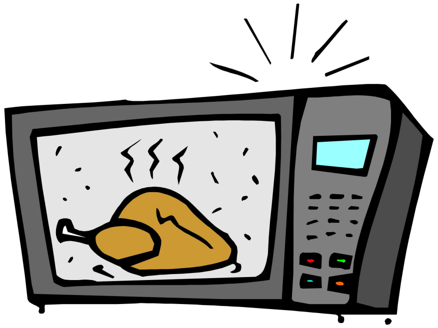
MIMO Systems

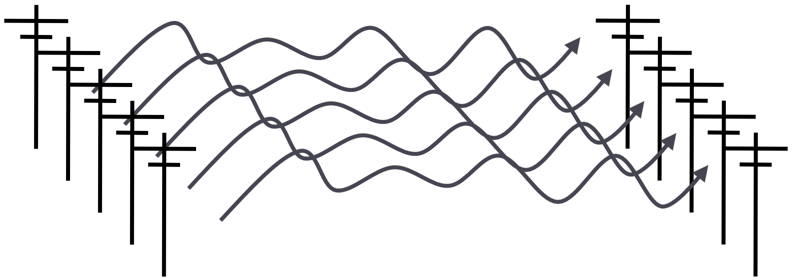
How Do We Increase Throughput in Wireless?

- Increase Power!



- Wired world
  - pull more wires!

- Wireless world
  - use concurrent streams!



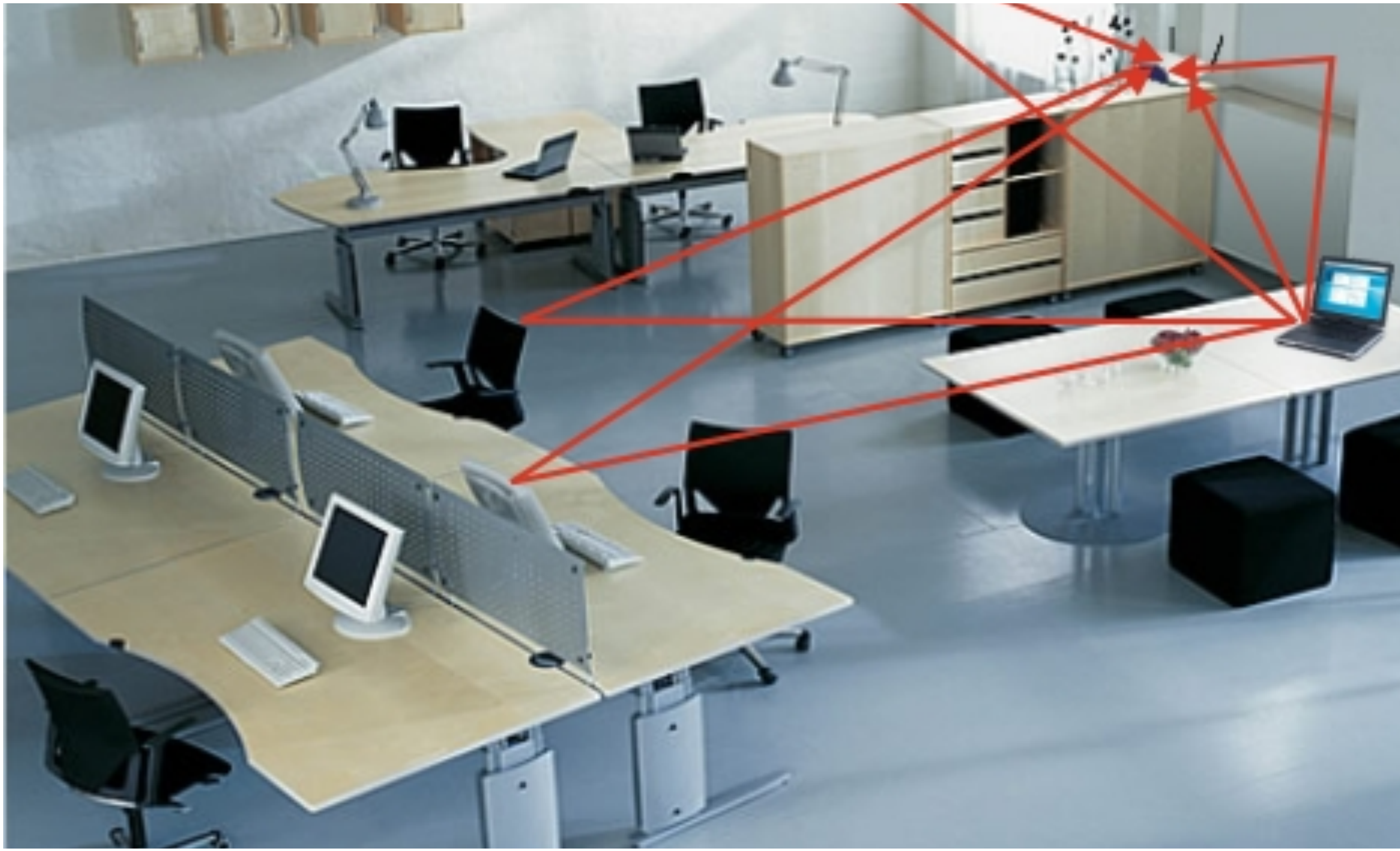
Why MIMO

- Motivation: current wireless systems
  - Capacity constrained networks
  - Issues related to quality and coverage
- MIMO exploits the space dimension to improve wireless systems
  - capacity, range and reliability
- MIMO-OFDM – the corner stone of future broadband wireless access
  - WiFi – 802.11n 802.11ac
  - WiMAX – 802.16e (a.k.a 802.16-2005)
  - 3G / 4G

