

HIGH SPEED PACKET ACCESS

Brzi paketni pristup

Mario Cvitković, B Sc

Faculty of Electrical Engineering and Computing
University of Zagreb
E-mail: mario.cvitkovic@fer.hr

Borivoj Modlic, Ph D

Faculty of Electrical Engineering and Computing
University of Zagreb
E-mail: borivoj.modlic@fer.hr

Gordan Šišul, Ph D

Faculty of Electrical Engineering and Computing
University of Zagreb
E-mail: gordan.sisul@fer.hr

UDK 004

Abstract

Data services and multimedia are expected to have significant growth over the next few years and will likely become the dominant source of 3G traffic. High Speed Downlink Packet Access (HSDPA) provides large enhancements over Wideband Code Division Multiple Access (WCDMA) for the downlink. HSDPA was standardized as part of Third Generation Partnership Project (3GPP) Release 5 and improved in later releases. The HSDPA peak data rate available in the terminals was initially 1.8 Mbps, but it has increased to 42 Mbps. HSDPA has been designed to increase downlink packet data throughput by means of fast physical layer retransmission and transmission combining as well as fast link adaptation controlled by the Node B – i.e. a base transmission station (BTS). High Speed Uplink Packet Access (HSUPA) was part of 3GPP Release 6 with the first specification version in December 2004. The HSUPA peak data rate in the initial phase is expected to be 1–2 Mbps with later phase pushing the data rate to 11.5 Mbps. HSDPA and HSUPA together form High Speed Packet Access (HSPA).

Sažetak

Očekuje se da će podatkovne usluge i multimedija imati značajan rast te će vjerojatno postati dominantan izvor 3G prometa u sljedećih nekoliko godina. Brzi paketski pristup u silaznom smjeru (HSDPA) pruža veliko unaprjeđenje u usporedbi sa širokopojasnim višestrukim pristupom po kodnoj raspodjeli (WCDMA) za silazni smjer. HSDPA je normiran kao Release 5 od strane 3GPP te je unaprjeđivan u daljnjim izdanjima. U početku je raspoloživa brzina prijenosa podataka u korisničkim uređajima iznosila 1,8 Mbit/s, ali je sad povećana na 42 Mbit/s. HSDPA je osmišljen kako bi povećao brzinu prijenosa podataka u silaznom smjeru te pritom se koristi tehnikama brzog ponovnog slanja podataka na fizičkom sloju, brzom prilagodbom veze u baznoj postaji, itd. Brzi paketski pristup u uzlaznom smjeru pojavio se kao dio 3GPP Release 6, a izišao je u prosincu 2004. U početnoj fazi HSUPA je omogućavala vršne brzine prijenosa podataka od 1 do 2 Mbit/s, dok trenutno omogućava brzine prijenosa podataka od 11,5 Mbit/s. Obje tehnologije, HSDPA i HSUPA zajedno, nazivaju se brzi paketski pristup (HSPA).

INTRODUCTION / Uvod

Since the first cell networks, dating from 80s of last century, wireless communications were directed for speech transport.

At the beginnings of wireless telephony, first generation 1G networks were based on analog technology – Nordic Mobile Telephony (NMT) i.e. which used frequency modulation (FM) for speech transfer and frequency shift keying (FSK) for signalization. This system had lot imperfections: international systems were incompatible, user equipment was too big and battery life was too short.

In 90s of the last century the second generation (2G) wireless mobile system called Global System for Mobile Communication (GSM) came into life. GSM has fixed main imperfection of 1G. It was a completely digital system with international conciliate and very good coverage with high density transmitters. Big disadvantage of this technology was very low data rate (9.6 Kbps) which is deficient for most services. There was no idea for GSM to be used as Local Area Network (LAN) – it was based on Circuit Switched Technology (CS).

Thus, the next generations of wireless mobile systems tend to integrate the speech transport and advanced data transfer. That resulted in GSM enhancements and new technologies. High Speed Circuit Switched Data (HSCSD) is one of them. It provides 57.6 Kbps transmission rate. General Packet Radio Service (GPRS) played an important role in transition to the third generation 3G wireless mobile system. GPRS implementation required the integration of the two new nodes: Serving GPRS Support Node (SGSN) and Gateway GPRS Support Node (GGSN). The downlink packets transfer rate is 115 Kbps. It is also possible to define the desired profile Quality of Service (QoS). Enhanced Data rates for Global Evolution (EDGE) was the last 2G system improvement. The purpose of EDGE was to provide high speed data transport using the existing resource of GSM network. For that purpose another modulation method was applied, 8 Phase Shift Keying (8 PSK), and transfer rates up to 230 Kbps may be reached (Medvid, 2006).

A new trend in technology and user requirements put higher criteria on data rate and mobility.

First 3G Wideband Code Division Multiple Access (WCDMA) networks were lunched during 2002. WCDMA enables peak data rates of 384 Kbps with latency 100–200 ms, which makes Internet access close to low-end Digital Subscriber Line (DSL) connections and provides good performance for most low-delay Internet Protocol

(IP) applications as well. By the end of 2005 there were 100 WCDMA networks and over 150 operators having frequency licenses for WCDMA operation. By December 2007 there were over 170 million WCDMA subscribers. As WCDMA mobile penetration increases, it allows WCDMA networks to carry larger share of voice and data traffic. WCDMA makes it possible to offer customers substantially more voice minutes with better quality and provides even more dramatic evolution in terms of base station capacity and hardware efficiency (Holma and Toskala, 2004).

In just a few years the Internet has transformed the way we access information, communication and entertainment services at home and at work. Broadband connections have made the Internet experience richer for millions of people and in the coming years, millions more will turn to wireless technology to deliver their broadband experience. To increase data transfer rates, new standards (improvement of WCDMA) were carried out. Third Generation Partnership Project (3GPP) standardized High-speed Downlink Packet Access (HSDPA) technology in Release 5, and High-speed Uplink Packet Access (HSUPA) in Release 6. HSDPA and HSUPA together are called High-speed Packet Access (HSPA) or 3.5G.

