White Paper

will'tek

HSDPA:
Measurement at terminals for the downlink data accelerator

boosting wireless efficiency

High Speed Packet Access, or HSPA in short, is the actual extension of the UMTS standard for WCDMA. Behind this abbreviation both standards HSDPA and HSUPA are hidden and D stands for Downlink, U for Uplink. The accelerator for data from the final device into the network is introduced step by step in 2008 and 2009. HSDPA has been retrofitted in many networks already and is available to users.

What does this supplement of the UMTS standard promise, actually? Does it have consequences on the measurements to be carried out on mobile phones and other UMTS terminals? HSDPA is meant as a supplement to the UMTS networks, because they would not work without the basic UMTS/WCDMA functionality.

With HSDPA, data rates of 1.8 and 3.6 Mbit/s are possible initially. Later they should be available at up to 10.8 Mbit/s in practice. This maximum usable data rate is dependent on the category of the respective terminal, that means from the type of receiver. The receiver architecture currently used in terminals (rake receiver) limits HSDPA data rates in first-generation devices to a maximum of 3.6 Mbit/s. In order to achieve higher data rates, the wireless devices need a new receiver architecture which is, however, still in the optimisation phase (Figure 1). In 2008, available devices are able only to process up to five so-called HS-PDSCHs[1]. The HS-PDSCH is a new physical code channel which is used to transport data to the devices. Up to 15 of these channels are available and can be made available to several or even only one device. This

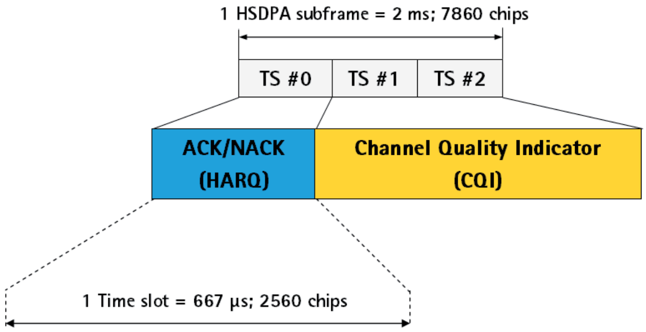

Figure 2: HS-DPCCH frame structure

is depending on different parameters, e.g. how the device has valued the quality of the radio channel.

A new uplink code channel

This "quality feedback" occurs on a new uplink code channel, the High Speed Dedicated Physical Control Channel (HS-DPCCH). This channel transmits the Channel Quality Indicator (CQI) which can take on one of 30 values characterising the transmission channel. Based on these indicators, the base station (Node B) can determine a suitable format to send the next bunch of data to the mobile device. The Node B selects parameters such as the number of HS-PDSCHs assigned to the device (maximum is five at present, but there will be 15 later on), or which modulation format can be used. The base station, however, is not bound to this feedback. One of the most important changes that HSDPA introduced in the 3G network architecture, is that the base station, not the Radio Network Controller (RNC) is responsible for repeatedly sending wrongly received data packets. In addition to sending the CQIs, the HS-DPCCH is used to transmit the base station response indicating if the data packet sent has been received correctly (Acknowledge) or incorrectly (Non-Acknowledge). The structure of the HS-DPCCH is shown in Figure 2.

These two tasks show how important this new uplink code channel is, and therefore all device measurements refer to it. As shown in the figure, the HSDPA time frame length has been reduced to 2 ms while standard WCDMA is using a 10 ms cycle.

