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Agenda item:

Source: **Philips**

Title: **Throughput of HSDPA**

Document for: **Discussion**

1. Introduction

This document presents some system level results on the performance of HSDPA. The intention is to highlight the possible throughput and capacity gains which might be achieved and draw some initial conclusions on the relative benefits of some of the features which have been proposed for inclusion in HSDPA.

In order to make the simulation and analysis more tractable a number of simplifying assumptions have been made compared with simulation conditions proposed elsewhere (e.g. R1-00-1093 and R1-00-1094). However, where such simplifications are used, it is generally intended that they should lead to a more optimistic estimate of potential performance, rather than a reduced one.

This document extends the results presented in R1-00-1045, with the simulation assumptions updated according to the comments received.

2. Simulation Parameters

The simulation assumptions detailed in this section are used, unless otherwise stated.

2.1 Link-level assumptions

The following are taken as a baseline for the results presented in this document

Parameter	**Value**	**Comments**
Propagation conditions	AWGN	Assumes stationary channel over duration of packet transmission, including any re-transmissions
Terminal speed	Zero	Stationary or slow moving terminals
Closed Loop power control	Off	
HSDPA Frame Length	Variable	Frame length is determined by number of bits in the packet
Channel coding	Idealised block code with soft decoding rates 1/3, 1/2, ¾	Performance assumed to be determined by minimum distance (see text). Overheads (CRC, tail bits etc) not included
Packet size	8000	Number of user bits per packet
ARQ	Soft combining	Retransmission of contents of the first packet
Maximum number of transmissions Control channel overheads	10 Not included	
Chip rate	3.84 Mcps	
Spreading factor	32	Other SF could be used if needed
Maximum number of spreading codes of SF=32 available	20	

2.2 System level assumptions

Parameter	Assumption	Comments
Cellular layout	Hexagonal Grid	Two rings of cell sites around the serving cell are considered
Sectors	1 or 3 per site	Results can be scaled for different numbers of sectors
Site to Site distance	2	Interference limited (no noise), so arbitrary distance scaling can be used
Antenna pattern	Unity gain inside sector Zero gain outside sector	Ideal assumption
Propagation model	$L = 37.6\mathrm{Log}_{10}[R]$	Interference limited, so absolute path loss not required
CPICH power	-10dB	10% of maximum total cell power
Other downlink channels Power allocated to HSDPA in the serving cell	-10dB Up to 80% of total cell power	10% of maximum total cell power
Average power allocated to HSDPA in each interfering cell	80% of total cell power	Together with CPICH and other downlink channels this gives 100% of maximum total cell power from each interfering cell. If power utilisation for HSDPA is lower than 80%, then interference would be reduced accordingly
Slow fading model	Log normal	Normal distribution in dB’s
Standard deviation of slow fading	5.6dB	Equivalent to 8dB standard deviation with 0.5 correlation between sites
Correlation between sectors	1.0	
Correlation between sites	0.0	
Active set size	No limit	Any one cell may be selected
Fast fading	Ricean with 12dB K factor	2Hz fading rate has been suggested for stationary terminals. Here it is assumed that this only affects the distribution of SIR over the terminals, not the SIR during a packet transmission
Error in SIR estimation	Stan Dev =1dB	Normal distribution in dB’s. This will affect site selection and selection of transmission scheme. The size of the error will depend on the averaging time. 1dB seems a reasonable value for a practical implementation.
Number of carriers	1	

2.3 Cell Layout and UE Placement

The cell layout is shown in Figure 1. The central cell site is assumed to contain the serving cell. However, if another cell offers a better SIR, it may be selected for the downlink transmission.

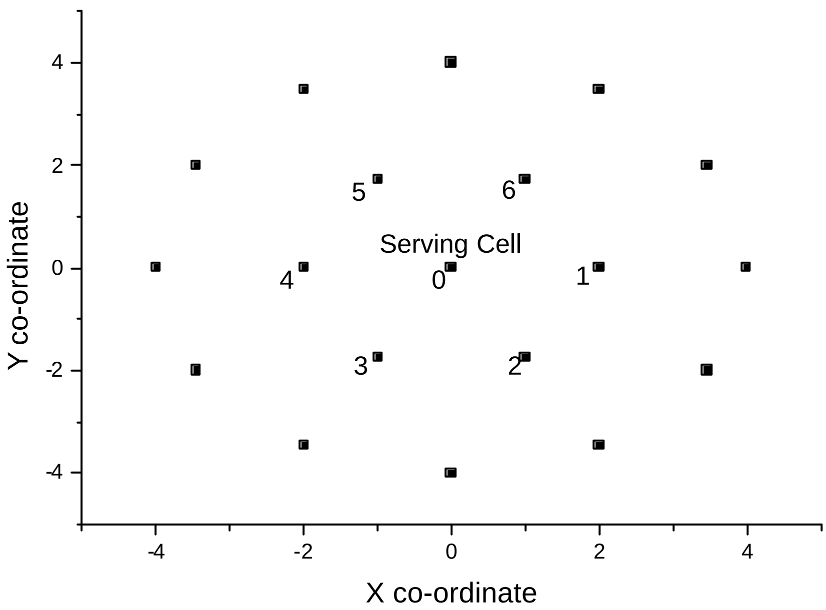

Figure 1 Base-site locations

The UE locations are selected with a uniform pseudo-random distribution. Since any sector in the region around the serving cell should be statistically equivalent, for convenience, the UE's are placed only in a region bounded by a triangle of width unity and height Tan(?/6). A typical set of 100 UE locations are shown in Figure 2. In practice more UE positions than this would be needed for reliable results.

