IEEE P802.22 Wireless RANs

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| MIMO Text for the Std.802.22b Standard: Receiver Side (CID 63, 64, 67, 68) | | | | |
| Date: 2014-09-15 | | | | |
| Author(s): | | | | |
| Name | Company | Address | Phone | email |
| Gabriel Porto Vilardi | NICT | 3-4, Hikarino-oka, Yokosuka, 239-0847, Japan | +81-46-847-5438 | gpvillardi@nict.go.jp |
| Masayuki Oodo | NICT | 3-4, Hikarino-oka, Yokosuka, 239-0847, Japan |  | moodo@nict.go.jp |
| Chang-Woo Pyo | NICT | 3-4, Hikarino-oka, Yokosuka, 239-0847, Japan |  | cwpyo@nict.go.jp |

Abstract

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

**Notice:** This document has been prepared to assist IEEE 802.22. It is offered as a basis for discussion and is not binding on the contributing individual(s) or organization(s). The material in this document is subject to change in form and content after further study. The contributor(s) reserve(s) the right to add, amend or withdraw material contained herein.

**Release:** The contributor grants a free, irrevocable license to the IEEE to incorporate material contained in this contribution, and any modifications thereof, in the creation of an IEEE Standards publication; to copyright in the IEEE’s name any IEEE Standards publication even though it may include portions of this contribution; and at the IEEE’s sole discretion to permit others to reproduce in whole or in part the resulting IEEE Standards publication. The contributor also acknowledges and accepts that this contribution may be made public by IEEE 802.22.

**Patent Policy and Procedures:** The contributor is familiar with the IEEE 802 Patent Policy and Procedures

<[**http://standards.ieee.org/guides/bylaws/sb-bylaws.pdf**](http://standards.ieee.org/guides/bylaws/sb-bylaws.pdf)>, including the statement "IEEE standards may include the known use of patent(s), including patent applications, provided the IEEE receives assurance from the patent holder or applicant with respect to patents essential for compliance with both mandatory and optional portions of the standard." Early disclosure to the Working Group of patent information that might be relevant to the standard is essential to reduce the possibility for delays in the development process and increase the likelihood that the draft publication will be approved for publication. Please notify the Chair Apurva N. Mody <[**apurva.mody@ieee.org**](mailto:apurva.mody@ieee.org)> as early as possible, in written or electronic form, if patented technology (or technology under patent application) might be incorporated into a draft standard being developed within the IEEE 802.22 Working Group. **If you have questions, contact the IEEE Patent Committee Administrator at <[patcom@ieee.org](mailto:patcom@ieee.org" \t "_parent)>**.

Appendix

(informative)

A.1. Multiple-input, multiple-output (MIMO) – Receiver Side Implementation

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

A.1.1 Receiver Side Implementation of Scheme in 9.15.2.1

The transmit scheme of Section 9.15.2.1 yields the received signals r1 and r2 given in 9.15.2.1 (3). After performing the following signal combination at the receiver,

(1)  
,

the estimated symbols are given by

 = s1 (|h1|2+|h2|2) + h1\*n1 + h2n2\*, (2)

= s2 (|h1|2+|h2|2) - h1n2\* + h2\*n1.

The diversity order provided by the Alamouti scheme is the same as the one provided by the maximum ratio combining (MRC) receiver with a single transmit antenna and two receive antennas. However, Alamouti scheme benefits from having the complexity transferred to the transmitter premises where device size is not a major constraint.

A.1.2. Receiver Side Implementation of Scheme in 9.15.2.2.

The transmit scheme of Section 9.15.2.2. has to be processed at the receiver side in the manner described in this section in order to obtain transmit diversity with array interference gain.

The receiver is composed of the blocks “channel estimator”, “combiner”, “array gain maximization” and “ML detection” in order to recover the transmitted symbols, however, with array-interference gain. 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. The aligned array interference 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. Consequently, IAm can be calculated beforehand and stored in RX device memory.



**Figure A.1.2-1.** Transmit Diversity with Array-Interference Gain for 2 TX Antennas (RX side).

The ‘channel estimator’ block performs channel estimation based on pilots. The estimation is then provided to the ‘combiner’ block and the ‘array gain maximization’ block.

The “Array Gain Maximization” blocks in RX 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 receiver sends the index *m*, in binary, to the ‘combiner’ block, which is collocated in the same RX device. For instance, if *m* = ‘1’, the ‘combiner’ block will utilize the weight *w1*, when it receives the signal from TX.

The ‘combiner block’ provides symbol estimate to the ‘maximum likelihood (ML) detector’ block.

