HSDPA and HSUPA Functional Testing

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Meeting the Needs of a Rapidly Evolving 3G Services Market

The market for broadband cellular data services is in a rapid state of change. Just a few years ago, UMTS technology was still at the early deployment phase with few services making use of the increased bandwidth and even fewer handsets supporting these services. Now, at long last, UMTS is slowly but surely becoming main-stream technology, with suitable handsets becoming available in the mid-price range, and therefore becoming accessible to a wider share of the end-user market.

As a result of this market evolution, operators and manufacturers alike are primarily looking for ways to deal with an increasing number of potential 3G subscribers and secondly to improve the user's experience with these broadband services. In technical terms this translates into the need to improve the capacity of 3G networks and the need to support higher peak data rates than the 384 kbps supported by Rel.99 UMTS, ideally while using the available 3G spectrum.

This need was already recognized at an early stage by the Third Generation Partnership Project, who had been given the task of producing 3G standards based on WCDMA. In 2000, a feasibility study was carried out as part of the 3GPP Rel-4 standardization activities, whose aim was to identify possible techniques for improving capacity and achievable peak data rates specifically in the downlink. This endeavour resulted in the approval of a range of enhancements as part of 3GPP Rel-5 which were collectively denoted as HSDPA (High-speed Downlink Packet Access).

With the advent of increasing numbers of interactive services, where content is generated rather than used by the end-user (which is evidenced through the emergence of services such as blogging and podcasting), came the need to cater for improved uplink usage capacity. The 3GPP Rel-6 feature known as “FDD Enhanced Uplink”, more commonly known as HSUPA (High-speed Uplink Packet Access) is addressing this requirement.

Both HSDPA and HSUPA introduce new functions in the 3G radio access network (i.e. the UTRAN); Node-B's and RNCs must be upgraded with appropriate software. As with any other technological advancement in cellular networks, these enhancements must be thoroughly tested – both at the functional and performance level – prior to being released for deployment.

The intention of this White Paper is to provide an introduction to both UTRAN enhancements, and to demonstrate which type of test requirements exist in the development / deployment of these new technologies.

HSDPA Overview

HSDPA has been designed to support peak data rates of 14.4 Mbps in one cell. The major enhancement to the UTRAN is the introduction of a new transport channel known as HS-DSCH (see Figure 1 and Table 1), plus two control channels for the uplink and downlink. As the name suggests, it is a shared channel which can be used by several users simultaneously – this specifically addresses the needs of applications with a bursty traffic profile.

The introduction of this new transport channel impacts several protocol layers; the most significant changes are in the physical and MAC layers. The following features enable the high throughput capabilities of HSDPA:

- HSDPA introduces an Adaptive Modulation and Coding (AMC) scheme, whereby modulation method and coding rate are selected based on information about channel conditions provided by the terminal and the Node-B. In the downlink HSDPA supports 16QAM as a higher-order modulation method for data

transmission under good channel conditions, in addition to QPSK which is already specified for use in WCDMA.
- HSDPA uses a Hybrid Automatic Repeat reQuest (HARQ) protocol to handle re-transmissions and to guarantee error-free data transmission. HARQ is a key element of the new MAC entity denoted as MAC-hs, which is located both in the Node-B and in the User Equipment (UE); see Figure 2.
- A fast packet scheduling algorithm, which allocates the HS-DSCH resources (such as time slots and codes) to the different users, is also implemented as part of Node-B functionality.

