DATA CAPABILITIES: GPRS TO HSDPA

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Introduction

Enhanced Data Rates for GSM Evolution (EDGE) has proven to be a remarkably effective cellular-data technology, and is now supported by operators and vendors worldwide. Meanwhile, deployment of UMTS, which has even more powerful data capabilities, is accelerating. High Speed Downlink Packet Access (HSDPA), an enhancement for Universal Mobile Telecommunications System (UMTS), will soon increase data capabilities even further. The result is a portfolio of complementary technologies that realize the potential of wireless data—the GSM family of data technologies.

Wireless data represents an increasing percentage of operator revenues. Beginning with the success of Short Message Service (SMS) in Europe and iMode in Japan, users and enterprises are beginning to embrace wireless data in a wide range of other applications, including e-mail, game downloads, instant messaging, ringtones, video, and enterprise applications such as group collaboration enterprise resource planning.

Though voice still constitutes most of cellular traffic and the bulk of service revenue, wireless data is beginning to appreciably add to service revenue. In a recent quarter one GSM operator (MM02) reported that over 20 percent of their service revenue was from wireless data. There are a number of important factors that are accelerating adoption of wireless data, including increased user awareness, innovative devices such as smartphones and global coverage. But two factors stand out: network capability and applications. Technologies such as EDGE and UMTS provide the capability to support a wide range of applications, including standard networking applications as well as those designed for wireless. Meanwhile, application and content suppliers are optimizing their applications, or in many cases developing entirely new applications and content to target the needs and desires of mobile users.

Computing itself is becoming ever more mobile, and notebooks, PDAs and smartphones are now prevalent. In fact, all phones are becoming “smart” with some form of data capability. Lifestyles and work styles themselves are increasingly mobile, with more and more people traveling for work, pleasure, or in retirement. Meanwhile, the Internet is becoming progressively more intertwined in the fabric of people’s lives, providing communications, information, enhancements for memberships and subscriptions, community involvements, and commerce. In this environment, wireless access to the Internet is a powerful catalyst for the creation of new services and new business opportunities for operators as well as third-party businesses.

As the benefits of these services become apparent, as the services themselves become more powerful thanks to higher throughput rates and quality-of-service mechanisms, and as service costs drop due to increased spectral efficiency, use will constantly grow. Wireline data already represents more than fifty percent of traffic within worldwide telecom networks. Though cellular data represents just a small portion of service revenue today[1], in all likelihood, similar growth will happen with cellular networks.

With data constituting a rising percentage of total cellular traffic, it is essential that operators deploy data technologies that meet customer requirements for performance and that are spectrally efficient, especially as data applications can demand significant network resources. Operators have a huge investment in spectrum and in their networks—data services must leverage these investments. It is only a matter of time before today’s over

[1] Ten percent in Europe and Asia, lower in North America.

1.5 billion cellular customers[2] start fully taking advantage of data capability. This presents tremendous opportunities and risks to operators as they choose the most commercially viable evolution path for migrating their customers.

The GSM family of data technologies, including General Packet Radio Service (GPRS), EDGE, UMTS - Wideband CDMA (WCDMA) and HSDPA, provides a powerful set of capabilities, spectral efficiencies, and means of deployment that maximizes revenue and profit potential.

(Note: though many use the terms "UMTS" and "WCDMA" interchangeably, in this paper we use "WCDMA" when referring to the radio interface technology used within UMTS and "UMTS" to refer to the complete system.)

Some of the important observations and conclusions of this paper include:

- Before EDGE was commercially deployed, a previous version of this paper projected performance gains for EDGE. Results from the field were exactly as predicted – EDGE more than triples GPRS data throughputs, delivering typical rates of 100 to 130 kilobits per second (kbps).
- UMTS is spectrally extremely efficient for high-data throughput services. It also offers high peak rates of 2Mbps with average rates between 220 kbps and 320 kbps, multimedia support, (e.g., conversational video), quality of service, and a smooth upgrade for future enhancements.
- HSDPA will be even more effective for enhancing WCDMA performance than EDGE was for enhancing GPRS performance, with a standard supporting peak rates of 14 Mbps and average throughput rates close to 1 Mbps.
- Unlike some competing technologies, GSM/GPRS/EDGE/WCDMA/HSDPA allows an operator to efficiently use their entire available spectrum for voice and data services.
- There is accelerating momentum globally in the deployment of EDGE and UMTS. GPRS/EDGE and UMTS are being deployed as complementary 3G technologies.
- As one of the first cellular technologies to feature adaptive modulation and coding schemes and incremental redundancy, EDGE is spectrally very efficient for medium-bandwidth applications.
- Operators will be able to do a simple software upgrade of their UMTS networks to support HSDPA much as they did to their GPRS networks to support EDGE.
- With a UMTS multi-radio network, a common core network can efficiently support GSM, GPRS, EDGE, WCDMA, and HSDPA access networks, offering high efficiency for both high and low data rates, and for high and low traffic density configurations.
- Ongoing UMTS evolution includes significant enhancements with each new specification release, including higher throughput rates, enhanced multimedia support, and integration with wireless LAN technology.

This paper begins with an overview of the market, looking at adoption of services, deployment of GSM-UMTS technologies and other wide-area wireless technologies. It then explains the capabilities as well as workings of the different technologies, including GPRS, EDGE, WCDMA and HSDPA. The emphasis of this section is to quantify real-world performance. The paper then examines the evolution from GPRS to HSDPA, including how increasing spectral efficiency will drive deployment.

[2] EMC World Cellular Database, August 2004.

Market

In considering the market, we review market adoption of wireless data, deployments of GSM/UMTS networks around the world, and how GSM/UMTS relates to other wireless technologies.

Market Adoption

While wireless data has always offered a tantalizing vision of always-connected mobile computing, adoption has been slower than for voice services. In the past two years, however, adoption has accelerated, finally some might say, thanks to a number of key developments. Networks themselves are much more capable, delivering higher throughputs at lower cost. Awareness of data capabilities has increased, especially through the widespread success of SMS, wireless e-mail, downloadable ringtones and downloadable games. Widespread availability of services has also been important. The features found in cellular telephones is expanding at a rapid rate, and today includes large color displays, graphics viewers, still cameras, movie cameras, MP3 players, instant messaging clients, e-mail clients, push-to-talk, downloadable executable content capability, and browsers supporting multiple formats. All of these capabilities consume data. Meanwhile, smartphones with their emphasis on a rich computing environment on the phone, represent the convergence of the personal digital assistant, a fully capable mobile computer and a phone in a device that is only slightly larger than the average cellular telephone. Many users would prefer to carry one device that "does it all."

As a consequence, this rich network and device environment is spawning the availability of a large range of wireless applications and content. Why? Application and content developers simply cannot afford to ignore this market because of its growing size, and its unassailable potential. And they aren't. Consumer content developers are already successful by providing downloadable ringtones and games. Enabled by 3G network capability, downloadable and streaming music and video are not far behind. In the enterprise space, all the major developers now offer mobilized "wireless-friendly" components for their applications. Acting as catalysts, a wide array of middleware providers address issues such as increased security (e.g., VPNs), switching between different networks (e.g., WLAN to 3G) and session maintenance under adverse radio conditions.

The wireless-data market has not yet reached the critical mass where adoption and content explode, but it is close, as suggested by the following market data. In 2003, wireless Internet usage grew 145% with 134 million people trying or using services.[3] This figure could grow to 600 million users by 2008.[4] Mobile Java applications are expected to grow from $1.4 billion in 2003 to $15.5 billion in 2008.[5]

According to a recent study by In-Stat MDR released July 15, 2004 "Understanding Decision-makers' and Decision-influencers' Dual Roles in the Implementation of Wireless Data in the Business Environment",

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[3] Source: Ipsos-Insight, based on interviews with more than 7,100 adults in 13 global markets, May 2004. From their report, "Face of the Web", May 11, 2004.

[4] Probe Research, "Mobile IP Users Population/2003 in Review", February 2004.

[5] Arc Group, "Mobile Application Platforms and Operating Systems - Enabling Technologies and The Evolving Role of Java", March 2004.

- Wireless data is becoming more important to enterprise companies. About 20% of IT budgets are dedicated to wireless data, which was defined as including wireless LAN and WAN equipment and services.
- About half of mid-size and large enterprises use wireless data today and another 30 percent are planning/evaluating future use. Three quarters of current WAN data user plan to increase their usage in the future.
- Common wireless data applications include email, access to the Web, and to spreadsheets and word processing documents. Future applications include instant messaging and Web-based applications.

This market data is encouraging, but realistically, the market is still in its infancy. Though awareness of services is higher than ever before, many people still do not understand the true range of data options available to them. For example, how many business users realize they can use their Bluetooth-equipped phone as a modem for their laptops? The number of enhanced mobile data applications is still low relative to its market potential. For example, it should be possible to request a taxi with one simple request on a mobile telephone which notifies the taxi company of a user's exact location, dispatches a taxi, and sends update messages indicating the taxi's arrival time. Services like this are coming, but they are not available yet as they require the integration of existing dispatch systems with geographic databases, location-based services and mobile commerce systems. In the enterprise space, the first stage of wireless data was essentially to replace modem connectivity. The next is to offer existing applications on new platforms such as smartphones. But the final, and much more important change, is where jobs are reengineered to take full advantage of continuous connectivity. All this takes time, but the momentum in the direction of increased efficiency, increased convenience and increased entertainment, all fueled by wireless data, is unstoppable.

The key for operators is to offer networks that can support the demands of wireless consumer and business applications as they grow, as well as to offer the complementary capabilities, such as message stores, e-commerce solutions, location-based services, QoS. This is where the GPRS to HSDPA data story is particularly compelling, because not only does it provide a platform for continual improvements in capabilities, but it does so over huge coverage areas and on a global basis.

Deployments

The size of the potential data market is extensive, and can readily be appreciated by looking at the scope of GSM/UMTS deployments that are occurring. Today, more than one billion subscribers are using GSM.[6] Nearly every GSM network in the world today supports GPRS.

EDGE is another success story. As of July, 2004, 114 operators in 68 countries from all over the world were working with EDGE. This includes 34 operators offering commercial service and 38 operators in active deployment.[7] EDGE has reached critical mass in terms of POPS, geography, infrastructure, and devices. EDGE operators represent over half a billion potential EDGE customers within their networks. Due to the very small incremental cost of including EDGE capability in GSM network deployment, virtually all

[6] EMC World Cellular Database, August 2004.

[7] Information compiled by 3G Americas from EMC World Cellular Database and public company announcements, August 2004.

new GSM infrastructure deployments are likely to be EDGE capable with virtually all new mid to high level GSM devices including EDGE as well.

UMTS deployments are also accelerating. There are forty-six commercial UMTS networks already in operation in twenty-four countries, with seventy-one more either pre-commercial, in planning, licensed or currently being deployed.[8]

The Shosteck Group anticipates that, "During 2007, we estimate 70 million new subscribers, bringing the total to 125-150 million..." In addition, the firm predicts that 110 million UMTS handsets will be sold in 2007.[9] Other leading analyst firms have predicted even higher subscriber counts.

Other Networks

Though GSM/GPRS/EDGE/UMTS/HSDPA networks are likely to dominate global cellular technology deployments, there are other wireless technologies being deployed, serving both wide areas and local areas. In this section, we look at the relationship between GSM/UMTS and some of these other network technologies.

CDMA2000, consisting principally of 1xRTT, 1xEV-DO and 1xEV-DV versions is the other major cellular technology deployed in many parts of the world. 1xRTT (One Carrier Radio Transmission Technology) is the most widely deployed version. A number of operators have deployed or are deploying 1xEV-DO (Evolved, Data Optimized), where a radio carrier is dedicated for high-speed data functions. 1xEV-DV (Evolved, Data Voice) allows both voice and high-speed data on the same radio channel, but is not ready for deployment. 1xEV-DO could eventually provide voice service using Voice over IP (VoIP) protocols, but this capability requires quality-of-service mechanisms within the network, and is not yet ready for deployment. With respect to GSM/UMTS, CDMA2000 is principally a competing technology. From a performance comparison, EDGE has higher average throughput than 1xRTT. Meanwhile, UMTS delivers a comparable user experience as 1xEV-DO, but today has the overwhelming advantage of supporting voice and data service across the available spectrum. Additionally, UMTS will deliver the economies of scale and opportunity for roaming represented by more than 119 licensed networks[10] in 42 countries[11].

In the local area, the IEEE 802.11 family of technologies has experienced rapid growth, mainly in private deployments. In addition, operators, including cellular operators, are offering hotspot service in public areas such as airports, restaurants and hotels. For the most part, hotspots are complementary with cellular-data networks, as the hotspot can provide broadband services in extremely dense user areas, and cellular networks can provide near-broadband services across much larger areas. Various organizations are looking at integrating wireless LAN service with GSM/UMTS data services, including the GSM Association which is developing recommendations for SIM-based authentication for hotspots and 3GPP which is developing an architecture as part of UMTS Release 6 that

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[8] See Appendix: Global UMTS Network Status, August 23, 2004

[9] The Shosteck Group (www.shosteck.com): Strategic Wireless Seminar, June 22-27, 2004 Tirennhia, Italy; white paper - "*UMTS - When and Why It Will Happen: Timetables and Forecasts*", September 2003; The Shosteck Group E-Stats.

[10] Includes two UMTS licenses tendered.

[11] See Appendix: Global UMTS Network Status, August 2004

defines how a common core network can support UMTS and WLAN radio-access networks.

Another wireless technology receiving considerable attention is promoted as "WiMAX", based on the IEEE 802.16-2004 standard. Developed originally for telecom backhaul in licensed bands, the current specification also supports broadband wireless services for non-mobile users as an alternative to DSL or cable modem types of services. A new version in development, IEEE 802.16e, adds mobility functions, beginning first with portability. Another IEEE standard in development is IEEE 802.20, whose goal is also to provide mobile broadband wireless services. This specification is in its earliest stages of definition with a somewhat uncertain future.

It is important to note that relative to some of these other technologies, UMTS technology is much more mature, and benefits from research and development that began in the early 1990s. UMTS has since been thoroughly trialed, tested and commercially deployed. Like all other complex technologies, UMTS has had its share of birthing pains. But its deployment is now accelerating with stable network infrastructure and attractive reliable mobile devices with rich capabilities. The Global Mobile Suppliers Association (GSA), an organization representing GSM manufacturers, cites that there are 75 UMTS/WCDMA terminals in the market as of August 2004.

