A Comprehensive Review of MIMO Antenna Technology

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Abstract **-** Mobile data, video, and TV services are now becoming an essential part of life of consumers. With the success factors of high-speed mobile broadband networks, Internet-friendly handheld devices (smartphones) and a wide variety of applications in place, consumer adoption curves for wireless data are showing the “hockey stick” effect on charts and, as wireless voice ARPU hits the flat rate ceiling, data ARPU is proving to be the next big growth engine for mobile operators. MIMO (Multiple Input Multiple Output) antenna technology is one of the key solutions available for the mobile operators to address this challenge. MIMO is a future broadband network technology, with tremendous performance gains for wireless LANs (WLANs), which can be implemented to increase peak data rates, in reducing latency and also to increase SNR-Signal to Noise Ratio. This paper demystifies the MIMO by discussing fundamental, evolution and enhancement of the MIMO technology which will be an indispensable part of future broadband communication. MIMO antenna systems are a magic ingredient in the quest for broadband wireless systems with higher capacity, performance and reliability.

***Keywords*-** ARPU, LAN, MIMO, WLAN.

I. INTRODUCTION

Mobile subscribers are growing rapidly and bandwidth demand due to data and video is increasing. According to Cisco Systems, in its annual Visual Networking Index Forecast 2009-2014, the global IP traffic will increase more than fourfold to 767 Exabyte by 2014 and video will represent more than 91 percent of all global consumers IP traffic. During that same time period, mobile data will increase by 39 times, doubling each year from 2009 to 2014, Cisco predicted. Considering that there were an estimated 5.3 Billion Mobile Cellular Subscriptions worldwide, including 940 million subscriptions to 3G services worldwide by December 2010, the tremendous opportunity for the uptake of wireless data services and applications is clear [6]. Fig. 1 shows the global mobile data growth. All radio communications systems, regardless of whether mobile radio networks like 3GPP UMTS or wireless radio networks like WLAN, must continually provide higher Data rates. In addition to conventional methods, such as introducing higher modulation types or providing larger bandwidths, this is also being achieved by using multiple Antenna systems (Multiple Input, Multiple Output) [1].

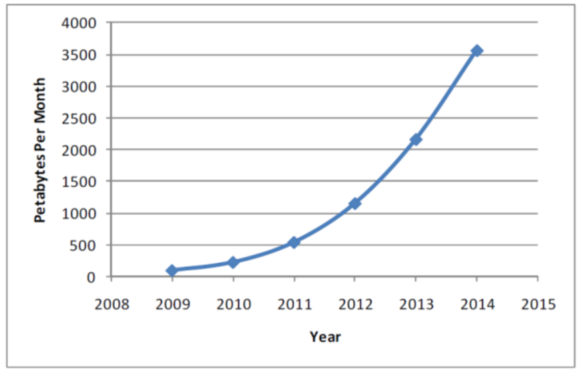

Fig. 1: Global Mobile Data Growth [5]

II. MIMO CHANNEL/ TECHNOLOGY

Higher transmission rates and better reliability are always desirable in communication systems. However, according to information theory, to increase one, the other has to be decreased, unless we are willing to use more system resources, such as power or bandwidth, which is not always possible. In this context, the use of the spatial dimension through MIMO strategies is mandatory in the next generation systems, such as long-term evolution (LTE) and LTE-Advanced. By using the spatial dimension, more degrees of freedom can be used to increase the data rates and/or the reliability of the system without the need of more system resources [8]. The following sections presents the evolution of MIMO technology.

A. SISO & SIMO

Most of the wireless communication systems developed before the mid-1990s may be referred to as single input single output (SISO) systems (see Fig. 2). Similarly, systems exploiting receive diversity with multiple antennas can be viewed as single input multiple output (SIMO) systems (see Fig. 3).

