IEEE P802.11
Wireless LANs

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| --- |
| Comment resolution on Space-Time Block Coding |
| Date: 2017-01-15 |
| Author(s): |
| Name | Affiliation | Address | Phone | email |
| Thomas Handte | Sony Europe Ltd. | Heldelfinger Strasse 61 | +49 711 5858 236 | thomas.handte @ sony.com |
| Dana Ciochina | Sony Europe Ltd. |  |  | dana.ciochina @ sony.com |

Abstract

This document proposes comment resolution to CIDs related to space-time block coding (STBC).
The following CIDs are considered 1617, 1627, 1835, 2029, 2030, 2031, and 2034.

Draft text changes are based on TGay D1.0 [1].

**Comments**

|  |  |  |  |
| --- | --- | --- | --- |
| **CID** | **Clause** | **Comment** | **Proposed Change** |
| 1617 | 30.5.9.5.3 | Space-time block coding is limited to one spatial stream only. It can be beneficial to generalize to more spatial streams | comment resolution will be provided |
| 2029 | 30.5.3.1 | The text is too restrictive as STBC can be applied to multple spatial streams | Relax the text and complete the STBC descritption |
| 2030 | 30.5.3.3.2 | STBC can be applied to multiple spatial streams, thus the description: if stbc is applied, a single spatial stream is mapped to 2 space time streams is too restrictive. | Replace "single" with "each" and complete the multiple STBC description for the SU-MIMO case |
| 2034 | 30.6.2.1 | OFDM mode should allow multiple STBC with multiple spatial streams | Please extend to N\_ss>=1 |

**Discussion**

Commenters propose to extend current 11ay STBC encoding to multiple streams for SC (1617, 2029, 2030) and OFDM (2034).

**Motivation**

* **STBC can exploit MIMO features of AP in asymmetric MIMO**
	+ APs typically have more MIMO features than STAs
	+ STBC provides transmit diversity in this case which can be used to
		- increase throughput, i.e. higher channel gain, higher modulation order
		- provide redundancy, i.e. more robust communication in case of shadowing or blockage
* **As of today, 11ay STBC encoding is limited to a single spatial stream (NSS=1)**
	+ Benefits of STBC in MIMO are too versatile to be limited to a single spatial stream
	+ STBC in CA is not possible as even NSS is prerequisite
* **Often effective channels can get block diagonal**
	+ i.e. channels have this structure $H=\left(\begin{matrix}H\_{1}&≈0\\≈0&H\_{2}\end{matrix}\right)$
		- $≈0$ means negligible interference
		- each $H\_{i}$ can either be fully occupied or be block diagonal matrix
	+ Appropriate beamforming and/or reordering (spatial mapping) may be required to achieve block diagonal shape
	+ Block diagonalization can even be an objective function for beamforming
	+ Block diagonal structure eases equalization
		- Each STBC encoded stream may be independently decoded at receiver
		- Reuse of single stream STBC receiver possible

**Proposal**

* **Generalization of the 11ay STBC encoding to support several spatial streams**
	+ Each spatial stream is independently STBC encoded
		- Multiplication of today’s STBC encoder
	+ Even number of space-time streams , i.e. NSTS=2NSS

|  |  |
| --- | --- |
| Today | Proposed |
|  |  |

**Simulation (see Appendix)**

* Feasibility of multi-stream STBC in LOS and NLOS
* Gain of STBC vs. CSD between 2.5 to 5.5dB
	+ Larger gain for lower number of receive antennas

Proposed Resolution: **Revised**

Draft text changes to implement STBC with multiple spatial streams is defined for SC and OFDM and proposed in DCN 11-18/0186r0 and includes:

* Each spatial stream is independently STBC encoded
	+ Support of max. NSS=4 streams in SU-MIMO (i.e. NSTS=8)
* Multi-stream STBC applies for SC and OFDM modulation
* Clarification that NSS>1 may be employed wherever necessary

*TGay Editor: Please modify “Table 27 TXVECTOR and RXVECTOR parameters (P220, L1)” as follows*

