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Re:	IEEE 802.16m-07/031- Call for Comments on Draft 802.16m Evaluation Methodology Document
Abstract	This contribution proposes to add the subsection to the Section '4.5.6. Practical Receiver Impairments' for reflect the effect of channel estimation impairment.
Purpose	For discussion and approval by TGm
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Channel Estimation Impairment Modeling

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1. Introduction

A naive PHY abstraction method inherently can not reflect the effect of imperfect channel estimation because the link performance generated in AWGN environment is used. This contribution provides a methodology to reflect the effect of channel estimation impairment and a verification of the proposed impairment modeling with simulation results. This contribution also provides text proposal for the Section 4 in the evaluation methodology document IEEE C802.16m-07/080r3.

2. Procedure of Verification

In this section, the procedure of verification is described to suggest a way to confirm the accuracy of the proposed channel estimation impairment modeling. The detail procedure is introduced as follows:

Figure 1 shows the example of the procedure of verification to easily understand. To see the accuracy of the impairment modeling, three different FER curves are required: (1) FER curve with ideal channel estimation (2) FER curve with real channel estimation (3) FER curve with real channel estimation applying the impairment modeling. Given the SNR on the n-th subcarrier during the k-th OFDM symbol, $SNR^{(0)}[n,k]$, the FER performance in FER curve (2) is FER_0. However, after applying the channel estimation impairment modeling the SNR including the effect of imperfect channel estimation, $SNR_1^{(0)}[n,k]$ is calculated from $SNR^{(0)}[n,k]$ shifted by $-\Delta$ (Δ is defined as the difference between $SNR_1^{(0)}[n,k]$ and $SNR^{(0)}[n,k]$). $SNR_1^{(0)}[n,k]$ is obviously smaller than $SNR^{(0)}[n,k]$. At the shifted SNR point, $SNR_1^{(0)}[n,k]$, the FER performance in FER curve (1) is given by FER_1. The similarity between FER_0 and FER_1 is a point of reference to see how accurately the impairment modeling is designed. It is equivalent to compare the similarity between FER curve (1) and FER curve (3) which is obtained from FER curve (2) shifted by $-\Delta$.

Therefore, the criterion of verification is to compare the FER curve (1) with the FER curve (3). If two curves are almost equivalent, we can see that the channel estimation impairment modeling is well designed. The below simulation results are plotted in the same format as these FER curves in Figure 1.

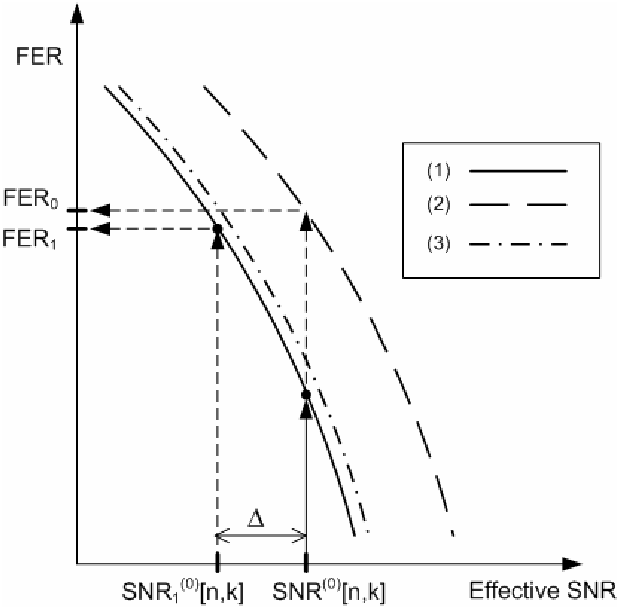

Figure 1 – An example of the procedure of verification. (1) With ideal channel estimation, (2) With real channel estimation, (3) With real channel estimation applying impairment modeling

3. Simulation Results

The performance criterion used is to compare the similarity between FER curve with ideal channel estimation and one with real channel estimation applying the impairment modeling. In particular, it shall be performed to verify the proposed impairment modeling in the different channel estimation schemes and various simulation conditions such as different MCS levels, the number of receive antennas. The detail simulation assumption is shown in Table 1.

