DATA CAPABILITIES:
GPRS to HSDPA and BEYOND

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Prepared by Peter Rysavy

RYSAVY RESEARCH

www.rysavy.com

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Introduction

Operators worldwide are about to start deploying High Speed Downlink Packet Access (HSDPA), one of the most powerful cellular-data technologies ever developed. HSDPA, which will be widely deployed by 2006, follows the successful deployment of Universal Mobile Telecommunications System (UMTS) networks around the world, and for many of these, will be a relatively straightforward upgrade. Meanwhile, Enhanced Data Rates for GSM Evolution (EDGE) has proven to be a remarkably effective cellular-data technology, and is now supported by a large number of operators and vendors worldwide. Looking further forward, standards bodies have already specified a series of enhancements for HSDPA, as well as other complementary follow-on capabilities including a faster uplink and IP-based multimedia capabilities. The result is a portfolio of complementary technologies that realize the potential of wireless data—the GSM family of data technologies. This paper discusses the capabilities of the GSM family of technologies, how they work, and their position relative to some competing 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 embracing wireless data in a wide range of other applications, including email, game downloads, instant messaging, ringtones, video, and also in enterprise applications such as group collaboration, enterprise resource planning, customer relationship management and database access.

Though voice still constitutes most of cellular traffic and the bulk of service revenue, wireless data is beginning to appreciably add to service revenue, approaching ten percent of ARPU, and constituting a multi-billion dollar industry. One GSM operator recently reported that more than twenty percent of their service revenue was from wireless data and many are reporting in the area of ten percent and rising. 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, UMTS and HSDPA 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.

Wireless data usage will continually grow 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. 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 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 more than 1.9 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, which today includes General Packet Radio Service (GPRS), EDGE, UMTS or Wideband Code Division Multiple Access (WCDMA)[3] and HSDPA, provides a powerful set of capabilities, spectral efficiencies, and means of deployment that maximizes revenue and profit potential. Beyond HSDPA, there are a number of planned enhancements that will further increase capabilities.

Following are some of the important observations and conclusions of this paper:

- UMTS/HSDPA represents tremendous radio innovation and capability, allowing it to support a wide range of applications, including voice and data on the same devices.
- The high spectral efficiency of HSDPA for data and WCDMA for voice provides UMTS operators a high capacity and efficient network for all services.
- Various enhancements are planned for HSDPA that will extend WCDMA/HSDPA capability even further, beginning with an enhanced uplink, advanced receivers, and then intelligent antennas/Multiple Input Multiple Output (MIMO).
- The 3rd Generation Partnership Project (3GPP) is developing a Long Term Evolution (LTE) technology path that has the goal of deploying next generation networks in the 2008 time frame with peak downlink speeds of 100 megabits per second (Mbps) and peak uplink speeds of 50 Mbps.
- Orthogonal Frequency Division Multiplexing (OFDM) is a good candidate technology for next generation systems employing wide radio channels. However, it does not offer compelling advantages over CDMA in radio channels of 10 MHz or less. Initial versions of IEEE 802.16e are likely to have spectral efficiency similar to HSDPA.
- 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).
- HSDPA will be even more effective for enhancing WCDMA performance than EDGE was for enhancing GPRS performance, providing a standard that will support peak theoretical rate of 14 Mbps and average throughput rates experienced by users of between 550-1100 kbps.

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

[2] Informa Telecoms & Media, September 2005.

[3] 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. HSDPA is an enhancement to WCDMA.

- GSM/GPRS/EDGE/WCDMA/HSDPA allows an operator to efficiently use their entire available spectrum for voice and data services, and to adjust spectral resources dynamically.
- There is accelerating momentum globally in the deployment of EDGE, UMTS and HSDPA. GPRS/EDGE and UMTS/HSDPA are being deployed as complementary third generation (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 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 local area network (WLAN) 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 to quantify real-world performance. Other wireless technologies, including CDMA2000 and WiMAX, are examined as well. Finally, the paper discusses the evolution from GPRS to HSDPA, as well as to future enhancements, including how increasing spectral efficiency will drive deployment.

Market

In considering the market, we review market adoption of wireless data and deployments of GSM/UMTS/HSDPA networks around the world.

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 several years however, adoption has accelerated, *finally* some might say, and 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 pervasive success of SMS, wireless email, 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, email clients, Push-to-talk over Cellular (PoC), downloadable executable content capability, and browsers supporting multiple formats. All of these capabilities consume data. Meanwhile, smartphones, with their emphasis of a rich computing environment on the phone, represent the convergence of: 1) the personal digital assistant; 2) a fully capable mobile computer; and 3) 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 expand rapidly, but it is close. Wireless data, though still a small percentage of total wireless revenues, generated billions of dollars of revenues for carries according to most analysts. IDC predicts that within a couple of years, wireless data will reach 15% of revenues, and that by 2009, wireless data will constitute 20% of wireless revenues.[4]

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

- 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 wireless wide area network (WAN) equipment and services.
- About half of mid-size and large enterprises use wireless data today and another 30% are planning/evaluating future use. Three quarters of current WAN data users 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 consumer 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? Many industry analysts agree that pricing for wireless data usage could also be seen as a possible barrier against widespread adoption. However, many analysts agree that with increased competition, economies of scale and greater network capacity, prices could possibly come down which will spur greater adoption.

The number of enhanced mobile data applications is still low relative to 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.

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[4] IDC, *IDC Forecasts Both U.S. Consumer and Business Wireless Subscriber ARPU to Trend Upward Through 2009* press release, April 14, 2005; *U.S. Consumer Wireless 2005-2009 Forecast: Growth Obscures Fundamental Shifts*. IDC study, April 2005 (IDC #33015) and U.S. Business Wireless Subscriber 2005-2009 Forecast IDC study, April2005 (IDC #33016).

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, quality-of-service (QoS) control and location-based service. This is where the GSM family of data technologies 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 1.5 billion subscribers are using GSM.[5] Nearly every GSM network in the world today supports GPRS.

EDGE is another success story. As of September 6, 2005, 180 operators in 95 countries around the world were working with EDGE. This includes 94 operators offering commercial service and 29 operators in active deployment.[6] EDGE has reached critical mass in terms of POPS, geography, infrastructure, and devices. EDGE operators today have 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 new GSM infrastructure deployments are also EDGE capable and nearly all new mid-to high-level GSM devices also include EDGE radio technology.

UMTS deployments are also accelerating. There are more than 80 commercial UMTS networks already in operation in more than 35 countries, with another 77 networks either pre-commercial, in deployment, planned, or licensed. There are also eighteen operators currently trialing UMTS networks.[7]

The Shosteck Group projects 200 to 250 million UMTS subscribers by December 2007 and the following sales of WCDMA handsets, including WCDMA/EDGE handsets[8]:

2004: 18 million
2005: 50 million
2006: 112 million
2007: 195 million
2008: 273 million

[5] Informa Telecoms & Media, World Cellular Information Service, September 2005.

[6] Information compiled by 3G Americas from Informa Telecoms & Media, World Cellular Information Service and public company announcements, September 2005; see Appendix C: Global EDGE Network Status, September 2005.

[7] Informa Telecoms & Media, World Cellular Information Service, September 2005; see Appendix B: Global UMTS Network Status, September 2005.

[8] "Forecast Handset Shipments by Technology, World Market, 2004-2008 (millions) (b_7)," *Shosteck E-STATS,* The Shosteck Group, Silver Spring, Maryland, continuous (www.shosteck.com).

Clearly, UMTS is developing significant global momentum, and is well positioned to become the dominant wireless technology by the end of the decade. Meanwhile, HSDPA is becoming a market reality, with 36 networks planned or in deployment, and three trials underway as of September 2005.[9]

Technology Capabilities

GPRS to HSDPA and beyond 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, email, 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 the needs of enterprises and consumers from these services. 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, 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 necessary for different applications. They are the following:

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

[9] Information compiled by 3G Americas from Informa Telecoms & Media, World Cellular Information Service and public company announcements, September 2005. See Appendix A: Global HSDPA Status, September 2005.

The following table summaries the capabilities of the different technologies.

Table 1: Comparison of Capabilities of Technologies[10]

	Peak Network Downlink Speed	Average User Throughputs for File Downloads	Capacity / Spectral Efficiency	Other Features
GPRS[11]	115 kbps	30 – 40 kbps		
EDGE	473 kbps	100 – 130 kbps	Double that of GPRS	Backward compatible with GPRS
UMTS - WCDMA	2 Mbps[12]	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[13]	550-1100 kbps[14]	Two and a half to three and a half times that of WCDMA	Backward compatible with WCDMA
3GPP Long Term Evolution	100 Mbps (Target goal)	10 Mbps (Target goal)	Two to four times higher than HSDPA (Target goal)	Goal of radio interface latency of less than 10 msec. (Target goal)
CDMA2000 1XRTT[15]	153 kbps	50-70 kbps[16]		
CDMA2000 1XEV-Data Optimized (DO)[17]	2.4 Mbps	400-700 kbps[18]		Optimized for data, VoIP in development
CDMA2000 1xEV-DO Rev A	3.1 Mbps	Slightly improved over EV-DO	70 to 100% capacity gain on uplink[19]	Optimized for VoIP and data

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[10] Source: Unless otherwise noted, based on 3G Americas' member contributions to this paper. Note that average throughputs depend on the degree of network loading and how operators have deployed and configured their networks. Predictions of average throughput are based on a number of different assumptions, and these assumptions vary by source. Hence, it can sometimes be misleading to directly compare claims from different sources.

[11] Coding schemes 1, 2.

[12] 384 kbps typical maximum rate of current devices.

[13] First devices are likely to have a maximum rate of 1.8 or 3.6 Mbps.

[14] 550 to 800 kbps expected with initial devices, 770 to 1100 kbps expected with later advanced mobile devices.

[15] Rel 0

[16] Source: Sprint promotional material.

[17] Rel 0

[18] Source: Verizon Wireless promotional material.

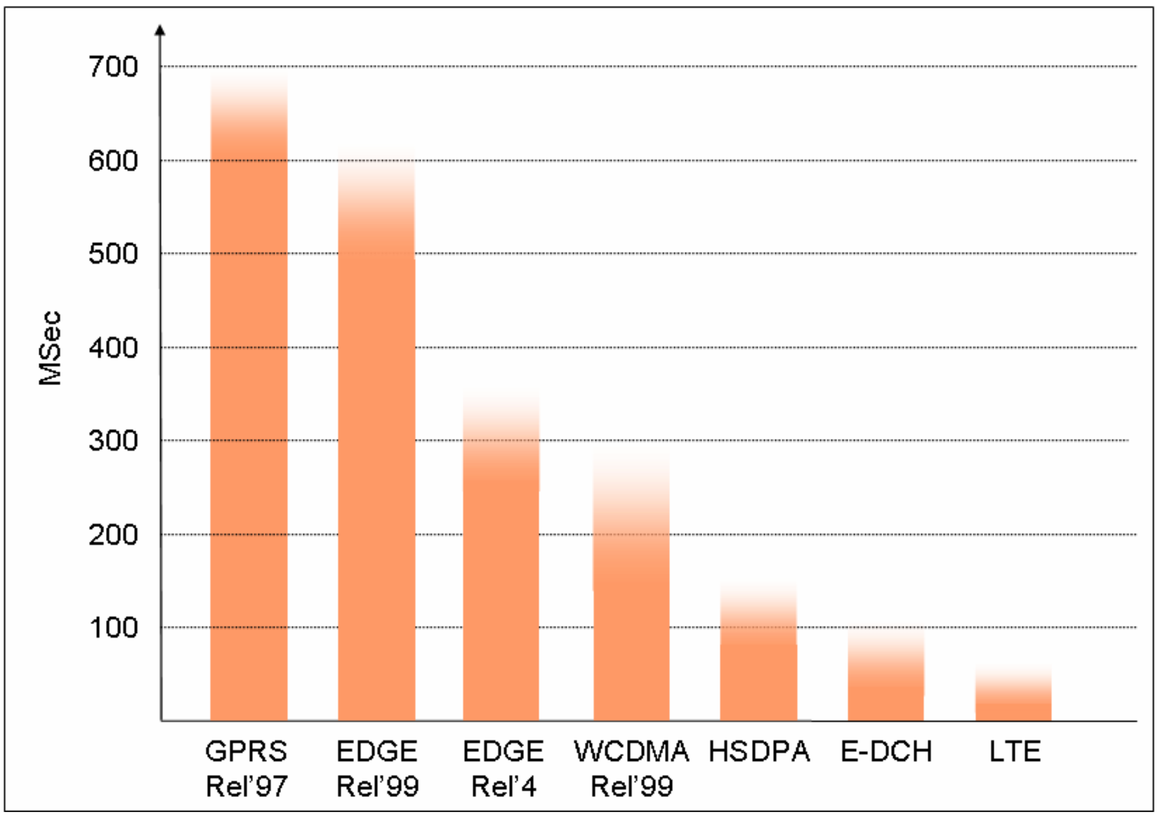
[19] Source: Qualcomm Spring 2005 Analyst Meeting.