Technology Capabilities

GPRS to HSDPA offers an increasing range of capabilities, supporting ever more demanding applications. GPRS, now available globally, already makes a wealth of applications feasible, including enterprise applications, messaging, e-mail, Web browsing, consumer applications, and even some multimedia applications. EDGE significantly expands the capability of GPRS, enabling richer Internet browsing, streaming applications, a greater scope of enterprise applications, and more multimedia applications. Then with UMTS and HSDPA, users can look forward to video phones, high-fidelity music, rich multimedia applications, and efficient access to their enterprise applications.

It is important to understand just what is important for users of these services, whether consumers or enterprises. The obvious needs are broad coverage, high data throughput and for enterprises, security. Less obvious needs, but as critical for effective application performance, is low latency, quality-of-service (QoS) control and spectral efficiency. Spectral efficiency, in particular, is of paramount concern, as it translates to higher average throughputs (and thus more responsive applications) for more users active in a coverage area. The discussion below, which examines each technology individually, shows how the progression from GPRS to HSDPA is one of increased throughput, increased security, reduced latency, improved QoS and increased spectral efficiency.

It is also helpful to specifically note the throughput requirements required for different applications. They are the following:

- Microbrowsing (e.g., WAP): 8 to 16 kbps
- Multimedia messaging: 8 to 32 kbps
- Video telephony: 64-384 kbps
- General purpose web browsing: 32 kbps to 384 kbps
- Enterprise applications, including e-mail, database access, virtual private networking: 32 kbps to 384 kbps
- Video and audio streaming: 32-384 kbps

Note that GPRS and EDGE already satisfy the demands of many applications. With UMTS and HSDPA, applications are faster and the range of supported applications expands.

The following table summaries the capabilities of the different technologies.

Table 1: Comparison of Capabilities of Technologies[12]

	Peak Network Downlink Speed	Average User Throughputs for File Downloads	Capacity	Other Features
GPRS[13]	115 kbps	30 – 40 kbps		
EDGE	473 kbps	100 – 130 kbps	Double that of GPRS	Backward compatible with GPRS
UMTS - WCDMA	2Mbps[14]	220 - 320 kbps	Increased over EDGE for high-bandwidth applications	Simultaneous voice and data operation, enhanced security, QoS, multimedia support, and reduced latency
UMTS - HSDPA	14 Mbps[15]	550-1100 kbps[16]	Two and a half to three and a half times that of WCDMA	Backward compatible with WCDMA
CDMA2000 1XRTT[17]	153 kbps	50-70 kbps[18]		
CDMA2000 1XEV-Data Optimized (DO)[19]	2.4 Mbps	300-500 kbps[20]		Optimized for data, VoIP in development

[12] Source: unless otherwise noted, based on 3G Americas member contributions to this paper.

[13] Coding schemes 1, 2.

[14] 384 kbps typical maximum rate of current devices.

[15] First devices are likely to have a maximum rate of 3.6 Mbps.

[16] 550 to 800 kbps expected with initial devices, 770 to 1100 kbps expected with later advanced mobile devices

[17] Rel 0

[18] Source: Sprint promotional material.

[19] Rel 0

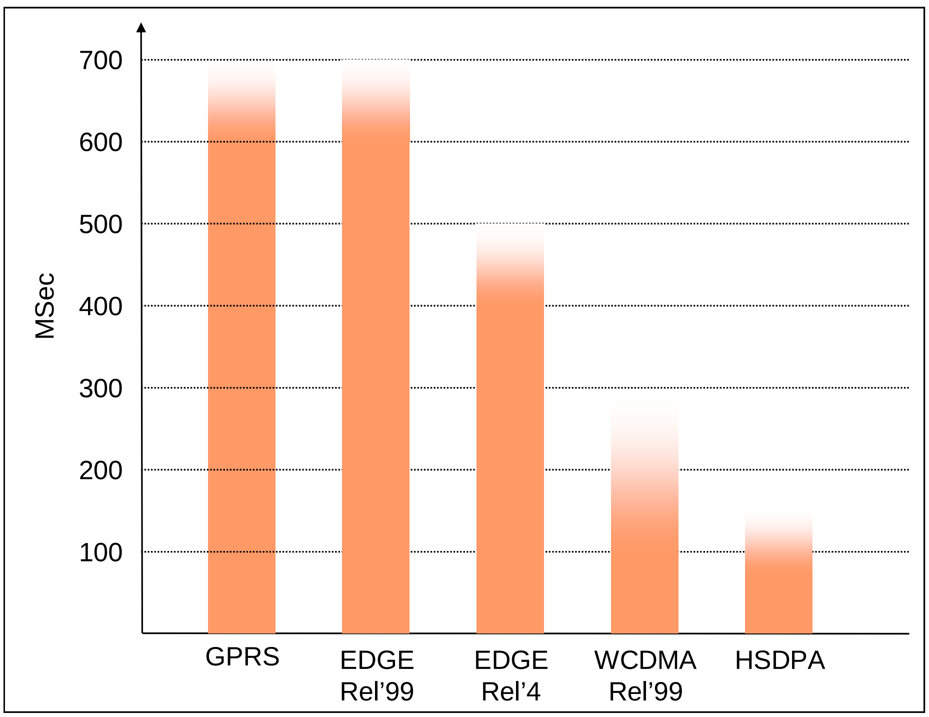
[20] Source: Verizon Wireless promotional material.

In the table above, GPRS, EDGE and WCDMA average user-throughput performance is based on actual field measurements across a large number of file downloads. “Prediction is very difficult, especially if it’s about the future”, This is a famous old quote from Nils Bohr, Nobel laureate Physicist. Rysavy Research’s 2002 wireless data anticipated EDGE average performance of 110-130 kbps and UMTS average performance of 200-300 kbps. The previous data capabilities predictions would have made Nostradamus proud as actual results from operator and vendor field results matched or exceeded the predicted results, validating the methodology used to predict performance. Not only are EDGE and UMTS data services meeting throughput expectations, they are performing extremely reliably in commercial and trial networks.

Given the successful transition from GPRS to EDGE, a performance gain of 2.5 to 3.5 for HSDPA can be anticipated with high confidence. The section below on HSDPA explains the advanced mechanisms used in HSDPA to achieve such impressive results.

Just as important as throughput is network latency, the round-trip time it takes data to traverse the network. Each successive data service reduces latency, with HSDPA expected to have latency approaching 100 msec. Note that there is some variation in latency based on network configuration and operating conditions. See Figure 1.

Figure 1: Latency of Different Technologies



As data capabilities continue to improve, and the cost of service (e.g., $ per Mbyte) decreases, not only will more existing networking applications become feasible for wireless networking, but more developers for both consumer and enterprise markets will see incentives to develop new content and applications. Coupled with complementary developments such as location-based services, mobile commerce infrastructure, and multimedia messaging, data applications will constitute an increasing revenue stream for operators.

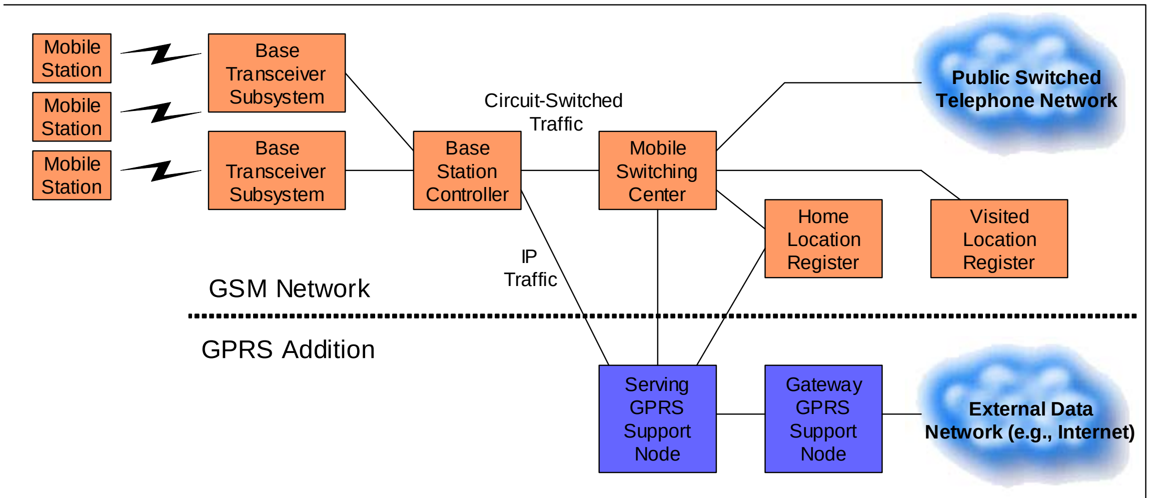
Discussions of spectral efficiency of the different technologies are covered in the next section, "The Path from GPRS to HSDPA." We now look at the capabilities and workings of the individual technologies in greater detail.

GPRS

GPRS is the world's most ubiquitous wireless data service, available in over 201 countries, with service from 217 operators and a choice of over 591 handsets. Various analysts predict unit sales of over 150 million GSM/GPRS devices in 2004. GPRS is a packet-based IP connectivity solution supporting a wide range of enterprise and consumer applications. GPRS networks operate as wireless extensions to the Internet, and give users Internet access as well as access to their organizations from anywhere. With average throughput rates of up to 40 using four time-slot devices, users have the same effective access speed as a modem, but with the convenience of being able to connect from anywhere.

To understand the evolution of data capability, we examine briefly how these data services operate, beginning first with the architecture of GPRS, as depicted in Figure 2.

Figure 2: GSM / GPRS Architecture



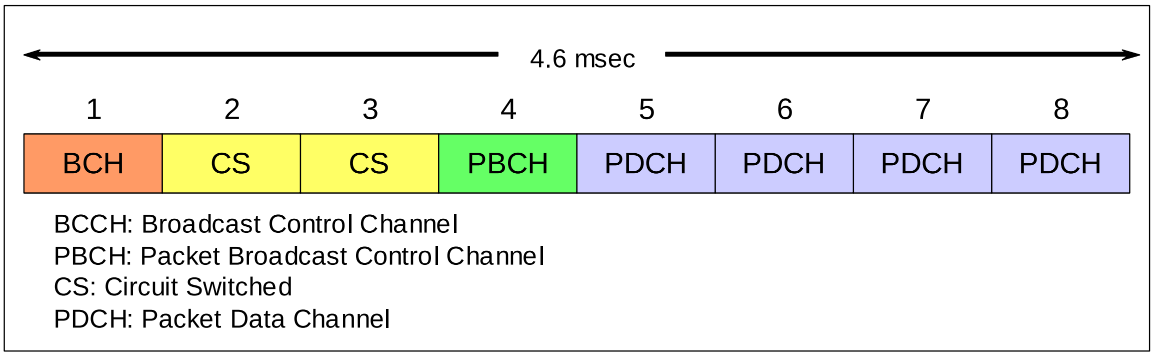
GPRS is essentially the addition of a packet-data infrastructure to GSM. The functions of the data elements are as follows:

1. The base station controller directs packet data to the Serving GPRS Support Node (SGSN), an element that authenticates and tracks the location of mobile stations.
2. The SGSN performs the types of functions for data that the mobile switching center performs for voice. There is one SGSN for each serving area, and it is often collocated with the MSC.
3. The SGSN forwards user data to the Gateway GPRS Support Node (GGSN), which is a gateway to external networks. There is typically one GGSN per external network (e.g., Internet). The GGSN also manages IP addresses, assigning IP addresses dynamically to mobile stations for their data sessions.

Another important element is the home location register (HLR), which stores users' account information for both voice and data service. What is significant is that this same data architecture supports data services in EDGE and UMTS networks, simplifying operator network upgrades.

In the radio link, GSM uses radio channels of 200 KHz width, divided in time into eight time slots that repeat every 4.6 msec, as shown in Figure 3. The network can have multiple radio channels (referred to as transceivers) operating in each cell sector. The network assigns different functions to each time slot, such as the broadcast control channel, circuit switched functions like voice calls or circuit-switched data calls, the packet broadcast control channel (optional), and packet data channels. The network can dynamically adjust capacity between voice and data functions, and can also reserve a minimum amount of resources for each service. This enables more data traffic when voice traffic is low, or likewise more voice traffic when data traffic is low, and maximizes the overall use of the network.

Figure 3: Example of GSM/GPRS Time Slot Structure



GPRS offers close coupling between voice and data services. While in a data session, users can accept an incoming voice call, which suspends the data session, and then resume their data session automatically when the data session ends. Users can also receive SMS messages and data notifications[21] while on a voice call. EDGE networks and devices behave in the same way.

With respect to data performance, each data time slot can deliver user data rates of about 10 kbps using coding schemes 1 and 2, and the network can aggregate up to four of these on the downlink with current devices to deliver users perceived data throughputs of up to 40 kbps. If there are multiple data users active in a cell sector, they share the available data channels. However, as demand for data services increases, operators can accommodate customers by assigning an increasing number of channels for data service limited only by their total available spectrum and radio planning.

With coding schemes 3 and 4, GPRS has greater flexibility in how the radio link allocates communicated bits between data and error control, resulting in increased throughput with higher signal quality. The result is throughput rates up to 33% higher and increased overall spectral efficiency of about 30%[22]. Coding schemes 3 and 4 are an option for operators. To boost GPRS performance and capacity even further, operators are deploying EDGE technology.

[21] Example: WAP notification message delivered via SMS.

[22] Exact gains depend on the frequency reuse applied.

EDGE

EDGE has proven extremely effective in field deployments, not only boosting data rates, and increasing capacity, but also providing an extremely resilient data link that for users, translates to reliable application performance.

EDGE is an official 3G cellular technology that can be deployed in an operators 850, 900, 1800 and 1900 MHz spectrum bands. A powerful enhancement to GSM/GPRS networks, EDGE increases data rates by a factor of three over GPRS and doubles data capacity using the same portion of an operators' valuable spectrum. It does so by enhancing the radio interface while allowing all the other network elements, including BSC, SGSN, GGSN, and HLR to remain the same. In fact, with new GSM/GPRS deployments, EDGE[23] is a software-only upgrade to the network. A GPRS network using the EDGE radio interface is technically called an Enhanced GPRS (EGPRS) network, and the combination of GSM and EDGE radio access networks is referred to as GERAN. EDGE is fully backwards compatible with GPRS and any application developed for GPRS will work with EDGE.