Table 1 Simulation Assumptions

Parameters	Values
System	WirelessMAN-OFDMA reference system
Subchannel	DL PUSC
FEC	CTC
Modulation (code rate)	QPSK(1/12), QPSK(1/2), 16QAM (1/2), 64QAM(5/9), 64QAM(5/6)
Fading channel	ITU-R, PedB 3km/h
Nep size	480
PHY abstraction	MMIB
Channel estimation scheme	Interpolation, frequency windowing
# of receive antennas	1, 2, 4

Channel estimation schemes

Two figures below compare the FER performance to see how accurately the effect of imperfect channel estimation is modeled when different channel estimation schemes such as interpolation and frequency windowing are used. To check the performance variance along channel estimation schemes, the single receive antenna is assumed.

In brief, the operation of interpolation channel estimation scheme is as follows: Firstly, the channel estimation on each pilot subcarrier is performed by using the least-square estimation scheme. Secondly, the channel estimates on each pilot subcarrier are averaging over the adjacent pilot subcarriers in OFDM symbol. Finally, the linear interpolation is performed with the channel estimates on the consecutive pilot subcarrier in frequency domain. In addition, the detail description of frequency windowing channel estimation scheme is described in Appendix.

In Figure 2, the interpolation channel estimation scheme is used at different MCS levels. Assuming the channel estimate is averaging over 3 adjacent pilots in OFDM symbol with equal averaging weights. With this assumption, we can obtain the parameters such as averaging gain and inter-symbol coherence loss when calculating the SNR applying the channel estimation impairment modeling. In addition, the averaged number of used pilot tones per subcarrier for channel estimation in frequency domain, ς is given by 23/14 based on the interpolation channel estimation scheme.

From the Figure 2, we can see that the FER curves (1) with ideal channel estimation is almost equivalent with those (3) with interpolation channel estimation scheme applying impairment modeling regardless of the MCS levels. So, we can conclude that the proposed modeling for the channel estimation impairment is well designed when the interpolation channel estimation is used.

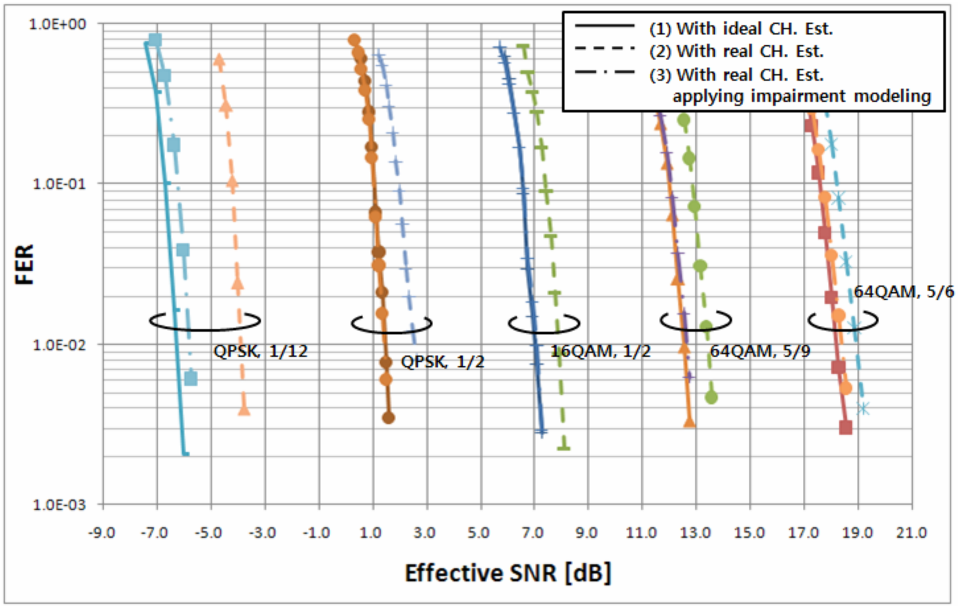

Figure 2 – FER performance comparison where the channel estimation is applied by interpolation scheme at 5 different MCS levels.