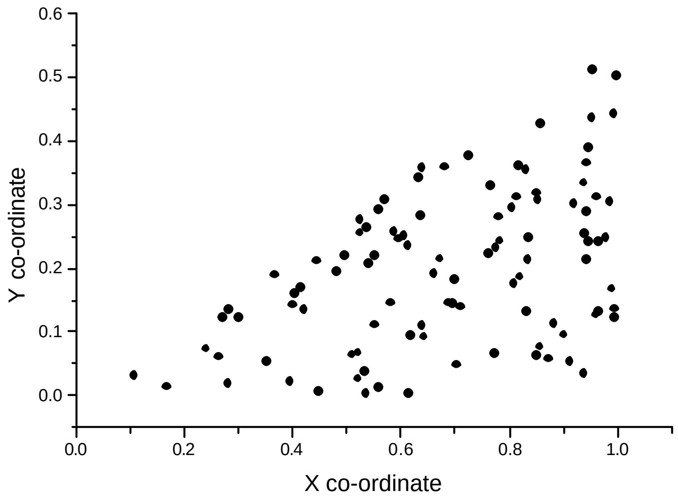

Figure 2 Example of random UE locations

2.4 UE mobility model

The UE is assumed to be stationary at each location to which a packet is transmitted, so that the SIR does not change during packet transmission. It is also assumed that the Ricean fading is sufficiently slow that the same SIR is maintained during any re-transmissions. If the probability of re-transmission is low (e.g. around 10%) then any errors due to this approximation will be further reduced.

2.5 Site Selection and SIR model

The path loss to each cell site is calculated, based on the path loss model and pseudo random values due to fast and slow fading. A pseudo random estimation error (? = 1dB) is also added to each path loss value. Then the site with the lowest path loss (including the estimation error) is selected for the packet transmission. The wanted signal is calculated from the selected site, assuming that all the power available for HSDPA is used. The interference is calculated as the sum of the power received from all the other sites, assuming that they all transmit the CPICH, the defined power level on the other channels and a power equal to the assumed value of the average power assigned to HSPDA. This allows the calculation of the received SIR.

This model thus assumes Fast Site Selection.

The AWGN channel model is justified on the basis that the channel can be considered stationary if the fading is not significant over the duration of the packet.

The use of an ideal sector antenna model means that the SIR value is not affected by the use of cell sectorisation. However, the total capacity per cell-site would be multiplied by the number of sectors.

2.6 Modulation and Coding Schemes

The following modulations are considered: QPSK, 16-QAM, 64-QAM. 8-PSK is not currently considered since it is not different enough from 16-QAM in terms of bandwidth efficiency and Eb/No. However, it could be added to the model. Analytical expressions are available for the symbol error rates of each modulation.

The channel coding is modelled as follows: Given the code rate, the packet is assumed to coded into a single code word. The minimum distance of the code word is assumed to be

$$d_{\min} = (n - k)/2$$

where:

n = total number of bits in the code word
k = number of information bits.

Note that this is a somewhat optimistic expression for binary codes.

The probability of a code word error using soft decision decoding can be estimated from:

$$P_M = (M - 1)\,Q\left(\sqrt{2\gamma_b R_c d_{\min}}\right)$$

where:

$$M = 2^k$$

$$Q(x) = \frac{1}{2} erf\left(\frac{x}{\sqrt{2}}\right)$$

$$\gamma_b = \text{SNR per bit}$$

$$R_c = \text{Code rate}$$

This expression can be used directly for QPSK, and also be adapted for 16-QAM and 64-QAM.

The following code rates are considered for the moment: 1/3, ½, ¾. It would be possible to add ¼ rate coding, but this adds only a little improvement in E_b/N_o compared with1/3 rate coding and anyway is not currently present in R'99.

We also assume that different numbers of spreading codes (SF=32) can be allocated, up to a maximum of 20.

The different combinations of modulation/code rate/spreading code considered are as follows:

Scheme	Modulation	Code rate	Number of spreading codes (SF=32)	TTI (ms) (for 8000 bit user packet)
1	QPSK	1/3	1	100
2	QPSK	1/3	2	50
3	QPSK	1/3	3	33.3
4	QPSK	1/3	5	20
5	QPSK	1/3	7	14.3
6	QPSK	1/3	10	10
7	QPSK	1/3	14	7.14
8	QPSK	1/3	20	5
9	QPSK	½	20	3.33
10	QPSK	¾	20	2.22
11	16-QAM	½	20	1.67
12	16-QAM	¾	20	1.11
13	64-QAM	¾	20	0.741

Table 1 Transmission Schemes

The aim in choosing these schemes was to provide a wide enough dynamic range with sufficient granularity that the selected scheme can be assumed to be close to the optimum one.

