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Antenna selection for performance enhancement of MIMO Technology in Wireless LAN

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Abstract

The demand for Wireless Network hardware has experienced phenomenal growth during the past several years. The most commonly known component to enhance the performance of Wireless network is Multiple Input Multiple Output (MIMO) system. It exploits the radio channel by means of multi-path propagation; where the transmitted information bounces off walls, doors and other objects before reaching the receiving antennas multiple times via different routes and with different time delay. MIMO harnesses multi-path with a technique known as space division multiplexing. The transmitting Wireless device actually split a data stream into multiple parts called spatial streams, for transmission. This enhances the data rate. There are two features that focus on improving MIMO performance; called beamforming and diversity. By increasing the number of physical antennas at both transmitter and receiver enhances the performance of MIMO system. To achieve the desired performance the system can be designed in such a way that the number of physical antenna selection at both transmitter and receiver should maximize the performance and optimize the entire system cost.

Keywords: *Wireless Network, MIMO, Spatial diversity, QoS and OFDM.*

1. Introduction

There are intrinsic differences between a wired network and a wireless network with the ability to instantaneously setup and tear down a network probably being one of the most notable differences. Unlike a wired network, where resources are always available and can be dependent on, a wireless network can make no guarantees, about network resources. Most wireless technologies can support considerably less band-width than that provided by wired technologies. Available bandwidth is a function of the wireless medium, and the condition of the environment in which the wireless device is deployed. Parameters like distance, fading, delay spread, Doppler-effect, interference by other wireless devices and noise, obstacles, blind spots, atmospheric conditions etc., can change the network behavior unpredictably. Such adverse conditions have to be over come in order to make QoS viable in a wireless network. The challenge is to provide QoS in a wireless environment, because of the constant change in the property of the wireless media. It is understood that by increasing the number of antenna elements both at the transmitter and the receiver side, the performance and the receiver capacity of the channel can be enhances. This system is called Multiple Input Multiple Output (MIMO) system. It comprises multiple antennas both at transmission and receiver side.

- **Multi-path environment**

  In the transmission side, MIMO encodes a single high-rate data stream by splitting it and transmitting it across spatially separated antennas as in fig. 1. Having two streams instead of one, enables either the delivery of twice the throughput by keeping the same rate for each of the streams, or extending the reach of the original stream since each of the lower-rate streams can use lower constellations and require a lower Signal-to-Noise Ratio (SNR) to be recovered.

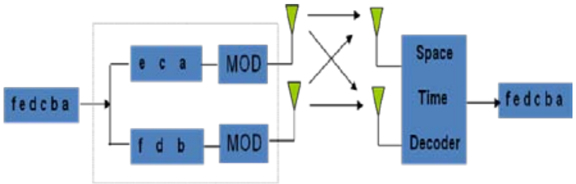

Fig. 1. Data encoding in MIMO system

The implementation cost of a MIMO system increases as the number of antennas increases. If we map the cost versus performance it is clear that, after a specific numbers of transmitting and receiving antennas the performance will remain stable and cost increases. In this paper we analyzed the performance and cost of MIMO system with different combinations of transmitting and receiving antennas.

We organize the rest of this paper as follows; section II provides a background of the need for Quality of Service (QoS) in a WLAN. In section III we explained the role of MIMO in enhancing the performance of the wireless channel. Section IV gives details about the QoS issues in wireless networks and MIMO solution, and section V illustrates the optimal number antennas required for a MIMO system followed with the conclusion.

2. Need for QoS in WLAN

A signal transmitted in a wireless network is susceptible to all kinds of fadings in an underlying channel. This will results in the variation of bandwidth, latency in data delivery in a wireless network and makes QoS guarantees very important. An intelligent adaptive QoS solution could be the answer to mitigate the unpredictable nature of the medium leading to the signal fading and better utilization of the network channel. Some of the practical applications of QoS requirements are; Video streaming, audio streaming, 1394 serial bus transmission, VoIP, wireless home networking, etc. MIMO is one of the technologies to garble these QoS issues. In which using multiple antennas at both transmitter and receiver ends we can exploit the wireless channel much more efficiently. Here multiple data streams are sent from the number of transmitters to the receivers using multiple channels, which potentially enhancing the data rate at the receiver. This MIMO advantage can be achieved without requiring extra bandwidth and power. The performance of MIMO is closely related to the multipath richness of the environment when the system is employed.

