

Continued HSPA Evolution of mobile broadband

The success of mobile broadband is driving the demand for higher data rates and greater cell capacity. The industry is addressing this demand by evolving HSPA through 3GPP Releases 7, 8 and 9.

✦ JOHAN BERGMAN, DIRK GERSTENBERGER, FREDRIK GUNNARSSON AND STEFAN STRÖM

Operators can study HSPA performance by simulating realistic deployments of 3GPP Release 7. Looking ahead, HSPA will need to support the growing success of mobile broadband. This implies even more high-volume users with high bit-rate requirements, lower latency, and longer battery times. Accordingly, Release 8 features multicarrier operation, higher-order modulation in combination with MIMO, and enhancements to common states. For Release 9, 3GPP is discussing support for more than 100Mbps using up to 20MHz of spectrum.

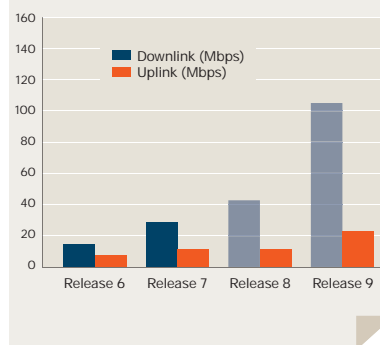
WCDMA/UMTS and HSPA are a huge global success. There are now more than 300 million WCDMA/UMTS subscribers. Of these, more than 60 million have high-speed packet access (HSPA), and this group is growing by four million subscribers a month. Having been deployed in more than 200 commercial networks, and representing 90 percent of the UMTS networks in 100 countries, HSPA now accounts for 70 percent of the traffic in UMTS networks worldwide. The key driver of this development is increased usage of mobile broadband

access. Therefore, in addition to deploying the downlink part of HSPA, 50 global operators have already deployed the enhanced uplink (EUL) functions introduced in 3GPP Release 6.¹

Most existing HSPA networks are based on the high-speed downlink packet access (HSDPA) and Enhanced Uplink functionality introduced in 3GPP Releases 5 and 6. However, all current commercial network deployments are being based on 3GPP Release 7, which thanks to higher-order modulation and support of multiple input, multiple output (MIMO) technology in the downlink, supports data rates of up to 28Mbps in the downlink and 11.5Mbps in the uplink. Other Release 7 features, such as continuous packet connectivity (CPC) and enhanced CELL_FACH state, improve capacity and battery times in user equipment (UE).²

The work of standardizing 3GPP Release 8 is now also complete. In the downlink, using either a combination of MIMO and 64QAM or dual-cell HSDPA for operation on two 5MHz carriers with 64QAM, data rates reach up to 42Mbps. Additional Release 8 features include enhancements to the common states, and Integrated Mobile Broadcast (IMB), which gives existing

FIGURE 1 Evolution of HSPA peak data rates by 3GPP Release.



WCDMA operators a cost-effective way of broadcasting data via 5MHz of unpaired spectrum.²

The evolution of HSPA does not stop there, however. Ongoing work to standardize 3GPP Release 9 focuses on the support of features that further increase bit rates: more than 100Mbps using three to four 5MHz blocks of downlink spectrum, and 23Mbps using two 5MHz blocks of uplink spectrum.

Release 7 performance

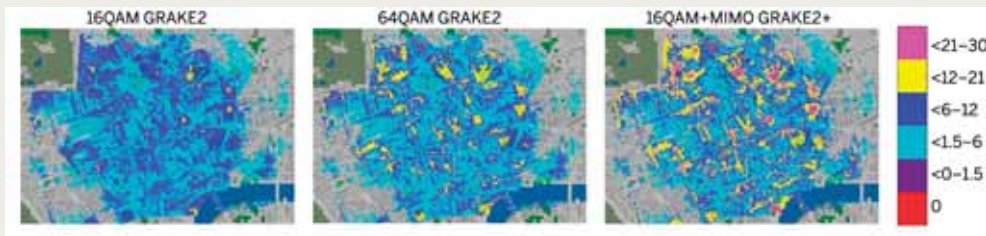
Worldwide network measurements show a clear and rapid growth in packet data carried over HSPA. For this reason, the importance of predicting HSPA performance in a real network environment has also increased.