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| STBC | FORMAT is EDMG | Indicates whether STBC is used.0: indicates no STBC (NSTS = NSS in the Data field).1: indicates STBC is used (NSTS = 2NSS ~~and~~ with NSS ~~= 1~~ in the Data field). | Y | Y |
| NUM\_STS | FORMAT is EDMG | Indicates the number of space-time streams.Value is an integer in the range 1 to 8 for an SU PPDU. For an MU PPDU, values are integers in the range 1 to 2 per user in the TXVECTOR, and 0 to 2 per user in the RXVECTOR.The addition of NUM\_STS over all users is in the range of 1 to 8.If STBC is employed the number of space-time streams shall be an even number.  | MU | Y |
|  | NOTE—In the “TXVECTOR” and “RXVECTOR” columns, the following apply: Y = Present; N = Not present: O = Optional; SU = indicates that the parameter is present for each spatial stream. Those parameters are conceptually supplied as an array of values indexed by values 0 to NUM\_STS – 1 if STBC is not applied or indexed by 0 to NUM\_STS/2-1 if STBC is applied; MU = indicates that the parameter is present once for an EDMG SU PPDU and present per user for an EDMG MU PPDU. Parameters specified to be present per user are conceptually supplied as an array of values indexed by values 0 to NUM\_USERS – 1; SU+MU = indicates that the parameter is present for each spatial stream and each user. Those parameters are conceptually supplied as a two dimensional array of values indexed by values 0 to NUM\_STS – 1 if STBC is not applied or 0 to NUM\_STS/2-1 if STBC is applied by 0 to NUM\_USERS – 1.NOTE—If the condition specified in the “Condition” is not satisfied, the parameter is not present in either the TXVECTOR or RXVECTOR. |

*TGay Editor: Please modify subclause “Table 36 -* *EDMG-Header-A field structure and definition for a SU PPDU (P248, L1)” as follows*

|  |  |  |  |
| --- | --- | --- | --- |
| **Field** | **Number of bits** | **Start bit** | **Description** |
| STBC Applied | 1 | 15 | Corresponds to the TXVECTOR parameter STBC. If set to 1, indicates that STBC was applied at the transmitter. Otherwise, set to 0.If set to 1, DCM SQPSK Applied and Phase Hopping field shall be set to 0. |
| … | … | … | … |
| DCM SQPSK Applied | 1 | 62 | Corresponds to the TXVECTOR parameter DCM\_SQPSK. If set to 1 and the PSDU is encoded using the EDMG SC mode, it indicates that DCM SQPSK modulation defined in 30.5.9.5.2 was applied at the transmitter.If set to 1 and the PSDU is encoded using the EDMG OFDM mode with two spatial streams, it indicates that DCM SQPSK modulation defined in 30.6.8.3.4 was applied at the transmitter.If set to 1, STBC Applied and Phase Hopping field shall be set to 0.In all other cases, this field is set to 0. |
| … | … | … | … |
| Phase Hopping | 1 | 93 | Corresponds to TXVECTOR parameter PHASE\_HOPPING. If set to 1 in an EDMG OFDM mode PPDU, this field indicates that phase hopping modulation is used. Otherwise this field is set to 0. If set to 1, STBC Applied and DCM SQPSK Applied field shall be set to 0.This field is reserved in an EDMG SC mode PPDU, or if the transmitter or receiver do not support phase hopping. |

*TGay Editor: Please modify subclause “30.5.3.1 General (P281, L4)” as follows*

30.5.3.1 General

EDMG and non-EDMG SC PPDU transmissions can be generated using a transmitter consisting of the following blocks:

* Scrambler scrambles the data to reduce the probability of long sequences of 0s and 1s; see 20.3.9 (Scrambler).
* LDPC encoder encodes the data to enable error correction. It pads the data with zeros to get an integer number of codewords and SC symbol blocks; see 30.5.9.5.
* Stream parser divides the output of the LDPC encoder into the groups of bits that are sent to different mapping devices. The sequence of the bits sent to different mapping devices is called a spatial stream; see 30.5.9.4.
* Constellation mapper maps the sequence of bits in each stream to constellation points (complex numbers); see 30.5.9.5.
* Interleaver performs interleaving inside a SC symbol block; see 30.5.9.5.4.
* STBC encoder spreads constellation points from NSS spatial streams into NSTS space-time streams using a space-time block code. SC mode defines ~~single~~ STBC schemes with ~~N~~~~SS~~ ~~= 1 and~~ NSTS = 2NSS; see 30.5.9.5.3.
* GI insertion prepends the SC symbol block with guard interval defined as a π/2-BPSK modulated Golay sequence; see 30.5.9.2.
* Preamble builder builds π/2-BPSK modulated Ga and Gb Golay sequences comprising the L-STF, L-CEF, EDMG-STF, and EDMG-CEF fields; see 30.10.
* Spatial mapper maps space-time streams to transmit chains. This may include one of the following, see 30.5.10.2:
* Direct mapping: constellation points from each space-time stream are mapped directly into the transmit chains.
* Indirect mapping: constellation points from each space-time stream are mapped to each transmit chain.
* Digital beamforming: each vector of constellation points from all of the space-time streams is multiplied by a matrix of steering vectors to produce the input to the transmit chains.
* Cyclic shift (CSD) insertion prevents the signal transmission from unintentional beamforming. A cyclic shift is specified per transmitter chain for non-EDMG duplicate PPDU transmission; see 30.5.3.3.1.
* Pulse shaping performs convolution of constellation points with shape filter impulse response with possible sampling rate change. For duplicate channel transmission, pulse shaping may include a relative time delay between the primary and secondary channels. The exact definition of shape filter impulse response is out of scope of this standard and is implementation specific.

*TGay Editor: Please modify subclause “30.5.3.3.2 EDMG portion of SU PPDU transmission (P283, L1)” as follows*

Figure 129 shows the transmitter blocks used to generate the EDMG portion of SU PPDU. The EDMG-STF and EDMG-CEF fields are generated using the Preamble builder block. The TRN field is generated using TRN builder block. The Data field of the PPDU is generated using the scrambler, LDPC encoder, constellation mapper, interleaver, and GI insertion blocks. If STBC encoder is applied, then ~~a single~~ NSS spatial streams ~~is~~are mapped to 2NSS~~two~~ space-time streams as defined in 30.5.9.5.3. The NSTS space-time streams are further mapped to NTX transmit chains, where NSTS ≤ NTX.

*TGay Editor: Please modify subclause “30.5.9.4.3 LDPC encoding (P307, L1)” as follows*

For each user, if STBC coding is applied, then ~~a single spatial stream~~  spatial streams ~~is~~are mapped to ~~two space-time streams~~  space-time streams as defined in 30.5.9.5.3. Otherwise, a one-to-one mapping of  spatial streams to  space-time streams shall be applied.

*TGay Editor: Please modify subclause “30.5.9.5.3 Space-time block coding (STBC) (P309, L3)” as follows*

* + - * 1. Space-time block coding (STBC)

The STBC performs mapping of NSS spatial streams to 2NSS space-time streams. STBC is applied to an EDMG PPDU if, in the EDMG header, the STBC field is set to 1. The number of STBC modulated spatial streams NSS is given by number of SS field in EDMG header. NSS shall not exceed four for a SU PPDU and one per user for an MU PPDU.

The mapping of each spatial stream iSS=1,…,NSS includes the following steps:

~~The STBC performs a single spatial stream to two space-time streams mapping and includes the following steps:~~

* The input encoded bits stream of ~~a single~~ spatial stream iss ~~are~~is broken into groups of NCBPB(iSS) × NCB bits, , where *q* denotes the group number. The STBC applies the encoding procedure defined in 30.5.9.4.3. The padding procedure requires that the total number of groups of NCBPB(iSS) × NCB bits shall be an even number.
* Each group of bits , *k* = 0, 1, …, *NSPB* × *NCB* – 1, is converted to the constellation point  following the rules defined in 20.6.3.2.4.
* STBC operates with symbol blocks , *q* = 0, 1, …, *NBLKS* – 1, and with blocks with inverted symbols order  of ~~a single~~ spatial stream iSS and assigns these blocks to two space-time streams.
* The modulated data symbols for the ~~first~~ odd space-time stream are defined as 
* The modulated data symbols for the ~~second~~ even space-time stream are defined as 
* STBC uses the same symbol blocking structure for a SU PPDU and an MU PPDU defined in 30.5.9.2.2.3 and 30.5.9.2.4, respectively.