3. Multiple Input Multiple Output (MIMO)

- **Higher throughput and extended reach**

  To meet the key requirements such as higher rate, extended range, and better spectral efficiency MIMO utilizes spatial multiplexing [2] (multiple antennas) on top of orthogonal frequency division multiplexing (OFDM) [8]. Coding the information across both the spatial and spectral domains by using multiple transmit and receive antennas, combined with OFDM modulation on each antenna, increases the diversity and with it the robustness. This enables MIMO to withstand channel impairments such as inter-symbol interference (ISI) and other interferences.

MIMO takes the advantage of multipath propagation to increase throughput, range/coverage, and reliability. Rather than combating multipath signals, MIMO achieves this by sending and receiving more than one data signal in a same radio channel at concurrently to accomplish this.

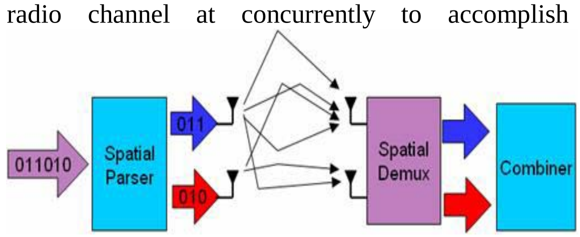

Fig.2. Multipath reflections

Communication using MIMO is the only way known to improve all three basic link performance parameters such as range, speed and reliability.

3.1 Significance of MIMO

In MIMO one coherent radio up-converter and antenna are used to transmit the multiple signals and more than one coherent radio down-converter and antenna receives the multiple signals. Using MIMO, the maximum data rate per channel grows linearly with the number of data streams transmitted in the same channel.

In addition to multiplying data rates within the same channel, properly designed MIMO systems can simultaneously improve coverage and reliability.

Wireless connection using MIMO systems enables increased spectral efficiency and link reliability for a given total transmitted power. Increased capacity is achieved by introducing additional spatial channels, which are exploited using space-time coding [4]. The spatial diversity [2] improves the link reliability by reducing the adverse effects of link fading and shadowing. The choice of coding and the resulting performance improvement are dependent upon the channel phenomenology.

MIMO systems uses an array of transmit and receive antennas for enormous gains in spectral efficiency by exploiting a rich multi-path fading environment.

4. QOS Issues in Wireless Networks and MIMO solutions

The adoption of multiple antenna techniques (MIMO) is expected to enhance the QoS of the wireless channel and the realization of re-configurable, robust and transparent operation across multiple antenna-technology wireless networks.

4.1 Shannon capacity for a wireless channels

If there is a single channel between the transmitter and receiver antenna, which is corrupted by an Additive White Gaussian Noise (AWGN) at a level of SNR denoted by ρ, the channel capacity is represented as;

$$C = \log_2(1+\rho) Bits/Sec/Hz \qquad (1)$$

where $\rho = \frac{E_s}{\sigma^2}$ (the channel SNR). The signals in a wireless channels are time varying and subject to random fading. In such a time varying and fading channel the capacity of the channel is $C = \log_2(1+\rho|h|^2) Bits/Sec/Hz$. (2)

Where *h* is the unit power complex Gaussian amplitude of the channel at an instant observation. This expression gives the capacity of wireless systems with single transmitter and receiver channel; single input single output (SISO) case. The capacity of the SISO channel is;

$C_{SISO} = \log_2\left\{1+\frac{P}{2\sigma^2}\right\} Bits/\sec/Hz$. It is clear that capacity takes at time very small value due to fading events.