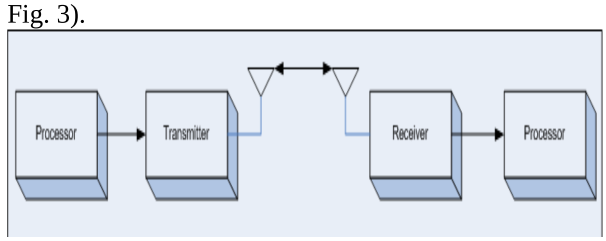

Fig. 2: Existing SISO Architecture [3]

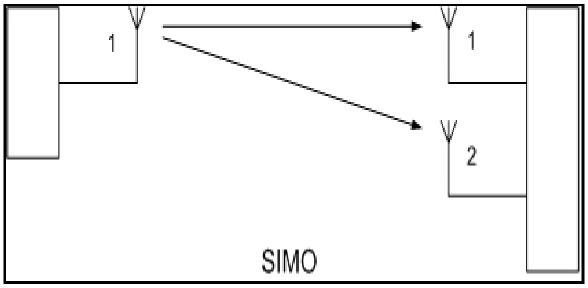

Fig. 3: SIMO [1]

B. SU-MIMO

When the data rate is to be increased for a single UE; this is called Single User MIMO (SU-MIMO)

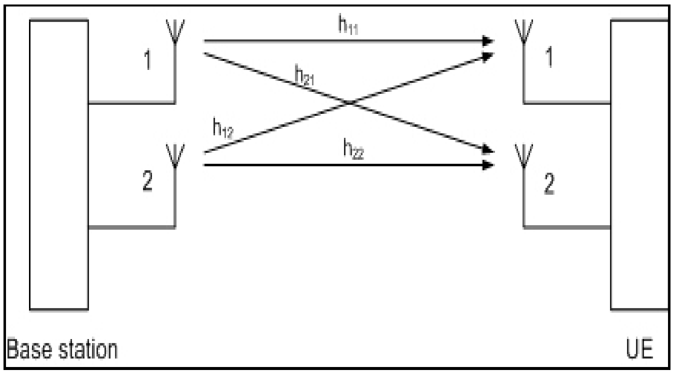

Fig. 4: SU-MIMO [1]

C. MISO

In this case, the same data is transmitted redundantly over two antennas. This method has the advantage that the multiple antennas and redundancy coding is moved from the mobile UE to the base station, where these technologies are simpler and cheaper to implement.

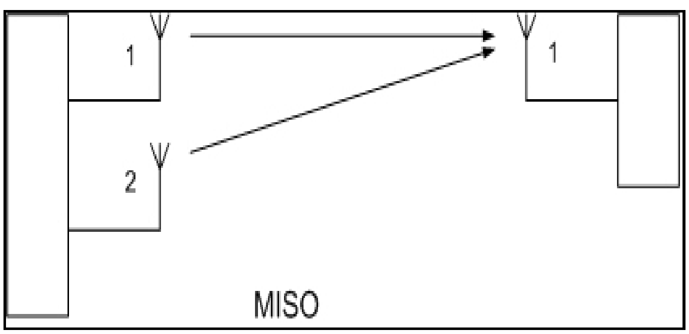

Fig. 5: MISO [1]

III. MIMO ARCHITECTURE

MIMO concepts have been under development for many years for both wireless and wire line systems. One of the earliest MIMO to wireless communications applications came in 1984 with groundbreaking developments MIMO systems offer a significant capacity improvement over SISO systems by exploiting diversity at both the transmitter and receiver [2]. With MIMO, the use of multiple antennas at both transmitter and receiver allows:

- Substantial increase in peak data rates
- Significantly higher spectrum efficiency, especially in low-interference environments
- Increased system capacity (number of users)
- Reduction in Latency
- Increase SNR