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. Rysavy Research's 2002 wireless data anticipated EDGE average performance of 110-130 kbps and UMTS average performance of 200-300 kbps. 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 technology from GPRS forward reduces latency, with HSDPA expected to have latency approaching 100 msec. The uplink Enhanced Dedicated Channel (E-DCH) brings latency down even further, as will 3GPP LTE. There are also ongoing improvements with each technology. See Figure 1.

Figure 1: Latency of Different Technologies[20]



[20] Source: 3G Americas' member companies. Measured between subscriber unit and Gi interface, just external to wireless network. Does not include Internet latency. Note that there is some variation in latency based on network configuration and operating conditions.

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 section "The Path from GPRS to HSDPA and Beyond." We now look at the capabilities and workings of the individual technologies in greater detail.

Technical Approaches (TDMA, CDMA, OFDM)

There has been a considerable amount of discussion in the industry about the relative benefits of time division multiple access (TDMA), code division multiple access (CDMA) and orthogonal frequency division multiplexing (OFDM.) Many times, one technology or the other is positioned as having fundamental advantages over another. However, any of these three approaches, when fully optimized, can effectively match the capabilities of any other. GSM is a case in point. Through innovations such as frequency hopping, the Adaptive Multirate (AMR) vocoder for voice, and EDGE for optimization of data performance, GSM was able to effectively compete with the capacity and data throughput of CDMA2000 1xRTT.

Despite the evolution of TDMA capabilities, the cellular industry has generally chosen CDMA for 3G networking technology[21]. While there are some significant differences between CDMA2000 and WCDMA/HSDPA such as channel bandwidths and chipping rates, both technologies use many of the same techniques to achieve roughly the same degree of spectral efficiency and expected typical performance. Techniques include items such as efficient schedulers, higher order modulation, and Turbo codes.

Today, people are asking whether OFDM provides any inherent advantage over CDMA. For systems employing less than 10 MHz of bandwidth, the answer is largely *no*. The fundamental advantage of OFDM is that because it transmits subchannels at a lower symbol rate, it addresses the problem of intersymbol interference, and greatly simplifies channel equalization. As such, OFDM systems, assuming they employ all the other standard techniques for maximizing spectral efficiency, may achieve slightly higher spectral efficiency than CDMA systems. However, advanced receiver architectures, including practical equalization approaches, are in development for CDMA systems and will nullify this advantage.

It is with larger bandwidths of 10 to 20 MHz, and in combination with advanced antenna approaches such as Multiple Input Multiple Output (MIMO) or Adaptive Antenna Systems (AAS) where OFDM enables less computationally complex implementations than those based on CDMA, and hence is more readily realizable in devices. However, recent studies have shown that the complexity advantage of OFDM may be quite small (i.e. less than a factor of two) if frequency domain equalizers are used for CDMA-based technologies. Still, the potential advantage of reducing complexity is one reason that the 3GPP is considering OFDM for its Long Term Evolution project. It is also one reason that newer wireless LAN standards that employ 20 MHz radio channels are based on OFDM. In other words, OFDM is currently a favored approach being considered for radio systems that have extremely high peak rates.

[21] EDGE, a TDMA technology, is officially designated a 3G technology by the ITU.

The following table summarizes the attributes of the different wireless approaches.

Table 2: Summary of Different Wireless Approaches

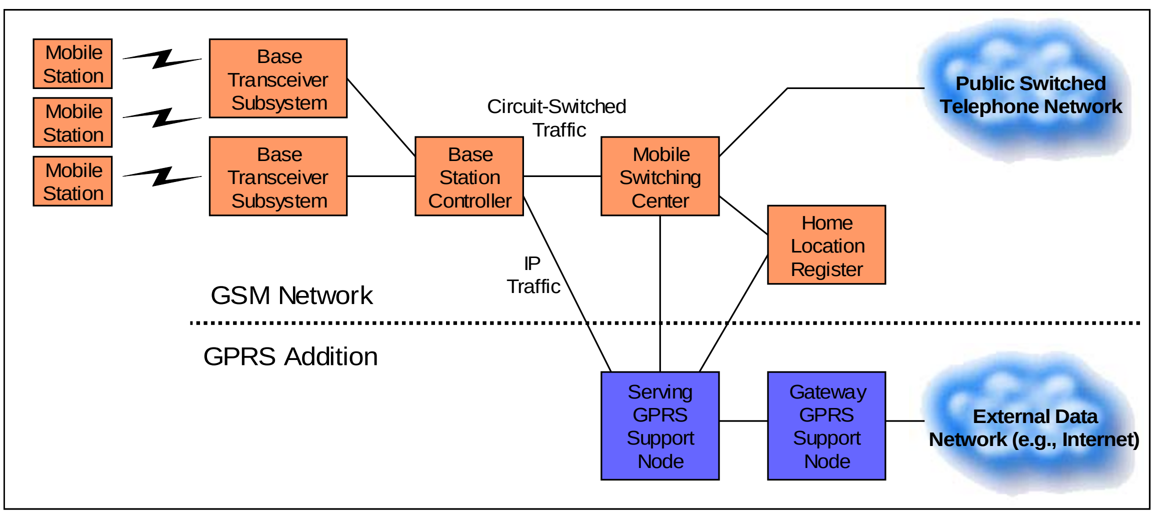
Approach	Technologies Employing Approach	Comments
TDMA	GSM, GPRS, EDGE, IS-136 TDMA	First digital cellular approach. Hugely successful with GSM.
CDMA	CDMA2000 1xRTT, CDMA2000 1xEV-DO, WCDMA, HSDPA, IEEE 802.11b	Basis for nearly all new 3G networks.
OFDM	WiMAX, Flarion Flash OFDM, 3GPP Long Term Evolution candidate technology, IEEE 802.11a, IEEE 802.11g, 3GPP2 Evolution, 3GPP2 Enhanced Broadcast Multicast Services (EBCMCS), Digital Video Broadcasting-H (DVB-H), Forward Link Only (FLO)	Effective approach for higher bandwidth radio systems and for high peak data rates in large blocks of spectrum.

GPRS

GPRS is the world's most ubiquitous wireless data service, available now with practically every GSM network. 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 kbps 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



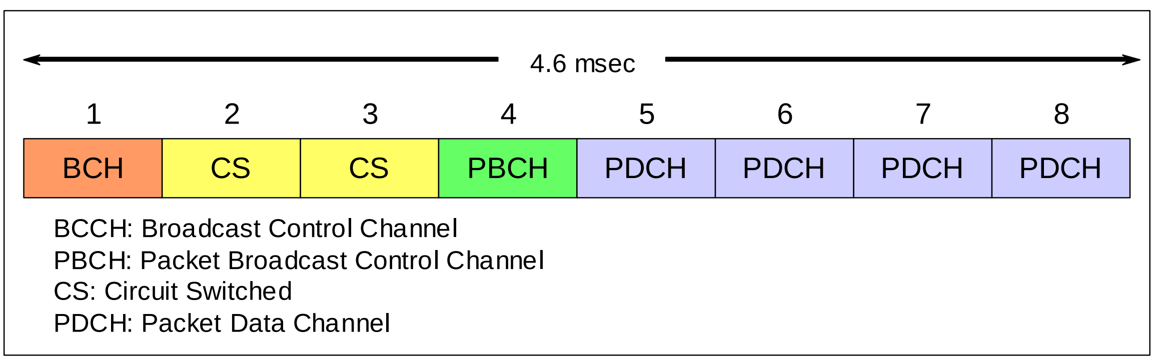
GPRS is essentially the addition of a packet-data infrastructure to GSM. The functions of the data elements are as follows:

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 Mobile Switching Center (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/HSDPA 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 voice session ends. Users can also receive SMS messages and data notifications[22] 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

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

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%[23]. Coding schemes 3 and 4 are an option for operators. To boost GPRS performance and capacity even further, many operators have deployed or are deploying EDGE technology.

EDGE

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

EDGE is an official 3G cellular technology that can be deployed within an operator's existing 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 Base Station Controller (BSC), SGSN, GGSN, and HLR to remain the same. In fact, with new GSM/GPRS deployments, EDGE[24] is a software-based 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, thus any application developed for GPRS will also 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[25] 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[26]. In contrast, GSM/GPRS modulation uses Gaussian Minimum Shift Keying (GMSK), which transmits one bit of information per radio symbol. The second technique employs 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 3.

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

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

[24] Assumes EDGE Release 99. EDGE Release 5 features require some enhancements to the core network.

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

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

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 3: EDGE Modulation and Coding Schemes[27]

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
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[28]. 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 kbps 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.

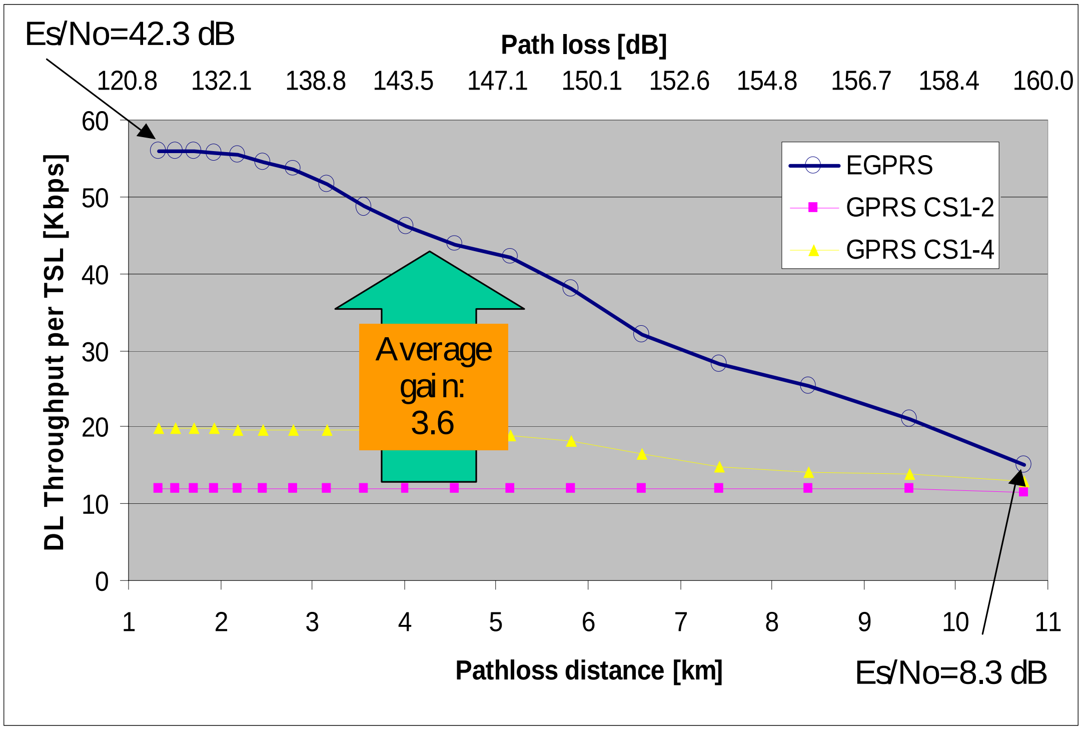
EDGE makes full use of the capacity in the available radio spectrum. In this regard, EDGE is as effective a technique for expanding data capacity as the AMR codec is for expanding voice capacity. The two working together result in GSM being an extremely efficient cellular technology.

