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Agenda Item: AH64: Enhanced Uplink

Source: Motorola

Title: Effect of non-ideal channel estimation on enhanced uplink system capacity

Document for: Information and Discussion for 10.5

Introduction

Single user system performance is evaluated for non-ideal channel estimation for 2ms E-DCH TTI for the specific example were a user is placed at a fixed location close to the cell but experiences Rayleigh fading. It is shown in this case that degradation from non-ideal channel estimation can be minimized by selecting an appropriate β_d/β_c ratio where β_d is for a 5 Kbps DPDCH used as a reference channel to drive outer loop power control and help determine MCS selection. User throughput increased 28% as $(\beta_d/\beta_c)^2$ was decreased from 2 to 0.25 achieving 94% of the throughput attained with ideal channel estimation. The SNR equations with channel estimation indicate that the effects of a poor pilot can be overcome with excess data signal power.

Derivation of System Uplink SNR equation with channel estimation

In [3], [4] a derivation of the uplink SNR (Eb/Nt) equation was developed which accounted for non-ideal channel estimation. These equations were also developed for this study and differ mainly from [3] [4] by including a variable representing the channel estimator bandwidth. The SNR terms are also computed over a frame (or sub-frame interval). The resulting uplink SNR equation is

$$E_b / N_{t_e-dch,cell,m} = \sum_{j=1}^{N_{tx}} \frac{N_{symb,j}}{TBS_j} \sum_{a=1}^{N_{antennas}} \sum_{k=1}^{N_{fingers,a}} \frac{\left(SNR_{e-dch,cell,a,m,k,j}\right)}{\left(1+\frac{1+SNR_{e-dch,cell,a,m,k,j}}{SNR_{chest,cell,a,m,k,j}}\right)} \qquad \textbf{(1)}$$

$$SNR_{e-dch,cell,a,m,k,i} = \frac{E_{s,e-dch,cell,a,m,k,i}}{N_t} \qquad (\rightarrow \Lambda_{i,p}\ [1][2]\ Lucent) \qquad \textbf{(2)}$$

$$SNR_{chest,cell,a,m,k,i} = \left(\frac{f_c}{2B_{chest}}\right)\frac{E_{c,pilot,cell,a,m,k,i}}{N_t} \qquad (\rightarrow a_{i,p}^2 \Gamma_{i,p}\ [1][2]\ Lucent) \qquad \textbf{(3)}$$

where

$N_{symb,j}$ is the number of modulation symbols per frame (or sub-frame)
TBS_j is the transport block size, B_{chest} is the channel estimator bandwidth in Hz
f_c is the chip rate (3840000)

The system simulator used the above SNR equations to account for non-ideal channel estimation for both the E-DCH and DPDCH.

System Simulation Results for non-ideal Channel Estimation

In this contribution, system simulation results are evaluated with non-ideal channel estimation for 2ms E-DCH TTI (frame size) without Hybrid ARQ under PA fading channels for various speeds. A single user example is used to simplify the analysis where the user location is chosen to achieve a throughput of close to 1Mbps. The UE traffic is a series of FTP calls where the UE selects the rate on a per TTI basis. UE Rate selection is based on comparing the available normalized power margin ($G_{e\text{-}dch}$) to a set of MCS thresholds where $G_{e\text{-}dch}$ is given by

$$G_{e-dch} = (P_{Maximum} - P_{dpcch} - P_{dpdch}) / P_{dpcch} = P_{Mar.gin} / P_{dpcch} = P_{e-dch} / P_{dpcch} = (b_{e-dch} / b_c)^2 \qquad \textbf{(4)}$$

A mapping from $G_{e\text{-}dch}$ to transmission rate is needed for the UE for enhanced uplink operation. The rate, modulation, and encoding rate or MCS (modulation coding set) is chosen based on Table 1 below. The available normalized power margin ($G_{e\text{-}dch}$) is compared to the MCS threshold value as shown in the last column of Table 1. The MCS chosen is the one with the threshold that $G_{e\text{-}dch}$ exceeded but less than the threshold belonging to the next consecutive MCS in the list. The MCS thresholds are computed based on the equation:

$$MCS_thresh(i) = Rate(i) / (R.eferenceRa\,te * dEcNt(i) * S(i)) \qquad \textbf{(1)}$$

where

- Rate(i) is the rate of MCS i,
- ReferenceRate is the rate of the reference channel (DPDCH) which in this case is 5Kbps,
- dEcNt(i) is a fixed scale factor to account for the delta Ec/Nt between MCS rates,
- S(i) is a scale factor for MCS i used to account for difference in Ec/Nt requirements between reference rate channel (DPDCH) and the E-DCH. There may be different S for 2ms and 10ms and for different channel conditions such as Pedestrian A and Pedestrian B.

Erased frames are counted toward the total delay in computing user throughput based on equation (6) below:

$$T_{user} = \frac{\sum_{i=1}^{N_{mcs}} TTI \cdot \#Tx(i) \cdot Rate(i)}{\sum_{i=1}^{N_{mcs}} TTI \cdot \#Tx(i) / (1 - FER(i))} \qquad \textbf{(2)}$$

Table 1 also summarizes the MCS levels simulated while Table 2 shows the simulation parameters. Only the E-DCH, DPDCH (5Kbps) and the associated DPCCH were turned on in the simulation. The HS-DPCCH and E-DPCCH were not enabled. Figure 3 shows the AWGN curves used in the system simulation to account for the different FER vs. Ec/Nt characteristics of the E-DCH for 2 msec and 10 msec TTI [1]. For non-ideal channel estimation, Table 3 contains the highest user throughput achievable for each β_d/β_c case given the constraint of a per MCS FER target of ~10%. The throughput is maximized by optimizing the MCS thresholds via the S vector. As β_d/β_c decreases the pilot power level increases resulting in higher channel estimator SNR and hence a higher (post combining) E-DCH and DPDCH symbol SNR (Es/Nt). From these tables and Figure 1 it is shown that User throughput increased 28% as $(\beta_d/\beta_c)^2$ was decreased from 2 to 0.25 achieving 94% of the throughput attained with ideal channel estimation.

