IEEE P802.22 Wireless RANs

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| MIMO Text for the Std.802.22b Standard: Transmitter Side (CID 57) |
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Abstract

This document provides the full text referent to MIMO systems (transmitter side) of the 802.22b standard.

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9.15. Multiple-input, multiple-output (MIMO)

Multiple-input-multiple-output (MIMO) system has attracted a great deal of attention since the mid-1990’s. It consists of multiple antennas at both transmitter and receiver, and are a breakthrough in wireless communication system design. Not limited to time and frequency dimensions, MIMO exploits the spatial dimension created by multiple antennas to achieve improvements in capacity and reliability. Moreover, the improvements come with neither addition of bandwidth nor increment of power, therefore, making MIMO a highly spectral efficient and reliable technique.

The MIMO channel can be made more robust against fading channels than each of its single-input-single-output (SISO) components by exploiting spatial diversity. Furthermore, MIMO channel creates the possibility to increase the transmission rate compared to SISO channel through spatial multiplexing; however, these two features cannot be fully exploited at the same time. A fundamental trade-off between rate increment and robustness against fading exists and must be decided according to the users needs.

In the context of IEEE 802.22b, the MIMO technique described hereafter is more appropriate for the link between base station and relay stations existing in the wireless network backbone of IEEE 802.22b based systems. On the other hand, implementing MIMO on the links between base station and CPEs or relay stations and CPEs is technically more challenging. This is due to the fact that the lower operating frequencies inherent to the TVWS bands require antennas with bigger physical sizes than the ones required by existing wireless communication systems operating at higher parts of the frequency spectrum.

9.15.1. MIMO pilot allocation

Text required.

9.15.1.1. Pilot allocation for 2 antennas

Text required.

9.15.1.2. Pilot allocation for 4 antennas

Text required.

9.15.2 Space Time Coding (STC)

The MIMO technique described in this section is common to both PHY Mode 1 and PHY Mode 2 of the PHY layer considered in this standard.

9.15.2.1 Transmit diversity using 2 antennas (Alamouti O-STBC)

Improvement in wireless link robustness against the deleterious effects of fading is achieved by the use of Orthogonal Space-Time Block Codes (O-STBCs) through exploitation of the extra degrees of freedom provided by the multi-input-multi-output (MIMO) channel.

Let us consider a wireless communications system with two antennas at the transmitter side and a single antenna at the receiver side. Additionally, let both transmit antennas, namely antenna one and two, be spaced at least half-wave length from each other and from which two symbols *s1* and *s2* are respectively transmitted (simultaneously) at a given symbol period *T*. If during the following symbol period *-s2\** and *s1\**, where \* represents complex conjugation operation, are now transmitted respectively from antenna one and two, we can represent the encoding scheme in the following manner,

G2 = , (1)

where the columns of the above encoding matrix represent the transmit antennas, the rows correspond to the symbol periods and *sn* is the symbol taken from a complex constellation *C* with *n* ∈ {1,2}.

Considering that the channel remains constant across two consecutive symbol periods, i.e., a block fading channel, we can write

h1(t) = h1(t+T) = h1, (2)

h2(t) = h2(t+T) = h2,

where *T* is the symbol period, *h1* and *h2* are the channels paths between the transmit antenna and the receive antenna. Thus, received signals are expressed by

r1 = h1s1 + h2s2 + n1, (3)

r2 = -h1s2\* + h2s1\* + n 2.

Here, n1 and n2 are zero-mean white complex Gaussian distributed noise values with variance σ2n /2 per dimension. The technique employed at the receiver side to obtain the spatial diversity is described in the Appendix section.

9.15.2.2. Transmit Diversity with Array-Interference Gain

The technique disclosed in this subsection is full rate based on array-interference constructive aggregation. Its objective is to improve the link reliability over conventional transmit diversity, i.e., Space-Time Block Codes (STBC). This technique intentionally creates aligned array interference so as to exploit its energy in the form of added array gain. As a result, the overall gain (diversity gain + array gain) reduces the bit-error probability (BEP) as compared to the diversity gain only yielded by conventional STBCs based systems.

9.15.2.2.1. Transmit Diversity with Array-Interference Gain for 2 antennas

In this subsection we describe the structure of a 2 transmit (TX) antennas (nt = 2) transmit diversity TDD system exploiting transmit array interference. Since the system is based on TDD, both transmitter and receiver operate in the same frequency channel, however, in different time-slots. In addition, in a TDD communication system, transmitter and receiver alternate their roles, i.e., the transmitter in time “Tn” is the receiver in the consecutive time “Tn+1”. A direct consequence of the aforementioned, is that both transmitter and receiver can estimate the wireless channel **H** during the time in each they are acting as receiver.

The vector **H** = [h1 h2] represents the multiple-input-single-output (MISO) channel between the base station and the single antennae receiver (RX) white space device.In the analyses presented hereafter, **H** is considered to be quasi-static.