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] Radio Link Control (RLC) throughputs. Application rates are typically 20% lower.

[28] 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[29]

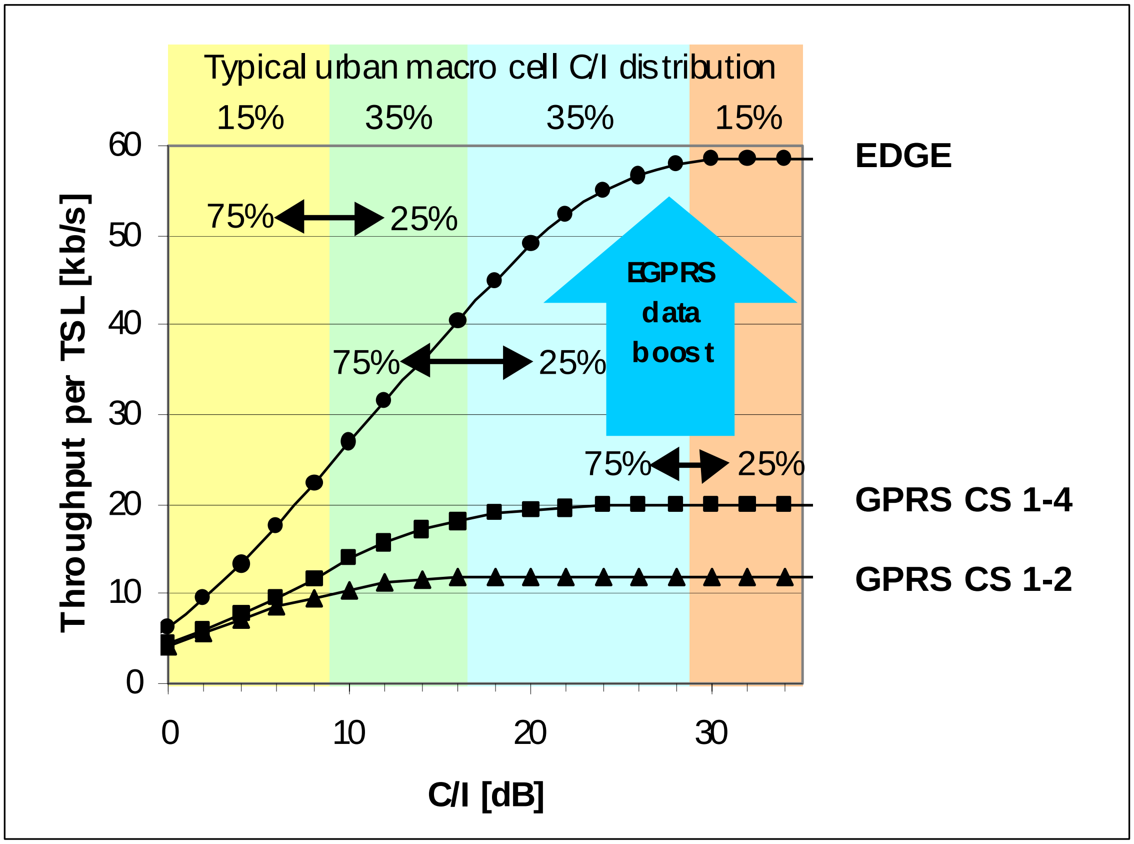


The second curve, as shown in Figure 5, depicts throughput per time slot versus C/I:

- 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 and blue sections) experiences a four times performance improvement
- 15% (in the pink section) experiences a five times performance improvement

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

Figure 5: EDGE Performance Improvement over Coverage Area[30]



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[31]. 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 (VoIP) telephony.

With respect to deployment, the GSM network can allocate GPRS and EDGE time slots in the 5/15 or 4/12 reuse layer[32] (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 data services with a certain amount of data capacity, and for this capacity to be readily increased as required.

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

[31] 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.

[32] *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.

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.

EDGE may also evolve beyond its current capabilities. The 3GPP is currently studying improvements to GSM and EDGE as part of Release 7. EDGE performance improvements would include a potential doubling of peak throughput speeds, a 50% increase in spectral efficiency, and a reduction of latency to 100 msec in the radio link. Some people refer to this 3GPP work item as "Evolved EDGE."

Other "Evolved EDGE" objectives include:

- Co-existing with existing frequency planning, facilitating deployment in existing networks
- Co-existing with legacy mobile stations by allowing both old and new stations to share the same radio resources
- Avoiding impacts on infrastructure by enabling improvements through a software upgrade

Beyond EDGE, operators can expand their data offerings even further with UMTS.

UMTS/WCDMA

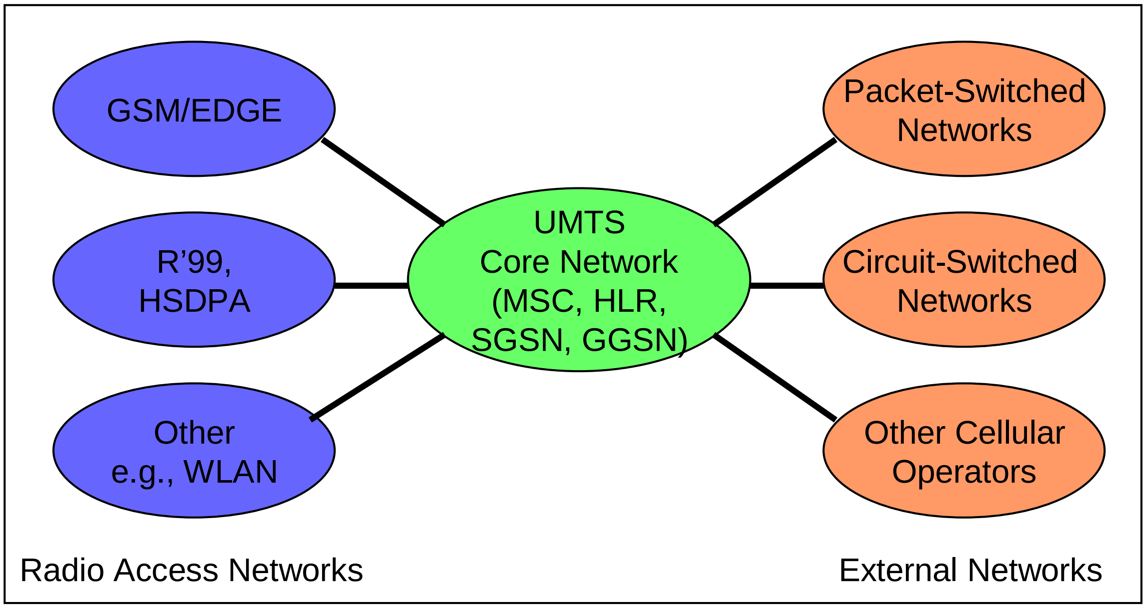
UMTS has garnered the overwhelming majority of new 3G spectrum licenses, with close to eighty commercial networks already in operation.[33]. Compared to emerging wireless technologies, UMTS technology is mature and benefits from research and development that began in the early 1990s. UMTS has been thoroughly trialed, tested and commercially deployed. UMTS deployment is now accelerating with stable network infrastructure and attractive reliable mobile devices with rich capabilities.

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, WCDMA, HSDPA and evolutions of these technologies. 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 section "The Path from GPRS to HSDPA and Beyond."

[33] See Appendix B: Global UMTS Network Status, September 2005.

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 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 direct-sequence spread-spectrum system. 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 wideband technology approach 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 as other users, or the network can assign users dedicated channels. 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, the maximum theoretical rate is just over 2 Mbps, achieved by combining 3 channels of 768 kbps. This rate is greatly increased with HSDPA, as discussed in the section on HSDPA. Though exact throughput depends upon the size of the channels that the operator chooses to make available, the capabilities of devices and the number of users active in the network, users can expect typical throughput rates in the downlink of 220 to 320 kbps with bursts to 384 kbps based on real-world trials and some commercial networks. Uplink throughput rates are typically 64 kbps. This satisfies most communications-oriented applications.

Channel throughputs are determined by the amount of spreading in the spectrum. With more spreading, such as that 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 spreading factors of 128 or 256, whereas a 384 kbps data channel uses a spreading factor of 8. The commonly quoted rate of more than 2 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 and network optimization, less than 200 msec is achievable.

The actual throughput speeds a user can obtain with WCDMA Release 99 depend on the radio access bearer (RAB) that the network assigns. Possible values include 768 kbps, 384 kbps, 128 kbps, 64 kbps, 32 kbps and 16 kbps. The different rates correspond to the amount of spreading. A lower degree of spreading results in more code space assigned to that RAB, and hence higher throughput. Most devices today have a maximum rate of 384 kbps.

The network assigns RABs based on available resources. It is possible for the network to multiplex multiple users onto a single RAB. How the network assigns RABs varies by infrastructure vendor.

Whereas EDGE is an extremely efficient technology for supporting low to medium-bandwidth users, WCDMA is extremely efficient for supporting higher-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.

IP Multimedia Subsystem

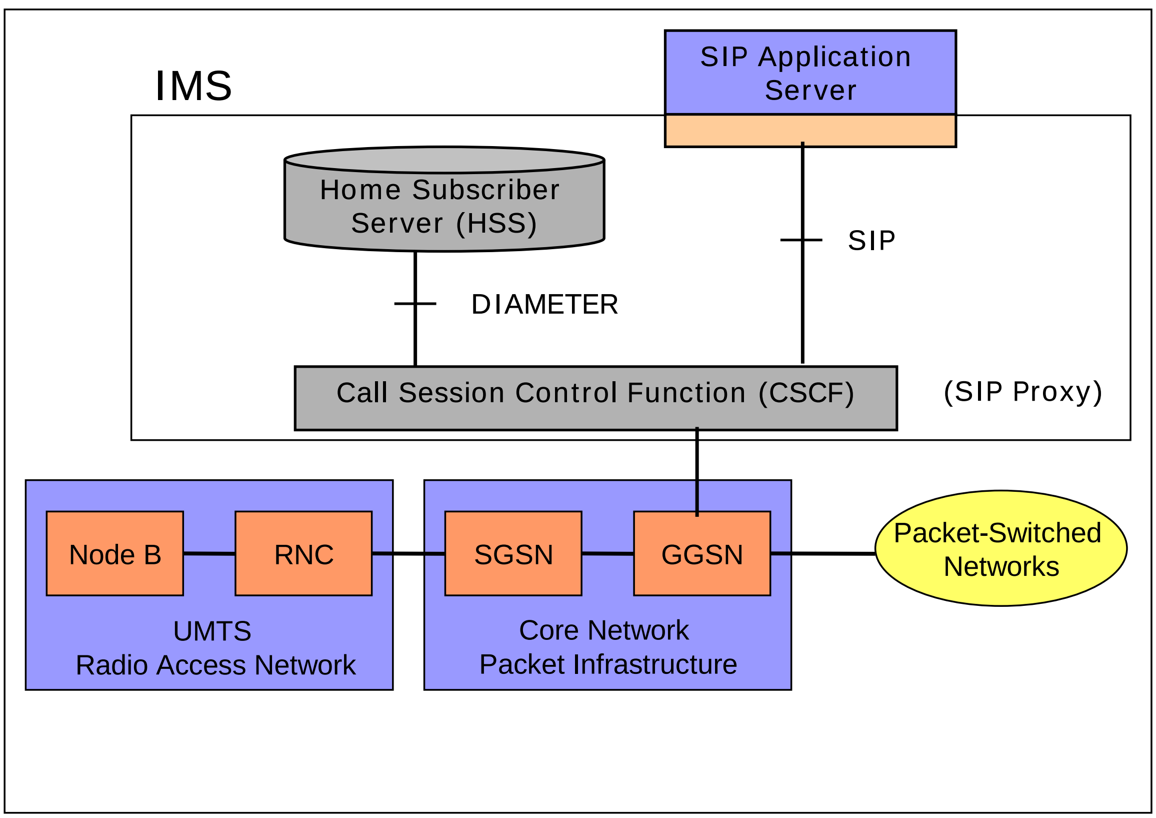
The QoS mechanisms in UMTS are an important component of the IP Multimedia Subsystem (IMS). IMS is essentially a service platform for operators to support IP multimedia applications. Potential applications include PoC, VoIP, streaming video, video conferencing, interactive gaming and so forth. IMS will enable mixed and dynamic services. For example, a user could be on a voice call, but suddenly want to enable a video connection, or want to transfer files. During an interactive chat session, the user could launch a voice call. Or while browsing the Web, the user could decide to speak to a customer-service representative.