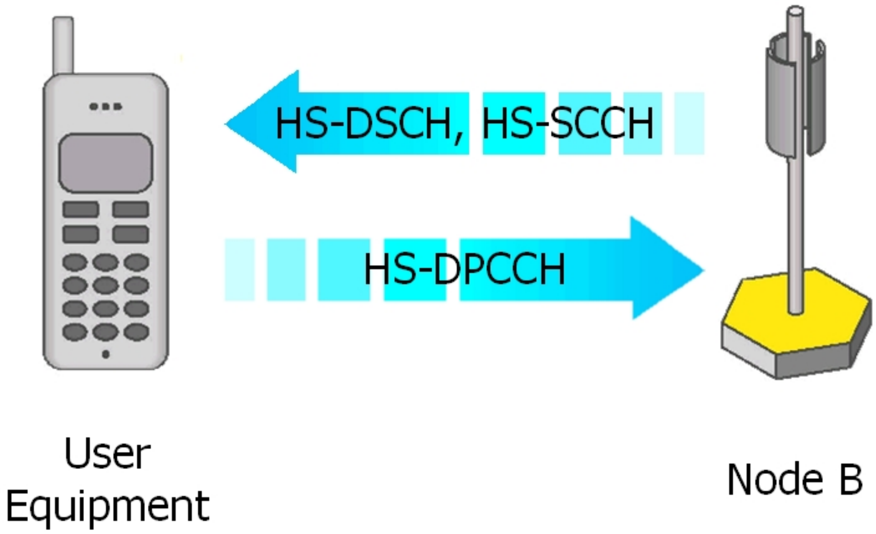

Figure 1 -- New transport and physical channels introduced by HSDPA

	Abbreviation	Name	Function
Downlink	HS-DSCH	High-Speed Downlink Shared Channel	Common transport channel for U-plane traffic.
	HS-SCCH	High-Speed Shared Control Channel	Common control channel including information such as UE identity.
Uplink	HS-DPCCH	High-Speed Dedicated Physical Control Channel	Feedback channel for HARQ ACK/NACK messages as well as for channel quality information.

Table 1 -- HSDPA specific transport and physical channels

As can be seen from this short feature overview some functions, previously reserved for the RLC protocol layer and to the Serving RNC (SRNC), have been moved down into the MAC protocol layer as well as moved into the Node-B. The proximity of time-critical functions, such as HARQ processing and packet scheduling, to the air-interface is essential, as the Transmission Time Interval (TTI) for HSDPA is specified at only 2 ms, one fifth of the minimum TTI specified for Rel. 99 WCDMA. In other words, re-transmissions as well as changes in modulation method and coding rate – among others – may take place every 2 ms. This low TTI clearly allows that the Node-B reacts faster to varying channel conditions, and HSDPA thus provides better performance for high throughput applications.

The HSDPA standards go further than the HS-DSCH and have the two following additional transport and physical layer channels:

- The High-Speed Shared Control Channel (HS-SCCH) is a downlink channel which is used to provide control information associated with the HS-PDSCH. It includes information such as the identity of the mobile terminal for which the next HSDPA subframe is intended, channel code set information and modulation scheme to be used for decoding the HS-DSCH subframes.

- The High-Speed Dedicated Physical Control Channel (HS-DPCCH) is an uplink control channel which is used to convey channel quality information (carried by CQI - Channel Quality Indicator - bits) as well as ACK/NACK messages related to the HARQ operation in the Node-B.

MAC Protocol Enhancements

HSDPA not only introduces new transport and physical layer channels, but also has an impact on higher-layer protocols, including the MAC layer. The Layer 1/Layer 2 protocol architecture for HSDPA is highlighted in Figure 2.

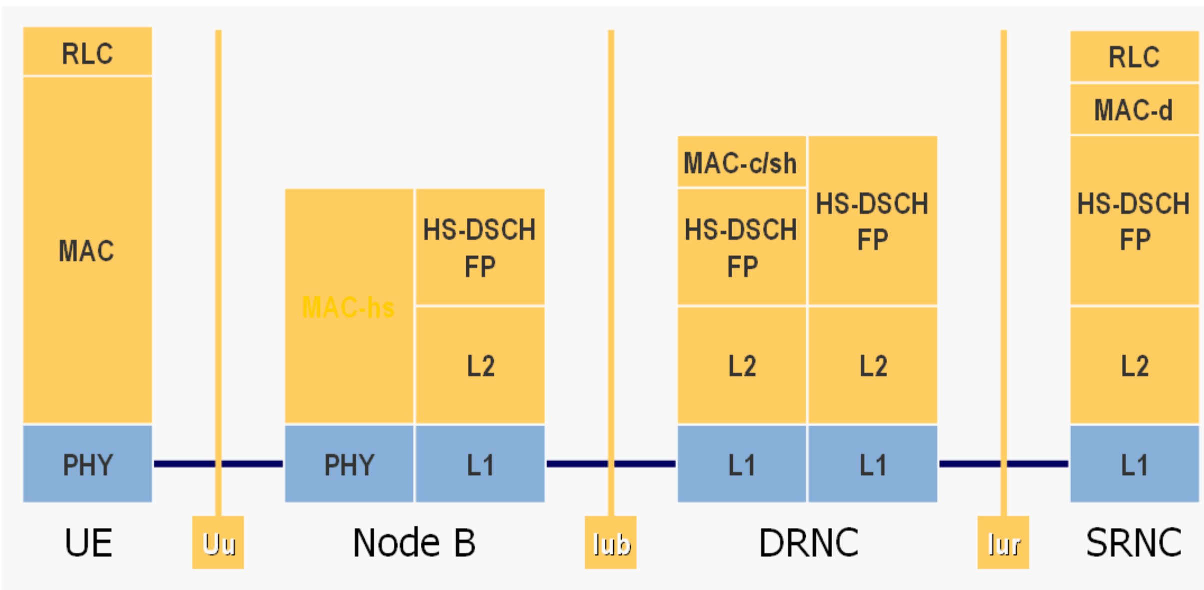

Figure 2 -- HSDPA L1/L2 Protocol Architecture (Source: 3GPP TS 25.308)