Figure 2 shows the normalized MCS thresholds for various β_d/β_c and the corresponding throughput achieved. As β_d/β_c decreases the pilot Ec/Nt increases along with the channel estimator SNR such that the (post combining) symbol SNR (Es/Nt) of the E-DCH and DPDCH increases for the same input SNR (at the input of the receiver). As expected and shown in Figure 2 the MCS thresholds for the highest rates must increase as the channel estimator SNR decreases for selected β_d/β_c in order to achieve the per MCS target FER (10% in this study).

The SNR equations with channel estimation indicate that the effects of a poor pilot can be overcome with excess data signal power. That is, normally the β_c needs to be 4 given $\beta_{e\text{-}dch}$ is set to 15 for optimum performance for high data rates (>1Mbps) else higher data Ec/Nt is required to achieve the same FER. Hence, if β_c is 1 compared to 4 then the E-DCH Ec/Nt would need to be 1.5dB higher to achieve 10% FER (Figure 4). As long as some minimum DPCCH Ec/Nt is achieved (e.g. Ec/Nt >= -30dB) then the increase in required E-DCH Ec/Nt to achieve 10% FER can be kept below 3dB even for vary large $\beta_{e\text{-}dch}/\beta_c$ ratios (see Figure 5).

Conclusions:

The following conclusions are drawn from the simulation results presented in this contribution:

1. The single user throughput lost due to non-ideal channel estimation can be minimized by selecting appropriate β_d/β_c. In the PA 3km/h example up to 94% of the ideal channel estimation throughput was attained by selecting $(\beta_d/\beta_c)^2$ =0.25 for a 5KHz DPDCH.
2. Decreasing $(\beta_d/\beta_c)^2$ from 2 to 0.25 increased user throughput by 28%.
3. The uplink SNR equations with channel estimation can more accurately capture the impact of pilot level on required post-combining symbol SNR which will be even more important with HARQ.
4. A reference MCS threshold set can be scaled by $2(\beta_d/\beta_c)^2$ to obtain the appropriate thresholds to use for each β_d/β_c case.
5. The SNR equations with channel estimation indicate that the effects of a poor pilot can be overcome with excess signal power. That is, normally the β_c needs to be 4 given $\beta_{e\text{-}dch}$ is set to 15 for optimum performance for high data rates (>1Mbps) else higher data Ec/Nt is required to achieve the same FER. Hence, if β_c is 1 compared to 4 then the E-DCH Ec/Nt would need to be 1.5dB higher to achieve 10% FER (Figure 4). As long as some minimum DPCCH Ec/Nt is achieved (e.g. Ec/Nt >= -30dB) then the increase in required E-DCH Ec/Nt to achieve 10% FER can be kept below 3dB even for vary large $\beta_{e\text{-}dch}/\beta_c$ ratios (Figure 5).
6. There could be some benefit to adaptively adjusting the β_c based on E-DCH rate from frame to frame (sub-frame to sub-frame) to mitigate the E-DCH Ec/Nt increase required for large $\beta_{e\text{-}dch}/\beta_c$ ratios where the DPCCH Ec/Nt drops down below -20dB [5]. Also when not transmitting on the E-DCH a lot of power would be wasted on the DPCCH which could avoided by adjusting the β_d/β_c ratio from frame to frame.

References

[1] Motorola, R1-03-0697, "Performance comparison between 2 ms and 10 ms frame size for E-DCH", Aug 25-29, 2003.

[2] Motorola, R1-03-0599, "Link Simulation Results for Enhanced Uplink – 2msec vs.10 msec", May 19-23, 2003.

[3] Lucent, R1-03-0082, "Link Prediction Methodology for System Level Simulations", January 7-10, 2003.

[4] Lucent, R1-03-0313, "Link Prediction Methodology for System Level Simulations", Feb 18-21, 2003.

[5] Motorola, R1-03-0700, "Power Control Methods for Enhanced Uplink", May 19-23, 2003.

Table 1 MCS Mapping for Enhanced Uplink WCDMA (2ms TTI, PA Case)

MCS level	MCS Rate	MCS EncRate	MCS Mod	dEcNt sfactor	S	mcs thresh rate/(RefRate*dEcNtSF*S)
	(bps)				(PA, 2ms)	(RefRate=5000bps)
1	10000	1/3	1	0.85	1.000	**2.4**
2	20000	1/3	1	0.89	0.980	**4.6**
3	24000	2/5	1	0.91	0.960	**5.5**
4	40000	1/3	1	0.95	0.940	**9.0**
5	48000	2/5	1	0.99	0.920	**10.5**
6	80000	1/3	1	1.09	0.900	**16.3**
7	96000	2/5	1	1.12	0.890	**19.3**
8	160000	1/3	1	1.23	0.860	**30.3**
9	192000	2/5	1	1.29	0.880	**33.8**
10	320000	1/3	1	1.44	0.600	**74.1**
11	384000	2/5	1	1.33	0.940	**61.4**
12	640000	1/3	2	1.40	0.720	**127.0**
13	768000	2/5	2	1.33	0.710	**162.7**
14	960000	1/2	2	1.20	0.780	**205.1**
15	1152000	3/5	2	1.06	0.705	**308.3**
16	1280000	2/3	2	0.99	0.690	**374.8**
17	1440000	3/4	2	0.86	0.745	**449.5**
18	1728000	3/5	3	0.71	0.705	**690.4**
19	1920000	2/3	3	0.62	0.640	**967.7**
20	2160000	3/4	3	0.57	0.680	**1114.6**

