THE NON-ENGINEER’S INTRODUCTION TO MIMO AND MIMO-OFDM

http://www.mimo.ucla.edu

Various schemes that employ multiple antennas at the transmitter and receiver are being considered to improve the range and performance of communication systems. By far the most promising multiple antenna technology today happens to be the so called multiple-input multiple-output (MIMO) system. MIMO systems employ multiple antennas at both the transmitter and receiver as shown in Figure .

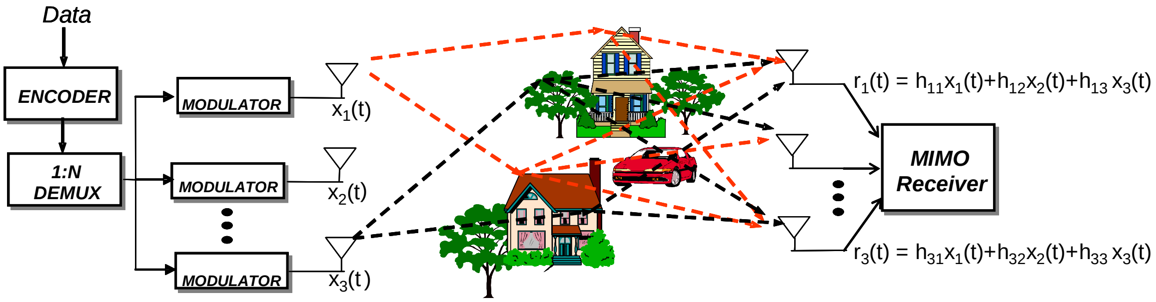

Figure 1 A Generic MIMO system

They transmit independent data (say $x_1, x_2, \ldots, x_N$) on different transmit antennas simultaneously and in the same frequency band. At the receiver, a MIMO decoder users M≥N antennas. Assuming N receive antennas, and representing the signal received by each antenna as r_j we have:

$$\begin{aligned}
r_1 &= h_{11}x_1 + h_{12}x_2 + \cdots + h_{1N}x_N \\
r_2 &= h_{21}x_1 + h_{22}x_2 + \cdots + h_{2N}x_N \\
&\vdots \\
r_N &= h_{N1}x_1 + h_{N2}x_2 + \cdots + h_{NN}x_N
\end{aligned}$$

As can be seen from the above set of equations, in making their way from the transmitter to the receiver, the independent signals {x1, x2, …, xN} are all combined. Traditionally this “combination” has been treated as interference. However, by treating the channel as a matrix, we can in fact recover the independent transmitted streams {xi}. To recover the transmitted data stream $\{x_i\}$ from the $\{r_j\}$ we must estimate the individual channel weights h_{ij}, construct the channel matrix ***H***. Having estimated ***H***, multiplication of the vector ***r*** with the inverse of ***H*** produces the estimate of the transmitted vector ***x***. This is equivalent to solving a set of N linear equations in N unknowns.

Because multiple data streams are transmitted in parallel from different antennas there is a linear increase in throughput with every pair of antennas added to the system. An important fact to note is that unlike traditional means of increasing throughput, MIMO systems do not increase bandwidth in order to increase throughput. They simply exploit the spatial dimension by increasing the number of unique spatial paths between the transmitter and receiver. However, to ensure that the channel matrix is invertible, MIMO systems require an environment rich in multipath. The table below shows the tremendous improvement in 99th percentile capacity of a wireless system employing MIMO based communications. A reasonable 5x5 system can provide 40x increase in capacity for the same signal to noise ratio (SNR).

99-percentile Capacity (b/s/Hz)		
	SNR = 12 dB	**SNR = 24 dB**
(1,1)	***0.3***	***1.8***
(5,5)	***12.5***	***28.5***
(10,10)	***29.2***	***62.0***

The above table suggests that without increasing bandwidth (a very expensive commodity) or total transmit power, we can achieve substantial throughput improvement by going to MIMO. This has significant ramifications as it suggests that operators can provide broadband services within the current spectrum that they have purchased from the FCC. Staying at the current carrier frequencies implies that: (a) Signals can propagate further thus reducing the cost of overall network deployment, and; (b) RF subsystems can be built using today's well understood and inexpensive processes.

MIMO-OFDM combines OFDM and MIMO techniques thereby achieving spectral efficiency and increased throughput. A MIMO-OFDM system transmits independent OFDM modulated data from multiple antennas simultaneously. At the receiver, after OFDM demodulation, MIMO decoding on each of the subchannels extracts the data from all the transmit antennas on all the subchannels. The block diagram of a MIMO-OFDM system in shown in Figure .

