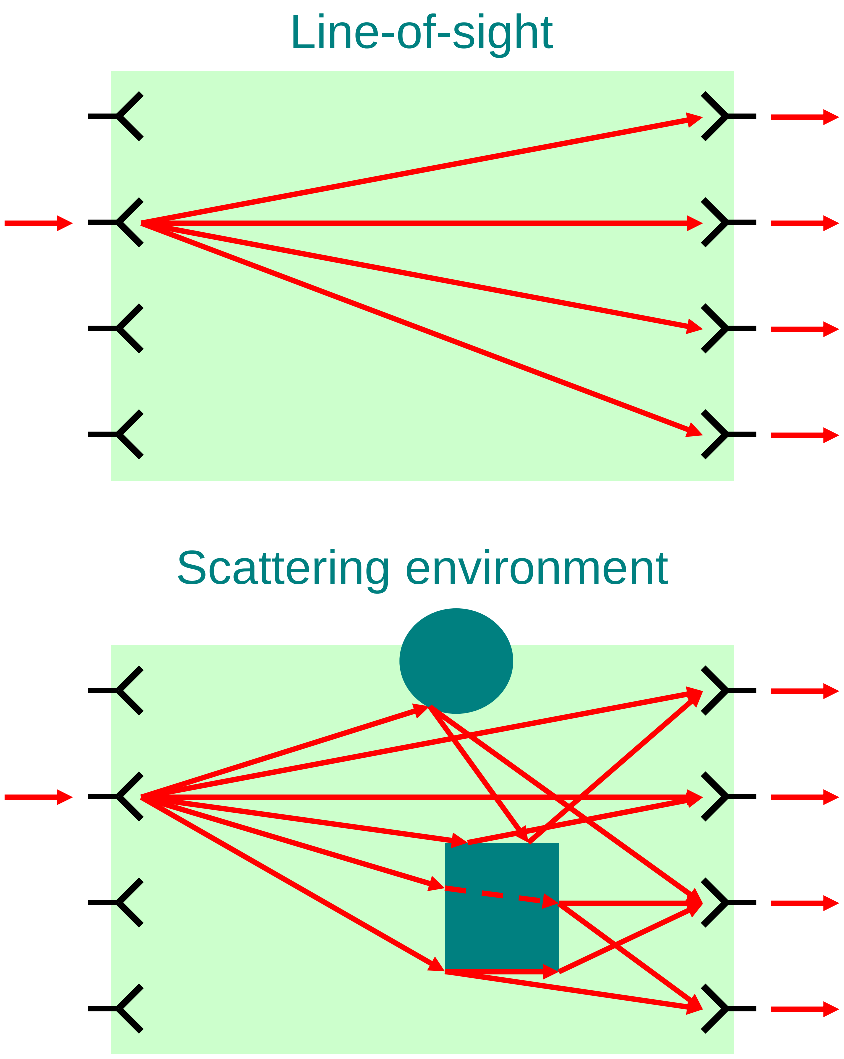


Environment Properties

An environment with many signal paths is a good prerequisite for MIMO.

MIMO is applicable in line-of-sight as well as scattering environments.

Signal environments are often non-stationary and unpredictable.



Imbalance and Correlation

Capacity is reduced by two defects – imbalance and correlation.

Imbalance is affected by...

- Antenna gains
- Radiation patterns
- Path loss
- Fading

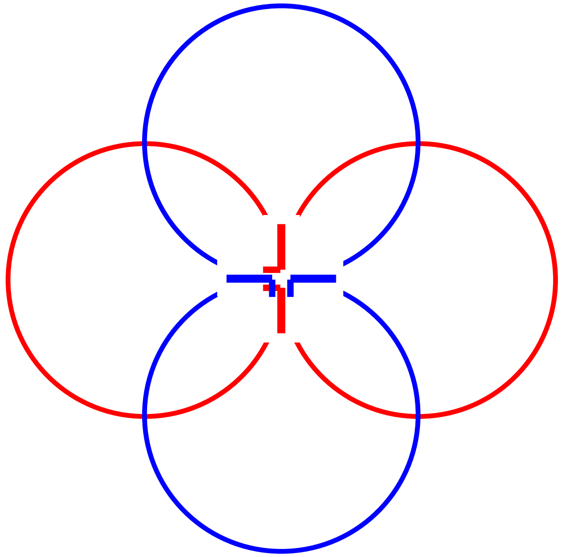
Correlation is affected by...