EDGE employs three advanced techniques in the radio link that allow EDGE to achieve extremely high spectral efficiency for narrowband cellular-data[24] services. The first technique is the addition of a new modulation scheme called Octagonal Phase Shift Keying (8-PSK) that allows the radio signal to transmit three bits of information in each radio symbol[25]. In contrast, GSM/GPRS modulation uses Gaussian Minimum Shift Keying (GMSK), which transmits one bit of information per radio symbol. The second technique is multiple coding schemes, where the network can adjust the number of bits dedicated to error control based on the radio environment. EDGE has five coding schemes available for 8-PSK and four coding schemes for GMSK, providing up to nine different modulation and coding schemes. See Table 2. EDGE dynamically selects the optimum modulation and coding scheme for the current radio environment in a process called link adaptation. In the third technique, if blocks of data are received in error, EDGE retransmits data using different coding. The newly received information is combined with the previous transmissions, significantly increasing the likelihood of a successful transmission. This mechanism which provides an effective link gain of around 2 dB, assures the fastest possible receipt of correct data and is called *incremental redundancy*.

Table 2: EDGE Modulation and Coding Schemes[26]

Modulation and Coding Scheme	Modulation	Throughput per Time Slot (kbps)
MCS-9	8-PSK	59.2
MCS-8	8-PSK	54.4
MCS-7	8-PSK	44.8

[23] Assumes EDGE release 99. EDGE release 5 features require some enhancements to the core network.

[24] *Narrowband data* refers to rates of up to about 100 kbps.

[25] *A radio symbol* is the momentary change of phase, amplitude or frequency to the carrier signal to encode binary data

[26] RLC throughputs. Application rates are typically 20% lower.

Modulation and Coding Scheme	Modulation	Throughput per Time Slot (kbps)
MCS-6	8-PSK	29.6
MCS-5	8-PSK	22.4
MCS-4	GMSK	17.6
MCS-3	GMSK	14.8
MCS-2	GMSK	11.2
MCS-1	GMSK	8.8

The resulting throughput per time slot with EDGE can vary from 8.8 kbps under adverse conditions to 59.2 kbps with a very good carrier-to-interference (C/I) ratio. In comparison, GPRS delivers 12 kbps with coding scheme 2 (the most commonly used scheme today) and 20 kbps with the optional coding scheme 4[27]. Though EDGE can theoretically provide 59.2 kbps in each of eight time slots, adding up to a peak network rate of 473.6 kbps in eight time slots, actual user data rates are typically in the 100 to 130 range with four time-slot devices, more than three times higher than GPRS.

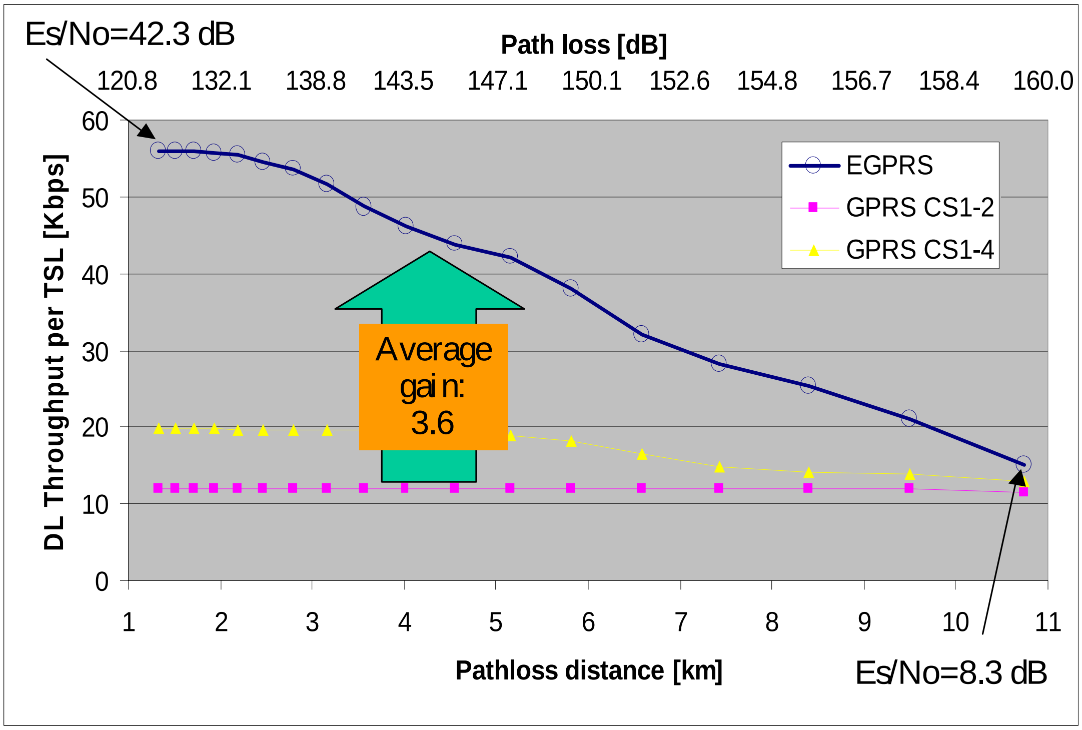
By sending more data in each time slot, EDGE also increases spectral efficiency by 150% relative to GPRS using coding schemes 1 and 2, and by 100% relative to GPRS using coding schemes 1 through 4.

EDGE makes full use of the capacity in the available radio spectrum. In this regard, EDGE is as effective a technique for expanding data capacity as the Adaptive Multi-rate (AMR) codec is for expanding voice capacity. The two working together result in GSM being an extremely efficient cellular technology.

Since EDGE benefits from higher C/I, one question is whether the higher rates are available throughout the entire coverage area. EDGE will indeed accomplish this. There are two sets of curves that illustrate the performance gain. The first, as shown in Figure 4, illustrates downlink throughput (kbps per time slot) versus path-loss distance out to 11 Km. The average gain over this distance for EGPRS over GPRS coding schemes 1-4 is 2.6. The average gain over GPRS coding schemes 1-2 is 3.6.

[27] RLC throughputs. Layer 1 throughputs are 13.4 kbps per time slot for CS2 and 21.4 kbps per time slot for CS4.

Figure 4: Throughput Versus Distance for EGPRS/EDGE[28]

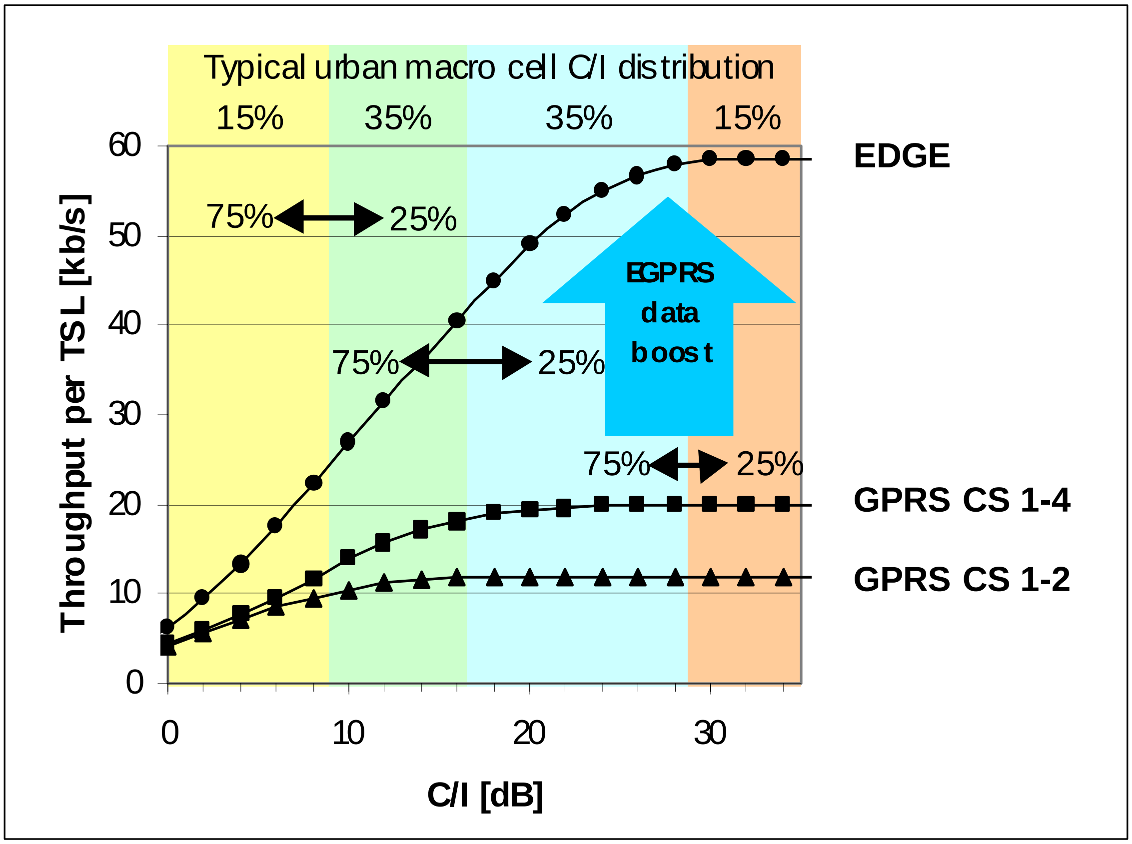


The second curve, as shown in Figure 5, depicts throughput per time slot versus C/I:

- 15% of the coverage area, shown in the yellow section, experiences a two-fold performance improvement relative to GPRS (coding schemes 1-2).
- 70% (in the green section) experiences a four times performance improvement.
- 15% (in the pink section) experiences a five times performance improvement.

[28] Source: 3G Americas member company. Coverage limited scenario.

Figure 5: EDGE Performance Improvement over Coverage Area[29]



In Figure 5, the horizontal double-tipped arrows show how the 15%, 50% and 85% colored borders that depict the C/I distribution in the cell shift depending on network load[30]. The diagram uses a 50% network load, and the arrows show how C/I and throughputs vary between 25% and 75% network load.

Beyond improvements in radio performance, EDGE supports another important feature, namely the same quality-of-service architecture as used by UMTS, which is discussed in the next section. This architecture is based on release 99 of 3GPP specifications. Successive releases build on this foundation with support added for services such as multimedia and voice-over-IP telephony.

With respect to deployment, the GSM network can allocate GPRS and EDGE time slots in the 5/15 or 4/12 reuse layer[31] (which includes the broadcast control channel) as well as in 1/3 reuse or even 1/1 reuse hopping layers. This flexibility facilitates the launch of

[29] Source: 3G Americas member companies. 7 Km cell site distance, 1/3 reuse.

[30] Network load represents what percentage of the time slots in the system are fully utilized. For example, 100% load means all timeslots across the system are fully utilized, at full power, and 50% load means half of the timeslots across the system are in use, at full power.

[31] *4/12 re-use* means that available radio channels are used across four cells, each with three sectors. Each sector has 1/12 of the total channels. The pattern is repeated every four cells.

data services with a certain amount of data capacity, and for this capacity to be readily increased as required.

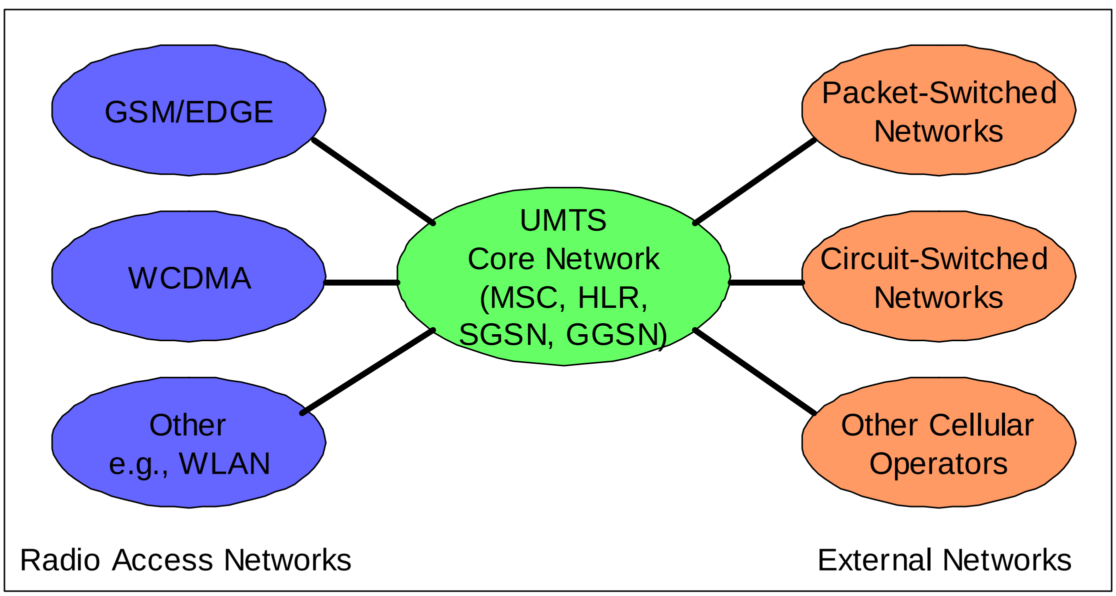
With the data capabilities and spectral efficiency of EDGE, and the spectral efficiency of GSM for voice services, operators can use GSM technology to deliver a broad range of data services that will satisfy their customers for quite some time. Beyond EDGE, operators can expand their data offerings even further with UMTS.

UMTS/WCDMA

UMTS has garnered the overwhelming majority of new 3G spectrum licenses, with forty-six commercial networks and sixty-six more pre-commercial, planned or in deployment[32]. UMTS employs a wideband CDMA radio-access technology. The primary benefits of UMTS include high spectral efficiency for voice and data, simultaneous voice and data capability for users, high user densities that can be supported with low infrastructure cost, and support for high-bandwidth data applications. Operators can also use their entire available spectrum for combined voice and data services.

Additionally, operators will be able to use a common core network that supports multiple radio access networks, including GSM, GPRS, EDGE, and WCDMA. This common core network can use the same network elements as GPRS, including the SGSN, GGSN, MSC, and HLR. This is called the UMTS Multi-radio network, and gives operators maximum flexibility in providing different services across their coverage areas. See Figure 6. How operators can evolve their networks to use common elements is the subject of the next section, The Path from GPRS to HSDPA.

Figure 6: UMTS Multi-Radio Network



The UMTS radio access network consists of base stations referred to as Node B (corresponding to GSM base transceiver systems) that connect to radio network controllers (corresponding to GSM base station controllers). The RNCs connect to the core network as do the BSCs. In networks with both GSM and WCDMA access networks

[32] See Appendix; Global UMTS Network Status, August 23, 2004

available, the network can hand over users between these networks. This is important for managing capacity, as well as for areas where the operator has continuous GSM coverage but has only deployed WCDMA in some locations. In addition, the network can select the radio access network best suited for a user based on user preferences and current network loading.

