

3rd-5th of April 2002, Sophia Antipolis, France

Source: Nokia
Title: Node B transmit modulation accuracy requirements for HSDPA
Agenda Item: 6.1
Document for: Discussion

1. Introduction

The effect of *high speed downlink packet access* (HSDPA) modulation accuracy in multi-user and multi-code transmissions [1] was presented in the last WG4 meeting. Base station manufacturers were encouraged to perform studies for the modulation accuracy requirements for the HSDPA transmissions.

In this document, we first present a brief theoretical analysis of modulation accuracy requirements for the higher order modulation schemes employed in HSDPA, in order to establish an estimate of the desirable range of improvement relative to the current Release'99 requirements. Secondly, we continue to show how the various key system assumptions regarding HSDPA deployment influence the requirements for modulation accuracy of the Node B.

This paper is mainly concerned with the *Peak Code Domain Error (PCDE)*, which is believed to be the key parameter to be studied as far as the impact of Node B modulation accuracy on HSDPA RF performance is concerned.

This paper is not meant as a proposal for a specific numerical value for the Node B PCDE but rather as a discussion document to illustrate some of the important issues to be considered in setting this requirement in a meaningful way. Traditionally, WG4 has used relatively simple EbNo link budget analysis to arrive at the PCDE requirements. We question such a simple approach for HSDPA, which is based on a different type of link adaptation concept compared to Transmission Power Control (TPC) used for Release'99 channels.

In this contribution, we consider and compare three methodologies for deriving a range of suitable values for the Node B PCDE required for effectively supporting HSDPA:

1. Simple PCDE minimum requirements needed to decode the TFRCs specified with HSDPA.
2. Simple "translation" of the existing Release'99 requirements to HSDPA.
3. System simulation results to illustrate the impact of Node B limited transmit modulation accuracy on HSDPA performance.

We use the assumption of an ideal UE rake receiver throughout the system simulations in order to concentrate our attention on the impairments due to Node B only, however, it should be noted that the relative impact of the Node B PCDE on HSDPA performance will be smaller, when UE imperfections are taken properly into account.

2. Background

HSDPA is a new feature introduced in the UMTS radio access network as of 3GPP Release'5 specifications. HSDPA is backwards compatible and can be introduced gradually into the network. HSDPA is a capacity evolution of UTRA and an enabler for high speed data services. QPSK and 16QAM are the used modulation methods with HSDPA. The *adaptive modulation and coding* (AMC) scheme of HSDPA will introduce higher order modulation compared to Release'99 specifications.

Since 16QAM is not mandatory for the Node B, it makes sense to consider PCDE requirements specifically for 1) a Node B that supports QPSK only and 2) a Node B that supports both, QPSK and 16QAM modulation. In this paper, we shall denote these two sets of requirements as "QPSK-" and "16QAM requirements" respectively, although for the latter case, we suggest that the improvement should apply equally to both, the QPSK and 16QAM based channels. Considering the sources for modulation inaccuracies, we do not believe that different requirements should be specified for QPSK and 16QAM for the same Node B.

3. General Considerations regarding PCDE Requirements

With the introduction of 16QAM and lower coding efficiency, UTRA/HSDPA becomes more sensitive to limited transmit modulation accuracy since we have to transmit more user bits per symbol. Consequently, this leads to higher Eb/No requirements and higher sensitivity to modulation inaccuracies compared to current Release'99 requirements. In order to make an allowance for this, there are several possible solutions:

- Increase the minimum specified code power level compared to existing specifications to decrease sensitivity to imperfections.
- Maintain the minimum code power specification but increase the modulation accuracy in order to compensate for the spectral efficiency loss of the higher order modulation and coding schemes.
- A combination of the above methods.

The current PCDE requirement with SF=256 has been derived from the assumption that the lowest possible code power is -28 dBc, where dBc refers to the maximum Node B output power. The allowed interference (due to PCDE) from other codes is -33 dBc, so we have a minimum symbol to noise margin of 5 dB for the Release'99 QPSK case. The existing specifications are consistent in such a manner that the same PCDE requirements also apply to other lower spreading factors than 256 (e.g. the power per code increases consistently). For instance, the minimum code power for SF=16 corresponds to -28 dBc + 10*log10(256/16) or approximately -16 dBc.