The statistics can be extracted from the random capacity related with different practical design aspects. The average capacity ' C_a ' average of all occurrences of *C* gives information on the average data rate offered by the link. The outage capacity C_o is defined as the data rate that can be guaranteed with a high level of capacity for reliable service; $prob\{C \geq C_o\} = 99.9\%$. Using a MIMO system with multiple antennas at both the ends we can achieve transmit and receive diversity. It results in a significant increase in both C_a and C_o.

4.2 Using multiple antennas - Transmit and Receive diversity

A receive diversity includes 'N' antennas at the receiving end and a single antenna (SIMO) at the transmitter, the channel is now included with 'N' distinct coefficients $h = [h_1, h_2, ...h_N]$, Where h_i is the channel amplitude from the transmitter to the i^{th} receiver antenna, where $i = 1,2,3,......N$ .The expression for the random capacity can be generalized to,

$$C = \log_2(1+\rho hh^*) Bits/Sec/Hz . \qquad (3)$$

Where * denote the transpose conjugate.

In transmit diversity we will have M antennas at the transmitters and one antenna at the receiver [1]. As the number of antennas are varied we can find that there is a reduction in fading and increase in SNR. This clearly indicates that by having transmit and receive diversity with the help of multiple antennas both at transmitting and receive ends will enhance the outage capacity performance, attributable to the spatial diversity effect but this effect saturates with number of antennas.

4.3 Capacity of MIMO link:

The MIMO system considered here is having M transmitters and N receivers. The channel is represented by a matrix of size $[M \times N]$ with random independent element dented by H. The capacity is derived form the expression, $C = \log_2[\det(I_M + \frac{\rho}{N} HH^*)]$ (4)

where ρ, is the average SNR at any receiving antenna. The advantage of the MIMO can be significant both in average and outage capacity. For a large number, of antennas where M=N, the average capacity increases linearly with M; $C_a \approx M \log_2(1+\rho)$ In general the capacity will grow proportional with the smallest number of antennas $\min(M,N)$ outside and no longer inside the log function. Therefore in theory and in the case of idealized random channel, limits capacities can be realized, provided we can afford the cost and space of many antennas and RF chains.

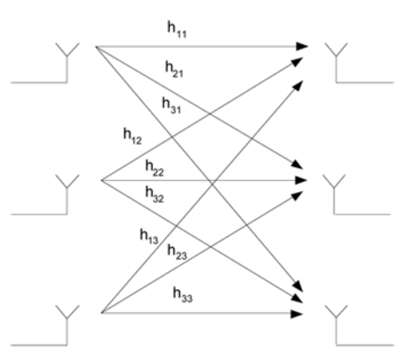

Fig. 3, MxN channel transmission in MIMO

Where '*x*' *is* the channel input at the transmitter and 'y' is the output at the receiver and *n* is the noise corresponding to the receive antennas. The channel fading in a non-line of sight (NLOS) link is represented as *h* and h_{ij} is the fading of the channel corresponding to the path from transmit antenna *j* to receive antenna *i*. $y = Hx + n$. This is

$$\begin{bmatrix} y_1 \\ y_2 \\ . \\ . \\ . \\ y_N \end{bmatrix} = \begin{bmatrix} h_{11}h_{12}..........h_{1M} \\ h_{21}h_{22}..........h_{2M} \\ .... \\ h_{N1}h_{N2}........h_{NM} \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \\ . \\ . \\ . \\ x_M \end{bmatrix} + \begin{bmatrix} n_1 \\ n_2 \\ . \\ . \\ . \\ n_N \end{bmatrix} \quad (6)$$

Where

$$\underline{y} = \begin{bmatrix} y_1 \\ y_2 \\ \vdots \\ y_N \end{bmatrix}, \quad \underline{x} = \begin{bmatrix} x_1 \\ x_2 \\ \vdots \\ x_M \end{bmatrix}, \quad \underline{n} = \begin{bmatrix} n_1 \\ n_2 \\ \vdots \\ n_N \end{bmatrix},$$

$$H = \begin{bmatrix} h_{11} & h_{12} \cdots h_{1M} \\ h_{21} & h_{22} \cdots h_{2M} \\ \vdots & \vdots \quad \cdots \quad \vdots \\ h_{N1} & h_{N2} \cdots h_{NM} \end{bmatrix}.$$

$$y_1 = h_{11}x_1 + h_{12}x_2 + ...h_{1M} + n_1$$

$$y_2 = h_{21}x_1 + h_{22}x_2 + ...h_{2M} + n_2$$

where . . . . .