Whereas GSM is a spread-spectrum system based on time division in combination with frequency hopping, WCDMA is a spread-spectrum system based on direct sequence. WCDMA is spectrally more efficient than GSM, but it is the wideband nature of WCDMA that provides its greatest advantage—the ability to translate the available spectrum into high data rates. This results in flexibility to manage multiple traffic types, including voice, narrowband data, and wideband data.

WCDMA allocates different codes for different channels, whether for voice or data, and can adjust the amount of capacity, or code space, of each channel every 10 msec. WCDMA creates high bandwidth traffic channels by reducing the amount of spreading (using a shorter code). Packet data users can share the same codes and/or time slots as other users, or the network can assign users dedicated channels and time slots. One enhancement over GPRS is that the control channels that normally carry signaling data can also carry small amounts of packet data, which reduces setup time for data communications.

In WCDMA, data channels can support peak rates of over 2 Mbps of data. Though exact throughput depends on what size channels the operator chooses to make available, capabilities of devices and the number of users active in the network, based on real-world trials and some commercial networks, users can expect typical throughput rates in the downlink of 220 to 320 kbps with bursts to 384 kbps. Uplink throughput rates are typically 64 kbps. This will satisfy almost any communications-oriented application. Whereas the average rates of 220-320 kbps are slightly below that quoted by Verizon's EV-DO, AT&T Wireless noted on their July 20, 2004 UMTS launch conference call that the user experience is expected to be similar when downloading or transferring files. Additionally, UMTS is already being deployed by many carriers around the world and has both scale and scope advantages over competing technologies.

Channel throughputs are determined by the amount of spreading in the spectrum. With more spreading, such as used with voice channels, there is greater redundancy in the data stream and the operator can employ more channels. In comparison, a high-speed data channel has less spreading, and a fewer number of such channels are available. Voice channels use a spreading factor of 128, whereas a 384 kbps data channel uses a spreading factor of 8. The commonly quoted rate of more than two Mbps throughput for UMTS is achieved by combining three data channels of 768 kbps, each with a spreading factor of four. WCDMA has significantly lower network latency than GPRS/EDGE, with about 200 to 300 milliseconds (msec) measured in actual networks. Through careful planning, less than 200 msec is achievable.

Whereas EDGE is an extremely efficient technology for supporting low-bandwidth users, WCDMA is extremely efficient for supporting high-bandwidth users (e.g., 100 kbps and higher). In a UMTS Multi-radio network, operators can allocate EDGE channels to the low-bandwidth users and WCDMA channels to other users, thus optimizing overall network performance and efficiency.

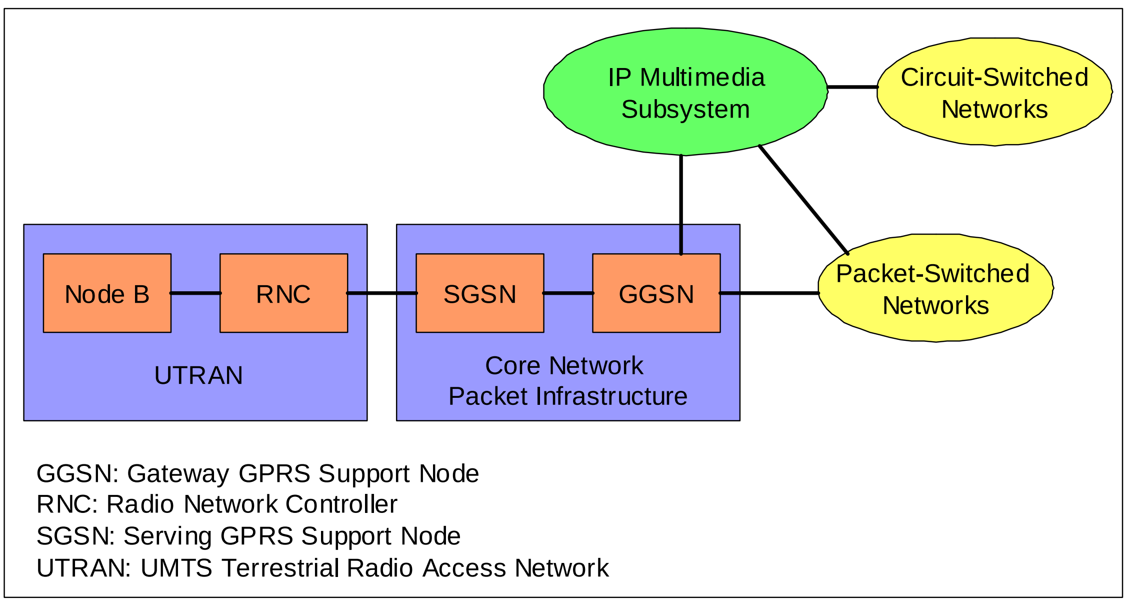
To further expand the number of applications that can operate effectively, UMTS employs a sophisticated quality-of-service architecture for data that provides for four fundamental traffic classes, including:

1. **Conversational.** Real-time interactive data with controlled bandwidth and minimum delay such as voice-over-IP or video conferencing.
2. **Streaming.** Continuous data with controlled bandwidth and some delay such as music or video.
3. **Interactive.** Back-and-forth data without bandwidth control and some delay, such as Web browsing.
4. **Background.** Lower-priority data that is non-real-time such as batch transfers.

This QoS architecture involves negotiation and prioritization of traffic in the radio access network, the core network, and in the interfaces to external networks such as the Internet. Consequently, applications can negotiate quality-of-service parameters on an end-to-end basis between a mobile terminal and a fixed-end system across the Internet or private intranets. This capability is essential for expanding the scope of supported applications, particularly for multimedia, including packetized video telephony and voice over IP.

The QoS mechanisms are also an important aspect of another UMTS architecture called the IP Multimedia Subsystem, an IP-centric approach in which the network handles all traffic, whether voice or data, as IP traffic, and routes it through the SGSN and GGSN. This effectively eliminates the mobile switching center. IMS controls telephone functions and multimedia sessions using the Internet Engineering Task Force (IETF) standard Session Initiation Protocol (SIP), and directs voice traffic either directly to the Internet, to private IP networks, or through a gateway to circuit-switched telephone networks. IMS is part of 3GPP release 5 and release 6 specifications. See Figure 7.

Figure 7: IP Multimedia Subsystem



The benefits of using IMS include more efficient use of radio resources (because all communication is handled in the packet domain), tighter integration with the Internet, and a lower cost infrastructure that is based on IP building blocks and is common between voice and data services. This allows operators to deliver data and voice services at lower cost, and thus provide these services at lower prices, further driving demand and usage.

HSDPA and Beyond

High Speed Downlink Packet Access is a tremendous performance upgrade to WCDMA for packet data that delivers peak rates of 14 Mbps and that is likely to increase average throughput rates to about 1 Mbps, a factor of up to three and a half times over WCDMA. HSDPA also increases spectral efficiency by a similar factor. Available in 3GPP Rel'5, operators will trial HSDPA in 2004 and 2005 with commercial availability by the end of 2005 or early 2006. NTT DoCoMo and Cingular Wireless, with HSDPA planned for launch in 2005, are expected to be the first operators to deploy HSDPA. HSDPA is fully backwards compatible with WCDMA, and any application developed for WCDMA will work with HSDPA. The same radio channel can simultaneously service WCDMA voice and data users, as well as HSDPA data users. HSDPA will also have significantly lower latency, expected at close to 100 msec.

HSDPA achieves its high speeds through similar techniques that amplify EDGE performance past GPRS, including higher-order modulation, variable coding and incremental redundancy, as well as through the addition of powerful new techniques such as fast scheduling. HSDPA takes WCDMA to its fullest potential for providing broadband services, and is the highest-throughput cellular-data capability defined. The higher spectral efficiency and higher speeds not only enable new classes of applications, but also support a greater number of users accessing the network.

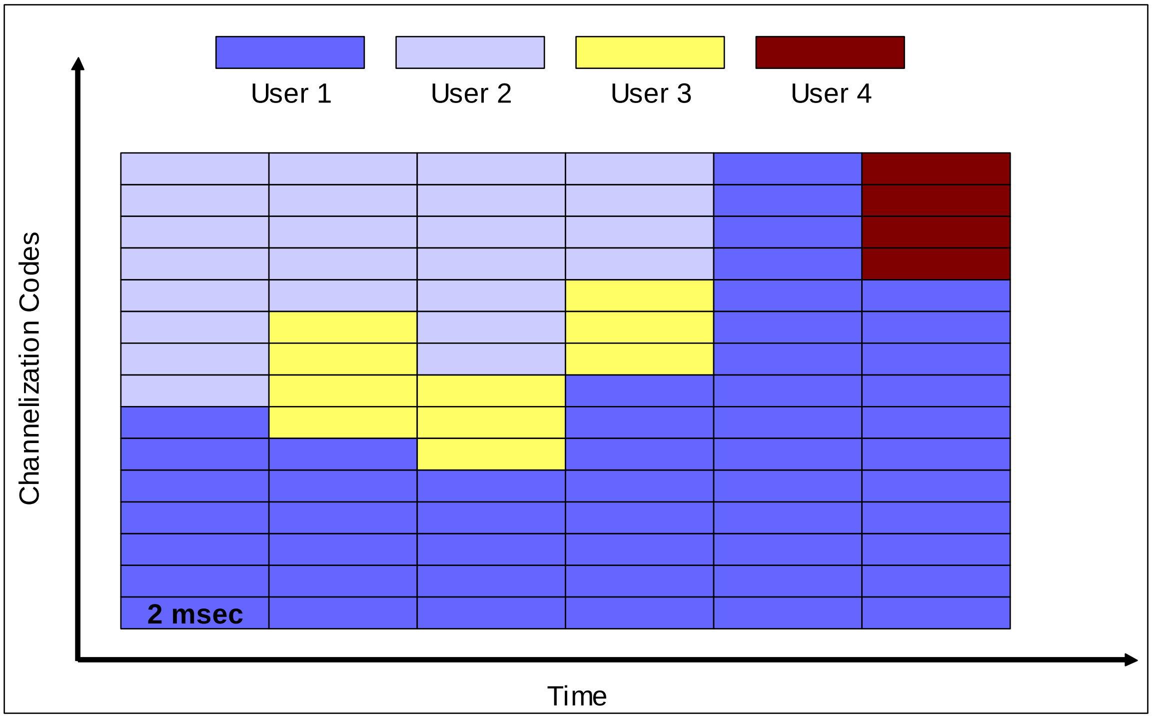
HSDPA achieves its performance gains from the following radio features:

- High speed channels shared both in the code and time domains
- Short transmission time interval (TTI)
- Fast scheduling
- Higher-order modulation
- Fast link adaptation
- Fast hybrid automatic-repeat-request (ARQ)

These features function as follows. First, HSDPA uses high speed data channels called High Speed - Downlink Shared Channels (HS-DSCH). Up to 15 of these can operate in the 5 MHz WCDMA radio channel. Each uses a fixed spreading factor of 16. User transmissions are assigned to one or more of these channels for a short transmission time interval of 2 msec, significantly less than the interval of 10 to 20 msec used in WCDMA. The network can then readjust which users are assigned which HS-DSCH every 2 msec. The result is that resources are assigned in both time (the TTI interval) and code domains (the HS-DSCH channels).

Fast scheduling exploits the short TTI by assigning channels to the users with the best instantaneous channel conditions, rather than in a round-robin fashion. Since channel conditions vary somewhat randomly across users, most users can be serviced using optimum radio conditions, and can hence obtain optimum data throughput. The system also makes sure that each user receives a minimum level of throughput. The result is referred to as "proportional fair scheduling." Figure 8 illustrates different users obtaining different radio resources.

Figure 8: High Speed – Downlink Shared Channels (Example)



HSDPA uses both the modulation used in WCDMA, namely Quadrature Phase Shift Keying (QPSK) and under good radio conditions, an advanced modulation scheme, 16 Quadrature Amplitude Modulation (16 QAM). The benefit of 16 QAM is that four bits of data are transmitted in each radio symbol as opposed to two with QPSK. 16 QAM increases data throughput, while QPSK is available under adverse conditions.

Depending on the condition of the radio channel, different levels of forward error correction (channel coding) can also be employed. For example, a three quarter coding rate means that three quarters of the bits transmitted are user bits and one quarter are error correcting bits. The process of selecting and quickly updating the optimum modulation and coding rate is referred to as fast link adaptation. This is done in close coordination with fast scheduling described above.

Table 3 shows the different throughput rates achieved based on the modulation, the coding rate, and the number of HS-DSCH codes in use. Note that the peak rate of 14.4 Mbps occurs with a coding rate of 4/4, 16 QAM and all 15 codes in use.

Table 3: HSDPA Throughput Rates

Modulation	Coding Rate	Throughput with 5 codes	Throughput with 10 codes	Throughput with 15 codes
QPSK	1/4	600 kbps	1.2 Mbps	1.8 Mbps
	2/4	1.2 Mbps	2.4 Mbps	3.6 Mbps
	3/4	1.8 Mbps	3.6 Mbps	5.4 Mbps
16 QAM	2/4	2.4 Mbps	4.8 Mbps	7.2 Mbps
	3/4	3.6 Mbps	7.2 Mbps	10.7 Mbps

	4/4	4.8 Mbps	9.6 Mbps	14.4 Mbps

Another HSDPA technique is referred to as Fast Hybrid Automatic Repeat Request (Fast Hybrid ARQ.) “Hybrid” refers to a process of combining repeated data transmissions with prior transmissions to increase the likelihood of successful decoding and “fast” refers to the error correcting mechanisms being implemented in the Node-B (along with scheduling and link adaptation), as opposed to the Base Station Controller in GPRS/EDGE. Managing and responding to real-time radio variations at the base station as opposed to an internal network node reduces delays and further improves overall data throughput.

Using the approaches just described, HSDPA maximizes data throughputs, maximizes capacity and minimizes delays. For users, this translates to better network performance under loaded conditions, faster application performance, a greater range of applications that function well, and increased productivity.