However, since fast power control is not used with HSDPA there is a conceptual difference between HSDPA and Release'99 modes of operation. With HSDPA, the code power setting is semi-static and changed to optimize packet scheduling rather than the fading characteristics of the multi-path channel.

Nevertheless, one issue of high importance to setting the Node B requirements is the minimum code power level that is specified for the PCDE test. This code power level should be low enough to capture the true dynamics of a deployed HSDPA/UTRA system. Since we are operating with adaptive modulation and coding rather than fast power control and have a semi-fixed HSDPA power allocation, we assume that HS-DSCH will be operated at higher average power than the minimum specified power per code of Release'99, in order to ensure robust operation of the AMC schemes. The minimum code power for a single HSDPA code channel can be calculated assuming that 25% of the total Node B transmit power is reserved for all common channels including the downlink HSDPA control channel (HS-SCCH). With HSDPA, we will need to support 16QAM operation with 15 multi-codes to achieve the maximum data rate of 10 Mbps specified for HSDPA. When there are 15 channels reserved for HSDPA with 75% of transmit power we have a minimum code power, $P_{code,min}$, of $10*\log_{10}(0.75/15) = -13$ dBc. This is considered to be the worst case.

3.1. Minimum PCDE requirements based on TFRC detection capability

In this subsection, we shall derive a first PCDE requirement based on criteria for TFRC detection capability.

As the HSDPA code power is assumed to be semi-static, the concept of a fading margin is somewhat different from Rel'99 channels, e.g. due to the link adaptation / AMC operation. From packet scheduling and code/power resource allocation considerations, we have above calculated a typical needed minimum code power level for HSDPA. Now, consider that the PCDE essentially sets the maximum available symbol-to-noise ratio (E_sNo) at the UE, even in an ideal, non-fading channel. If we assume that we will not be able to cancel out this Node B internally generated distortion, we have to ensure that the E_sNo available due to PCDE alone is high enough so that the UE is able to detect the least robust TFRC (e.g. QPSK3/4 and 16QAM3/4 respectively). The E_sNo available at the UE is limited by (ideal channel)

$$E_sNo \leq \frac{P_{code,min}}{PCDE(SF = 16)} \quad \Leftrightarrow \quad PCDE(SF = 16) \leq \frac{P_{code,min}}{E_sNo_{req}}$$

The basic approximate demodulation requirements for a low BLER of 0.001 (to allow also very delay sensitive traffic to be carried on the HS-DSCH) are shown in Table 1. The results are based on link level simulations in the Pedestrian A environment for 3 kmph. We may foresee much worse environments in field deployment, but it is expected that the highest bit rates will only be available in very favourable channel conditions. For each of the requirements, the corresponding minimum PCDE requirement has been listed. It should be noted that a BLER of 0.001 is neither assumed to be a frequent, nor throughput efficient mode of HSDPA operation; this value has been picked here in order to just have a simple worst case assumption.

Table 1 - Minimum PCDE requirements based on TFRC detection capability (QPSK, rate 1/2 is included as a Rel'99-like reference but requirements are based on HS-DSCH).

TFRC	EsNo for 0.001 BLER	PCDE (SF=16), $P_{code,min} = -13$ dBc
QPSK, rate $\frac{3}{4}$	≥ 6.0 dB	≤ -19.0 dB
16QAM, rate $\frac{3}{4}$	≥ 11.5 dB	≤ -24.5 dB
QPSK, rate $\frac{1}{2}$	≥ 2.1 dB	≤ -15.1 dB

Note that in reality, these requirements only allow detection in the case with perfect channel quality, negligible noise and inter cell interference, and ideal UE demodulation performance. Hence, some margin must be added to these numbers and also other target BLER value needs to be considered.

3.2. Estimation of the required PCDE for HSDPA/16QAM based on the Rel'99 PCDE Requirements

In this subsection, we shall derive an alternative PCDE requirement based on “translating” the existing Rel'99 PCDE specification to HSDPA.