HSPA is the undisputed leader in mobile broadband services, as it provides:

- an ecosystem of unrivalled breadth and depth, covering both traditional mobile terminals and personal consumer devices such as notebooks, ultra mobile PCs, cameras, portable game consoles and music players,
- unmatched economies of scale that benefit all players in the ecosystem, which are uniquely available to a technology that is part of the 3GPP family of standards, currently serving over two billion subscribers,
- ever-improving performance, with commercially-proven transmission bit-rates up to 14Mbps today and up to 42Mbps in the near future,
- highly economic urban and rural coverage, with up to 200km cell range and measured speeds in excess of 2Mbps at the cell border,
- clearly defined and easily adopted evolution path.

HSDPA KEY TECHNOLOGIES / HSDPA ključne tehnologije

HSDPA represents the Universal Mobile Telecommunication System (UMTS) improvement which is based on WCDMA. Compared to UMTS several new channels have been introduced for the HSDPA operation (Holma and Toskala, 2006).

For the user data there is High-Speed Downlink Shared Channel (HS-DSCH). For the associated signaling needs there are High-Speed Shared Control Channel (HS-SCCH) and High-Speed Dedicated Physical Control Channel (HS-DPCCH). Figure 1 depicts the channels and data transfer directions needed for HSDPA operation in Release 5.

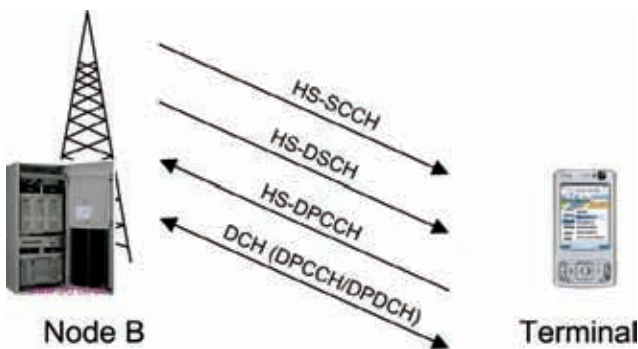


Figure 1. HSDPA channels
Slika 1. HSDPA kanali

There are also important changes in the protocol layer. Adaptive Modulation and Coding (AMC) is used to select the best modulation technique and coding scheme in dependence of frequently received channel state information. The other new key technology is the physical layer retransmission called fast Hybrid Automatic Repeat Request (H-ARQ) which is now controlled by BTS.

Implementation of HSDPA requires changes in the physical layer, while protocol changes require new Medium Access Control (MAC) called MAC-hs. The radio resource management (RRM) functionality with HSDPA and HSUPA has experienced changes compared with Release 99. In Release 99 the scheduling control was based in the radio network controller (RNC) while in the base station (BTS or Node B in 3GPP terminology) there was mainly power control related functionality. In Release 99 if there were two RNCs involved for the connection, the scheduling was distributed (Figure 2). The serving RNC (SRNC) – the one being connected to the core network for that connection – would handle the scheduling for the dedicated channels (DCHs) and the one actually being connected to the base transceiver station (BTS) would handle the common channel (like FACH). As scheduling has been moved to the BTS, there is now a change in the overall RRM architecture. The SRNC will still retain control of handovers and is the one which will decide the suitable mapping for quality of service (QoS) parameters (Figure 3).

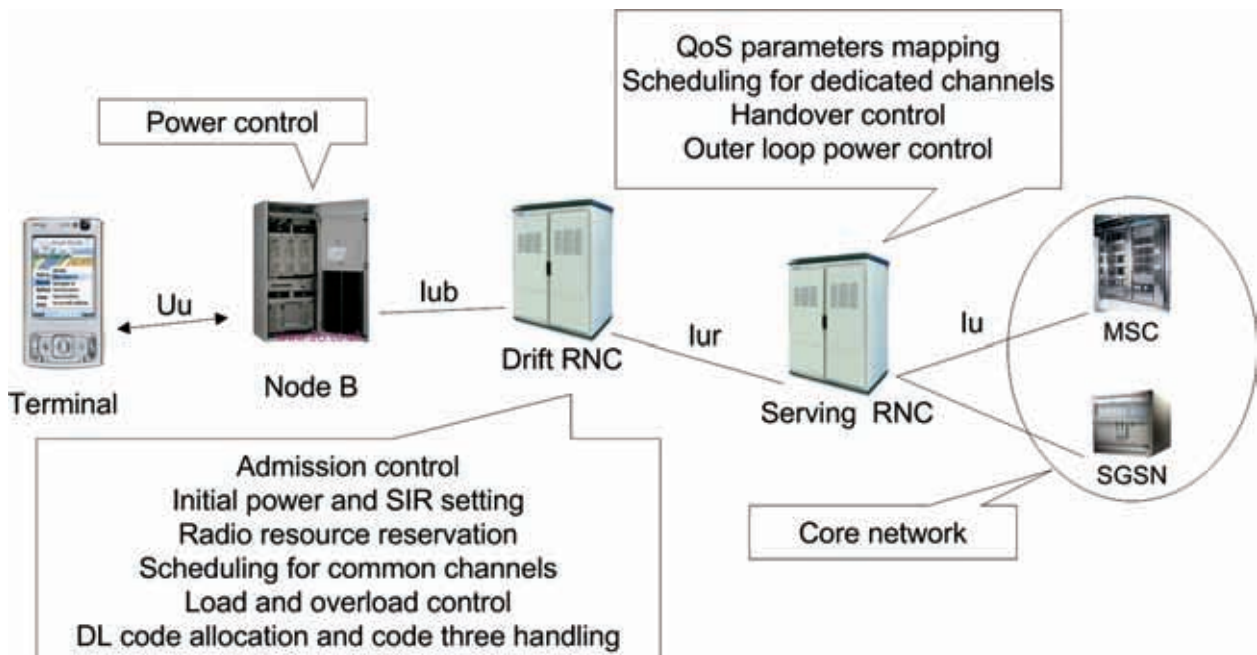


Figure 2. R99 radio resource management architecture
Slika 2. R99 radijska upravljačka arhitektura