[1] HS-PDSCH – High Speed Physical Downlink Shared Channel

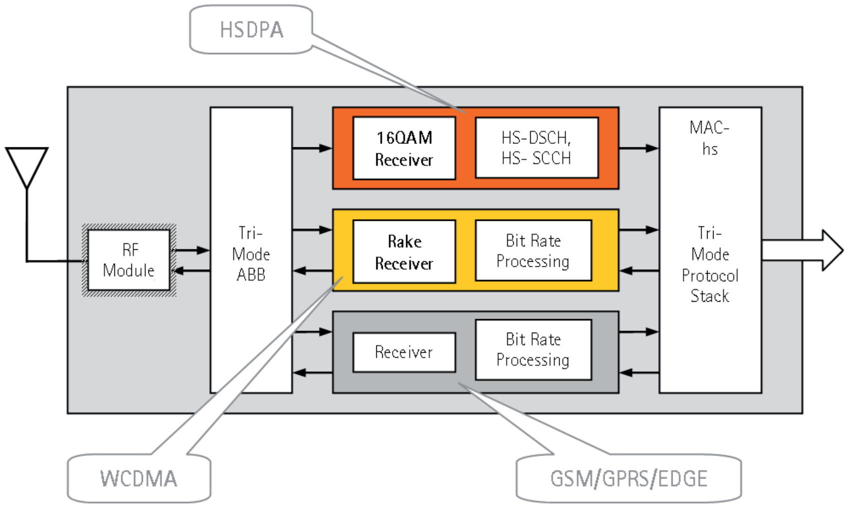

Figure 1: New receiver architecture in mobile devices required

More innovations, extended timing on the air interface

New and complex signalling algorithms have been implemented that are necessary to set up a connection. In addition, a trigger event tuned to the HS-DPCCH must be integrated with the test system. Compared to the timing defined for UTRA FDD in 3GPP Release 99/4, the two most important downlink channels – P-CPICH und P-CCPCH – are transmitted in synchronisation with the WCDMA time frame (10 ms duration). This time frame consists of 15 time slots of 667 µs each. With a defined chip rate of 3.84 Mcps each slot includes 2560 chips. Both synchronisation channels P-SCH und S-SCH are synchronised with the edges of these time slots.

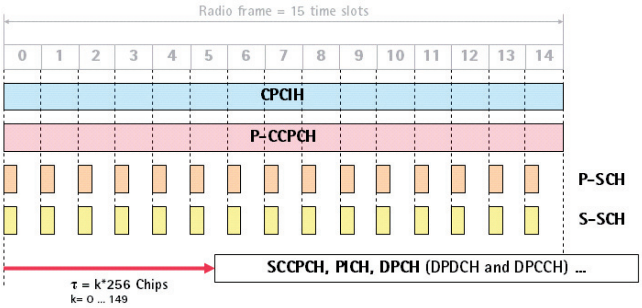

Figure 3: Timing on the WCDMA air interface (3GPP Rel. 99/4)

As shown in Figure 3, all other code channels such as the DPCH[2] can be transmitted with a defined offset. This offset is in the range between 0 and 38,144 chips, or between 0 and 9934 µs. Test sets typically allow to adjust the offset to allow the timing of the terminal under test to be examined.

These considerations were necessary to understand how the DPCH offset affects the HSDPA measurements. The start of the HS-DPCCH and therefore the trigger event are coupled with the transmission of HS-PDSCH(s). The HS-DPCCH is sent in a defined time difference from the HS-PDSCH. This is necessary to allow the mobile phone or data card some time for analysing and processing the received the data. There are almost 500 ms – or 7.5 time slots – until the device reacts on the data channel(s) assigned.

The HS-PDSCH used to transmit the data packets, in turn starts two time slots after the HS-SCCH (High Speed Shared Control Channel, compare Figure 4). This code channel was introduced with 3GPP Release 5; it is used to inform the wireless device in the downlink of the number of data channels used to transmit the data packets, and how the channels are modulated. This information is sent in the very first HS-SCCH time slot. The other two time slots contain additional information required by the device to correctly analyse the data channel. Depending on the CQI value delivered back, the modulation scheme may be either QPSK or 16QAM. 16QAM, however, requires a fairly good transmission path, i.e. a good signal to noise ratio. It is important to note that the HS-SCCH is transmitted in synchronisation with the P-CCPCH and therefore also in sync with a WCDMA time frame. As a side note, the information channels HS-SCCH and HS-DPCCH are always QPSK-modulated even if the data transport channel HS-PDSCH is 16QAM-modulated.

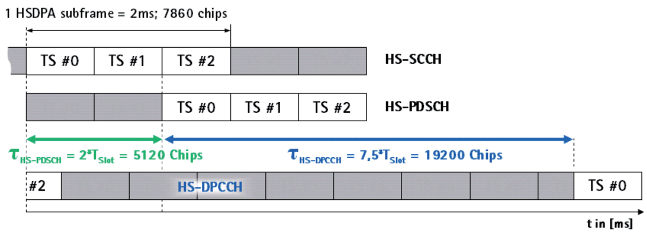

Figure 4: Timing in the downlink relative to the HS-DPCCH

Figure 5 shows the complete HSDPA timing on the air interface as introduced with the new code channels and algorithms. So the downlink DPCH (DL DPCH) can be transmitted with an offset. The DL DPCH data reach the the wireless device with a certain delay that depends on the environment (multipath fading). The device now responds to the information and data contained in the DPCH, and sets a defined offset of 1024 chips, i.e. about 267 µs. This offset is the DL-UL difference. Depending on the start of the DL DPCH the HS-PDSCH obtains a resulting offset from the HS-PDSCH called TTX difference. This is marked in red in Figure 5.