Several factors affect networks and slow throughput rates. Examples include non-optimized RBS site positions, propagation losses (due, for example, to buildings), antenna feeder cable losses, and non-optimized tilt angles and parameter settings. These aspects cause performance to deviate from the theoretical 3GPP peak rates. ❧

BOX A Terms and abbreviations

3GPP	Third Generation Partnership Project	IMB	Integrated mobile broadcast
CPC	Continuous packet connectivity	MIMO	Multiple input, multiple output
DRX	Discontinuous reception	QAM	Quadrature amplitude modulation
EUL	Enhanced uplink	UE	User equipment
HARQ	Hybrid automatic repeat request	UTRAN	UMTS terrestrial radio access network
HSDPA	High-speed downlink packet access	WCDMA	Wideband code-division multiple access
HSPA	High-speed packet access		

FIGURE 2 HSPA Evolution downlink bit rates in Mbps over the analyzed area, 15 allocated DL codes.



❖ Predicted live network performance with 3GPP Release 7

To assess the performance of HSPA Evolution technology in realistic network deployments, researchers have combined detailed network information with comprehensive and flexible simulation tools. The procedure has employed network modeling in TEMS CellPlanner®, live network traffic data and forecasts, and dedicated simulation tools.⁵ The scenario was based on a major city network in Western Europe. To limit the number of feature combinations, only the downlink was presented. Furthermore, the features were combined as they are expected to appear in products:

- ❖ The baseline (3GPP Release 6) consists of mobile terminals that use 16QAM and GRAKE2 (type 3) receivers.⁶
- ❖ More advanced mobile terminals use 64QAM.
- ❖ The most advanced mobile terminals support 16QAM and MIMO. They also feature GRAKE2+ (type 3i) receivers and employ inter-cell interference suppression.

The cell-planning tool was configured with detailed information about the network. This information included site positions, antenna heights and orientations, and tilt angles. In addition, a high-resolution map of the area was used that provided terrain elevations, land usage and detailed building information. In the studied example, about 50 percent of the area is covered with buildings. With this setup, a propagation model (developed by Ericsson and tuned with measurements from the area) predicted the path loss to every part of the area.

Using recorded traffic data, the pro-

cedure also predicted traffic volume per cell, including the anticipated indoor/outdoor traffic volume ratio.

The high-speed data traffic load model shows the probability of the RBS transmitting in a given cell (air interface utilization). Utilization depends on the served data volume per cell and user throughput. The higher the user throughput, the faster the buffers are emptied, which leads to lower utilization. The served traffic volume per cell during one hour (3600 seconds) is calculated as follows:

$$\text{throughput} \times \text{utilization} \times \text{time}$$

Therefore, given the 16QAM starting point in Figure 4, a throughput of 7Mbps and 5 percent utilization serves a data volume demand of $7 \times 0.05 \times 3600 = 1260$ megabits or 0.16 gigabytes per hour.

This volume – the served traffic volume per hour per cell (expressed as gigabytes per hour per cell) – is used for comparing the features of HSPA Evolution.

To further evaluate performance over the area, researchers transferred the traffic data as well as path loss and network-configuration information derived using the cell-planning tool to a dedicated simulation tool.

Downlink performance of HSPA Evolution: low load scenario

When first deployed, HSPA Evolution techniques will be used on a limited basis. It is anticipated, for example, that air interface utilization will be just 10 percent. This means that few other cells will contribute to inter-cell interference at any given time. Figure 2 illustrates the perceived bit rate of a scheduled user (visualized in terms of bit rates over the

analyzed area). The merits of 64QAM, MIMO and advanced UE receivers are evident.

The rate coverage plots indicate the variation of the downlink rates relative to distance from the base station, interference level, and building losses. Large indoor building areas have the lowest bit rates (operators may already have provided coverage to these areas using dedicated indoor solutions, but this was not modeled).

To facilitate a relative comparison of HSPA Evolution features, Figure 3 provides cumulative distribution functions (CDF) of the bit rates in Figure 2. Compared with the baseline configuration of 16QAM and GRAKE2, it was observed that 64QAM and GRAKE2 give significant gains in 20 percent of the analyzed area, and 16QAM+MIMO with GRAKE2+ receivers give significant gains in 30 percent of the analyzed area.