Table 2. Simulation Parameters

Simulation Parameter	*Value*
No. of slots/frame	3 or 15
No. of chips/second	3.84 Mcps
E-DCH TTI	2 msec
Modulation	BPSK/QPSK/8PSK
Hybrid ARQ	Not supported
Max number of Tx	NA
Channels	Rayleigh Fading, PA 3km/hr
Receiver	Rake
Channel Estimation	BW=600Hz
Inner-Loop PC	ON, TPC Stepsize=0.5dB
Outer-Loop PC	ON Initial OL Threshold = $0.3(\beta_d/\beta_c)^2$
PC delay and error	2 slots, 0%
No. of antennas	2
Reference Channel	DPDCH 5Kbps, 10%FER
$(\beta_d/\beta_c)^2$ $\beta_{e\text{-}dch}/\beta_c$ is variable	0.25 to 2.0 evaluated -- depends on rate selected

Table 3 System simulation single user results for different β_d/β_c

2ms, PA 3km/h Simulation Cases	Rise (dB)		%Rise Outage (dB)					FER	User T-put
BR =(βd/βc)^2	Avg	Stdev	4.0	4.5	5.0	5.5	6.0	(%)	(Kbps)
Ideal Chest, BR=2.00	1.6	1.3	5.4	3.0	1.5	0.6	0.1	9.9	1271
Ideal Chest, BR=0.50	1.6	1.3	5.4	3.0	1.6	0.6	0.1	9.2	1271
Ideal Chest, BR=0.25	1.6	1.3	5.4	3.0	1.5	0.6	0.2	8.3	1271
BR=0.25	1.6	1.3	5.5	2.9	1.6	0.6	0.1	9.3	1194
BR=0.50	1.6	1.3	5.4	3.0	1.5	0.6	0.2	9.6	1140
BR=0.75	1.6	1.3	5.4	3.0	1.6	0.6	0.1	9.8	1092
BR=1.00	1.6	1.3	5.4	3.0	1.5	0.6	0.2	11.0	1046
BR=1.50	1.6	1.3	5.4	3.0	1.5	0.6	0.2	9.7	989
BR=2.00	1.6	1.3	5.4	3.0	1.6	0.6	0.1	10.5	932

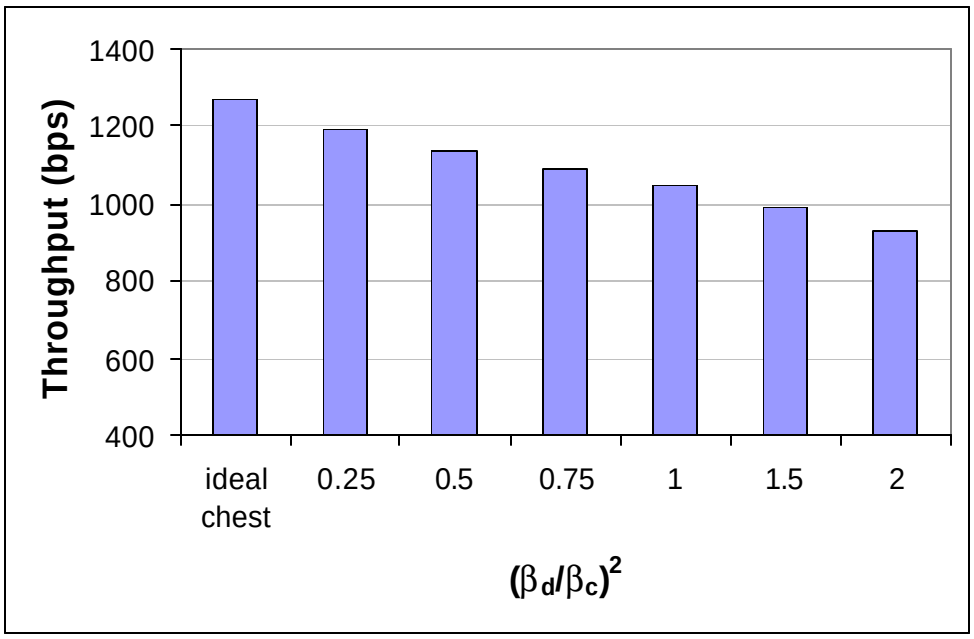


Figure 1. User throughput for different β_d/β_c given non-ideal channel estimation.

