

Evolving WCDMA

Tomas Hedberg and Stefan Parkvall

WCDMA is rapidly emerging as the leading global third-generation (IMT-2000) standard, providing simultaneous support for a wide range of services with different characteristics on a common 5 MHz carrier. The current WCDMA specification fully satisfies the IMT-2000 requirements, including support for data rates of up to 2 Mbit/s in indoor or small-cell outdoor environments, wide-area coverage at rates of up to 384 kbit/s, and support for high-rate packet-data and circuit-switched services. Thus, the introduction of third-generation cellular systems allows operators to offer a vast selection of services to meet subscriber demands. Ericsson's WCDMA products are positioned to guarantee cost-effective delivery of these services.

When launching a WCDMA network, most operators will initially focus on delivering stable coverage over a large area—capacity is a lesser concern. The initial deployment will also support essential end-user services, including radio access bearers for circuit- and packet-switched data communication as well as location-based services.

Over time, the capacity requirements will increase as more and more subscribers enter the system. Likewise, greater support will be needed for end-user services—that is, multimedia services, high-precision location services, and high-speed packet-data services will become increasingly important. These evolving requirements can be supported through enhancements and additions of new functionality in the current WCDMA standard (R99) and through future additions to it.

In this article, the authors discuss ways of evolving the Ericsson family of WCDMA products. Because packet data is expected to have an increasingly important role, the scope of this article is mostly limited to packet data services. The authors outline enhancements to the current standard and propose a subsequent evolution.

Services and system overview

Wideband code-division multiple access (WCDMA) systems are designed to be service-independent, in order to accommodate a flexible introduction of new services and a mixture of services. This is true especially in the packet domain, where the evolution of the wireless Internet is expected to undergo rapid development. Obviously, this implies that the UMTS terrestrial radio access network (UTRAN) must be connected both to circuit-switched and packet-switched core networks (Figure 1). Service independence is enabled by the *Iu* interface, which provides service-agnostic radio access bearers (RAB) that correspond to a requested quality-of-service (QoS) level. There are four basic classes of service:

- conversational (low delay, strict ordering of data);
- streaming (modest delay, strict ordering);
- interactive (modest delay); and
- background (no delay guarantees).

These classes represent the requirements put on delay and sequence integrity. Within the classes a number of parameters are used to stipulate, in detail, the desired QoS level. To fully support flexible QoS through the *Iu* interface, UTRAN also has several options in the *Uu* air interface. Greater flexibility on the air interface can improve performance by enabling different options in accordance with the service requirements and operational environment. The standard does not advocate any particular choice of options to fulfill the required QoS, which is to say that it is up to the network to decide how it will use them.

As noted above, to provide all services and extensions to the circuit-switched and packet-switched domains, UTRAN must connect to them. The circuit-switched services will probably not evolve into high bandwidths, and as an alternative to them, similar services will exist in the packet-switched domain. In contrast, Internet applications, such as Web browsing, file transfers, sound samples, and movie clips, already use the considerable bandwidths provided by fixed Internet access transport media. Thus, in all likelihood, the greatest demand for high user bit rates will be in the packet domain. In the near future, capacity for these higher bit rates can be garnered from better algorithms within the current standard. Initially, Ericsson's products will include interactive radio access bearers up to 384 kbit/s

BOX A, TERMS AND ABBREVIATIONS

3GPP	Third-generation Partnership Project	RAB	Radio access bearer
AMR	Adaptive multirate	RBS	Radio base station
ARQ	Automatic repeat request	RF	Radio frequency
DECT	Digital enhanced cordless telecommunications	RLC	Radio link control
DPCH	Dedicated physical channel	RNC	Radio network controller
DSCH	Downlink shared channel	ROHC	Robust header compression
GSM	Global system for mobile communication	RTP	Real-time protocol
HSDPA	High-speed downlink packet-data access	SDU	Service data unit
HS-DSCH	High-speed DSCH	STTD	Space-time transmit diversity
IETF	Internet Engineering Task Force	TCP	Transmission control protocol
IMT-2000	International Mobile Telecommunications-2000	TTI	Transmission time interval
IP	Internet protocol	UDP	User datagram protocol
MAC	Medium access control	UE	User equipment
QoS	Quality of service	UMTS	Universal mobile telecommunications system
QPSK	Quadrature phase-shift keying	UTRAN	UMTS terrestrial radio access network
		WCDMA	Wideband code-division multiple access