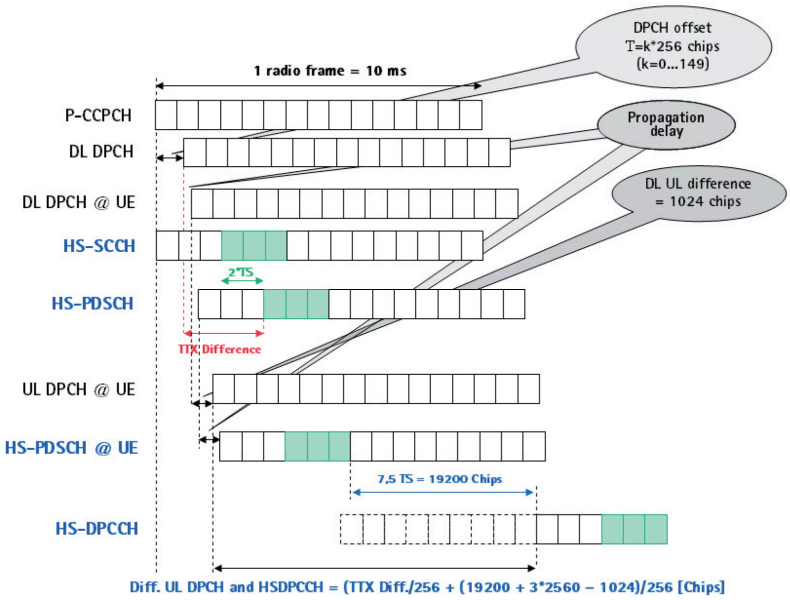

Figure 5: HSDPA timing

2 As the downlink is operated in time multiplex, the DPDCH (dedicated data channel to a UE) and the DPCCH (dedicated signalling channel to a UE) are jointly referred to as the DPCH in this paper.

As the start of the HS-DPCCH depends on the start of the HS-PDSCH, the TTX Difference affects it directly. This means that the HS-DPCCH is running behind the UL DPCH, i.e. the associated DPCCH and DPDCH, by a defined value that can be derived from the TTX difference and therefore from the DPCH offset. All the transmitter measurements that have been modified by 3GPP with Release 5[3] for HSDPA, are associated with the trigger event relating to the start of the HS-DPCCH. These transmitter measurements are as follows:

- Maximum output power with the HS-DPCCH (TS 34.121, chapter 5.2A),
- Adjacent channel power (ACLR[4]; TS 34.121, chapter 5.10A),
- Spectrum emission mask (SEM[5]; TS 34.121, chapter 5.9A),
- Modulation error (EVM[6]; TS 34.121., chapter 5.13.1A).
- HS-DPCCH power control (TS 34.121, chapter 5.7A)

The receiver measurements relate to reception and processing of HS-(P)DSCH and HS-SCCH.

- HS-DSCH demodulation (TS 34.121, chapter 9.2.1),
- HS-SCCH detection performance (TS 34.121, chapter 9.4.).

In addition to these defined and mandatory measurements, there are additional tests for a more detailed analysis of the mobile phone or data card under test. More information on these tests is given below.

Power spectrum, spectrum emission mask

With the introduction of the new HS-DPCCH code channel in the uplink, power transients are more likely to occur. This phenomenon rather appears when the HS-DPCCH does not start with the time slot for the UL DPCH as is most usually the case. In addition, the uplink uses I/Q multiplex i.e. the signalling channel (DPCCH) is mapped onto the Q path while the data channel (DPDCH) is mapped onto the I path. With more than one data channel being sent, all data channels are set to a spreading factor (SF) of 4. This way, up to six DPDCHs can be sent in the uplink. This process is called multicode, but it has not yet found its way into real products. Depending on the number of DPDCHs, the HS-DPCCH is multiplexed onto either the I or the Q path. The spreading factor for the HS-DPCCH is 256, as is that for the UL DPCCH; the code number being used varies depending on the multiplexing (see table in Figure 6).