IMS by itself does not provide all these applications. Rather, it provides a framework of application servers, subscriber databases and gateways to make them possible. The exact services will depend on operators and application developers who make these applications available to operators.

The core networking protocol used within IMS is Session Initiation Protocol (SIP), which includes companion protocol Session Description Protocol (SDP), used to convey configuration information such as supported voice codecs. Other protocols include Real Time Protocol (RTP) and Real Time Streaming Protocol (RTSP) for transporting actual sessions. Though specified by 3GPP, IMS is relatively independent of the radio access network, and can, and likely will, be used by other radio access networks, or even wireline networks. Operators are already trialing IMS and one initial application that is under consideration, Push-to-talk over Cellular, is being specified by the Open Mobile Alliance. Other applications include picture and video sharing that occur in parallel with voice communications. Operators looking to roll out VoIP over networks could also use IMS. IMS is part of 3GPP Release 5 and Release 6 specifications.

As shown in the following figure IMS operates just outside of the packet core.

Figure 7: IP Multimedia Subsystem



The benefits of using IMS include handling all communication 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 potentially deliver data and voice services at lower cost, and thus provide these services at lower prices, further driving demand and usage. IMS will also play a role in the convergence of wireless and wireline networks.

UMTS TDD

Most deployments of WCDMA and HSDPA are based on frequency division duplex (FDD), where the operator uses different radio bands for transmit and receive. An alternative approach is called time division duplex (TDD) where both transmit and receive functions alternate in time on the same radio channel. 3GPP specifications include a TDD version of UMTS called UMTS TDD.

TDD does not provide any inherent advantage for voice functions, which needs balanced spectrum, namely the same amount of capacity in both the uplink as the downlink. Many data applications, however, are asymmetric with often the download consuming more bandwidth than the uplink, especially for applications such as Web browsing or multimedia downloads. A TDD radio interface can dynamically adjust the downlink to uplink ratio accordingly, and hence can balance both forward link and reverse link capacity. The vendor IP Wireless has commercialized the UMTS TDD.

An even greater consideration, however, relates to available spectrum. Various countries around the world, including Europe, Asia and the Pacific region have licensed spectrum available specifically for TDD systems. For this spectrum, UMTS TDD is a good choice. It is also a good choice in any spectrum that does not have a guard band between forward and reverse links.

In the U.S., there is no spectrum specifically allocated for TDD systems. UMTS TDD is not a good choice in FDD bands as it would generate considerable interference for mobile devices operating in FDD mode. One potential band for UMTS TDD is the Broadband Radio Service (BRS) band at 2.5 MHz, previously called Multichannel Multipoint Distribution Service (MMDS) band. Nextel is currently evaluating UMTS TDD in this band.

TD-SCDMA

Time Division Synchronous CDMA (TD-SCDMA) is one of the official 3G wireless technologies being developed mostly for deployment in China. Its primary attribute is that it is designed to support very high subscriber densities, making it a possible alternative for wireless local loop. TD-SCDMA uses the same core network as UMTS. However, the technology has not yet matured sufficiently to be deployed nor have there been any commercial announcements by operators choosing to deploy it. At this time, there are no planned deployments in any country other than China; however, TD-SCDMA could theoretically be deployed anywhere unpaired spectrum is available, such as the bands licensed for UMTS TDD, assuming regulatory issues were appropriately resolved.

HSDPA

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 Release 5, operators will trial HSDPA in 2005 with commercial availability by the end of 2005 or early 2006. There are currently 19 operators that have made commitments to HSDPA. Cingular Wireless is expected to be the first operator to launch HSDPA and has stated that they will cover 15-20 markets by year-end 2005. NTT DoCoMo is expected to quickly follow Cingular and deploy HSDPA in early 2006. HSDPA is fully backwards compatible with WCDMA Release 99, and any application developed for WCDMA will work with HSDPA. The same radio carrier 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 has the highest theoretical peak throughput of any cellular technology currently available. 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.

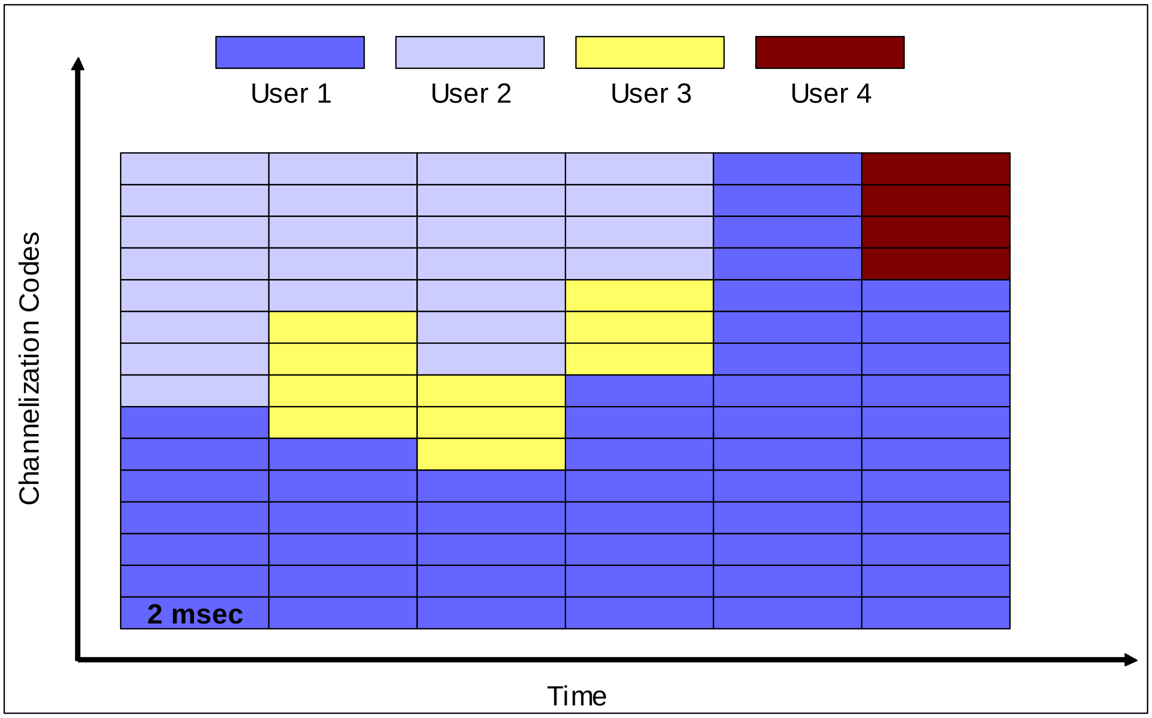
HSDPA achieves its performance gains from the following radio features:

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

These features function as follows:

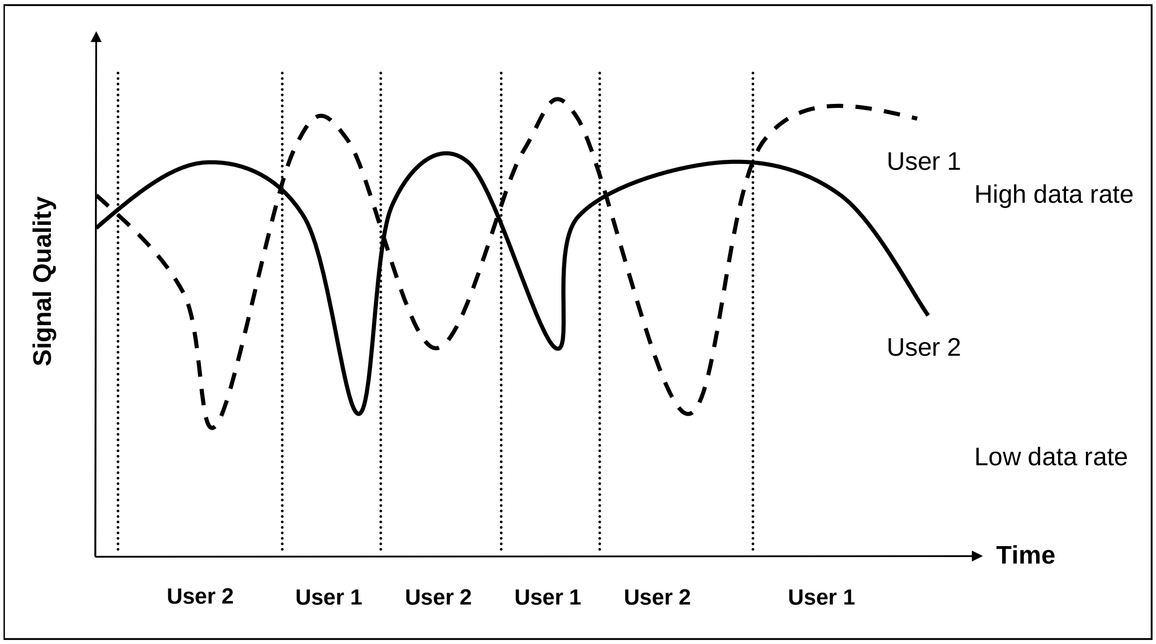
High Speed Shared Channels and Short Transmission Time Interval: First, HSDPA uses high speed data channels called High Speed - Downlink Shared Channels (HS-DSCH). Up to 15 of these can operate in the 5 MHz WCDMA radio channel. Each uses a fixed spreading factor of 16. User transmissions are assigned 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 how users are assigned to different 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). Figure 8 illustrates different users obtaining different radio resources.

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



Fast Scheduling and User Diversity: 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. Figure 9 shows how a scheduler might choose between two users based on their varying radio conditions, namely to emphasize the user with better instantaneous signal quality. With about 30 users active in a sector, the network achieves significant user diversity and significantly higher spectral efficiency. The system also makes sure that each user receives a minimum level of throughput. The result is referred to as "proportional fair scheduling."

Figure 9: User Diversity



Higher Order Modulation: 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.

Fast Link Adaptation: 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 4shows 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 4: 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

Fast Hybrid Automatic Repeat Request: 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.

Field results validate the theoretical throughput results. Using devices based on 5 codes and QPSK modulation, vendors have measured consistent throughput rates in excess of 1 Mbps[34].