downlink. Furthermore, bearers for all QoS classes and many parameter options will provide a broad range of opportunities to provide services efficiently. In the long term, the standard will continue to evolve to provide the performance needed for future applications.

Enhancements within the current standard

The current release of the 3GPP standard (R99) provides a large toolbox of methods that can be employed to improve the performance of specific applications. Depending on the network design, the enhancements can benefit the end-user, the operator, or both. To begin with, Ericsson's products will provide general methods; more specific methods will be added in later releases. Outlined below are some possible areas of improvement, eventually culminating in high-speed downlink packet-data access (HSDPA). This list, which emphasizes packet data, is neither exhaustive nor has it been sorted in any particular order. But the items have been grouped in terms of coverage, capacity, and service. Several of the techniques can increase coverage and capac-

ity, so the division between the groups should not be considered definitive. The intention is to give the reader some idea of possible future enhancements to Ericsson's line of WCDMA products. Some of these consist of software upgrades; others will require new hardware. Knowing that the evolution of network performance must be cost-effective, Ericsson has designed its systems to accommodate gradual evolution.

Coverage

Load sharing between UTRAN cells

UTRAN transmit power requirements increase with cell load. Therefore, given fixed maximum uplink and downlink power limits, greater load means less coverage. One way of postponing the splitting of cells is to add carriers in existing sites. Likewise, by restricting the load on one cell belonging to a group of co-located cells, it is possible to maximize site range and thereby postpone the addition of costly radio base station (RBS) sites. The mechanisms that enable these measures are:

- cell individual thresholds, which cause user equipment that employs cell selection to prefer certain co-located cells,

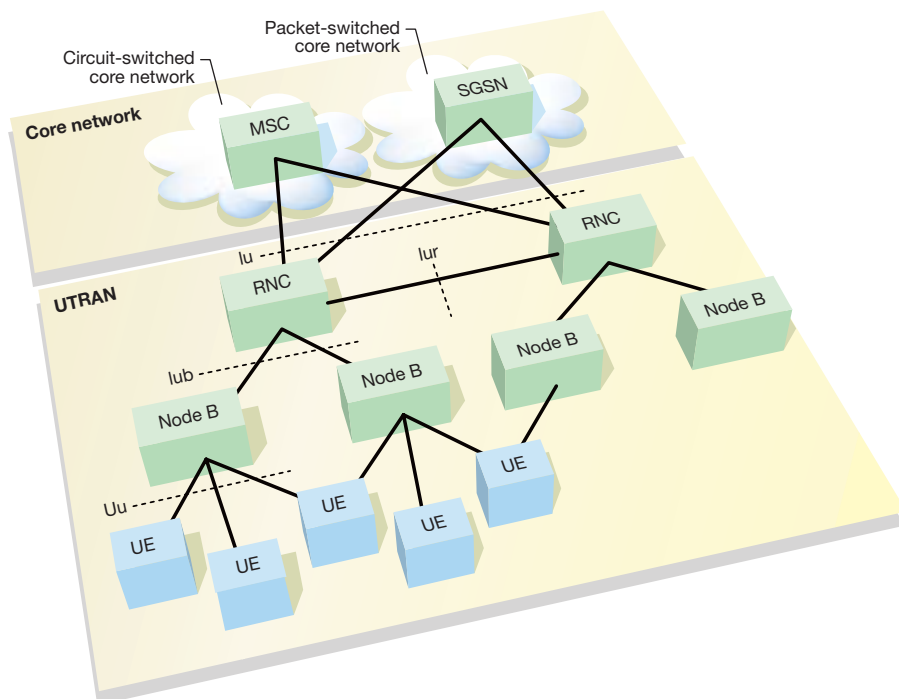


Figure 1
UTRAN connected to packet-switched and circuit-switched networks.

