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SYSTEM LEVEL DESIGN CONSIDERATIONS FOR HSUPA USER EQUIPMENT

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ABSTRACT

Within Release 6 of the 3GPP standards, one of the most important features is High Speed Uplink Packet Access (HSUPA) or enhanced DCH (E-DCH), which is the uplink counterpart for High Speed Downlink Packet Access (HSDPA). Most notable improvements, when compared to the R99 specification, are the achievable peak data rate of 5.76 Mbps, reduced latency due to a shortened transmission time interval and increased uplink cell throughput. This has been achieved by the use of multi-code transmission on the uplink, together with an improved forward error correction scheme including the use of hybrid automatic repeat request operating between the UE and the nodeB and a tighter (nodeB based) control of the uplink resources.

In this paper, system level design considerations are derived which point out the design problems one faces when designing a HSUPA compliant UE. First, the HSUPA system is explained, then the receiver is analysed in more detail and finally, considerations for the RF transmitter block are shown.

1. INTRODUCTION

High Speed Uplink Packet Access (HSUPA), or enhanced DCH (E-DCH) as it is referred to within the 3GPP specifications, is the most recent extension of the 3GPP set of physical layer specifications [1]-[4]. It extends the R99 uplink channels to reach higher peak data rates (up to 5.76Mbps), higher overall uplink throughput and lower packet latency. This is achieved by employing an HSDPA like forward error correction scheme including hybrid automatic repeat request (ARQ) with the use of multi-codes, shorter transmission time intervals (TTI) and the use of spreading factor 2 (SF2). Additionally, the control of the uplink resources has been moved from the radio network controller (RNC) based system to a nodeB based system, which allows a closer control and better utilisation of the available uplink bandwidth among the UEs.

2. HSUPA SYSTEM

The HSUPA extensions are implemented as an add-on to the previously standardised R99 uplink channels (DPDCH and DPCCH) and R5 uplink channel (HS-DPCCH). The improvements of the uplink channels have been achieved by changing the forward error correction scheme and by employing a tighter (nodeB based) control of the uplink transmissions. Therefore, two new uplink channels have been defined (E-DPCCH and E-DPDCH) to convey control and data information from the UE to the nodeB and three new downlink channels (absolute grant channel (E-AGCH), relative grant channel (E-RGCH) and ARQ indicator channel (E-HICH)) have been added to transmit control information from the nodeB to the UE.

The forward error correction scheme is similar to the scheme used by HSDPA. It uses a TTI of 2 msec or 10 msec employing hybrid ARQ (HARQ) to reduce the required SNR at the nodeB and thereby also reduces the created uplink interference. To implement a reliable HARQ, the E-DPCCH carries as control information the transport format indicator and the retransmission sequence number. By doing so, synchronisation of the UE and the nodeB is ensured even if the uplink reception has been corrupted during a particular HARQ process. On the downlink, the E-HICH carries the acknowledgement field informing the UE whether an uplink packet has been received error free.

The closer control of the uplink resource is implemented by a granting scheme, whereby the serving cell issues a grant (maximum E-DPDCH to DPCCH power ratio) to the UE. The grant gives the UE a right to transmit a certain uplink data rate and thereby contribute a given uplink interference. The grant is conveyed from the nodeB to the UE via the absolute grant channel (E-AGCH) or the relative grant channel (E-RGCH). To issue the correct grant, the control algorithm needs to know how much data is awaiting transmission in the UE (i.e. the status of the RLC buffers). This is conveyed coarsely via the 'happy bit' on the E-DPCCH or more detailed via scheduling information that is embedded in the MAC-es payload carried on the E-DPDCH.

Figure 1 depicts the communication channels that exist between the UE and the terrestrial access network for a three way soft handover situation. On the left, the involved cells are shown, where the top cell has a distinct function and is termed the 'serving cell'. This cell is the main communication peer and contains the grant issuing algorithm. Note that the serving cell can be paired with a non-serving cell to form a radio link set and then the E-RGCH and E-HICH channels from both cells convey the same information.