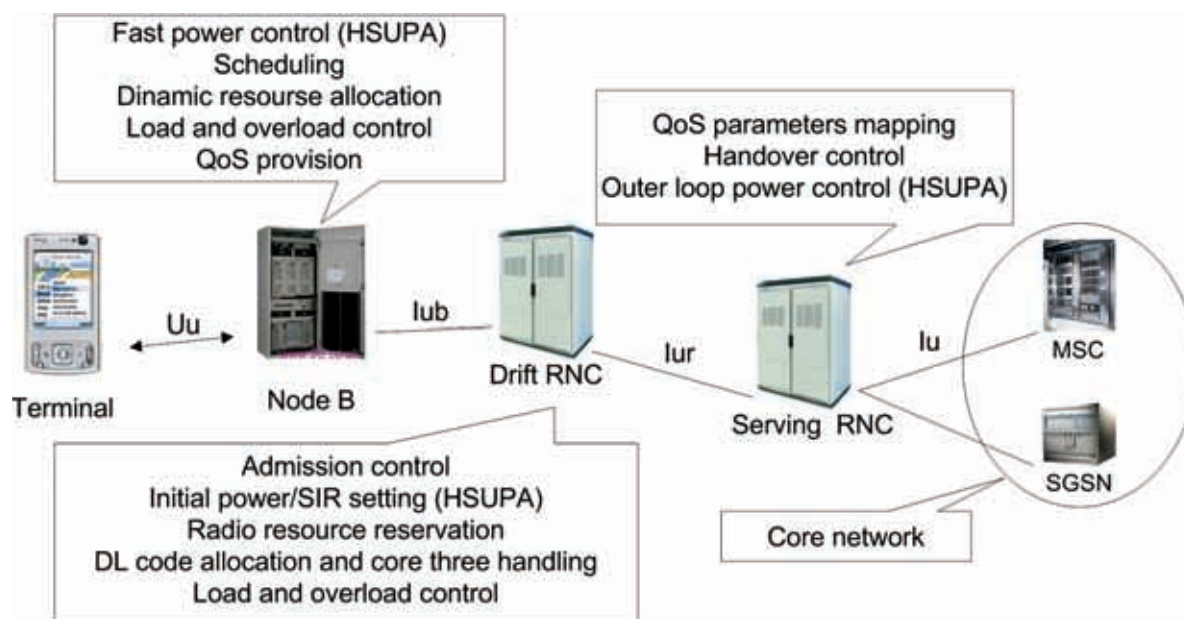


Figure 3. HSPA RRM Release 6 architecture

Slika 3. HSPA Release 6 radijska upravljačka arhitektura

CHANGES IN PHYSICAL AND LOGICAL CHANNEL STRUCTURE / Promjene u fizičkoj i logičkoj strukturi kanala

High-Speed Physical Downlink Shared Channel is used for carrying the user data in downlink and represents transport mechanism for the logical HSDPA channel HS-DSCH. Though, 3GPP standards specify 15 HS-PDSCH per cell (3GPP TS 25.211 version 6.7.0, Release 6, 2005). The actual number employed depends on

the number of codes supported by the terminal or system, operator settings and system capacity (Chen et al, 2005). A fixed value can be set or algorithms for dynamic behavior can be introduced to maximize the code utilization on a shared Release 99/HSDPA carrier. Figure 4 displays an example showing how codes are dynamically allocated per TTI to one or more users (Ericsson white paper, 2007).

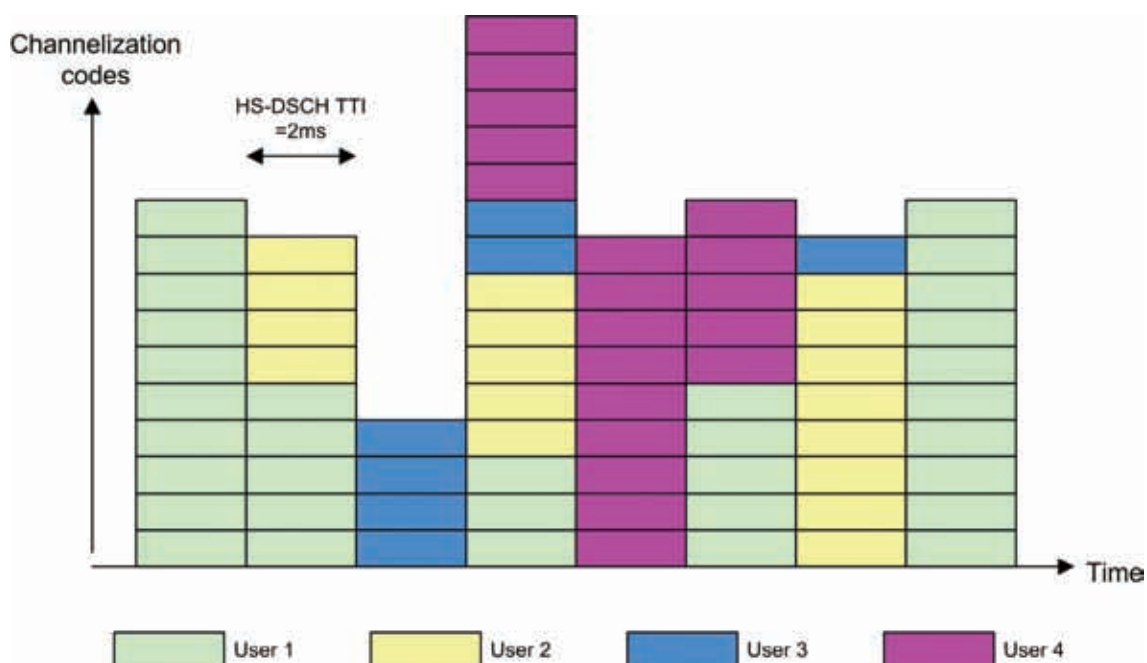


Figure 4. Dynamic code allocation

Slika 4. Dinamičko dodjeljivanje kodova

High-Speed Downlink Shared Channel is a downlink transport channel and it may be used by all cell users. HS-DSCH applies channelization code resource shared between users. Dynamic sharing between users is done in time domain, every 2ms. This channel supports fast link adaptation, H-ARQ and scheduling (Holma and Toskala, 2006). The key differences from the Release 99 DCH-based packet data operation are:

- Lack of fast power control. Instead, link adaptation selects the suitable combination of codes, coding rates and modulation to be used.
- Support of higher order modulation compared to the DCH. With 64QAM the number of bits carried per symbol is quadrupled in favorable conditions compared with the QPSK in Release 99.
- User allocation with the base station based scheduling every 2 ms, with fast physical layer signaling. With DCH the higher layer signaling from the RNC allocates semi permanent code (and a spreading factor) to be used. The transmission time interval (TTI) is also longer with the DCH, allowing values such as 10, 20, 40 or 80 ms. (The longest is limited in the specific case of small data rates that have a spreading factor of 512).
- Use of the physical layer retransmissions and retransmission combining, while with the DCH – if retransmissions are used – they are based on RLC level retransmissions.
- Lack of soft handover. Data are sent from one serving HS-DSCH cell only.
- Lack of physical layer control information on the HS-PDSCH. This is carried on the associated DCH (uplink power control, etc.) instead on the HS-SCCH for HSDPA.
- Multicode operation with a fixed spreading factor. Only spreading factor 16 is used, while with the DCH the spreading factor may be a static parameter between 4 and 512.
- With HSDPA only turbo-coding is used, while with the DCH convolution coding may also be used.
- No discontinuous transmission (DTX) on the slot level. The HS-PDSCH is either fully transmitted or not transmitted at all during the 2-ms TTI.

HSDPA operation needs uplink physical layer feedback information from the terminal to the base station to enable the link adaptation and physical layer retransmission. That uplink feedback information is transmitted in the High-Speed Dedicated Physical Control Channel. The HS-DPCCH uses the fixed

spreading factor of 256 and has 2ms/three-slot structure (Figure 5). The first slot is used for HARQ feedback that informs the base station whether the packet was decoded correctly or not. The two remaining slots are used for Channel quality information (CQI) which, respectively, informs the base station scheduler of the data rate the terminal is expected to be able to receive at a given moment.

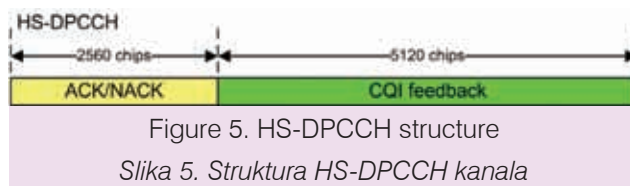


Figure 5. HS-DPCCH structure
Slika 5. Struktura HS-DPCCH kanala

High-Speed Shared Control Channel is used to carry time critical signalling information which allows the terminal to demodulate the information correctly. Therefore it has two slots offsets compared to the HS-DSCH (Figure 6). The spreading factor of 128 allows 40 bits per slot to be carried. As part of the information needs to be available prior to the HS-DSCH use, it is divided in two parts. The first part carries the information to enable the de-spreading as well as the modulation information. The second part contains less urgent information, such as which ARQ process is being transmitted.

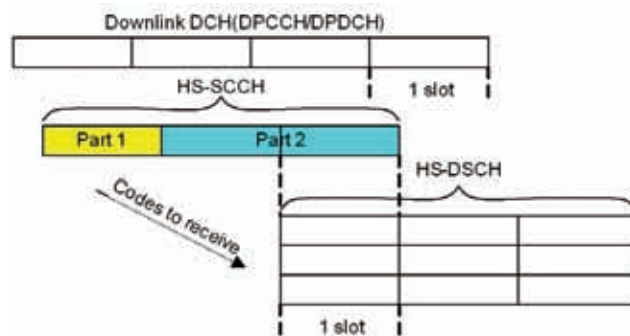


Figure 6. Relative timing between HS-SCCH and HS-DSCH
Slika 6. Vremenska razlika između HS-SCCH i HS-DSCH kanala

CHANGES IN PROTOCOL STRUCTURE / Promjene u strukturi protokola

To enable fast link adaptation, fast H-ARQ and fast scheduling method, it was necessary to import the new MAC sub layer called MAC-hs. Mac-hs is defined on the base station (BTS) while MAC-d protocol layer is retaining in the radio network (RNC) structure.

Short time transmission interval / Kratko vrijeme odašiljanja

Compared with UMTS, HSDPA uses much shorter time transmission interval (TTI) of 2ms. There is no discontinuous transmission (DTX) on the slot level as with the DCH, while the code resource (recall allocation of a downlink code with the fixed spreading factor) with the DCH is partially filled with lower data rates. That is the main reason for reducing latency on the air interface. The total delay time is decreased for 75ms. The performance for the end users, that use TCP/IP services, is sensibly improved (round trip time is significantly shorter). Channel codes from the shared code resource are dynamically allocated every 2 ms, or 500 times per second.

Sharing transmission channel / Dijeljenje odašiljačkog kanala

HSDPA is using HS-DSCH for downlink. User multiplex in the time domain is possible because the spreading factor (SF) 16 is applied. Codes for the user are provided only during data transmission, which leads to the more efficient code and power resource using. It is providing max 15 codes, but the number of codes in use is terminal depended (Figure 4).

Scheduling methods / Postupci raspoređivanja

Since more users share the HS-DSCH it is necessary to have a scheduling method, to provide the access for all users. The scheduling process determines which terminal will transmit data in the particular time interval and select the appropriate transfer rate. Scheduling is implemented in MAC-hs protocol on BTS. Main idea is to favor the data traffic on the terminal that has the best air link. Figure 7 shows the scheduling method that depends on the air link characteristics. HSDPA uses three scheduling algorithms: proportional fair scheduling algorithm, round robin algorithm and max C/I ratio algorithm.