Different types of MAC entities are identified for different classes of transport channels. In 3GPP Rel. 99, dedicated and common transport channels are differentiated, and consequently, the MAC layer contains a MAC-d and a MAC-c entity. The introduction of HSDPA made it necessary to define a new entity called the MAC-hs. As opposed to Rel. 99 specifications, where the MAC layer is implemented in the RNC, the MAC-hs is used in Node-B to take into account the requirement for a high-performance implementation of the standard.

The Node-B MAC-hs is responsible for handling layer-2 functions related to the HS-DSCH, and includes the following functions:

- Handling of the HARQ protocol, including generation of ACK and NACK messages.

- Re-ordering of out-of-sequence subframes. Note that this is actually a function of the RLC protocol; however, this protocol layer is not implemented in the Node-B for the HS-DSCH. Therefore, the MAC-hs must take over some of the critical tasks of the RLC. Subframes may arrive out-of-sequence as a result of the re-transmission activity of the HARQ processes.

- Multiplexing and de-multiplexing of multiple MAC-d flows onto/from one MAC-hs stream.

- Downlink packet scheduling.

Control Plane Protocols

The introduction of HSDPA also requires additions and modifications to control plane protocols used within the UTRAN, i.e. specifically the following protocols:

- The Radio Resource Control (RRC) protocol, which is responsible for a multitude of UTRAN specific functions, including (signalling) radio bearer management.
- The Node-B Application Part (NBAP) protocol, which is implemented at the I_{ub} interface (i.e. the interface between Node-B and the RNC). NBAP essentially enables the RNC to manage resources in Node-B. The HS-DSCH constitutes an additional type of Node-B resource, which also needs to be managed using the NBAP protocol.
- The Radio Network Subsystem Application Part (RNSAP), implemented at the I_{ur} interface between two RNCs, is also affected by HSDPA, since in this case HSDPA related resources in Node B are managed by a Serving RNC which is different from the Node B's Controlling RNC.

User Plane Protocols

The relevant user plane protocol used to convey HS-DSCH transport blocks within the UTRAN is the HS-DSCH Frame Protocol (HS-DSCH FP), cf. Figure 2. The Frame Protocol, as the name suggests, is generally responsible for 'packaging' a set of Transport Blocks (the basic unit of data passed from the MAC layer to the physical layer) into a format that can be transmitted over UTRAN's transport network (which is ATM-based for Rel. 99 UMTS). Additional functions supported by the Frame Protocol include Node and transport channel synchronization.

An important HS-DSCH FP function is related to the need to control the flow of MAC-d PDUs in the HS-DSCH being sent from the RNC to the Node-B. Since Node-B buffers are limited, some form of flow control is necessary. This is achieved with dedicated HS-DSCH FP messages being exchanged between RNC and Node-B (see Figure 3). The Capacity-Request message is sent by the RNC to the Node-B to indicate that data is ready for transmission. Depending on the current buffer status within Node-B, this network element says how many (if any) MAC-d Protocol Data Units (PDUs) the RNC is allowed to transmit in a given time period, via the Capacity-Allocation message.

