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Title	Enhancements of Space-Time Codes for the OFDMA PHY
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Re:	802.16e/D3
Abstract	Low decoding complexity improved space-time codes with full rate and full diversity for 4 Tx – rate 1 configuration.
Purpose	To propose enhancements of the space-time codes in 802.16e/D3.
Notice	
Release	
Patent Policy and Procedures	

Enhancements of Space-Time Codes for the OFDMA PHY

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Introduction

We propose a low decoding complexity (symbol by symbol decoding) improved space-time code with full rate and full diversity for ~~2 Tx – rate 2,~~ 4 Tx – rate 1 configuration. ~~, 4 Tx rate 2 and 4 Tx rate 4. While these codes are specified as Space-time codes, they may also be used as Space-Frequency codes or as hybrids~~.

Proposed enhancements

~~STC for 2 Tx-Rate 2 transmission~~

~~We propose to add the transmission matrix:~~

~~Removed 2x2 STC code~~

~~The proposed change is guided by the fact that the transmission new matrix C provides diversity gain while maintaining the rate and multiplexing gain [1] [2] of the existing transmission matrix B in Section 8.4.8.3.3. It is easily checked that any two entries of the matrix are statistically uncorrelated as in the case of the existing matrix B. The new matrix C has rank 2, indicating a transmit diversity order 2 which is due to "spreading" of the variables whereas the rank for the existing matrix B is 1. The code admits decoding with a simple decoding algorithm of similar complexity as the typical decoding algorithm for matrix B.~~

~~Removed BER Curve for 2x2 STC code~~

~~Figure 1: FEC-Block error rate of proposed matrix C compared with the FEC block error rate of existing matrix B (pure spatial multiplexing). The simulation was performed in a 802.16 simulation using the FUSC subcarrier allocation scheme and using the ITU Pedestrian B channel model in a 5 MHz channel. The transmit and receive antennas where assumed to be uncorrelated. The coding was performed with rate ½ tailbiting convolutional coding.~~

STC for 4 Tx – Rate 1 code:

We propose to replace the existing transmission matrix

$$A = \begin{bmatrix} s_1 & -s_2^* & 0 & 0 \\ s_2 & s_1^* & 0 & 0 \\ 0 & 0 & s_3 & -s_4^* \\ 0 & 0 & s_4 & s_3^* \end{bmatrix}.$$

with the new the transmission matrix A_1 which is defined as follows:

Let the complex symbols to be transmitted be x_1, x_2, x_3, x_4 which take values from a square QAM constellation. Let $s_i = x_i e^{j\theta}$ for i=1,2,3,4, where $\theta = \frac{1}{2}\tan^{-1} 2$ and let

$\tilde{s}_1 = s_{1I} + js_{3Q}$; $\tilde{s}_2 = s_{2I} + js_{4Q}$; $\tilde{s}_3 = s_{3I} + js_{1Q}$; $\tilde{s}_4 = s_{4I} + js_{2Q}$ where $s_i = s_{iI} + js_{iQ}$.

The proposed Space-Time-Frequency code for 4Tx-Rate 1 configuration is

$$A_1 = \begin{bmatrix} \tilde{s}_1 & -\tilde{s}_2^* & 0 & 0 \\ \tilde{s}_2 & \tilde{s}_1^* & 0 & 0 \\ 0 & 0 & \tilde{s}_3 & -\tilde{s}_4^* \\ 0 & 0 & \tilde{s}_4 & \tilde{s}_3^* \end{bmatrix}$$

~~where~~ $\cancel{x_i = s_{iI}\cos\theta - s_{iQ}\sin\theta,\ y_i = s_{iI}\sin\theta + s_{iQ}\cos\theta}$ ~~and~~ $\cancel{\theta = \frac{1}{2}\tan^{-1} 2}$. The first two columns correspond to the two OFDM symbols and one subcarrier. Similarly the last two columns correspond to the same two OFDM symbols, but for the next subcarrier. Let $H^{(1)} = [H_1(1) \quad H_2(1) \quad H_3(1) \quad H_4(1)]$ be the channel coefficients for the first subcarrier. The channel is assumed to be quasi-static for two OFDM symbols, but could be varying across the subcarriers. Let $H^{(2)} = [H_1(2) \quad H_2(2) \quad H_3(2) \quad H_4(2)]$ be the channel coefficients for the second subcarrier. Then, the received signal (assuming a single receive antenna) on the first sub-carrier is given by