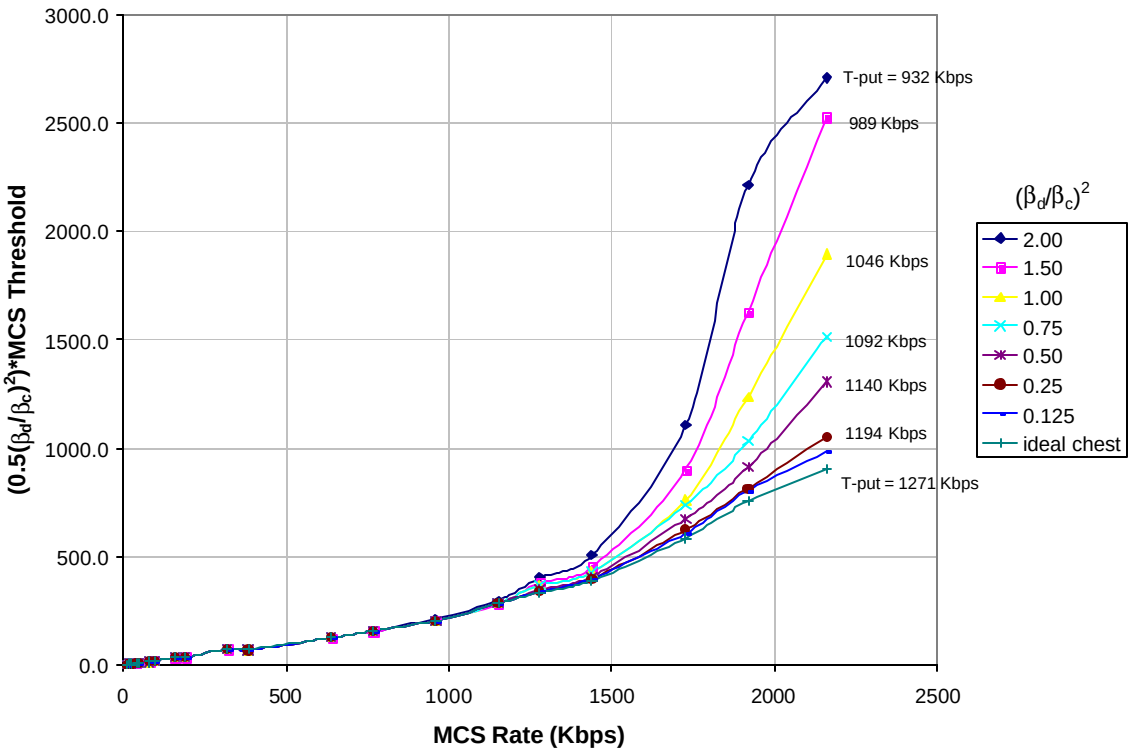


Figure 2. MCS thresholds for different b_d/b_c given non-ideal channel estimation (2ms TTI, PA 3km/h, 0.5dB TPC step size)

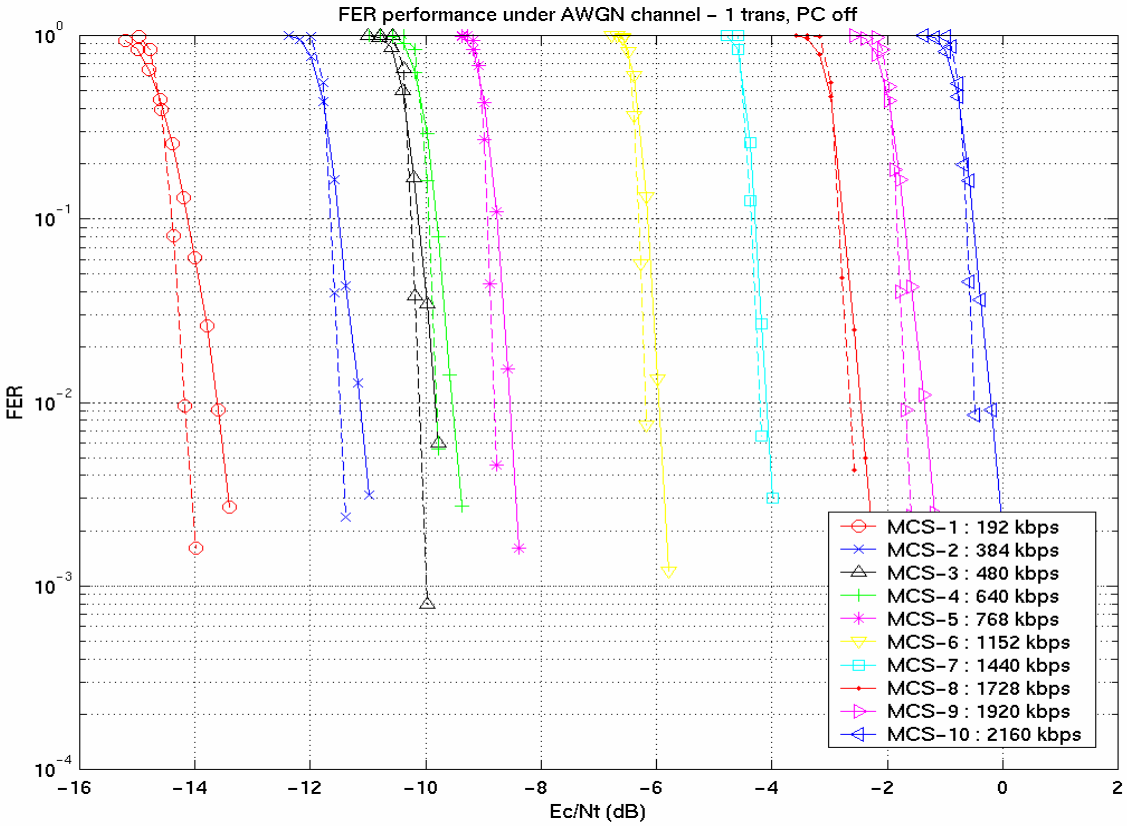


Figure 3. AWGN receiver performance for 2ms and 10ms TTIs. H-ARQ and Power Control were off and non-ideal channel estimation was used.