Downlink performance of HSPA Evolution: increasing load

Rapid growth in HSPA data traffic in most established WCDMA networks generates considerable load in the HSPA downlink; this corresponds to larger data volumes per cell (and higher utilization). Figure 4 shows the average downlink bit rate over the service area for load levels of roughly 0.2 to 2.3GB per hour per cell. This corresponds to between 5 and 70 percent utilization of the air interface.

FIGURE 3 Bit rate CDF for 16QAM (GRAKE2), 64QAM (GRAKE2) and 16QAM+MIMO (GRAKE2+) UEs.

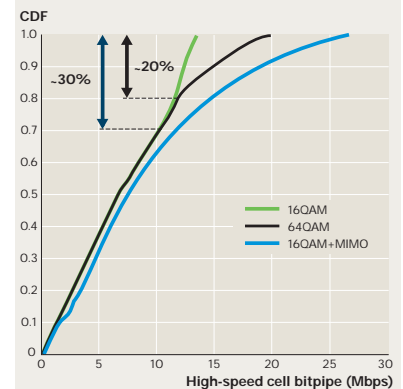
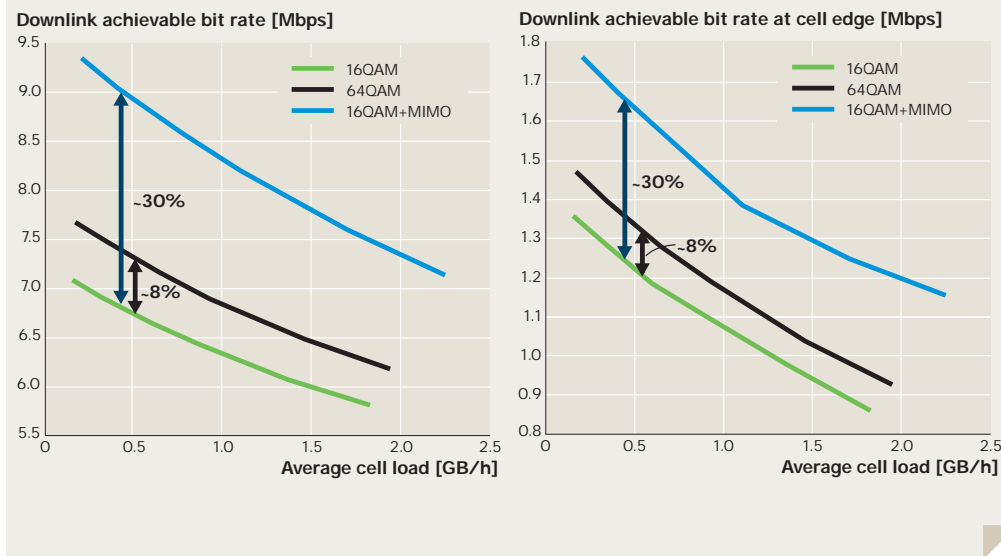


FIGURE 4 HSPA Evolution downlink bit rate over the area at 5 percent (low traffic volume) to 70 percent utilization (high traffic volume). Left: Average. Right: 10th percentile.



Compared with 16QAM with GRAKE2, 16QAM+MIMO with GRAKE2+ gives a 30 percent gain in average bit rate over the entire range of loads. In addition, the very introduction of 64QAM yields an 8 percent gain in average bit rate over the entire range of loads.

Operators can use the improved performance of 16QAM+MIMO with GRAKE2+ to boost capacity and give more users the chance to experience mobile broadband. For instance, given an average bit rate of 7Mbps, one can provide 2.3GB of data per hour in each cell. Compare this with the reference case, which is only 0.2GB per hour.

Specific focus should also be put on indoor aspects. Indeed, the majority of subscribers use mobile broadband while indoors. In many instances, they also experience the worst propagation conditions, which is to say their conditions match that of “cell edge users,” even though they are far from the edges of the cell. Figure 3 shows the bit rates at the worst 10 percent of the area, which is an indication of performance in indoor locations.

Mobile broadband service offerings put requirements on bit rates over the entire service area. That is, operators often tend to express performance goals in terms of throughput; for example,

1Mbps throughput over 90 percent of a given area.

