Wireless MIMO-Antenna Based Communication System

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Abstract
We investigate the effects of fading correlations on wireless communication systems employing multiple antennas at both the receiver and the transmitter side of the link, so called multiple-input multiple-output (MIMO) systems. The use of multiple antennas for wireless communication system has gained overwhelming interest during the last decade- both in academia and industry. Multiple antennas can be used in order to accomplish a multiplexing gain, diversity gain or antenna gain. thus , enhancing the bit rate , error performance or the signal-to-noise-plus-interference ratio of wireless system, respectively. With an enormous amount of yearly publications, the field of multiple antenna systems, often called MIMO systems, has evolved rapidly. Desired attributes can be obtained like significant increase in spectral efficiency and data rates, high Quality–of–Service (QoS)-bit error rate, wide coverage, low deployment, maintenance and operation cost. The objective of this literature survey is to provide non specialist working in the general area of digital communication with a comprehensive overview of this exciting research field.

1. Introduction

How is it possible to design reliable high-speed wireless communication system? Wireless communication is based on radio signals. Traditionally, wireless applications were voice-centric and demanded only moderate data rates, while most high-rate applications such as file transfer or video streaming were wireline applications. In recent years, however, there has been a shift to wireless multimedia applications, which is reflected in the convergence of digital wireless networks and the internet. For example, cell phones with integrated digital cameras are ubiquitous already today. One can take a photo, email it to a friend – and make a phone call, of course.

In order to guarantee a certain quality of service, not only high bit rates are required, but also a good error performance. However, the disruptive characteristics of wireless channels, mainly caused by multipath signal propagation (due to reflec-tions and diffraction) and fading effects [6] make it challenging to accomplish both of these goals at the same time. In particular, given a fixed bandwidth, there is always a fundamental trade-off between bandwidth efficiency (high bit rates) and power efficiency (small error rates).

In particular, channel coding is typically employed, so as to overcome the detrimental effects of multipath fading. However, with regard to the ever-growing demands of wireless services, the time is now ripe for evolving the antenna part of the radio system. In fact, when utilizing multiple antennas, the previously un-used spatial domain can be exploited. The great potential of using multiple antennas for wireless communications has only become apparent during the last decade. In particular, at the end of the 1990s multiple-antenna techniques were shown to provide a novel means to achieve both higher bit rates and smaller error rates [5]. In addition to this, multiple antennas can also be utilized in order to mitigate co-channel interference, which is another major source of disruption in (cellular) wireless communication systems. Altogether, multiple-antenna techniques thus constitute a key technology for modern wire-less communications.

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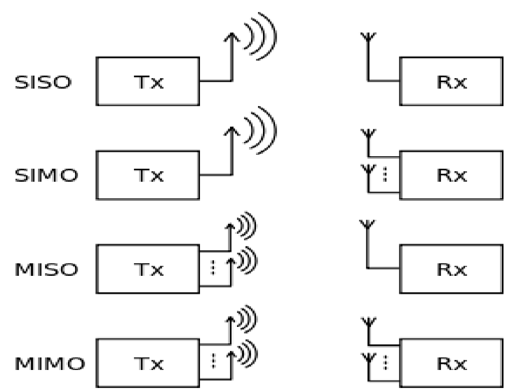
Multiple-Input Multiple-Output (MIMO) technology is a wireless technology that uses multiple transmitters and receivers to transfer more data at the same time. Wireless products with 802.11n support MIMO. This is part of the technology that allows 802.11n to reach much higher speeds than products without 802.11n.

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 [5]. It is one of several forms of smart antenna technology. A point to be noted is that the terms input and output refer to the radio channel carrying the signal, not to the devices having antennas.



Multi-antenna MIMO (or Single user MIMO) technology has been developed and implemented in some standards .e.g.802.11n products. SISO/SIMO/MISO are degenerate cases of MIMO. Multiple-input and single-output (MISO) is a degenerate case when the receiver has a single antenna. Single-input and multiple-output (SIMO) is a degenerate case when the transmitter has a single antenna.

Single-input single-output (SISO) is a radio system where neither the transmitter nor receiver has multiple antennas.

The benefits [1] of multiple antennas for wireless communication systems are summarized in Fig.2. In the sequel, they are characterized in more detail.

A. Higher Bit Rates with Spatial Multiplexing

Spatial multiplexing techniques simultaneously transmit in-dependent information sequences, often called layers, over multiple antennas. Using *M* transmit antennas, the overall bit rate compared to a single-antenna system is thus enhanced by a factor of *M* without requiring extra bandwidth or extra transmission power. Channel coding is often employed, in order to guarantee a certain error performance. Since the individual layers are superimposed during transmission, they have to be separated at the receiver using an interference-cancellation type of algorithm (typically in conjunction with multiple receive antennas). A well-known spatial multiplexing scheme is the Bell-Labs Layered Space-Time Architecture (BLAST). The achieved gain in terms of bit rate (with respect to a single-antenna system) is called multiplexing gain.