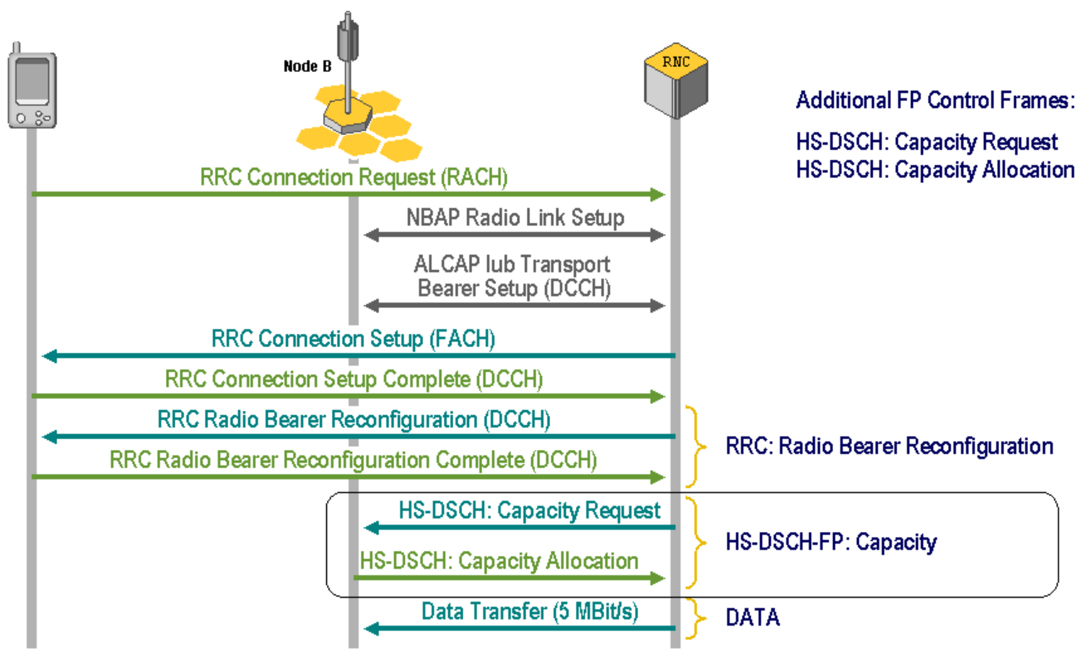

Figure 3 – Signaling procedure for data transmission over the HS-DSCH

Test Scenarios for HSDPA

As highlighted earlier, there is a need to perform a thorough test of network elements within the UTRAN prior to releasing them for deployment. Verifying the correct implementation of user plane and control plane procedures is only one part of the testing issues that need to be addressed. Since user data is being exchanged at high throughputs between the Node-B and the RNC, there is also a need to carry out performance testing of Node-Bs and RNCs. In other words, one of the questions that needs to be addressed is whether the capacity allocation algorithms used, particularly in Node-B, are able to correctly handle user data arriving at the highest possible throughput (i.e. up to a theoretical maximum of 14.4 Mbps) from the RNC.

In case of functional testing, a typical scenario is highlighted in Figure 4. In this case, the protocol tester simulates an RNC, i.e. generates appropriate messages towards the Node-B according to the test scenarios developed by the test engineer. All underlying protocol layers which are not subject to, but are required for, the test case are automatically emulated by the tester. This specific scenario also includes the emulation of the Core Network, i.e. of the SGSN , GGSN and HLR. In this way, the correct implementation of control plane procedures across the I_{ub} interface can be verified.

In this scenario, the Node-B is the Device under Test (DUT). Other scenarios might require the RNC to be tested, whereby the Node-B and UE would be simulated by the protocol tester.