Figure 6 shows a block diagram for generating the HSDPA uplink signal. The figure highlights the case where one data channel (DPDCH) is used. In this case, the HS-DPCCH is multiplexed onto the Q path. This is the general case for WCDMA measurements and now also for HSDPA measurements. All measurements defined for WCDMA, both on the transmitter and the receiver, are based on so-called reference measurement channels (RMC). These channels define the configuration and the DPCCH to DPDCH power ratio, both in the downlink and the uplink. The most important channel is the RMC 12.2 kbps which is a simulated voice channel; this channel must be supported by any wireless WCDMA device. All the measurements relate to this RMC 12.2 kbps. As HSDPA is built up on the basic WCDMA functionality, the general connection setup uses this RMC. In other words: The RMC 12.2 kbps is necessary to establish an HSDPA connection between test instrument and mobile phone. In addition, the category of the device is important. The twelve available categories are described by six so-called Fixed Reference Channels Handset (FRC H-Set). These FRC H-Sets 1 through 6 provide information about the number of data channels that can be assigned to a wireless device, and which modulation scheme it supports (just QPSK or 16QAM in addition). So the connection setup is realised through an RMC 12.2 kbps and the FRC H-Set accord-

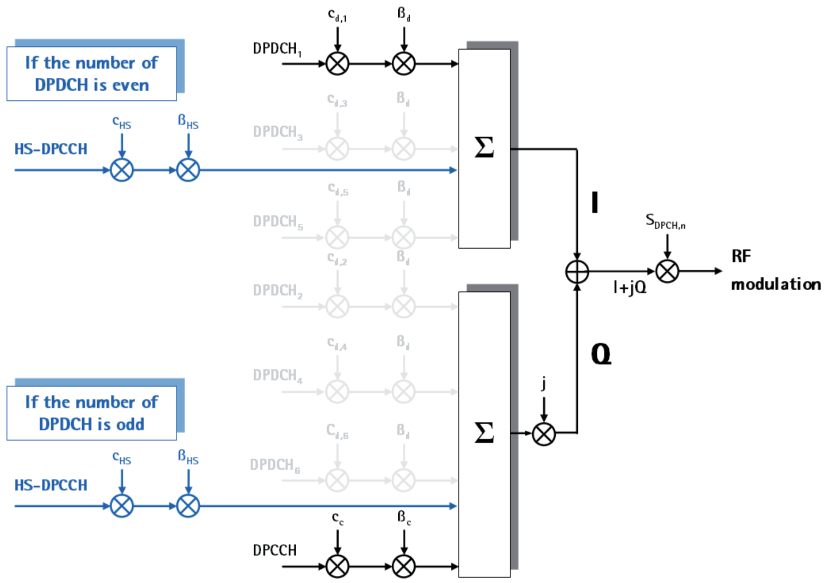

Figure 6: I/Q multiplex for the HS-DPCCH uplink

[3] See 3GPP Release 5 TS 34.121
[4] ACLR – Adjacent Channel Leakage Power Ratio
[5] SEM – Spectrum Emission Mask
[6] EVM – Error Vector Magnitude

ing to the category of the device. Before the channels can be assigned, the UE (user equipment) must have registered in the simulated, HSDPA-capable radio cell (Circuit Switch (CS) Attach) and set up a connection to the packet-switched part of the simulated network (Packet Domain (PS) Attach). As part of that, the device conveys its category (1-12) to the test instrument. In a normal network the base station is now informed which resources are available to the UE. With the test instrument a supported FRC H-Set can be selected and a data connection can be established. For reasons of simplicity the test specification defines all the measurements for FRC H-Set 1, which means that all the devices must be able to cope with this configuration.