B. Smaller Error Rates through Spatial Diversity

Similar to channel coding, multiple antennas can also be used to improve the error rate of a system, by transmitting and/or receiving redundant signals representing the same in-formation sequence. By means of two-dimensional coding in time and space, commonly referred to as space-time coding, the information sequence is spread out over multiple transmit antennas. At the receiver, an appropriate combining of the redundant signals has to be performed. Optionally, multiple receive antennas can be used, in order to further improve the error performance (diversity reception). The advantage over conventional channel coding is that redundancy can be accommodated in the spatial domain, rather than in the time domain. Correspondingly, a diversity gain and a coding gain can be achieved without lowering the effective bit rate compared to single-antenna transmission.

C. Improved Signal-To-Noise Ratios and Co-Channel-Interference Mitigation using Smart Antennas

In addition to higher bit rates and smaller error rates, multiple-antenna techniques can also be utilized to improve the signal-to-noise ratio (SNR) at the receiver and to suppress co-channel interference in a multiuser scenario. This is achieved by means of adaptive antenna arrays, also called smart antennas or software antennas in the literature. Using beam-forming techniques, the beam patterns of the transmit and receive antenna array can be steered in certain desired directions, whereas undesired directions (e.g., directions of significant interference) can be suppressed (‘nulled’). Beamforming can be interpreted as linear filtering in the spatial domain. The SNR gains achieved by means of beamforming are often called antenna gains or array gains.

D. Development of the Field

Extensive research on multiple-antenna systems for wireless communications, often called multiple-input multiple-output (MIMO) system started less than ten years ago. The great interest was mainly fueled by the pioneering works of Telatar Foschini and Gans Alamouti and Tarokh, Seshadri, and Calderbankat the end of the 1990’s. On the one hand, the theoretical results in promised significantly higher bit rates compared to single-antenna systems. Specifically, it was shown that the (ergodic or outage) capacity, i.e., the maximum bit rate at which error-free transmission is theoretically possible, of a MIMO system with M transmit and N receive antennas grows (approximately) linearly with the minimum of M and N.

MIMO can be divided into three main categories- spatial multiplexing or SM, diversity coding and beam forming.

Wireless Generations

1G – This was introduced in early 1980s which used for Analog Communication techniques like analog Cell Phones operating on 150 MHZ Frequency.

2G - This was introduced in late 1980s which used for Digital Communication techniques with TDM, FDM or CDMA. This was used for the transmission of Voice signal operating on GSM 900 MHZ with GPRS 56Kbps to 114 kbps. After this 2.5G is also introduced which is a stepping stone between 2G and 3G cellular wireless technologies 3G- This introduced just recently. The UMIT - Universal Mobile Telecommunications System is one of the third-generation (3G) cell phone technologies, which is also beams are not a good analogy. When the receiver has multiple antennas, the transmit beam forming cannot simultaneously maximize the signal level at all of the receive antenna and precoding is used. Note that precoding requires knowledge of the channel state information (CSI) at the transmitter.

2. Spatial Multiplexing Techniques

As discussed in the Introduction, three types of fundamental gains can be obtained by using multiple antennas in a wireless communication system: A multiplexing gain, a diversity gain, and an antenna gain. In this section, we will mainly focus on the multiplexing gain.

Spatial multiplexing [4] 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, the receiver 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 with or without transmit channel knowledge. Spatial multiplexing can also be used for simultaneous transmission to multiple receivers, known as space-division multiple access or Multi-user MIMO. The scheduling of receivers with different spatial signatures allows good separability.

3. Spatial Diversity Technique

In contrast to spatial multiplexing techniques, where the main objective is to provide higher bit rates compared to a single-antenna system, spatial diversity techniques predominantly aim at an improved error performance [1]. This is ac-accomplished on the basis of a diversity gain and a coding gain. Indirectly, spatial diversity techniques can also be used to enhance bit rates, when employed in conjunction with an adaptive modulation/channel coding scheme.

There are two types of spatial diversity, referred to as macroscopic and microscopic diversity. Macroscopic (large-scale) diversity is associated with shadowing effects in wire-less communication scenarios, due to major obstacles between transmitter and receiver (such as walls or large buildings). Macroscopic diversity can be gained if there are multiple transmit or receive antennas, that are spatially separated on a large scale. In this case, the probability that all links are simultaneously obstructed is smaller than that for a single link.

Microscopic (small-scale) diversity is available in rich-scattering environments with multipath fading. Microscopic diversity can be gained by employing multiple co-located antennas. Typically, antenna spacing's of less than a wavelength are sufficient, in order to obtain links that fade more or less independently. Similar to macroscopic diversity, the diversity gains are due to the fact that the probability of all links being simultaneously in a deep fade decreases with the number of antennas used.

4. Smart Antenna and Beamforming

Multiple antennas offer not only increased data rates and improved error rates. They can also be utilized, in order to improve the SNR at the receiver and to suppress co-channel interference (CCI) in a multiuser scenario, thus improving the SNR at the receiver(s). Both goals can be achieved by means of beam forming techniques.