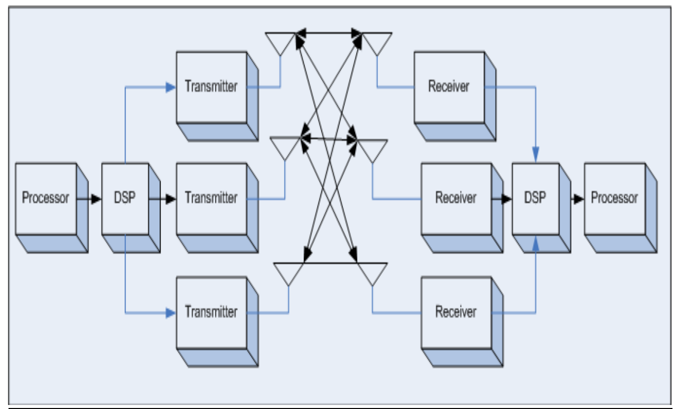

Fig. 6: MIMO Architecture [3]

IV. POWER AND COMPATIBILITY

MIMO approach can increase effective transmit power by the square of the number of transmit antennas. With two transmit antennas, for instance, the system effectively quadruples transmit power. This increase has two components: power gain and array gain. The power gain results from multiple transmit antennas delivering more power into the air, thus increasing the total amount of energy by the number of antennas. A two transmitter MIMO system delivers twice the power, for example. The array gain results from focusing the delivered energy in the direction of the receiver (beam forming), so that less is wasted in other directions. With two transmit antennas, the fraction of total energy sent in the desired direction doubles. Thus the combination of these two effects results in a net increase in effective transmits power of up to four times [2].

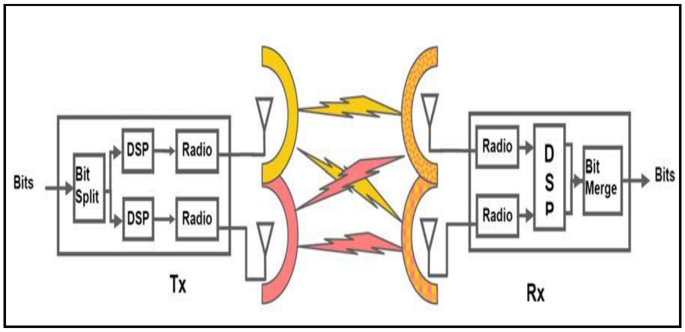

Fig. 7: Spatial multiplexing is a MIMO technique in which multiple data streams transmit at the same frequency but over different spatial channels. Standard 802.11abg devices can not demultiplex these data streams, and thus cannot improve throughput with this technique [2].

One data stream is multiplexed (divided) between multiple transmitting antennas and sent over separate spatial channels. The receiver then demultiplexes the spatial streams to recover the original data. The multiplexed signal can only be demultiplexed by a device using the same proprietary MIMO implementation.

This MIMO approach holds great promise for increasing future channel bandwidth, but the approach is incompatible with today's 802.11abg devices. That is, a spatial multiplexing transmitter can still communicate with a standard 802.11abg receiver, but not using spatial multiplexing techniques. Such products must fall back to single transmitter/single receiver mode when used with standard 802.11 devices. In these cases, the benefits of spatial multiplexing MIMO are lost.

V. ADVANTAGES AND DISADVANTAGES

A. Advantages:

The advantages of a MIMO-based WLAN are increased range, throughput and robustness of the data link. In traditional WLAN systems, these objectives are traded off against one another as there is a relationship between data-rate and range. MIMO is not immune to these tradeoffs, but due to the multiple transmitters/receivers and DSP technology, all three of these critical parameters are greatly improved. MIMO systems demonstrate greater overall throughput using two separate methods. First, the ability to provide a higher data-rate vs. range means improved throughput over a much larger coverage range than traditional SISO antennas. Second, additional throughput can be gained by operating the MIMO AP with 40 MHz channels to increase the available bandwidth for the signal and increase the channel bit rate. While the first technique is applicable to any client device, the second requires a MIMO based client to utilize the additional channels.