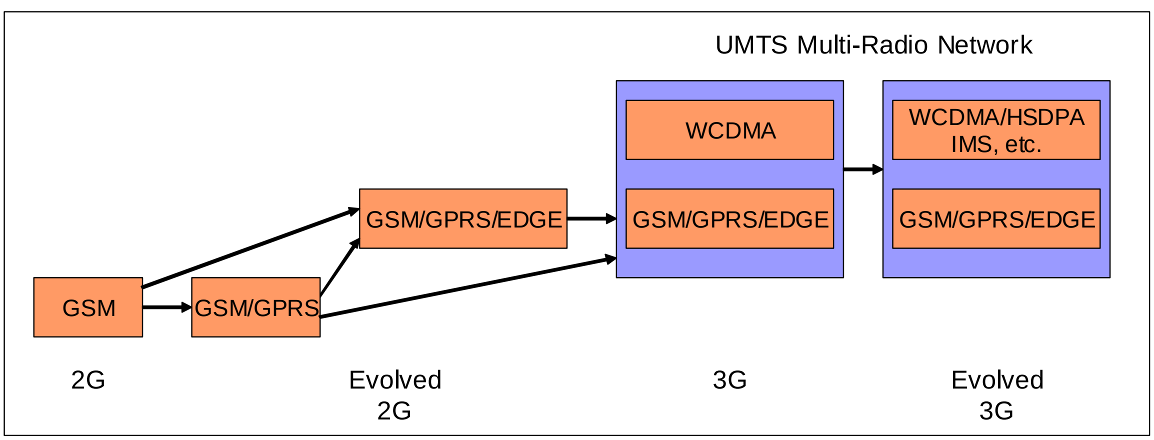
Despite HSDPA’s capabilities, researchers and developers are working on additional enhancements. First devices will support five codes with a peak rate of 3.6 Mbps. Subsequent devices will support ten to fifteen codes with a peak rate of 10.7 Mbps.

Other enhancements include two-branch diversity reception and equalizers in mobile devices. These improvements will occur one to two years after the initial deployment of HSDPA. Simulations show these features to further improve user data rates and network capacity. Relative to WCDMA Rel’99, these features will increase HSDPA performance from a factor of 2.5 to a factor of 3.5. Further evolution of HSDPA peak data rates can be achieved with multiple-input multiple-output (MIMO) antenna techniques of 3GPP Rel.'6. No changes are required to the networks except increased capacity within the infrastructure to support the higher bandwidth.

The Path from GPRS to HSDPA

This section discusses the evolution of data capability from GPRS to HSDPA and the stages available to operators to evolve their networks. This progression, as shown in Figure 9, happens in multiple phases, first with GPRS, then EDGE, then WCDMA, followed by evolved 3G capabilities such as HSPDA, the Internet Multimedia Subsystem and eventually all-IP networks.

Figure 9: Evolution of Cellular Technologies



GSM operators first enhanced their networks to support data capability through the addition of GPRS infrastructure, with the ability to use existing cell sites, transceivers and interconnection facilities. Operators who deployed GSM more recently (e.g., AT&T Wireless, Cingular Wireless, Rogers Wireless, Telecom Personal) installed GSM and GPRS simultaneously. More recently, operators have been upgrading their GPRS networks to EDGE with extremely good results.

EDGE Deployment

Though EDGE is a highly sophisticated radio technology, it uses the same radio channels and time slots as GSM and GPRS, so it does not require additional spectral resources other than to accommodate loading. By deploying EDGE, operators can use their existing spectrum more efficiently. For newer GSM/GPRS networks in areas such as the Americas, EDGE is mostly a software upgrade to the BTS and the BSCs, as the transceivers in these networks are already EDGE capable. Some carriers have reported the cost to upgrade to EDGE from GSM/GPRS as low as US$1 to $2 per POP[33]. The same packet infrastructure supports both GPRS and EDGE. An increasing number of GPRS terminals support EDGE, thus making EDGE available to an increasing number of subscribers.

Many operators that originally planned on using only UMTS for next-generation data services are now deploying EDGE as a complementary 3G technology. There are multiple reasons, including:

1. EDGE provides a high-capability data service in advance of UMTS.
2. EDGE provides data capabilities for the “sweet spot” of 100 kbps needed by the majority of communications-oriented applications.
3. EDGE has proven itself in the field as a cost-effective solution and is now a mature technology.
4. Operators are utilizing their existing spectrum assets and lowering their overall 3G capital expenditures.
5. EDGE is very efficient spectrally, allowing operators to support more voice and data users with existing spectrum.
6. Operators can maintain their EDGE networks as a complementary service offering even when they roll out UMTS.

It is important to note that EDGE technology is continuing to improve. For example, Rel’4 significantly reduces EDGE latency (network round-trip time), from a typical 700 amount of msec to 500 msec.

UMTS Deployment

To expand capability and capacity further, operators are now deploying UMTS worldwide. Though UMTS involves a new radio-access network, several factors will facilitate deployment. First is that most UMTS cell sites can be collocated in GSM cell sites, facilitated by multi-radio cabinets that can accommodate GSM/EDGE as well as UMTS equipment. Second is that much of the GSM/GPRS core network can be used. While the

[33] *POP* refers to population.

SGSN needs to be upgraded, the mobile switching center needs only a simple upgrade and the GGSN can stay the same.

Once deployed, operators will be able to minimize the costs of managing GSM and UMTS networks, as these networks share many of the same aspects, including:

- Packet-data architecture
- Quality-of-service architecture
- Mobility management
- Subscriber account management

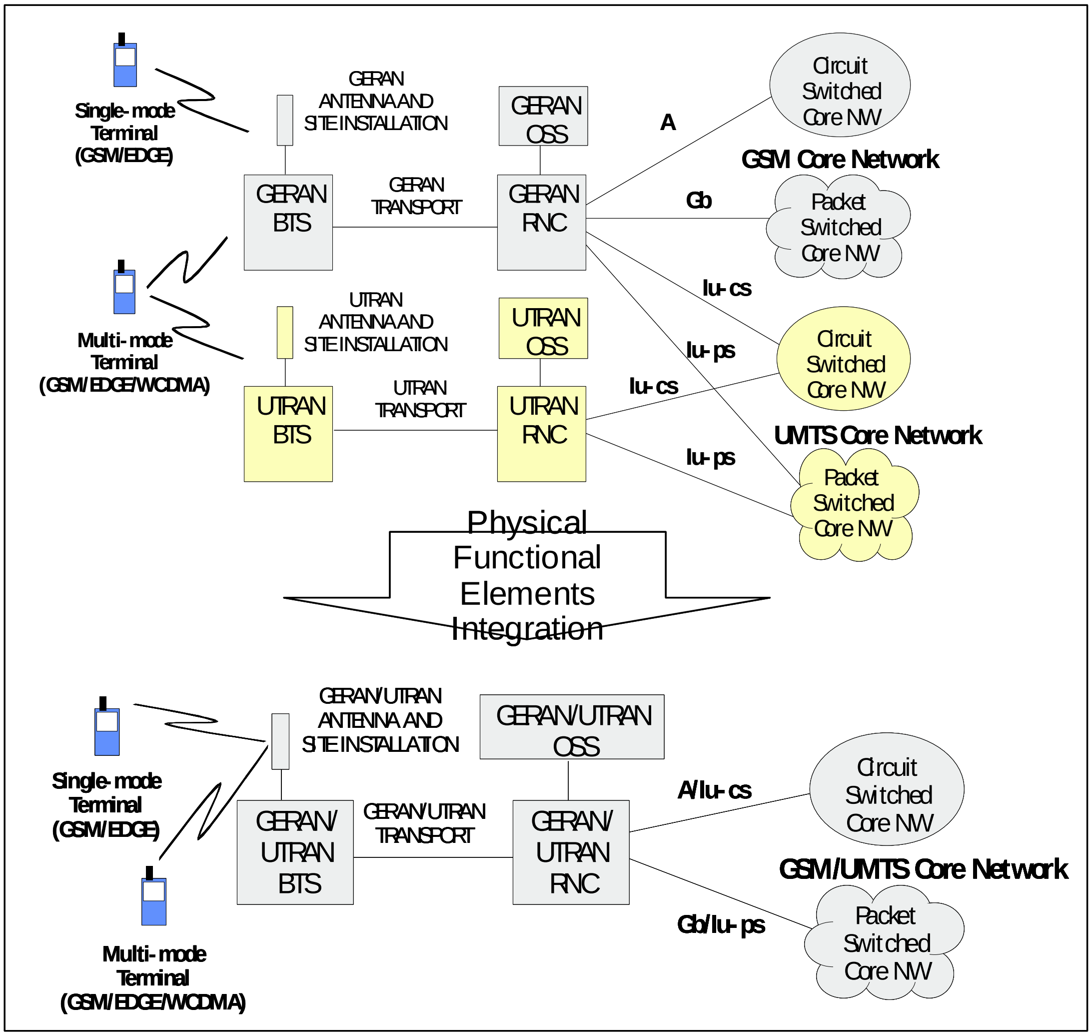
Deployment of UMTS will occur in several stages, beginning first with a portion of the coverage area having UMTS, progressing through continuous UMTS coverage, and then reaching highly integrated, multi-radio operation. Table 4 shows this progression.

Table 4: Deployment Progression of UMTS

Deployment Stage	Characteristics
Initial UMTS deployment	Only a portion of coverage area has UMTS GSM/GPRS/EDGE provides continuous coverage UMTS provides enhanced features and capacity relief for GSM
Enhanced interworking of UMTS and GSM/EDGE	Continuous UMTS coverage Higher loading in UMTS Users assigned to bands based on service and load demands
Full Multi-radio network capability	Dense deployment of UMTS, including microcells Integration of GERAN and UTRAN core equipment Seamless quality-of-service integration Addition of new radio technologies, such as WLANs

Over time, the separate GSM/EDGE access network (called GERAN) and UMTS access network (called UTRAN) and core infrastructure pieces will undergo consolidation, as shown in further detail in Figure 10. This will lower total network cost and improve integrated operation of the separate access networks.

Figure 10: Integration of UMTS and GSM/EDGE Core Network Equipment[34]



For actual users with multi-mode devices, the networks they access will be largely transparent. Today, most UMTS phones also support GSM/GPRS, and already UMTS phones with EDGE capability are emerging.

HSPDA and Other Advanced Functions

The prior discussion has considered the deployment integration of UMTS with GSM/EDGE networks, but it is important to realize that the capabilities of UMTS itself continue to advance, with new features and capabilities added at successive release milestones. Some features of the different 3GPP specification releases include:

- **Release 99:** Completed. First deployable version. Most deployments today are based on Release 99. Support for GSM/EDGE/GPRS/WCDMA radio access networks.

[34] Reprinted with permission of the publisher John Wiley & Sons, Ltd. from "GSM, GPRS and EDGE Performance." Copyright 2002 by John Wiley & Sons, Ltd. This book is available at bookstores, www.amazon.com, and at www.wiley.com, or call (732) 469-4400.

- **Release 4:**[35] Completed. Multi-media messaging support. Efficient interconnection of core network infrastructure over IP network backbones.
- **Release 5:** Completed. HSDPA and first phase of IP-based Multimedia Services (IMS).
- **Release 6**: Under development. Second phase of IMS, WCDMA/WLAN interworking, common radio resource management (GERAN/UTRAN), Multiple Input Multiple Output (MIMO) antenna systems for higher user data rates, and High-Speed Uplink Packet Access (HSUPA) through the use of Enhanced Uplink Dedicated Channels (EUDCH).

Of all these capabilities, it is HSDPA that will provide users the most significant enhancement. The attraction of HSDPA is that it is fully compatible with WCDMA, and can be deployed as a software-only upgrade to newer WCDMA networks. This approach has already proven to be extremely effective with GPRS upgrades to EDGE. HSDPA, which uses many of the same proven radio techniques that EDGE applied to GPRS, is essentially the same strategy applied to WCDMA. WCDMA provides the stable foundation while HSDPA delivers further potential of the radio channel.

The result in as an overwhelming advantage of UMTS over competing technologies: the ability today to provide voice and data services across the whole available radio spectrum, to offer these services simultaneously to users, and to do so in a spectrally efficient manner.

Spectral Efficiency Comparisons

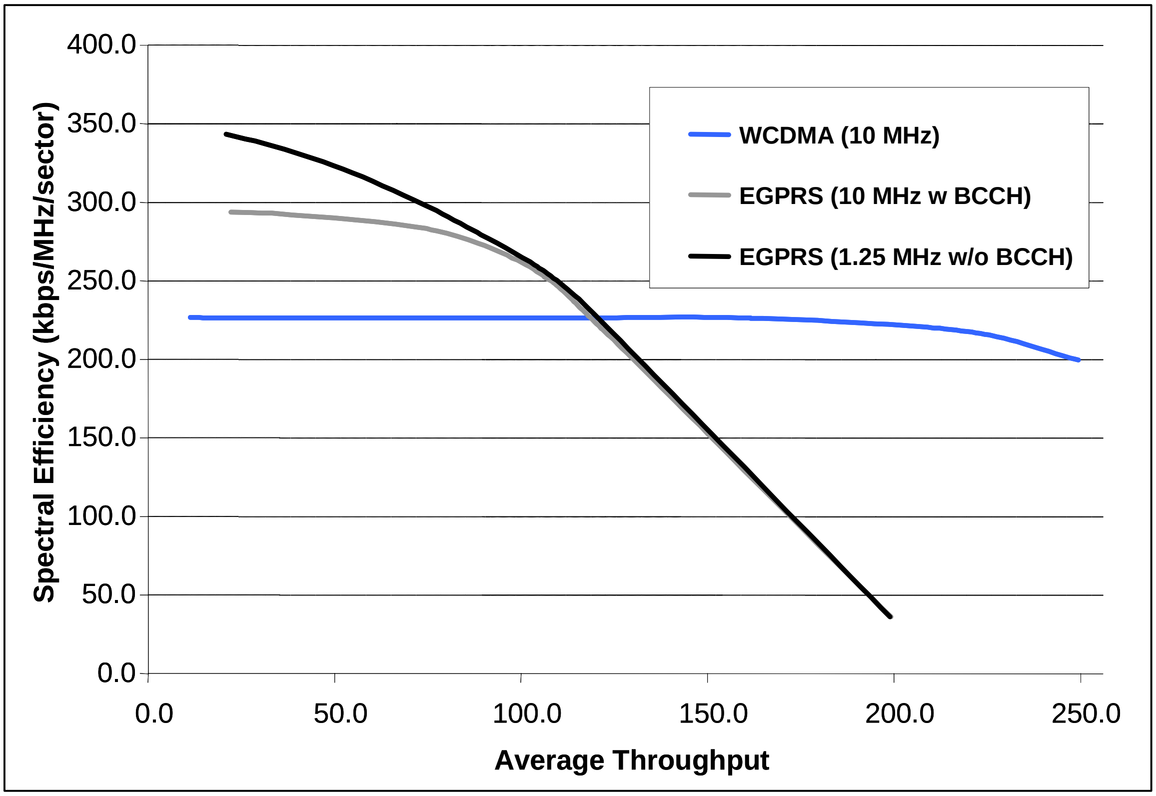
To better understand the reasons for deploying the different data technologies, we need to quantify their spectral efficiency. The evolution of data services is one of an increasing numbers of users with ever higher bandwidth demands. As the wireless data market growths, deploying wireless technologies with high spectral efficiency will be of paramount importance.