. . . . .

$$y_N = h_{N1}x_1 + h_{N2}x_2 + ...h_{NM} + n_N$$

A MIMO system with transmit or receive beamforming [3] we have a full diversity of the order of MN, which results the antenna gain as;

$$\max(M, N) \leq antennagain \leq MN$$

The MIMO channel capacity expression with $\rho = \frac{E_s}{\sigma^2}$ is;

$$C = E_H \left\{ \log_2 \det \left[I_m + \frac{P}{T} w \right] \right\} \quad (7)$$

where $E_H\{\ .\ \}$ denotes the expectation over H

$$m = \min(M, N) \quad (8)$$

I_m is the MxN identity matrix. P is the average SNR per receiver antenna. w is given by

$$w = \begin{cases} HH^H & if \quad N \leq M \\ H^H H & if \quad M \leq N \end{cases}$$

where the operator H^H indicates the hermitian of matrix H. The capacity of a MIMO channel with M transmit and N receive antennas with respect to the Rayleigh distribution of fading is;

$$C_{MIMO} = \min(M, N) \log_2 \left[1 + \frac{P}{2\sigma^2} \right]. \quad (9)$$

where σ- is the complex Gaussian random variable. The multiplexing gain of a MIMO system, compared with SISO is;

$$multiplexing\ gain = \frac{C_{MIMO}}{C_{SISO}} \quad (10)$$

$$i.e, \quad m = \min(M, N)$$

The antenna combination in MIMO are like 2x1, 2x2, 3x2, 3x3, 4x1, 4x2, 4x4, what happens as the number of transmitting and receiving antennas are increased linearly?.

5. Bit Error RATE (BER) and performance relations

There are important matrices to measure the overall performance of wireless system using MIMO technology. The equation for throughput calculation is one such measure. It is given as; $Throughput = R(1 - BER)^L$ where BER is the bit error rate, L is the frame length and R is the retransmission rate.

This provides a way to calculate the throughput for MAC SAP (MAC service access point) according to the IEEE 802.11n specification.

The BER can be minimized with respect to the three variables, namely antenna size, modulation and frame aggregation constant. The value of these weights can be found out through empirical or analytical results, such that it gives us the best trade off between robustness and transmission rate depending on the channel conditions. The noisier the channel more number of antenna is required to maintain the channel to provide better performance, the same BER requirement specified by the upper layers. As the number of antenna increases the diversity order increases thus this result in diversity and spatial multiplexing gains.

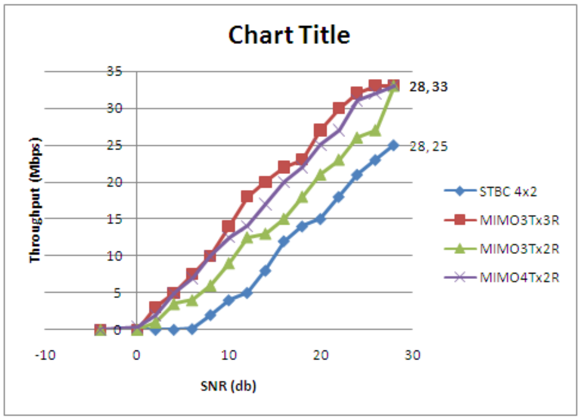

Fig. 4 Throughput variation with PHY layer

From the graph it is observed that given a specific throughput or channel utilization or BER requirement by the higher (PHY) layers. It is possible to predict the physical layer parameters that would match these requirements. Since the physical layer decides upon these parameters dynamically, depending upon the channel conditions, it presents a much smother view of the existing channel conditions it presents a much smother view of the existing channel condition by the upper layers.