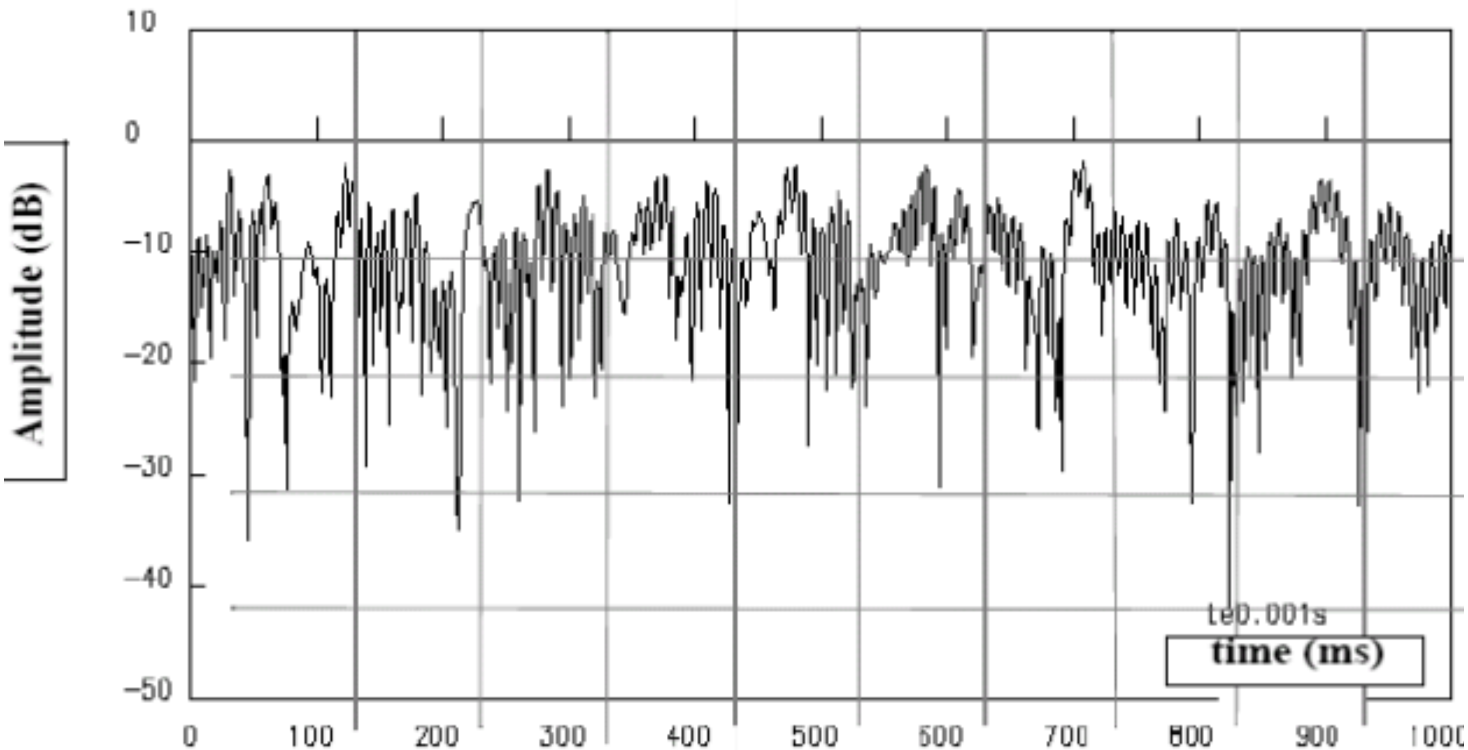
SISO - Single Input/Single Output

Method	Capacity
SISO	$B \log_2(1 + r)$

Multipath is Unavoidable



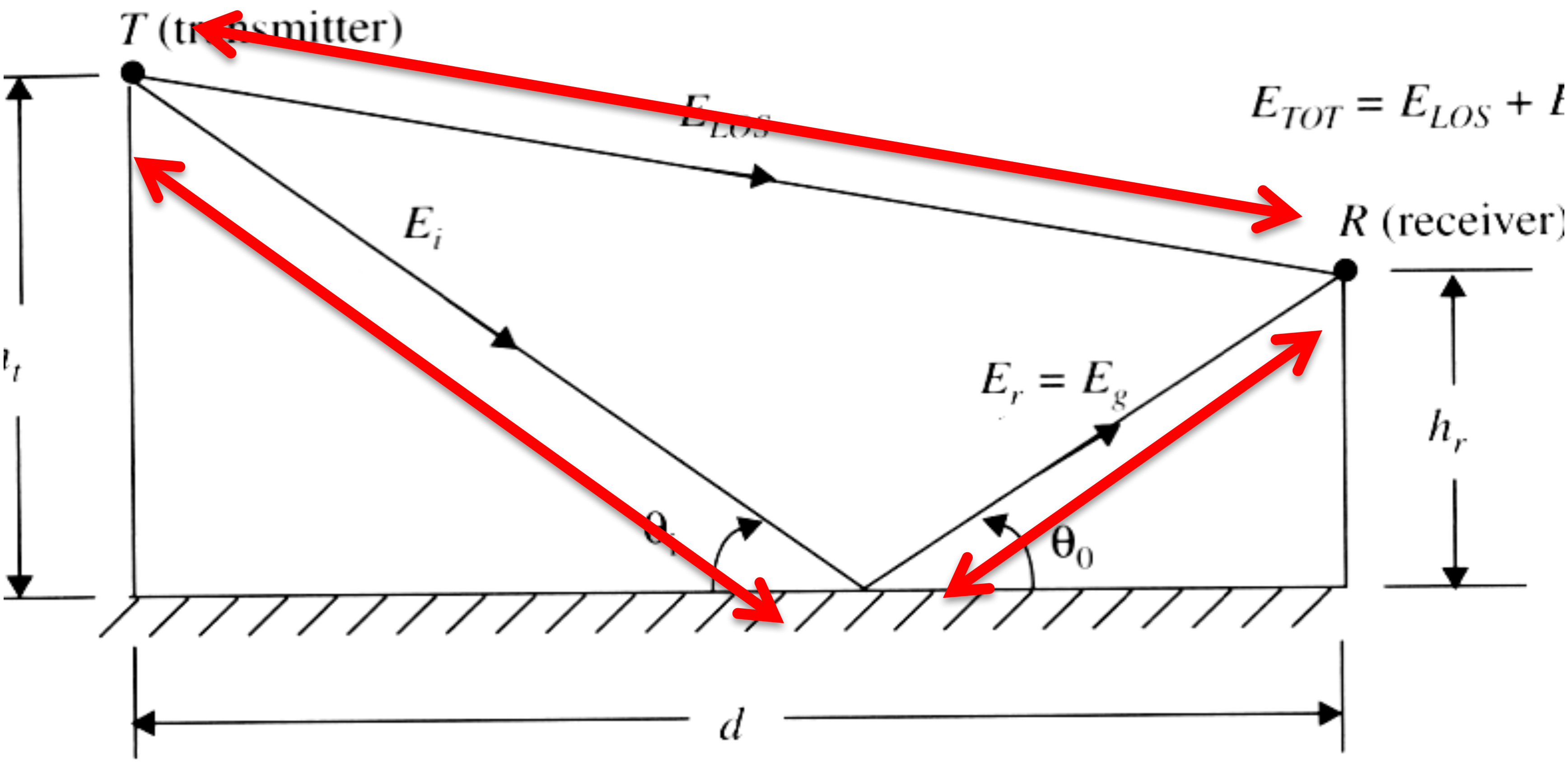
Fading becomes time-variant



Received SNR influenced by:

- Tx and Rx location
- Variation of channel fading over time

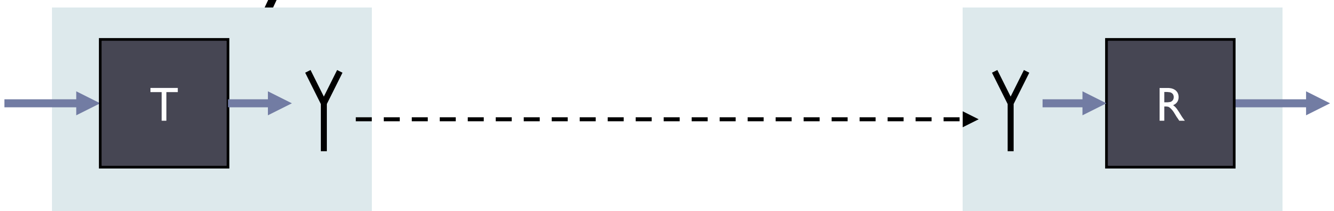
Different Propagation time



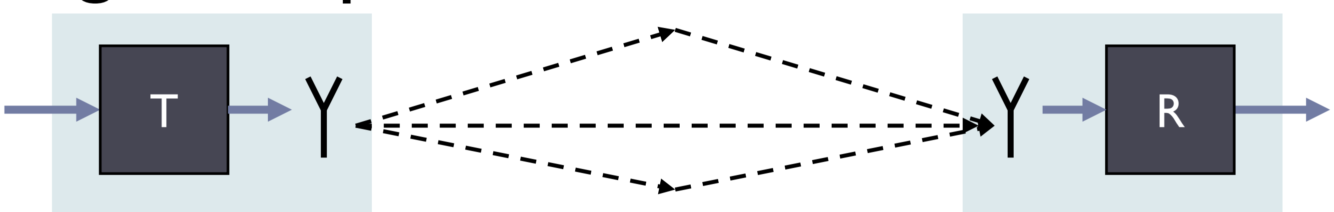
Two-ray ground reflection model.