The steps between different schemes are (approximately) equivalent to changing the TTI by a factor of around 0.7 between each scheme. The TTI is calculated on the basis of the time needed to transmit a packet of 8000bits. In a practical implementation some account would need to be taken of how the transmissions could be organised within a defined frame structure. This might result in the choice of a different set of parameters.

As a reference condition it is assumed that all the available power for HSDPA is used for all the transmission schemes. However, the power could also be adjusted (see Annex A: Optimised transmission with QPSK)

2.7 ARQ Scheme

The following ARQ schemes are considered

- **A**: Re-transmission of failed packets, discarding of erroneous packets
- **B**: Re-transmission of failed packets, soft combining of all received packets. The effective SIR is then N?SIR$_1$, where N is the number of transmissions and SIR$_1$ is the SIR of the first transmission.
- **C**: For each failure, transmission of an amount of additional redundancy equivalent to the first transmission. When the transmissions are combined, the effective code rate is then R_1/N where R_1 is the code rate of the first transmission.
- **D**: For each failure, transmission of an amount of additional redundancy such that when the transmissions are combined the effective code rate is $R_1/(1.4^{N-1})$ This means that the code rate is reduced in more uniform steps than with option C. However, the re-transmitted packet size is not constant.

A maximum of 10 re-transmissions is allowed.

Scheme B is used as the reference condition.

Note that after a few retransmissions the code rates resulting from the use of schemes C and D may become to low to be practical, but the intention is to study the potential performance benefits of the technique, rather than consider the detailed feasibility of implementation.

2.8 Selection of Transmission Scheme

The transmission scheme (e.g. from those in Table 1) is selected on the basis of the calculated received SIR, but with the addition of a pseudo random estimation error (? = 1dB). The aim is to minimise the expected total energy required to send the packet. In the case that the same power is used for all packets, this is equivalent to minimising the transmission time (including the expected number of re-transmissions).

If the different transmission schemes can use different power levels (see Annex A: Optimised transmission with QPSK) the selection can be based on total energy required to send the packet. In this case, to give a better indication of the system resources used, the selection should also take into account the fact that energy is required to send other channels (e.g. CPICH).

2.9 Throughput and Capacity

The capacity of the system is defined here as the throughput in bits per second per carrier per cell.

Throughput = Number_of_bits_received / Sum_of_packet_transmission_times

In the case of uniform packet size:

Number_of_bits_received = Packet_size x Number_of_packets

2.10 Data Traffic Model

In each simulation all packets are assumed to contain the same number of bits (8000). Only transmission of individual packets if considered. One packet is sent to each UE location, and information such as the required transmission duration for each transmission option is calculated, (based on the SIR at that location).

For our estimation of throughput, the details of the data source are not important.

2.11 Packet Scheduling

It is assumed that the packet transmission duration (including re-transmissions) is determined by the selected transmission scheme (i.e. modulation, channel coding rate, number of spreading codes and possibly spreading factor, together with the local SIR. Each packet is sent in using the whole of the available HSDPA resource, bearing in mind that the system may be code or power limited for that particular packet.

Other approaches to scheduling could be considered, for example, sending packets in parallel in the time domain using different channelisation codes. The delivery time for a packet would be increased, but (ignoring any differences in scheduling efficiency) the total throughput should be similar.

In our estimation of system throughput, the delays due to packet scheduling are not considered. Therefore the transmission order of packets (and any re-transmissions) is not important, except for the assumption that any re-transmissions experience the same channel conditions as the first transmission.

This model of scheduling also assumes that there are no constraints due to downlink frame structure when mapping the transport blocks to the channel. The transport block size is assumed to be the same as the packet size. The TTI is assumed to be determined by the selected transmission scheme. As examples, for the currently considered transmission schemes for an 8000 bit packet the TTI would be from 100ms (QPSK, 1/3 rate coding and SF=32) to 0.741ms (64-QAM, ¾ rate coding and 20 codes with SF=32). In practice there is likely to be some loss in throughput due to the use of a fixed frame structure.

The fairness of the scheduler should be discussed. Two types can be considered.

?? **Fair Scheduling**: All packets are transmitted. The disadvantage is that significant radio resources may be required to deliver packets over channels where the SIR is poor.

?? **Unfair Scheduling**: Packets to be transmitted over channels with poor SIR can be delayed, but to improve throughput, some packets must be rejected (i.e. discarded and never transmitted). The degree of unfairness could be defined in terms of the fraction of packets which are rejected.