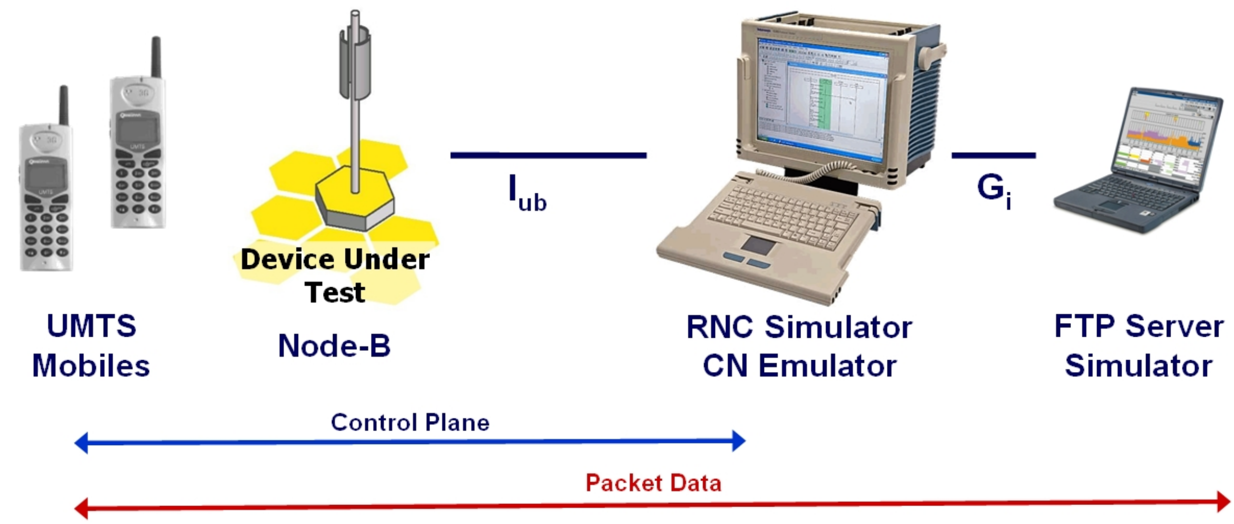

Figure 4 – Test scenario for HSDPA

In another test scenario, the goal is to verify the Node-B's internal memory management and to test whether its implementation is able to cope with high-throughput user traffic from one or more terminals. In this case, the protocol which needs to be simulated is the HS-DSCH FP (cf. Figure 3); other protocols needed to setup the required radio bearers (i.e. RRC and NBAP) are emulated by the protocol tester. Actual traffic is delivered as shown in the case highlighted in Figure 4 by an external FTP server simulator, which, for example, could be connected via Ethernet to the protocol tester. In this scenario, the test case could consist of gradually increasing rate of U-plane traffic up to 14.4 Mbps, to determine whether buffer overflow occurs at any point in time in Node-B. Another test case would consist in simulating traffic to multiple UEs in order to verify the Node-B's resource allocation function. Figure 5 shows an example of a visualization of HS-DSCH FP messages on Tektronix K1297-G35 protocol tester.

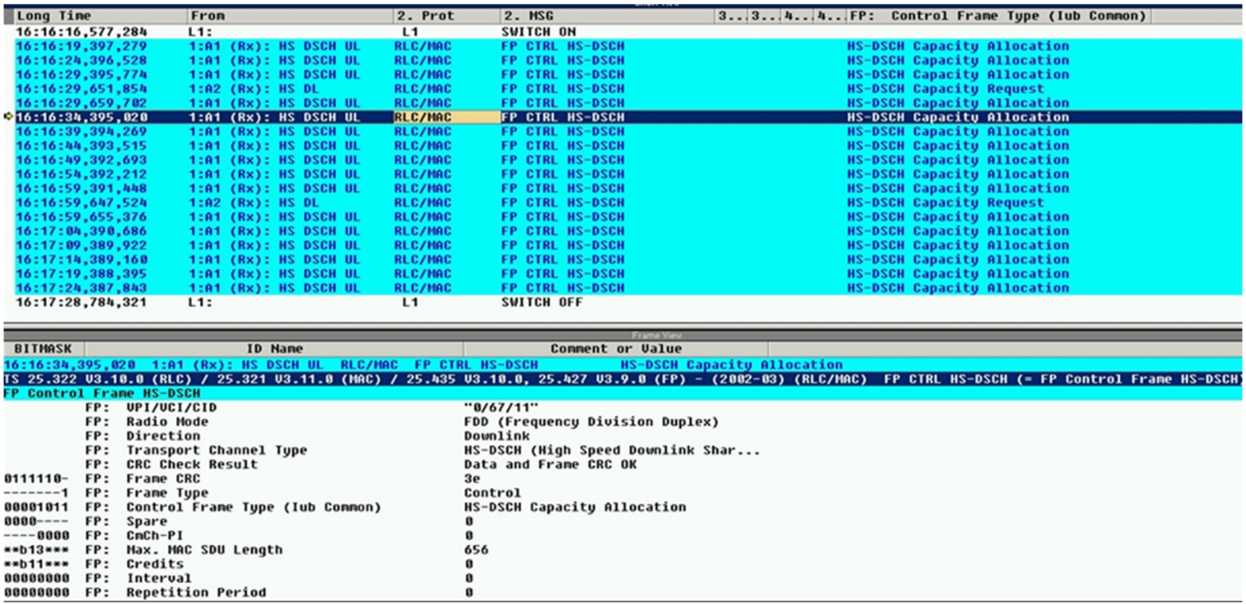

Figure 5 – Visualization of HS-DSCH FP messages.

HSUPA Overview

The goal of HSUPA is to improve capacity and data throughput and reduce the delays in dedicated channels in the uplink. The main enhancement offered by the 3GPP specifications is the definition of a new transport channel denoted as E-DCH (Enhanced Dedicated Channel). The maximum theoretical uplink data rate that can be achieved is 5.6 Mbps. As with HSDPA, E-DCH relies on improvements implemented both in the PHY and the MAC layer. However, one difference is that HSUPA does not introduce a new modulation scheme; instead it relies on the use of QPSK, the existing modulation scheme specified for WCDMA. As a result, HSUPA does not implement AMC either. Refer to Table 2 for a comparison of significant similarities and differences between HSDPA and HSUPA.