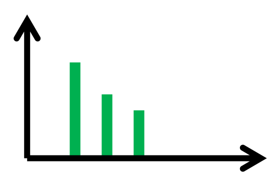
Simple Channel Model

- No diversity:



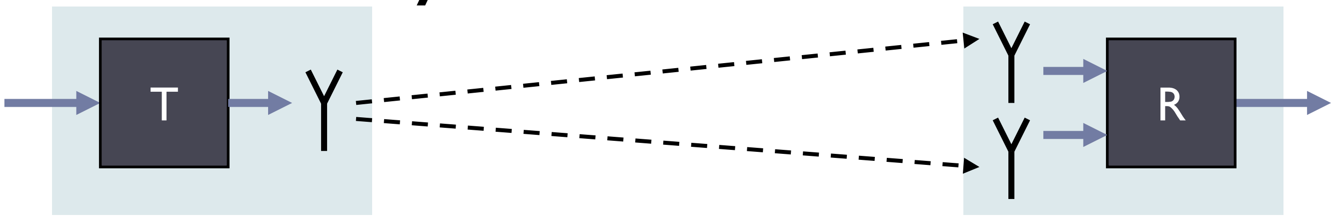
- Adding multi-path:



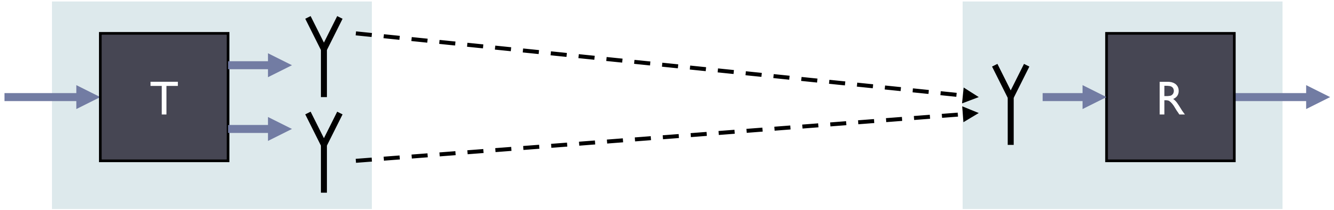


Can we Benefit from This?

- Receive diversity:

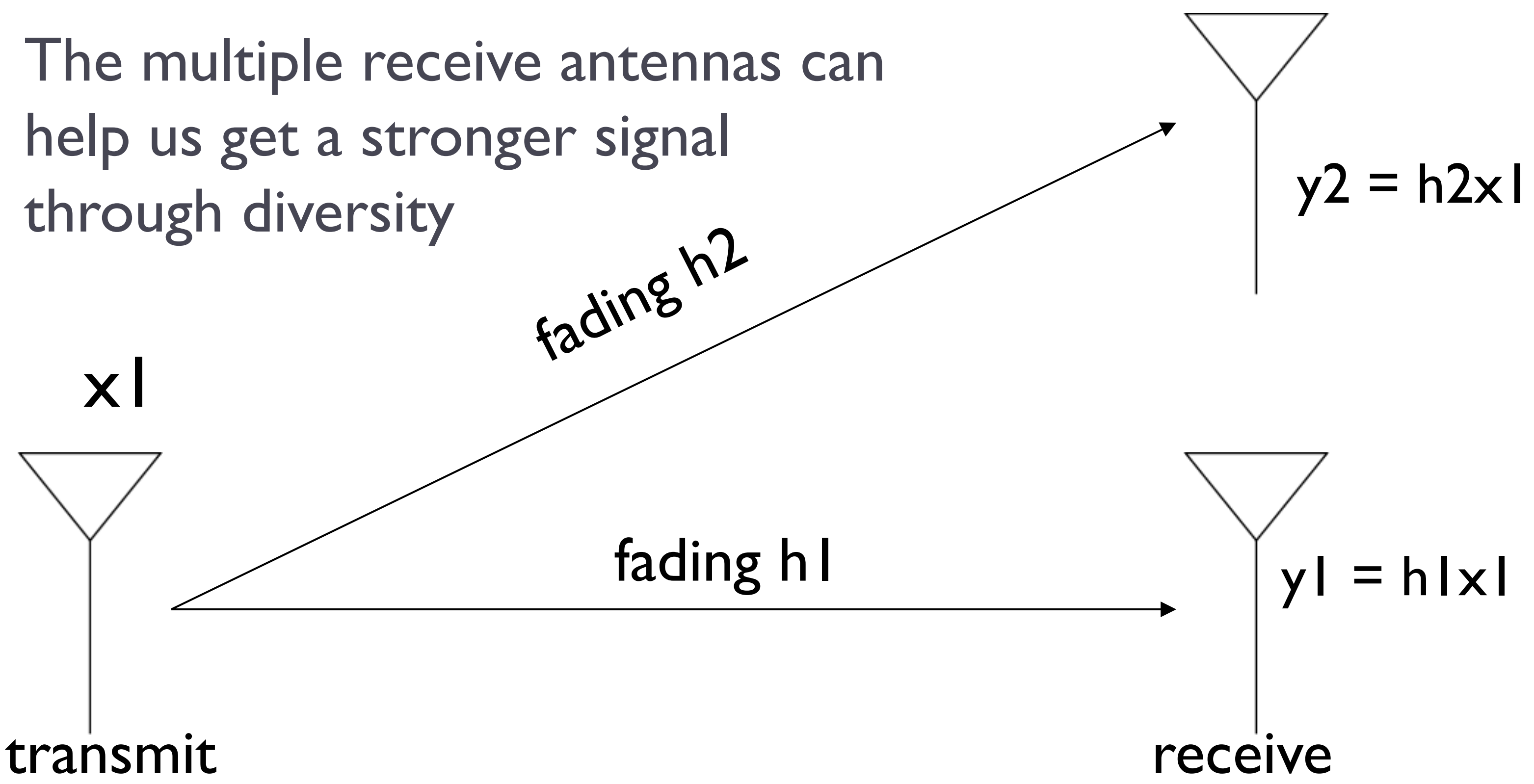


- Transmit diversity:



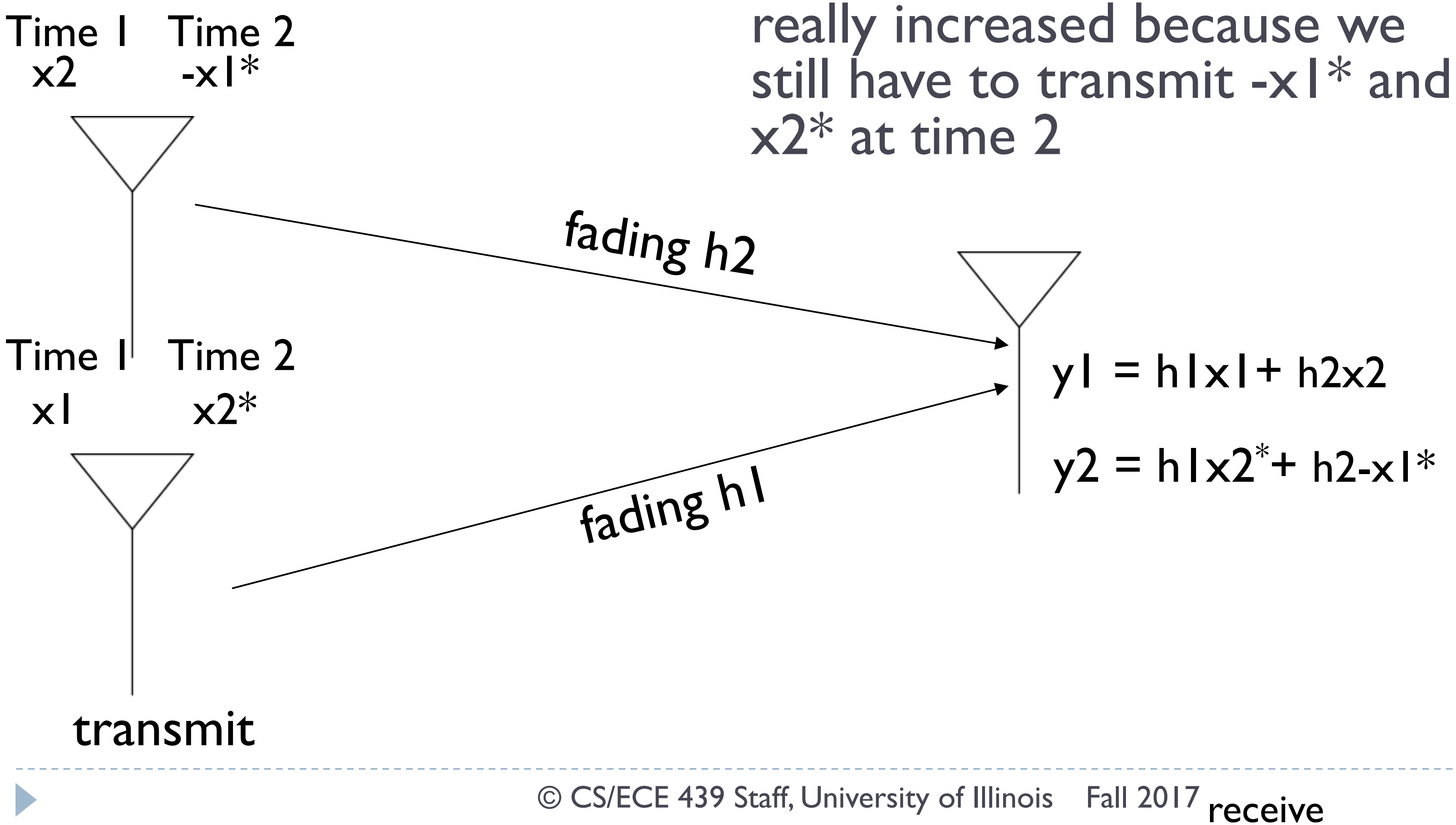
SIMO - Single Input/Multiple Output

- Spatial Diversity
  - The channel capacity has NOT increased
  - The multiple receive antennas can help us get a stronger signal through diversity



MISO - Multiple Input/Single Output

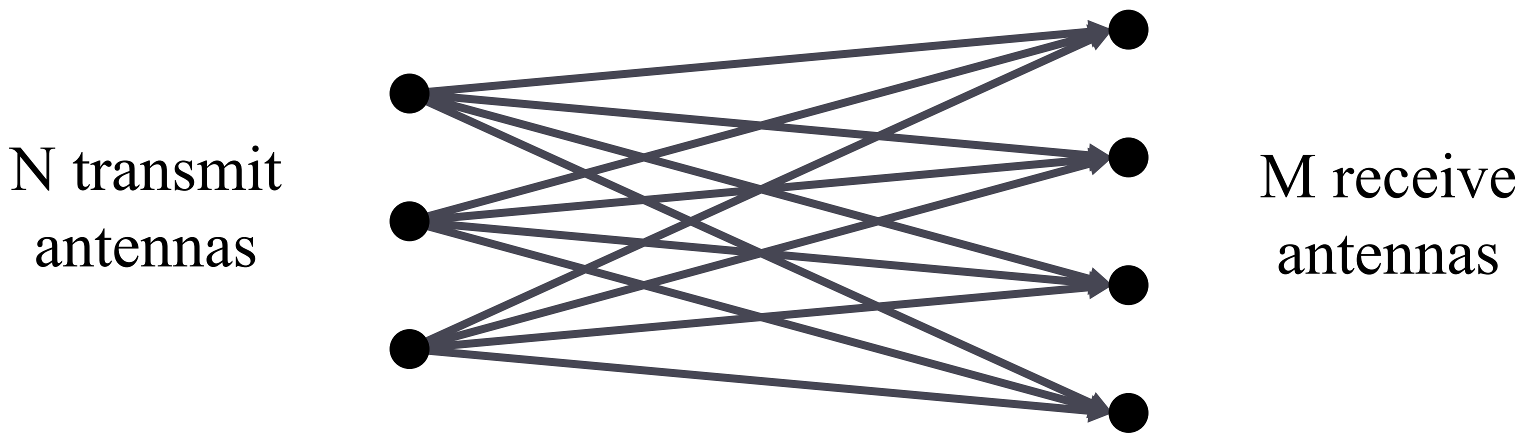
- Time Diversity
  - The channel capacity has not really increased because we still have to transmit -x1* and x2* at time 2



Channel Capacity for SISO, MISO, SIMO

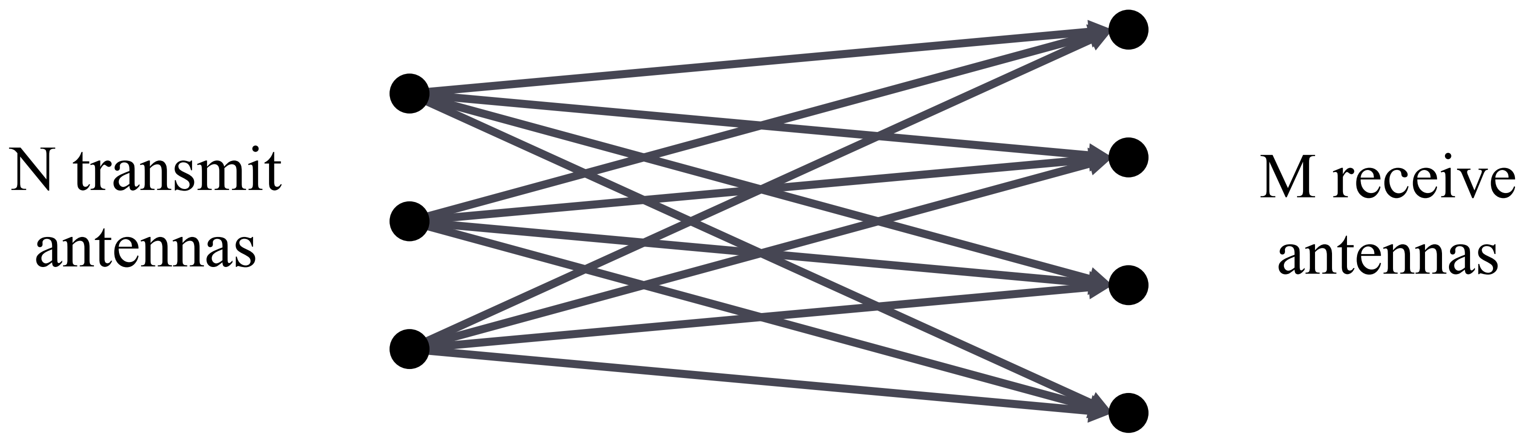
Method	Capacity
SISO	$B \log_2(1 + r)$
Diversity (1xN or Nx1)	$B \log_2(1 + rN)$
Diversity (NxN)	$B \log_2(1 + rN^2)$