- thereby reducing load in other cells; and
- maximum cell capacity—admission control thus limits the traffic capacity of certain co-located cells for user equipment that employs handover.

Blind handover

Inter-frequency and inter-system handover depend on radio frequency (RF) measurements of candidate cells. Compressed mode has been included in the specification to allow for these measurements. Three methods exist, but only one of them (which can be used for interactive and background radio access bearers) does not require higher peak power. In cases of limited coverage, there might not be any margin for the peak power required by the other methods. In these cases, the UTRAN system can be informed of suitable candidates (that is, of surrounding cells) and execute handover without user equipment measurements.

Fast congestion control

Fast congestion control provides smart handling of power peaks in the radio base station, for instance, by discarding best-effort data to distant user equipment that requires high power levels at the RBS. Discarded data units are reported missing by the user equipment and retransmitted by the system at a later time. Thus, a system that follows this scheme can operate closer to maximum downlink power without violating overall QoS.

Capacity enhancements

Open-loop transmit diversity

Open-loop transmit diversity, where the downlink data is transmitted over two antennas simultaneously using a special form of coding, is included in the 3GPP standard as space-time transmit diversity (STTD). This technique is mainly suitable for slow-

moving user equipment in environments with little or no inherent multipath diversity, and can increase capacity by up to 40%, although in environments with more multipath, the gain is less—less than 10%. Obviously, this gain in capacity can be transformed into an increase in user data rate.

Microcell support and hierarchical cell structures

Loss of orthogonality in the downlink implies an increase in intracell interference. Microcells typically provide the best radio conditions, which translates into greater capacity. In macrocells, the loss of orthogonality can be more severe than in microcells with no significant multipath propagation. Indeed, the difference in cell capacity can be nearly 200%. Given that it supports microcells and hierarchical cell structures, UTRAN will thus attempt to direct user equipment to microcells. However, fast-moving user equipment, which is identified by frequent cell reselection, will be directed to a macro cell.

Inter-cell and inter-system load sharing

Load sharing across co-located UMTS cells improves trunking efficiency and the likelihood of high-bit-rate services. Usually, the objective is to equalize the load on co-located cells, yielding a 5-10% gain in trunking efficiency. Similarly, by directing low-bit-rate services to GSM when traffic load is heavy, WCDMA can better support high-bit-rate services.

Header compression

The IETF has recently standardized robust header compression (ROHC), which is an algorithm for compressing the headers of RTP/UDP/IP traffic. Soon, the IETF will also conclude its work on TCP header compression. Robust header compression typically reduces the header overhead from 40 bytes to 1 or 2 bytes. Obviously, this gives significant gains in capacity—up to 100% for services, such as packet-based voice, which require the frequent transmission of small packets. Lesser gains—about 5%—are obtained for Web browsing, file transfer and e-mail services.

Downlink shared channel

The downlink shared channel (DSCH) provides common code resources that can be shared by several users. This has the potential to improve the capacity for bursty services, since the sharing of resources reduces

TABLE 1, DIFFERENT METHODS OF ENABLING INTER-FREQUENCY MEASUREMENTS

Method	Peak/average	Suitable for
Layer 3 scheduling	0 dB	Data with low delay constraints
SF/2	3–5 dB	Most cases
Puncturing	1.5 dB	Voice

the potential channelization code limitations that might occur if each user is allocated a dedicated channel. Furthermore, the power peaks of a shared channel are more easily controlled than those of a set of corresponding dedicated channels. Notwithstanding, the DSCH does not support soft handover. Therefore, compared to a dedicated channel, it might be less suitable for users close to cell borders. The DSCH shares several properties with the high-speed DSCH (HS-DSCH) used in the HSDPA evolution. However, HSDPA differs in some aspects and provides significantly higher bit rates and lower delays than the DSCH.