In Figure 3, the frequency windowing channel estimation scheme is used at different MCS levels. Likewise the interpolation channel estimation scheme, we assumed that the channel estimate is averaging over 3 adjacent pilots in OFDM symbol with equal averaging weights. With this assumption, we can also obtain the parameters such as averaging gain and inter-symbol coherence loss when calculating the SNR applying the channel estimation impairment modeling. In addition, the averaged number of used pilot tones per subcarrier for channel estimation in frequency domain, ς is given by 31/14 based on the frequency windowing channel estimation scheme.

Figure 3 shows that the FER curves (1) with ideal channel estimation are almost equivalent with those (3) with frequency windowing channel estimation scheme applying impairment modeling, except for the case of 64QAM, 5/6 code rate. This is because frequency windowing channel estimation scheme inherently does not show the proper FER performance in the high SNR region. Nevertheless, the proposed modeling for the frequency channel estimation impairment is well designed in the overall MCS levels.

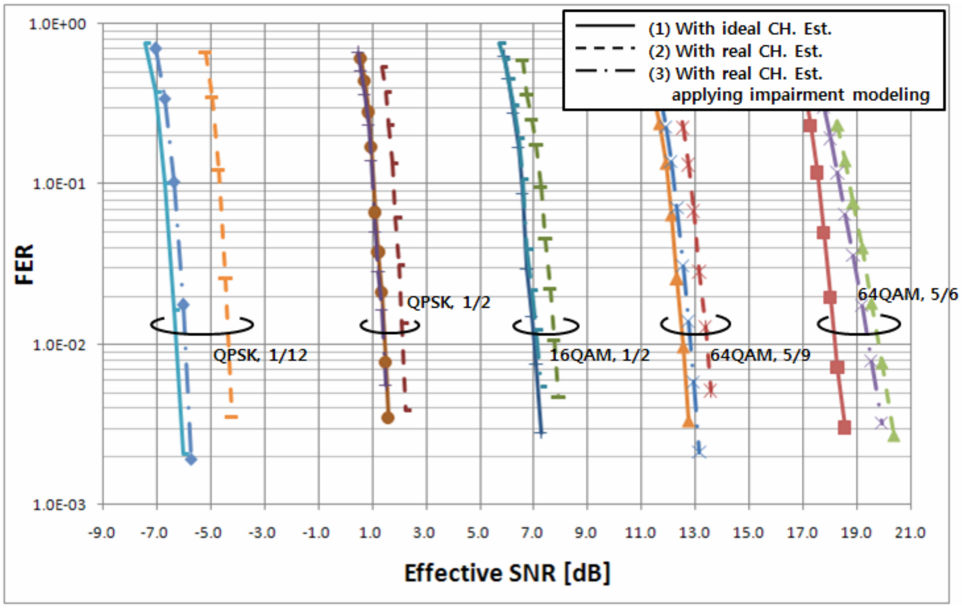

Figure 3 – FER performance comparison where the channel estimation is applied by frequency windowing scheme at 5 different MCS levels.

Number of receive antennas

In Figure 4, the FER curves at the different number of receive antennas are shown to verify the proposed modeling for the channel estimation impairment. Assuming the interpolation channel estimation scheme and two different MCS levels (e.g. QPSK 1/2 and 16QAM 1/2) are used in this simulation.

From the comparison, the FER curves (1) with ideal channel estimation are nearly same as those (3) with interpolation channel estimation scheme applying impairment modeling regardless of the number of receive antennas.