Due to the reasons explained in the last section, a direct use of the Rel'99 PCDE specification approach for HSDPA may not be applicable; especially since both, modulation and code rate are changed with HSDPA. However, let us assume for compatibility reasons that we will maintain the existing Release'99 PCDE requirements to ensure backwards compatibility of Node B. We shall further assume that a HS-DSCH channel employing QPSK, rate $\frac{1}{2}$ corresponds to a Release'99 channel (here we can use convolutional rate $\frac{1}{2}$ coding up to turbo rate $\frac{1}{3}$ coding). Hence to allow the higher code rate we would require a PCDE tightening of

$$\text{PCDE tightening} = 6.0 \text{ dB} - 2.1 \text{ dB} = 3.9 \text{ dB},$$

in which the EsNo values of Table 1 have been used from the QPSK TFRCs. However, as noted from the discussion in the previous section, the nominal code power for HSDPA is -13 dBc and -16 dBc for Release'99 SF=16 channels. Hence, for the QPSK case we see that maintaining the PCDE specification actually indicates a 3 dB improvement since we expect a general increase of the code power, thereby reducing the effect of Node B limited transmit modulation accuracy. Hence, measured on the QPSK SF=16, we could adapt a total PCDE requirement of

$$\text{PCDE(QPSK,SF=16)} \leq -33 \text{ dB [rel-99 PCDE value]} + 10 \cdot \log_{10}(256/16) \text{ dB [SF ratio of different requirement]} - 3.9 \text{ dB [projected tightening of PCDE]} + 3.0 \text{ dB [estimated increase of Node B code power]} = -21.9 \text{ dB}.$$

Release'99 QPSK PCDE requirement with SF=16 is $-33 \text{ dB} + 10 \cdot \log_{10}(256/16) = -21 \text{ dB}$. Hence, we would need to improve the QPSK PCDE requirement by 0.9 dB compared to Release'99 specifications.

Since link adaptation operated at the -13 dBc power level also implies operating with 16QAM in favourable channel conditions, we also need to consider the demodulation requirements of 16QAM compared to QPSK. Due to issues of block length and turbo coder performance, we need to consider the symbol-to-interference ratio (EsNo) required to obtain some basic BLER. This depends on the environment, the code rate, and the accuracy of the channel estimates in the UE. In Figure 1, the additional EsNo required to operate 16QAM at the same BLER as QPSK is plotted for different environments, assuming idealized RAKE demodulation at the UE.

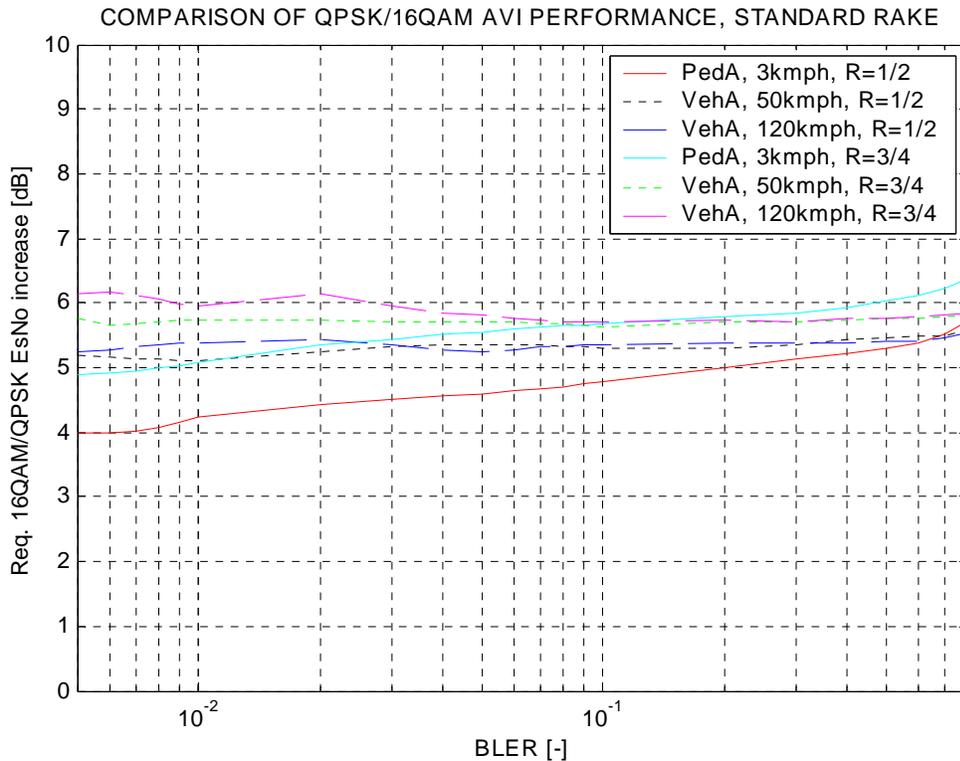


Figure 1 - Illustration of additional EsNo requirement for 16QAM over QPSK for same BLER. *R* denotes the employed turbo code rate in the simulation.