*TGay Editor: Please modify subclause “30.6.2.1 General (P336, L9)” as follows*

* + - 1. General

An EDMG OFDM PPDU transmission may be generated using a transmitter consisting of the following blocks:

1. Scrambler scrambles the data to reduce the probability of long sequences of 0s and 1s; see 30.6.8.1.
2. LDPC encoder encodes the data to enable error correction. It pads the data with zeros to get an integer number of codewords and OFDM symbols; see 30.6.8.2.
3. Stream parser divides the output of the LDPC encoder into the groups of bits that are sent to different mapping devices. The sequence of the bits sent to different mapping devices is called a spatial stream; see 30.6.8.2.
4. Constellation mapper maps the sequence of bits in each stream to constellation points (complex numbers); see 30.6.8.3.
5. Interleaver performs interleaving inside an OFDM symbol; see 30.6.8.3.9.
6. STBC encoder spreads constellation points from NSS spatial streams into NSTS space-time streams using a space-time block code. OFDM mode defines ~~single~~ STBC schemes with ~~N~~~~SS~~ ~~= 1 and~~ NSTS = 2NSS; see 30.6.8.3.10.
7. Preamble builder builds symbols of EDMG-STF and EDMG-CEF fields in frequency domain; see 30.6.3 and 30.6.4.
8. TRN builder builds symbols of TRN field; see 30.9.2.2.5.
9. Spatial mapper maps space-time streams to transmit chains. The spatial mapping is applied per subcarrier basis and may include one of the following (see 30.6.9.2):
	1. Direct mapping: constellation points from each space-time stream are mapped directly into the transmit chains.
	2. Indirect mapping: constellation points from each space-time stream are mapped to each transmit chain.
	3. Digital beamforming: each vector of constellation points from all of the space-time streams is multiplied by a matrix of steering vectors to produce the input to the transmit chains.
10. Cyclic shift (CSD) insertion prevents the transmission from unintentional beamforming. A cyclic shift is specified per transmitter chain for pre-EDMG portion of PPDU transmission; see 30.5.3.3.1.
11. IDFT applies Inverse Discrete Fourier Transform to the input block of subcarriers.

GI insertion and windowing prepends the OFDM symbol with a guard interval defined as a cyclic extension of the OFDM symbol in time domain and applies a window function; see 30.6.8.3.

*TGay Editor: Please modify subclause “30.6.2.2.2 EDMG portion of SU PPDU transmission (P337, L28)” as follows*

* + - * 1. EDMG portion of SU PPDU transmission

Figure 147 shows the transmitter blocks used to generate the EDMG portion of an SU PPDU. The EDMG-STF and EDMG-CEF fields are generated using the preamble builder, IDFT, and GI insertion blocks. The TRN field is generated using the TRN builder, IDFT, and GI insertion blocks. The Data field is generated using the scrambler, the LDPC encoder, the constellation mapper, the interleaver, IDFT, and GI insertion blocks. If the STBC encoder is applied, then ~~a single~~ NSS spatial streams ~~is~~ are mapped to 2NSS~~two~~ space-time streams as defined in 30.6.8.3.10. The NSTS space-time streams are further mapped to NTX transmit chains, where NSTS ≤ NTX.

*TGay Editor: Please modify subclause “30.6.8.2.3 LDPC encoding (P352, L9)” as follows*

For each user, if STBC coding is applied, then ~~a single spatial stream~~  spatial streams ~~is~~ are mapped to ~~two space-time streams~~  space-time streams as defined in 30.6.8.3.10. Otherwise, a one-to-one mapping of  spatial streams to  space-time streams shall be applied.