Symbols vectors are transmitted through **H** and noise is added at the receiver as shown in Fig. 9.15.2.2.1-1. The transmitter is composed of two blocks, namely, ‘array gain maximization’ and ‘transmit vector selector’. The aforementioned blocks are described in the following subsections.

In 2 TX antennas systems, a total of two unique transmit vectors Gm, for *m* ∈ {0,1} exists. As it will be explained in the following, each Gm yields a single interference, which is aligned to the original signal thus improving system robustness towards fading. The total interference has components coming from all antennas in the array thus it is hereafter called aligned array interference IAm. It should be noted that IAm, where *m* ∈ {0,1}, are functions of the fading channel **H**, and both TX and RX can estimate **H** due to the reciprocity of up-link/down-link.



**Figure** 9.15.2.2.1-1**.** Transmit Diversity with Array-Interference Gain for 2 TX Antennas (TX side).

Channel estimation is performed by the ‘channel estimator’ block (see Appendix 9.15.2.2.1. for implementation of the receiver side) based on pilots. The estimation is then provided to the ‘array gain maximization’ block.

The “Array Gain Maximization” blocks in TX performs



in order to compare all the IAm and selects the one that has the maximum value.

Following, the “array gain maximization” block at the transmitter sends *m* inherent to the maximum array interference to the “transmit vector selector” block, which selects Gm to be transmitted over the channel **H** since Gm will yield the maximum array gain.

##### Array Gain Maximization Block

In the array gain maximization block, the array interference IAm is stored as a function of **H.**

* Array Interference IA0

* Array Interference IA1

In order to select the most aligned interference, the ‘array gain maximization’ block performs



The ‘array gain maximization’ block at the TX directly sends *m* to the collocated ‘transmit vector selector’. For the following implementation examples consider that *m* is represented by 3 bits.

##### Transmit Vector Selector Block

* Transmit if *m* is ‘000’;

* Transmit if *m* is ‘001’;

where *s* is a symbol taken from a complex constellation *C*.

9.15.2.2.2. Transmit Diversity with Array-Interference Gain for 4 antennas

##### Array Gain Maximization Block

In the case of 4 TX antennas, there are eight unique Gm together with their respective IAm as well as *wm*, m ∈ {0,1,2,3,4,5,6,7}.

In order to select the most aligned interference, the ‘array gain maximization’ block performs,

The ‘array gain maximization’ block at the transmitter sends *m* to the ‘transmit vector selector’ block collocated at the transmitter.

##### Transmit Vector Selector Block

* Transmit if *m* is ‘000’;

* Transmit if *m* is ‘001’;

* Transmit if *m* is ‘010’;

* Transmit if *m* is ‘011’;

* Transmit if *m* is ‘100’;

* Transmit if m is ‘101’;

* Transmit if *m* is ‘110’;

* Transmit if *m* is ‘111’;

The above procedure partially (transmitter side only) describes how to obtain diversity added with array gain for systems with multiple antennas at the transmitter side. Note that the transmitter steps described here must be followed by the receiver steps described in the Appendix Section A.1.2..

If more than one antenna is available in the receiver terminal, maximum ratio combining (MRC) can be utilized to significantly enhance link reliability. For simplicity, in the following example consider that the number of antennas available at the receiver is 2. The technique, however, can be utilized for any number of receive antennas.

In order to use MRC, little modification is necessary to what has been presented. The ‘Array Gain Maximization’ block, now, performs

for 2 TX antennas, and

for 4 TX antennas. Here, IAm is the array interference in the first RX antenna, given in the previous sections and I’Am represents the array interferences in the second RX antenna. Since the channel to the second RX antenna is given by **H** = [h3 h4], for two TX antennas, and **H** = [h5 h6 h7 h8], for 4 TX antennas, I’Am becomes

or

.

The ‘array gain maximization’ block at the transmitter sends *m* to the collocated ‘transmit vector selector’ block.

9.15.3 Spatial Multiplexing

The MIMO technique described in this section is common to both Mode 1 and PHY Mode 2 of the PHY layer considered in this standard.

9.15.3.1 Spatial Multiplexing using 2 Antennas

Previous sections have described methods to improve wireless link robustness against the deleterious effects of fading. Two spatial diversity techniques were described, namely Alamouti Code and a form of transmit diversity, which exploits the antenna array interference to obtain extra diversity gain. One application example of the aforementioned techniques is link-range extension between IEEE 802.22b CPEs in order to service a wider geographical area. This is fundamental whenever the antennas of both CPEs are positioned relatively low due to the strong signal attenuation characteristic to near ground wave propagation.

This section, however, describes a highly spectral efficient technique that significantly enhances the IEEE 802.22b system throughput. Spatial multiplexing transmits independent and separately encoded signals, i.e. streams, from each transmit antenna, therefore reusing (or multiplexing) the space dimension. In IEEE 802.22b systems, enhanced data-rate enables CPEs with bandwidth-hungry applications, e.g., such as wireless video transmissions for monitoring purposes, or it can increase the density of CPEs with data-rate comparable to legacy IEEE 802.22 standard.