As seen from the figure, the worst case difference seems to be on the order of 6 dB increase in EsNo in realistic BLER operating conditions. That is, to operate 16QAM at some BLER target, we need to have an EsNo improvement of approximately 4 - 6 dB compared to QPSK. Hence, to be able to use 16QAM at the lowest code power suggests that one may need to increase the Node B PCDE requirements by about 6 dB compared to Release'99 specifications. Hence, we estimate the required PCDE level for the Node B (16QAM, SF=16 measurement channel) as follows:

$$\text{PCDE}(16\text{QAM}, \text{SF}=16) \leq -21.9 \text{ dB} - 6.0 \text{ dB} = -27.9 \text{ dB}.$$

We would then obtain the same margin for 16QAM as has been specified for QPSK.

3.3 Comments on Other Proposals

Another way of simply deriving the PCDE requirements has previously been proposed in [4]. Here it was suggested that the EVM should be tightened from 17.5% to 13.5% for 16QAM. Since the PCDE is the main concern for HSDPA, we can relate this to a corresponding tightening in the PCDE requirement based on the proposal in [4]:

$$\text{PCDE tightening} = 10\log_{10}(0.1752/0.1352) = 2.3 \text{ dB},$$

assuming that the error is evenly distributed among the codes. Hence, tightening the EVM from 17.5% to 13.5% is equivalent to a 2.3 dB tightening of the PCDE and thus is in line with the arguments presented here. The absolute tightening is in the range between the results obtained in the sections 3.1 and 3.2.

3.4 Results from simulation studies regarding the impact of PCDE on HSDPA system performance

While the arguments of the above Rel'99 based derivation for the PCDE are plausible, the method does not necessarily cater for all foreseen circumstances of HSDPA deployment and thus may either under- or overestimate the required PCDE for a given maximum allowed system throughput degradation. Therefore, the following system throughput simulations were

conducted to study the impact of the PCDE in the range of $-36 \text{ dB} \pm 3 \text{ dB}$ (defined at SF=256 level) for a variety of system assumptions. The system assumptions are considered to have an impact on the influence of the PCDE on the cell total system throughput (listed in no particular order):

1. Channel conditions.
2. Distribution of the G-factor across the connections of a cell utilizing HSDPA. There are e.g. significant differences between macro cells and micro cells, in that the latter ones emphasize the higher G-factor values to a larger extent.
3. The provision of HSDPA capacity/throughput and its *variation* across the cell range. This is related to the characteristics of the assumed HSDPA packet scheduling algorithms.

The results presented in this section show the impact of the PCDE on the overall cell throughput of HSDPA as a function of the used HSDPA codes when varying these system assumptions. In doing so, the following general assumptions were used:

- System scenario same as the one presented in [5].
- For the UE, a RAKE-receiver has been assumed. Ideal channel estimates are assumed and no UE implementation margin is considered.
- 40 % of the Node B total Tx power was allocated to HSDPA.
- Same PCDE level was applied to both QPSK and 16QAM channels.
- A fair throughput packet scheduler (FT PS) and a fair time (or link adaptation packet scheduler (LA PS)) have been used during the simulations.
- We assume a link adaptation delay of 2 ms and a log-normal E_s/N_0 estimation error with a variance of 2 dB (significant link adaptation error).

Also the case of PCDE = -99 dB has been added here for reference (i.e. representing the case of ideal Node B transmission).

First, let us consider Figure 1 which shows the average cell throughput for a *micro cell case*, which is a very favourable environment for HSDPA throughput performance. Two groups of curves are considered, corresponding to LA PS and FT PS respectively. For the fair throughput scheduling the capacity is basically set by the user(s) in the worst conditions. These users are dominated by inter-cell interference rather than by limited transmit modulation accuracy and thus the impact of increasing the PCDE is somewhat limited. Note that the figure considers different HSDPA power/code allocation scenarios, catering for the possibility that HSDPA operation may be either code- or power limited, depending on the operational circumstances. The area of interest regarding the number of codes and equivalent code power corresponds to the case where 5 - 8 codes are allocated to HSDPA. The benefit of improving the PCDE is much less for higher code powers as expected. Going from a PCDE of -33 dB to -36 dB yields an average gain of 9%. Further improving PCDE to -39 dB yields an additional gain of 6%.