Figure 11 shows the spectral efficiency in kbps per MHz per sector versus average user throughput in kbps. The vertical (Y) axis of the graph shows the maximum load that the network can support for the throughput requirement that is expressed in the horizontal (X) axis. The figure compares EDGE (or EGPRS) versus WCDMA.

For average throughput, the simulations show that EDGE has the greatest spectral efficiency for data rates below 100 kbps. For data rates above 100 kbps, WCDMA has greater spectral efficiency. In the instance where EDGE is deployed in a 1.25 MHz band without a control channel and using two transceivers, spectral efficiency is even greater.

[35] After Release 99, release versions went to a numerical designation instead of designation by year.

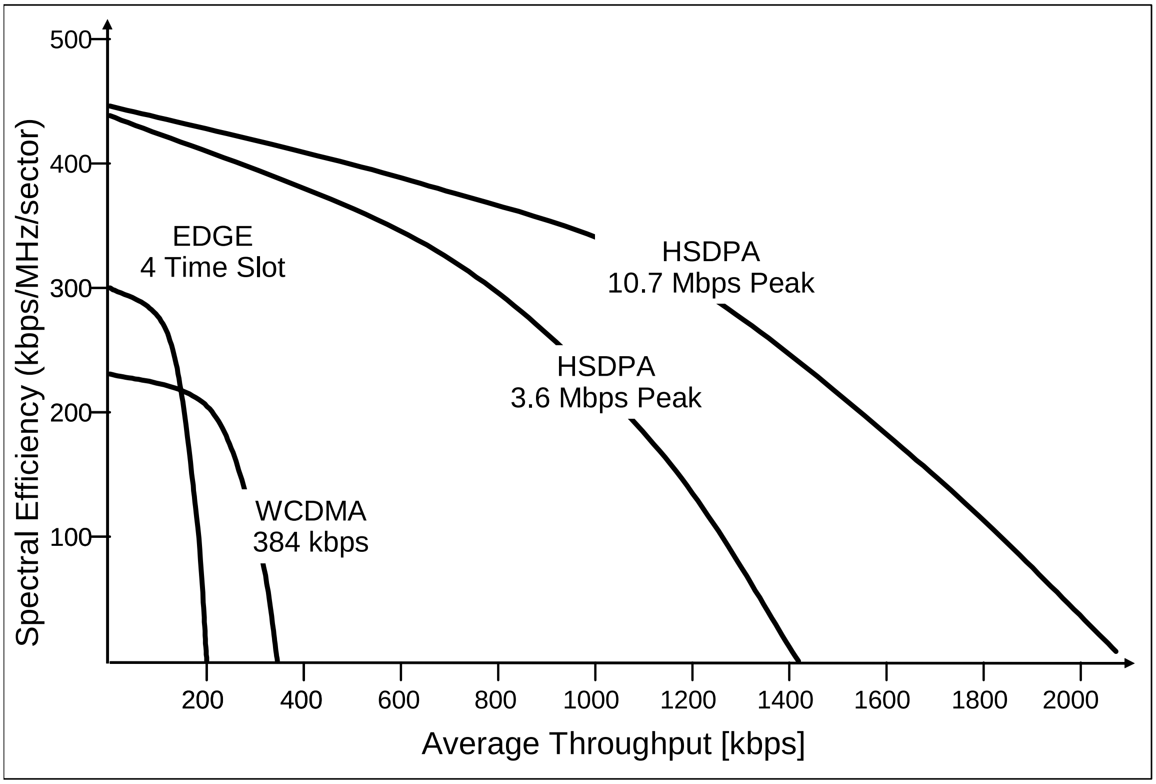
Figure 11: Spectral Efficiency Comparison Based on Average Throughput[36]



As shown in Figure 12 which adds HSDPA to the figures above, HSDPA has even higher spectral efficiency. HSDPA with 3.6 Mbps peak rate refers to initial devices supporting 5 codes and HSDPA with 10.7 Mbps peak rate refers to later devices supporting 15 codes.

[36] Source: Joint analysis by 3G Americas members. Assumptions include: Typical urban deployment. Maximum path loss conditions are 152 dB. 5 Km intercell distance. The propagation model is “Path Loss Model for Vehicular Test Environment” described in ETSI TR 101 112 V3.2. The traffic model assumes 100% FTP traffic. Each new user downloads a file of 120 Kbytes. If the user is blocked, the user re-tries after 5 seconds. For EGPRS/EDGE, 1/3 frequency reuse with no frequency hopping. Devices use four time slots.

Figure 12: HSDPA Spectral Efficiency[37]

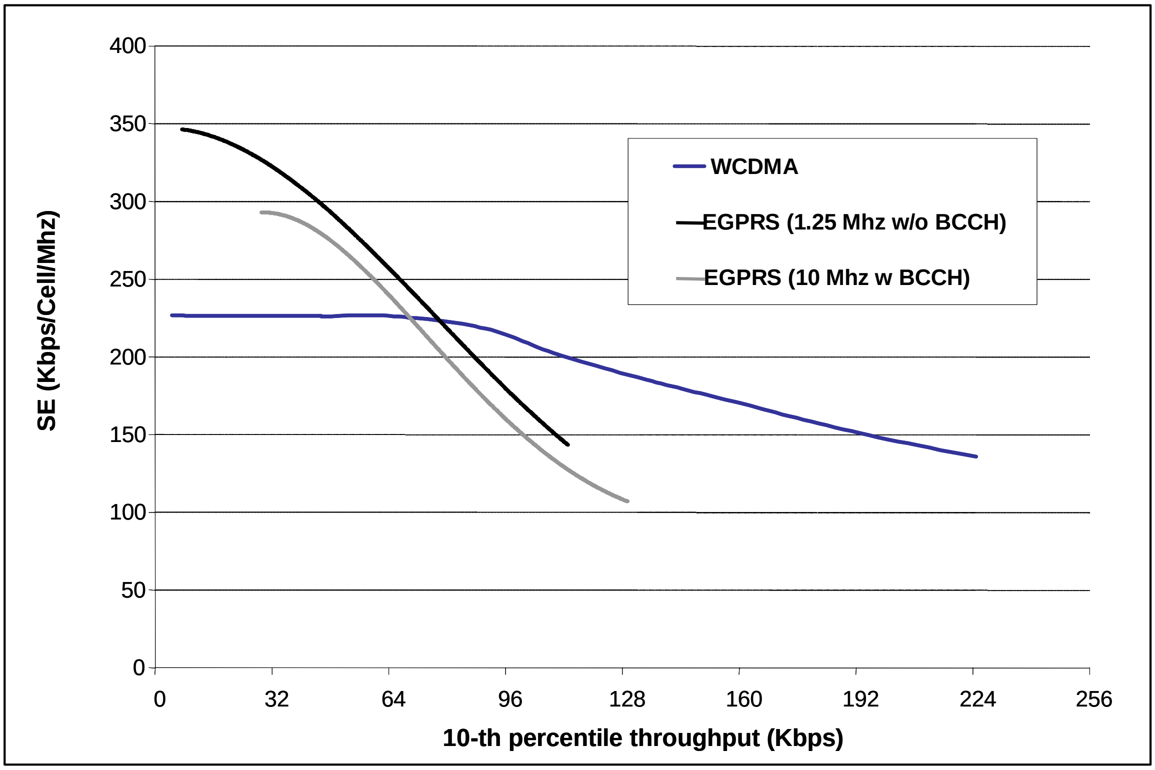


The simulations show HSDPA has the one of the highest spectral efficiencies and the highest supported data rates of any cellular system.

The next figure shows the spectral efficiency in kbps per MHz per sector versus tenth-percentile throughput in kbps, and again compares EDGE (or EGPRS) with WCDMA. The significance of using tenth-percentile data is that ninety percent of users obtain data rates greater than that amount. This approach avoids scenarios where a subset of users, due to good radio conditions, account for a disproportionate amount of aggregate throughput. In this comparison, EDGE is the most spectrally efficient technology below 72 kbps.

[37] Source: 3G Americas member companies. HSDPA assumptions: hexagonal 3-sector macro cell with 65-degree antennas, single antenna transmitter at BTS, single antenna reception in user equipment, rake receiver in user equipment, proportional fair scheduler, low mobile speed, best effort data.

Figure 13: Spectral Efficiency Comparison Based on 10-th Percentile Throughput[38]

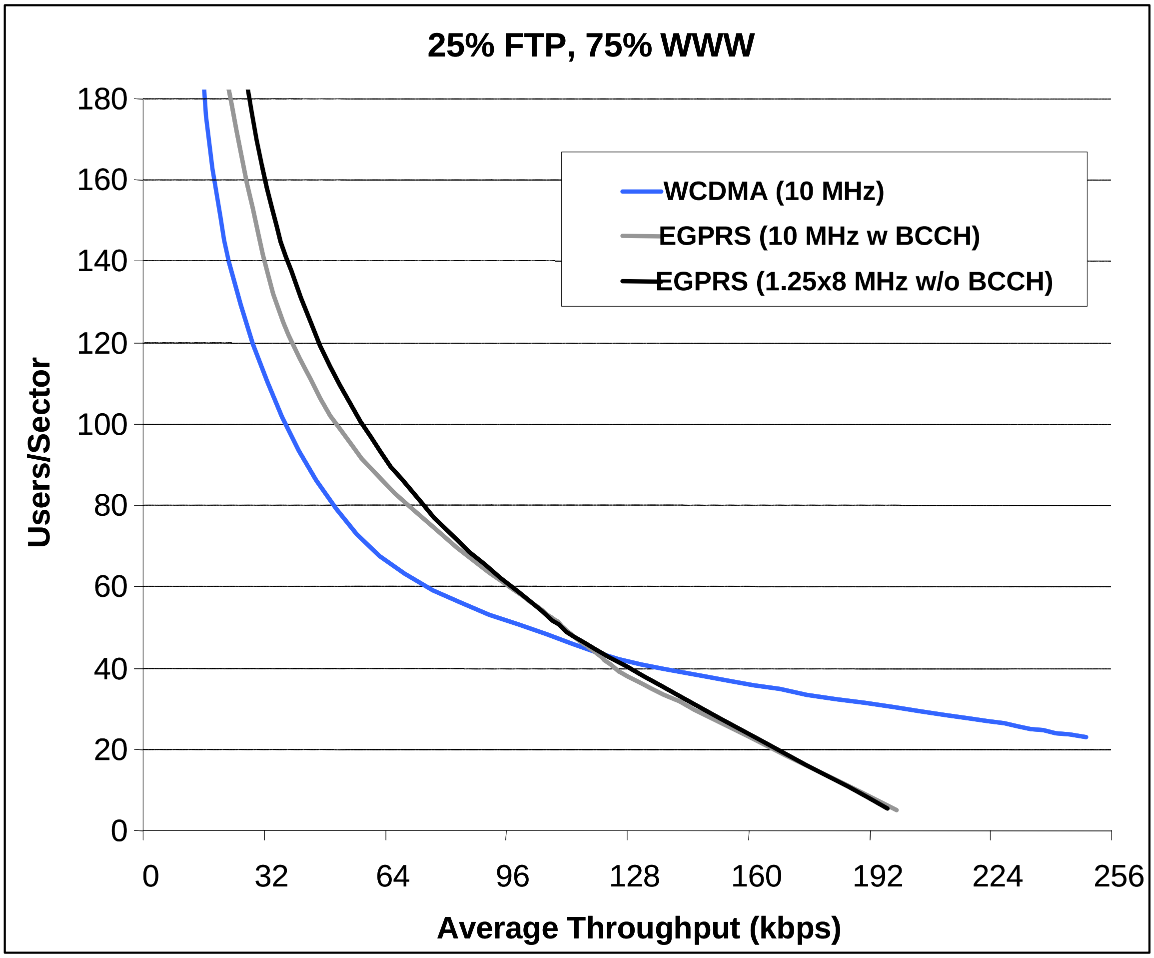


Note that for throughputs below 32 kbps, tenth-percentile spectral efficiency is similar to the average-throughput spectral efficiency. At higher throughputs, however, tenth-percentile spectral efficiency is lower than average-throughput spectral efficiency for all the technologies discussed.

The final comparison is to show the number of users that can be supported per sector in 10 MHz versus average throughput. This is based on the same assumptions as in Figure 11 and Figure 13, though using a different data-traffic model, and provides an alternate comparison of spectral efficiency. Clearly, these networks can support the greatest number of users at lower data rates. Once again, EDGE performs extremely well for lower data rates, supporting one hundred and sixty users per sector in 10 MHz at 32 kbps of throughput and ninety users per sector at 64 kbps.

[38] Source: Joint analysis by 3G Americas' members. Assumptions (same as prior figure) include: Typical urban deployment. Maximum path loss conditions are 152 dB. 5 Km intercell distance. The propagation model is "Path Loss Model for Vehicular Test Environment" described in ETSI TR 101 112 V3.2. The traffic model assumes 100% FTP traffic. Each new user downloads a file of 120 Kbytes. If the user is blocked, the user re-tries after 5 seconds. For EGPRS/EDGE, 1/3 frequency reuse with no frequency hopping. Devices use four time slots.

Figure 14: Users per Sector in 10 MHz versus Average Throughput[39]



Relative to WCDMA, simulations show that HSDPA will increase capacity by a further 55% based on a simple "round-robin" scheduling scheme. By using a more advanced scheduling scheme such as "proportional-fair scheduling", HSDPA can realize further capacity gains, averaging 50%. See Figure 15. Further gains are available through advanced mobile stations that employ multiple antennas. In total, the simulations show that relative to WCDMA, HSDPA will increase capacity by a factor of 2.5 to 3.5.

