MULTIPLE-INPUT AND MULTIPLE-OUTPUT (MIMO)

INTRODUCTION

1. In radio, multiple-input and multiple-output, or MIMO, is the use of multiple antennas at both the transmitter and receiver to improve communication performance. It is one of several forms of smart antenna technology. Note that the terms input and output refer to the radio channel carrying the signal, not to the devices having antennas. MIMO technology has attracted attention in wireless communications, because it offers significant increases in data throughput and link range without additional bandwidth or increased transmit power. It achieves this goal by spreading the same total transmit power over the antennas to achieve an array gain that improves the spectral efficiency (more bits per second per hertz of bandwidth) and/or to achieve a diversity gain that improves the link reliability (reduced fading).

PRINCIPLE

2. The concept of spatial multiplexing (SM) using MIMO was introduced in 1993. The multi-user MIMO concept of Space-Division Multiple Accesses (SDMA) was proposed in 1991. In 1996, new approaches to MIMO technology were refined, considering a configuration where multiple transmit antennas are co-located at one transmitter to improve the link throughput effectively. Bell Labs was the first to demonstrate a laboratory prototype of spatial multiplexing in 1998, where spatial multiplexing is a principal technology to improve the performance of MIMO communication systems.

WIRELESS STANDARDS

3. MIMO with Orthogonal Frequency-Division Multiple Access Technology (MIMO-OFDMA). In 2005, Airgo Networks had developed an IEEE 802.11n precursor implementation based on their patents on MIMO. Following that in 2006, several companies (including at least Broadcom, Intel and Marvell) fielded a MIMO-OFDM solution based on a pre-standard for 802.11n Wi-Fi standard. Also in 2006, several companies (Beceem communications, Samsung, Runcom Technologies, etc.) had developed MIMO-OFDMA based solutions for IEEE 802.16e WiMAX broadband mobile standard. All upcoming 4G systems will also employ MIMO technology. Several research groups have demonstrated over 1 Gbit/s prototypes

FUNCTIONS OF MIMO

4. MIMO can be sub-divided into three main categories, pre-coding, spatial multiplexing (SM) and diversity coding.

(a) Precoding. Precoding is multi-stream beam forming, in the narrowest definition. In more general terms, it is considered to be all spatial processing that occurs at the transmitter. In (single-stream) beam forming, the same signal is emitted from each of the transmit antennas with appropriate phase and gain weighting such that the signal power is maximized at the receiver input. The
benefits of beam forming are to increase the received signal gain, by making signals emitted from different antennas add up constructively and to reduce the multipath fading effect. In line-of-sight propagation, beam forming results in a well defined directional pattern. However, conventional beams are not a good analogy in cellular networks which are mainly characterized by multipath propagation. When the receiver has multiple antennas, the transmit beam forming cannot simultaneously maximize the signal level at all of the receive antennas and precoding with multiple streams is often beneficial. Note that precoding requires knowledge of channel state information (CSI) at the transmitter and the receiver.

(b) **Spatial Multiplexing.** Spatial multiplexing requires MIMO antenna configuration. In spatial multiplexing, a high rate signal is split into multiple lower rate streams and each stream is transmitted from a different transmit antenna in the same frequency channel. If these signals arrive at the receiver antenna array with sufficiently different spatial signatures and the receiver has accurate CSI, it can separate these streams into (almost) parallel channels. Spatial multiplexing is a very powerful technique for increasing channel capacity at higher signal-to-noise ratios (SNR). The maximum number of spatial streams is limited by the lesser of the number of antennas at the transmitter or receiver. Spatial multiplexing can be used without CSI at the transmitter but can be combined with precoding if CSI is available. Spatial multiplexing can also be used for simultaneous transmission to multiple receivers, known as space-division multiple access or multi-user MIMO, in which case CSI is required at the transmitter. The scheduling of receivers with different spatial signatures allows good separability.

(c) **Diversity Coding.** Diversity Coding techniques are used when there is no channel knowledge at the transmitter. In diversity methods, a single stream (unlike multiple streams in spatial multiplexing) is transmitted but the signal is coded using techniques called space-time coding. The signal is emitted from each of the transmit antennas with full or near orthogonal coding. Diversity coding exploits the independent fading in the multiple antenna links to enhance signal diversity. Because there is no channel knowledge, there is no beam forming or array gain from diversity coding. Diversity coding can be combined with spatial multiplexing when some channel knowledge is available at the transmitter.

5. Multi-antenna MIMO (or Single user MIMO) technology has been developed and implemented in some standards.

(a) **Special Cases.**

(i) Multiple-Input and Single-Output (MISO) is a special case when the receiver has a single antenna.

(ii) Single-Input and Multiple-Output (SIMO) is a special case when the transmitter has a single antenna.
(iii) Single-Input Single-Output (SISO) is a conventional radio system where neither the transmitter nor receiver has multiple antennas.

(b) **Some Limitations.** The physical antenna spacing is selected to be large over multiple wavelengths at the base station. The antenna separation at the receiver is heavily space constrained in hand sets, though advanced antenna design and algorithm techniques are under discussion.

**MULTI-USER TYPES**

6. Recently, results of research on multi-user MIMO technology have been emerging. While full multiuser MIMO (or network MIMO) can have a higher potential, practically, the research on (partial) multiuser MIMO (or multi-user and multi-antenna MIMO) technology is more active.

(a) **Multi-User MIMO (MU-MIMO).** In recent 3GPP and WiMAX standards, MU-MIMO is being treated as one of the candidate technologies adoptable in the specifications by a number of companies. For these, MU-MIMO is more feasible for low complexity cell phones with a small number of reception antennas, whereas single-user SU-MIMO's higher per-user throughput is better suited to more complex user devices with more antennas.