*TGay Editor: Please modify subclause “30.6.8.3.10 Space-time block coding (P359, L8)” as follows*

* + - * 1. Space-time block coding

The space-time block coding (STBC) for the EDMG OFDM mode maps ~~a single~~NSS spatial streams to 2NSS ~~two~~ space-time streams. STBC is applied to an EDMG PPDU if, in the EDMG header, the STBC field is set to 1. The number of STBC modulated spatial streams NSS is given by number of SS field in EDMG header. NSS shall not exceed four for a SU PPDU and one per user for an MU PPDU.

The mapping of each spatial stream iSS=1, …, NSS ~~and~~ includes the following steps for the data subcarriers mapping:

1. The input bits of ~~a single~~ spatial stream iSS are broken into the groups of *NCBPS(iSS)* bits, , where *q* denotes the group number. The STBC applies the encoding procedure defined in 30.6.7. The padding procedure requires that the total number of groups of *NCBPS(iSS)* bits shall be an even number.
2. Each group of bits , *k* = 0, 1, …, *NSD* - 1 is converted to the constellation point , *q* = 0, 1, …, *NSYM* - 1,following the rules defined in 20.5.3.2.4.
3. The modulated data sequence *D*(*iSTS* = ~~1~~2iSS-1, *n*, *k*) for the ~~first~~ odd space-time stream is defined by inserting zeros from –*NSR* to *NSR* and then inserting data at tones *Md*(*k*) defined in 30.6.1.5 as follows:

,

, *k* = 0, 1, …, *NSD* - 1

1. The modulated data sequence *D*(*iSTS* = 2iSS, *n*, *k*) for the ~~second~~ even space-time stream is defined by inserting zeros from –*NSR* to *NSR* and then inserting data at tones *Md*(*k*) defined in 30.6.1.5 as follows:

,

, *k* = 0, 1, …, *NSD* - 1

1. The modulated pilot sequence *P*(*iSTS* = ~~1~~2iSS-1, *n*, *k*) for the ~~first~~ odd space-time stream is defined by inserting zeros from –*NSR* to *NSR* and then inserting pilots at tones *Mp*(*k*) defined in 30.6.1.4 as follows:

,

,
*k* = 0, 1, …, *NSP* - 1

1. The modulated pilot sequence *P*(*iSTS* = 2iSS, *n*, *k*) for the ~~second~~ even space-time stream is defined by inserting zeros from –*NSR* to *NSR* and then inserting pilots at tones *Mp*(*k*) defined in 30.6.1.4 as follows:

,

,
*k* = 0, 1, …, *NSP* - 1

In the above procedure, index *n* = 0, 1, …, *NSYM* / 2– 1, pilot sequences *PNSP*(*iSTS* = ~~1~~2iSS-1, *k*) and *PNSP*(*iSTS* = 2iSS, *k*) are defined in 30.6.1.6 and *p*(*n*) defines a bit coming from the scrambler defined in 20.5.3.2.2 with shift register x1, x2,…, x7 initialized to all ones for the *n* = 0 OFDM symbol.

For SQPSK and QPSK modulations, STBC shall apply static tone pairing (STP) subcarriers mapping.

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| **CID** | **Clause** | **Comment** | **Proposed Change** |
| 1627 | 30.7 | STBC is declared to be optional but there is no capability for this feature. | Add STBC capability |

Commenter proposes to add STBC capability.

Proposed Resolution: **Revised**

STBC capability is added in Sec. 9.4.2.250.4 “PHY Capability field”

*TGay Editor: Please modify subclause “9.4.2.250.4 PHY Capability field (P59, L1)” as follows*

9.4.2.250.4 PHY Capability field

The PHY Capability field is defined in Figure 33.

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
|  | B0 | B1 | B2 | B3 | B4 | B5 | B6 |
|  | Phase Hopping Supported | Open Loop Precoding Supported | DCM π/2-SQPSK Supported | Short CW Punctured Supported | Short CW Superimposed Supported | Long CW Punctured Supported | Long CW Superimposed Supported |
| Bits: | 1 | 1 | 1 | 1 | 1 | 1 | 1 |