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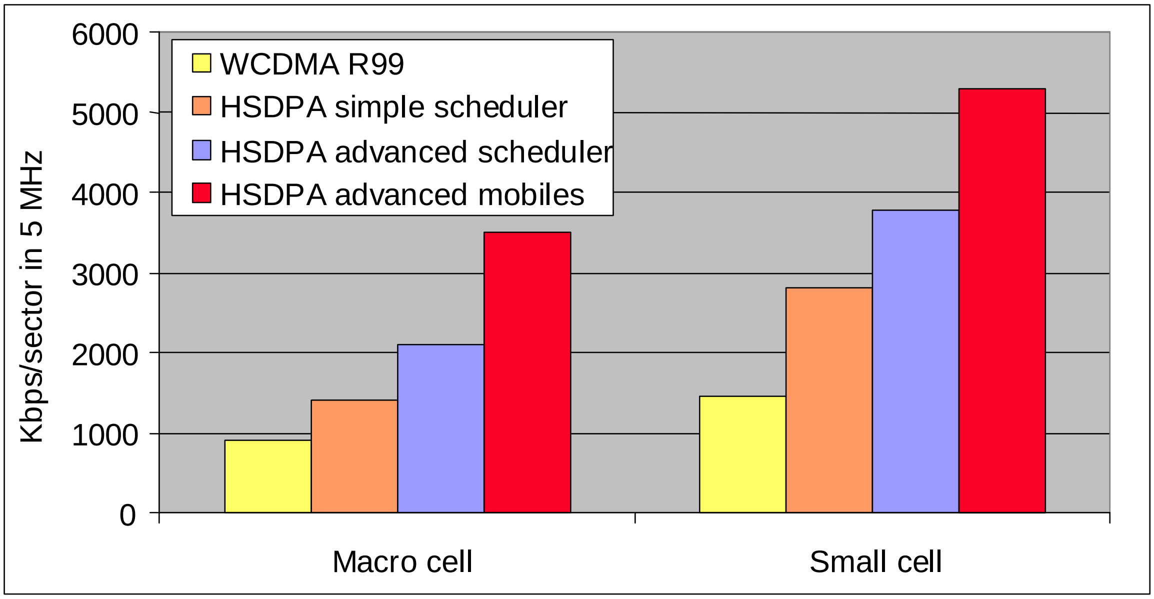
[39] Source: 3G Americas member companies. Assumptions (same as prior two figures except for data-traffic modeling) include: Typical urban deployment. Maximum path loss conditions are 152 dB. 5 Km intercell distance. The propagation model is "Path Loss Model for Vehicular Test Environment" described in ETSI TR 101 112 V3.2. For EGPRS/EDGE, 1/3 frequency reuse with no frequency hopping. Devices use four time slots. Data traffic is modeled as follows: 25% of users engaged in continuous file transfer; 75% of users engaged in Web browsing, downloading pages of 67.5 Kbytes with 14.5 seconds of reading time between pages during which time no data transfer occurs.

Figure 15: HSDPA Capacity[40]



Conclusion

This paper has described the data capabilities of GPRS to HSDPA. This evolution occurs in successive stages, with each stage increasing data throughput, increasing spectral efficiency, reducing network latency and adding new features such as quality-of-service and multimedia support. The migration and benefits of the evolution from GPRS to HSDPA is both practical and inevitable. Combined with the ability to roam globally, huge economies of scale, widespread acceptance by operators, complementary services such as multimedia messaging and a wide variety of competitive handsets, the result is a compelling technology family for both users and operators. UMTS has already been selected by some one hundred operators and has support from nearly all major regional standardization bodies. It offers an excellent migration path for GSM operators and as well as an effective technology solution for greenfield operators.

EDGE performance results in deployed networks have proven earlier Rysavy Research predictions correct by providing data speeds of 100-130 kbps. EDGE has delivered a remarkably effective and efficient technology for upgrading GPRS capability. EDGE, by employing sophisticated techniques such as higher-order modulation, variable coding schemes, link adaptation and incremental redundancy, doubles network capacity and increases average data throughputs by a factor of three. For many networks, EDGE is a software upgrade, and can be done at minimal incremental cost. In fact, many networks are becoming EDGE capable through a normal process of GSM infrastructure expansion and updating.

Beyond EDGE, operators are deploying UMTS technology to provide average speeds of 220 kbps to 320 kbps (six to eight times wireline dial up), which bring an entire new set of capabilities, particularly the support for high-bandwidth applications. Whereas EDGE is extremely efficient for narrowband data services, the WCDMA radio link is extremely efficient for wideband services. EDGE and WCDMA provide the capabilities to make entire

[40] Source: Aggregated data from contributions to 3G Americas.

cities and countries "broadband hotspots." Unlike competing technologies, WCDMA today also offers users simultaneous voice and data, and allows operators to support voice and data across their entire available spectrum. Combined with a comprehensive quality-of-service framework and multimedia support, a network using both EDGE and WCDMA provides an optimal solution for a broad range of usages.

UMTS is further enhanced by the deployment of High Speed Downlink Packet Access, an extremely fast data service with anticipated average speeds of about 1 Mbps, and peak speeds of up to 14 Mbps, the highest rate available for any cellular technology. HSDPA achieves its high speeds through similar techniques that propel EDGE performance past GPRS as well as through the addition of powerful new techniques such as fast scheduling. Like EDGE, HSDPA can be deployed as software-only upgrade and is currently being trialed with commercial availability expected in late 2005 or 2006.

With the continued growth in mobile computing, powerful new handheld computing platforms, an increasing amount of mobile content, multimedia messaging, mobile commerce, and location services, wireless data will inevitably become a huge industry. GPRS to HSDPA provides the most robust portfolio of technologies and the optimum framework for realizing this potential.

This white paper was written for 3G Americas by Rysavy Research (http://www.rysavy.com) and utilized a composite of statistical information from multiple resources.

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Appendix

EDGE Technology Worldwide *(data as of August 25, 2004)*

COUNTRY	OPERATOR	COMMERCIAL	FREQUENCY	STATUS
NETWORKS IN SERVICE				
Algeria	Orascom Télécom Algérie	Jul-04	900	In Service
Argentina	CTI Movil	Mar-04	1900	In Service
Bahrain	MTC Vodafone	Jan-04	900	In Service
Barbados	AT&T Wireless Group	Nov-03	800	In Service
Bermuda	Telecom/AT&T Wireless	Nov-03	1900	In Service
Brazil	Telecom Americas/Claro	Mar-04	1800	In Service
Brazil	TIM	Jun-04	1800	In Service
Canada	Rogers Wireless	Nov-03	850/1900	In Service
Cayman Islands	AT&T Wireless	Nov-03	1900	In Service
Chile	Telefonica Movil	Oct-03	1900	In Service
China	China Mobile	Jul-04	900/1800	In Service
Croatia	VIPNet	Apr-04	900	In Service
Estonia	EMT	Jun-04	900/1800	In Service
Finland	Elisa	Jun-04	900/1800	In Service
Finland	Telia Sonera	Oct-03	900/1800	In Service
Hong Kong (China)	CSL	Sep-03	900/1800	In Service
Hungary	T-Mobile (Westel)	Oct-03	900/1800	In Service
India	Airtel (Bharti)	Jul-04	900/1800	In Service
India	Hutchinson Max Telecom	Jul-04	900/1800	In Service
India	IDEA Cellular	Jul-04	900/1800	In Service
Israel	CellCom Israel	Jun-04	1800	In Service
Italy	TIM Italy	May-04	900/1800	In Service

COUNTRY	OPERATOR	COMMERCIAL	FREQUENCY	STATUS
Kuwait	MTC-Vodafone	Jun-04	900/1800	In Service
Lithuania	Bité GSM	Dec-03	900/1800	In Service
Malaysia	DiGi	May-04	1800	In Service
Mexico	Telefonica Moviles (TMM)	Jul-04	1900	In Service
Puerto Rico	AT&T Wireless	Nov-03	1900	In Service
Slovakia	EuroTel Bratislava	Jun-04	900/1800	In Service
Slovenia	Si.Mobile – Vodafone	Mar-04	900/1800	In Service
Sri Lanka	Dialog GSM / Telekom Malaysia	Mar-04	1800	In Service
Sri Lanka	Mobitel	Jan-04	1800	In Service
Thailand	AIS	Oct-03	900	In Service
USA	AT&T Wireless	Nov-03	1900	In Service
USA	Cingular Wireless	Jun-03	850/1900	In Service
NETWORKS IN DEPLOYMENT				
Bahrain	Batelco		900/1800	In Deployment
Brunei	DataStream Technology		900	In Deployment
Chile	Entel PCS		1900	In Deployment
Cyprus	Investcom (Scancom)		900	In Deployment
Czech Republic	T-Mobile		900/1800	In Deployment
Ecuador	America Movil (Conecel dba Porta)		850	In Deployment
Finland	Ålands Mobiltelefon AB		900/1800	In Deployment
Ghana	Scancom		900	In Deployment
Hong Kong (China)	Peoples		1800	In Deployment
Hungary	Pannon		900/1800	In Deployment
Indonesia	Indosat		900/1800	In Deployment
Jordan	Mobilcom		900	In Deployment
Kazakhstan	GSM Kazakhstan		900	In Deployment
Kuwait	Wataniya Telecom		900/1800	In Deployment
Mexico	Telcel		1900	In Deployment
Montenegro	ProMonte		900	In Deployment
Netherlands	Telfort		1800	In Deployment
Norway	Netcom (Telia Sonera)		900/1800	In Deployment
Norway	Telenor Mobile		900/1800	In Deployment
Peru	TIM		1900	In Deployment

COUNTRY	OPERATOR	COMMERCIAL	FREQUENCY	STATUS
Philippines	Digitel/Sun Cellular		1800	In Deployment
Philippines	GLOBE		900/1800	In Deployment
Philippines	SMART		900/1800	In Deployment
Poland	Polkomtel/ Plus GSM		900/1800	In Deployment
Romania	Orange Romania		900	In Deployment
Russia	Mobile TeleSystems (MTS)		900/1800	In Deployment
Russia	Uralsvyazinform		900/1800	In Deployment
Serbia	Telekom Srbija/YUG 03		900	In Deployment
South Africa	MTN		900	In Deployment
Switzerland	Swisscom Mobile		900/1800	In Deployment
Thailand	DTAC		1800	In Deployment
Ukraine	Kyivstar GSM		900/1800	In Deployment
USA	Cellular One of NE Arizona		1900	In Deployment
USA	Corr Wireless		800/1900	In Deployment
USA	Dobson Communications		850/1900	In Deployment
USA	T-Mobile USA		1900	In Deployment
USA	Triton PCS		1900	In Deployment
USA	Westlink (Kansas)		1900	In Deployment
NETWORKS PLANNED				
Anguilla	Cable & Wireless		850	Planned
Antigua & Barbuda	Cable & Wireless		850	Planned
Barbados	Cable & Wireless		850	Planned
Bermuda	BTC Mobility		1900	Planned
British Virgin Islands	CCT Boatphone		800/1900	Planned
Cayman Islands	Cable & Wireless		1900	Planned
Colombia	America Movil		850	Planned
Colombia	Colombia Movil		850	Planned
Denmark	Sonofon		900	Planned
Dominica	Cable & Wireless		850	Planned
France	Bouygues Telecom		900/1800	Planned
Grenada	Cable & Wireless		850	Planned
Guatemala	Sercom		1900	Planned
Guyana	Cel Star		900	Planned

COUNTRY	OPERATOR	COMMERCIAL	FREQUENCY	STATUS
Ireland	Meteor		900/1800	Planned
Jamaica	Cable & Wireless		1900	Planned
Montserrat	Cable & Wireless		850	Planned
St. Kitts & Nevis	Cable & Wireless		850	Planned
St. Lucia	Cable & Wireless		850	Planned
St. Vincent & the Grenadines	Cable & Wireless		850	Planned
Thailand	TA Orange		1800	Planned
Turks & Caicos Islands	Cable & Wireless		850	Planned
USA	Centennial Wireless		800	Planned
USA	Cincinnati Bell Wireless		1900	Planned
USA	EDGE Wireless		1900	Planned
USA	Viaero (NECCI)		800/1900	Planned
USA	Western Wireless		800/1900	Planned
NETWORKS IN TRIAL				
Brazil	Oi		1800	Trial
China	China Unicom		900	Trial
Czech Republic	EuroTel Praha		900/1800	Trial
Hong Kong (China)	Sunday		1800	Trial
India	IDEA Cellular		900/1800	Trial
Indonesia	Telkomsel		900/1800	Trial
Serbia	Mobtel Srbija		900	Trial
EDGE-CAPABLE NETWORKS				
Argentina	Telecom Personal		1900	EDGE-capable
Argentina	Unifon		1900	EDGE-capable
Canada	Microcell		1900	EDGE-capable
Greece	TIM Hellas		900	EDGE-capable
Kazakhstan	Kar-Tel		900	EDGE-capable
Russia	SMARTS		900/1800	EDGE-capable
Russia	Vimpelcom		900/1800	EDGE-capable
Ukraine	DCC/Astelit			EDGE-capable

Source: Information compiled by 3G Americas from EMC World Cellular Database and public company as of August 23, 2004.

EDGE Equipment

A growing number of manufacturers and software/application providers support EDGE.

