

HSDPA performance and evolution

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Operators around the world are rapidly introducing high-speed downlink packet access (HSDPA) services into their WCDMA networks. On September 22, 2006, fifty-nine networks already offered commercial HSDPA services.

The authors present the results of HSDPA measurements made in live, commercial networks supplied by Ericsson. They also describe WCDMA hardware and software features from Ericsson that contribute to these excellent results. Finally, they describe future enhancements to HSDPA technology that will further improve performance.

Market situation

HSDPA is making impressive inroads in the commercial service arena. On September 22, 2006, the Global mobile Suppliers Association (GSA) reported that 121 HSDPA networks had been planned, were being deployed, or had been launched. Moreover, 59 of these already offered commercial HSDPA services. Likewise, 58 HSDPA devices had been launched as of September 18, 2006.¹

Numerous operators thus do already, or will soon, offer mobile data services based on HSDPA. To target mobile as well as fixed usage, many operators have also introduced attractive pricing strategies with flat-rate tariffs. In some cases, HSDPA represents the first opportunity end users have had to access broadband services because fixed broadband access has not been available where they work or live.²⁻³

HSDPA-capable devices

The majority of HSDPA devices launched to date are category-12 devices – that is, they support a maximum of five HSDPA codes and QPSK modulation.⁴ The maximum speed (layer-1 peak rate) of category-12 devices over the air interface is 1.8Mbps. After making adjustments for radio-protocol overhead, the peak rate for layer-2 (MAC-hs) error-free transmission is 1.6Mbps. And because the HSDPA systems target a radio block error rate (BLER) of 10%, the available radio bandwidth to end users is 1.5Mbps. HSDPA devices that support 16QAM modulation have also recently been released. These category-6 devices have a maximum speed of 3.6Mbps over the air interface; end-user bandwidth is 3.1Mbps.

Measuring HSDPA performance

The measurements made using category-12 (QPSK only) terminals were conducted

in Europe during the first half of 2006 in commercial WCDMA networks supplied by Ericsson. The measurements made using category-6 terminals were carried out in live networks in Asia in August 2006. In both cases, the results are comparable with predictions of previous theoretical analysis.⁵

Results from live networks

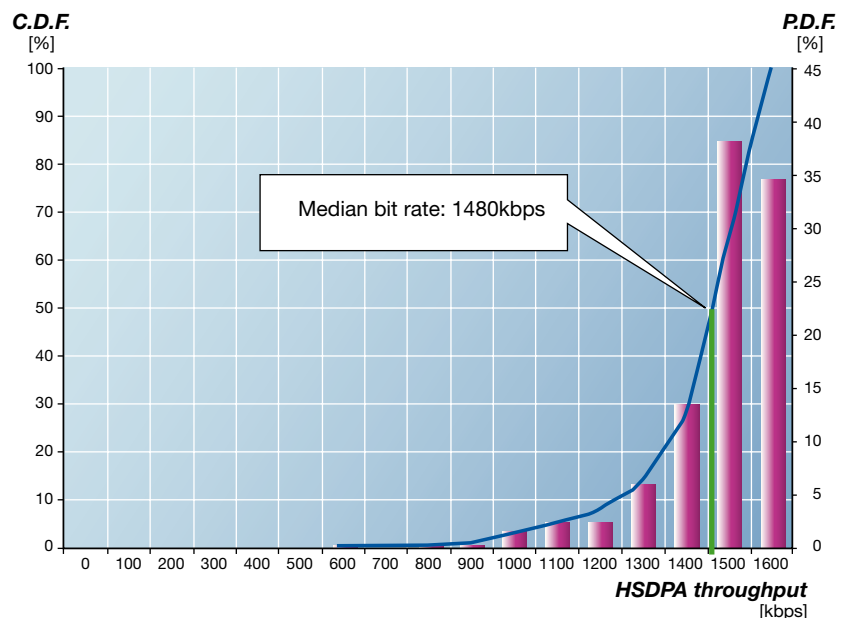
HSDPA throughput

The test area for measurements using category-12 terminals consisted of 40 HSDPA sites generally separated by a site-to-site distance of 500m. The test environment was typical urban with a mix of offices, shopping and restaurant areas, living areas, and an open area. The network contained live R99 traffic (voice and data) and HSDPA traffic on the same frequency car-

rier. All measurements were made on layer-2 (MAC-hs) which, given a 10% retransmission rate for the HSDPA channel, has a maximum bit rate of 1.5Mbps. Three test cases were defined in the test area:

- Good: Stationary testing with good signal strength close to the transmission site (Figure 1). Measurements showed that performance was very close to the maximum theoretical bit rate of 1.5Mbps (including the 10% retransmission rate). Moreover, only a fraction of RBS output power was used.
- Poor: Stationary testing with poor signal strength at the edge of the WCDMA coverage area (Figure 2). The median bit rate was 0.9Mbps. This positive result shows the potential to reach very good HSDPA bit rates even in poor radio environments. Therefore, HSDPA performance deep inside indoor environments can still be good. The good throughput, in spite of poor radio conditions, can be attributed to the ability of the radio base station (RBS) to transmit all available output power to HSDPA devices – thanks to flexible allocation of power between HSDPA and R99 traffic.
- Mobile: Testing in an area covered by 12 sites. Approximately 100 cell changes took place during the test, which consisted of one hour of driving (Figure 3). The median

Figure 1
HSDPA bit-rate: stationary during good radio conditions.



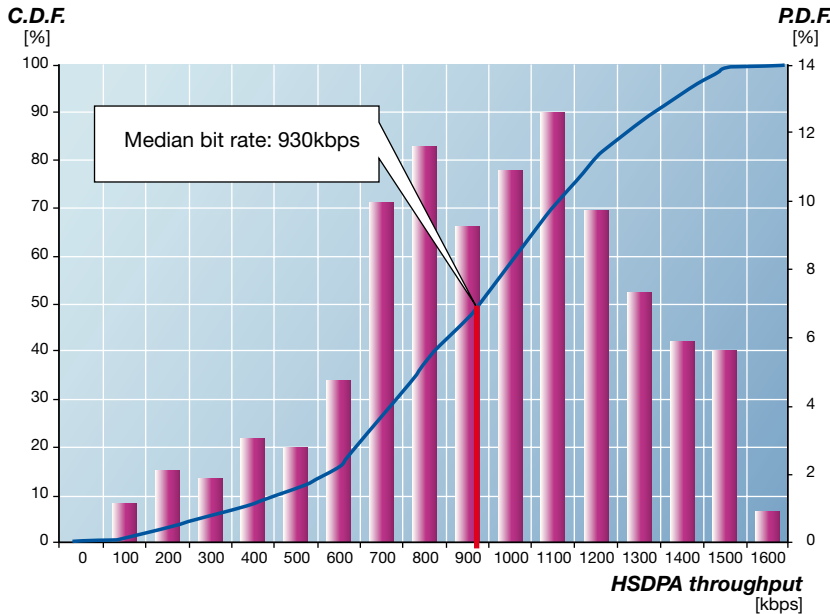
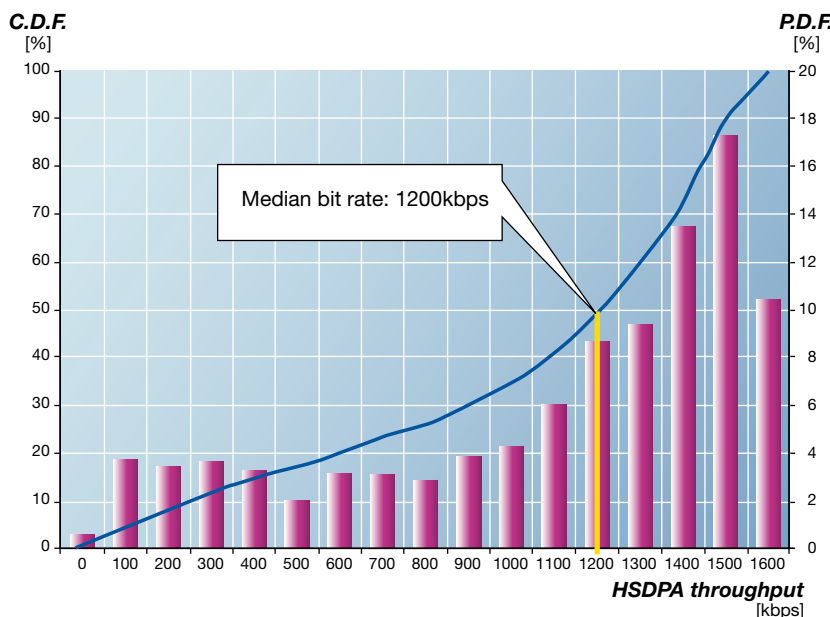