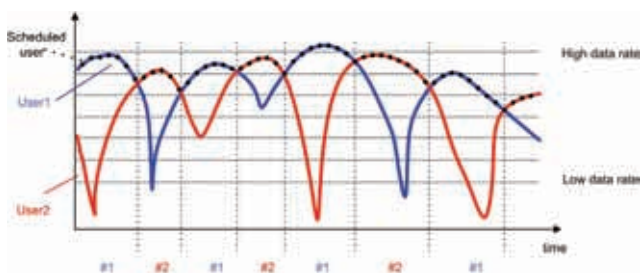


Figure 7. Scheduling method
Slika 7. Postupak raspoređivanja

Proportional fair scheduling algorithm favors the users with a good air link, but at the same time provide enough resource for the users with a bad air link. Round robin algorithm takes only delay into account. Priority has the user with longer waiting "in line". Algorithm is simple, but it has worse performance compared to afore mentioned algorithm. Max C/I ratio algorithm assigns the channel to the user with the best air link, but it does not affect channel allocation fairness. Traffic priorities can also be taken into account. For example, streaming services can be prioritized ahead of background users. The selection of the algorithm is traffic type and quantity dependent.

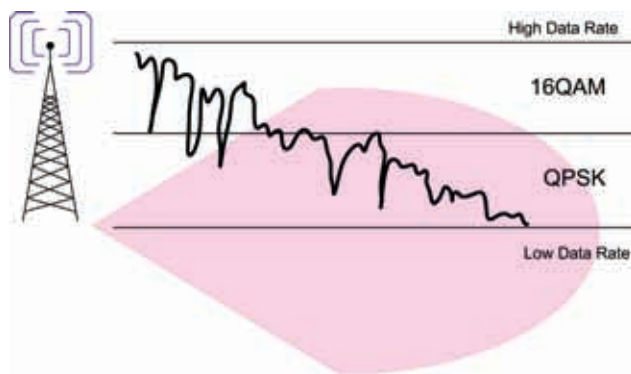


Figure 8. Data rate is adjusted on instantaneous radio conditions basis

Slika 8. Brzina prijensa podataka bira se ovisno o stanju radijskog kanala

Link adaptation / Prilagodba veze

In HSDPA two main WCDMA features, variable spreading factor and fast power control, are replaced with the Adaptive Modulation and Coding (AMC). Link adaptation is very dynamic as it operates with 2ms granularity with the HS-DSCH. In addition to the scheduling decision, the MAC-hs in the BTS will also decide every 2ms which coding and modulation combination is to be transmitted. Link adaptation is based on the physical layer CQI being provided by the terminal.

Table 1. Example of the CQI tables

Tablica 1. Primjer CQI tablica

16QAM terminal with 10 codes

CQI values	Transport block size	Number of HS-PDSCH codes	Modulation	Reference power adjustment Δ
0	N/A	N/A		
1	137	1	QPSK	0
2	173	1	QPSK	0
14	2583	4	QPSK	0
15	3319	5	QPSK	0
16	3565	5	16QAM	0
24	11418	8	16QAM	0
25	14411	10	16QAM	0
26	14411	10	16QAM	-1
27	14411	10	16QAM	-2
28	14411	10	16QAM	-3
29	14411	10	16QAM	-4
30	14411	10	16QAM	-5

QPSK-only terminals with 5 codes

CQI values	Transport block size	Number of HS-PDSCH codes	Modulation	Reference power adjustment Δ
0	N/A	N/A		
1	137	1	QPSK	0
2	173	1	QPSK	0
3	233	1	QPSK	0
14	2583	4	QPSK	0
15	3319	5	QPSK	0
16	3319	5	QPSK	-1
17	3319	5	QPSK	-2
18	3319	5	QPSK	-3
29	3319	5	QPSK	-14
30	3319	5	QPSK	-15

Except QPSK HS-DSCH can use 16QAM and 64 QAM modulation schemes as well. The 16QAM and QPSK constellations are displayed in Figure 9. By having more constellation points (16 or 64 instead of 4) more bits can be carried per symbol (4 or 6 instead of 2 bits per symbol).

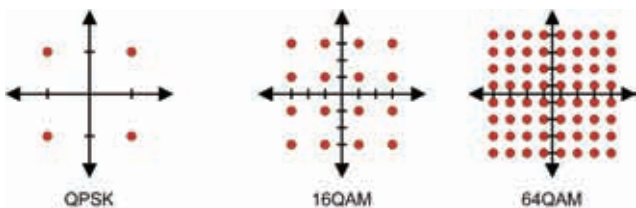


Figure 9. QPSK, 16QAM and 64QAM constellations

Slika 9. QPSK, 16QAM i 64QAM dijagrami stanja

The higher order modulation application introduces additional decision boundaries (Figure 9). With 16QAM or 64QAM, it's no longer sufficient to have only the phase figured out correctly but the amplitude needs to be estimated as well (Modlic and Modlic, 1995). This explains why signal quality needs to be better when using 16QAM or 64QAM instead of QPSK. Because of that 16QAM and especially 64QAM application requires better receivers (3GPP TS 25.213 version 6.4.0, Release 6, 2005). Using the link adaptation, the network will gain from the power control dynamics limitation in the downlink. CQI information takes other aspects into

account besides just the signal strength or C/I. By just switching from QPSK to 16QAM and by playing with the coding rates and the number of codes the total dynamic range can reach 30 dB. In Table 2 there are the data rates which depend on the modulation scheme and the effective code rate (Ishii et al, 2004).

Table 2. HSDPA Data rates

Tablica 2. HSDPA brzine prijena podataka

Modulation	Effective code rate	Max. throughput (Mbps)
QPSK	1/4	1.8
QPSK	2/4	3.6
QPSK	3/4	5.3
16QAM	2/4	7.2
16QAM	3/4	10.7
64QAM	0.98	21.1

Fast Hybrid Automatic Repeat Request / Brzi hibridni automatski zahtjev za ponovnim slanjem podataka

The HARQ functionality consists of a two-stage rate matching functionality which allows tuning the redundancy version of different retransmissions when using non-identical retransmissions. HARQ can be operated in two different ways, with identical or with non-identical retransmissions.