- Antenna correlation
- Antenna separation
- Number of and locations of scatterers
- Pinhole effect

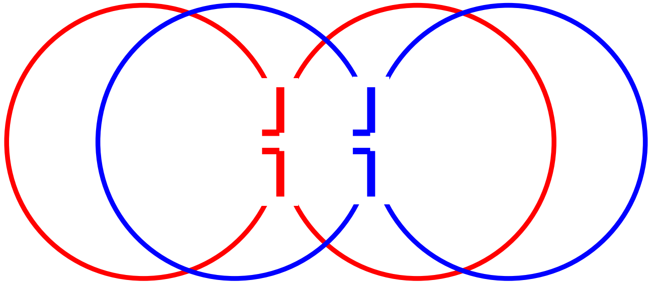
MIMO Antennas for Terminals

The correlation between received signals equals the orthogonality between the radiation patterns.

For antennas located close to each other, orthogonality can be achieved through radiation patterns with different coverage, or different polarization ... but what happens to the balance?



Antennas with the same coverage and polarization provides good balance ... but orthogonality can only be achieved through separation.



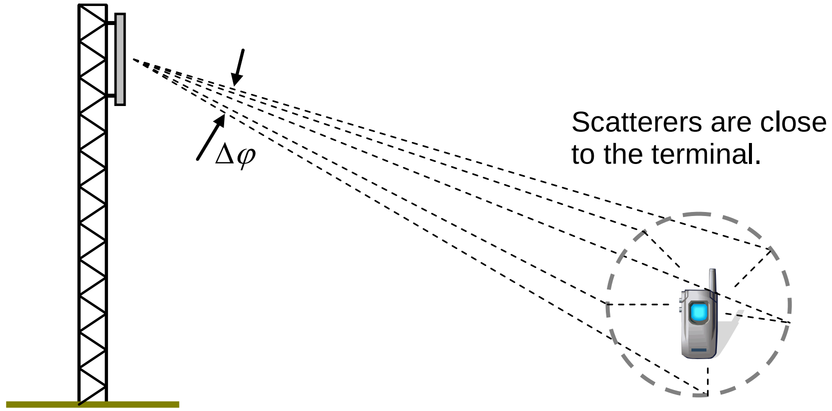
Coherence Distance

The correlation, or coherence, between signals received by two antennas depends on the distance between them and the angular spread of the incident fields.

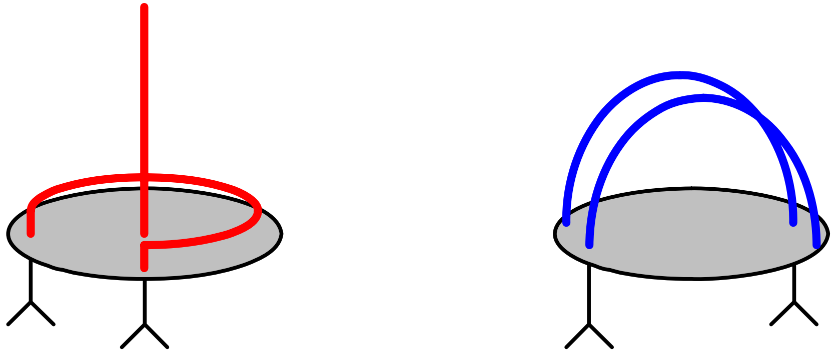
If the 3 dB width of the incident fields is $\Delta\varphi$, the coherence distance is approximately