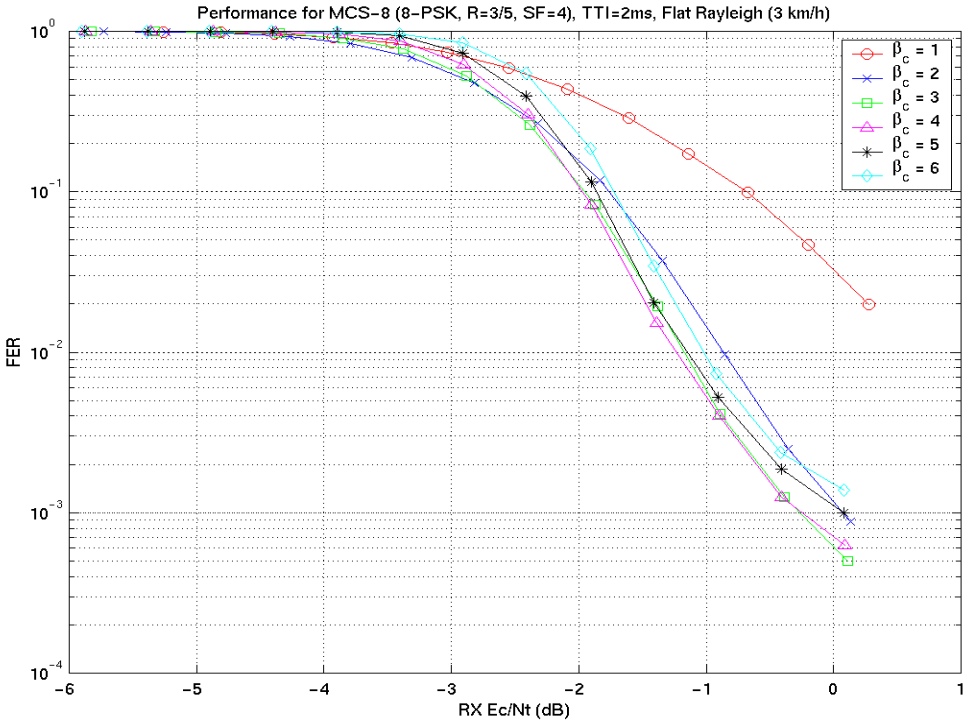


Figure 4. Performance of MCS-18 (1.728Mbps) at various beta_c for Flat Rayleigh fading channel (3 km/h), 1dB PC step size with 4% error, non-ideal channel estimation, 6 pilot bits (6/2/0/2 format). *(note MCS-8 is alternative labeling for link simulation)*

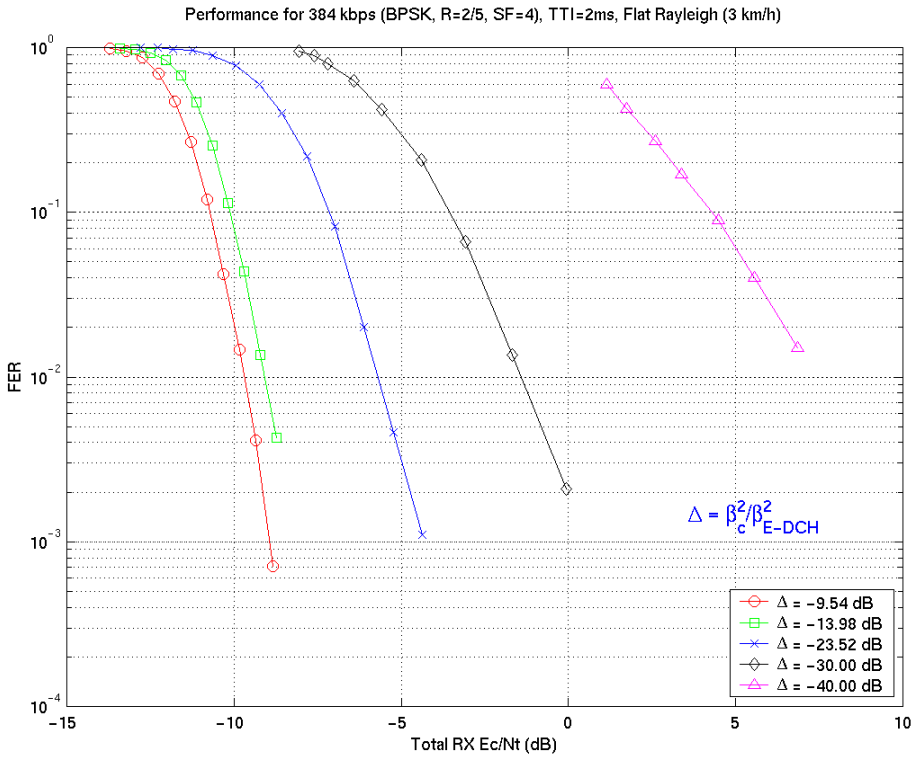
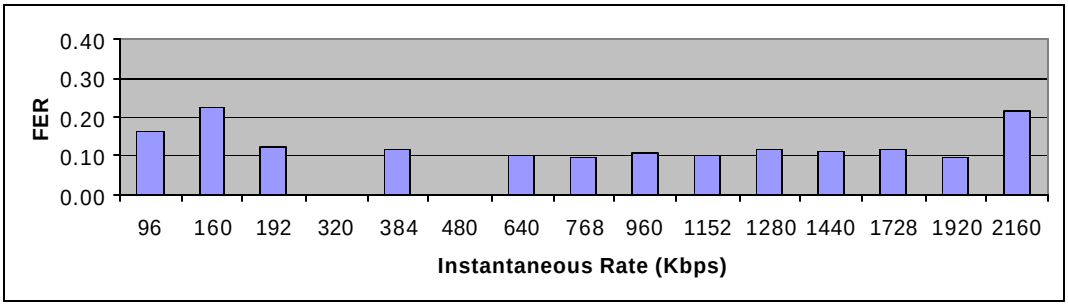
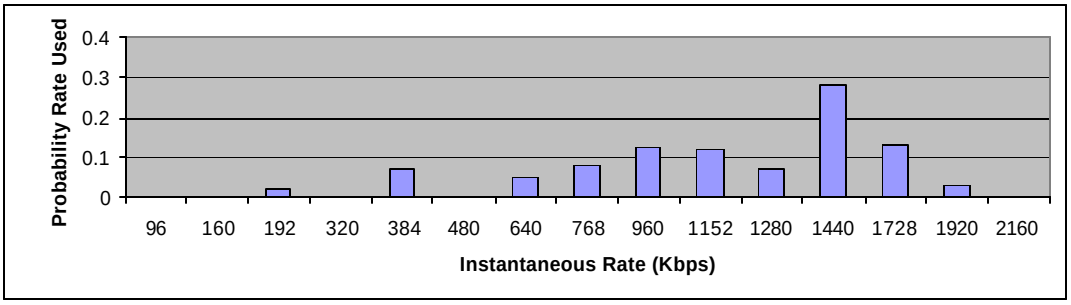


Figure 5. Performance of 384 kbps MCS at various pilot-to-data power ratios (?) for Flat Rayleigh fading channel (3 km/h), 1dB PC step size with 4% error, non-ideal channel estimation, 6 pilot bits (6/2/0/2 format).