The use of identical retransmissions is called soft combining. When using soft combining the rate matching functionality is identical between transmissions. Regardless of the number of retransmissions, the rate matching operation is always unchanged for every transmission of the same packet. The terminal receiver has to store the received samples as soft values. This operation needs more fast memory. The reasonable terminal memory size is limited.

Non-identical retransmission is also called incremental redundancy. It uses different code rates for different retransmissions. The relative number of parity bits to systematic bits is variable as well. This solution requires more memory in the receiver and has been accommodated to the user capabilities. The terminal, with identical parameters but larger soft memory capability, can manage incremental redundancy even at the maximum data rate.

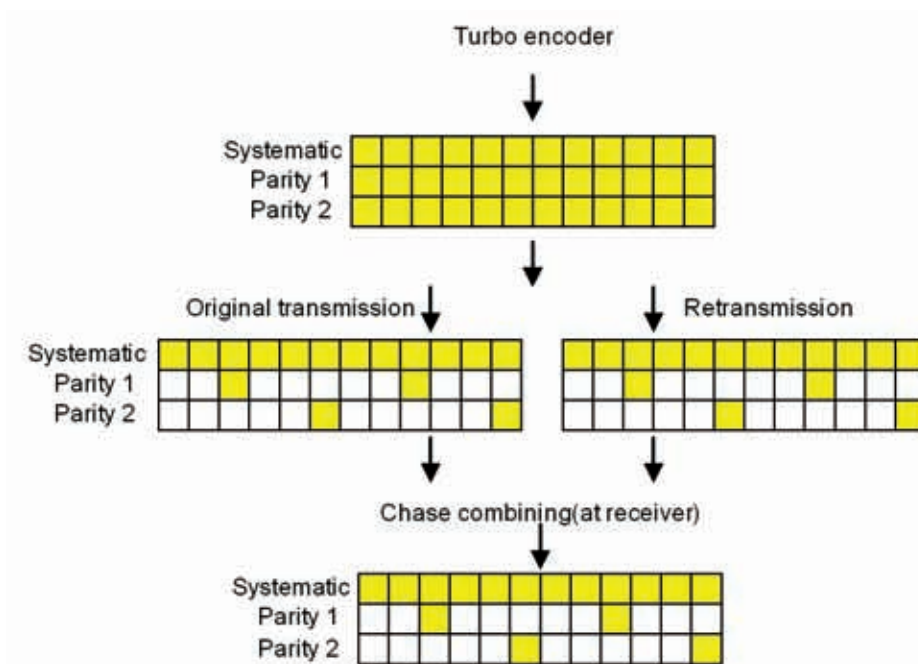


Figure 10. Chase (soft) combining principle with identical retransmissions

Slika 10. Primjer kombiniranja uz identičnu retransmisiju

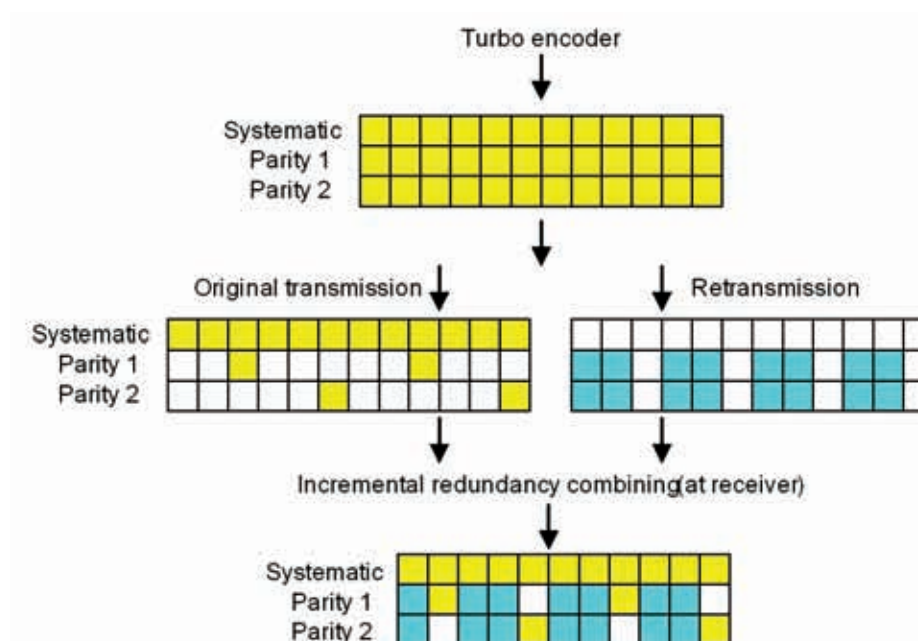


Figure 11. Principle with non-identical retransmissions

Slika 11. HARQ princip s različitom retransmisijom

HSDPA terminal categories / Kategorije HSDPA korisničkih uređaja

HSDPA requires new user equipments (UE). An HSDPA-enabled UE must contain the processing power to handle fast hybrid ARQ, multi-code processing, etc. Twelve different terminal categories have been defined to accommodate low- and high-end implementations, as shown in Table 1.

Difference between terminals categories includes, for instance, the support of modulation scheme QPSK, 16QAM and/or 64QAM. Categories 6 and 12 support

3.6 Mbps and 1.8 Mbps respectively, with five HS-DSCH codes. Another distinction is the number of codes supported by the UE. For instance the UE that supports ten codes can achieve up to 7.2 Mbps where a 15-code UE supports rates of up to 14 Mbps. The initial HSDPA devices were based on Category 12 and they support the maximum bit rate on Layer 1 of 1.8 Mbps. Category 6 data cards and handheld devices are already being introduced, the rate is increased to 3.6 Mbps. Category 8 devices, introduced in the first quarter of 2007, offer peak data rates of 7.2 Mbps (Mulvey, 2007).

