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Various MIMO Antenna Systems with Applications

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Abstract – Multiple Input Multiple Output (MIMO) transmission systems promise high data rates and a good reliability for a given signal to noise ratio and a fixed bandwidth. It offers significant capacity gains over traditional single-input single-output channels. The purpose of this paper is to do analyse the various existing types of MIMO systems and their applications with specifications. The comparative analysis of various types of MIMO system are studied in Single User MIMO (SU-MIMO) with Multi User MIMO (MU-MIMO) and Open loop MIMO with Close loop MIMO system. MIMO applications are considered by exploring the main specifications of the IEEE industry standards like HSPA+ (3GPP Release 7/8), LTE (3GPP Release 8), WiMAX (802.16e-2005), WLAN (802.11n).

Index Terms – MIMO, Single User MIMO, Multi User MIMO, Open Loop MIMO, Closed Loop MIMO, Space Time Transmit Diversity, Spatial Multiplexing, HSPA+, LTE, WiMAX, WLAN.

1. INTRODUCTION

Multiple Input Multiple Output (MIMO) offers an alternative by increasing the number of antennas to improve the performance of the wireless system without the need of more spectrum. In MIMO, the multipath fading is a cause of degradation for wireless systems and is used to improve the system performance. The same information is transmitted from multiple antennas and received at multiple antennas simultaneously. Since the fading for each link between a pair of transmit and receive antennas can usually be considered as independent, the probability of accurately detected information is increased. Multiple transmit and receive antennas also allow notch compensation of one channel by non-notches of other channel [1]. The multiple antennas allow MIMO systems to perform Precoding (multi-layer Beamforming), Diversity Coding (Space Time Coding) and Spatial Multiplexing. Beamforming consists of transmitting the same signal with different gain and phase called weights over all transmit antennas such that the received signal is maximized. Diversity consists of transmitting single space time coded stream through all antennas. Spatial Multiplexing increases network capacity by splitting a high rate signal into multiple lower rate streams and transmitting them through the different antennas. The result of using these MIMO techniques is the higher data rate or longer transmit range without the need of additional bandwidth and transmit power.

The two major classifications to determine types of MIMO systems. The comparative studies based on the number of user and the technology are discussed in the below two parts.

(1) Single User MIMO (SU-MIMO) vs. Multi User MIMO (MU-MIMO)

(2) Open loop MIMO vs. Close loop MIMO

2. SINGLE USER MIMO (SU-MIMO) VS. MULTI USER MIMO (MU-MIMO)

The MIMO system can be classified based on the number of users connecting, the two different methods to connect to the network from the receiver end are discussed in this section.

2.1. Single User MIMO (SU-MIMO)

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

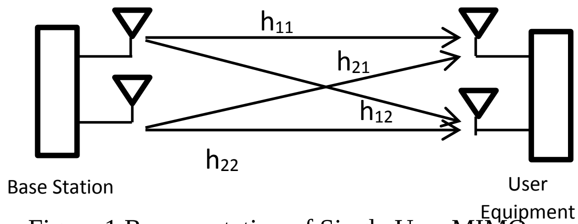

Figure 1 Representation of Single User MIMO

2.2. Multi User MIMO

When the individual streams are assigned to various users, this is called Multi User MIMO (MU-MIMO). This mode is particularly useful in the uplink because the complexity on the UE side can be kept at a minimum by using only one transmit antenna. This is also called collaborative MIMO.