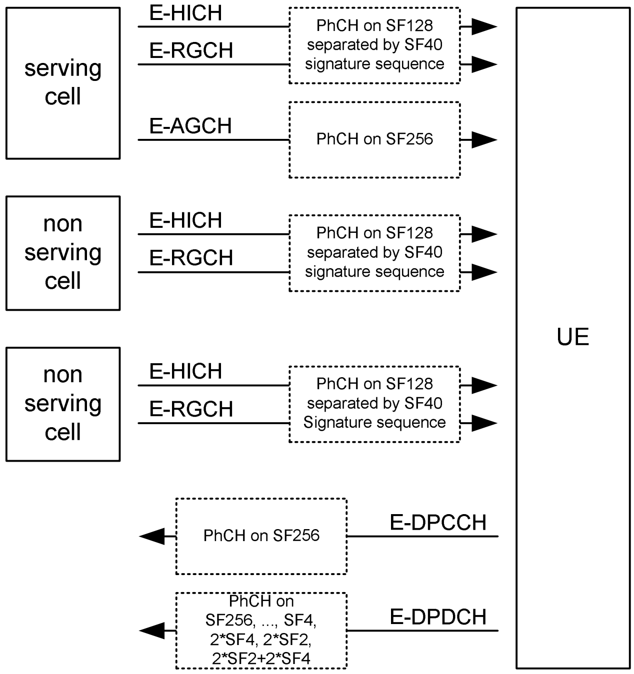

Figure 1: HSUPA Specific Physical Channels

The UE emits its uplink transmission (E-DPCCH and E-DPDCH) and each cell tries to receive it. On successful reception, the cells send an acknowledgement on their E-HICH channels to the UE. Whenever the UE receives an acknowledgement from any cell, it assumes the packet to be received correctly by the network and initiates the transmission of a new packet. If no positive acknowledgement is received, then the UE initiates the retransmission of the same packet.

The serving cell issues grants to its UEs and thereby gives them the right to contribute a certain uplink power rise. The non-serving cells only have the right to reduce the current grants of the UEs if they cause too much interference on their uplinks. To achieve this, they can send 'down' commands via their E-RGCH channels. Each UE reduces its grant whenever it receives a 'down' command from any cell involved; otherwise it follows the grant given by its serving cell.

3. FEC PERFORMANCE

As mentioned earlier, the FEC for the HSUPA system is similar to the FEC used by the HSDPA system [2].

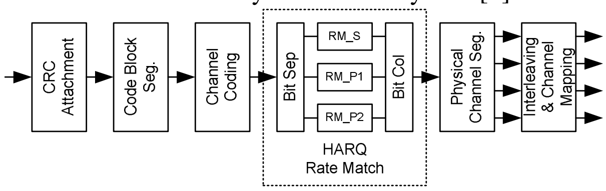

Figure 2: HSUPA Encoding Chain (UE)

Figure 2 shows the encoding chain for the E-DPDCH as given by [2]. When compared to the HSDPA encoding chain, the first rate matching stage has been removed because the memory requirements in the network for the incremental redundancy buffers are not considered an issue.

Another differentiator with respect to HSDPA is that typically repetition is used for the rate matching instead of puncturing. This is caused by the fact that on the uplink every UE uses its own scrambling code and therefore the whole code tree is available. This is also reflected in the spreading factor selection algorithm [2], where a lower spreading factor or more number of codes is chosen if puncturing would be required instead of using puncturing. If neither lower spreading factor nor more number of codes are available, then puncturing is employed (depending on the signalled value $PL_{non\text{-}max}$).