Feature	**HSDPA**	**HSUPA**
Peak Data Rate	14.4 Mbps	5.6 Mbps
Modulation Scheme(s)	QPSK, 16QAM	QPSK
TTI	2 ms	2 ms (optional) / 10 ms
Transport Channel Type	Shared	Dedicated
Adaptive Modulation and Coding (AMC)	Yes	No
HARQ	HARQ with incremental redundancy; Feedback in HS-DPCCH	HARQ with incremental redundancy; Feedback in dedicated physical channel (E-HICH)
Packet Scheduling	Downlink Scheduling (for capacity allocation)	Uplink Scheduling (for power control)
Soft Handover Support (U-Plane)	No (in the Downlink)	Yes

Table 2 – Feature comparison between HSDPA and HSUPA.

Physical Channels

At the physical layer, the definition of the E-DCH introduces five new physical layer channels (see Figure 6 and Table 3).

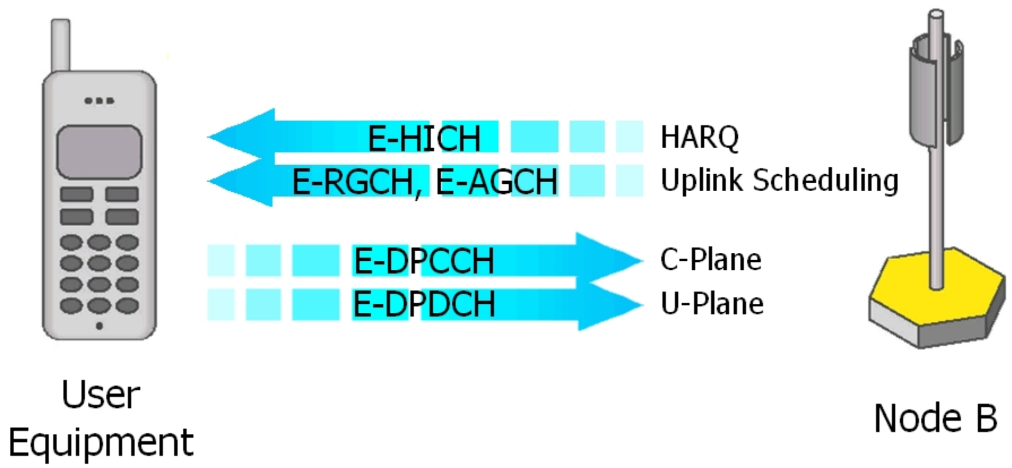

Figure 6 - New physical channels introduced by HSUPA.

	Abbreviation	Name	Function
Uplink	E-DPDCH	Enhanced Dedicated Physical Data Channel	This is the physical channel used by E-DCH for the transmission of user data.
	E-DPCCH	Enhanced Dedicated Physical Control Channel	Control channel associated with the E-DPDCH providing information to the Node-B on how to decode the E-DPDCH.
Downlink	E-AGCH	Absolute Grant Channel	Provides an absolute power level above the level for the DPDCH (associated with a DCH) that the UE should adopt.
	E-RGCH	Relative Grant Channel	Indicates to the UE whether to increase, decrease or keep unchanged the transmit power level of the E-DCH.
	E-HICH	HARQ Acknowledgement Indicator Channel	Used by Node-B to send HARQ ACK/NACK messages back to the UE.

Table 3 – E-DCH Transport and Physical Channel Definition

The E-HICH has a similar function to HSDPA's HS-DPCCH, namely that it is used to provide HARQ feedback information (ACK/NACK). However, it does not contain CQI information, since HSUPA does not support Adaptive Modulation and Coding.

Just as with HSDPA, the Node-B contains an uplink scheduler for HSUPA. However, the goal of the scheduling operation is completely different compared with that of HSDPA. The aim of HSDPA is to allocate HS-DSCH resources (in terms of time slots and codes) to multiple users, the goal of the uplink scheduler is to allocate only as much capacity (in terms of transmit power) to the individual E-DCH users as is necessary to ensure that Node-B does not have a "power-overload".

Clearly, the transmit power of a UE is directly related to the data rate at which it transmits information, as a result of the spreading operation inherent with WCDMA (i.e. high bit-rate transmissions require a low spreading factor to fill the 5 MHz bandwidth of WCDMA, resulting in a higher transmit power than for low bit rate applications which require a high spreading factor). Furthermore, the more UEs transmitting at the same time, the more interference they cause for each other. The Node-B can only tolerate a maximum amount of interference before it is no longer able to decode the transmissions of individual UEs. Since E-DCH is a dedicated channel, it is very likely that multiple UEs will be transmitting at the same time, therefore causing interference at the Node-B. The Node-B must therefore regulate the power level of individual UEs transmitting in the E-DCH in order to avoid arriving at this "power ceiling". This transmit power regulation is thus equivalent to "scheduling" uplink capacity for each UE transmitting with E-DCH. In other terms, the uplink scheduling mechanism is nothing more than a very fast power control mechanism.