$$[Y_1^1 \quad Y_2^1] = H^{(1)} A_1(1:2) + noise$$

and for the second sub-carrier is given by

$$[Y_1^2 \quad Y_2^2] = H^{(2)} A_1(3:4) + noise$$

where Y_k^j denotes the received symbol on the j^th^ subcarrier at time k. $A_1(1:2)$ denotes the 1^st^ and 2^nd^ columns of A_1 and similarly, $A_1(3:4)$ denotes the 3^rd^ and 4^th^ colums of A_1. The above measurements can be re-written as follows:

$$[Y_1^1 \quad Y_2^1 \quad Y_1^2 \quad Y_2^2] = [H_1(1) \quad H_2(1) \quad H_3(2) \quad H_4(2)] \begin{bmatrix} Alamouti(\tilde{s}_1, \tilde{s}_2) & 0 \\ 0 & Alamouti(\tilde{s}_3, \tilde{s}_4) \end{bmatrix}$$

~~This proposed change is guided by the following reasons: (i) The transmit diversity gain of A_1 is 4 whereas that of A in [1] is only 2; (ii) A_1 admits a decoupled symbol-by-symbol decoding for the variables which leads to a fast ML decoding (analogous to the Alamouti code for 2Tx). Fig. 1 shows the performance of this code using decoupled ML decoding of low complexity for QPSK.~~

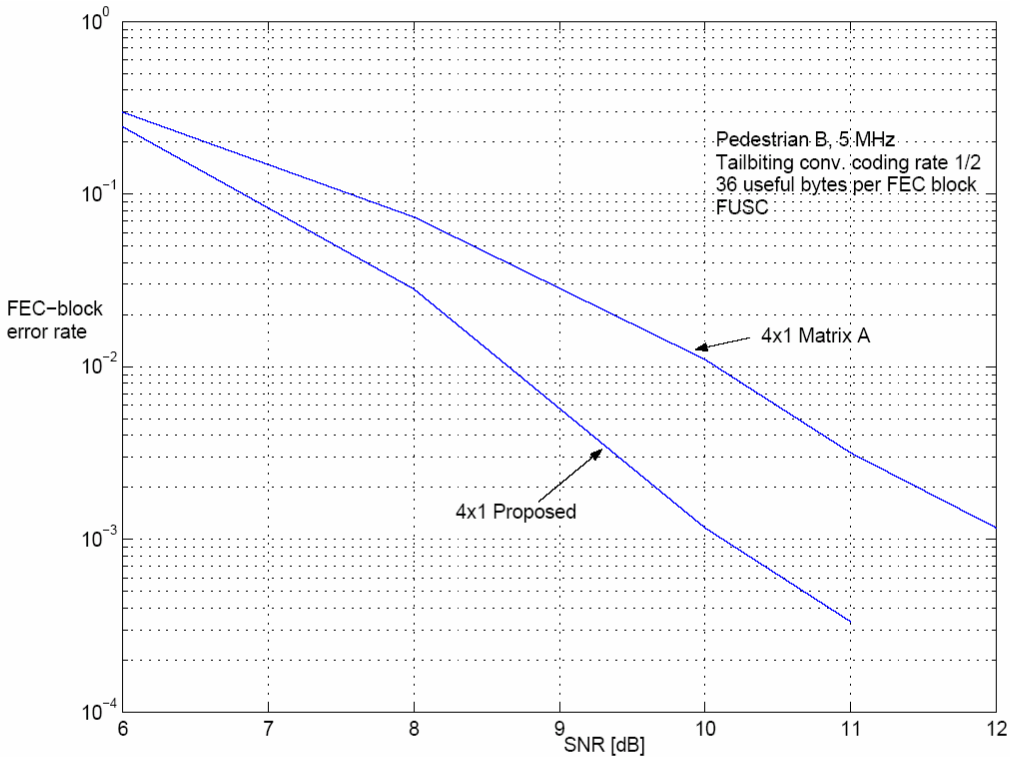

Figure 1: Performance comparison for 4Tx-Rate 1 the current matrix A in the standard and proposed matrix A_1 for Pedestrian-B channel model, QPSK modulation, and Tail-biting Convolutional Code with Hard Decision Decoding.