Evaluation of features in Release 7

In the scenario presented above, the gain from MIMO and GRAKE2+ receivers in the downlink is 30 percent over a large range of loads (Figure 4). In addition, MIMO and the more advanced receivers gave significantly improved rates in 30 percent of the analyzed area and noticeable improvements in almost the entire area (Figure 3).

Alternatively, a simple software

upgrade (non-MIMO) from 16QAM to 64QAM gave an 8 percent gain in throughput rates (Figure 4). This simple measure provided a significant gain in approximately 20 percent of the area (Figure 3).

Features in Release 8

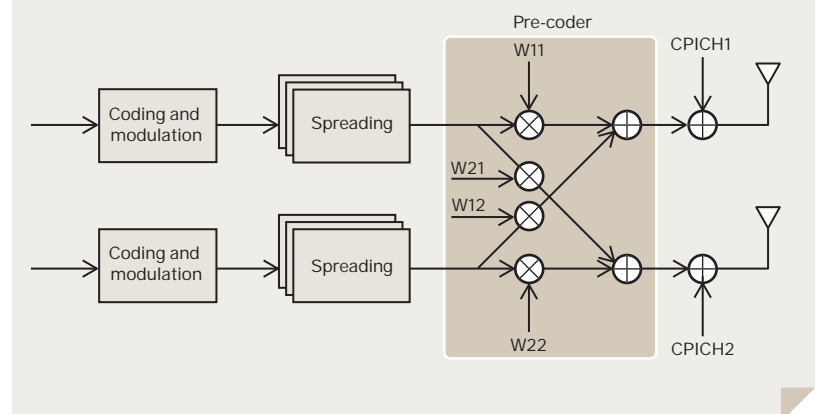
MIMO with 64QAM modulation in downlink

Release 8 combines MIMO and 64QAM modulation (two features in Release 7) to boost the peak downlink rate over a single 5MHz carrier to 42Mbps.

The term MIMO (multiple input, multiple output) refers to the use of more than one transmit antenna in the base station and more than one receive antenna in UEs. The transmitter chain for the standardized MIMO scheme applies separate coding, modulation and spreading for up to two transport blocks transmitted over two parallel streams, thereby doubling the achievable peak rate in the downlink. The UE radio propagation conditions determine how many streams (one or two) will be transmitted.

In Release 7, 16QAM is the highest-order modulation used in combination with MIMO. Therefore, four bits can be transmitted per modulation symbol, resulting in a peak rate of 28Mbps. The upgrade to 64QAM in Release 8 allows six bits to be transmitted per symbol, which increases the peak rate by 50 percent to 42Mbps. To the greatest possible extent, the introduction of MIMO with 64QAM modulation reuses the protocol changes introduced in Release 7 for MIMO and 64QAM respectively.² ❖❖

FIGURE 5 The MIMO transmitter chain.



❖ Dual-carrier operation in downlink
 In deployments where multiple downlink carriers are available, multicarrier operation offers an attractive way of increasing coverage for high bit rates. Release 8 introduces dual-carrier (adjacent carrier) operation in the downlink. This technique doubles the peak rate from 21Mbps to 42Mbps without MIMO – it doubles the rate for users with typical bursty traffic during a data burst; therefore, it also doubles the average user throughput, which translates into a substantial increase in cell capacity.³

Figure 6 shows the UTRAN side of the layer-2 (L2) architecture.⁴ A dual-carrier (the 3GPP term is dual-cell) user can be scheduled in the primary serving cell as well as in a secondary serving cell over two parallel HS-DSCH transport channels. All non-HSDPA-related channels reside in the primary serving cell, and all physical layer procedures are essentially based on the primary serving cell. Either carrier can be configured to function as the primary serving cell for a particular user. As a consequence, this technique facilitates load balancing. As with MIMO, the two transport channels perform hybrid automatic repeat request (HARQ) retransmissions, coding, and modulation independent-

ly. Unlike MIMO, however, a different number of channelization codes can be used to transmit the two transport blocks. The two carriers may thus utilize a different number of channelization codes allocated for HS-DSCH.

In terms of complexity, adding a dual-carrier receiver to UEs is roughly comparable to adding a MIMO receiver.³ Because the two 5MHz carriers are adjacent, they can be received using a single 10MHz radio receiver, which might well be the case if the UE is LTE-capable.