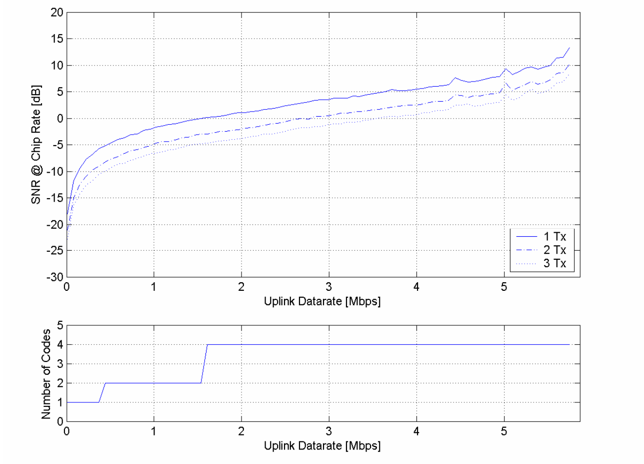

Figure 3: FEC Performance, BLER=1%, Chase Combining

Figure 3 shows the required SNR ($E_C^{E-DPDCH}/N$) at chip level to receive the data packets for a block error rate (BLER) of 1% assuming an AWGN channel. The simulation uses a TTI of 2 msec with varying transport block sizes from 16 bits to 11484 bits which are reflected in the different data rates. The three lines denote the required SNR for different numbers of retransmissions. The simulations employed Chase combining and one can see the combining gain of 3 dB between one transmission and two transmissions, and of 4.8 dB between one transmission and three transmissions. The number of multicodes selected by the spreading factor selection is shown at the bottom of the figure. Note that 80% and 33% have been assumed for $PL_{non\text{-}max}$ and PL_{max}, respectively.

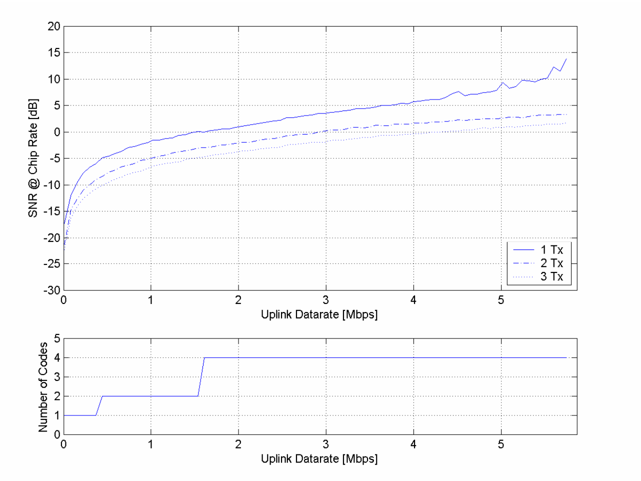

Figure 4: FEC Performance, BLER=1%, Incremental Redundancy

Figure 4 shows the performance of the forward error correction module for the same set-up but using incremental redundancy as defined in [2]. One can see the gain in required SNR that can be achieved by using incremental redundancy instead of Chase combining especially for high data rate transmissions. For lower data rates, hardly any difference is visible between the two options since here repetition coding is used instead of puncturing as explained earlier.

4. RECEIVER REQUIREMENTS

The main increase in requirements on the UEs receiver is the additional channels that are transmitted by the cells (E-AGCH, E-RGCH and E-HICH), c.f. Figure 1. The E-AGCH is protected by convolutional coding and transmitted on an SF256 channelisation code and therefore the requirements on the RF front-end do not increase when compared to the requirements imposed by the R99 and R5 downlink channels. The E-RGCH and E-HICH are transmitted on an SF128 channelisation code but additional protection is provided by the signature spreading (spreading factor 40) and the repetition for at least 3 slots. Therefore, these channels do not increase the RF requirements also.

In terms of computational complexity, the loading on the receiver is slightly increased since all these channels are low data rate. One complication is that the E-RGCH and the E-HICH use a ternary modulation (UP/HOLD/DOWN and ACK/DTX/NACK, respectively) which needs to be decoded but no reference power level is known at the UE to set the decoding threshold.

One increase in complexity stems from the fact that the MAC-e/es has an increased computational complexity when compared to the MAC-d and has to be performed under strict turn-around times which makes an interesting real-time implementation challenge.

5. ANALOG FRONTEND REQUIREMENTS

In this section, the requirements on the analogue front-end caused by the HSUPA transmission are explored. Therefore, Section 5.1 explores the required Error Vector Magnitude (EVM) of the transmitter chain to ensure an acceptable implementation loss. Section 5.2 derives the increase in peak-to-average power ratio the power amplifier has to cope with.