Spreading is an important advantage of CDMA technology compared to the well-known FDMA/TDMA system GSM, and plays an important role for the measurements. Spreading to the defined chip rate of 3.84 Mcps is achieved through spreading codes, and effects a process gain in the receiver, which is a basic characteristic of CDMA systems. This process gain is a function of the spreading factor and can be calculated using the formula in Figure 7. The table provides an overview of the process gain that can be achieved when the adequate spreading factor is used.

$$E_{Chip} = \frac{E_b}{\text{Spreading Factor}}$$
$$= E_b - 10 * \log(\text{Spreading Factor})$$
$$\frac{E_{Chip}}{N_0} = \frac{E_b}{N_0} - 10 * \log(\text{Spreading Factor})$$
$$\text{processgain [dB]} = 10 * \log(\text{Spreading Factor})$$

Spreading Factor	Process gain
4	6 dB
8	9 dB
16	12 dB
32	15 dB
64	18 dB
128	21 dB
256	24 dB
512	27 dB

Figure 7: Process gain and spreading factor

The DPCCH is always spread with a factor of 256, code #0 as laid down in the specification. The RMC 12.2 kbps data channel (DPDCH), however, is always spread with a factor 64 using code #16. Spreading with these two different spreading factors effectively means that the signalling channel (DPCCH) can be transmitted with a power level of 6 dB lower than that of the data channel. The two channels are therefore weighted with power factors (β_c and β_d). This level ratio β_c/β_d between DPDCH and DPCCH is 8/15 for an RMC 12.2 kbps. Similar to DPCCH and DPDCH, the HS-DPCCH again is provided with a power factor (β_{HS}). As the HS-DPCCH only carries signalling information its weighing factor β_{HS} depends on the signalling information at hand ($\Delta_{HS\text{-}DPCCH}$). The factor effectively depends on whether an ACK/NACK or a CQI value is sent. Additionally the power level of the DPCCH (β_c) is important because the weighing factor for the HS-DPCCH is coupled to it. β_{HS} is calculated according to Formula 1 as follows:

$$\beta_{HS} = \beta_C * 10^{\left(\frac{\Delta_{HS-DPCCH}}{20}\right)}$$

Formula 1: Determining the weighing factor for the HS-DPCCH

Based on these definitions and explanations, the maximum output power including the HS-DPCCHs can be checked. Exceeding the maximum allowable transmit power (see Figure 8) could mean that a complete radio cell is blocked by a defective device. It comes at no surprise that with the introduction of the new uplink code channel the defined limits change as well. Depending on the power ratio of the standard uplink channels (DPCCH/DPDCH, ßc/ßd) which is adjustable, the maximum power and the upper and lower limit are reduced. The following table gives the details.

Ratio of β_c and β_d for all values of β_{HS}	Power class III		Power class IV	
β_c/β_d = 1/15, 12/15	+24 dBm	+1.7/-3.7 dB	+21 dBm	+2.7/-2.7 dB
β_c/β_d = 13/15, 15/8	+23 dBm	+2.7/-3.7 dB	+20 dBm	+3.7/-2.7 dB
β_c/β_d = 15/7, 15/0	+22 dBm	+3.7/-3.7 dB	+19 dBm	+4.7/-2.7 dB

Table 1: Changes in the power classes and limits

The specification defines four subtests with four preferred combinations of these parameters. The maximum power for these four combinations should be checked and must not exceed the new limit values.

As mentioned already, the wireless device may exceed the maximum allowable transmit power with the transmission of the ACK/NACK or CQI signalling information on the HS-DPCCH. This is more likely to occur when the start of the HS-DPCCH is not in sync with that of the DPCCH. This is the case when the DL DPCH is transmitted with an offset. The device then has to keep the power within the limits defined for its power class. The test specification stipulates a power vs. time measurement for this case (see 3GPP Release TS 34.121, chapter 5.7A) in which the output power of the device is determined at different points in time, averaged and compared with the applicable limits.

The code domain spectrum should also be considered as it changes with the application of HSDPA. Depending on the number of data channels, the HS-DPCCH appears in the I or Q path. Of interest here is the power value used to transmit the HS-DPCCH, as it keeps changing with the information transmitted on the DPCCH. The analysis of the code domain spectrum may reveal if there is an impact on the adjacent code channels or not (see Figure 8).