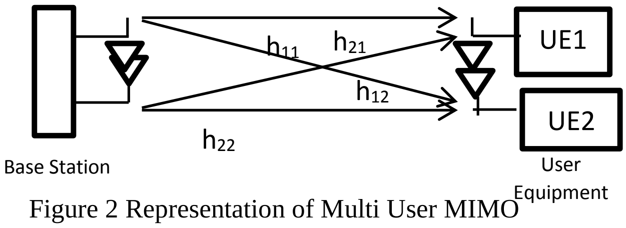

Figure 2 Representation of Multi User MIMO

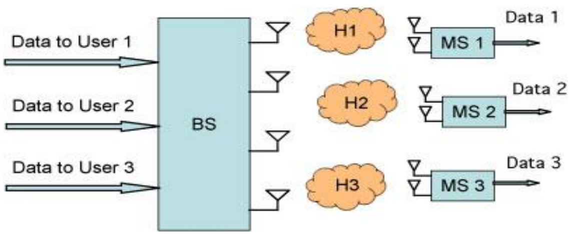

Figure 3 Multiple User MIMO Communication

In a multiuser MIMO (MU-MIMO) system, a base station communicates with multiple users. On the downlink, known as the MIMO broadcast channel, the base station sends different information streams to the users. On the uplink, the base station receives different information from the users. Other variations of MU-MIMO involve full or partial multi-cast of data. MU-MIMO has been used extensively in 3GPP LTE Advanced.

3. OPEN LOOP MIMO VS. CLOSED LOOP MIMO

MIMO configurations can be represented as either Open Loop or Closed Loop. In application, MIMO terminology has most often been in reference to Open Loop MIMO techniques. Beamforming also known as Transmitter Adaptive Antenna (TX-AA) techniques comes under the category of Closed Loop MIMO techniques.

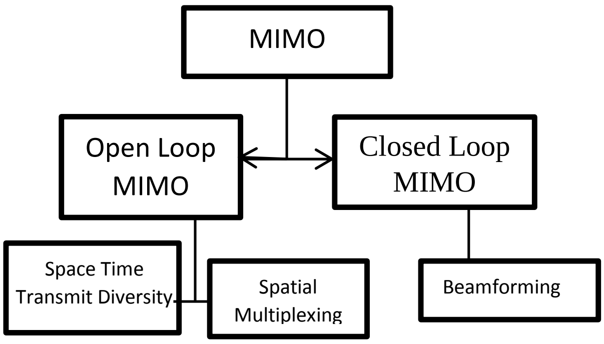

Figure 4 Technological classification of MIMO

3.1. Open loop MIMO

With Open Loop MIMO, the communications channel does not utilize explicit information regarding the propagation channel. Common Open Loop MIMO techniques include Space Time Transmit Diversity (STTD), Spatial Multiplexing (SM) and Collaborative Uplink MIMO.

3.1.1. Space Time Transmit Diversity (STTD) MIMO

Space-time block coding based transmit diversity (STTD) is a method of transmit diversity used in UMTS third-generation cellular systems. STTD is optional in the UTRANN air interface but mandatory for user equipment. STTD utilizes space-time block code (STBC) in order to exploit redundancy in multiply transmitted versions of a signal. The same data is coded and transmitted through different antennas, which effectively doubles the power in the channel. This improves Signal Noise Ratio (SNR) for cell edge performance.

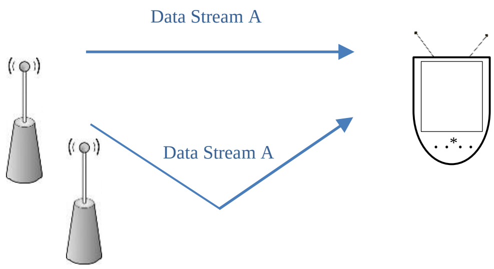

Figure 5 Space Time Block Coding

3.1.2. Spatial Multiplexing (SM) MIMO

Spatial multiplexing is transmission techniques in MIMO wireless communication to transmit independent and separately encoded data signals, so-called streams, from each of the multiple transmit antennas. Therefore, the space dimension is reused, or multiplexed, more than one time. SM delivers parallel streams of data to CPE by exploiting multi-path. It can double (2x2 MIMO) or quadruple (4x4) capacity and throughput. SM gives higher capacity when RF conditions are favourable and users are closer to the BTS.