Figure 2
HSDPA bit-rate: stationary during poor radio conditions.

Figure 3
HSDPA bit-rate: mobile test.



bit rate was 1.2Mbps. There was a large spread of HSDPA bit rates, because the HSDPA device passed through a variety of radio conditions along the drive route. The HSDPA bit rate adapted quickly to the different radio conditions.

In virtually every situation, the HSDPA device enjoyed better download bit rates than R99 devices.

Thanks to the recent availability of category-6 terminals, it is now also possible to evaluate the performance of higher-order modulation (16QAM). The potential of using 16QAM is up to double that of the QPSK-only bit rate. Measurements with 16QAM devices under good radio conditions in a live network showed a throughput of 3.1Mbps. In a mobile environment, the measured throughput for a pedestrian end user was 2.1Mbps; the bit rate for an end user in a car driving at 60km/h was 1.7Mbps. In a poor radio environment, the measured throughput was 1.5Mbps. These results clearly show that 16QAM significantly increases the bit rates in live networks.

Latency

End-to-end latency, which is the average time it takes for a small IP packet to travel from a mobile terminal (or laptop) through the HSDPA system to an internet server and back, is a critical component that affects end-user perception of TCP/IP-based applications. Latency has been measured in numerous commercial HSDPA networks. Depending on network design and core network supplier, the average latency in WCDMA radio access networks supplied by Ericsson is between 70 and 95ms. The measured average end-to-end latency in a finely tuned commercial network with core and radio equipment from Ericsson was 70ms.

Performance

Ericsson has a powerful HSDPA implementation with many strong features that optimize HSDPA performance.

RBS design

A robust and efficient base station architecture enhances HSDPA performance.⁶ Rapid (500 times per second) and dynamic allocation of output power, ultra-linear power amplifiers, transmit (TX) chain linearity, and fast congestion control (1500 times per second) contribute significantly to the positive results reported in this article. In particular, the excellent results in the mobile and poor

radio test environments are directly attributable to radio base station design. Ericsson's base stations, for example, optimally share output power between HSDPA and non-HSDPA traffic every transmission time interval (500 times per second) without the need for partitioning.

Single-carrier implementation

Operators who add HSDPA to a WCDMA network can reuse the existing cell carrier, mixing HSDPA and non-HSDPA (voice and data) traffic. A second cell carrier should only be added when the combined (anticipated or measured) traffic in the cell justifies this extra investment.

CQI adjustment

Mobile devices report the quality of the downlink channel via channel quality indicator (CQI) reports to the mobile network. Using these reports, the system continuously optimizes performance (at 10% BLER) by choosing the best transmission speed for the next TTI.

Not all devices report CQI in the same way, however, which can lead to inefficient usage of network resources and unfair treatment of end users in the scheduler. Ericsson has thus developed a CQI adjustment feature that looks at the number of acknowledgements and non-acknowledgements in previous transmissions to an end user and adjusts the reported values to correspond with the actual quality of the downlink channel. CQI adjustment stabilizes BLER for the HSDPA channel. In the mobile drive test, for example, it reduced BLER from 41% to 10%.