Although in practice the scheduling should be based on the estimated SIR, we can obtain an indication of the possible benefit from using unfair scheduling by rejecting those packets with the longest transmission times from the calculation of throughput. Note that such a procedure does not consider any effect on delay.

The use of an unfair scheduler can be considered as a form of admission control, in that mobiles with poor radio links will not be sent any data packets.

In the analysis presented here it is assumed that the service is offered in such a way that the required QoS is maintained across a coverage area which covers a substantial part of the cell. If it were acceptable to offer a service in only part of a cell, then further improvements in throughput might be achieved. However, it is not clear that this would be satisfactory to users.

3 Simulation Results

The results presented here were obtained under the basic assumptions in section 2, with modulation schemes up to 64QAM, ARQ option B (soft combining), fair scheduler etc. One simulation run was carried out with 500 UE locations and 1 packet sent to each location. Unless otherwise stated the same set of pseudo-random values for shadowing, fast fading and SIR estimation error are used in each case.

3.1 Base Station Selection

Figure 3 shows the number of the base station site selected as a function of the distance from the serving cell. The base station numbering is as shown in Figure 1. Not surprisingly, site 0 (serving cell) is always selected for locations less than about 0.6 of the nominal cell radius. Over the whole simulation the probability of the UE selecting a different cell is about 0.254.

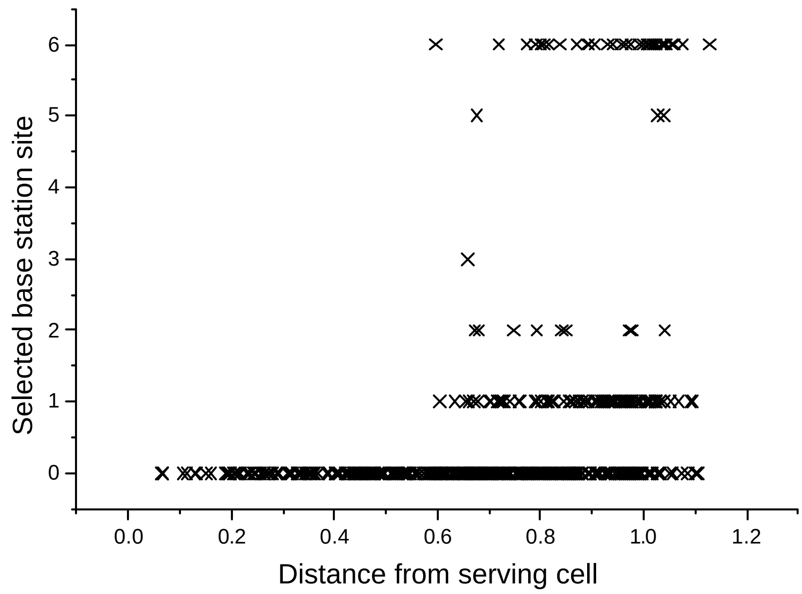

Figure 3 Selected base station site as a function of distance from serving cell

The same data is plotted in histogram form in Figure 4, where we can see that the alternative sites 2 and 6 are selected most often. This is to be expected as these sites are closest to the sector containing the UE locations considered for the throughput calculations.

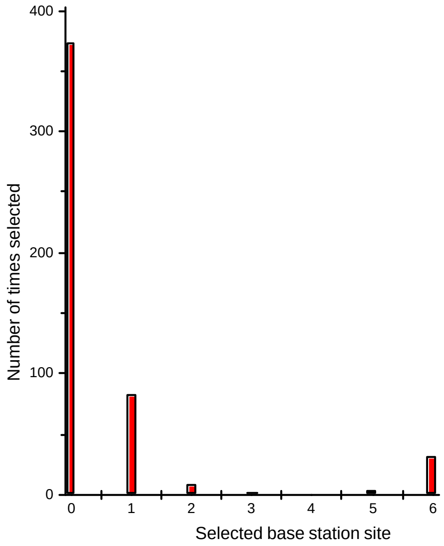

Figure 4 Histogram of selected base station site

Figure 5 shows the relationship between SIR and distance from the serving cell. Deviations from a smooth curve are largely due to shadowing.

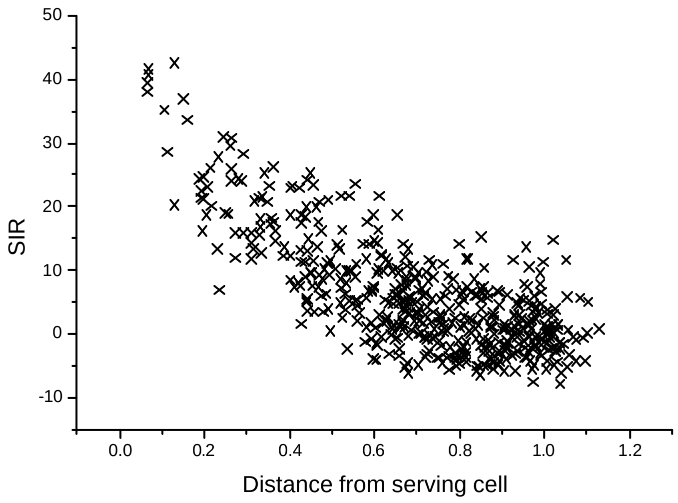

Figure 5 Scatter diagram of SIR vs distance

Figure 6 shows a histogram of SIR values, with typical values between -5 and 20dB, with a peak at around 0dB