MIMO - Multiple Input/Multiple Output



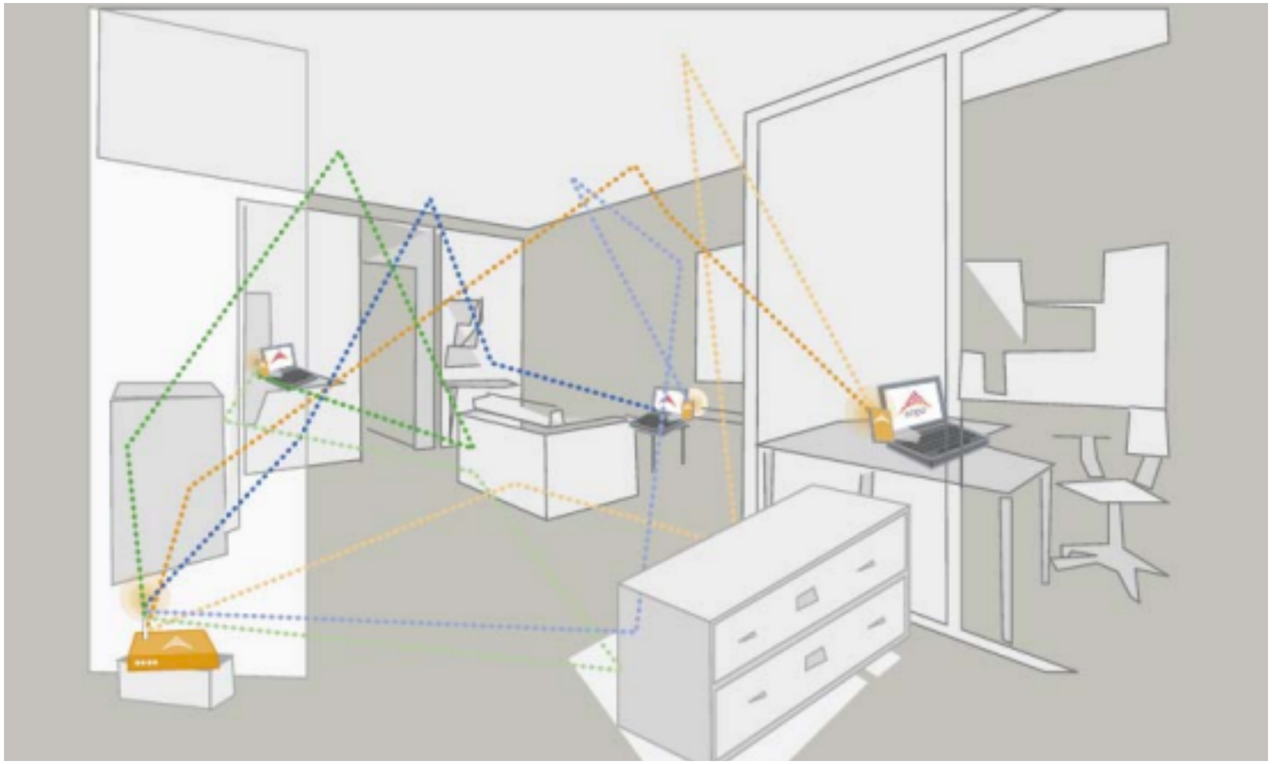
- N x M subchannels
- Fading on channels is largely independent
  - Assuming antennas are separate ½ wavelength or more

MIMO - Multiple Input/Multiple Output



- Combines ideas from spatial and time diversity
  - e.g. 1 x N and N x 1
- Very effective if there is no direct line of sight
  - Subchannels become more independent

MIMO Increases Range

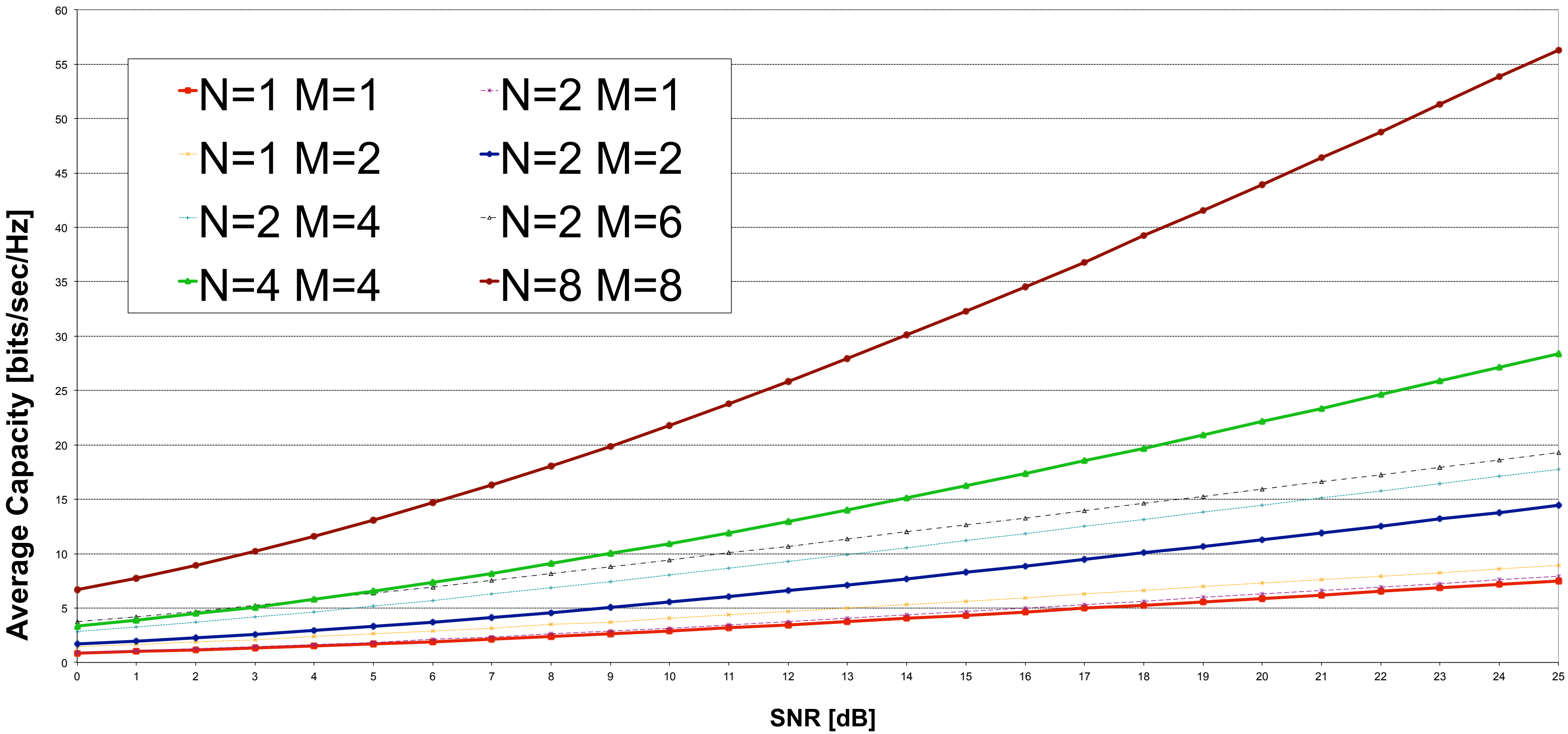


- Each multipath route is separate channel
- Traditional radios are confused by this multipath, while MIMO takes advantage of these "echoes"

