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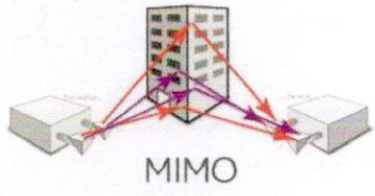
ANNEXURE-J

MIMO

In radio, **multiple-input and multiple-output**, or **MIMO** (/ˈmaɪmoʊ, ˈmiːmoʊ/), is a method for multiplying the capacity of a radio link using multiple transmission and receiving antennas to exploit multipath propagation.[1] MIMO has become an essential element of wireless communication standards including IEEE 802.11n (Wi-Fi 4), IEEE 802.11ac (Wi-Fi 5), HSPA+ (3G), WiMAX, and Long Term Evolution (LTE). More recently, MIMO has been applied to power-line communication for three-wire installations as part of the ITU G.hn standard and of the HomePlug AV2 specification.[2][3]



MIMO exploits multipath propagation to multiply link capacity.

At one time, in wireless the term "MIMO" referred to the use of multiple antennas at the transmitter and the receiver. In modern usage, "MIMO" specifically refers to a practical technique for sending and receiving more than one data signal simultaneously over the same radio channel by exploiting multipath propagation. Although the "multipath" phenomenon may be interesting, it is the use of orthogonal frequency-division multiplexing (OFDM) to encode the channels that is responsible for the increase in data capacity. MIMO is fundamentally different from smart antenna techniques developed to enhance the performance of a single data signal, such as beamforming and diversity.

Contents

History

Early research

MIMO is often traced back to 1970s research papers concerning multi-channel digital transmission systems and interference (crosstalk) between wire pairs in a cable bundle: AR Kaye and DA George (1970),[4] Branderburg and Wyner (1974),[5] and W. van Etten (1975, 1976).[6] Although these are not examples of exploiting multipath propagation to send multiple information streams, some of the mathematical techniques for dealing with mutual interference proved useful to MIMO development. In the mid-1980s Jack Salz at Bell Laboratories took this research a step further, investigating multi-user systems operating over "mutually cross-coupled linear networks with additive noise sources" such as time-division multiplexing and dually-polarized radio systems.[7]

Methods were developed to improve the performance of cellular radio networks and enable more aggressive frequency reuse in the early 1990s. Space-division multiple access (SDMA) uses directional or smart antennas to communicate on the same frequency with users in different locations within range of the same base station. An SDMA system was proposed by Richard Roy and Björn Ottersten, researchers at ArrayComm, in 1991. Their US patent (No. 5515378 issued in 1996[8]) describes a method for increasing capacity using "an array of receiving antennas at the base station" with a "plurality of remote users."

Invention

Arogyaswami Paulraj and Thomas Kailath proposed an SDMA-based inverse multiplexing technique in 1993. Their US patent (No. 5,345,599 issued in 1994[9]) described a method of broadcasting at high data rates by splitting a high-rate signal "into several low-rate signals" to be transmitted from "spatially separated transmitters" and recovered by the receive antenna array based on differences in "directions-of-arrival." Paulraj was awarded the prestigious Marconi Prize in 2014 for "his pioneering contributions to developing the theory and applications of MIMO antennas. ... His idea for using multiple antennas at both the transmitting and receiving stations – which is at the heart of the current high speed WiFi and 4G mobile systems – has revolutionized high speed wireless."[10]

In an April 1996 paper and subsequent patent, Greg Raleigh proposed that natural multipath propagation can be exploited to transmit multiple, independent information streams using co-located antennas and multi-dimensional signal processing.[11] The paper also identified practical solutions for modulation (MIMO-OFDM), coding, synchronization, and channel estimation. Later that year (September 1996) Gerard J. Foschini submitted a paper that also suggested it is possible to multiply the capacity of a wireless link using what the author described as "layered space-time architecture."[12]

Greg Raleigh, V. K. Jones, and Michael Pollack founded Clarity Wireless in 1996, and built and field-tested a prototype MIMO system.[13] Cisco Systems acquired Clarity Wireless in 1998.[14] Bell Labs built a laboratory prototype demonstrating its V-BLAST (Vertical-Bell Laboratories Layered Space-Time) technology in 1998.[15] Arogyaswami Paulraj founded Iospan Wireless in late 1998 to develop