Packet data booster

Higher bit rates (and consequently better system throughput) can be obtained by granting users who enjoy favorable radio conditions more than their fair share of power (resources) in the downlink (the concept of trading fairness for capacity is further refined in HSDPA). This technique is mainly suitable for radio access bearers with less stringent delay requirements, such as interactive radio access bearers.

Advanced antenna solutions

Advanced antenna solutions can be used for improving coverage and, more importantly, capacity. In the downlink, the underlying idea is to manage interference by controlling the directions in which power is transmitted. In the uplink, the antenna solely processes directions that constructively contribute to the received signal. Interference management is especially beneficial to high-power cases that typify high-rate data users.

One approach consists of fixed multibeam solutions—that is, of multiple beams that point in different directions. To reduce pointing errors, a few of these beams can be combined. This approach helps relax the requirements put on the coherency between the different beams and modest complexity.

Another, more elaborate approach involves advanced steered-beam solutions that form individual beams for the terminals in order to maximize performance and control the distribution of interference. These solutions generally yield better performance but are also more complex. They are thus positioned further into the future compared to fixed-beam solutions.

A third solution is to employ space-time processing. Open-loop transmit diversity

(STTD) is considered a simple form of space-time processing for the downlink. For more advanced schemes, the standard might need to be updated.

Service

All-IP support

All-IP core networks require radio access bearers for packet-switched voice, streaming media, and signaling. It should be possible to provide these simultaneously with present-day interactive and background radio access bearers. Furthermore, packet-switched conversational and streaming radio access bearers need a packet-switched handover procedure that guarantees the QoS in the target cell. These additions to the standard will be specified in Release 5 (R5).

Wideband AMR

A new 7 kHz bandwidth voice codec is being standardized in 3GPP for Release 4 (R4). The required end-to-end control signaling will be determined in Release 5. One possible area of application is packet voice—for example, NetMeeting conference calls.



Figure 2
WCDMA base station.

HSDPA—improved support for best-effort services

With few exceptions, the enhancements described above can be applied within the current standard. However, to improve support for best-effort packet data, the 3GPP is currently working on an evolution of WCDMA known as high-speed downlink packet data access (HSDPA). This enhancement is scheduled for inclusion in Release 5 of the 3GPP specifications. HSDPA will increase capacity, reduce round-trip delay, and increase peak data rates up to 8-10 Mbit/s. To achieve these goals, a new shared downlink channel, called the high-speed downlink shared channel (HS-DSCH) is being introduced. In addition, three fundamental technologies, which are tightly coupled and rely on the rapid adaptation of the transmission parameters to the instantaneous radio conditions, are being introduced with this channel:

- fast-link adaptation technology enables the use of spectral-efficient higher-order modulation when channel conditions permit (for example, during a fading peak), and reverts to robust QPSK modulation during less favorable channel conditions (for example, when experiencing a fading dip);