Uplink Enhanced Dedicated Channel (E-DCH)

Whereas HSDPA optimizes downlink performance, the Enhanced Dedicated Channel (E-DCH) is a set of improvements that optimizes uplink performance, including higher throughputs, reduced latency and increased spectral efficiency. E-DCH is sometimes referred to as High Speed Uplink Packet Access (HSUPA). E-DCH will result in approximately an 85% increase in overall cell throughput on the uplink and to approximately a 50% gain in user throughput. E-DCH also reduces packet delays by up to 50%.

There are a number of benefits to an improved uplink. For instance, there are user applications that transmit large amounts of data from the mobile station, such as a user sending a video clip or a business user sending a large presentation file. But it is also beneficial to balance the capacity of the uplink with the capacity of the downlink for future applications such as voice over IP.

[34] For example, August 9, 2005 Vodafone Italy and Nokia announced HSDPA test results of 1.5 Mbps peak throughput.

E-DCH achieves its performance gains through the following approaches:

- A dedicated channel that is shared in time between different users
- A short transmission time interval (TTI), as low as 2 msec, that allows faster responses to changing radio conditions and error conditions
- Fast Node B based scheduling, that allows the base station to efficiently allocate radio resources
- Fast Hybrid Automatic Repeat Request, that improves the efficiency of error processing

The combination of TTI, fast scheduling and fast Hybrid ARQ serve also to reduce latency which can benefit many applications as much as improved throughput.

QoS mechanisms defined for UMTS all operate with E-DCH, including Conversational, Streaming, Interactive and Background classes.

E-DCH can operate with or without HSDPA in the downlink, though it is likely that most networks will use the two approaches together. The improved uplink mechanisms also translate to better coverage, and for rural deployments, larger cell sizes.

E-DCH can achieve different throughput rates based on various parameters such as the number of codes used, the spreading factor of the codes, the TTI value and the transport block size in bytes, as illustrated in Table 5.

Table 5: E-DCH Peak Throughput Rates

E-DCH Category	Codes x Spreading	TTI	Transport Block size	Data rate
1	1 x SF4	10	7296	**0.73 Mbps**
2	2 x SF4	10	14592	**1.46 Mbps**
2	2 x SF4	2	2919	**1.46 Mbps**
3	2 x SF4	10	14592	**1.46 Mbps**
4	2 x SF2	10	20000	**2 Mbps**
4	2 x SF2	2	5837	**2.9 Mbps**
5	2 x SF2	10	20000	**2 Mbps**
6	2xSF2 + 2xSF4	10	20000	**2 Mbps**
6	2xSF2 + 2xSF4	2	11520	**5.76 Mbps**

Other Spectral Efficiency/Throughput Enhancements

Other enhancements include mobile receive diversity and advanced receiver architectures in mobile devices. These improvements will occur one to two years after the initial deployment of HSDPA. Performance aspects of these two techniques are specified in 3GPP Release 6 specifications.

Mobile receive diversity relies on optimal combining of received signals from separated receiving antennas. The antenna spacing yields signals that have somewhat independent fading characteristics, and hence the combined signal can more be more effectively decoded, resulting in a downlink capacity gain of up to 50%. Receive diversity is effective even for small devices such as PC Card modems and smartphones.

Current receiver architectures based on rake receivers are effective for speeds up to a few megabits per second. But at higher speeds, the combination of reduced symbol period and multi-path interference results in inter-symbol interference, and diminishes rake receiver performance. This problem can be solved by advanced receiver architectures, such as channel equalizers that yield an additional 20% gain over HSDPA with receive diversity. Alternative advanced receiver approaches include interference cancellation and generalized rake receivers. Different vendors are emphasizing different approaches.

What makes these enhancements attractive is that no changes are required to the networks except increased capacity within the infrastructure to support the higher bandwidth. Moreover, the network can support a combination of devices, including both earlier devices that do not include these enhancements and those that do. Device vendors can selectively apply these enhancements to their higher-performing devices.

Another area of investigation as part of 3GPP Release 7 is Multiple Input Multiple Output. MIMO refers to a technique that employs multiple transmit antennas and multiple receive antennas in combination with multiple radios and multiple parallel data streams. The transmitter sends different data over each antenna. Whereas multipath is an impediment for other radio systems, MIMO actually exploits multipath, relying on signals to travel across different communications paths. This results in multiple data paths effectively operating somewhat in parallel, and through appropriate decoding, results in a multiplicative gain in throughput. Tests of MIMO have proven very promising in wireless local area networks operating in relative isolation where interference is not a dominant factor. Gains in cellular data networks, however, remain to be fully evaluated.

While MIMO can significantly improve peak rates, other techniques such as Space Division Multiple Access (SDMA) may be even more effective than MIMO for improving capacity in high spectral efficiency systems using a reuse factor of 1. 3GPP is studying SDMA for 3GPP Release 7.

3GPP participants are also studying Voice over IP over HSDPA/E-DCH channels. 3GPP Release 6 provides efficient VoIP with seamless mobility while 3GPP Release 7 work includes means of further improving VoIP efficiency. VoIP will potentially add voice capacity compared to current WCDMA circuit-switched voice channels.

Multimedia Broadcast/Multicast Service (MBMS)

An important new feature of 3GPP Release 6 is Multimedia Broadcast/Multicast Service. MBMS is a point-to-multipoint service where multiple users receive the same information using the same radio resource. This makes for a much more efficient approach for delivering content such as videos clips to which multiple users have subscriptions. In a broadcast, every subscriber unit in a service area receives the information, whereas in a multicast, only users with subscriptions receive the information. Service areas for both broadcast and multicast can span either the entire network or a specific geographical area.

3GPP Long Term Evolution

Though HSDPA and E-DCH and other planned enhancements offer a highly efficient broadband wireless service that will likely enjoy success for the remainder of the decade, 3GPP has started working on a project called Long Term Evolution (LTE) that will allow operators to offer even more advanced services. The project is currently in its early stages, and specific approaches have not yet been decided. The goals of the project are as follows:

- Increase spectral efficiency over Release 6 by a factor of two to four
- Support flexible bandwidth, ranging from 1.25 MHz to 20 MHz
- Support peak rates of 100 Mbps on the downlink and 50 Mbps on the uplink
- Reduce latency to 10 msec round trip time between user equipment and the base station, and less than 100 msec transition time from inactive to active

The work plan calls for a detailed (stage 2) description by 2006, from which full specifications can follow. Networks could be ready by the 2008 time frame. The overall intent is to provide for an extremely high performance radio access technology that can readily co-exist with HSDPA and earlier networks.

3GPP Long Term Evolution may employ a radio link based on MIMO-OFDM as it is one of the various technology enhancements under consideration in the project.

4G

Networks based on LTE objectives should address market needs in the 2008 to 2012 period. After that, it is possible that operators will deploy fourth generation (4G) networks, using LTE technology as a foundation. There are no official standards efforts or formal definitions yet for 4G, but there is research, and a general consensus among researchers that 4G networks could deliver peak rates of 1 Gigabit per second (Gbps), be fully IP based, and support full network agility for handovers between different types of networks, e.g., 4G to 3G to WLAN.

The International Telecommunications Union (ITU) has a framework for 4G in ITU-R Working Party 8F, and has published a document, Recommendation ITU-R M.1645 "Framework and overall objectives of the future development of IMT-2000 and systems beyond IMT-2000." Another ITU objective is to make new services available in new globally harmonized spectrum.

Competing Technologies

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

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 currently 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. At the end of July 2005, there were twenty-two EV-DO networks available worldwide.[35] 1xEV-DV (Evolved, Data Voice) allows both voice and high-speed data on the same radio channel, but is not ready for

[35] Source: www.cdg.org, July 29, 2005.

deployment, and currently has waning industry support with no commercial commitments.

EV-DO uses many of the same techniques for optimizing spectral efficiency used in HSDPA, such as higher order modulation, efficient scheduling, turbo coding and adaptive modulation and coding. For these reasons, it achieves spectral efficiency that is very close to HSDPA. The 1x technologies operate in 1.25 MHz radio channels, compared to the 5 MHz channels used with UMTS. This results in lower theoretical peak rates, but average throughputs for the same level of network loading are similar. In 2004, some CDMA operators first quoted typical throughput rates for EV-DO between 300-500 kbps, but recently operators have started quoting higher data rates in the range of 400 to 700 kbps[36].

The current versions of networks are based on the EV-DO Rev 0 specification. EV-DO Rev A incorporates a more efficient uplink which has spectral efficiency close to that of E-DCH. Commercial availability of EV-DO Rev A is expected in the second half of 2006, enabling field trials in the same period.

One challenge for EV-DO operators is that they cannot dynamically allocate their entire spectral resources between voice and high-speed data functions. The EV-DO channel is not available for circuit voice, and the 1xRTT channels only offer medium speed data. In the current stage of the market where data only constitutes a small percentage of total network traffic, that is not a large issue, but as data usage expands, this limitation will cause suboptimal use of radio resources.

However, 1xEV-DO could eventually provide voice service using VoIP protocols through EV-DO Rev A, which includes quality-of-service mechanisms in the network as well as significant IP protocol optimizations to reduce packet overhead. One vendor has indicated that they expect infrastructure to support VoIP on EV-DO Rev A in the 2007 to 2008 timeframe, and one large EV-DO operator has indicated that they could deploy VoIP in the 2008 to 2009 time frame.

Another limitation of using a separate channel for EV-DO data services is that it currently prevents users from being able to engage in simultaneous voice and high-speed data services as is possible with UMTS and HSDPA.

CDMA2000 is clearly a viable and effective wireless technology, and to its credit, many of its innovations have been brought to market ahead of competing technologies. With respect to competition with the GSM family of technologies today, the GSM family of technologies, including UMTS has more than 1.5 billion subscribers, which is more than five times the total number of subscribers as the CDMA family of technologies.[37]

WiMAX

Like GSM/UMTS, WiMAX is not a single technology, but a family of technologies. The original specification, IEEE 802.16 was completed in 2001, and was intended primarily for telecom backhaul applications in point-to-point, line-of-sight configurations using spectrum above 10 GHz. This original version of IEEE 802.16 uses a radio interface based on a single carrier waveform.

The next major step in the evolution of the IEEE 802.16 occurred in 2004 with the release of the IEEE 802.16-2004 standard, which added multiple radio interfaces,

[36] Source: Verizon BroadbandAccess Web page, July 29, 2005; Sprint press release July 7, 2005.

[37] Source: Informa Telecoms & Media, World Cellular Information Service, July 2005.

including one based on OFDM. IEEE 802.16-2004 also supports point-to-multipoint communications, sub 10 GHz operation, and non line-of-sight communications. Like the original version of the standard, operation is fixed, meaning that subscriber stations are typically immobile. Potential applications include wireless ISP service, local telephony bypass, an alternative to cable modem or DSL service, and cellular backhaul for connections from cellular base stations to operator infrastructure networks. Vendors can design equipment for either licensed or unlicensed bands.

Vendors are planning to deliver initial compliant equipment in late 2005. This standard does not compete directly with cellular-data and private Wi-Fi networks, and can thus provide complementary services. In addition to operator-hosted access solutions, private entities such as municipal governments, universities and corporations will be able to use this version of WiMAX in unlicensed bands (e.g., 5.8 GHz band) for local connectivity.

The IEEE is now working on IEEE 802.16e which adds mobility capabilities including: support for radio operation while mobile; handovers across base stations; and handovers across operators. Ratification of the standard is expected in the next year. Unlike IEEE 802.16-2004 that operates in both licensed and unlicensed bands, IEEE 802.16e will only be feasible in licensed bands. IEEE 802.16e mobility is likely to occur in several stages, beginning initially with nomadic use where users turn off or suspend their connections between locations. The next stage will be pedestrian mobility where users can maintain their connections while moving at slow speeds. Finally, equipment will support operation at speeds typical of cars or trains. Operators could start deploying mobile WiMAX in the 2007 to 2008 timeframe.