##### Array Gain Maximization Block

In the array gain maximization block, the array interference IAm is stored as a function of **H** (see the “Array Gain maximization Block” in Section 9.15.2.2.1.)

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



The ‘array gain maximization’ block at the receiver sends *m* to the collocated ‘combiner block’. For the following implementation examples consider that *m* is represented by 3 bits.

##### Combiner Block

Let and denotes transpose operation and *n*, the zero-mean additive white Gaussian noise (AWGN).



* If the ‘combiner’ block receives *m = 000* from the ‘array gain maximization’ block, the received signal is

.



The combiner, then, utilizes



for the combination. However, for the specific case of m = 000, multiplying vector *wm* is not necessary and left here for illustration purposes only. The ‘combiner’ block performs the following combination,



which is, then, passed to the ML detector to perform the symbol estimation.

* If the ‘combiner’ block receives m = 001, then,



The combiner, then, utilizes



yielding,



This is, then, passed to the ML detector to perform the symbol estimation.

In a 4 TX antennas system, the receiver has to perform the following steps:

##### Array Gain Maximization Block

In the case of 4 TX antennas, there are eight IAm (see the “Array Gain Maximization Block” in Section 9.15.2.2.2) 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 receiver sends *m* to the ‘combiner’ block collocated at the receiver.

##### Combiner Block

##### Letand for the sake of simplicity in the example, the channel estimation be perfect, i.e., .



* If the ‘combiner’ block receives m = 000 from the ‘array gain maximization’ block, it utilizes



to perform the combination



which is, then, passed to the ML detector to perform the symbol estimation.

* If the ‘combiner’ block receives m = 001 from the ‘array gain maximization’ block, it utilizes



and performs the following combination,



which is, then, passed to the ML detector to perform the symbol estimation.

* If the ‘combiner’ block receives m = 010 from the ‘array gain maximization’ block, it utilizes



and performs the following combination,



which is, then, passed to the ML detector to perform the symbol estimation.

* If the ‘combiner’ block receives m = 011 from the ‘array gain maximization’ block, it utilizes



and performs the following combination,



which is, then, passed to the ML detector to perform the symbol estimation.

* If the ‘combiner’ block receives m = 100 from the ‘array gain maximization’ block, it utilizes



and performs the following combination,



which is, then, passed to the ML detector to perform the symbol estimation.

* If the ‘combiner’ block receives m = 101 from the ‘array gain maximization’ block, it utilizes



and performs the following combination,



which is, then, passed to the ML detector to perform the symbol estimation.

* If the ‘combiner’ block receives m = 110 from the ‘array gain maximization’ block, it utilizes



and performs the following combination,



which is, then, passed to the ML detector to perform the symbol estimation.

* If the ‘combiner’ block receives m = 111 from the ‘array gain maximization’ block, it utilizes



and performs the following combination,



which is, then, passed to the ML detector to perform the symbol estimation.

The above procedure must follows the steps described in Sections 9.15.2.2.1 and 9.15.2.2.2 in order to obtain diversity added with array gain for systems with multiple antennas at the transmitter, however, with single antenna at the receiver. Bellow, extension to system configuration consisting of multiple receiving antennas is presented.

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 and I’Am can be found in Section 9.15.2.2.

The ‘array gain maximization’ block at the receiver sends *m* to the collocated ‘combiner block’. The ‘combiner block’ will combine the received signal, just as described in the previous sections, in order to deliver to the ML detector. Note that is given in the previous sections and is given by



with y’ being the signal received by the second RX antenna and **H** = [h3 h4], for 2TX, or **H** = [h5 h6 h7 h8], for 4 TX.

The technique described above is full rate and yields full spatial diversity added to antenna array gain thus yielding better link reliability.

A.1.3. Receiver Side Implementation of Scheme in 9.15.3

In this section we provide examples on how to process the signals received by transmissions following the scheme described in Section 9.15.3. in order to obtain throughput enhancements.

Spatial Multiplexing Signal Detection for a system with 2 TX antennas:

Several receiver techniques exist to obtain the estimate of the transmitted symbols and . In this section the linear zero-forcing (ZF) method is described along with its ordered successive interference cancelation (OSIC) variant. Employing the following weight matrix,

***Z = (HHH)-1HH****,* **(3)**

the ZF method intends to cancel the interference between symbols *s1* and *s2* by

**. (4)**

Substituting (2) and (3) into (4), yields

***s* + *(HHH)-1HHn****.* **(5)**

or

= + **(6)**

Obviously, perfect recovery, i.e., nulling of interference, is not achieved due to the presence of an enhanced noise component ***(HHH)-1HHn*** in (5) and (6).