The two physical scheduling channels E-RGCH and E-AGCH tell a UE how to regulate its transmit power level. In case of the E-RGCH, the UE is instructed to either increase or decrease the transmit power level by one step, or alternatively to keep the current transmit power level unchanged. In the case of the E-AGCH, the Node-B provides an absolute value for the power level of the E-DCH at which the UE should transmit.

MAC Protocol Enhancements

In addition to introducing new physical channels, E-DCH also introduces new MAC entities for the UE, the Node-B and the SRNC. These MAC entities are known as MAC-e and MAC-es (see Figure 7) and are mapped onto network elements as follows:

- The MAC-e is implemented both in the UE and in Node-B. Its main function involves the handling of HARQ retransmissions and scheduling. This is a low-level MAC layer which is very close to the physical layer.
- The MAC-es entity is implemented in the UE and the SRNC. In the UE, it is partially responsible for multiplexing multiple MAC-d flows onto the same MAC-es stream. In the SRNC, it is the entity which takes care of in-sequence delivery of MAC-es PDUs (see below), de-multiplexing of the MAC-d flows and distributing these flows into individual queues according to their QoS characteristics. These MAC-d flows may correspond to individual PDP contexts at the Iu-PS interface with different QoS profiles (e.g. streaming vs. background).

E-DCH, as opposed to HS-DSCH, supports soft handover. This explains why the MAC layer for E-DCH is split between the Node-B and the SRNC – while Node-B takes care of time-critical functions such as HARQ processing and scheduling, the associated MAC-es entity located in the SRNC takes care of in-sequence delivery of MAC-es frames, which may emanate from different Node-Bs currently serving the UE.

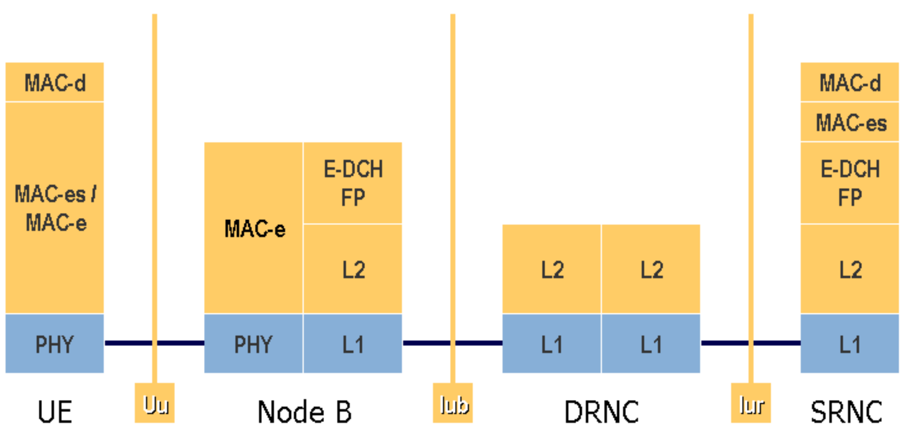

Figure 7 – Protocol architecture for E-DCH (Source: 3GPP TS 25.309)

A further difference with HS-DSCH is that E-DCH may support both a TTI of 2 ms and 10 ms (HS-DSCH mandates a TTI of 2 ms). Which TTIs are mandatory specifically depends on the UE category.

Test Scenarios for HSUPA

A possible test scenario for HSUPA is highlighted in Figure 8. In this scenario, the DUT is the RNC. The goal of the test scenario is to verify that the MAC-es layer correctly de-multiplexes the individual MAC-d flows from the MAC-es stream and re-orders the individual MAC-d PDUs into individual re-ordering queues. A further goal of the test is to verify that this re-ordering is implemented according to the QoS requirements of the individual MAC-d flows. In one test case, only one UE could be simulated to verify that the basic MAC-es function is correctly implemented in the RNC. In another test case, multiple UEs could be simulated to verify that the MAC-es layer in the RNC is capable of correctly differentiating all UEs from each other.