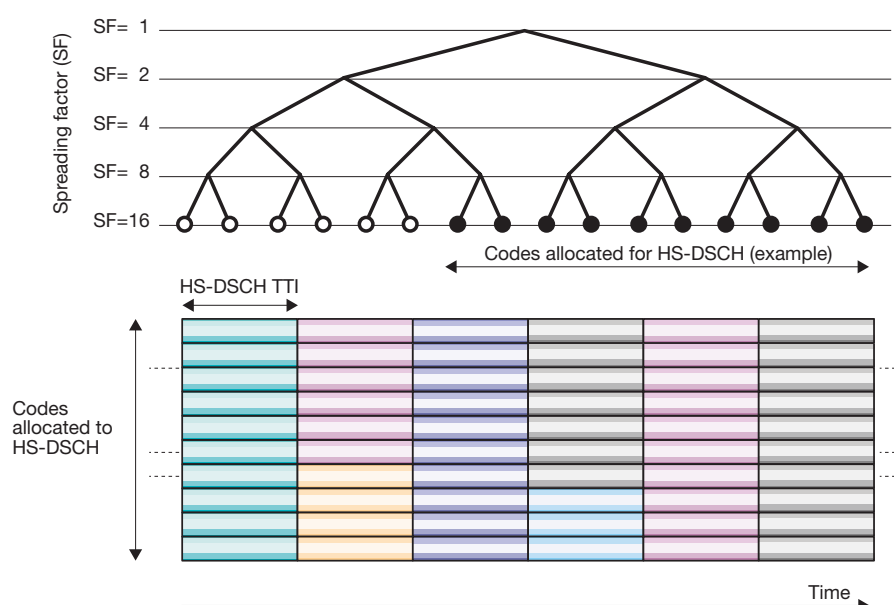
- fast hybrid automatic-repeat-request (ARQ) technology rapidly requests the retransmission of missing data entities and combines the soft information from the original transmission and any subsequent retransmissions before any attempts are made to decode a message; and
- fast scheduling of users sharing the HS-DSCH—this technique, which exploits multi-user diversity, strives to transmit to users with favorable radio conditions.

With the basic principles above, there is a possibility of unequal service provision, offering higher data rates to users in favorable conditions.

HSDPA architecture

The basic technologies being considered for HSDPA rely on the rapid adaptation of transmission parameters to match channel conditions. Accordingly, the corresponding functions, such as fast link adaptation and fast scheduling, should be placed close to the air interface, preferably in Node B. In the present-day WCDMA architecture (Figure 1), the scheduling and transport-format selections are performed in the radio network controller (RNC). Thus, for HSDPA, it is advantageous to move parts of the functionality from the RNC to Node B, forming a new Node B entity, MAC-HSDPA.

Figure 3
Example of the code and time structure for the HS-DSCH.



Notwithstanding, some RNC entities, such as radio link control (RLC) and media access control (MAC), should remain in their current location. The functions of the RNC include ciphering and in-order delivery of data (these are functions provided by the RLC). In soft-handover scenarios between two separate Node Bs, the RNC can guarantee that no data will be lost even if the hybrid ARQ mechanism in Node B fails.

The extended features of Node B should thus not be seen as a replacement of the RNC, but rather as a complement, which (in terms of the RNC) provides a highly reliable channel that supports high data rates.

General channel structure

As mentioned above, HSDPA introduces a new transport channel, HS-DSCH, which will primarily be used for best-effort packet data. Much like the current DSCH, the HS-DSCH corresponds to a common channelization code resource shared by several users. The HS-DSCH is allocated to users on the basis of transmission time interval (HS-DSCH TTI). To reduce delays, increase the granularity in the scheduling process, and facilitate better tracking of the time-varying channel conditions, HS-DSCH will employ a shorter (2 ms) TTI than the current minimum 10 ms WCDMA TTI. The HS-DSCH code resource consists of several channelization codes—with a spreading factor of 16—set aside for the HS-DSCH. The primary way of sharing this resource is in the time domain, in which case the HS-DSCH code resource is allocated to one user at a time. In some cases, it can be beneficial to support simultaneous transmission to, say, 2-4 users within the same TTI using distinct parts of the set of channelization codes allocated for HS-DSCH.

Besides user data, Node B must also transmit associated control signaling to user equipment (UE). The next UE (or multiple UE, in the case of code multiplex) scheduled for the HS-DSCH (in the upcoming HS-DSCH TTI) must be notified. Likewise, additional lower-layer control information must be transmitted—for example, the transport format, which includes the modulation and coding schemes to be used and hybrid ARQ-related information. This control information solely applies to user equipment that is sending or receiving data on the HS-DSCH and can therefore be transmitted on a shared control channel. As with the current DSCH, every UE to which data can be transmitted on the HS-DSCH has an asso-

ciated dedicated physical channel (DPCH). The DPCH is used to carry power control commands for the associated uplink, and if needed, other services, such as circuit-switched voice.