Let us consider the 2x2 wireless communications depicted in Fig. 9.15.3.1-1. The channel gains between the ith transmit antenna and the jth receive antenna *hj,i* is represented by the MIMO channel matrix

***H*** = $\left[\begin{matrix}h\_{1,1}&h\_{1,2}\\h\_{2,1}&h\_{2,2}\end{matrix}\right]$.

Additionally, let both transmit antennas, namely antenna one and two, be spaced at least half-wave length from each other and from which two symbols *s1* and *s2*, taken from an arbitrary complex constellation *C*, are simultaneously transmitted. Representing the transmitted symbols by the vector ***s*** *=* [*s1 s2*]*T* and the noise at the receive antennas by ***n*** = [*n1 n2*]*T*, also illustrated in Fig. 9.15.3.1-1, we can represent the received signals as

$\left[\begin{array}{c}y\_{1}\\y\_{2}\end{array}\right] $= $\left[\begin{matrix}h\_{1,1}&h\_{1,2}\\h\_{2,1}&h\_{2,2}\end{matrix}\right]∙\left[\begin{array}{c}s\_{1}\\s\_{2}\end{array}\right] $+ $\left[\begin{array}{c}n\_{1}\\n\_{2}\end{array}\right]$, **(1)**

or

***y*** *=* ***H***$∙$***s + n****.*  **(2)**

Here, *nj* is the zero-mean white complex Gaussian distributed noise with variance σ2n/2 per dimension and T denotes transpose operation.



Figure 9.15.3.1-1 - Schematic Representation of Spatial Multiplexing technique.

9.15.3.2 Spatial Multiplexing using 4 Antennas

Previous sections have described spatial multiplexing with 2 Tx and 2 Rx antennas. This section illustrates the same technique, however, for 4 Tx and 4 Rx antennas.

Consider a 4x4 wireless communications system. The channel gains between the ith transmit antenna and the jth receive antenna *hj,i* is represented by the MIMO channel matrix

***H*** = $\left[\begin{matrix}\begin{matrix}h\_{1,1}&h\_{1,2}\\h\_{2,1}&h\_{2,2}\end{matrix}&\begin{matrix}h\_{1,3}&h\_{1,4}\\h\_{2,3}&h\_{2,4}\end{matrix}\\\begin{matrix}h\_{3,1}&h\_{3,2}\\h\_{4,1}&h\_{4,2}\end{matrix}&\begin{matrix}h\_{3,3}&h\_{3,4}\\h\_{4,3}&h\_{4,4}\end{matrix}\end{matrix}\right]$

Similarly to the 2x2 case, let all antennas be spaced at least half-wave length from each other from where four symbols *s1*, *s2*, *s3*, *s4*, taken from the arbitrary complex constellation *C* are simultaneously transmitted. The transmitted symbols vector is ***s*** *=* [*s1 s2 s3 s4*]*T* and the noise at the receive antennas is ***n***  = [*w1 w2 w3 w4*]*T* with the received signals also given by ***y*** *=* ***H***$∙$***s + n****.*

9a.14 MIMO pilot allocation

When using MIMO scheme for PHY Mode 2, the data allocation to tile is changed to accommodate multiple antennas transmission for the channel estimation. MIMO pilot allocations for the cases of 2 TX antennas and 4 TX antennas are described in 9a.14.1-1 and 9a.14.1-2, respectively. Each subsection includes both DS and US pilot allocations for multiple transmit antennas.

9a.14.1 Pilot allocation for 2 antennas

In the case of two (2) transmit BS antennas, the DS data allocation to tile is changed (Figure 9a.14.1-1) to accommodate two antennas transmission for channel estimation. Figure 9a.14.1-1 replaces Figure M1 in 9a.6.1.1 when MIMO is enabled.



Figure 9a.14.1-1 DS tile structure for 2 TX antennas

In the case of two (2) transmit CPE antennas, the US data allocation to tile is changed (Figure 9a.14.1-2) to accommodate two antennas transmission for channel estimation. Figure 9a.14.1-2 replaces Figure N1 in 9a.6.1.2 when MIMO is enabled.



Figure 9a.14.1-2 US tile structure for 2 TX antennas

9a.14.2 Pilot allocation for 4 antennas

In the case of four (4) transmit BS antennas, the DS data allocation to tile is changed (Figure 9a.14.2-1) to accommodate four antennas transmission for channel estimation. Figure 9a.14.2-1 replaces Figure M1 in 9a.6.1.1 when MIMO is enabled.



Figure 9a.14.2-1 DS Tile structure for 4 TX antennas

In the case of four (4) transmit CPE antennas, the US data allocation to tile is changed (Figure 9a.14.2-2) to accommodate four antennas transmission for channel estimation. Figure 9a.14.2-2 replaces Figure N1 in 9a.6.1.2 when MIMO is enabled.



Figure 9a.14.2-2 US tile structure for 4 TX antennas

9a.14.3 Space Time Coding (STC)

The MIMO technique is common to PHY Mode 1 and PHY Mode 2. Please refer to the Section 9.15.2.