HSDPA mobility

The drive test included around 100 hand-offs between sites and sectors (Figure 4). The HSDPA standard stipulates that HSDPA end-user traffic may derive from only one cell carrier at a time. Notwithstanding, in Ericsson's implementation, the associated signaling channels in both the uplink and downlink can be connected to different sectors of the same site (softer handover) and to sectors of different sites (soft handover) at the same time. Based on continuous evaluation of the quality of the links from every involved sector, the system determines which cell can most favorably carry end-user HSDPA traffic. Changes to other sectors can be made almost instantaneously without having to fall back to R99-based data channels. This greatly improves mobile HSDPA performance.

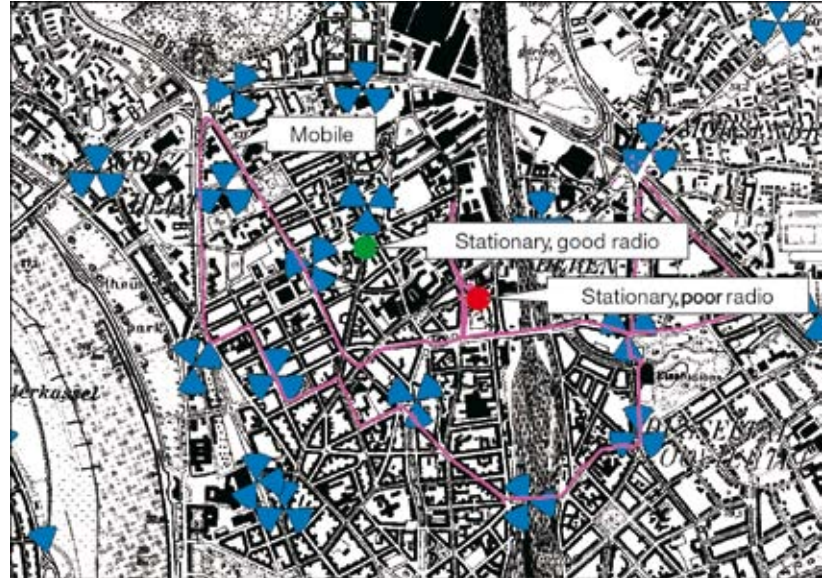


Figure 4
The mobile drive route (purple) and the location of the stationary testing spots (green = good radio conditions; red = poor radio conditions).

Results from the tests show that cell changes did not have a negative impact on file transfers and internet browsing. A high bit rate was maintained, and the very short radio interruptions caused virtually no noticeable delay for the tested applications.

Future developments

The first commercial HSDPA services and network implementations have proven to be attractive and robust, providing significant improvement over other technologies. But this is just the beginning – future enhancements will include code multiplexing, more HSDPA codes and dynamic code allocation, advanced receiver technologies, enhanced schedulers, enhanced uplink (E-UL) and evolution of the standards.

Code multiplexing

With HSDPA, data transmission can be divided in time and codes (code multiplexing) to accommodate several users per transmission time interval (TTI). Code multiplexing makes it possible to use all available codes per TTI, even if the codes are not all supported by a given end-user's device. For instance, three users with a five-code device can be served simultaneously during the same TTI. Code multiplexing also enables combined transmissions when several users' RBS-

buffered data does not fill up an entire TTI. It can even reduce delay for active end users in a cell by reducing waiting time while transmissions are being scheduled.

Delay-sensitive applications with short, bursty data packages, such as voice over IP (VoIP), will benefit from code multiplexing when HSDPA usage increases in a network.⁷

More HSDPA codes and dynamic code allocation

The introduction of end-user devices that can handle 10 or even 15 codes will increase maximum transmission rates to 14.4Mbps. At the same time, however, it will become necessary to allocate codes dynamically, because fixed allocation of 10 to 15 codes on a sector carrier for HSDPA seriously reduces the available codes for R99 traffic. During periods of high voice load, the codes should be assigned to voice and R99 data traffic. The rest of the time, they can be used for additional HSDPA traffic, especially when used in combination with code multiplexing. For this purpose, Ericsson has implemented a unique dynamic code-allocation feature. The ability to mix HSDPA and non-HSDPA traffic reduces the need for early introduction of extra cell carriers, thereby increasing spectrum efficiency and reducing network-related capital expenditures (CAPEX) and operating expenses (OPEX).