For the LA PS, users have equal transmission time and, hence, high quality users are favoured more by this scheduling method. While the users under FT PS obtain similar throughput irrespective of their location within the cell, users under LA PS, which are close to the Node B may receive a much larger throughput than users at the edge of the cell (in a similar way as shown in Figures 5, 6 in [5]). Thus, this PS method has increased the overall cell throughput by some 95%, however, at the expense of a large variation of the allocated capacity/throughput/QoS as a function of the cell location. Correspondingly, the use of higher order TFRCs increases and the system becomes more susceptible to limited transmit modulation accuracy. Going from a PCDE of -33 dB to -36 dB yields an average throughput gain of 20%. Going to -39 dB yields an additional gain of 20% showing that here the channel quality is good enough to fully utilize a PCDE level of -39 dB. Again, the gain of improving the PCDE is significantly reduced as the code power is increased.

40% HSDPA power - 2dB/2ms EsNo est. err/delay - Microcell/PedA3

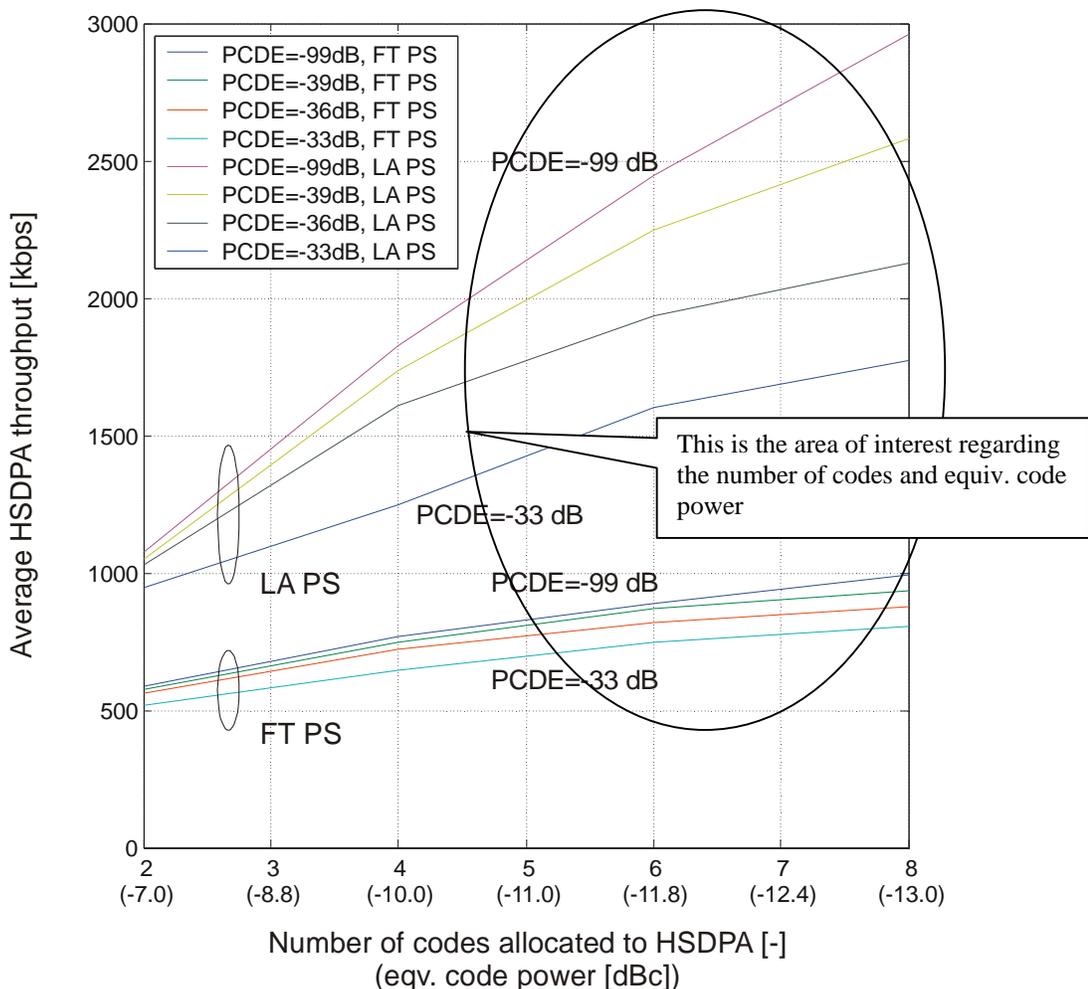


Figure 1 - HSDPA throughput results for microcell Pedestrian A environment (3 kmph).