For an improved bit-error-rate (BER) and packet-error-rate (PER) performance, OSIC technique successively cancels components from the received signal until one of the data streams is detected. Although this method leads to increase in complexity, it is however not significant in the face of BER and PER improvements.

From Fig. A.1.3-1, it can be easily understood the principle of OSIC detection. The symbol, from a parallel stream, which is estimated first, is then subtracted from the originally received signal yielding a reduced interference signal. This reduced interference signal is used in the following stage of the OSIC detection where the other symbol will be estimated. Here, *i* refers to the estimation order which does not necessarily follows the same symbol order, i.e., *si* could be *s2*while *si+1*, *s1*. There are several criteria to select the symbol estimation order, e.g., SNIR-based order, SNR-based order, column norm-based order with the latter being adopted through this section.

In order to determine the estimation order we rewrite (1) as

= + . **(7)**



Figure A.1.3-1 - Schematic diagram of SM detection based on OSIC technique.

From (7) it is clear that symbols *s1* and *s2* have their magnitude affected by the norm of ||***H:,1***||and||***H:,2***||,denoting first and second columns of ***H***, respectively. It is therefore obvious to estimate the symbols according to the order of the norms of ***H***.

The first symbol *si* is estimated by the ith row of ***Z****,*

**y**,  **(8)**

yielding

,  **(9)**

which is then mapped to the possible transmitted symbol from the constellation *C* with the closest Euclidian distance to it.

Once the first estimation occurs, the mapped is then used in the next stage to estimate ,

.  **(10)**

In the case that is correctly estimated, mapping (10) to the symbol with closest Euclidian distance from *C* yields. For instance, consider that and it was correctly estimated. It can be easily seen that (10) becomes

+  **(11)**

yielding,

+  **(12)**

In the case that is not correctly estimated, error propagation occurs thus compromising BER and PER performances.

Spatial Multiplexing Signal Detection for a system with 4 TX antennas:

Linear zero-forcing (ZF) method yields the estimated symbols ***s* + *(HHH)-1HHn***due to **,** where ***Z = (HHH)-1HH***, where **H** represents Hermitian operator.

Similarly to the 2x2 case, improved bit-error-rate (BER) and packet-error-rate (PER) performance can be obtained through OSIC technique. Here we detail the OSIC technique applied to a 4x4 SM-MIMO system. The symbol, from a parallel stream, which is estimated first, is then subtracted from the originally received signal yielding a reduced interference signal. This reduced interference signal is used in the following stage of the OSIC detection where another symbol will be estimated and then subtracted from the signal in order to further reduce interference. This procedure is repeated until all symbols are estimated.

Again considering column norm-based order, ||***H:,1***||, ||***H:,2***||, ||***H:,3***|| and||***H:,4***||, and for illustrations purposes, considering that ||***H:,1***|| > ||***H:,2***|| > ||***H:,3***|| >||***H:,4***||, the symbols are estimated in the following order:

The first symbol *s1* is estimated by the 1th row of ***Z****,*

**y**,  **(1)**

yielding

,  **(2)**

which is then mapped to the possible transmitted symbol from the constellation *C* with the closest Euclidian distance to it.

Generating the reduced interference (provided that ) signal,

.  **(3)**

A new MIMO matrix is constructed by deleting the 1st column, i.e.,

,

with  ***= (H)-1H***.

Then, is estimated by

**. (4)**

Again, a further reduced interference signal (provided that ) is generated by

,  **(5)**

along with

and ***= (H)-1H***.

Estimation of follows,

**. (6)**

Finally, the last reduced interference signal (provided that ) is generated by

,  **(7)**

along with

and  ***= (H)-1H***.

The last estimation follows,

**. (8)**

Note that precoder-based spatial multiplexing could be employed by exploiting the channel reciprocity inherent to TDD systems. This is due to the fact that both the down-link (DL) and the up-link (UL) of TDD systems operate in the same frequency however in different time-slots and thus are highly correlated. The channel state information (CSI) can be obtained by the Tx side during (UL) transmissions.

Once CSI is known, the Tx transmits the , where ***W*** is the NtxNs precoding matrix with Nt referring to the number of transmit antennas and Ns to the number of streams. For instance, for the 4x4 SM-MIMO with zero-forcing considered above, **W = αH-1**,

, (9)

due to Tx power constraints and where *Tr* represents the trace of

After dividing the received signal **α,**  it then becomes

**(10)**

or

**(11)**