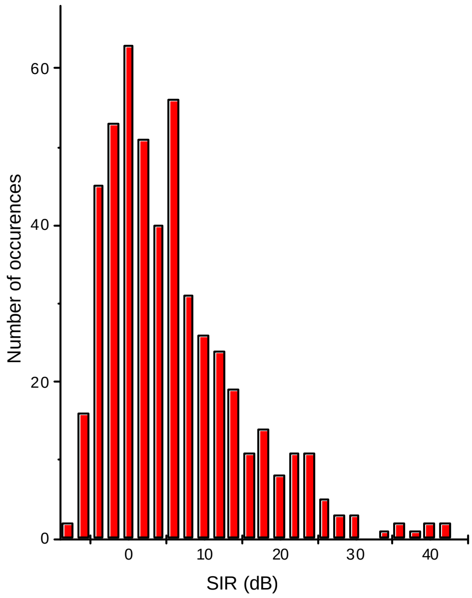

Figure 6 Histogram of SIR per packet

SIR estimation errors have been included in the simulation (standard deviation 1dB). The scatter diagram in Figure 7 shows the estimated SIR vs the true SIR..

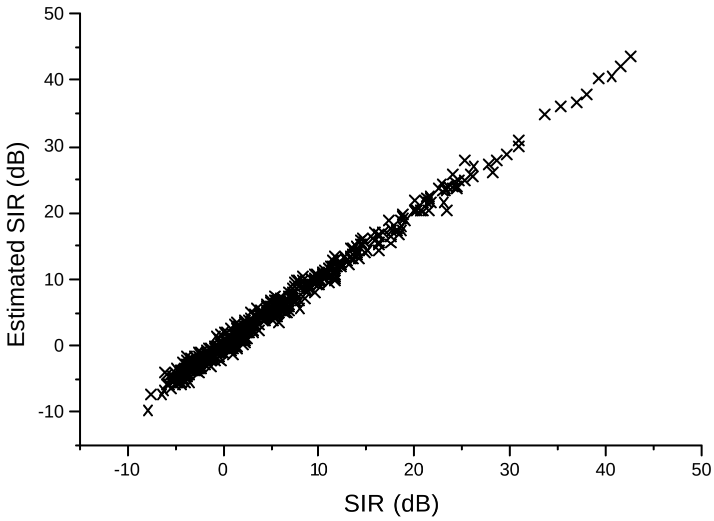

Figure 7 Scatter diagram of estimated SIR vs true SIR

The selection of the transmission scheme is made to minimise the expected transmission duration for the packets, 8000 user bits in this case, (including re-transmissions). This is done based on the estimated SIR and the selected scheme is shown as a function of SIR in Figure 8.

Schemes below about 6 are not used. These correspond to 10 or fewer spreading codes, and the SIR is unlikely to be low enough to require this amount of processing gain.

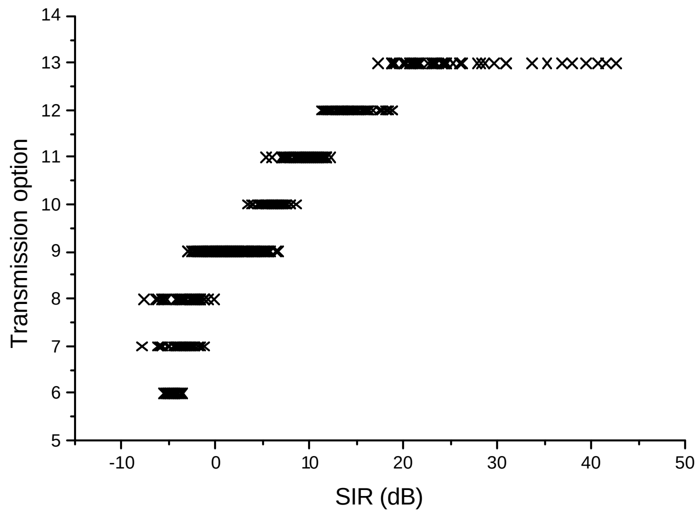

Figure 8 Selected transmission scheme vs SIR

Figure 9 shows a histogram of the use of each modulation scheme (per packet). It can be seen that QPSK with 20 spreading codes and ½ rate coding (scheme 9)is chosen frequently most frequently. This is consistent with the peak of the distribution in Figure 6 at about 0dB SIR, which, from inspection of Figure 8, would typically result in selection of scheme 9