4.1 Beamforming

Beamforming [7] can be interpreted as linear filtering in the spatial domain. Consider an antenna array with *N* antenna elements, which receives a signal from a certain direction. Due to the geometry of the antenna array, the impinging radio-frequency (RF) signal reaches the individual antenna elements at different time instants, which causes phase shifts between the different received signals. However, if the underlying complex baseband signal is assumed to be a narrowband signal, it will not change during these small time differences. If the direction of the impinging signal is known, the phase differences of the RF signals can be compensated by means of phase shifters or delay elements, before the received signals are added up. As a result, the overall antenna pattern of the phased array will exhibit a maximum in the direction of the impinging signal. This principle is called conventional beam forming.

Beam forming or spatial filtering is a signal processing technique used in sensor arrays for directional signal transmission or reception. This is achieved by combining elements in a phased array in such a way that signals at particular angles experience constructive interference while others experience destructive interference. Beam forming can be used at both the transmitting and receiving ends in order to achieve spatial selectivity. The improvement compared with omnidirectional reception/transmission is known as the receive/transmit gain (or loss).

Beam forming can be used for radio or sound waves. It has found numerous applications in radar, sonar, seismology, wireless communications, radio astronomy, acoustics, and biomedicine. Adaptive beam forming is used to detect and estimate the signal-of-interest at the output of a sensor array by means of optimal (e.g., least-squares) spatial filtering and interference rejection.

In the figure given above, a block to be understood is space time preceding and space time decoding.

Precoding: Precoding is multi-stream beamforming, in the narrowest definition. In more general terms, it is considered to be all spatial processing that occurs at the transmitter. In (single-layer) beamforming, the same signal is emitted from each of the transmit antennas with appropriate phase (and sometimes gain) weighting such that the signal power is maximized at the receiver input. The benefits of beamforming 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 the absence of scattering, beamforming, results in a well defined directional pattern, but in typical cellular conventional beams are not a good analogy. 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 used. Note that precoding requires knowledge of channel state information (CSI) at the transmitter.

Space time code: A **space–time code** (STC) is a method employed to improve the reliability of data transmission in wireless communication systems using multiple transmit antennas [2]. STCs rely on transmitting multiple, redundant Copies of a data stream to the receiver in the hope that at least some of them may survive the physical path between transmission and reception in a good enough state to allow reliable decoding.

4.2 Mimo Advantages

The increased bandwidth lets wireless networks serve more users at a given data rate than they could without MIMO. MIMO's higher speeds are critical for letting wireless networks handle data-intensive multimedia files. The increased bandwidth also lets wireless networks serve more users at a given data rate than they could without MIMO. And the increased range of MIMO LANs' base stations would let large businesses serve their entire organization with fewer stations, thereby saving them money. Because the technology reduces the effects of interference and can focus on better-quality signals, MIMO networks use less radio-transmission power than other wireless networks, so there is less battery drain on portable systems and less chance of interference with or from other systems. In addition, because MIMO sends transmissions along multiple paths, most of the signals can avoid objects and other sources of interference that cause fading and interruptions. And senders can adjust the power and phase given to antennas to steer signals toward the paths with the best transmission quality. More precise steering could minimize the interference a sender causes or receives. MIMO's signaling properties could also help create more robust wireless security. It would be difficult for hackers to set up their receivers to properly receive all of the signals that have been broken up and sent via multiple antennas along different paths.

5. Applications of Mimo

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. The IEEE 802.16e standard incorporates MIMO-OFDMA. The IEEE 802.11n standard, released in October 2009, recommends MIMO-OFDM. 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, e.g., multi-user MIMO (MU-MIMO). MIMO technology can be used in non-wireless communications systems. One example is the home networking standard ITU-T G.9963, which defines a powerline communications system that uses MIMO techniques to transmit multiple signals over multiple AC wires (phase, neutral and ground).

6. Technical Challenge

Designing MIMO systems, which send signals over multiple transmission paths, is a challenge[3], particularly because most wireless engineers have worked only on systems designed to Use one transmission path, according to Raleigh. Also, MIMO has worked well in a laboratory environment between two fixed nodes. However, said Stanfords Goldsmith, there are questions about how well it will work in a real-world environment between mobile nodes.

7. Conclusion

Researchers are now focusing on two popular coding schemes for using MIMO to carry traffic: orthogonal fre-quency-division multiplexing, sup-ported by companies such as Airgo and lucent, and code-division multiple access. Already, MIMO has become part of the IEEE 802.16d wireless net-working standard. Numerous vendors, such as Airgo and Lucent, are promoting MIMO as the IEEE's next 802.11 standard, 802.11n, which the organization expects to complete by2006. In addition, the Third Generation Partnership Project, a collaboration of telecommunications standards organi-zations, is evaluating MIMO for cellular networks.

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