Channel Capacity for MIMO

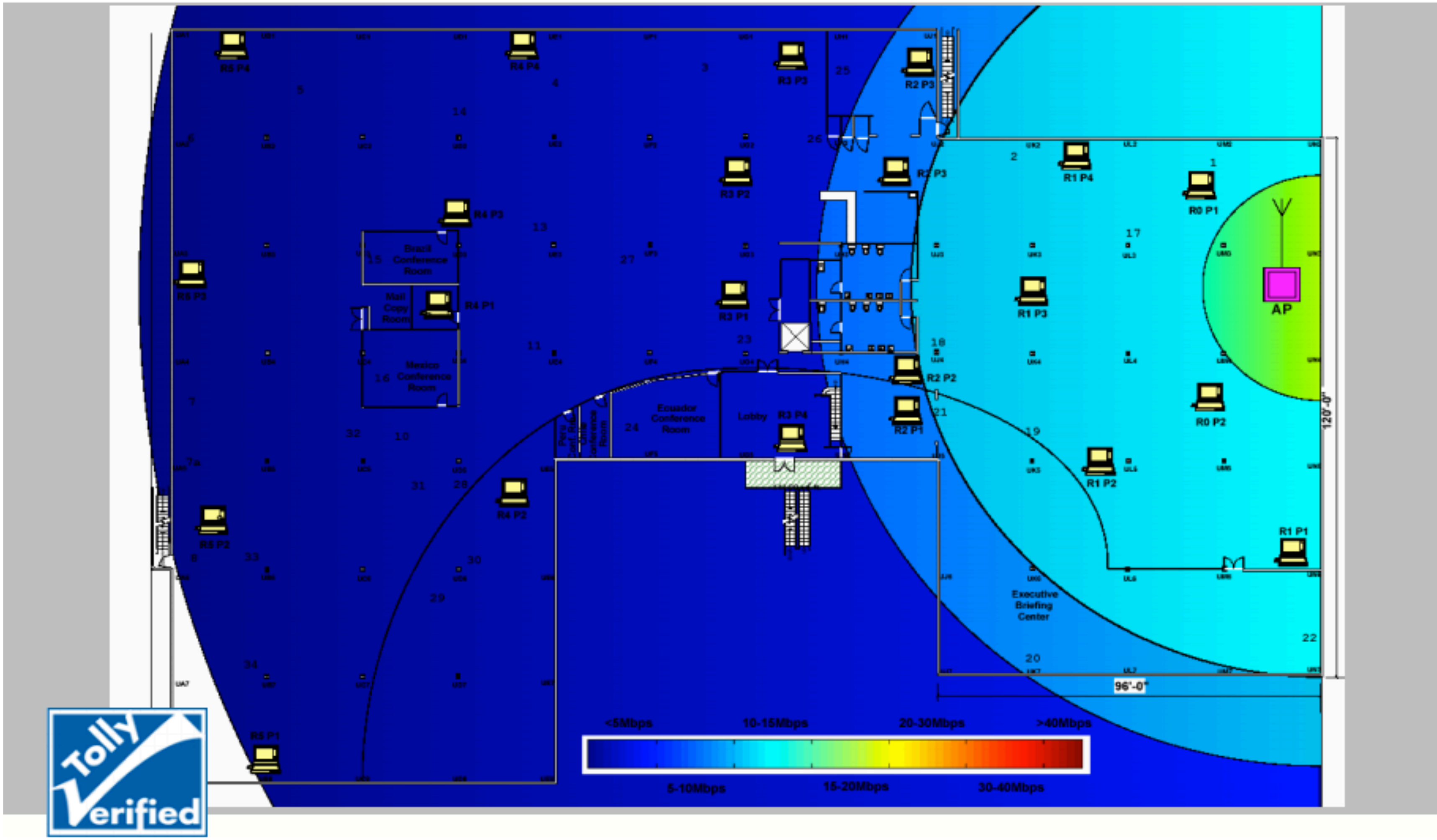
Method	Capacity
SISO	$B \log_2(1 + r)$
Diversity (1xN or Nx1)	$B \log_2(1 + rN)$
Diversity (NxN)	$B \log_2(1 + rN^2)$
Multiplexing	$NB \log_2(1 + r)$

Average capacity of a MIMO Rayleigh fading channel

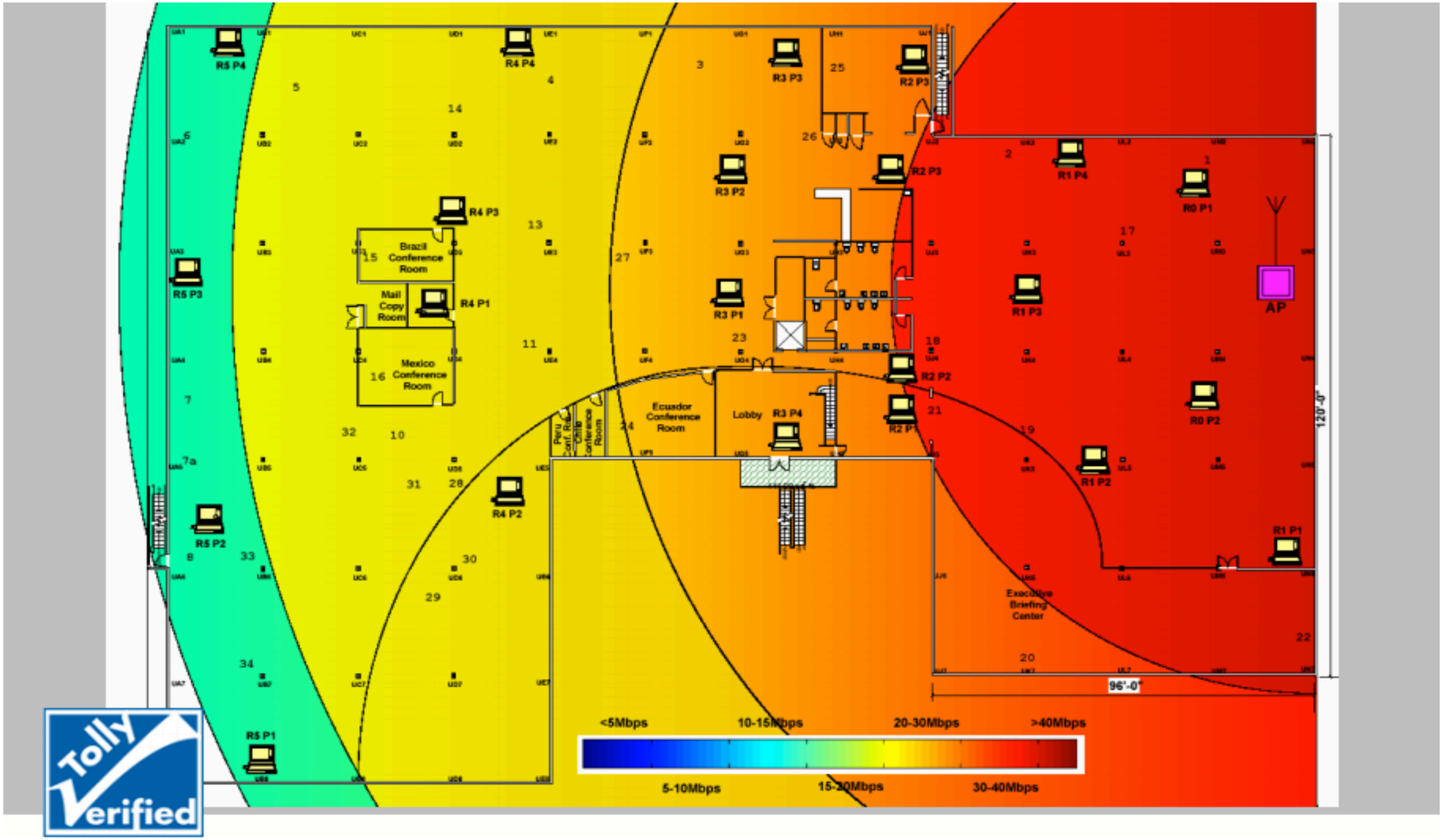


Source: R.A. Carrasco, Space-time Diversity Codes for fading Channel, *Staffordshire University*