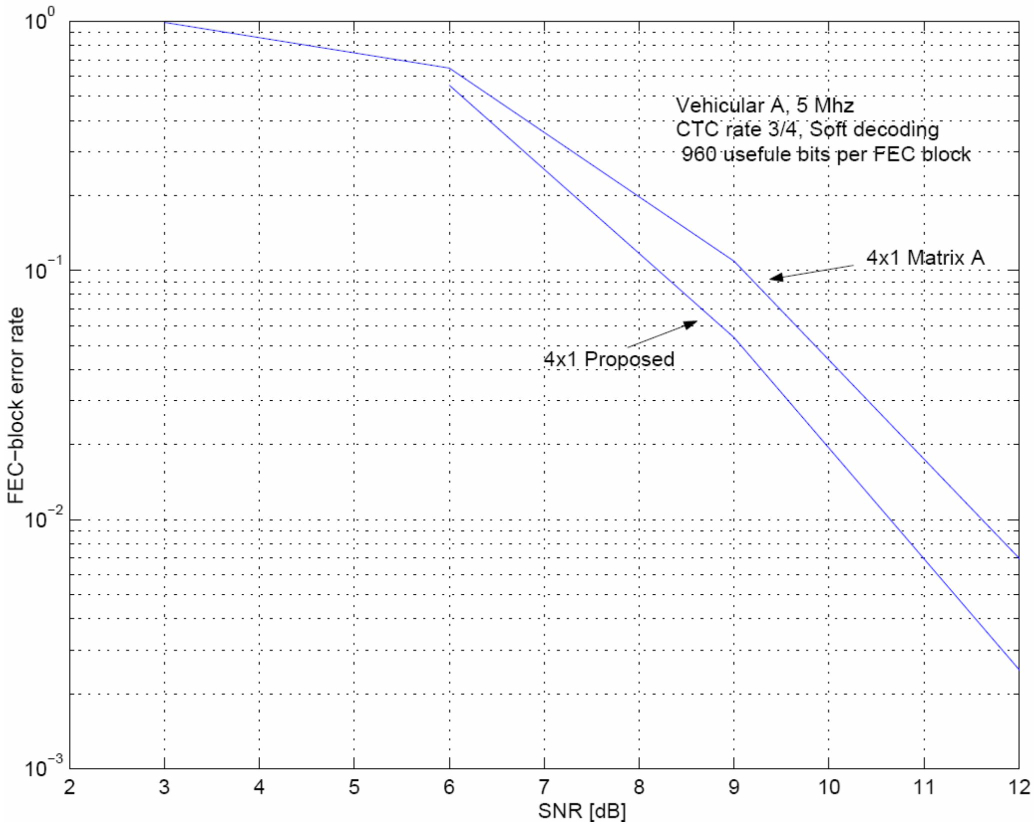

Figure 2: Performance comparison for 4Tx-Rate 1 the current matrix A in the standard and proposed matrix A_1 for Vehicular-A channel model, QPSK modulation, and rate ¾ Convolutional Turbo Code with Soft Decision Decoding.

~~STC for 4Tx-Rate 2:~~

~~We propose to replace the transmission matrix B with the transmission matrix B' given by~~

~~Removed 4x2 STC code~~

~~where, with $Re[s]$ and $Im[s]$ denoting the real and imaginary part of a complex variable s and $\theta = 0.5 tan^{-1} 2$.~~

~~Removed BER Curve for 4x2 STC code~~

~~The proposed code gives more coding gain than the current transmission matrix B with MMSE detection as shown in Figure 2.~~

~~Figure 3: Performance comparison (uncoded) for the 4Tx-Rate 1 matrix B currently in the standard and the proposed matrix B' for QPSK modulation in a flat Rayleigh fading channel with MMSE type receivers.~~