5.1 Error Vector Magnitude

EVM is a commonly used quantity to also describe the performance of a transmitter or receiver chain. It is derived from the signal-to-noise ratio measured on a constellation and the relation is given as:

$$SNR = -20 \cdot \log_{10}\left(EVM\right) \qquad (1)$$

where SNR is the resulting signal-to-noise ratio in dB. The quantity of EVM is typically given as a percentage and is required to be at least 17.5% in the Release 5 specifications [6] for the uplink transmission. Note that this corresponds to an SNR of 15.1 dB on the constellation.

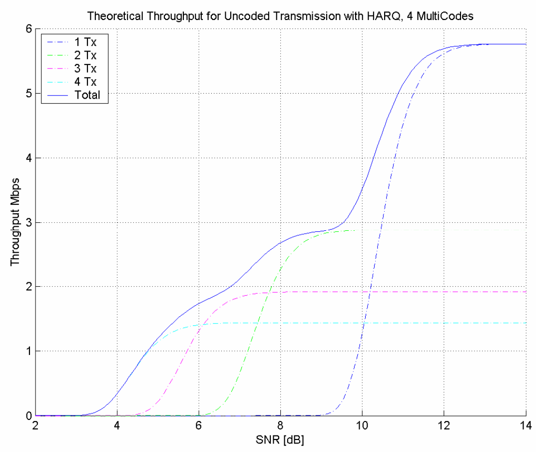

Figure 5: Uncoded Transmission Performance with HARQ

To derive the required EVM, one has to look at the most demanding transmission scenario, which is, in the case of HSUPA, the peak data rate of 5.76 Mbps with hardly any forward error correction. Here, a 2 msec TTI and 2*SF2+2*SF4 BPSK modulated codes are used. This results in 11520 bits to be transmitted over the air every TTI. Note that the largest transport block size possible for a 2 msec TTI is 11484 [8] and therefore, the worst case coding rate is given as

$$R = \frac{TBS + CRC}{PHY} = \frac{11484 + 24}{11520} = 99.9\% \qquad (2)$$

where CRC denotes the number of bits used for cyclic redundancy check and PHY denotes the number of bits conveyed on the air interface. Based on this coding rate, one can see that in the worst case, almost no error protection is available to the E-DPDCH and therefore one can use the required SNR for an uncoded system.

Figure 5 shows the throughput that is achieved by an uncoded HSUPA transmission of 11520 bits through an AWGN channel for varying SNR. The blue dashed line hereby shows the performance that is expected for a single transmission of every transport block. Note that the probability of a block error P_B is easily derived and is:

$$P_B = \left(1 - \left(1 - P_b\right)^{TBS}\right) \qquad (3)$$

where TBS is the transport block size (i.e. 11520) and P_b is the probability of bit error for BPSK which is dependent on the SNR [5]. This equation is derived based on the assumption that all bits within the transport block have to be received correctly for the transport block to be received correctly, and that the corrupting noise is uncorrelated between the individual bits.

The throughput T (for one transmission) is then given as:

$$T = \frac{TBS}{TTI} \cdot \left(1 - P_B\right) \tag{4}$$

where TTI is the transmission time interval (i.e. 2 msec). The green dashed line shows the expected throughput if every transport block was transmitted twice and therefore a 3 dB gain of required SNR can be observed, but the peak data rate drops by a factor of two.

In the real system, the HARQ algorithm would request a retransmission whenever a transport block has been received in error. The resulting throughput is then given by the solid blue line in Figure 5.

Based on the results shown in Figure 5 (and equally in Figure 3 and Figure 4), it can be seen that for a transmission of 5.76 Mbps across the HSUPA air interface, a SNR of 13 dB has to be achieved at the input to the forward error correction module. The corrupting noise should be the additive noise of the transmission channel and should not be dominated by the imperfections added by the transmitter and therefore, these imperfections should result in an SNR 10 dB or 20 dB better than the required SNR. This would result in an implementation loss of 0.41 dB or 0.04 dB, respectively. According to (1), this then results in a required EVM of 7.1%[1] or 2.2%[2], respectively. Note that this exceeds substantially the current requirement of 3GPP [1] which defines an EVM of 17.5%.