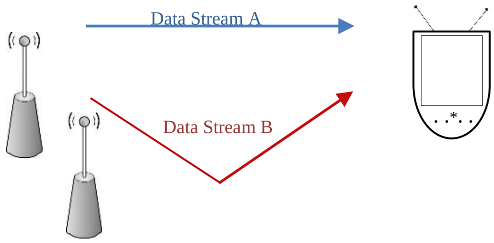

Figure 6 Spatial Mutiplexing (MIMO-SM)

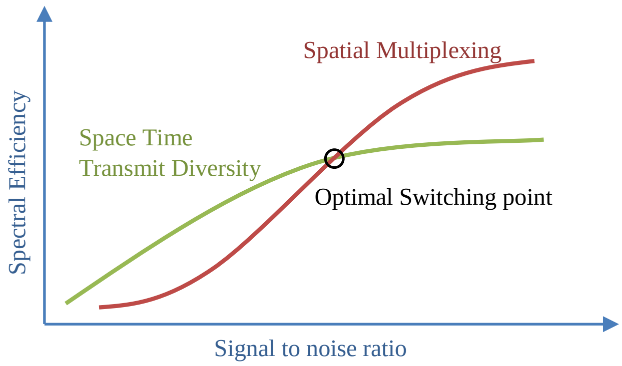

Figure 7 MIMO Adaptive Mode Selection

STTD outperforms SM when SNR is weak whereas when SNR is higher SM is well suited. STTD improves the SNR for cell edge users while SM provided higher capacity when user is in good RF condition and are closer to the radio tower. An ideal wireless system employing MIMO techniques will support both STTD and SM. The system will calculate an optimal switching point and dynamically shift between the two approaches to offer the necessary coverage or capacity gain demanded from the network at any given time or location.

3.2. Closed loop MIMO

Antenna technologies are the key in increasing network capacity. It started with sectorized antennas. These antennas illuminate 60 or 120 degrees and operate as one cell. In GSM, the capacity can be tripled, by 120 degree antennas. Adaptive antenna arrays intensify spatial multiplexing using narrow beams. Smart antennas belong to adaptive antenna arrays but differ in their smart direction of arrival (DoA) estimation. Smart antennas can form a user-specific beam. Optional feedback can reduce complexity of the array system.

Beamforming is the method used to create the radiation pattern of an antenna array. It can be applied in all antenna array systems as well as MIMO systems. It improves the range of data rates and receive interference tolerance. It also reduces transmit interference. The goal of beamforming is to diagonalize the channel matrix.

Smart antennas are divided into two groups:

- Phased array systems (switched beamforming) with a finite number of fixed predefined patterns
- Adaptive array systems (AAS) (adaptive beamforming) with an infinite number of patterns adjusted to the scenario in real time

Switched beamformers electrically calculate the DoA and switch on the fixed beam. The user only has the optimum signal strength along the center of the beam. The adaptive beamformer deals with that problem and adjusts the beam in real time to the moving UE. The complexity and the cost of such a system is higher than the first type.

4. APPLICATIONS OF MIMO

In present scenarios MIMO is one of the recent advancements in the wireless communication. Some of the implementations of MIMO in various IEEE standards for wireless communication are discussed below.

4.1. HSPA+ (3GPP Release 7/8)

The introduction of 64QAM modulation and MIMO in the downlink makes a peak data rate of 28 Mbps (Rel. 7) possible. In Rel. 7 MIMO and 64QAM cannot be used simultaneously. Since Rel. 8 the simultaneous use is possible which leads to peak data rates up to 42 Mbps. Uplink MIMO is not provided. MIMO was introduced in the form of a double transmit antenna array (D-TxAA) for the high speed downlink shared channel (HS-DSCH). With D-TxAA, two independent data streams can be transmitted simultaneously over the radio channel using the same WCDMA channelization codes. After spreading and scrambling, precoding based on weight factors is applied to optimize the signal for transmission over the mobile radio channel. Four precoding weights w_1 to w_4 are available. The first stream is multiplied withw_1 and w_2, the second stream is multiplied with w_3 and w_4. The weights can take the following values:

$$w_3 = w_3 = {}^{1}/_{\sqrt{2}}$$

$$w_4 = -w_2$$

$$w_2 \in \left\{\frac{1+j}{2}, \frac{1-j}{2}, \frac{-1+j}{2}, \frac{-1-j}{2}\right\}$$