(b) **PU 2 RC.** PU 2 RC allows the network to allocate each antenna to a different user instead of allocating only a single user as in single-user MIMO scheduling. The network can transmit user data through a codebook-based spatial beam or a virtual antenna. Efficient user scheduling, such as pairing spatially distinguishable users with codebook based spatial beams is additionally discussed for the simplification of wireless networks in terms of additional wireless resource requirements and complex protocol modification.

(c) **SDMA.** SDMA represents either space-division multiple access or super-division multiple access where super emphasises that orthogonal division such as frequency and time division is not used but non-orthogonal approaches such as superposition coding are used.

(d) **Macro Diversity MIMO.**

(i) A form of space diversity scheme which uses multiple transmit or receive base stations for communicating coherently with single or multiple users which are possibly distributed in the coverage area, in the same time and frequency resource.

(ii) The transmitters are far apart in contrast to traditional micro diversity MIMO schemes such as single-user MIMO. In multi-user macro diversity MIMO scenario, users may also be far apart. Therefore, every constituent link in the virtual MIMO link has distinct average link SNR. This difference is mainly due to the different long-term channel impairments such as path loss and shadow fading which are experienced by different links.
Macro diversity MIMO schemes pose unprecedented theoretical and practical challenges. Among many theoretical challenges, perhaps the most fundamental challenge is to understand how the different average link SNRs affects the overall system capacity and individual user performance in fading environments.

(e) **MIMO Routing.** Routing a cluster by a cluster in each hop, where the number of nodes in each cluster is larger or equal to one. MIMO routing is different from conventional (SISO) routing since conventional routing protocols route node by node in each hop.

**MIMO TESTING**

7. MIMO signal testing focuses first on the transmitter/receiver system. The random phases of the subcarrier signals can produce instantaneous power levels that cause the amplifier to compress, momentarily causing distortion and ultimately symbol errors. Signals with a high PAR (peak-to average ratio) can cause amplifiers to compress unpredictably during transmission. OFDM signals are very dynamic and compression problems can be hard to detect because of their noise-like nature. Knowing the quality of the signal channel is also critical. A channel emulator can simulate how a device performs at the cell edge, can add noise or can simulate what the channel looks like at speed. To fully qualify the performance of a receiver, a calibrated transmitter, such as a Vector Signal Generator (VSG) and channel emulator can be used to test the receiver under a variety of different conditions.

8. Conversely, the transmitter's performance under a number of different conditions can be verified using a channel emulator and a calibrated receiver, such as a vector signal analyzer, understanding the channel allows for manipulation of the phase and amplitude of each transmitter in order to form a beam. To correctly form a beam, the transmitter needs to understand the characteristics of the channel. This process is called channel sounding or channel estimation. A known signal is sent to the mobile device that enables it to build a picture of the channel environment. The mobile device sends back the channel characteristics to the transmitter. The transmitter can then apply the correct phase and amplitude adjustments to form a beam directed at the mobile device. This is called a closed loop MIMO system. For beam forming, it is required to adjust the phases and amplitude of each transmitter. In a beam former optimized for spatial diversity or spatial multiplexing, each antenna element simultaneously transmits a weighted combination of two data symbols.

**APPLICATIONS OF MIMO**

10. There are various applications of MIMO, some of them are enumerated below:-

(a) Spatial multiplexing techniques make the receivers very complex, and therefore they are typically combined with Orthogonal Frequency Division Multiplexing (OFDM) or with Orthogonal Frequency Division Multiple Access (OFDMA) modulation, where the problems created by a multi-path channel are handled efficiently.
(b) MIMO is also planned to be used in Mobile radio telephone standards such as recent 3GPP and 3GPP2. In 3GPP, High-Speed Packet Access plus (HSPA+) and Long Term Evolution (LTE) standards take MIMO into account. Moreover, to fully support cellular environments, MIMO research consortia including IST-MASCOT propose to develop advanced MIMO techniques.

(c) MIMO technology can be used in non-wireless communications systems. One example is the home networking standard ITU-T G.9963 which defines a power line communications system that uses MIMO techniques to transmit multiple signals over multiple AC wires (phase, neutral and ground).

CONCLUSION

11. MIMO is one technology being considered for 802.11n, a standard for next-generation 802.11 that boosts throughput to 100M bit/sec. In the meantime, proprietary MIMO technology improves performance of existing 802.11a/b/g networks. Wi-Fi, Long Term Evolution (LTE) and many other radio, wireless and RF technologies are using the new MIMO wireless technology to provide increased link capacity and spectral efficiency combined with improved link reliability using what were previously seen as interference paths. MIMO-based Wi-Fi routers utilize the same network protocols and signal ranges that non-MIMO routers do. The MIMO products achieve higher performance by more aggressively transmitting and receiving data over Wi-Fi channels. MIMO signaling technology can increase network bandwidth, range and reliability at the potential cost of interfering with other wireless equipment.

12. To exploit the benefits the virtual wires offer, MIMO uses multiple, spatially separated antennas. MIMO encodes a high-speed data stream across multiple antennas. Each antenna carries a separate, lower-speed stream. Multipath virtual wires are utilized to send the lower-speed streams simultaneously. As a result of the use multiple antennas, MIMO wireless technology is able to considerably increase the capacity of a given channel. By increasing the number of receive and transmit antennas it is possible to linearly increase the throughput of the channel with every pair of antennas added to the system. This makes MIMO wireless technology one of the most important wireless techniques to be employed in recent years. As spectral bandwidth is becoming an ever more valuable commodity for radio communications systems, techniques are needed to use the available bandwidth more effectively. MIMO wireless technology is one of these techniques.

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