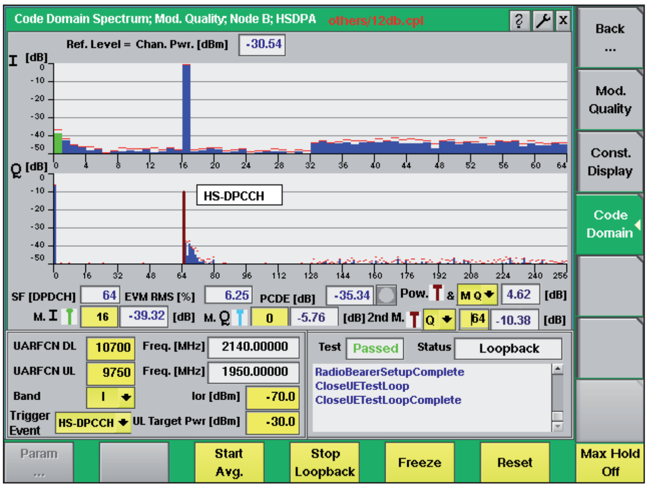

Figure 8: Code domain power while transmitting the HS-DPCCH

In addition to the modified measurement of the maximum output power, the adjacent channel leakage power ratio (ACLR) and the spectrum emission mask (SEM) are of interest. These allow to examine the impact in the adjacent channels which is assumed to be growing; narrowband interference can be identified this way. The limits defined for WCDMA change only minimally; they are adjusted upwards.

In order to evaluate the signal quality from the wireless device, the modulation error, in particular the error vector magnitude (EVM), should be considered because it is an important signal measurement. As mentioned before, the modulation scheme in the uplink is Dual BPSK. Despite the new code channel, the EVM limit has not changed. This also means that there is less margin; the requirements on the I/Q modulator in the mobile phone or wireless data card have become tougher.

Receiver testing

By measuring the power in different ways, testing the spectrum and evaluating the signal quality, engineers and technicians ensure that the transmitter of the wireless device is working perfectly. What is still open is how the receiver can be tested. In general– including GSM and WCDMA – this is achieved by way of BER or BLER measurements. The receiver measurements to be carried out on an HSDPA-capable terminal, however, are designed to analyse reception of both new code channels (HS-SCCH and HS-(P)DSCH). Some of these measurements require another signal source: a fading simulator that can generate defined signals (fading profiles). These fading profiles simulate various environments and movement of the terminal, e.g. moving at walking speed or inside a car. This type of tests is necessary in R&D lab to evaluate the receive characteristics of prototypes. Production lines tend to utilise rack systems more often than in the past, so the necessary equipment could be installed even in manufacturing. A rack usually contains multiple tools, signal generators and analysers, mobile phone testers that are jointly controlled by one piece of software. It is a matter of time if this kind of measurements are conducted in production.

The third segment, the service area, will certainly omit these measurements. A service centre is paid for throughput; there is no time for specific tests. A normal service centre will concentrate on normal transmitter measurements.

However, this measurement can also be performed without additional equipment and allows service engineers to assess the quality of the receiver. The measurement is generally based on determining the data throughput rate at constant RF parameters such as the output power. In HSDPA, the base station repeats a packet transmission if the terminal sends a NACK, as is the case with WCDMA. HSDPA changes the way in which the packet is retransmitted because it is reformatted. There are different and very complex possibilities. The channel coding type can be changed, for example, or different bits are omitted in the transmission. The bits previously punctured are added again or all bits are re-arranged. If 16QAM is being applied as the modulation format, the bits can even be moved within the individual quadrants, or re-arranged. A data packet is sent up to four times, and the specification stipulates which of the procedures listed is applied in what retransmission. The test instrument can now log each (re-) transmission (ACK, NACK, DTX) and can calculate a block error rate (BLER) based on the ACKs, NACKs and DTX values. With the help of this BLER and the known downlink configuration, an average data throughput rate can be determined.

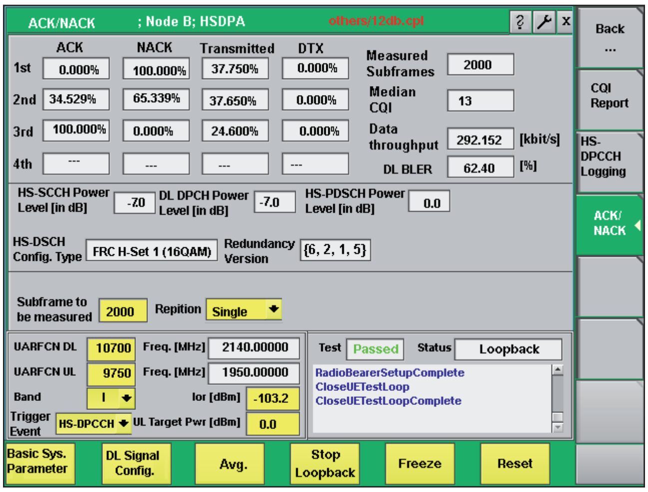

Figure 9: Determining the BLER and the data throughput

Additionally, the receiver quality can be assessed without additional external instruments. One of these measurements evaluates the CQI (channel quality indicator) which is used to report the transmission channel quality to the base station (Node B) on the HS-DPCCH. This CQI also defines the data rate that the device can process without the BLER exceeding a value of 10%. For this measurement, the test instrument selects a transport format corresponding to a reported CQI of 16. A separate CQI table is defined for the device categories; see Table 2.