IEEE 802.16e employs many of the same mechanisms as HSDPA to maximize throughput and spectral efficiency, including high-order modulation, efficient scheduling, efficient coding, dynamic modulation and coding, and hybrid ARQ (HARQ). The principal difference from HSDPA is its use of OFDM. As discussed in the “Technical Approaches (TDMA, CDMA, OFDM)” section above, OFDM provides a potential implementation advantage for wide radio channels (e.g., 10 to 20 MHz). In 5 to 10 MHz radio channels, there is no evidence indicating that IEEE 802.16e will have any significant performance advantage on the downlink. This is shown in the “Evolution of Spectral Efficiency” section, where HSDPA and IEEE 802.16e are expected to exhibit similar spectral efficiency on the downlink.

OFDM systems, including IEEE 802.16e, do exhibit greater orthogonality on the uplink, however, and so IEEE 802.16e may have slightly greater uplink spectral efficiency than even E-DCH. Note however that IEEE 802.16e achieves its greatest spectral efficiency in a 1/1 reuse pattern where each sector uses the same radio channel. Another deployment option for IEEE 802.16e is 1/3 where each cell site uses the same frequency band, but each sector uses one of three radio channels. The 1/3 configuration is not spectrally as efficient as 1/1.

Flash OFDM

Fast Low-Latency Access with Seamless Handoff OFDM (Flash OFDM) is a proprietary wireless networking technology developed by Flarion Technologies. This company has recently agreed to be purchased by Qualcomm for a reported $600-800 million. A number of operators in Asia and Europe are trialing Flash OFDM. The largest single deployment commitment is in Finland where the government has granted an operating license for a nationwide network using frequencies released from NMT analog service in the 450 MHz band.

Flash OFDM is based on OFDM in 1.25 MHz radio channels. Flash OFDM employs frequency hopping in the tones (subchannels), which provides frequency diversity, and enables 1/1 reuse. The network is all IP based, and implements voice functions using VoIP. Flarion claims typical downlink speeds of 1 to 1.5 Mbps and typical uplink speeds of 300 to 500 kbps, with typical latency of 50 msec.

From a spectral efficiency point of view, Flash OFDM is claimed to achieve approximately the same downlink value as HSDPA in combination with mobile receive diversity and approximately the same uplink value as E-DCH. Since the technology is proprietary, details are not available for an objective assessment. But if these values are correct, it indicates that UMTS, using a CDMA-based approach, achieves the same performance levels as Flash OFDM. Flash OFDM has a time-to-market advantage in that its equipment is already available, but has a major disadvantage in having support from only a small vendor base, and not being an open standards-based technology. The technology is a candidate for the IEEE 802.20 standardization effort, but this standard is far from completion.

Wi-Fi

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, fast-food 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. The GSM Association is developing recommendations for SIM-based authentication for hotspots and 3GPP is developing an architecture as part of UMTS Release 6 that defines how a common core network can support UMTS and WLAN radio-access networks.

Market Fit

3G and WiMAX technologies encompass a huge range of evolving capability. But how well do these technologies actually address market needs? The following table matches technology capabilities with different market segments.

Table 6: Wireless Technology Fit for Market Needs

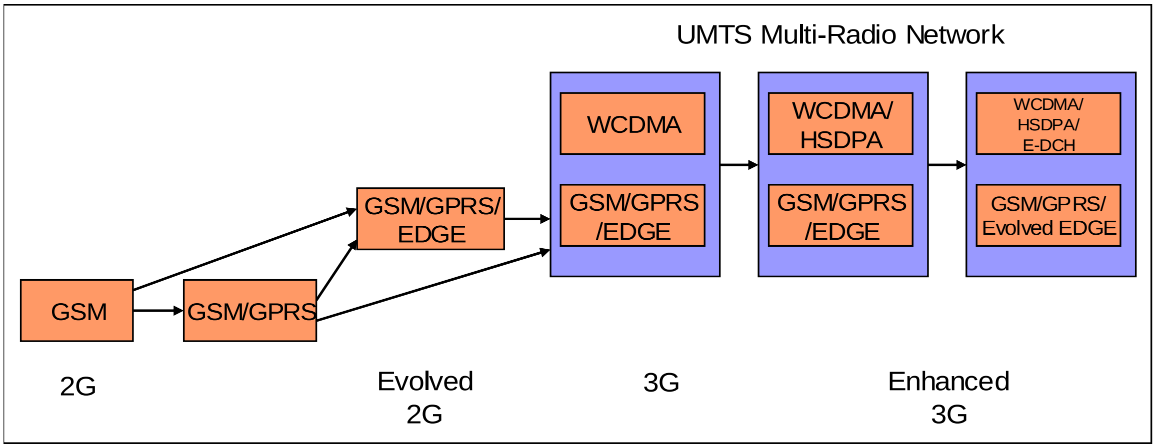
Segmentation Variable		Wireless Data Market Needs	Wireless Technology Fit
Fixed versus Mobile	Fixed	Broadband capability must be competitive against wireline options. Continuous coverage not required.	3G not intended to compete against wireline approaches. Fixed WiMAX will compete in this area, though mostly for areas where wireline is not available.
	Mobile	Good throughput necessary, but does not have to meet landline performance. Continuous coverage in coverage areas. Nationwide service offerings.	3G will be available in top markets with fallback to 2.5G services in other areas. Operators considering Mobile WiMAX networks, but no deployment commitments at this time.

Segmentation Variable		Wireless Data Market Needs	Wireless Technology Fit
Enterprise versus Consumer	Enterprise	Nationwide service offerings. Unlimited usage service plans. Choice in devices including modem cards, smartphones and data-capable mobile phones.	3G technologies will provide coverage in top markets with fallback to 2.5G for other areas. Mobile WiMAX will potentially offer service in dense population areas. All technologies will likely have unlimited usage service plans. 3G technologies will have widest device selection.
	Consumer	Wide range of feature phones with multimedia features.	3G technologies will have greatest selection of multimedia feature phones.
Urban versus Rural	Urban	High capacity to serve large numbers of subscribers. Broadband speeds desirable.	3G and Mobile WiMAX will both have high capacity and the ability to deliver broadband speeds.
	Rural	Good coverage in low density areas, achieved by large radius cells. High data throughputs a lesser priority.	These areas in the Americas are most likely to be served by 2.5 G technologies in near term and 3G in longer term.
Developed versus Emerging Markets	Developed	Value added services such as broadband data and wireless email.	3G networks can both provide broadband data. Mobile WiMAX networks will eventually be able to also offer broadband services. 3G operators likely to provide the greatest number of value-added services.
	Emerging	Basic telephony services supporting high population densities. Data a much lower priority.	UMTS, CDMA2000 and fixed WiMAX can all provide basic telephony services with data options.
Application Type	Laptop	High data throughputs.	3G can deliver high data throughputs and is available in PC Card or embedded formats. Mobile WiMAX will eventually be able to do the same.
	Smartphone	Medium data throughputs and wide coverage areas.	2.5/3G best choice due to data support and wide coverage areas.
	Feature Phone for Multimedia	High data throughputs and wide coverage areas.	3G best choice due to data support and wide coverage areas.

The Path from GPRS to HSDPA and Beyond

This section discusses the evolution of data capability from GPRS to HSDPA and the stages available for operators to evolve their networks. This progression, as shown in Figure 10, happens in multiple phases, first with GPRS, then EDGE, then WCDMA, followed by evolved 3G capabilities such as HSDPA, the Internet Multimedia Subsystem and E-DCH.

Figure 10: 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 installed GSM and GPRS simultaneously; these include AT&T Wireless (now part of Cingular), Cingular Wireless, Rogers Wireless, and Telecom Personal.

More recently, operators have been upgrading their GPRS networks to EDGE with extremely good results, and many operators are now also deploying UMTS networks, with HSDPA capability about to be launched.

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[38]. The same packet infrastructure supports both GPRS and EDGE. An increasing number of GPRS terminals support EDGE, thus making EDGE available to ever more 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.

[38] *POP* refers to population.

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, Release 4 significantly reduces EDGE latency (network round-trip time), from typically 500 to 600 msec to about 300 msec.

Devices themselves are increasing in capability. Dual Transfer Mode (DTM) mode devices, expected in the 2006 time frame, will allow simultaneous voice and data communications with both GPRS and EDGE devices. For example, during a voice call users will be able to retrieve e-mail, do multimedia messaging, browse the Web, and do Internet conferencing.

DTM is a 3GPP specified technology that enables new applications like video sharing, while enhancing service continuity when operators introduce WCDMA/HSDPA. Typically, a DTM end-to-end solution requires only a software upgrade to the GSM/EDGE radio network.

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 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

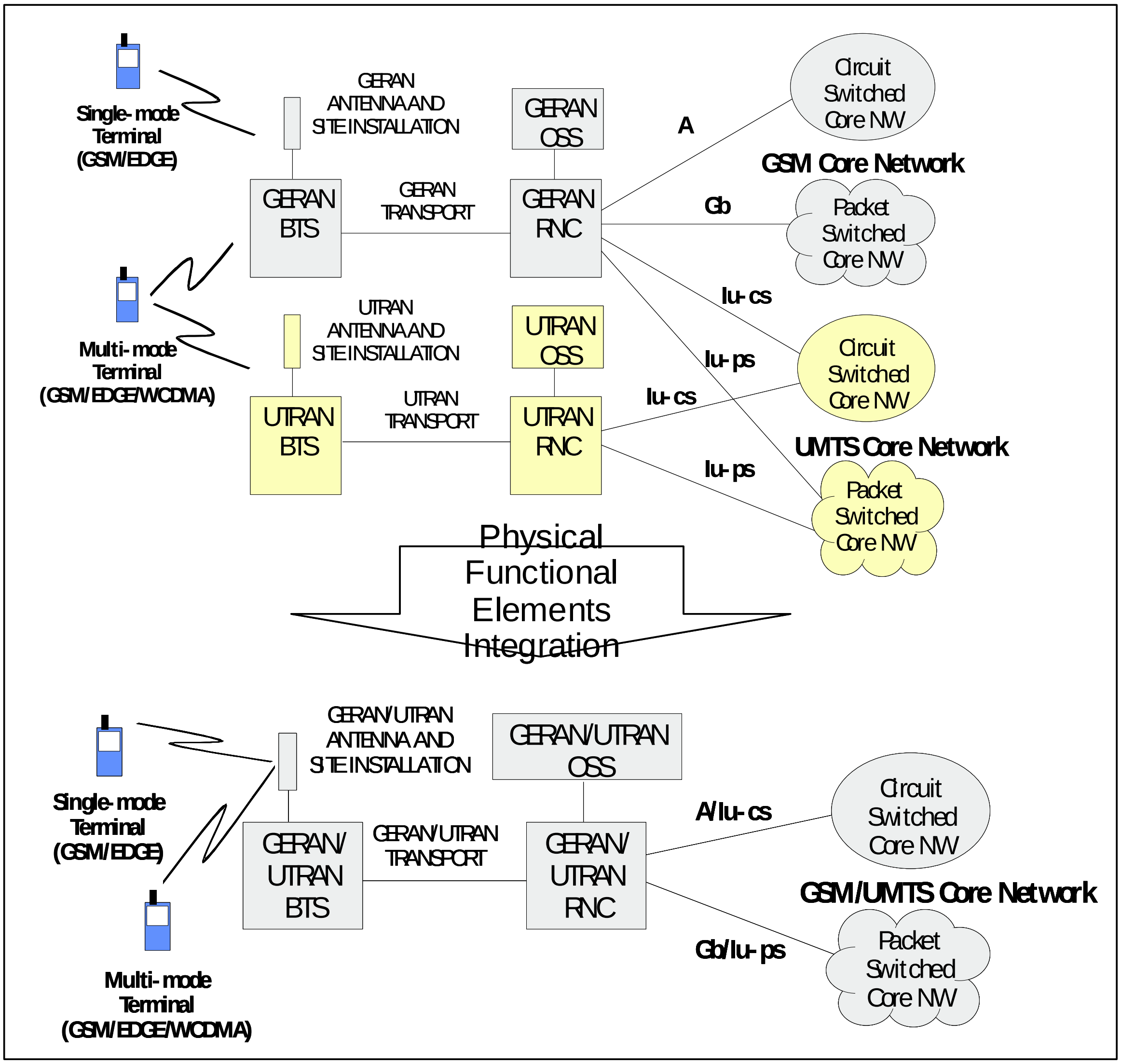
Deployment of UMTS will occur in several stages, beginning first with a portion of the coverage area having UMTS, progressing through continuous UMTS coverage, and then reaching highly integrated, multi-radio operation. Table 7 shows this progression.