Note that w_1 is always fixed, and only w_2 can be selected by the base station. Weights w_3 and w_4 are automatically derived from w_1 and w_2, because they have to be orthogonal. The base station selects the optimum weight factors based on proposals reported by the UE in the uplink. In addition to the use of MIMO in HS-DSCH, the weight information must be transmitted to the UE via the HS-SCCH control channel. Although MIMO is not provided in the uplink, MIMO-relevant information still does have to be transmitted in the uplink. The UE sends a precoding control indication (PCI) and a channel quality indication (CQI) in the HS-DPCCH, which allows the base station to adapt the modulation, coding scheme, and precoding weight to the channel conditions.

4.2. LTE (3GPP Release 8)

UMTS Long Term Evolution (LTE) was introduced in 3GPP Release 8. The objective is a high data rate, low latency and packet optimized radio access technology. LTE is also referred to as E-UTRA (Evolved UMTS Terrestrial Radio Access) or E-UTRAN (Evolved UMTS Terrestrial Radio Access Network). The basic concept for LTE in downlink is OFDMA and uplink is SC-FDMA, while MIMO technologies are an integral part of LTE. Modulation modes are QPSK, 16QAM, and 64QAM. Peak data rates of up to 300 Mbps (4x4 MIMO) and up to 150 Mbps (2x2 MIMO) in the downlink and up to 75 Mbps in the uplink are specified.

- Downlink

In LTE, one or two code words are mapped to one to four layers ("layer mapper" block). To achieve multiplexing, a precoding is carried out ("precoding" block). In this process, the layers are multiplied by a precoding matrix W from a defined code book and distributed to the various antennas. This precoding is known to both the transmitter and the receiver. In the specification, code books are defined for one, two, and four antennas, as well as for spatial multiplexing and transmit diversity.

- Uplink

In order to keep the complexity low at the UE end, MU-MIMO is used in the uplink. To do this, multiple UEs, each with only one Tx antenna, use the same channel.

4.3. WiMAX (802.16e-2005)

WiMAX promises a peak data rate of 74 Mbps at a bandwidth of up to 20 MHz. Modulation types are QPSK, 16QAM, and 64QAM.

Wi-Max is used to provide broadband wireless connectivity over a substantial geographical area such as large metropolitan city. It has been designed to evolve a set of air interfaces based on a common MAC protocol but physical layer specifications having an air interface support in 2-11 GHz band having both licensed and license exempt spectrum. Wi Max can use radio bandwidth that can vary from 1.25 MHz to 28 MHz in steps of 1.75 MHz in 2GHz to 11 GHz band. It also uses multicarrier OFDMA scheme with MIMO antenna technique to achieve transmission data rate as high as 155 Mbps. WiMAX equipment can operate in different FDD or TDD configuration and operate in different frequency bands of 5.8 GHz, 3.5 GHz and 2.5 GHz [5].

- Downlink

The WiMAX 802.16e-2005 standard specifies MIMO in WirelessMAN-OFDMA mode. This standard defines a large number of different matrices for coding and distributing to antennas. In principle, two, three or four TX antennas are possible. For all modes, the matrices A, B, and C are available. In the STC encoder block, the streams are multiplied by the selected matrix and mapped to the antennas.

- Uplink

In Uplink-MIMO only different pilot patterns are used. Coding and mapping is the same like in non-MIMO case. In addition to single user MIMO (SU-MIMO) two different user can use the same channel (collaborative MIMO, MU-MIMO).