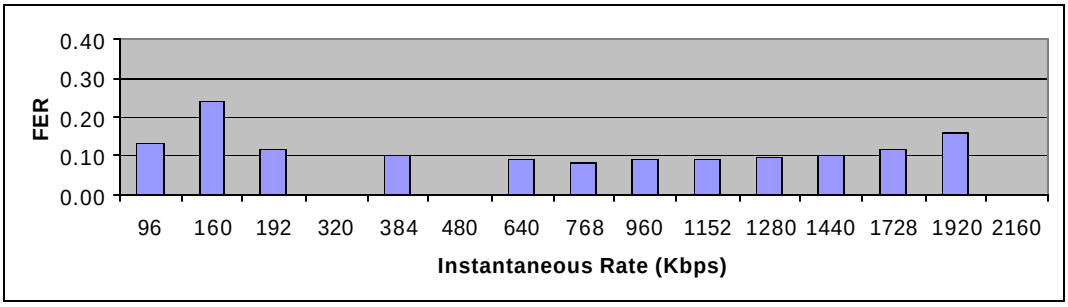
ANNEX A – Single User FER and Rate PDFs for various β_d/β_c and non-ideal Channel Estimation

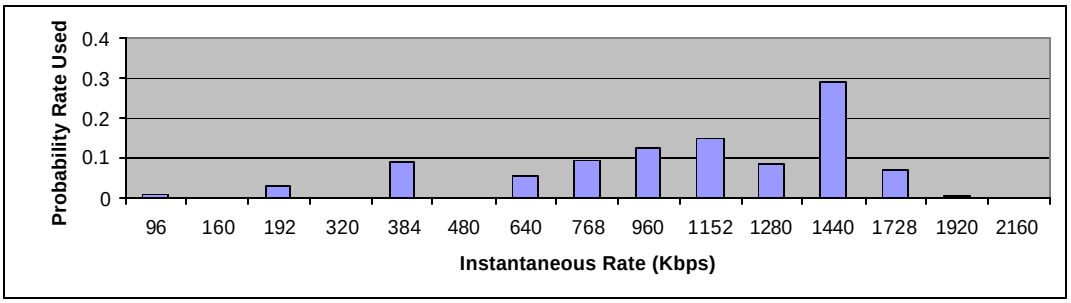
2ms TTI, PA 3km/h, with Channel Estimation, Bd/Bc=1.0



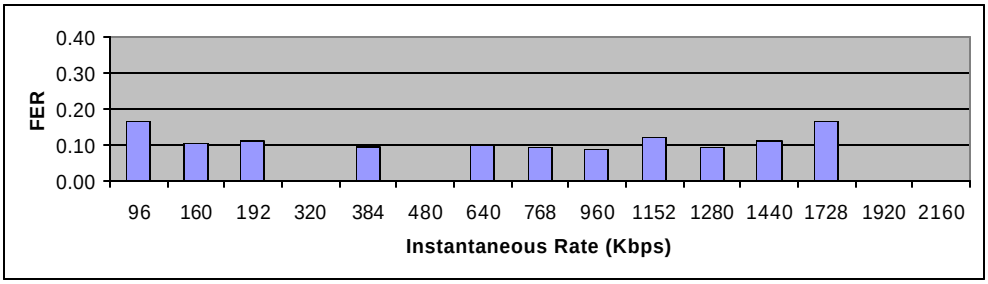


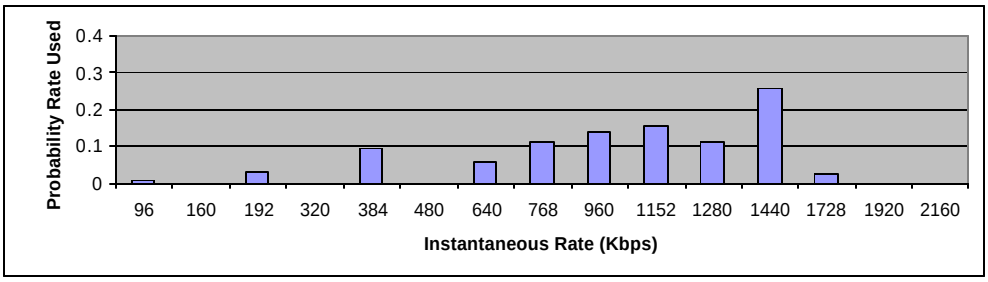
2ms TTI, PA 3km/h, with Channel Estimation, Bd/Bc=sqrt(1.5)



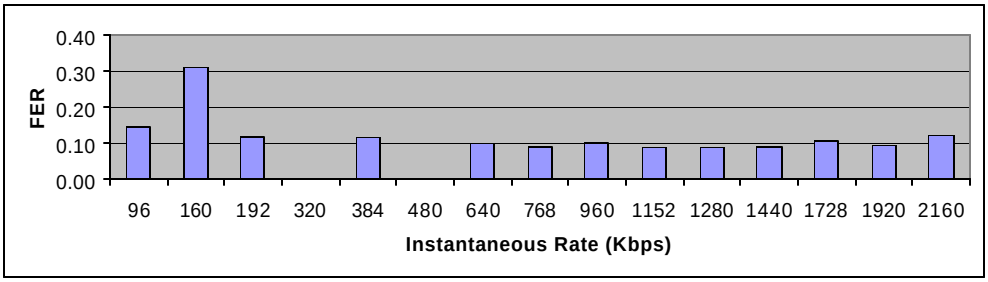


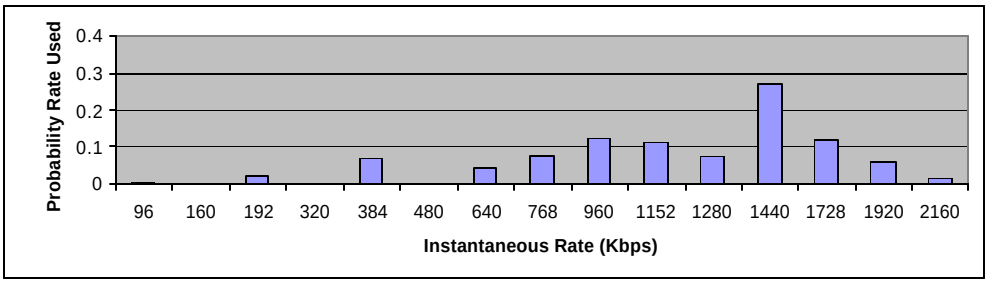
2ms TTI, PA 3km/h, with Channel Estimation, Bd/Bc=sqrt(2.0)