Fast link adaptation

As mentioned above, higher-order modulation in conjunction with link adaptation is a way of maximizing the instantaneous use of the fading radio channel. By transmitting the HS-DSCH at (in principle) constant power—that is, without fast downlink power control—the modulation and coding schemes can be selected to maximize throughput on the downlink. Note: the use of link adaptation instead of fast power control does not mean that the HS-DSCH power cannot vary for other reasons, such as variations in the power used by other downlink channels. Node B selects the modulation and coding schemes that match the instantaneous radio conditions. The selection can be based on several criteria according to a combination of UE measurement reports, the instantaneous power of the associated DPCH, and buffer size.

Fast hybrid ARQ

Hybrid ARQ (through which, prior to decoding, soft information from retransmissions requested by user equipment is combined with soft information from the original transmission) greatly improves performance and adds robustness against link-adaptation errors. It also serves to fine tune the effective code rate and compensates for errors made by the link-adaptation mechanism. If all data in a TTI is correctly decoded, an acknowledgement is sent to Node B, using the associated uplink dedicated physical control channel. But if the data in a TTI is decoded incorrectly, retransmission is requested within a few TTIs. Once the data has been retransmitted, the user equipment combines the previous versions of data with the retransmitted version (soft combining). This greatly increases the probability of successful decoding. Retransmissions are requested until the data has been decoded correctly or until the maximum (predetermined) number of attempts has been made. Since the hybrid ARQ mechanism resides in Node B, retransmissions can be requested rapidly.

Fast scheduling

The scheduler is a key element of the design. It controls the allocation of the channel to

users, and to a large extent, it determines the overall behavior of the system. The scheduler exploits the multi-user diversity and strives to transmit to users when radio conditions permit high data rates. Notwithstanding, it also maintains a certain degree of fairness. Fundamentally, greater allowable variance in QoS means greater system capacity. Herein lies one of the main enhancements for best-effort service, which by definition allows for a relatively large spread in quality. Since there is no need to standardize the scheduling algorithm, different schedulers can be used for different scenarios. Instead, the scheduler can be designed to suit the requirements of different operators and environments. Information on which the scheduler can base its decisions includes (but is not limited to)

- the predicted channel quality, as used by the link adaptation;
- the current load of the cell; and
- traffic priority classes.

Upgrading and evolving the network

Infrastructure upgrades

Because most applications are not green-field, the reuse of existing infrastructure is

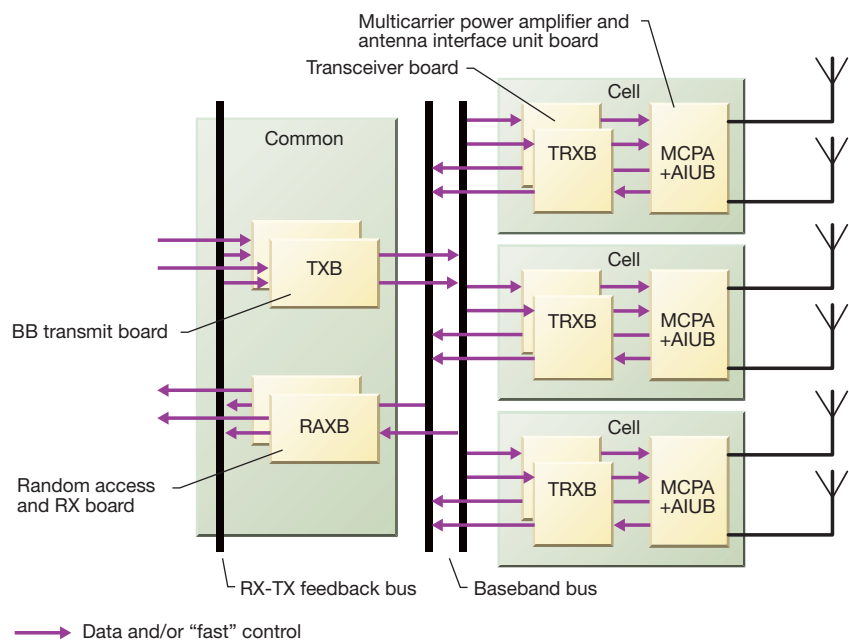
of utmost importance. This applies to all parts of the network, but the migration of radio base stations is of paramount interest. Due to the large number of radio base station sites, frequent on-site updates cause major logistic problems.