Table 3. HSDPA terminal categories
Tablica 3. Kategorije HSDPA korisničkih uređaja

Category	Max. number of HS-DSCH codes	Modulation	MIMO	Max. data rate [Mbit/s]
1	5	QPSK, 16QAM	-	1.2
2	5	QPSK, 16QAM	-	1.2
3	5	QPSK, 16QAM	-	1.8
4	5	QPSK, 16QAM	-	1.8
5	5	QPSK, 16QAM	-	3.6
6	5	QPSK, 16QAM	-	3.6
7	10	QPSK, 16QAM	-	7.2
8	10	QPSK, 16QAM	-	7.2
9	15	QPSK, 16QAM	-	10.1
10	15	QPSK, 16QAM	-	14.4
11	5	QPSK	-	0.9
12	5	QPSK	-	1.8
13	15	QPSK, 16QAM, 64QAM	-	17.6
14	15	QPSK, 16QAM, 64QAM	-	21.1
15	15	QPSK, 16QAM	+	23.4
16	15	QPSK, 16QAM	+	27.9
19	15	QPSK, 16QAM	+	35.3
20	15	QPSK, 16QAM, 64QAM	+	42.2



Figure 12. Ultra-portable notebook and digital camera, with built in HSPA connectivity
Slika 12. Prijenosno računalo i digitalna kamera s ugrađenom HSPA tehnologijom

HSUPA KEY TECHNOLOGIES / HSUPA ključne tehnologije

Introduced in WCDMA 3GPP Release 6, HSUPA adds a new transport channel to WCDMA called Enhanced Dedicated Channel (E-DCH) (Ericsson white paper, 2007). Third Generation Partnership Project (3GPP) term was not HSUPA, but enhanced dedicated channel (E-DCH). The usage of the term 'HSUPA' instead of E-DCH follows the trend that began with the employment of the term 'HSDPA'; and using the term 'HSUPA' synonymously for corresponding 'uplink improvement' has been widely adopted in the wireless industry, though not officially covered in 3GPP specifications. Enhanced Uplink improves uplink performance with reduced latency, increased data rates and increased capacity, making it a natural complement to HSDPA (introduced in Release 5) for high-performance packet data applications. Enhanced Uplink transmission provides several new features. As with HSDPA, introducing these new features has minimal impact on the existing radio interface protocol architecture. New MAC entities are also introduced alongside the existing ones in the UE, base station and the RNC. High uplink bit-rates are desirable from both system and end-user perspectives. It is also very important that a relatively high data rate is likely to be supported wherever a user is located – that is, coverage of a given data rate should be as high as possible. As with HSDPA, Enhanced Uplink can use the same frequency carrier as Release 99. In order to meet these targets, Enhanced Uplink supports several new features:

- Multi code transmission,
- Short Transmission Time Interval,
- Fast hybrid Automatic Repeat request,
- Fast scheduling.

While similar techniques have been applied for HSDPA, there are some fundamental differences between the uplink and the downlink. The shared resource in the uplink is the interference (total received

power) at the base station, which depends on the decentralized power resource in each UE. In the downlink, the shared resource consists of transmission power and channelization codes, and is centralized to the base station. This difference has implications for the scheduler design.

In contrast to HSDPA, the new uplink channel, that is introduced for Enhanced Uplink, is not shared between users, but is dedicated to a single user. Up to four codes can be used to increase the uplink data rate.

Short Transmission Time Interval / Kratko vrijeme odašiljanja

WCDMA 3GPP Release 99 uses a TTI of 10 ms, 20 ms or 40 ms in the uplink.

Enhanced Uplink operates with a TTI of 2 ms or 10 ms in the uplink. A short TTI enables significant reduction in the overall latency and provides the means for the other features to adapt rapidly.

Fast hybrid Automatic Repeat request / Brzi hibridni automatski zahtjev za ponovnim slanjem podataka

The fast hybrid ARQ protocol is similar to the one used for HSDPA. The base station can rapidly request retransmission of erroneously received data, which provides better robustness and lower retransmission latencies. Soft handover is possible with Enhanced Uplink. For a soft handover, all involved base stations and sectors attempt to decode the data. If an ACK is received from at least one of them, the UE considers the data to be successfully received. Fast hybrid ARQ with soft combining can be exploited not only to provide robustness against unpredictable interference, but also to improve link efficiency.

Fast scheduling / Brzo raspoređivanje

In the uplink, the common resource shared among the terminals is the amount of tolerable interference; that is,

Table 4. HSDPA, HSUPA and DCH comparison table
Tablica 4. Tablica usporedbe HSDPA, HSUPA i DCH tehnologija

Feature	DCH	HSDPA (HS-DSCH)	HSUPA (E-DCH)
Variable spreading factor	Yes	No	Yes
Fast power control	Yes	No	Yes
Adaptive modulation	No	Yes	No
BTS based scheduling	No	Yes	Yes
Fast L1 HARQ	No	Yes	Yes
Soft handover	Yes	No	Yes
TTI length [ms]	80,40,20,10	2	10, 2

the total received power at the base station. The amount of common uplink resources, a terminal is using, depends on the data rate used. Generally, the higher the data rate, the larger the required transmission power and the higher the resource consumption.

Fast scheduling enables rapid resource reallocation between UEs, exploiting the 'burstiness' in packet data transmissions. It also enables the system to admit a larger number of high-data rate users and rapidly adapts to interference variations – leading to an increase both in capacity and the likelihood that a user will experience high data rates.

The scheduling algorithm is not standardized and different scheduling strategies can be implemented. This flexibility is useful, as different environments and traffic types can have different requirements on the scheduling strategy. A UE can, for instance, be scheduled from just one base station or from several base stations at the same time. In the latter case, soft handover must be supported for the Enhanced Uplink. The UE is not only informed about the interference level in its own cell, but also about interference levels in the neighboring cells. The UE output power can be reduced if the interference level is too high in the neighboring cells. Soft handover, supported in the uplink, provides a macro diversity gain of 1.5 dB.