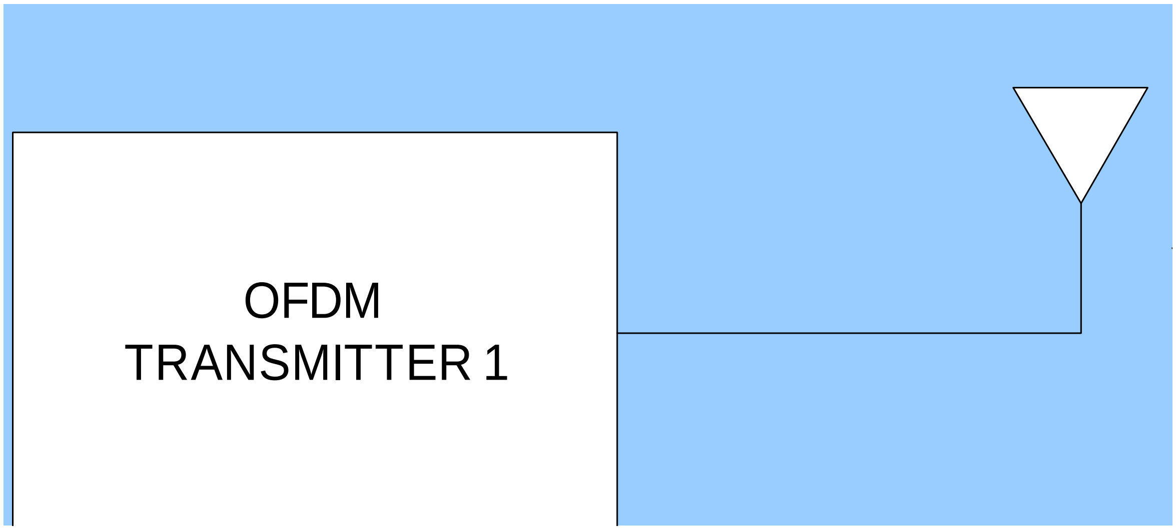

Figure 2 A MIMO-OFDM system

INTRODUCTION TO OFDM

Orthogonal Frequency Division Multiplexing (OFDM) is a popular modulation scheme that is used in wireless LAN standards like 802.11a, g, HIPERLAN/2 and in the Digital Video Broadcasting standard (DVBT). It is also used in the ADSL standard, where it is referred to as Discrete Multitone modulation. OFDM modulation divides a broadband channel into many parallel subchannels. This makes it a very efficient scheme for transmission in multipath wireless channels. The use of an FFT/IFFT pair for modulation and demodulation make it computationally efficient as well.

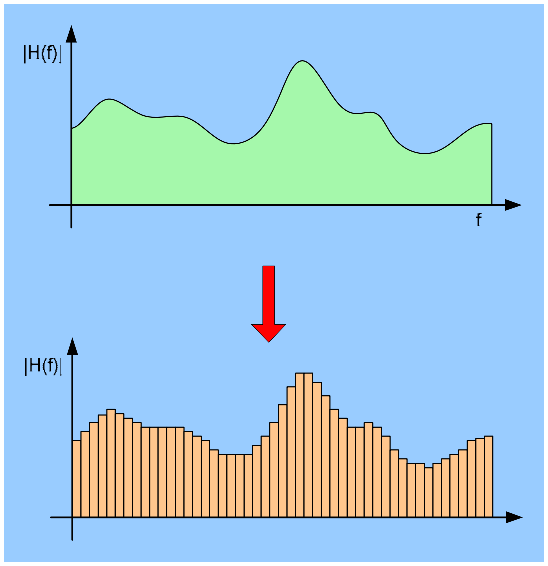

Figure 3 A broadband channel divided into many parallel narrowband channels

The transmitted signals arrive at the receiver after being reflected from many objects. Sometimes the reflected signals add up in phase and sometimes they add up out of phase causing a "fade". This causes the received signal strength to fluctuate constantly. Also, different subchannels are distorted differently as shown in Figure . An OFDM receiver has to sense the channel and correct these distortions on each of the subchannels before the transmitted data can be extracted. OFDM is effective in correcting such frequency selective distortions.

OFDM has many advantages over other transmission techniques. One such advantage is high spectral efficiency (measured in bits/sec/Hz). The "Orthogonal" part of the name refers to a precise mathematical relationship between the frequencies of the subchannels that make up the OFDM system. Each of the frequencies is an integer multiple of a fundamental frequency. This ensures that even though the subchannels overlap they do not interfere with each other. This results in high spectral efficiency.

The use of IFFT and FFT for modulation and demodulation results in computationally efficient OFDM modems. The block diagram of an OFDM modulator and demodulator are shown in Figure .

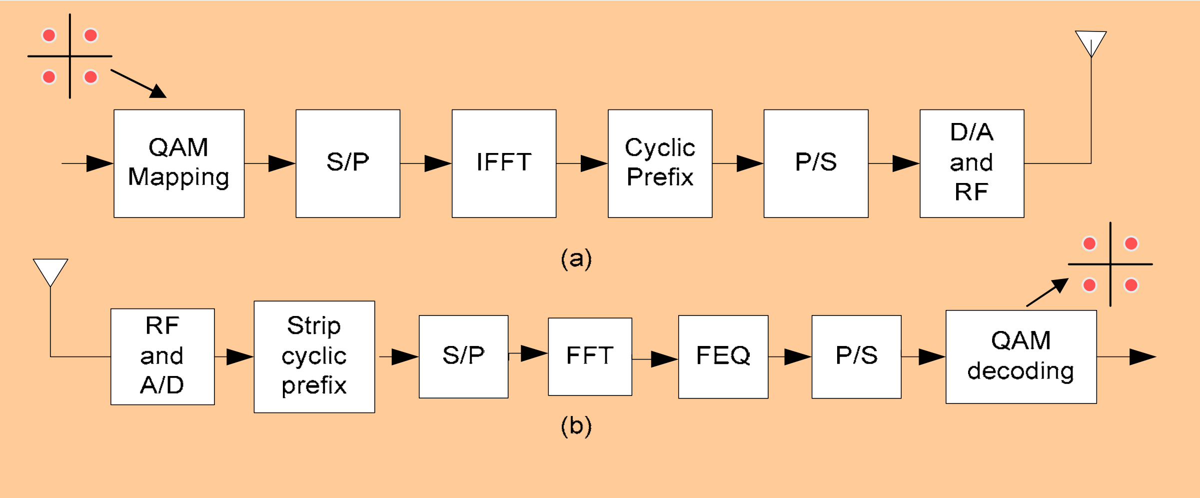

Figure 4 An OFDM (a) Modulator and (b) Demodulator