4.4. WLAN (802.11n)

WLAN as defined by the 802.11n standard promises a peak data rate of up to 600 Mbps at a bandwidth of 40 MHz. Modulation types are BPSK, QPSK, 16QAM, and 64QAM. It is backward compatible with the previous standards 802.11 a/b/g. With up to four streams, it supports up to a maximum of four antennas. WLAN differentiates between spatial streams (SS) and space-time streams (STS). If $N_{SS} < N_{STS}$, then a space-time block encoder STBC distributes the SS to the STS and adds transmit diversity by means of coding. The IEEE 802.11n WLAN standards provides a series of enhancement technique to both the physical layer and MAC layers leading throughput of up to 100 Mbps. The standards include MIMO – OFDM technology and 40 MHz operation to the physical layer. 802.11n operates on both the 2.4 GHz and the lesser used 5 GHz bands. Support for 5 GHz bands is optional. It operates at a maximum net data rate from 54 Mbit/s to 600 Mbit/s. The IEEE has approved the amendment and it was published in October 2009. Prior to the final ratification, enterprises were already migrating to 802.11n networks.

5. CONCLUSION

The MIMO system allows a significant performance improvement at the cost of an increased signal processing complexity. By the using SU-MIMO or MU-MIMO coupled with open loop MIMO or closed loop MIMO system a significant improvement of the signal bandwidth can be achieved. Also there are new technologies that endorse MIMO system by using this as their core technology. In the present scenario, high data rates are provided by WLAN, WiMax and LTE/ LTE-Advanced (LTE-A). Developing a wireless system with more spectral efficiency under varying channel condition is a key challenge to provide more bit rates with limited spectrum.

REFERENCES

[1]. J. Kaur and M. L. Singh and R. S. Sohal, “Performance of Alamouti scheme with convolution for MIMO system” in 2nd International Conference on Recent Advances in Engineering Computational Sciences (RAECS), 2015.

[2]. W. Y. Y. C. G. K. Yong S. Cho, Jaekwon Kim, MIMO-OFDM Wireless Communications with MATLAB, 2010.

[3]. S. Alamouti, “A simple transmit diversity technique for wireless communications,” in IEEE Journal on Selected Areas in Communications, vol. 16, no. 8, Oct 1998, pp. 1451–1458.

[4]. J. Jootar, J. Zeidler, and J. Proakis, “Performance of alamouti space-time code in time-varying channels with noisy channel estimates,” in IEEE Wireless Communications and Networking Conference, vol. 1, 3 2005, pp. 498–503.

[5]. D. Gesbert, M. Kountouris, R. W. Heath, Jr., C.-B. Chae, and T. Sälzer (Oct 2007). "Shifting the MIMO Paradigm: From Single User to Multiuser Communications". IEEE Signal Processing Magazine 24 (5): 36–46.

[6]. "WiMAX and the IEEE 802.16m Air Interface Standard" (PDF). WiMAXforum.org. WiMAX Forum. April 2010. Retrieved 28 October 2013.

[7]. L. Zheng and D. N. C. Tse (May 2003). "Diversity and multiplexing: A fundamental tradeoff in multiple-antenna channels". IEEE Trans. Inf. Th. 49 (5): 1073–1096.

[8]. Branka Vucetic and Jinhong Yuan, "Performance Limits of Multiple-Input Multiple-Output Wireless Communication Systems Space-Time Coding", 2003 John & Sons, Ltd ISBN: 0-470-84757-3

[9]. David Gesbert, Mansoor Shafi, Da-shan Shiu, Peter J. Smith and Ayman Naguib, "From Theory to Practice: An Overview of MIMO Space-Time Coded Wireless Systems", IEEE Journal on Selected Areas in Communications, VOL. 21, NO. 3, APRIL 2003 281, Tutorial Paper

[10]. Ayman Naguib et all., "Increasing data rate over wireless channels", IEEE Signal Prog. Mag., May 2000