If we instead consider a *macro cell case* in Figure 2 it is clear that the cell throughput is much smaller than for the micro cell case due to the channel conditions and a less favourable G-factor distribution in macro cells. In this respect, HSDPA achieves a much lower absolute throughput in the macro cell scenario when compared to the micro cell scenario. Consequently, HSDPA is less susceptible to the PCDE in the macro cell case and, but generally, the trends of improving Node B modulation accuracy are similar to the micro cell case. For both packet scheduling methods the benefit of improving the PCDE is again much less for higher code powers, as expected. Going from a PCDE of -33 dB to -36 dB yields an average gain of 5% for FT PS and 10% for LA PS. Going to -39 dB yields an additional gain of 3% for FT PS and 4% for LA PS.

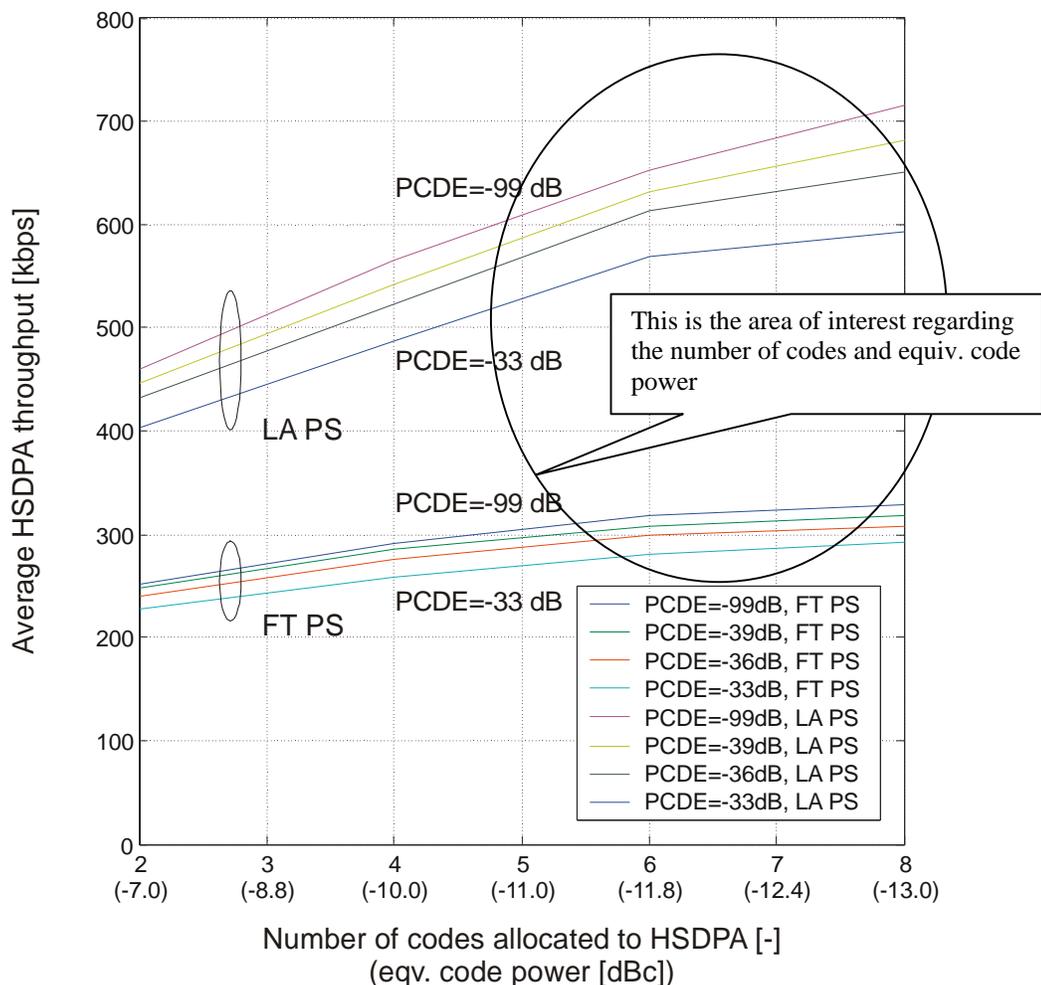


Figure 2 - HSDPA throughput results for macrocell Vehicular A environment (3 kmph).