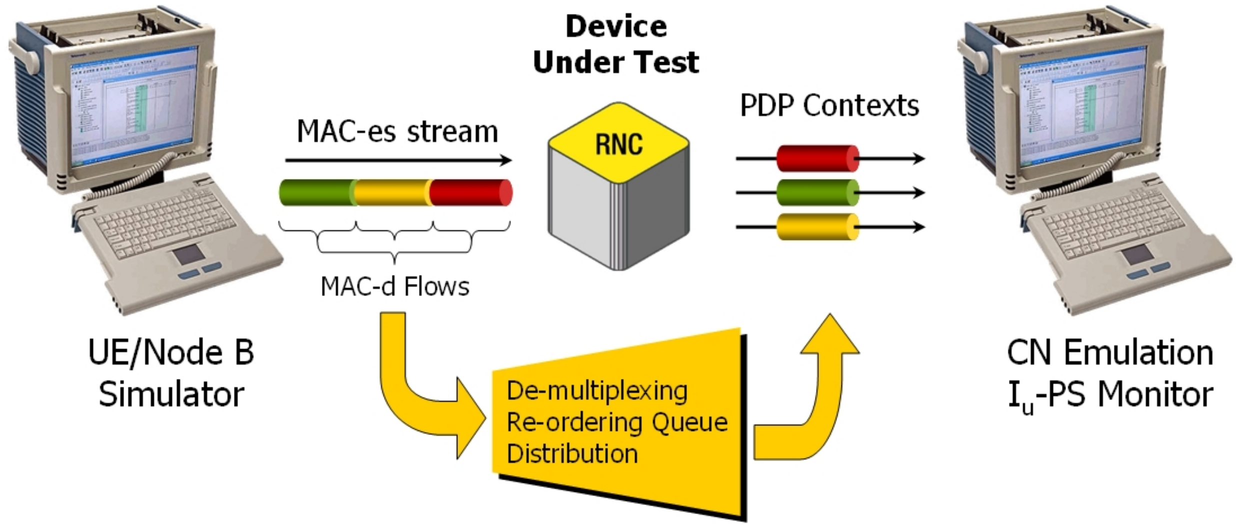

Figure 8 – Test scenario for HSUPA

In this test configuration, the protocol tester acts on the one hand as a UE and Node-B simulator. It simulates U-plane traffic according to the test engineer's test case definition, and emulates all necessary signalling protocols required prior to establishing an MAC-es stream between the UE and the RNC. The traffic generated may correspond to the transmission e.g. of a video file together with the sending of an E-Mail with a large attachment (this all depending on the specific test case).

On the "other side" of the RNC, the protocol tester could implement a Core Network emulation in order to ensure that the required PDP contexts are established. Furthermore, the U-plane traffic across the Iu-PS interface would need to be decoded and visualized on the protocol tester. Mapping between MAC-d flows and PDP contexts is possible since the allocation of user traffic on MAC-d flows can also be visualized on the protocol tester.
Note that the UE/Node-B Simulator and the CN Emulation / Iu-PS Monitor can be implemented through one single test device; Figure 8 shows two separate devices to help visualize how the protocol tester works.

Conclusions

The introduction of new mobile network features, such as HSDPA and HSUPA, always sets stringent requirements for testing related network node products. Functional testing, however, is not just about testing implementations to see if they comply with the standards, in the way that C-Plane and U-Plane procedures between standardized interfaces are checked.

Functional testing is also, to a large extent, required for checking that network node internal algorithms, e.g. related to buffer management, queuing, etc… are doing what they are supposed to do. Not only should these algorithms and the related software and hardware be able to operate under normal conditions (with user traffic running at average data rates), but they should also be able to handle user traffic up to the maximum specified throughput. Test platforms meeting these requirements ensure that manufacturers can build future-proof solutions, and also ensure that operators successfully use such solutions. Tektronix is committed to providing such test solutions that will meet both the need for wide-ranging test functions as well as the necessary performance.

Acronyms

16QAM	16ary Quadrature Amplitude Modulation
ACK	Acknowledge
AMC	Adaptive Modulation and Coding
CQI	Channel Quality Indication
DUT	Device Under Test
E-DCH	Enhanced Dedicated Channel
FDD	Frequency Division Duplex
FP	Frame Protocol
GGSN	Gateway GPRS Support Node
HSDPA	High-Speed Downlink Packet Access
HSUPA	High-Speed Uplink Packet Access
NACK	Negative Acknowledge
PDU	Protocol Data Unit
QPSK	Quadrature Phase Shift Keying
RLC	Radio Link Control
RNC	Radio Network Controller
RRC	Radio Resource Control
SGSN	Serving GPRS Support Node
SRNC	Serving RNC
TTI	Transmission Time Interval
UE	User Equipment
UTRAN	UMTS Terrestrial Radio Access Network
WCDMA	Wideband Code Division Multiple Access