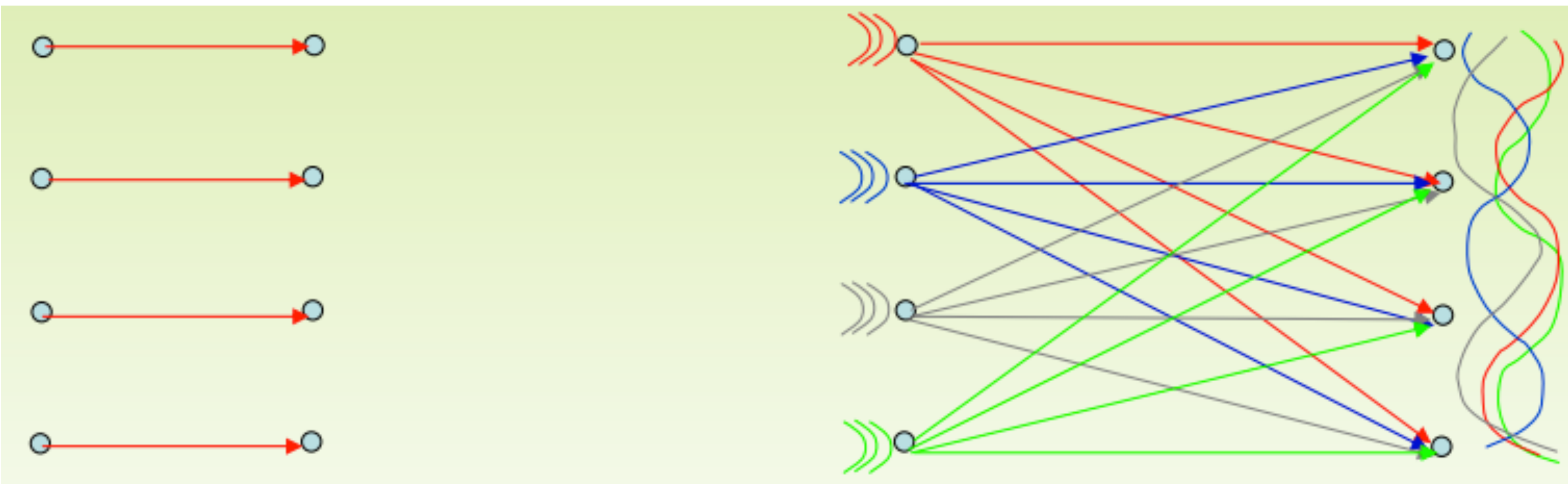
SISO in Office Space



MIMO in Office Space



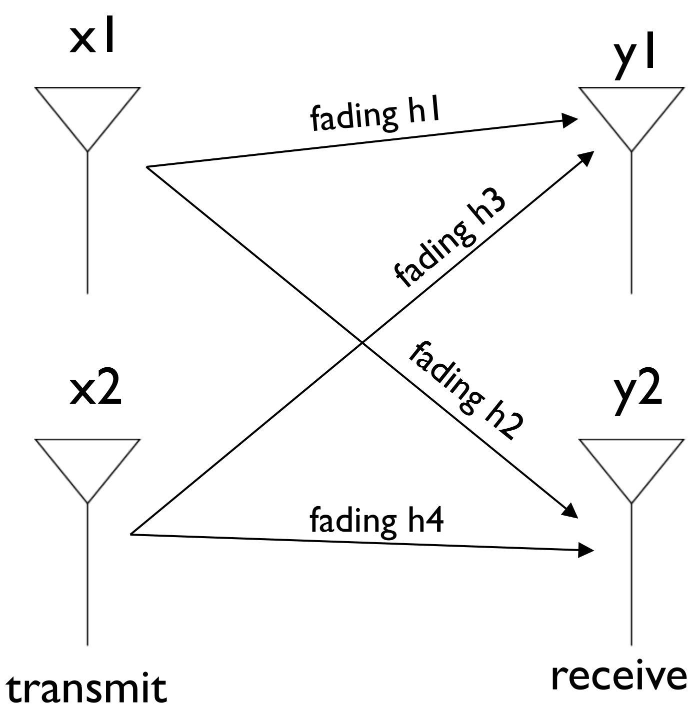
How To Separate Multiple Streams



Laser diodes Wireless Signals

MIMO - An Intuition

- 2 transmitting and 2 receiving antennas adds a degree of freedom
  - Assumption: h coefficients of fading are independent, and uncorrelated.



$$\begin{vmatrix} y_1 \\ y_2 \end{vmatrix} = \begin{vmatrix} h_1 & h_2 \\ h_3 & h_4 \end{vmatrix} \begin{vmatrix} x_1 \\ x_2 \end{vmatrix} + \begin{vmatrix} w_1 \\ w_2 \end{vmatrix}$$

y1 = h1x1+ h2x2

y2 = h3x1+ h4x2

We have a set of linear equations

y = Hx + w

All 2 degrees of freedom are being utilized in the MIMO case, giving us **Spatial Multiplexing.**

Impact of Channel Model

- MIMO performance is very sensitive to channel matrix invertibility
- The following degrades the conditioning of the channel matrix:
  - Antenna correlation caused by:
    - small antenna spacing, or
    - small angle spread
  - Line of sight component compared with multipath fading component:
    - multipath fading component, close to i.i.d. random, is well conditioned
    - Line of sight component is very poorly conditioned.

MIMO Discussion

- Need channel matrix H: use training with known signal

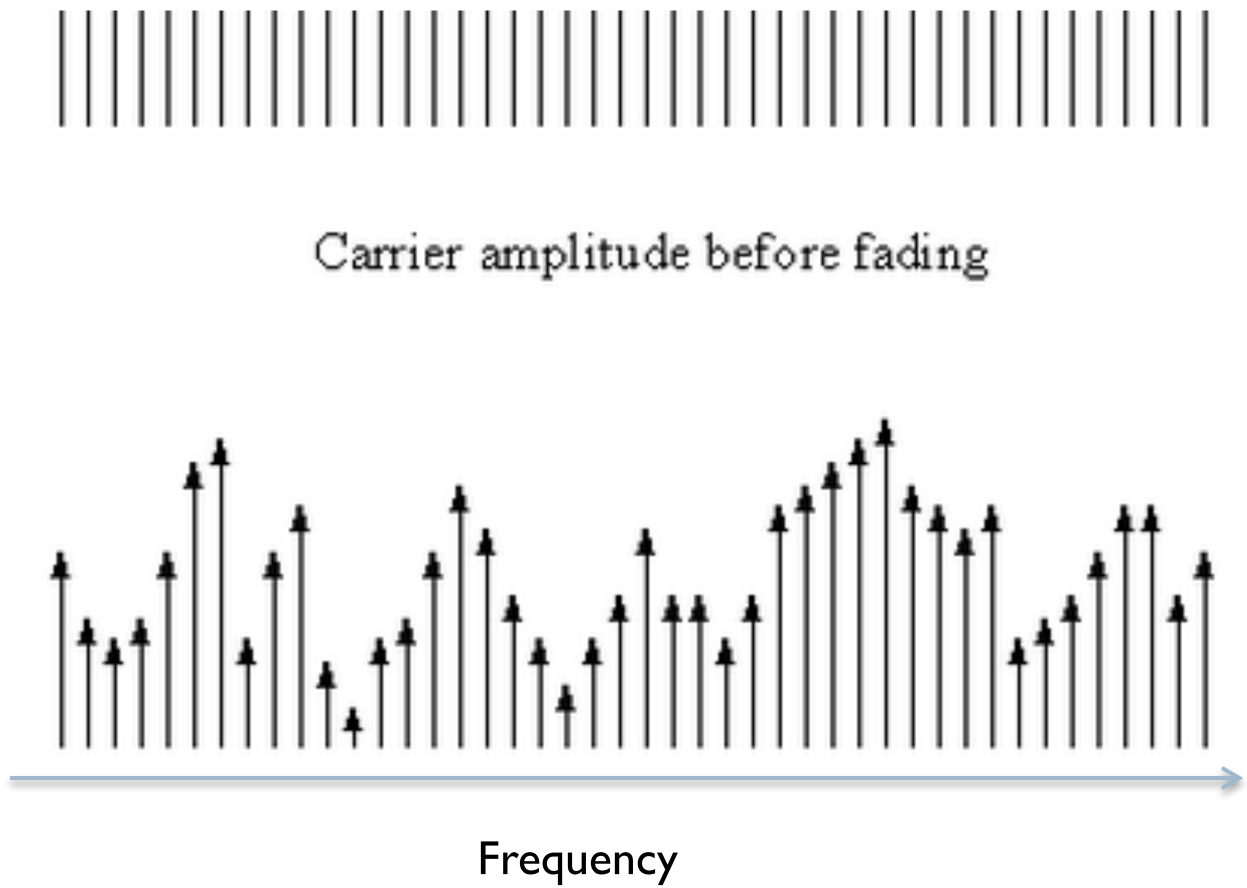
- MIMO is used in 802.11n in the 2.4 GHz band
  - Can use two of the non-overlapping "WiFi channels"
  - Raises lots of compatibility issues
  - Potential throughputs of 100 of Mbps

- IEEE 802.11ac can use up to 160MHz channels

- Not only maximizing throughput between two nodes:
  - Beamforming
  - Multi-User MIMO