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Advanced receiver technology

The introduction of advanced receiver technologies, such as generalized Rake (G-Rake) and receive diversity, in end-user devices will improve downlink channel quality and increase HSDPA speed. In contrast to Rake receivers, which solely try to optimize the signal, G-Rake receivers optimize the signal-to-impairment ratio (S/I) by both maximizing the signal and minimizing interference.⁸ Gains from G-Rake technology can be enhanced further with a receive-diversity antenna solution.

QoS and enhanced scheduler design

As a shared resource, HSDPA employs schedulers in the RBS to allocate available resources to end users. As HSDPA traffic in

the network increases, it will become more and more important to choose a scheduler strategy that best fits the traffic mix in the cell.

Future schedulers will prioritize certain traffic streams in order to improve the performance of end-user applications. VoIP, streaming sessions, and traffic for premium users, for instance, can be prioritized ahead of other traffic. This will allow operators to differentiate their service offering in terms of applications and end-user support.

Enhanced uplink

Enhanced uplink (E-UL), introduced in 3GPP Release 6, will enable speeds of up to 5.8Mbps in the uplink. Ericsson has been demonstrating E-UL since March 2005. The

first commercial products should reach the market in the beginning of 2007. The combination of HSDPA and E-UL is called high-speed packet access (HSPA).

Apart from improving uplink performance, E-UL improves HSDPA performance by making more room for acknowledgement traffic and by reducing overall latency.

Standards evolution

At present, work is underway to standardize the next releases of 3GPP, thereby ensuring that future end-user and operator requirements and expectations will be met. The main objectives are to further improve service provisioning and reduce end-user and operator costs. These objectives will be met by providing higher data rates, reducing latency, and increasing system capacity. The evolution of HSPA (called HSPA evolution) and the long-term evolution of 3G (LTE) are being discussed for future releases.

HSPA evolution targets data speeds of 40Mbps in the downlink and 12Mbps in the uplink on 5MHz of bandwidth. This can be achieved by introducing multilayer transmission, also called multiple input, multiple output (MIMO) transmission. MIMO can be used to increase data rates by transmitting parallel streams to a single end-user in combination with higher-order modulation in the uplink and downlink. Ericsson's demonstration of HSPA with MIMO at the CTIA Wireless 2006 event in Las Vegas, USA, showed downlink speeds of up to 28Mbps.

LTE is a new access technology that targets data speeds of 100Mbps in the downlink and 50Mbps in the uplink on 20MHz of bandwidth.⁹

Conclusion

HSDPA is rapidly becoming a commercial reality in numerous networks around the world. Measurements made in live networks show impressive performance. The strengths of Ericsson's WCDMA radio network design

- positively influence end-user perception of HSDPA performance; and
- minimize the need for operators to deploy additional cell carriers in order to support new HSDPA services.

Following a strong start, HSDPA will continue to evolve through numerous performance enhancements that will both make HSDPA services more appealing to end users and provide the system capacity that is needed to support rapid HSDPA service uptake.

TERMS AND ABBREVIATIONS

3GPP	Third Generation Partnership Project	MAC-hs	Media access control for HSDPA
16QAM	16-quadrature amplitude modulation	MIMO	Multiple input multiple output
BLER	Block error rate	OPEX	Operating expenditure
CAPEX	Capital expenditure	PDF	Probability distribution function
CDF	Cumulative distribution function	QoS	Quality of service
CQI	Channel quality indicator	QPSK	Quadrature phase-shift keying
CTIA	Cellular Telecommunications Industry Association	R99	3GPP release 99
E-UL	Enhanced uplink	RAN	Radio access network
GSA	Global mobile Suppliers Association	S/I	Signal-to-impairment ratio
HSDPA	High-speed downlink packet access	TCP	Transmission control protocol
HSPA	High-speed packet access	TTI	Transmission time interval
IP	Internet protocol	TX	Transmit
LTE	Long term evolution (of 3G)	WCDMA	Wideband code-division multiple access