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|  | B7 B9 | B10 B12 | B13 | B14 | B15 |
|  | SC Maximum Number of SU-MIMO Spatial Streams Supported | OFDM Maximum Number of SU-MIMO Spatial Streams Supported | NUC TX Supported | NUC RX Supported | π/2-8-PSK Supported |
| Bits: | 3 | 3 | 1 | 1 | 1 |

|  |  |  |
| --- | --- | --- |
|  | B16 B17 | B18 B23 |
|  | STBC supported | Reserved |
| Bits: | 2 | 6 |

Figure 33 —PHY Capability field format

The STBC Supported subfield is set to 1 to indicate that the STA supports single stream STBC reception. It is set to 2 to indicate that the STA supports one or more spatial stream STBC reception. In this case the maximum number of spatial streams which can be decoded is limited by the minimum of four and the value of SC/OFDM Maximum Number of SU-MIMO Spatial Streams Supported subfield. Otherwise, this subfield is set to 0. The STBC supported subfield value of 3 is reserved.

|  |  |  |  |
| --- | --- | --- | --- |
| **CID** | **Clause** | **Comment** | **Proposed Change** |
| 1835 | 30.5.3.3.2 | The text calls out "If STBC encoder is applied then a single spatial stream is mapped to two space-time streams...." Figure 129 transmitter block diagram references the STBC encoder as described in the text, but the drawing doesn't match the text. | For clarity in Figure 129 add a box around the STBC encoder encapsulating 2 steams similar to the drawing shown in Figure 130. Or add text "as shown in Figure 130 for User 1." |

Commenter asks for clarification of Figure 129 that STBC encodes a single spatial stream.

Proposed Resoluion: **Revised**

STBC description has been changed to support multiple spatial streams in SU-MIMO. Consequently, there is no need anymore to change the Figure or reference.

|  |  |  |  |
| --- | --- | --- | --- |
| **CID** | **Clause** | **Comment** | **Proposed Change** |
| 2031 | 30.5.3.3.3 | STBC can be applied to multiple spatial streams, thus the description: if stbc is applied, a singke spatial stream is mapped to 2 space time streams is too restrictive. | Replace "single" with "each" and complete the multiple STBC description for the MU-MIMO case |

Commenter proposes to extend STBC encoding to multiple streams for SC MU-MIMO

Proposed Resolution: **Reject**

**Discussion**

The number of streams in MU-MIMO is limted to two per user. This limit has been introduced because simulations have shown that the MU-MIMO channel rarely supports more than two orthorgonal streams per user.
A single stream STBC encoder already achieves the limit of two space-time streams which are preferably mapped to orthorgonal streams. Generalizing for more STBC encoded streams would imply that at least four space-time streams can be assigned to a single user.

**References**

[1] 802.11ay Draft 1.0

SP

Do you agree to accept comment resolutions for CIDs 1617, 1627, 1835, 2029, 2030, 2031, and 2034 as proposed in 11-18/0186r0?

**Appendix**

* **Simulation parameters**
	+ SC PHY
	+ MIMO channel model configuration #4 [2]
		- Setup A
			* 4 Tx, 4 Rx, LOS & NLOS
			* Tx & Rx: Polarization multiplex to separate streams, spatial multiplex for STBC encoded streams
		- Setup B
			* 4Tx, 2 Rx, LOS & NLOS
			* Tx: Polarization multiplex to separate streams, spatial multiplex for STBC encoded streams
			* Rx: Polarization multiplex only
	+ MMSE FD equalizer
		- Duplication of single stream STBC receiver
	+ Benchmark
		- 2 stream CSD
		- 1 stream CSD / STBC
	+ Evaluation
		- CCDF of received SNR after equalizer
* **Simulation – Setup A**



* + STBC more robust against noise as CSD
		- In LOS/NLOS, 2 stream STBC achieves 3.5/2.5 dB higher SNR as 2 stream CSD
	+ STBC more robust against multiplex interference as CSD
		- In LOS/NLOS, the multiplex loss is 3.8/3.5dB for STBC and 5.2/5.3dB for CSD
* **Simulation – Setup B**



* + STBC more robust against noise as CSD
		- In LOS/NLOS, 2 stream STBC achieves 5.5/4.5 dB higher SNR as 2 stream CSD
	+ Gain of STBC over CSD increases with lower number of Rx antennas