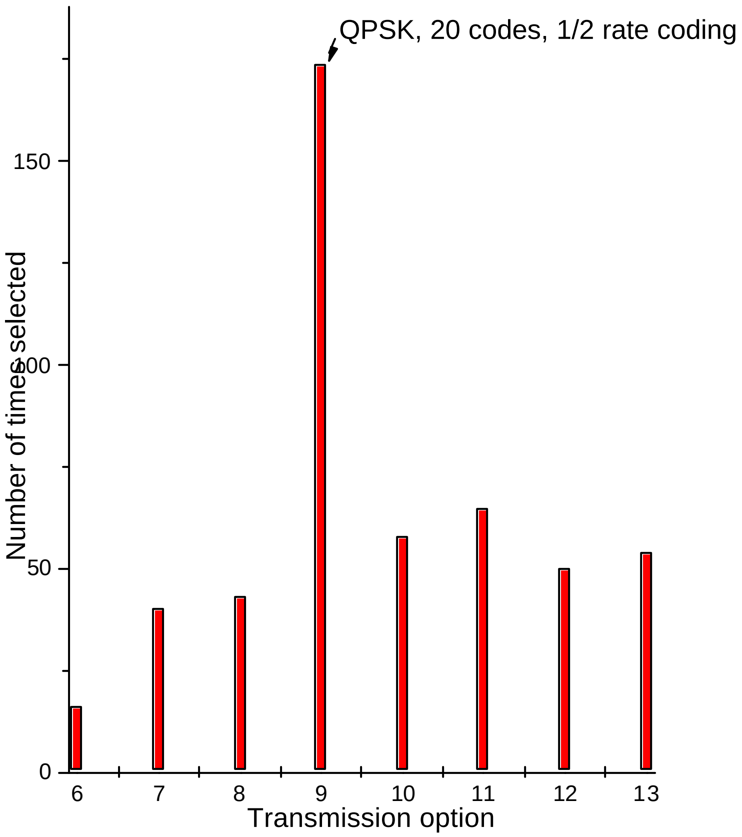

Figure 9 Histogram of use of transmission schemes

3.2 Packet Transmission Time

The expectation value of transmission time for each packet is calculated from the true SIR. This is shown as a function of SIR in Figure 10. It can be seen that the transmission time is strongly quantised to be a multiple of the duration a single transmission. This is because the packet failure rate vs SIR curve is very steep. This means that for any given SIR, the packet is almost certain to fail until the accumulated received energy (after combining re-transmissions) is sufficient to decode the packet, in which case the probability of success is then almost 100%. Furthermore it can be seen that more then two transmissions is a rare event.

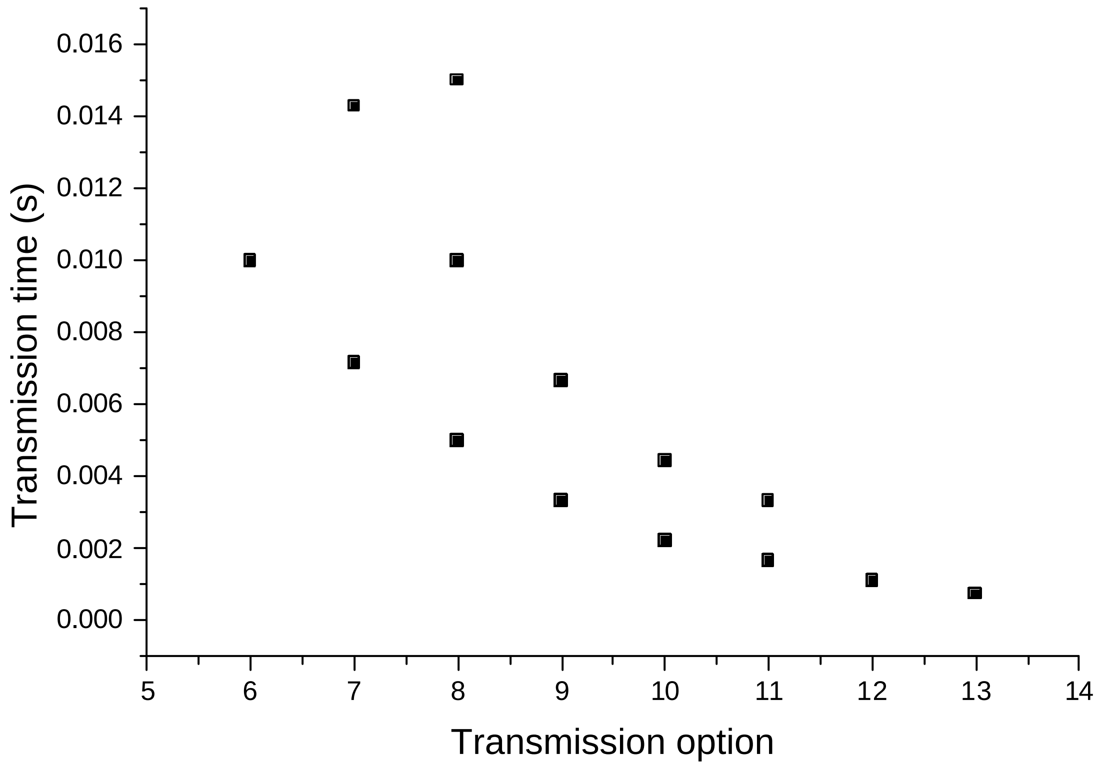

Figure 10 Scatter diagram of packet transmission time as function of transmission option

The average number of re-transmissions per packet is 0.11.