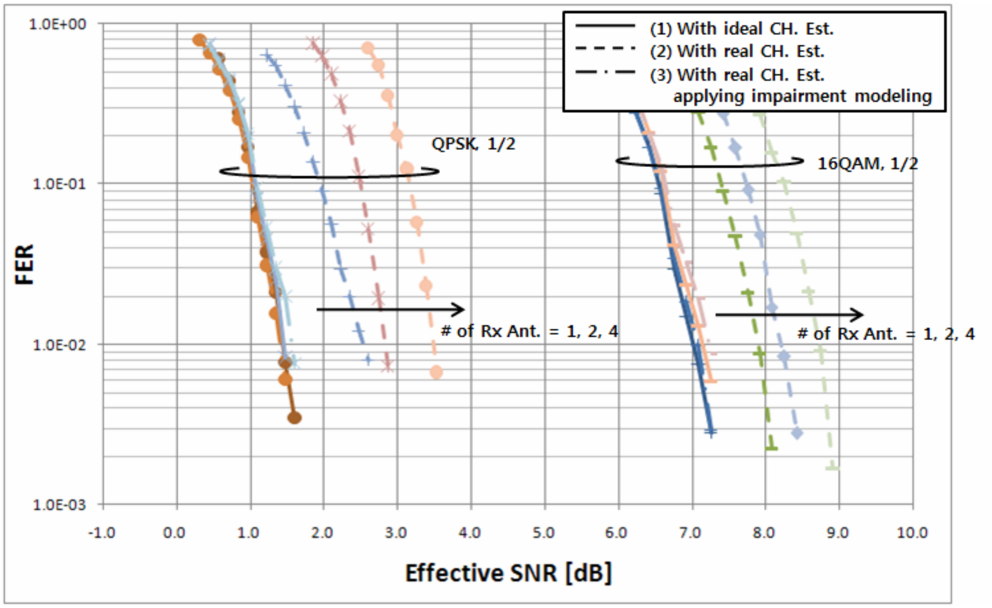

Figure 4 – FER performance comparison according to the number of receive antennas at 2 different MCS levels (e.g. QPSK 1/2, 16QAM 1/2).

4. Conclusions

Based on simulation results above, it is confirmed that the proposed modeling for channel estimation impairment is well designed in the various simulation environments including the different MCS levels, the number of receive antennas and the different channel estimation schemes.
Note that the channel estimation methods used in this document are only examples and other methods of channel estimation are possible. In case other methods are used, the proponent needs to justify the parameters used for modeling (e.g. α, β, ζ).

5. Appendix

Frequency windowing channel estimation scheme

In Figure 5, the structure of DL PUSC subchannel used in this simulation is shown to give the information on frequency windowing channel estimation scheme. Assuming the 3 adjacent pilot tones in OFDM symbol are utilized to estimate the channel state information (e.g. a[-1], a[0], …, a[4]). The detail description of frequency windowing channel estimation is as follows:

i. h[0] = a[0], h[4] = a[1], h[8] = a[2], h[12] = a[3].
ii. h[1] = (a[-1]+a[0]+a[1])/3, h[3] = h[5] = (a[0]+a[1]+a[2])/3, h[7] = h[9] = (a[1]+a[2]+a[3])/3, h[11] = h[13] = (a[2]+a[3]+a[4])/3.
iii. h[2] = (a[0]+a[1])/2, h[6] = (a[1]+a[2])/2, h[10] = (a[2]+a[3])/2.

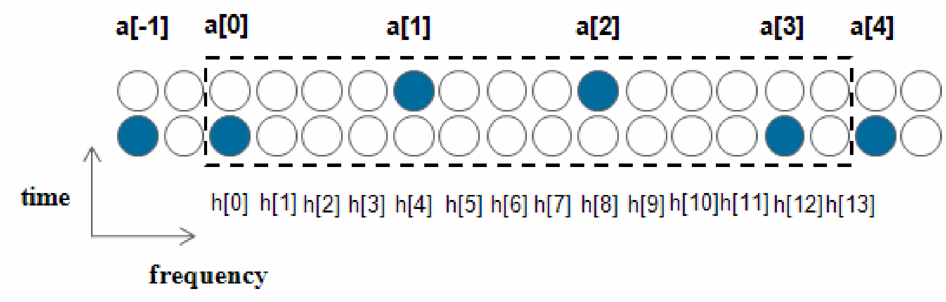

Figure 5 – Frequency windowing channel estimation scheme in DL PUSC subchannel

6. Proposed Text for Section on Practical Receiver Impairments

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[*Add the following text after the line#30 of the page72 in C802.16m-07/080r3*]