Table 7: 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 11. This will lower total network cost and improve integrated operation of the separate access networks.

Figure 11: Integration of UMTS and GSM/EDGE Core Network Equipment[39]



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

Another important aspect of UMTS deployment (including HSDPA) is the expanding number of available radio bands, as shown in Figure 12, and corresponding support from infrastructure and mobile equipment vendors. The fundamental system design and networking protocols remain the same for each band; only the frequency-dependent portions of the radios have to change.

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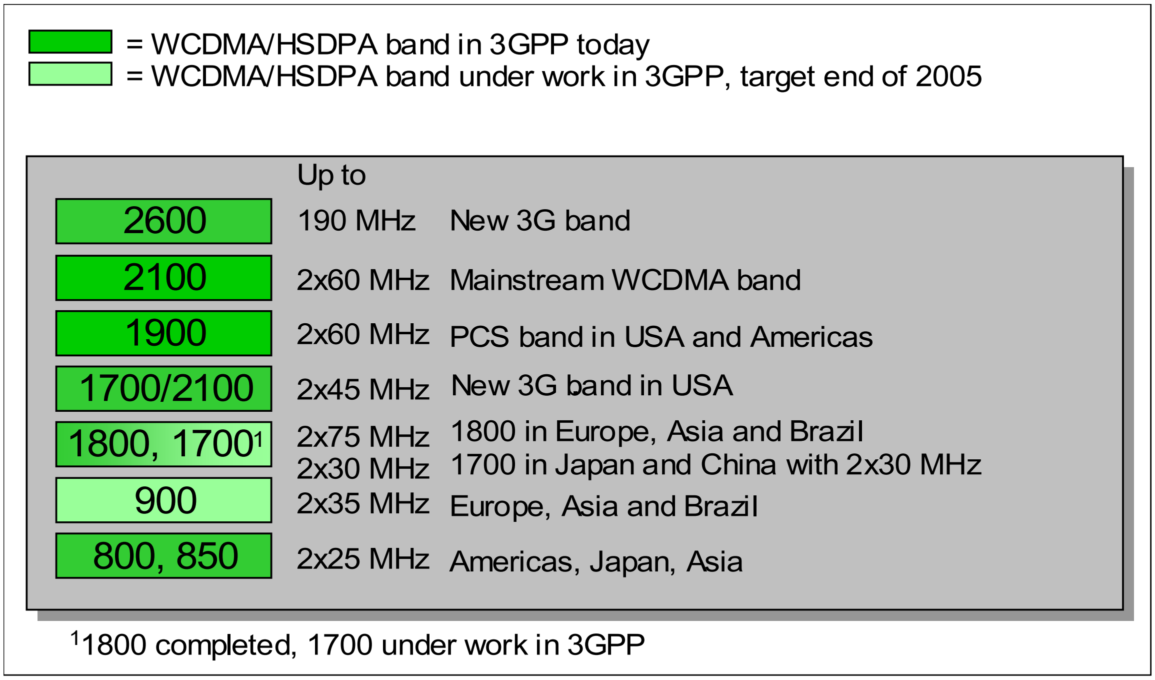
Figure 12: Bands for UMTS Deployment[40]



HSDPA 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.
- **Release 4:**[41] 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, close to completion. Includes uplink enhancement through the Enhanced Dedicated Channel, enhanced multimedia support through Multimedia Broadcast/Multicast Services (MBMS), performance specifications for advanced receivers, WLAN integration option, and second phase of IMS.
- **Release 7**: Under development. Current plans include fine tuning and incremental improvements of features from previous releases. The result will be performance enhancements, improved spectral efficiency, increased capacity and

[40] Source: 3G Americas' member company.

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

better resistance to interference. Improvements to enable high quality, high efficiency VoIP over HSDPA and E-DCH are another area of investigation.

Of all these capabilities, it is HSDPA that will provide users with 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 approach applied to WCDMA. WCDMA provides the initial foundation while HSDPA and E-DCH deliver the full inherent potential of the radio channel.

New features such as HSDPA, E-DCH and MBMS are being designed so that the same upgraded UMTS radio channel can support a mixture of terminals, including those based on Release 99, Release 5 and Release 6. In other words, a network supporting Release 5 features (e.g., HSDPA) could support Release 99, Release 5 terminals as well as Release 6 terminals (e.g., E-DCH) operating in a Release 5 mode, and alternatively a network supporting Release 6 features could support Release 99, Release 5 and Release 6 terminals. This flexibility assures the maximum degree of forward and backward compatibility.

The evolution of HSDPA devices is likely to follow the following course:

1. Initial devices are likely to support 5 codes with QPSK modulation for peak rates of 1.8 Mbps, or 5 codes with both QPSK and 16 QAM modulation for peak rates of 3.6 Mbps.
2. Devices in the 2006 time frame will support more codes (e.g., 10 codes) and both QPSK and 16QAM modulation. These improvements will enable peak rates of 7.2 Mbps.
3. Devices will implement mobile receive diversity in the 2006 to 2007 time frame, increasing spectral efficiency by 50%.
4. Devices will implement E-DCH in the 2006 to 2007 time frame for enhanced uplink performance.
5. Devices will implement advanced receiver architectures in the 2006 to 2008 time frame.

One deployment option for HSDPA is a flat architecture that provides Internet access with minimal network infrastructure. In this approach, the network does not require a radio network controller, and optionally also does not need the SGSN/GGSN.

Once HSDPA and E-DCH become available, operators will have the option of moving voice traffic over to these high-speed data channels using VoIP. This may increase voice capacity to some degree, but more importantly, it will allow operators to consolidate their infrastructure on an IP platform, and to offer innovative new applications that combine voice with data functions.

The result of capabilities such as HSDPA, E-DCH and other advanced functions is a compelling 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.

Evolution of Spectral Efficiency

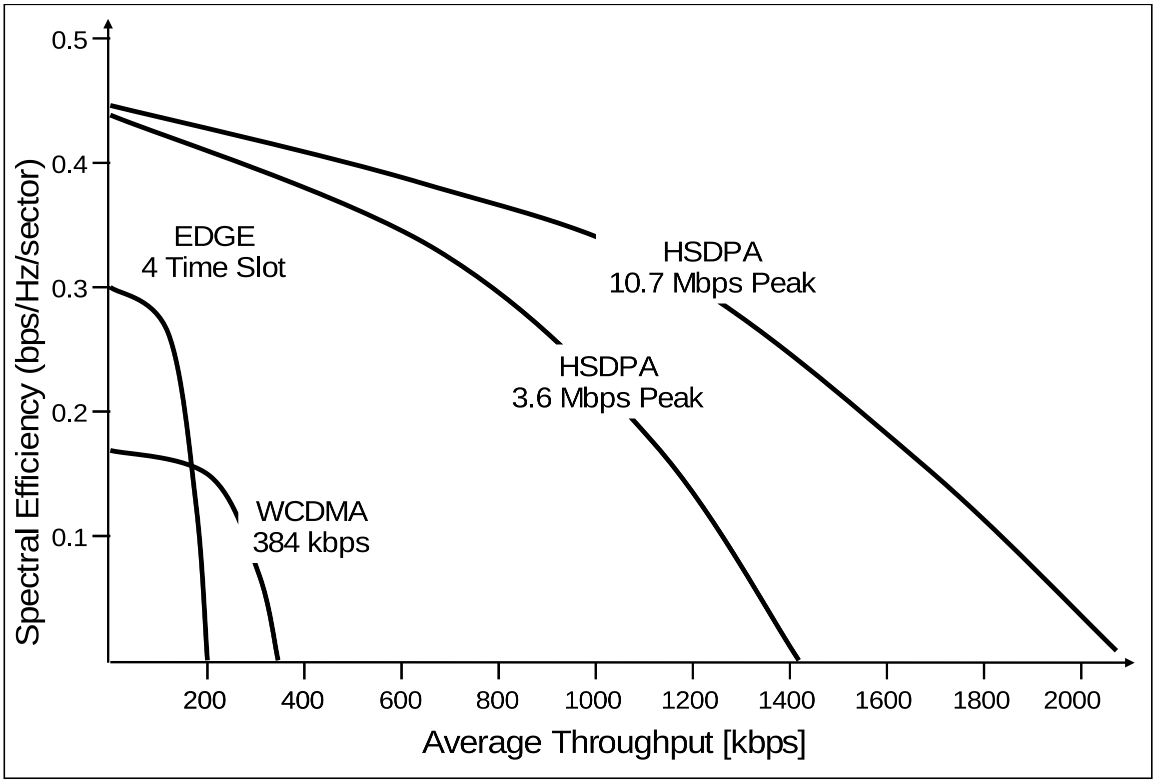
To better understand the reasons for deploying the different data technologies, and to better predict evolution of capability, we need to quantify their spectral efficiency. The evolution of data services is one of an increasing number of users with ever higher bandwidth demands. As the wireless data market growths, deploying wireless technologies with high spectral efficiency will be of paramount importance. Keeping all other things equal, such as frequency band, amount of spectrum and cell site spacing, an increase in spectral efficiency translates almost directly to a proportional increase in the number of users supported at the same load per user, or an increase in throughput available to each user for the same number of users. Delivering broadband services to large numbers of users can best be achieved with systems having high spectral efficiency, especially since the only other alternatives are to use more spectrum or to deploy more cell sites.

Increased spectral efficiency comes at a price, however. It generally implies greater complexity for both user equipment and base station equipment. Complexity can arise from increased numbers of calculations performed to process signals, or from additional radio components. Hence, operators and vendors must balance market needs against network and equipment cost.

The roadmap for the GSM family of technologies provides a wide portfolio of options to increase spectral efficiency. The exact timing for deploying these options is difficult to predict because much will depend on the growth of the wireless-data market, and what types of applications become popular.

The following figure plots spectral efficiency versus throughput for the GSM family. 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.