Enhancements to common states

Users should always be kept in the state that gives the best trade-off between data rate availability, latency, battery consumption and usage of network resources. As a complement to the data rate enhancements made to the dedicated state (CELL_DCH), 3GPP has also made significant enhancements to the common states (URA_PCH, CELL_PCH and CELL_FACH).

Release 7 introduces HSDPA mechanisms in the common states in order to improve their data rates, latency and code usage.² Release 8 introduces corresponding enhancements in the uplink, allowing base stations to configure and dynamically manage up to 32 common

BOX B
Simulating with real data

The method of using real network data in simulations may not always show the full potential of a technology, but collaborating operators appreciated the effort to create results that come as close to anticipated network performance as possible. An overview of bit rates (as shown in Figure 2) helps operators to quickly get a feel for the benefits of each new feature.

Enhanced Uplink resources in each cell. This enhancement improves latency and data rates for keep-alive messages (for example, from VPN or messenger applications) as well as web-browsing events, providing a seamless transition from EUL in common state to EUL in dedicated state.

As a further improvement of the CELL_FACH state, Release 8 introduces discontinuous reception (DRX), which significantly reduces battery consumption. DRX is now supported in all common and dedicated states.

Release 9 features

Evolved multicarrier operation in downlink

Following the introduction in Release 8 of dual-carrier operation in the downlink, 3GPP is now discussing operation on multiple 5MHz carriers.

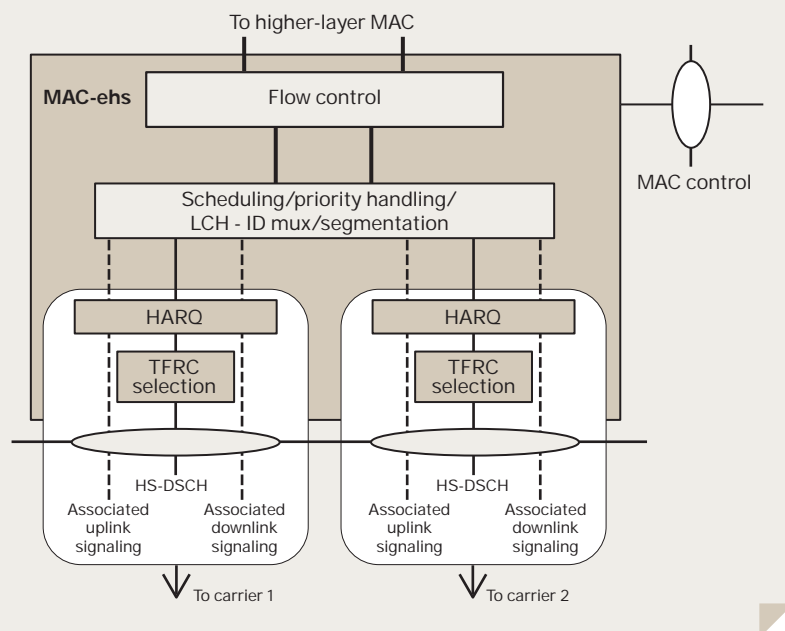
Multiband operation of multiple carriers allows a single user to simultaneously aggregate and use the spectrum distributed over different bands. This gives operators greater flexibility when using available spectrum.

Increasing the number of carriers that UEs receive from two to four doubles the peak rate and achievable user throughput. For bursty traffic, this translates into substantially greater capacity, either as a larger number of users at a given data rate, or as a higher data rate for a given number of users. To substantially boost spectral efficiency, 3GPP is studying the combination of dual-carrier operation and MIMO with 64QAM in the downlink, thereby doubling the peak data rate to 84Mbps. Similarly, they are studying the combination of MIMO, 64QAM and up to four downlink carriers to support peak data rates of more than 100Mbps.

Multicarrier operation in uplink

The enhanced data rates in the downlink call for improved data rates in the uplink. Introducing support for dual-carrier operation in the uplink will double the peak rate to 23Mbps while keeping UE complexity at a reasonable level. Initial investigations indicate that available bandwidth limits performance more than the UE transmit power. Therefore, by making use of greater bandwidth for data transmission, operators can distribute interference over

FIGURE 6 Layer-2 architecture for dual-carrier operation in the downlink.



two carriers. In summary, uplink multi-carrier operation increases availability as well as coverage of high data rates in the uplink.