This results in an assured QoS for these layers. A dynamic physical layer also translates to better link layer performance, because of lesser retransmissions. Also in a WLAN as the mobile node (MN) moves away from the base station, the received signal strength reduces. In such noisy channels this scheme can decrease latency and decrease the channel access time. This increases the overall throughput of the WLAN system.

5.1 Optimal number of antennas required for MIMO

In a WLAN with MIMO system the throughout enhancement and latency reduction is possible by considering the physical layer parameters like the number of antenna elements. The numbers of antennas at both the transmitter and receiver end are varied adaptively based on channel condition to minimize the BER (bit error rate). Depending upon the channel conditions the cross layer entity decides whether or not to increase or decrease the number of antennas. This in terms improves the QoS and hence there is an enhanced performance [11].

The upper layers decide the requirements of the number of antennas. For example the nosier the channel, more number of antennas are required to maintain the same BER. The increase in the number of antennas facilitates more paths between the transmitter and receiver and thus increases the diversity order. This results in the diversity and spatial multiplexing gain. As a result of this the BER reduces for a given SNR. That is BER is inversely proportional to the number of antenna elements.

If the received signal becomes correlated the system will be forced to reduce the number of streams resulting in reduced throughput. In other words MIMO system can have a larger variation in throughput even at the same distance. By increasing the number of received antennas [5] the probability than uncorrelated signal can reach the receiver increases. So, receivers with more number of antennas have higher probability of maintaining higher number of streams, with an increased throughput. Simply adding more antennas does not improve the performance linearly, but rather saturates up the number of uncorrelated signals calculated. Therefore the performance variation of the MIMO system based on the number of antennas both in sending and receiving side is,

$$\cong f_P[s \times (1 - e^{-(M \times N)})] \qquad (11)$$

Where s – the number of streams (uncorrelated signals measured by the receiver chains)

M - Number of transmitter chains

N - Number of receiver chains

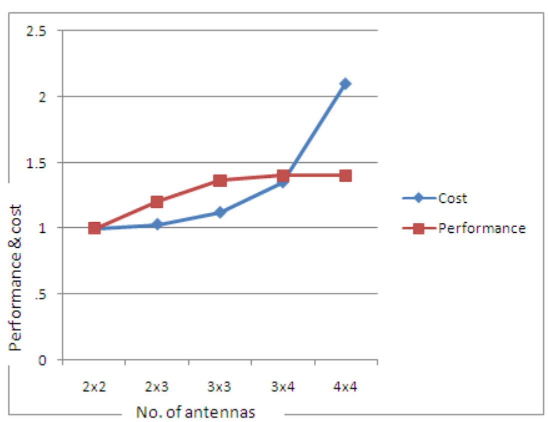

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Fig. 5. Cost and performance vaiation based on Antenna selection

In the above expression it is clear that as we increase the number of transmitting and receiving antennas, the performance increases proportionally. By increasing the number of antenna elements the complexity of the MIMO system architecture increases which in turn increases the cost exponentially while the performance saturates. In fig. 4, a MIMO system with 3x3 antennas the performance curve is above the cost curve. However when the complexity of the MIMO system reaches 3x4 configurations the return on investment is not favorable.

6. Conclusion

MIMO technology is aimed at meeting the challenges of distributing streaming video and audio in a home environment. MIMO technology is at the core of this next-generation communication technology. The use of MIMO enables higher data transmission rates by a factor equal to the number of streams and the ability to establish a wireless connection with NLOS. Better SNR compared to legacy SISO systems can enable developing wireless video solutions to extend reach as compared to legacy approaches.

Additionally, features including new aggregation schemes to improve the MAC efficiency and support the latest QoS standards can also improve the overall performance. These features provide increased throughput, range and robustness in the face of interference, and create an enhanced, reliable user experience. As discussed in this paper, each of these features has its own merits. However, only the complete package combining all the necessary elements can provide the breakthrough abilities required to push the home wireless network to the next level, enabling reliable video delivery over WLAN with appropriate number of transmitting and receiving antennas.

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