To facilitate migration, Ericsson's radio base stations are usually designed to accommodate years of feature upgrades by means of remote software loading. For instance, most of the updates discussed above are software upgrades. Early preparation for larger updates, which involve new hardware, such as for adaptive antennas and HSDPA, is neither economically nor technically feasible. In this case, it is better to aim for efficient on-site hardware upgrades. Ericsson's modular radio base station architecture (Figure 4) has been designed to accommodate change and will be used for several upcoming releases.

Introducing HSDPA services

HSDPA is scheduled to be part of Release 5 of the WCDMA standard. Thanks to the design of HSDPA, no separate carrier will be needed to introduce HSDPA services. Thus, R99 and HSDPA terminals will be able to camp simultaneously on the same carrier. HSDPA is just one added channel, which can be used by compatible user equipment.

Figure 4
Architecture of the radio base station.



This permits smooth introduction of HSDPA—that is, operator investments can be kept in proportion to traffic demand.

Initially, the HSDPA services will probably only be offered in part of the network—for example, at hot spots such as airports and indoor offices. When the user leaves the area where HSDPA is offered, an ongoing call can transparently be switched from the HS-DSCH to any of the channels already existing in R99 using the channel switching and handover mechanism provided by WCDMA. For the end-user, the only noticeable effect of leaving the HSDPA area is a drop in performance (lower data rates). Thus, operators need not upgrade all cells in the network simultaneously. Instead, they can gradually evolve the network as the demand for capacity increases. Furthermore, the fraction of a cell's resources used by HSDPA can be dynamically configured to match long-term traffic variations.

Indoor environments represent one deployment scenario in which the high data rates of HSDPA can be exploited to their full extent. Initially, the most cost-effective way of providing indoor coverage can be expected from using conventional base station technology with distributed antenna solutions. The benefits of this approach are performance tuning and centralized supervision along the same lines as in current cellular systems. Auto-configuring systems, such as DECT, usually require a larger number of base stations.

Where terminals that support HSDPA are concerned, different user-equipment capability classes will be defined. A low-end terminal with limited memory and modulation schemes will not support the highest data rates, whereas a high-end terminal that supports every modulation and coding

scheme can provide full capacity. This implies that users who expect good propagation conditions—for instance, users in wireless LAN-like environments or fixed wireless subscribers—can fully exploit their positions with a high-end terminal without imposing extra costs on users who settle for medium data rates and less expensive terminals. An interesting aspect of best-effort systems is that user terminals with better receiver performance immediately increase the obtainable data rate. Thus, there is incentive for providing improved receiver algorithms.

New spectrum, when available, can also be exploited by HSDPA. A likely scenario is to reserve additional spectrum for downlink applications, either for general WCDMA use or for HSDPA-only systems.

Conclusion

WCDMA is a flexible standard that provides simultaneous support for a wide variety of services on a single carrier. By gradually introducing enhancements to the network, operators can expand their service offerings and meet growing demands for capacity in a cost-effective way.

Improved radio network algorithms for use in the current standard will increase capacity. In several cases, the enhancements can be introduced through remote software upgrades.

The introduction of HSDPA, in Release 5 of the standard, will greatly enhance the support of best-effort packet data.

Ericsson's line of WCDMA products, with their modular architecture, enables a successive increase in performance, allowing operators to satisfy customer demands in a cost-effective manner.

TRADEMARKS

NetMeeting is a registered trademark of Microsoft Corporation in the United States and/or other countries.