The previous results have shown the impact of PCDE in overall cell throughput terms. While the total cell throughput is perhaps the most important metric, it should also be discussed how the PCDE impacts the TFRC selection probability and thus the coverage of eg. 16QAM. We have seen that with the FT PS method we still serve the users in bad conditions adequately. Hence, for this case the probability of using 16QAM seen over all users is very limited indeed. For link adaptation scheduling (LA PS), on the other hand, we use round robin with equal time slot allocation, which will favour potential 16QAM users in good channel conditions. Hence, for the study of PCDE impact on TFRC selection probability it seems more reasonable to assume LA PS. The selection probabilities for the micro cell and macro cell scenarios have been plotted in Figure 3 and Figure 4 respectively.

40% HSDPA power - 2dB/2ms EsNo est. err/delay - Microcell/PedA3

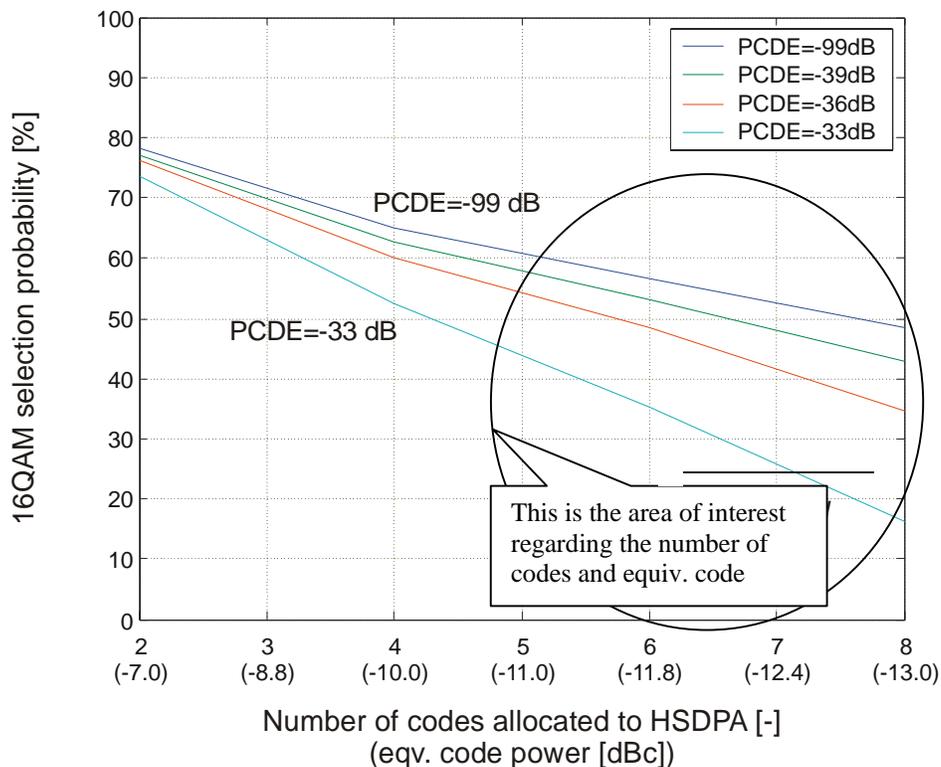


Figure 3 - 16QAM selection probability for microcell Pedestrian A case (3 kmph).