UE category	Transport Block Size	# of HS-PDSCH	Modulation	Power adjustment	N_{IR}
1 to 6	3565	5	16QAM	0	9600
7, 8	3565	5	16QAM	0	19200
9	3565	5	16QAM	0	28800
10	3565	5	16QAM	0	28800
11, 12	3319	5	QPSK	-1	4800

Table 2: CQI value 16 for all the device categories

The configuration of the downlink channels is retained during the first phase of the test (CQI = 16) and the CQI value delivered back is logged 2000 times. The CQI median value is determined. 90% or 1800 of the CQI values delivered back must be in the range 'Median CQI - 2' < Median CQI < 'Median CQI + 2' otherwise the test is not passed. If this phase of the test is passed a second phase is initiated. The transport format on the downlink channels is adapted so that it equals the median CQI. The above procedure is repeated, but the ACKs, NACKs and transmit breaks (DTX) are counted. If the relationship in Formula 2 is lower than 0.1, the procedure is repeated for the value 'Median CQI - 1'.

$$\frac{NACK + DTX}{ACK + NACK + DTX} < 0.1$$

Formula 2: Determining the BLER

If it is larger the above test is repeated for the 'Median CQI + 2' value. Again the ACKs, NACKs and DTX values are logged 1000 times and the configuration of the downlink channels is maintained even if the HS-DPCCH transmits a different CQI value. Formula 2 is applied again. If the ratio is below 0.1, i.e. the BLER is below 10%, the test is considered as passed.

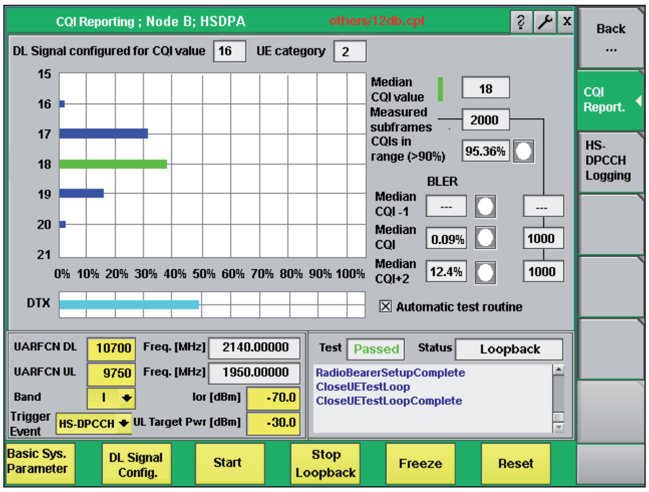

Figure 10: CQI reporting

Summary

With HSDPA, a complex extension has been introduced in the WCDMA networks. Its technical parameters could support a second boom in the mobile phone industry. This, however, depends on several factors. It is not only the new and complex signalling algorithms that pose high demands on the test instruments; the modified and new measurements also have a share in this. The types of measurements on mobile phones and data cards did not change, however – at least for the uplink signal. Power, spectrum and modulation continue to be analysed and assessed. The difficulty lies with the associated signalling algorithms. Timing plays an important role. The newly introduced uplink code channel HS-DPCCH on which the measurements are based, starts more or less in sync with the standard uplink DPDCH and DPCCH, depending on the downlink parameters. A new and unsynchronous code channel always changes the crest factor, i.e. the ratio of peak to average power. This leads to interference in the adjacent code channels. Due to the introduction of new downlink channels it is also necessary to check if the mobile phone or data card can decode the transmitted data correctly. The all-known BER and BLER measurements are not applicable here as usually but are used with modifications. In short: HSDPA involves important and interesting new features, but also entails a complex behaviour with strong effects on measurement technology.

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