Conclusion

The success of mobile broadband is driving the demand for higher data rates and greater cell capacity. The industry is addressing this demand by evolving HSPA (HSPA Evolution) through 3GPP Releases 7, 8 and 9.

The predicted live network performance of Release 7 showed that MIMO gives a 30 percent gain in user throughput over the entire range of loads, and 64QAM is an attractive intermediate step.

Release 8 boosts the peak data rate in the downlink to 42Mbps by either a combination of MIMO and 64QAM or dual-carrier operation with 64QAM. Dual-carrier techniques will also double the experienced user throughput throughout the network. In addition, Release 8 reduces battery consumption by introducing DRX in CELL_FACH. It also substantially improves the uplink capacity by introducing EUL mechanisms in all common states.

Further steps of HSPA Evolution might involve operation on several 5MHz carriers. Therefore, Release 9 might support

- ❖ MIMO, 64QAM and four downlink carriers, giving peak data rates of more than 100Mbps; and
- ❖ dual carriers in the uplink, giving 23Mbps.

In summary, HSPA Evolution gives operators a cost-effective way of migrating mobile broadband access toward 4G. ❖

Stefan Ström



❖ joined Ericsson in 1990 to work with GSM radio network system design. In 1996 he changed roles to

work with Pacific Bell/Cingular West Key Account Management and radio network access issues in California, USA. In 1999, he returned to Sweden and GSM product and system management to work with radio network and inter-radio access technology functions. He is currently a member of Business Unit Networks, Development Unit Radio Systems and Technology, where he works in close cooperation with network operators analyzing coming RAN features in real networks. Stefan holds an M.Sc. in electrical engineering from the Royal Institute of Technology, Stockholm.

Dirk Gerstenberger



❖ holds a Dipl.-Ing. degree in electrical engineering from the University of Paderborn, Germany. He

joined Ericsson in 1997 to work with system design, specifically Ericsson's experimental WCDMA system and the first commercial WCDMA radio base station products. Since 1999 he has actively participated in WCDMA/HSPA and LTE standardization in 3GPP RAN WG1 – he has served as chairman of this work group since 2003. Dirk is currently Senior Specialist in the area of WCDMA Radio Access Evolution at Business Unit Networks, Product Development Unit WCDMA RAN. He is also a recipient of the 2008 Inventor of the Year award.

Johan Bergman



❖ received an M.Sc. in engineering physics from Chalmers University of Technology, Göteborg, Sweden.

He joined Ericsson in 1996 to work with radio design for GSM and PDC base stations. From 1998 to 2005, Johan helped design baseband algorithms for Ericsson's experimental and commercial systems for WCDMA/HSPA. Since 2005, he has worked with WCDMA/HSPA L1 standardization within 3GPP TSG RAN WG1 and with WCDMA/HSPA RAN system design.

Fredrik Gunnarsson



❖ received an M.Sc. and a Ph.D. in electrical engineering from Linköping University, Sweden. He

joined Ericsson Research in 2001 but is also a part-time Associate Professor in automatic control at Linköping University. His research on HSPA Evolution and LTE considers a wide range of aspects from signal processing and radio resource management to planning, optimization, modeling and the simulation of realistic networks.

Acknowledgements

❖ The authors express their heartfelt thanks to Anette Borg, Klas Johansson and Magnus Persson for the valuable input they provided to this article.

References

1. www.umts-forum.org, "300 million UMTS subscribers: mobile broadband goes global", October 6, 2008
2. Bergman, J., Ericsson, M., Gerstenberger, D., Göransson, B., Peisa, J. and Wager S.: HSPA Evolution — Boosting performance of mobile broadband access. Ericsson Review, Vol. 85(2008):1, pp. 32-37
3. 3GPP, TR 25.825 "Dual-Cell HSDPA operation" V1.0.0, May 2008
4. 3GPP, TS 25.308 "HSDPA Overall Description Stage 2" V8.4.0, December 2008.
5. TEMS CellPlanner, <http://www.ericsson.com/tems>.
6. Bottomley, G., Cairns, D., Cozzo, C., Fulghum, T., Khayrallah, A., Lindell, P., Sundelin, M. and Wang, Y.-P.: Advanced receivers for WCDMA terminal platforms and base stations. Ericsson Review, Vol. 84(2006):2, pp. 54-58