A histogram of packet transmission times is given in
Figure **11**. Again, the peak corresponds to transmission option 9, with a duration of about 0.0045s but almost half the packets take less time than that to send.

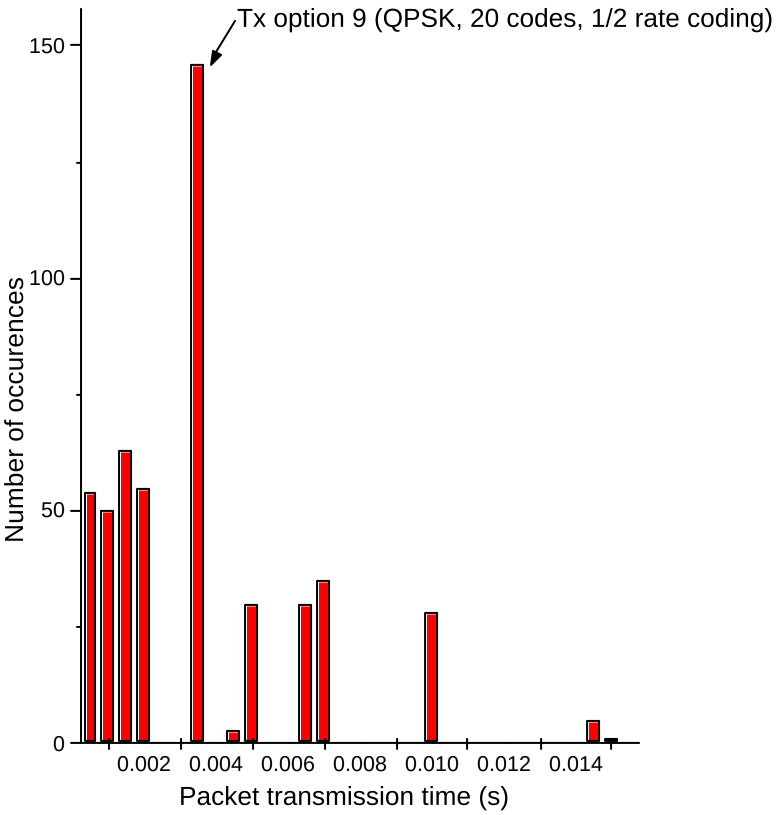

Figure 11 Histogram of packet transmission times

However, the use of downlink capacity is proportional to the product of transmission time and the number of times the transmission time occurs. This total transmission time for each packet transmission time is shown in Figure 12. This is the same data as shown in Figure 11, but weighted to reflect the true impact on downlink throughput. Now it is apparent that the throughput is dominated by packets with transmission times longer than 0.004s, which correspond to transmission options with a code rate of less than ½ and fewer than 20 spreading codes.

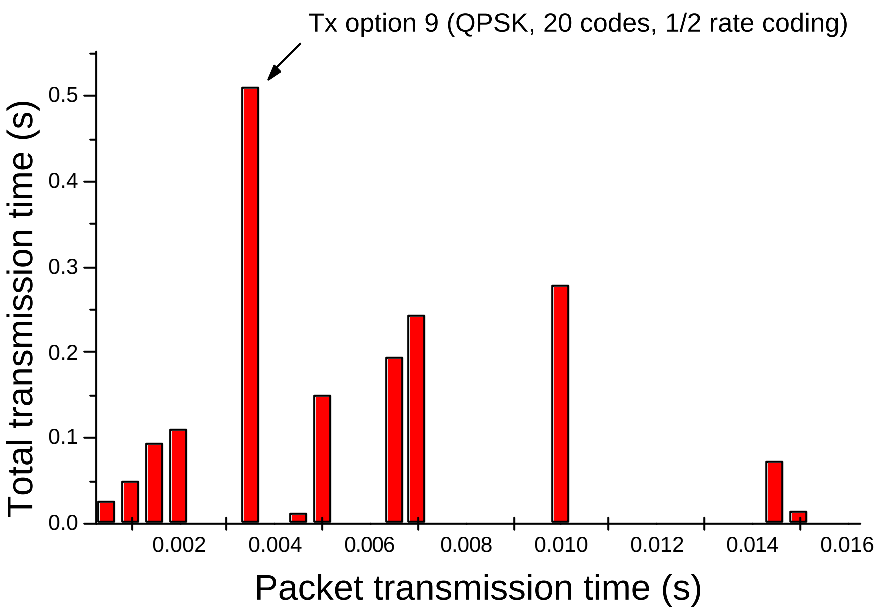

Figure 12 Total transmission time for each packet transmission time

The total throughput (corresponding to the data in Figure 12) is 2.2Mbps per carrier per cell.