4.5.6.1. Channel Estimation Loss

The per-tone post processing SINR for SIMO on the n-th subcarrier during the k-th OFDM symbol, including the effect of imperfect channel estimation and pilot weighted do-product operation is given by

$$SINR_1^{(0)}(n,k) = E_H\left[SINR^{(0)}(n,k), SINR_{Pilot}^{(0)}(n,k), SINR^{(0)}(n,k)\cdot SINR_{Pilot}^{(0)}(n,k)\right] \qquad (1)$$

where $E_H[x,y] = \frac{1}{x^{-1}+y^{-1}}$ denotes the harmonic sum of x and y. $SINR_{Pilot}^{(0)}(n,k)$ is the SINR of channel estimation used to demodulate the n-th subcarrier during the k-thy OFDM symbol.

The SINR of channel estimate $SINR_{Pilot}^{(0)}(n)$ is computed as follows: Assuming white noise, equal power on data and pilot tones, and least-squares channel estimation, the SINR of channel estimate is given by

$$SINR_{Pilot}^{(0)}(n,k) = E_H\left[\varsigma\cdot SINR_{PA}^{(0)}(n,k)\cdot\alpha[k], \frac{1}{\beta[k]}\right] \qquad (2)$$

where $\alpha[k]$ is the gain from averaging the channel estimate across multiple OFDM symbols and $\beta[k]$ models the inter-symbol coherence loss due to Doppler. ς is the averaged number of used pilot tones per subcarrier for channel estimation in frequency domain and could be changeable according to the channel estimation schemes. $SINR_{PA}^{(0)}(n,k)$, the SINR before diversity combining across the receive antennas, is given by

$$SINR_{PA}^{(0)}\left(n,k\right)=\text{Max.}\left\{SINR^{(0)}\left(0,n,k\right),\cdots,SINR^{(0)}\left(N_{Rx}-1,n,k\right)\right\} \qquad (3)$$

where $SINR^{(0)}\left(i,n,k\right)$ is the SINR on the i-th receive antenna and n-th subcarrier during the k-th OFDM symbol, and N_{Rx} is the number of receive antennas. $\text{Max.}\left\{x,y,z\right\}$ denotes the maximum value among *x, y* and *z.*

Suppose the channel estimate used to demodulate the data symbols in the k-th OFDM symbol is obtained by combining/averaging pilot tones from adjacent OFDM symbols. Prior to inter-symbol averaging, the pilot tones are assumed to be normalized by the relative pilot gains on the adjacent OFDM symbols. If the channel estimate averaging weights are $\left[c_{0,k},c_{1,k},\cdots,c_{J-1,k}\right]$, and the relative pilot gains are $\left[\gamma_{0,k},\gamma_{1,k},\cdots,\gamma_{J-1,k}\right]$ the averaging gain $\alpha\left[k\right]$ and the inter-symbol coherence loss $\beta\left[k\right]$ are given by

$$\alpha\left[n\right]=\frac{\left|\sum_{j=0}^{J-1}\frac{c_{j,k}}{\sqrt{\gamma_{j,k}}}\right|^2}{\sum_{j=0}^{J-1}\frac{\left|c_{j,k}\right|^2}{\gamma_{j,k}}}, \qquad \beta\left[n\right]=\left|1-\sum_{j=0}^{J-1}c_{j,k}\exp\left(2\pi f_d\tau_{j,k}\right)\right|^2 \qquad (4)$$

where $\tau_{j,k}$ is the time offset between the OFDM symbol associated with the averaging weight $c_{j,k}$, and the k-th OFDM symbol containing the data subcarrier to be demodulated. f_d is the Doppler frequency.

---End of the text---