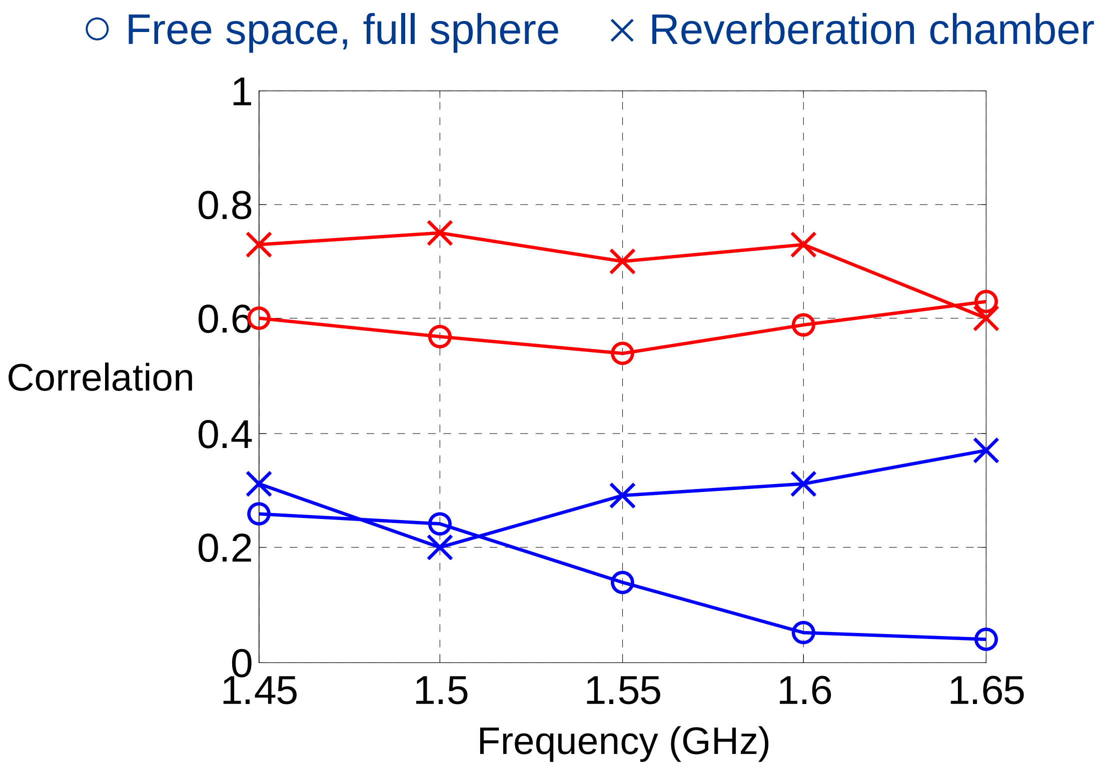
$$D_c \approx \frac{\lambda}{2\sin(\Delta\varphi)}$$

With omnidirectional incidence the coherence distance is about $\lambda/3$.



Correlation Measurements

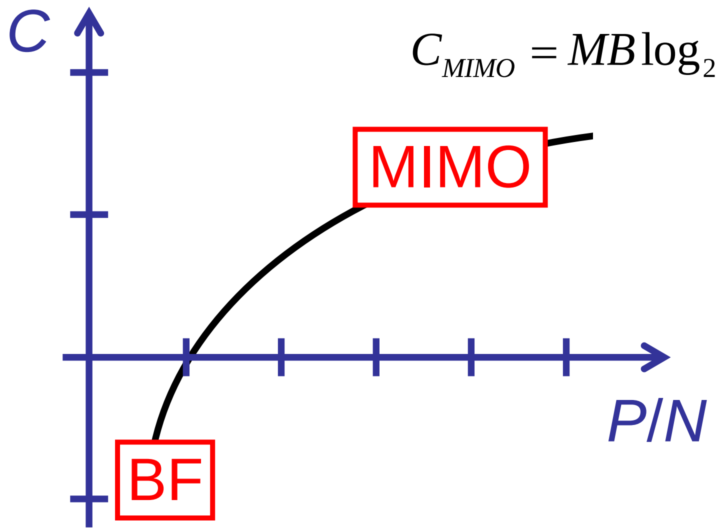




What is Best: MIMO or Beamforming?

Which gives the highest capacity depends on *P/N.*

$$C_{MIMO} = MB\log_2\left(1+\frac{P}{N}\right)$$



$$C_{BF} = B\log_2\left(1+M^2\frac{P}{N}\right)$$

P/N>1: Form as many orthogonal signals as possible and divide the power between them.

P/N<1: Form <u>one</u> signal and put all power in it.

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MIMO and Diversity

Some say that MIMO is transmit and receive diversity in combination.

Others say ”MIMO” when the purpose is to increase channel capacity, and ”diversity” when the purpose is to counteract fast fading, in turn to improve signal reliability.

The increase in capacity that MIMO brings can of course be used to resend data, in order to improve signal reliability.

MIMO Research Issues

- What does MIMO cost in terms of computations, latency, battery life-time, etc?
- Can MIMO encoding/decoding be implemented in hardware?
- How is MIMO performance verified in a lab?
- Can we change an environment to be more MIMO friendly?