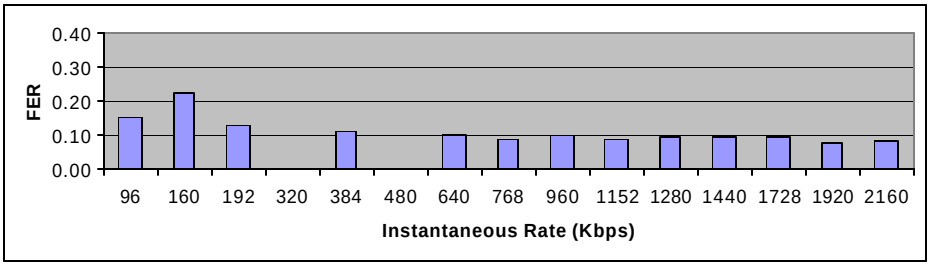


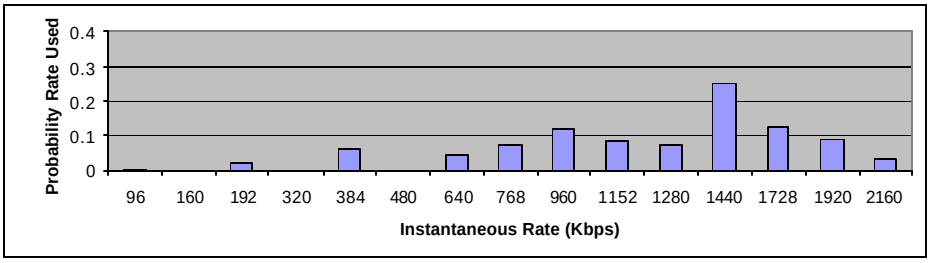
2ms TTI, PA 3km/h, with Channel Estimation, Bd/Bc=sqrt(0.75)



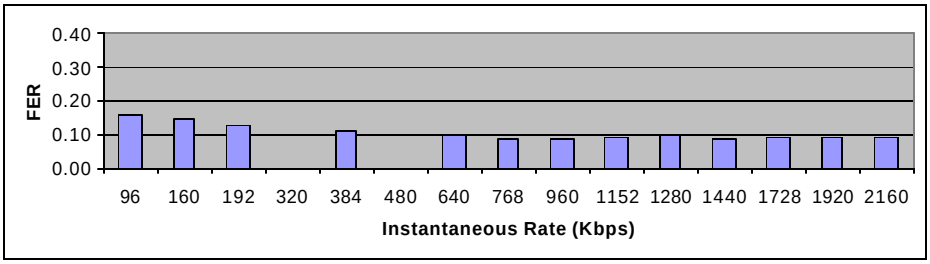


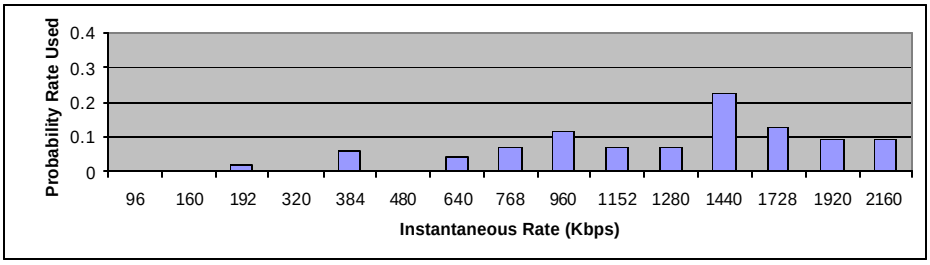
2ms TTI, PA 3km/h, with Channel Estimation, Bd/Bc=sqrt(0.50)