Enhanced Uplink terminal categories / Kategorije korisničkih uređaja s naprednom uzlaznom vezom

Enhanced Uplink will require new UEs, which must have the processing power to handle the new functionality described above. Six different terminal categories have been defined to accommodate low- and high-end implementations, as shown in Table 5. The distinctions between terminal categories include the TTI time supported. Some categories support TTI of only 10 ms, while others support both 2 ms and 10 ms. Another difference is the number of codes used and their spreading factor. The initial Enhanced Uplink devices are based on the Category 3 and support the maximum bit-rate on Layer 1 of 1.4 Mbps.

FUTURE TRENDS / Daljnji razvoj

HSPA is evolving further over the time. Different enhancements are being introduced in different 3GPP releases. With HSPA evolved, higher-order modulations can be supported in both the uplink (16QAM) and downlink (64QAM). 16QAM modulation enables peak data rates of up to 12 Mbps in the uplink, while 64QAM modulation enables peak data rates of up to 21 Mbps in the downlink. In addition, 2x2 MIMO (Multiple Input Multiple Output) is supported in the downlink with HSPA evolved. It uses two antennas and effectively doubles the peak rate in the downlink enabling the peak data rate of 28 Mbps. When 2x2 MIMO is combined with 64QAM, the peak data rate of up to 42 Mbps is enabled in the downlink. Latency will also be further reduced with HSPA evolved.

Further work for long-term evolution is going to be based on pursuing single-carrier frequency division multiple access (SC-FDMA) for the uplink transmission and orthogonal frequency division multiplexing (OFDM) in the downlink direction. SC-FDMA means having frequency resource allocated to one user at a time (sharing is also possible) which achieves similar orthogonal uplink as in the OFDM principle. The reason for not taking OFDM in the uplink as well is in the resulting poor signal waveform properties for high-performance terminal amplifiers. With SC-FDMA there is a cyclic prefix added to the transmission to enable low-complexity frequency domain equalization in the base station receiver.

CONCLUSION / Zaključak

The only constant in mobile networks is the continuous progress of quality and quantity of services. The HSDPA offers few times better performance compared to UMTS. It provides the end user a wide range of applications and more comfortable use of the existing applications. Thus, if WCDMA penetration continues broader HSDPA deployment may be expected. Its implementation is very simple and an UMTS network can be upgraded at a low cost.

Table 5. HSUPA terminal categories
Tablica 5. Kategorije HSUPA korisničkih uređaja

UE Category	Codes x spreading	TTI 10 or 2 ms	Layer 1 peak rate 10 ms TTI	Layer 1 peak rate 2 ms TTI
Category 1	1 x SF4	10 ms	0.73 Mbps	-
Category 2	2 x SF4	Both	1.46 Mbps	1.46 Mbps
Category 3	2 x SF4	10 ms	1.46 Mbps	-
Category 4	2 x SF2	Both	2.0 Mbps	2.96 Mbps
Category 5	2 x SF2	10 ms	2.0 Mbps	-
Category 6	2 x SF2 + 2 x SF4	Both	2.0 Mbps	5.76 Mbps

REFERENCES / *Literatura*

1. 3GPP, Technical Specification Group RAN, Physical channels and mapping of transport channels onto physical channels (FDD), 3GPP TS 25.211 version 6.7.0, Release 6, 2005. from www.3gpp.org
2. 3GPP, Technical Specification Group RAN, Multiplexing and channel coding (FDD), 3GPP TS 25.212 version 6.7.0, Release 6, 2005. from www.3gpp.org
3. 3GPP, Technical Specification Group RAN, Spreading and modulation (FDD), 3GPP TS 25.213 version 6.4.0, Release 6, 2005. from www.3gpp.org
4. Ericsson white paper. 284 23-3087. Basic concepts of HSPA (2007, February), available at http://www.ericsson.com/technology/whitepapers/3087_basic_conc_hspa_a.pdf
5. Ericsson white paper. 284 23-3119. HSPA, the undisputed choice for mobile broadband (2007, May), available at http://www.ericsson.com/technology/whitepapers/HSPA_the_undisputed_choice_for_mobile_broadband_Rev_a.pdf
6. Holma, H., & Toskala, A. (2006). HSDPA/HSUPA for UMTS. Chichester, UK: John Wiley & Sons.
7. Holma, H., & Toskala, A. (2004). WCDMA for UMTS (3rd ed). Chichester, UK: John Wiley & Sons.
8. Ishii, H., & Hanaki, A., & Imamura, Y., & Tanaka, S., & Usuda, M., & Nakamura, T. (2004, May). Effects of UE capabilities on high speed downlink packet access in WCDMA systems. Vehicular Technology Conference, 2077 - 2085
9. Love, R., & Ghosh, A., & Weimin Xiao, & Ratasuk, R. (2004, September). Performance of 3GPP high speed downlink packet access (HSDPA). Vehicular Technology Conference, 3359 - 3363
10. Medvid, I. (2006, January). Prikaz funkcionalnosti brzog paketnog pristupa silaznom vezom. Ericsson revija, 5-18.
11. Modlic, B., & Modlic, I. (1995). Modulacije i modulatori. Zagreb, Croatia: Školska knjiga.
12. Mulvey, D. (2007, March). HSPA. Communications Engineer, 38 - 41
13. Peisa, J., & Wager, S., & Sagfors, M., & Torsner, J., & Goransson, B., & Fulghum, T., & Cozzo, C., & Grant, S. (2007, April). High Speed Packet Access Evolution - Concept and Technologies. Vehicular Technology Conference, 819 - 824
14. Tao Chen, & Huibin Lin, & Zhigang Yan, & Jing Liu, & Muller, A. (2005, September). Code utilization in HSDPA. Wireless Communications, Networking and Mobile Computing, 389 - 392.
15. Voigt, J., & Deissner, J., & Hubner, J., & Hunold, D., & Mobius, S. (2005). Optimizing HSDPA performance in the UMTS network planning process. Vehicular Technology Conference, 2384 - 2388
16. Zanier, P., & Soldani, D. (2005, September). A simple approach to HSDPA dimensioning. Personal, Indoor and Mobile Radio Communications, 883 - 887

Rukopis primljen: 27. 10. 2009.