~~*STC for 4Tx-Rate 4:*~~

~~We propose to add a transmission matrix D given by:~~

~~Removed 4x4 STC code with Rate 4~~

~~where~~

$$c_{11} = s_1 + s_2 u + s_3 u^2 + s_4 u^3,$$
$$c_{12} = a\left(s_{13} + s_{14} uv + s_{15} u^2 v^2 + s_{16} u^3 v^3\right),$$
$$c_{13} = a\left(s_9 + s_{10} uv^2 + s_{11} u^2 + s_{12} u^3 v^2\right),$$
$$c_{14} = a\left(s_5 + s_6 uv^3 + s_7 u^2 v^2 + s_8 u^3 v\right),$$
$$c_{21} = s_5 + s_6 u + s_7 u^2 + s_8 u^3,$$
$$c_{22} = s_1 + s_2 uv + s_3 u^2 v^2 + s_4 u^3 v^3,$$
$$c_{23} = a(s_{13} + s_{14} uv^2 + s_{15} u^2 + s_{16} u^3 v^2),$$
$$c_{24} = a\left(s_9 + s_{10} uv^3 + s_{11} u^2 v^2 + s_{12} u^3 v\right),$$
$$c_{31} = s_9 + s_{10} u + s_{11} u^2 + s_{12} u^3,$$
$$c_{32} = s_5 + s_6 uv + s_7 u^2 v^2 + s_8 u^3 v^3,$$
$$c_{33} = s_1 + s_2 uv^2 + s_3 u^2 + s_4 u^3 v^2,$$
$$c_{34} = a\left(s_{13} + s_{14} uv^3 + s_{15} u^2 v^2 + s_{16} u^3 v\right),$$
$$c_{41} = s_{13} + s_{14} u + s_{15} u^2 + s_{16} u^3,$$
$$c_{42} = s_9 + s_{10} uv + s_{11} u^2 v^2 + s_{12} u^3 v^3,$$
$$c_{43} = s_5 + s_6 uv^2 + s_7 u^2 v + s_8 u^3 v^2,$$
$$c_{44} = s_1 + s_2 uv^3 + s_3 u^2 v^2 + s_4 u^3 v,$$

~~where~~ $u = e^{\frac{2\pi}{16} j}$, $v = e^{\frac{2\pi}{4} j}$ ~~and~~ $a = e^{j0.5}$.

~~This change is proposed since the transmission matrix E provides diversity gain while maintaining the rate and multiplexing gain of the transmission matrix C currently in the standard. As in the case of 2Tx Rate 2 code, the matrix E has rank 4, indicating a transmit diversity order 4 which is due to spreading of the variables whereas the rank for the current code C is 1.~~

Specific text changes

[Modify the following sections of 802.16e/D3]

~~8.4.8.3.3 Transmission schemes for 2-antenna BS (page 97):~~

~~Add the transmission matrix C given by:~~

~~Deleted matrix C~~

8.4.8.3.4 Transmission schemes for 4-antenna BS (page 98):

Replace the existing transmission matrix A:

$$A = \begin{bmatrix} s_1 & -s_2^* & 0 & 0 \\ s_2 & s_1^* & 0 & 0 \\ 0 & 0 & s_3 & -s_4^* \\ 0 & 0 & s_4 & s_3^* \end{bmatrix}.$$

With A_1 shown below:

$$A_1 = \begin{bmatrix} \tilde{s}_1 & -\tilde{s}_2^* & 0 & 0 \\ \tilde{s}_2 & \tilde{s}_1^* & 0 & 0 \\ 0 & 0 & \tilde{s}_3 & -\tilde{s}_4^* \\ 0 & 0 & \tilde{s}_4 & \tilde{s}_3^* \end{bmatrix}.$$

where the complex symbols to be transmitted are x_1, x_2, x_3, x_4 which take values from a square QAM constellation and $s_i = x_i e^{j\theta}$ for i=1,2,3,4, where $\theta = \frac{1}{2}\tan^{-1} 2$ and also let

$$\tilde{s}_1 = s_{1I} + js_{3Q}\,;\ \tilde{s}_2 = s_{2I} + js_{4Q}\,;\ \tilde{s}_3 = s_{3I} + js_{1Q}\,;\ \tilde{s}_4 = s_{4I} + js_{2Q} \quad \text{where } s_i = s_{iI} + js_{iQ}\,.$$

~~with the transmission matrix given by~~

~~removed matrix~~

~~where~~ $x_i = s_{iI}\cos\theta - s_{iQ}\sin\theta$~~,~~ $y_i = s_{iI}\sin\theta + s_{iQ}\cos\theta$ ~~and~~ $\theta = tan^{-1}2$~~. The complex symbols~~ s_i ~~take values from a QAM signal set.~~