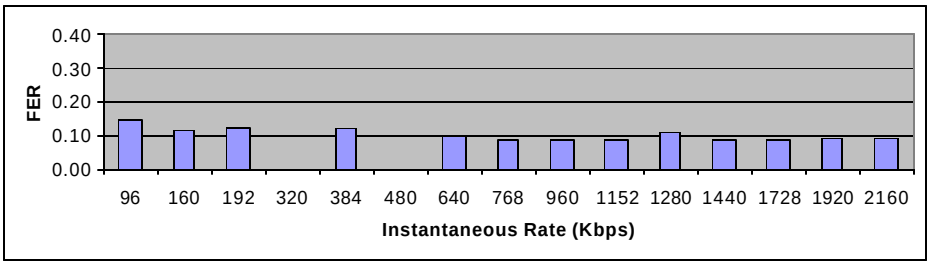


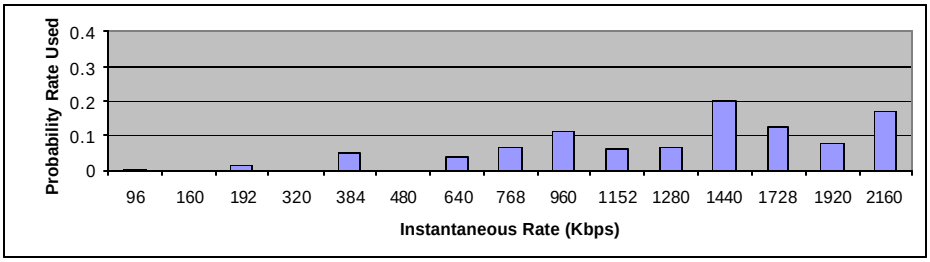
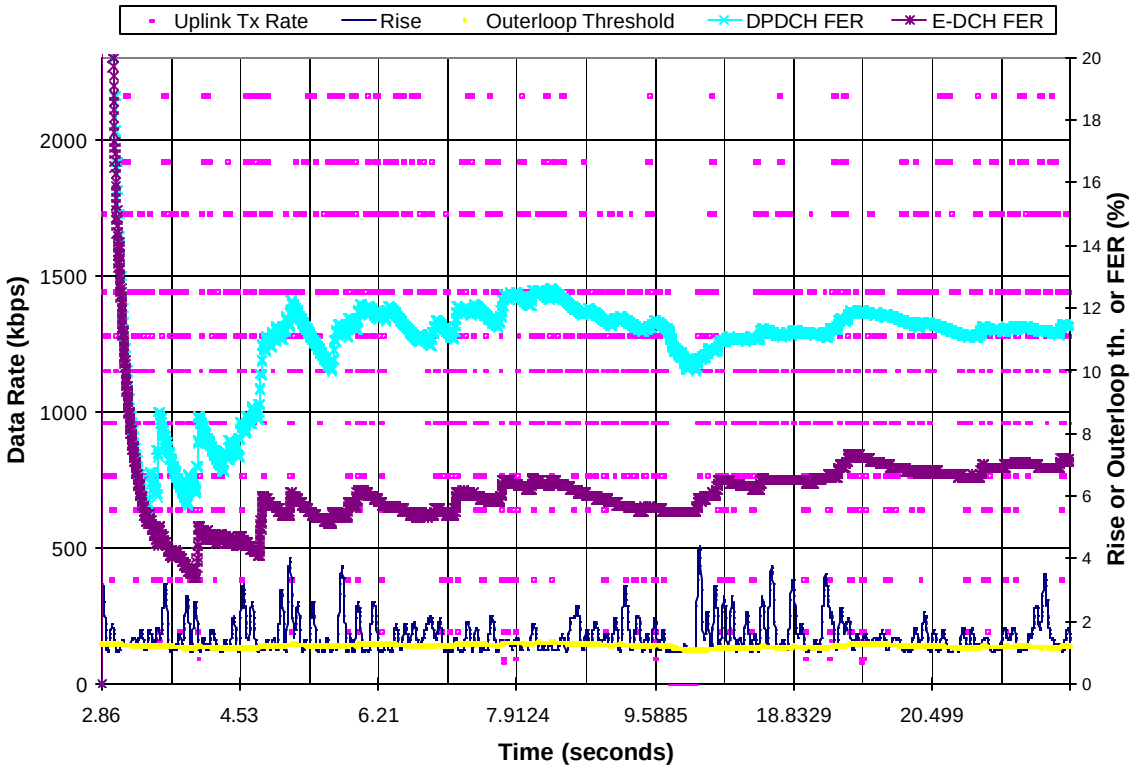
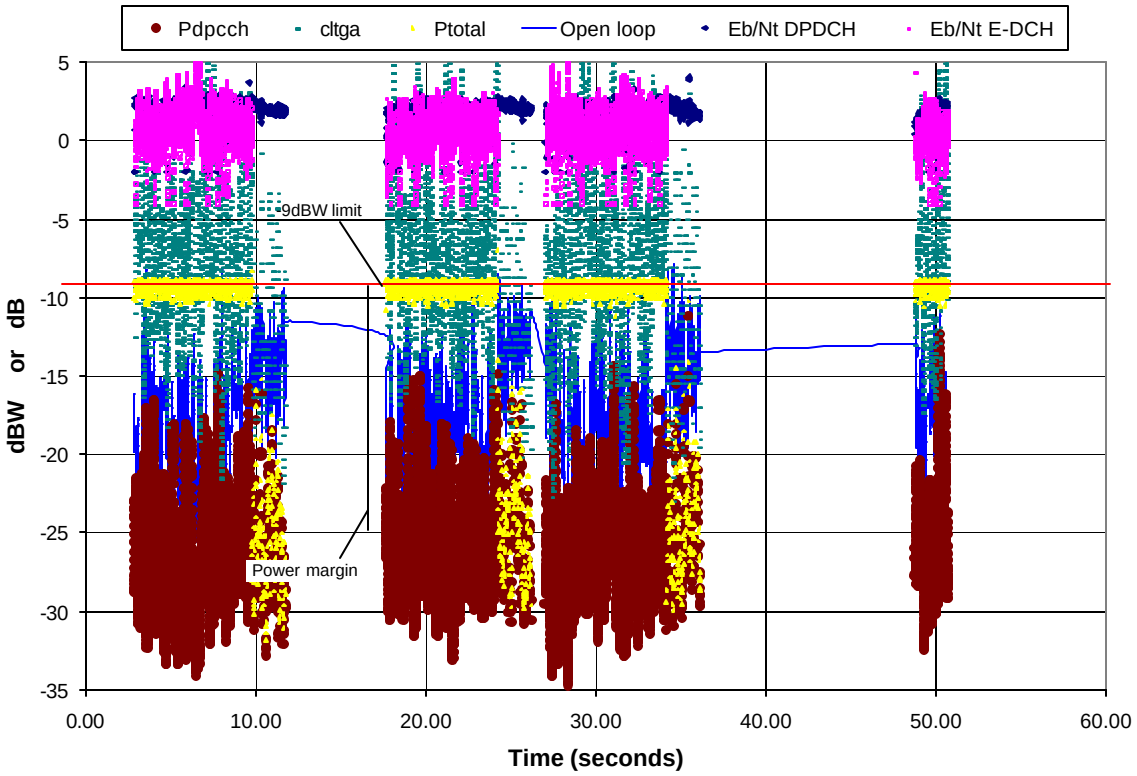
2ms TTI, PA 3km/h, with Channel Estimation, Bd/Bc=sqrt(0.25)





2ms TTI, PA 3km/h, with Ideal Channel Estimation, Bd/Bc=sqrt(0.50)





ANNEX B – Time Series Example
2ms TTI, PA 3km/h, Non-Ideal Channel estimation, Bd/Bc=sqrt(0.25)