B. Disadvantages:

MIMO is not without its drawbacks, although there are relatively few when balanced against the gains. These are largely due to the increased component costs within an Access Point required for the MIMO implementation. Multiple antennas, and the use of higher performing CPU and DSP chips mean that, initially, manufacturer's costs of goods per AP may rise, however, as these components become mass produced it is likely that their prices will quickly fall. Additionally, the operation of multiple radio chains requires more power than the SISO (legacy) systems, both in transmit and receive operations. Clients that use standby mode to preserve battery life may have shorter cycle times, but work is already underway by client manufacturers to operate in single chain mode until a "wake-up" signal is detected.

VI. COMPARISON OF SISO AND MIMO

The theoretical capacity bound as depicted in Figure 9 states that as there are increase in the number of transmitting and receiving antennas, the capacity (C) of the wireless channel tends to

$$C_\infty = \frac{SNR}{\ln 2} \text{ bps/Hz},$$

Where, we can compare this to the throughput (C_{SISO}) of the perfect single-input–single-output (SISO) system, which is given by Shannon's capacity formula per unit bandwidth as follows:

$$C_{SISO} = \log(1+SNR) \text{ bps/Hz}.$$

One can see the gain to achieve by increasing antennas at the transmitter and receiver (See Fig. 8.

Also, the data in the following tables show the comparison between SISO and MIMO at 54Mbps and 6 Mbps throughput.

Table 1: MIMO vs. SISO @ 54Mbps [3]

Parameter	SISO	MIMO
Tx Power	20 dB	14 dBm
Tx Antenna Gain	2 dBi	2 dBi
Rx Receiver Sensitivity	-70 dBm	-80 dBm
Fade Margin	15 dBm	15 dBm
Loss Coefficient	3	3
54 Mbps Range	17m	23m
54 Mbps Coverage	908 sqm	1662 sqm

Table 2: MIMO vs. SISO @ 6Mbps [3]

PARAMETER	SISO	MIMO
Tx Power	20 dB	22 dBm
Tx Antenna Gain	2 dBi	2 dBi
Rx Receiver Sensitivity	-88 dBm	-95.5 dBm
Fade Margin	15 dBm	15 dBm
Loss Coefficient	3	3
54 Mbps Range	68m	141m
54 Mbps Coverage	14,527 sqm	62,458 sqm

VII. CONCLUSION

The demand for higher data rates at better quality of service is challenged by scarce usable radio resource and time-varying radio environment affected by fading and multipath. Utilizing multiple antennas at the receiver and transmitter is widely touted as the key technique that markedly improves the data rate on longer range without consuming extra bandwidth or transmits power. This technology is also referred as multiple-input multiple-output (MIMO) communication. MIMO antenna systems are a magic ingredient in the quest for broadband wireless systems with higher capacity, performance, reliability, higher peak data rates, high SNR, low level of latency. In this paper we have given an overview of MIMO technology including its evolution, technical features architecture and future enhancements.

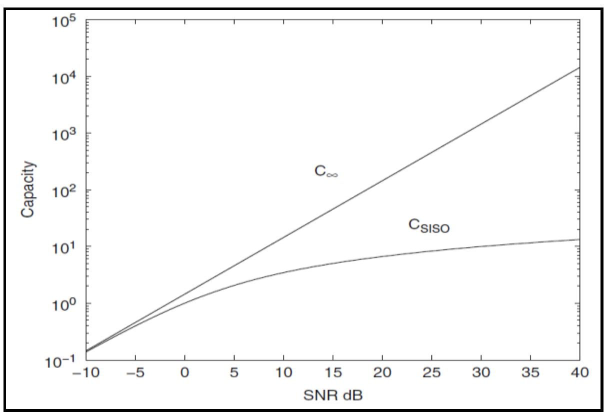

Fig. 8: Multiple antennas at the transmitter and receiver compared with single-input–single output System [7]

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