5.2 Peak to Average Power Ratio

Another issue HSUPA transmitters have to contend with is the increase in peak-to-average power ratio (PAPR) of the transmitted signal. A Release 6 compliant mobile needs to be able to transmit up to 7 channelisation codes in its uplink (1xDPCCH, 1xHS-DPCCH, 1xE-DPCCH and 4xE-DPDCH) which increases the required PAPR.

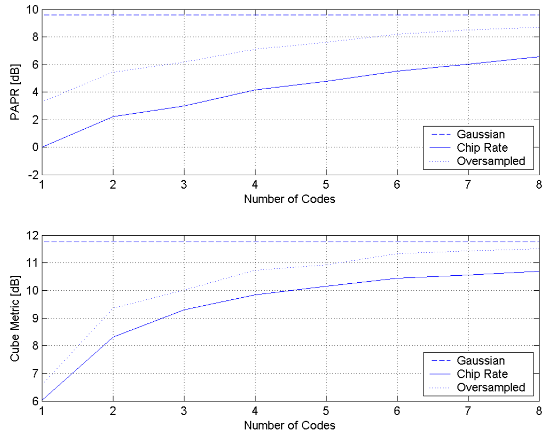

Figure 6: Peak-to-Average Ratio

Figure 6 shows the PAPR for a clipping probability of 10^{-4} and the cubic metric as proposed in [7] for a varying number of codes in the uplink signal. The solid line is the value obtained at chip rate, the dotted line is the value obtained after RRC pulse shaping at an oversampling rate of 8, and the dashed line is the Gaussian reference which serves as an upper bound. The values are obtained by simulation and equal powers of the constituent channels have been assumed. Closer investigation of the possible amplitude ratios show that this assumption yields the worst case PAPR. Typical selections of channel gains result in lower PAPR values. Note that the clipping probability of 10^{-4} has been chosen for a test and measurement mobile and a good trade-off has to be found to balance degradation caused by EVM and PAPR.

For one code, the uplink signal after scrambling is a QPSK signal and therefore the chip rate signal yields a PAPR of 0 dB and the oversampled signal has a PAPR of 3 dB. For the highest number of codes, the results already approach the values obtained by a Gaussian distribution. This is to be expected since the central limit theorem states that adding uncorrelated random processes always tend to a Gaussian distribution.

In essence, when the UE wants to transmit an HSUPA compliant uplink signal, it has to operate with a PAPR of about 9 dB which is equivalent to an increase by about 6dB over the current R99 specification.

6. CHALLENGES

Albeit the standardisation of the HSUPA system has been finalised recently and first test equipment for the testing as well as first products have appeared on the market, the whole operation and performance of the HSUPA system is still to be demonstrated. Especially the operation and performance of the granting scheme, where the scheduler in the serving cell hands-out grants to the UEs, and the UEs decide according to a E-TFC selection algorithm how much data to transmit, is still open to investigation and testing.

[1] This is calculated using (1) and assuming an SNR of 23dB (13dB required SNR and 10dB back-off)

[2] This is calculated using (1) and assuming an SNR of 33dB (13dB required SNR and 20dB back-off)

7. CONCLUSIONS

In this paper, first the recently standardised high speed uplink packet access is described. Then the forward error correction module for the data channels is analysed in more detail and requirements on the receiver for the downlink channels are analysed. Next the requirements on the analogue front-end for the transmit chain are derived.

Summarising, one can see that HSUPA does not increase the requirements on the analogue front-end for the receiver of the UE and does only marginally increase the computational load in a UE receiver. The main impact is on the analogue backend for the UEs transmitter, where a substantially better performance in terms of EVM and PAPR is required to carry the high data rates as standardised by 3GPP. The EVM limit has to decrease to between 2.2% and 7.1% depending in the acceptable implementation loss and the PAPR demands increase to 9dB.

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