~~Replace the existing transmission matrix B with the transmission matrix by~~

~~removed matrix B~~

~~where, with~~ $Re[s]$ ~~and~~ $Im[s]$ ~~denoting the real and imaginary part of a complex variable~~ s ~~and~~ $\theta = 0.5tan^{-1}2$~~,~~

~~deleted matrix~~

~~Add the transmission matrix D given by~~

~~removed matrix D~~

~~where~~

$$c_{11} = s_1 + s_2 u + s_3 u^2 + s_4 u^3,$$
$$c_{12} = a\left(s_{13} + s_{14}uv + s_{15}u^2v^2 + s_{16}u^3v^3\right),$$
$$c_{13} = a\left(s_9 + s_{10}uv^2 + s_{11}u^2 + s_{12}u^3v^2\right),$$
$$c_{14} = a\left(s_5 + s_6 uv^3 + s_7 u^2v^2 + s_8 u^3 v\right),$$
$$c_{21} = s_5 + s_6 u + s_7 u^2 + s_8 u^3,$$
$$c_{22} = s_1 + s_2 uv + s_3 u^2v^2 + s_4 u^3v^3,$$
$$c_{23} = a(s_{13} + s_{14}uv^2 + s_{15}u^2 + s_{16}u^3v^2),$$
$$c_{24} = a\left(s_9 + s_{10}uv^3 + s_{11}u^2v^2 + s_{12}u^3v\right),$$
$$c_{31} = s_9 + s_{10}u + s_{11}u^2 + s_{12}u^3,$$
$$c_{32} = s_5 + s_6 uv + s_7 u^2v^2 + s_8 u^3v^3,$$
$$c_{33} = s_1 + s_2 uv^2 + s_3 u^2 + s_4 u^3v^2,$$
$$c_{34} = a\left(s_{13} + s_{14}uv^3 + s_{15}u^2v^2 + s_{16}u^3v\right),$$
$$c_{41} = s_{13} + s_{14}u + s_{15}u^2 + s_{16}u^3,$$
$$c_{42} = s_9 + s_{10}uv + s_{11}u^2v^2 + s_{12}u^3v^3,$$
$$c_{43} = s_5 + s_6 uv^2 + s_7 u^2 v + s_8 u^3v^2,$$

$$c_{44} = s_1 + s_2 u v^3 + s_3 u^2 v^2 + s_4 u^3 v,$$

~~where~~ $u = e^{\frac{2\pi}{16}j}$, $v = e^{\frac{2\pi}{4}j}$ ~~and~~ $\alpha = e^{j0.5}$.

~~[Modify the Table 277a in Section 8.4.5.3.4 in page 73 in [3]]~~

~~Table 277a -OFDMA downlink STC_ZONE IE format~~

~~Syntax~~	~~Size (bits)~~	~~Notes~~
~~STC_ZONE_IE() {~~		
~~Extended DIUC~~	~~4~~	~~STC/ZONE=0x01~~
~~Length~~	~~4~~	~~Length = 0x02~~
~~Permutation~~	~~2~~	~~00 = PUSC permutation~~ ~~01 = FUSC permutation~~ ~~10 = Optional FUSC permutation~~ ~~11 = Optional adjacent subcarrier permutation~~
~~Use All SC indicator~~	~~1~~	~~0 = Do not use all subchannels~~ ~~1 = Use all subchannels~~
~~STC~~	~~2~~	~~00 = No STC~~ ~~01 = STC using 2 antennas~~ ~~10 = STC using 4 antennas~~ ~~11 = FHDC using 2 antennas~~
~~Matrix indicator~~	~~2~~	~~Antenna STC/FHDC matrix (see 8.4.8)~~ ~~00 = Matrix A~~ ~~01 = Matrix B~~ ~~10 = Matrix C (applicable to 4 antennas only)~~ ~~11 = Matrix D (applicable to 4 antennas only)~~ ~~Reserved~~
~~IDcell~~	~~6~~	
~~Reserved~~	~~3~~	~~Shall be set to zero~~
~~}~~		