EDGE vendors include:

- *Infrastructure:* Alcatel, Ericsson, Motorola, Nokia, Nortel Networks, Siemens
- *Handsets, PDAs, and customized devices:* Intermec, Itronix, LG Electronics, Motorola, NEC, Nokia, palmOne, Panasonic, Pantech Co. (Korea), Research In Motion, Samsung, Siemens, Sierra Wireless, Sony Ericsson
- *Application developers, system integration, middle solutions, and software solutions:* Agere Systems, Alcatel, Cisco Systems, Comarco Wireless, Comsys, Ericsson, HP, Gemplus, IBM, Intermec, Oracle, Research in Motion, Royal Philips Electronics, Siemens, Tropian, TTPCom
- *Chip manufacturing, design and testing:* Aeroflex (Racal), Agere Systems, Analog Devices, Broadcom, Infineon, Intel, Motorola, Texas Instruments, TTPCom

EDGE Devices

Vendor	Model	Frequency Bands GSM/GPRS/EDGE	Availability
LG Electronics	A7100	850/1800/1900	Provisional
Motorola	V725	800/1800/1900	2H 2004
Motorola	V551/V555	850/900/1800/1900	Q4 2004
Nokia	6200 (Americas) -------------------- 6220 (Europe/Asia Pacific/Africa)	850/1800/1900 (Americas) -------------------- 900/1800/1900 (Europe/Asia Pacific/Africa)	Available now
Nokia	3200	850/1800/1900 (Americas) ----------------------- 900/1800/1900 (Europe/Asia Pacific/Africa)	Available now
Nokia	6170	850/1800/1900	Available now
Nokia	6620 smartphone	850/1900/1800	Available now
Nokia	6630 smartphone	900/1800/1900	Available now
Nokia	6230	850/1800/1900 (Americas) -------------------- 900/1800/1900 (Europe/Asia Pacific/Africa)	Available now

Vendor	Model	Frequency Bands GSM/GPRS/EDGE	Availability
Nokia	5140	850/1800/1900 (Americas) ------------------------ 900/1800/1900 (Europe/Asia Pacific/Africa)	Available now
Nokia	6820	850/1800/1900 (Americas) ------------------------ 900/1800/1900 (Europe/Asia Pacific/Africa)	Available now
Nokia	6810	900/1800/1900	Q2 2004
Nokia	7700	900/1800/1900	Not commercially available
Nokia	9500 Communicator	850/1800/1900 (Americas) ------------------------ 900/1800/1900 (Europe/Asia Pacific/Africa)	Q4 2004 *
Nokia	N 12 GSM Module	850/1900 (Americas) -------------------- 900/1800 (Europe/Asia Pacific/Africa)	Q3 2004 -------------------- Q4 2003
Nokia	7200 (Outside the Americas only)	900/1800 (Outside the Americas only)	Available now (Outside the Americas only)
Samsung	D,E,P,S,V and X Series	Under development	
Sony-Ericsson	Z500 ------------------- Z500i	850/1800/1900 (Americas) -------------------- 900/1800/1900 (Europe/Asia)	Q3 2004 ------------------- Q4 2004
Sony-Ericsson	S710a	850/1800/1900	Q4 2004
Sony-Ericsson	GC82 EDGE PC Card	850/1900	Available now
Sony-Ericsson	GC83 EDGE PC Card ------------------- GC85 EDGE PC Card	850/1800/1900 -------------------- 900/1800/1900	Available now: Americas ------------------- Q4 2004: Europe
Sierra Wireless	AirCard® 775	850/900/1800/1900	Q3 2004
Sierra Wireless	MP 775 GPS wireless modem	850/900/1800/1900	Q3 2004
Siemens	MC75 Module	850/900/1800/1900	Q1 2005

* Device yet to be authorized by FCC rules, may not be offered for sale until FCC authorization is obtained.

(Source: Information compiled by 3G Americas from public company announcements, August 2004)

Global UMTS Network Status

EMC World Cellular Database & UMTS Forum		**Networks In Service**		**46**
August 19, 2004		**License Awarded**		**5**
		License Revoked		**7**
		License Tendered		**2**
		Planned/In Deployment		**55**
		Potential License		**32 in 17 countries**
		Pre-Commercial		**11**
		Status Unclear		**2**
		Trial		**12**
Country	**Operator**	**Status**	**Start Date**	**Opening**
NETWORKS IN SERVICE				
Australia	Hutchison 3G	In Service	Apr 2003	
Austria	Connect Austria	In Service	Dec 2003	
Austria	Hutchison 3G	In Service	May 2003	
Austria	Mobilkom	In Service	Apr 2003	
Austria	T-Mobile Austria	In Service	Dec 2003	
Austria	tele.ring	In Service	Dec 2003	
Bahrain	MTC Vodafone Bahrain	In Service	Dec 2003	
Belgium	Belgacom Mobile	In Service	May 2004	
Denmark	HI3G Denmark	In Service	Oct 2003	
France	SFR	In Service	Jun 2004	
Germany	E-Plus	In Service	Jun 2004	
Germany	O2	In Service	Jul 2004	
Germany	T-Mobile	In Service	May 2004	
Germany	Vodafone D2	In Service	May 2004	
Greece	Cosmote	In Service	May 2004	
Greece	STET Hellas	In Service	Jan 2004	
Guernsey	Wave Telecom	In Service	July 2004	
Hong Kong	Hutchison	In Service	Jan 2004	
Ireland	Vodafone Ireland	In Service	July 2004	
Israel	Cellcom Israel	In Service	Jun 2004	
Italy	H3G	In Service	Mar 2003	

Italy	TIM	In Service	May 2004	
Italy	Vodafone Omnitel	In Service	May 2004	
Japan	NTT DoCoMo	In Service	Oct 2001	
Japan	Vodafone	In Service	Dec 2002	
Korea	KTF	In Service	Dec 2003	
Korea	SKT	In Service	Dec 2003	
Luxembourg	P&T Luxembourg	In Service	Jun 2003	
Luxembourg	Tele2/Tango	In Service	July 2004	
Netherlands	KPN Mobile	In Service	July 2004	
Netherlands	Vodafone Libertel	In Service	Jun 2004	
Portugal	Optimus	In Service	Jun 2004	
Portugal	TMN	In Service	Apr 2004	
Portugal	Vodafone Telecel	In Service	May 2004	
Slovenia	Mobitel	In Service	Dec 2003	
Spain	Telefonica Moviles	In Service	May 2004	
Spain	Vodafone Espana	In Service	May 2004	
Sweden	Vodafone Swedem	In Service	Feb 2004	
Sweden	HI3G	In Service	May 2003	
Sweden	Svenska UMTS-Nät/Tele2	In Service	May 2004	
UAE	Etisalat	In Service	Jan 2004	
UK	Hutchison 3G	In Service	Mar 2003	
UK	Orange	In Service	July 2004	
UK	T-Mobile	In Service	Feb 2004	
UK	Vodafone	In Service	Feb 2004	
USA	AT&T Wireless Group	In Service	July 2004	
NETWORK LICENSES AWARDED				
Italy	Ipse 2000	License Awarded		
Norway	Hi3G Access Norway	License Awarded		Q4 2005
Switzerland	Team 3G	License Awarded		
Thailand	CAT	License Awarded		Q4 2006
Thailand	TOT	License Awarded		Q4 2005
LICENSES REVOKED OR SOLD				
Austria	3G Mobile	License Revoked/Sold		Q4 2003
	Note: Telefonica Moviles sold 3G Mobile license to Mobilkom Austria			

Germany	MobilCom Multimedia	License Revoked/Sold	Dec 2003
	MobilCom voluntarily hands back UMTS license		
Norway	Broadband Mobile	License Revoked/Sold	Nov 2002
	Declaration of bankruptcy		
Norway	Tele2 Norway	License Revoked/Sold	
	Tele2 gives up UMTS plans - returns license		
Portugal	OniWay	License Revoked/Sold	Q3 2003
	Operator extinct. Spectrum split between 3 remaining Portuguese operators		
Slovak Republic	Profinet	License Revoked/Sold	
	License withdrawn by regulator - payment failure		
Sweden	Orange Sweden	License Revoked/Sold	2003
	Orange exits UMTS market - sells license to Telia Sonera/Tele2 consortium		
LICENSE TENDER			
Estonia	-tba-	License Tender	Q2 2008
Norway	-tba-	License Tender	Dec 2004
NETWORKS PLANNED OR IN DEPLOYMENT			
Andorra	STA	Planned/In Deployment	Q4 2005
Australia	Optus	Planned/In Deployment	Sep 2005
Australia	Telstra	Planned/In Deployment	Dec 2005
Australia	Vodafone	Planned/In Deployment	Jun 2005
Belgium	BASE	Planned/In Deployment	Q1 2005
Belgium	Mobistar	Planned/In Deployment	Q4 2004
Czech Republic	Eurotel Praha	Planned/In Deployment	Q1 2006
Czech Republic	T-Mobile	Planned/In Deployment	Q1 2006
Denmark	Orange Denmark	Planned/In Deployment	Q4 2004
Denmark	TDC Mobil	Planned/In Deployment	Q4 2004
Denmark	Telia Denmark	Planned/In Deployment	Q4 2004
Estonia	EMT	Planned/In Deployment	Q4 2005
Estonia	Radiolinja	Planned/In Deployment	Q4 2006
Estonia	Tele2	Planned/In Deployment	Q4 2006
Finland	Elisa	Planned/In Deployment	Q4 2004
Finland	Finnish 2G	Planned/In Deployment	Q4 2004
Finland	Finnish 3G	Planned/In Deployment	Q4 2004
Finland - Republic of Åland	Alands Mobiltelefon	Planned/In Deployment	Q4 2004
Finland - Republic of Åland	Song Networks	Planned/In Deployment	Q4 2004

France	Bouygues Telecom	Planned/In Deployment		Q4 2005
Hong Kong	Hong Kong CSL	Planned/In Deployment		Q2 2004
Hong Kong	SmarTone	Planned/In Deployment		Q1 2005
Hong Kong	Sunday	Planned/In Deployment		Q1 2005
Italy	Wind	Planned/In Deployment		Q2 2004
Latvia	LMT	Planned/In Deployment		Q4 2004
Latvia	Tele2	Planned/In Deployment		Dec 2004
Liechtenstein	Orange	Planned/In Deployment		Q1 2005
Liechtenstein	Tele2	Planned/In Deployment		Q1 2005
Luxembourg	LuXcommunications	Planned/In Deployment		Q4 2004
Luxembourg	Orange Communications	Planned/In Deployment		Q4 2004
Malta	MobIsle Communications	Planned/In Deployment		Q4 2004
Malta	Vodafone	Planned/In Deployment		Q4 2004
Netherlands	Orange	Planned/In Deployment		Q4 2004
Netherlands	Telfort	Planned/In Deployment		Q4 2004
Netherlands	T-Mobile	Planned/In Deployment		Q4 2004
New Zealand	Vodafone New Zealand	Planned/In Deployment		Q1 2005
Norway	Netcom	Planned/In Deployment		Q4 2004
Norway	Telenor Mobil	Planned/In Deployment		Q3 2004
Poland	Centertel	Planned/In Deployment		Q1 2006
Poland	Polkomtel	Planned/In Deployment		Q1 2006
Poland	Polska Telefonia Cyfrowa	Planned/In Deployment		Q1 2006
Singapore	Singapore Telecom	Planned/In Deployment		Nov 2004
Singapore	StarHub	Planned/In Deployment		Dec 2004
Slovak Republic	EuroTel Bratislava	Planned/In Deployment		Q1 2006
Slovak Republic	Orange	Planned/In Deployment		Q1 2006
Spain	Amena	Planned/In Deployment		Oct 2004
Spain	Xfera	Planned/In Deployment		Q2 2004
Switzerland	Orange	Planned/In Deployment		Q4 2004
Switzerland	Swisscom Mobile	Planned/In Deployment		Q4 2004
Switzerland	TDC dSpeed	Planned/In Deployment		Q4 2004
Taiwan	Chunghwa Telecom	Planned/In Deployment		Q3 2004
Taiwan	FarEasTone	Planned/In Deployment		Q3 2004
Taiwan	Taiwan Cellular Corporation	Planned/In Deployment		Q3 2004
Taiwan	Taiwan PCS	Planned/In Deployment		Q3 2004

USA	Cingular Wireless	Planned/In Deployment		2005
POTENTIAL LICENSE				
Belgium	-tba-	Potential License		Q4 2008
Bulgaria	-tba-	Potential License		Q2 2007
Croatia	(x3) -tba-	Potential License		Q4 2006
Cyprus	-tba-	Potential License		Q1 2007
Czech Republic	-tba-	Potential License		Q2 2008
France	-tba-	Potential License		Q4 2008
Hungary	(x3) -tba-	Potential License		Q4 2007
Latvia	-tba-	Potential License		Jun 2007
Lithuania	(x3) -tba-	Potential License		Q2 2007
Poland	-tba-	Potential License		Q4 2006
Romania	(x4) -tba-	Potential License		Q3 2006
Russia	(x3) -tba-	Potential License		Q4 2005
Saudi Arabia	-tba-	Potential License		Q2 2007
Serbia	Telekom Srbija	Potential License		Q2 2005
Singapore	-tba-	Potential License		Q1 2006
Slovenia	(x2) -tba-	Potential License		Q2 2007
Turkey	(x4) -tba-	Potential License		Q4 2006
PRE-COMMERCIAL NETWORKS				
Finland	Sonera	Pre-commercial		Q4 2004
France	Orange France	Pre-commercial		Q3 2004
Greece	Panafon	Pre-commercial		Q3 2004
Ireland	Hutchison Whampoa	Pre-commercial		Q3 2004
Ireland	O2	Pre-commercial		Q3 2004
Israel	Partner Communications	Pre-commercial		Q4 2004
Malaysia	Maxis Communications	Pre-commercial		Aug 2004
Malaysia	Telekom Malaysia	Pre-commercial		Sep 2004
Monaco	Monaco Telecom	Pre-commercial		Q4 2004
Singapore	MobileOne	Pre-commercial		Oct 2004
UK	O2	Pre-commercial		Q3 2004
STATUS UNCLEAR				
Canada	Microcell Telecommunications	Status Unclear		
Germany	Group 3G	Status Unclear		
NETWORKS IN TRIAL				

China	China Mobile	Trial		
China	China Netcom	Trial		
China	China Railcom	Trial		
China	China Telecom	Trial		
China	China Unicom	Trial		
Croatia	VIPnet	Trial		Q4 2006
Isle of Man	Manx Telecom	Trial		Q1 2005
Lithuania	Omnitel	Trial		Q2 2007
South Africa	MTN	Trial		Q2 2005
South Africa	Vodacom	Trial		Dec 2004
Vietnam	MobiFone	Trial		
Vietnam	VinaPhone	Trial		

Potential License = Small level of speculation. Government policy or privatization process indicates that licensing opportunity may become available.

License Tender = Government has gone beyond setting out framework for license award and has also set a time schedule with proposed tender dates and number of licenses.

License Awarded = License has been awarded, but licensee currently shows no inclination to deploy network or has announced no roll-out. Examples of this include some UMTS operators in Europe.

Planned/in deployment - Licensee is in planning stages of deploying network or is actually building the network.

Pre-commercial = Operator has launched limited non-commercial trials, including those with "friendly" users. This includes the recent launch of 3G data cards targeted at the enterprise market by some European operators.

In Service = Operator has commercially launched its network to both consumer and enterprise market, with handsets available in retail outlets.

Trial = Operator is conducting a network trial. This is to be used when the operator has no specific license, but is conducting some sort of network trial. Most cases this is likely to be 3G.

Status Unclear = Refers to disputed license awards or instances when EMC is unclear of what is happening.

Abandoned = Licensee/operator abandons project/trial.

License Revoked/Surrendered = Licensee/operator involuntarily/voluntarily hands back license.

Private = Operator runs non-commercial network.

Closed = Operator closes network at end of license period or technology migration TACS to GSM etc. (i.e. not abandoned).

Merged = Operators merging or single band networks becoming dual-band (e.g. GSM 900 becoming GSM 900/1800).