40% HSDPA power - 2dB/2ms EsNo est. err/delay - Macrocell/VehA3

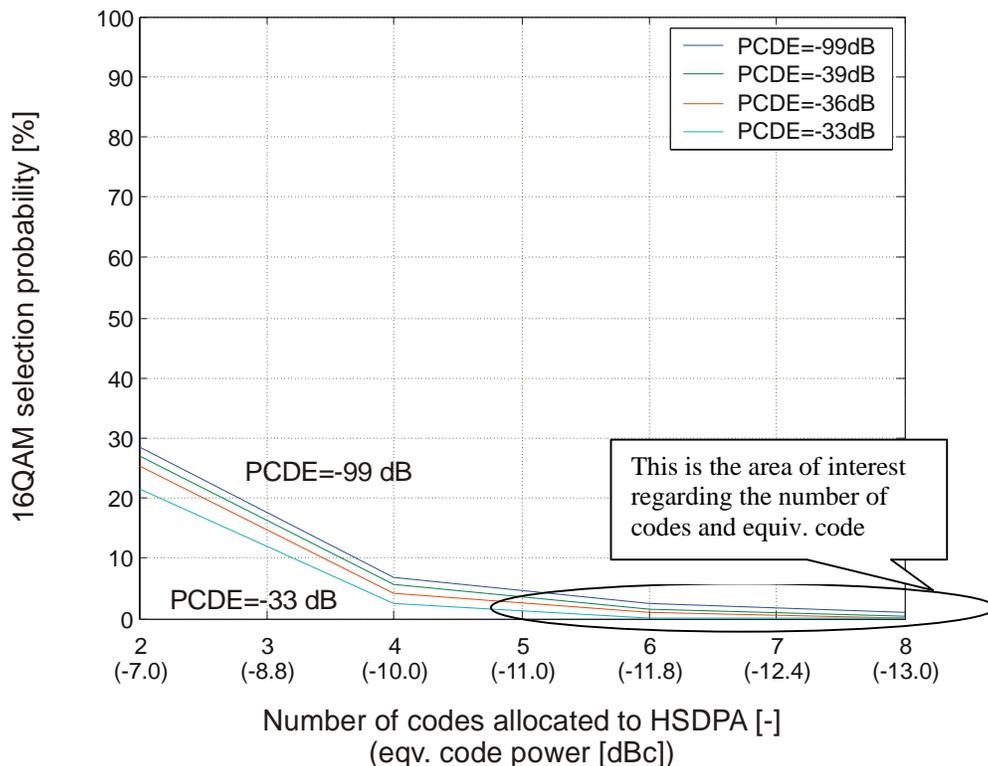


Figure 4 - 16QAM selection probability for macrocell Vehicular A case (3 kmph).

For the macro cell/Veh A case, 16QAM is not selected very often even for the higher power/code allocation, hence, the effect of improving the PCDE is not so significant in this case. It should be noted though that the throughput nevertheless was improved by 10% by improving the PCDE to -36 dB, which is then mainly a consequence of the QPSK performance being improved along with the 16QAM performance. For the micro cell/Ped A case, the 16QAM selection probability is much higher and we can see a larger effect when improving the PCDE. For the minimum code power simulation in the micro cell case, the 16QAM selection probability increases from 16% to 35% by improving PCDE to -36 dB and further to 43% by improving PCDE further to -39 dB.

4. Conclusions

As can be seen from the analysis made in this document HSDPA will have effect on the modulation accuracy requirements for the Node B. We have presented different methodologies for deriving PCDE requirements and the presented plausibility arguments and simulation results suggest that the Node B PCDE for HSDPA may need to be improved within a range of some 3 - 6 dB relative to current Rel'99 requirement, subject to a number of system assumptions regarding HSDPA deployment which WG4 will need to make.

In particular, it was shown that the susceptibility of HSDPA data throughput due to PCDE depends on a number of different factors, including but not limited to :

- a) distribution of the G-factor / cell types (micro, macro) as well as channel conditions,
- b) RRM code and power allocation strategies used in HSDPA,
- d) HSDPA capacity / QoS, provision and variation across the cell, as well as the packet scheduling method.

We should note that simulations conducted here assume ideal UE demodulation performance and that the gains of improving Node B PCDE will be smaller, when UE imperfections are taken properly into account. However, further assumptions regarding UE demodulation performance in WG4 should be known before a more conclusive analysis regarding requirements for Node B modulation accuracy can be made.

As a final remark, it should also be noted that the eventual requirements for RF performance should be set as a sensible trade off between HSDPA performance in realistic operating environments and Node B complexity and cost.

5. References

- [1] R4-020355, "Effect of HSDPA Modulation Accuracy in Multi-user Multi-code Transmissions", Motorola.
- [2] 3GPP TS25.141, "Base station conformance testing"
- [3] R4-011438, "Base Station Radio Transmission Requirements for HSDPA", Motorola.
- [4] R4-011439, "Effect of Modulation Accuracy on HSDPA Radio Link Performance". Motorola.
- [5] R4-020075, "Considerations on HSDPA System Scenarios". Nokia.