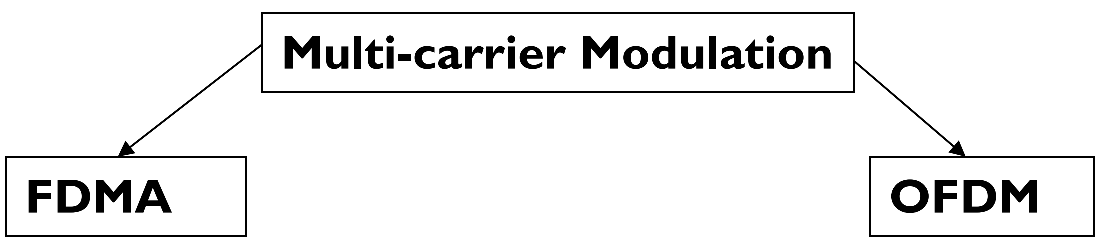
Orthogonal Frequency Division Multiplexing (OFDM)

Frequency Selective Fading



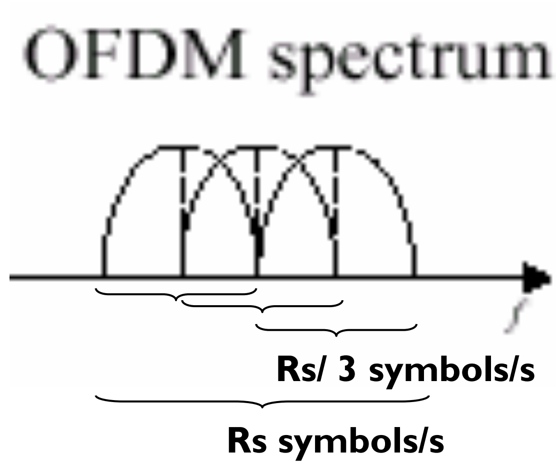
Orthogonal Frequency Division Multiplexing (OFDM)

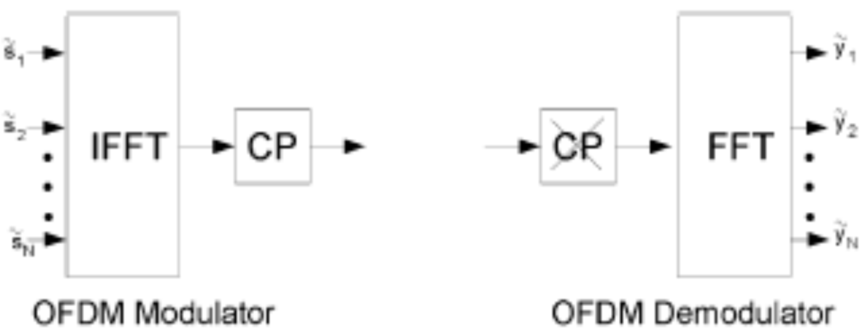
- Frequency selective fading causes Inter-Symbol Interference:
  - heavy degradation
- Most popular solution to compensate for ISI: equalizers
- Hdata rates (i.e.> 1 Mbps), equalizer complexity grows:
  - channel changes before you can compensate for it!
- Alternate solution:
  - Multi-carrier Modulation (MCM)



OFDM Spectral Efficiency

- The spectral efficiency of an OFDM-(PSK/ASK) system is same as compared to using the (PSK/ASK) system alone
  - Spec eff = log 2 M bits/s/Hz
- However, makes the difference between unusable and good channel

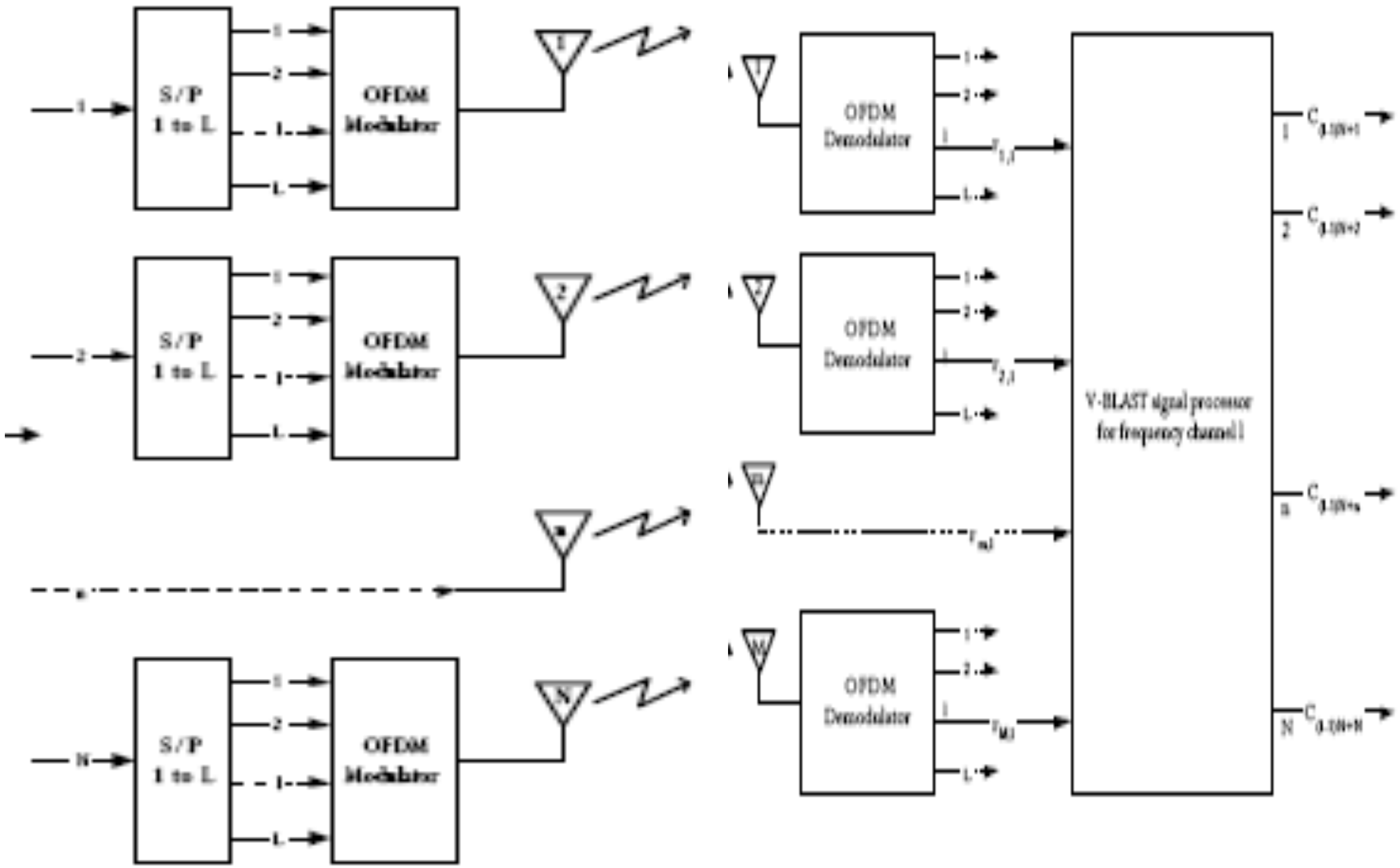




Adding the cyclic prefix

- easy to implement
- Used in IEEE 802.11A, .11G, HiperLAN, IEEE 802.16

MIMO-OFDM


S/P
1 to L
OFDM
Modulator
OFDM
Demodulator
V-BLAST signal processor
for frequency channel l

Channel State Information Matrix

- In a MIMO-OFDM system:
  - M Transmitting antennas
  - N Receiving antennas
  - Q subcarriers per channel

H = M x N x Q elements (complex values)

$\mathbf{h}_{m,n,q}$ is a complex number which represents the phase shifting and fading for a specific sub-channel