~~[Modify the Table 281a in Section 8.4.5.3.8 in page 74 in [3]]~~

~~Table 281aa – MIMO DL basic IE format~~

~~Matrix indicator~~	~~2~~	~~STC matrix (see 8.4.8.1.4)~~ ~~STC = STC mode indicated in the latest STC_Zone_IE().~~ ~~If (STC == 01) {~~ ~~00 = Matrix A~~ ~~01 = Matrix B~~ ~~10-11 = ReservedMatrix C~~ ~~11 = Reserved~~ ~~}~~ ~~elseif (STC == 10) {~~ ~~00 = Matrix A~~ ~~01 = Matrix B~~ ~~10 = Matrix C~~ ~~11 = ReservedMatrix D~~ ~~}~~

~~[Modify the Table 282a in Section 8.4.5.3.9 in page 74 in [3]]~~

~~Table 281aa – MIMO DL basic IE format~~

~~Matrix indicator~~	~~2~~	~~STC matrix (see 8.4.8.1.4)~~ ~~STC = STC mode indicated in the latest STC_Zone_IE().~~ ~~If (STC == 01) {~~ ~~00 = Matrix A~~ ~~01 = Matrix B~~ ~~10-11 = ReservedMatrix C~~ ~~11 = Reserved~~ ~~}~~ ~~elseif (STC == 10) {~~ ~~00 = Matrix A~~ ~~01 = Matrix B~~ ~~10 = Matrix C~~ ~~11 = ReservedMatrix D~~ ~~}~~

~~Table 99d—Compact_DL-MAP IE format for MIMO Control~~

~~Syntax~~	~~Size (bits)~~	~~Notes~~
~~MIMO_Compact_DL-MAP_IE() {~~		
~~DL-MAP Type~~	~~3~~	~~Type = 7~~
~~DL-MAP Sub-type = 3~~	~~5~~	~~MIMO Control = 0x04~~
~~Length~~	~~4~~	~~Length of the IE in Bytes~~

~~BITMAP length~~	~~4~~	~~in nibble~~
~~BITMAP~~	~~variable~~	~~size = BITMAP length x 4 bits~~
~~for (i = 0; i<count; i++) {~~		~~count = the number of '1' in BITMAP~~
~~STC~~	~~1~~	~~STC order~~ ~~0 = STC using 2 antennas~~ ~~1 = STC using 4 antennas~~
~~Closed loop~~	~~1~~	~~0 = Open loop~~ ~~1 = Closed loop~~
~~Matrix indicator~~	~~2~~	~~STC matrices (see 8.4.8.3)~~ ~~if (STC == 0) {~~ ~~00 = Matrix A~~ ~~01 = Matrix B~~ ~~10 11 = ReservedMatrix C~~ ~~11 = Reserved~~ ~~}~~ ~~else if (STC == 1) {~~ ~~00 = Matrix A~~ ~~01 = Matrix B~~ ~~10 = Matrix C~~ ~~11 = ReservedMatrix D~~ ~~}~~
~~Num_layer~~	~~2~~	
~~for (j=0;j<Num_layer; j++) {~~		
~~Layer_index~~	~~2~~	
~~DIUC~~	~~4~~	~~0-11 burst profiles~~
~~}~~		
~~}~~		
~~Padding~~	~~variable~~	~~The padding bits are used to ensure the IE size is integer number of bytes.~~
~~}~~		

References

~~[1] B.A.Sethuraman, B.Sundar Rajan and V.Shashidhar, "Full-diversity, High-rate Space-Time Block Codes from Division Algebras," IEEE Transactions on Information Theory, Vol.49, No.10, Oct. 2003, pp.2596-2616.~~

[1] Zafar Ali Khan, B. Sundar Rajan and Moon Ho Lee,"On single-symbol and double-symbol decodable STBCs," Proceedings of IEEE Intl. Symposium on Information Theory (ISIT-2003), Yokohama, Japan, June 2003, p.127.

~~[2] V.Shashidhar, B.Sundar Rajan and P.Vijay Kumar, "STBCs with optimal diversity-multiplexing trade-off for 2,3 and 4 transmit antennas," to appear Proceedings of IEEE International Symposium on Information Theory, June 27-July 3, 2004.~~

~~[3]~~ [2] IEEE P802.16e/D3 Air Interface for Fixed and Mobile Broadband Wireless Access Systems – Amendment for Physical and Medium Access Control Layers for Combined Fixed and Mobile Operation in Licensed Bands