Summary of Throughput Results

We take as a reference condition the basic assumptions in section 2, with modulation schemes up to 64QAM, ARQ option B (soft combining), fair scheduler etc. In this the total throughput is 2.23Mbps. From simulation results with different parameters we can calculate the relative effect on throughput of various features. These results are shown in Table 2

Feature	**Change in throughput (relative to reference condition)**
No site selection	-67%
16-QAM and QPSK only	-1%
QPSK only	-9%
QPSK only (with Tx power optimised according to Annex)	-4%
Unfair scheduler (5% packets rejected)	+13%
SIR estimation error increased from 1dB to 2dB rms	-13%
Improved ARQ (option C)	+10%
Improved ARQ (option D)	+19%

Table 2 Summary of results for cellular scenario

Note that for ARQ options C and D the average number of re-transmissions per packet was 0.72 1.19 respectively.

Conclusions

Considering the results presented above, we can draw the following conclusions for HSPDA applied to the cellular deployment scenario used as a reference:

(1) The use of 64QAM does not increase the throughput significantly
(2) The use of 16QAM offers some performance improvement compared with QPSK only (9%)
(3) If only QPSK is used then, the throughput can be improved by reducing the transmission power when full power is not required. The advantage of 16QAM is reduced to 5% throughput.
(4) The use of an unfair scheduler which rejects packets requiring a long transmission time can improve the thoughput significantly (up to 13% by rejecting 5% of packets)
(5) Performance is sensitive to the estimation error of the SIR.
(6) Improving the ARQ scheme may give 10-20% more throughput, but at the cost of more re-transmissions.
(7) Site selection is essential.
(8) For the ARQ algorithm used as the reference (Scheme B), the probability of failure of the first transmission is around 10%.

The following topics need more study:-

(1) Definition of service requirements (e.g. coverage)
(2) Simulation parameters suitable for indoor environments.
(3) Performance indoors, e.g. Possible benefit of high order modulations
(4) Practical link level performance of higher order modulations with realistic implementation
(5) Rate of site selection
(6) Optimisation of ARQ algorithm
(7) The accuracy with which the correct transmission scheme can be selected.

Although outside the scope of this document, comparison with results obtained for moving terminals would be desirable.

Annex A: Optimised transmission with QPSK

One important question raised in connection with HSPDA is the extent of the performance benefit obtained by use of high order modulation schemes.

Therefore some more detailed investigation of the performance obtained using only QPSK is worthwhile. Given the distribution of SIR's in a typical cellular deployment, it is apparent that when only QPSK is used, the transmission option giving fastest transmission will be selected very often. However, when the SIR is high the packet will not need to be transmitted with all the available power for successful first transmission. Therefore there will be a benefit in terms of interference to neighbouring cells if some lower power options are included, so that the transmit power can be reduced if the SIR allows.

Some simulations have been carried out with QPSK and combinations of code rate/spreading code and transmit power as follows:

Scheme	Modulation	Code rate	Number of spreading codes (SF=32)	Relative transmission power
1	QPSK	1/3	1	1
2	QPSK	1/3	2	1
3	QPSK	1/3	3	1
4	QPSK	1/3	5	1
5	QPSK	1/3	7	1
6	QPSK	1/3	10	1
7	QPSK	1/3	14	1
8	QPSK	1/3	20	1
9	QPSK	½	20	1
10	QPSK	¾	20	1
11	QPSK	¾	20	0.7
12	QPSK	¾	20	0.5
13	QPSK	¾	20	0.35
14	QPSK	¾	20	0.25
15	QPSK	¾	20	0.175
16	QPSK	¾	20	0.125
17	QPSK	¾	20	0.0875

Table 3 Transmission options for QPSK only, and optimised Tx power

To set a suitable interference level, in the adjacent cells the average fraction of the maximum power available for HSDPA which was actually used was set to 0.75 (i.e. 0.6 of the maximum total base station output). Under this condition the average fraction of the maximum power for HSDPA used in the central (serving) cell came to 0.77 for the current simulation.

The throughput per cell for this scenario is 2.14Mcps with a fair scheduler and 2.33Mbps with an unfair scheduler (rejecting 5% of packets)

Annex B: Cell selection

In order to study the impact of cell selection, some simulations were carried out where the selection of the serving cell (in the centre of the cell pattern in Figure 1) was forced, irrespective of the SIR.

In this case the throughput is 0.73Mbps

This result clearly shows the benefit of cell selection but does not give any indication of how fast it needs to be.

If site selection is driven mainly by changes in shadowing, then the typical timescale for this fading process depends on the channel model and terminal speed. The time needed for a terminal to travel a correlation distance of 50m will be of the order of 0.35 second for a terminal moving at (an extreme!) 500km/h. If site selection is to be ten time faster than this, then a site update every 35ms (i.e. about 3 or 4 of the current 10ms frames) would be required. This is within the capability of the current SSDT scheme.