Figure 13: GSM Family Downlink Spectral Efficiency[42]



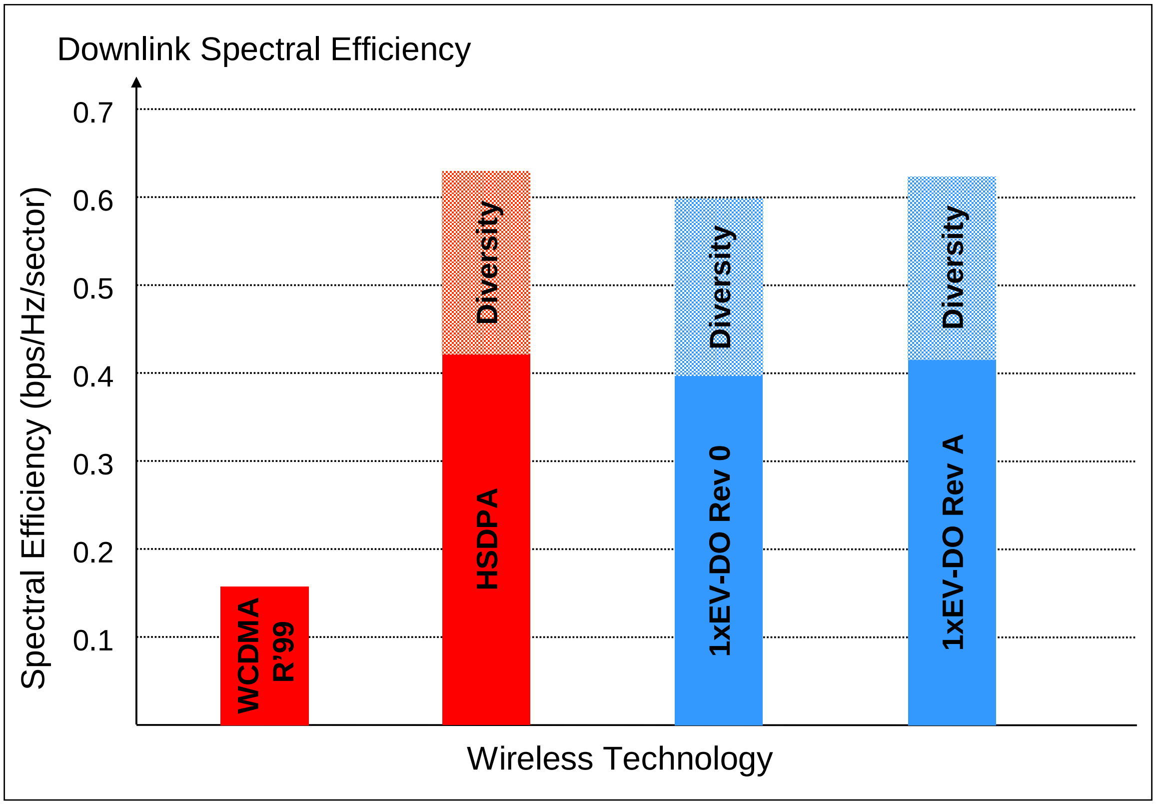
Note that spectral efficiency decreases with increasing average throughput, due to scheduling inefficiencies. This is the case for most wireless technologies. For average throughput, the simulations show that EDGE has high spectral efficiency for data rates below 100 kbps. For data rates above 100 kbps, WCDMA has greater spectral efficiency. But in all instances, HSDPA has the highest spectral efficiency.

Relative to WCDMA Release 99, simulations show that HSDPA will increase capacity by a factor of approximately 2.5 with initial devices. With subsequent enhancements, HSDPA will achieve a four times spectral efficiency improvement over WCDMA.

Figure 14 shows a comparison of the spectral efficiency of different wireless technologies on the downlink.

[42] 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. WCDMA spectral efficiency is lower than the last version of this paper due to removal of the WCDMA Downlink Shared Channel (DSCH).

Figure 14: Comparison of Downlink Spectral Efficiency[43]

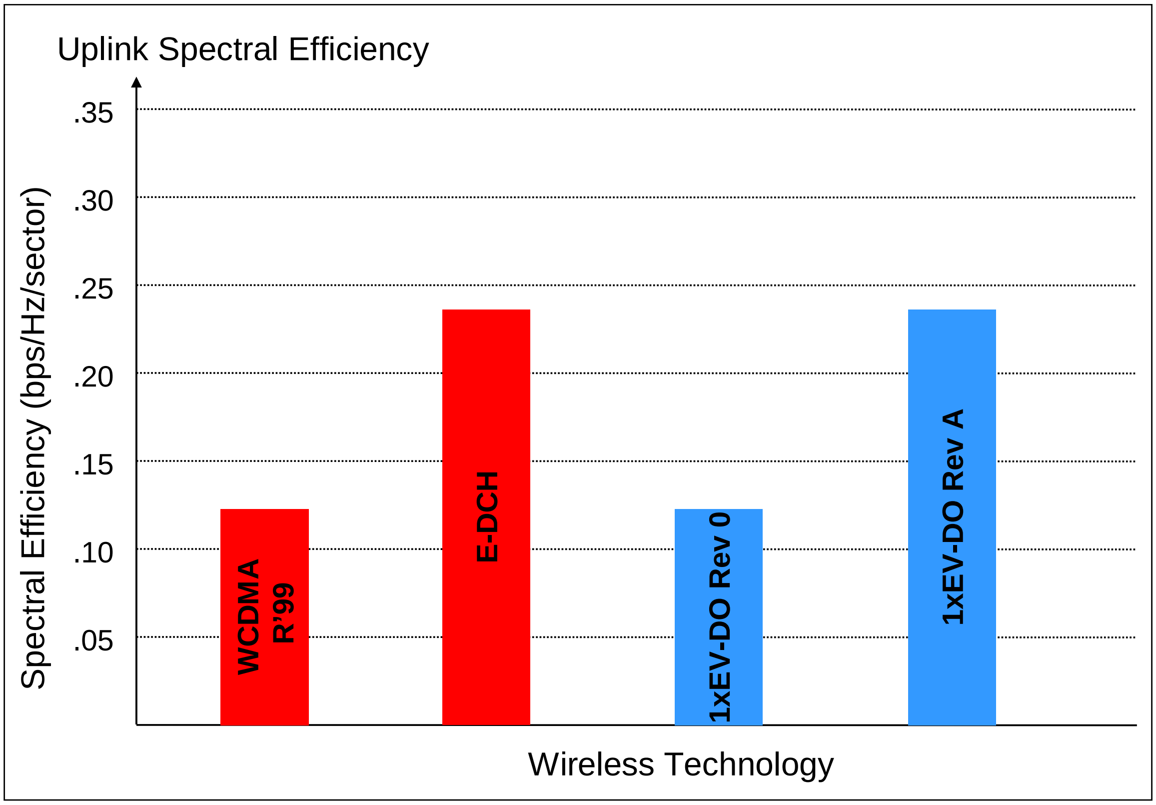


Mobile receive diversity provides a spectral efficiency gain of 50% for all technologies. HSDPA provides a spectral efficiency gain of approximately 2.5 times that of WCDMA Release 99. HSDPA and 1xEV-DO have fairly similar spectral efficiency. Relative to HSDPA, IEEE 802.16e, as shown in Figure 17, achieves similar or slightly higher spectral efficiency depending on the number of optimizations that are implemented, and assuming that no advanced antenna systems are used.

Figure 15 shows a comparison of the spectral efficiency on the uplink.

[43] Source: Joint analysis by 3G Americas' members. Assumptions include 25% AWGN + 37% PedA at 3km/h + 13% PedA at 30km/h + 13% VehA at 30km/h + 12% VehA at 100km/h. Simulations based on a 19-cell, 57-sector system with wrap-around. All the cells have radii of approximately 1km making the system interference limited. Pilot and MAC overhead are accounted for, cell throughputs are from radio link protocol layer, full buffer with no traffic modeling. Proportional fair scheduling.

Figure 15: Comparison of Uplink Spectral Efficiency for Different Technologies[44]



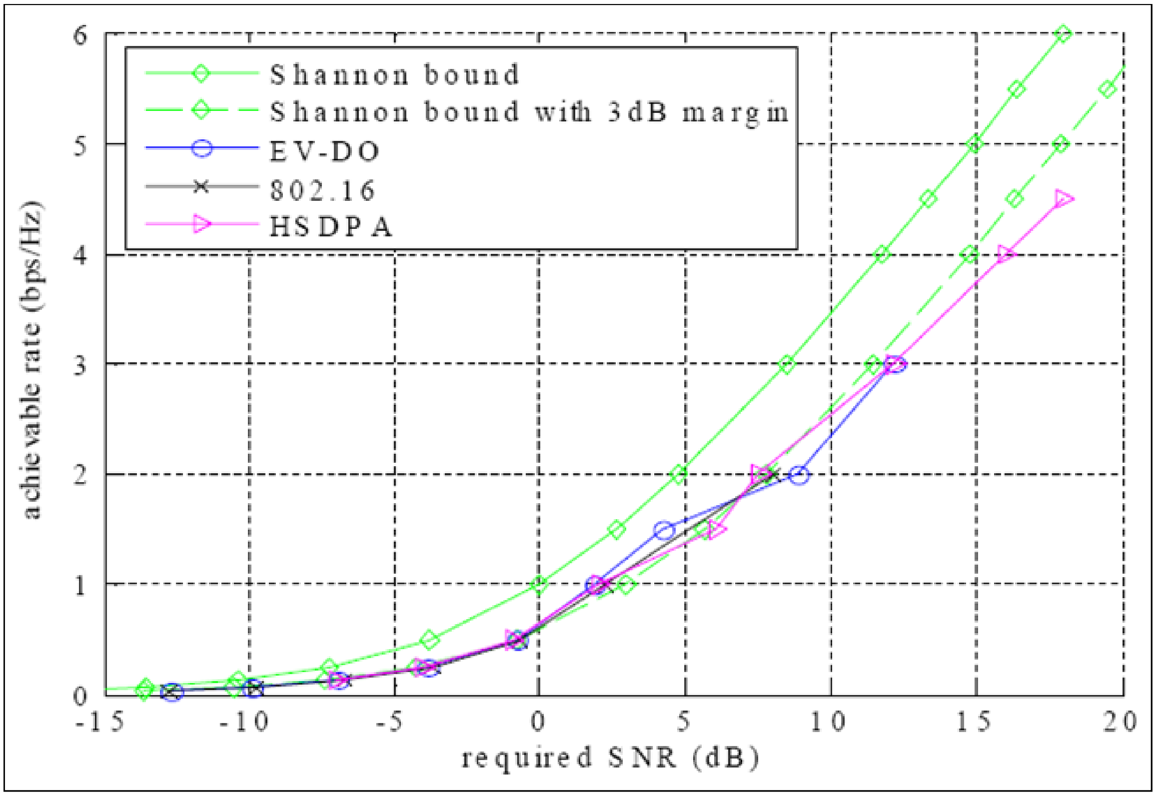
The Enhanced Dedicated Channel for UMTS significantly increases uplink capacity, as does Rev A for 1xEV-DO compared to Rev 0. OFDM-based systems exhibit slightly improved uplink capacity relative to CDMA technologies.

When determining the best area to focus future technology enhancements towards, it is interesting to note that HSDPA, 1xEV-DO, and 802.16e all have highly optimized link layers. In fact, as shown in Figure 16, the link layer performance of these technologies is approaching the theoretical limits as defined by the Shannon bound. The Shannon bound is a theoretical limit to the information transfer rate (per unit bandwidth) that can be supported by any communications link. The bound is a function of the signal to noise ratio (SNR) of the communications link. Figure 16 shows that HSDPA, 1xEV-DO, and 802.16e are all within 2-3 dB of the Shannon bound, indicating that from a link layer perspective there is not much room for improvement. This figure demonstrates that the focus of future technology enhancements should be on improving system performance aspects that improve and maximize the experienced SNRs in the system instead of investigating new air interfaces that attempt to improve the link layer performance. Examples of technologies that improve SNR in the system are those that minimize interference through intelligent antennas or interference coordination between sectors and cells. Note that MIMO techniques that use spatial multiplexing to potentially increase the overall information transfer rate by a factor proportional to the number of transmit antennas do not violate the Shannon bound since the per antenna transfer rate (i.e. the per communications link transfer rate) is still limited by the Shannon bound.

[44] Source: Joint analysis by 3G Americas' members. Same assumptions are prior figure.

This situation suggests that arguments over which wireless technology outperforms another are largely irrelevant, as all the technologies offer largely comparable performance. Users should concentrate instead on other factors, such as availability, pricing, coverage, roaming and devices.

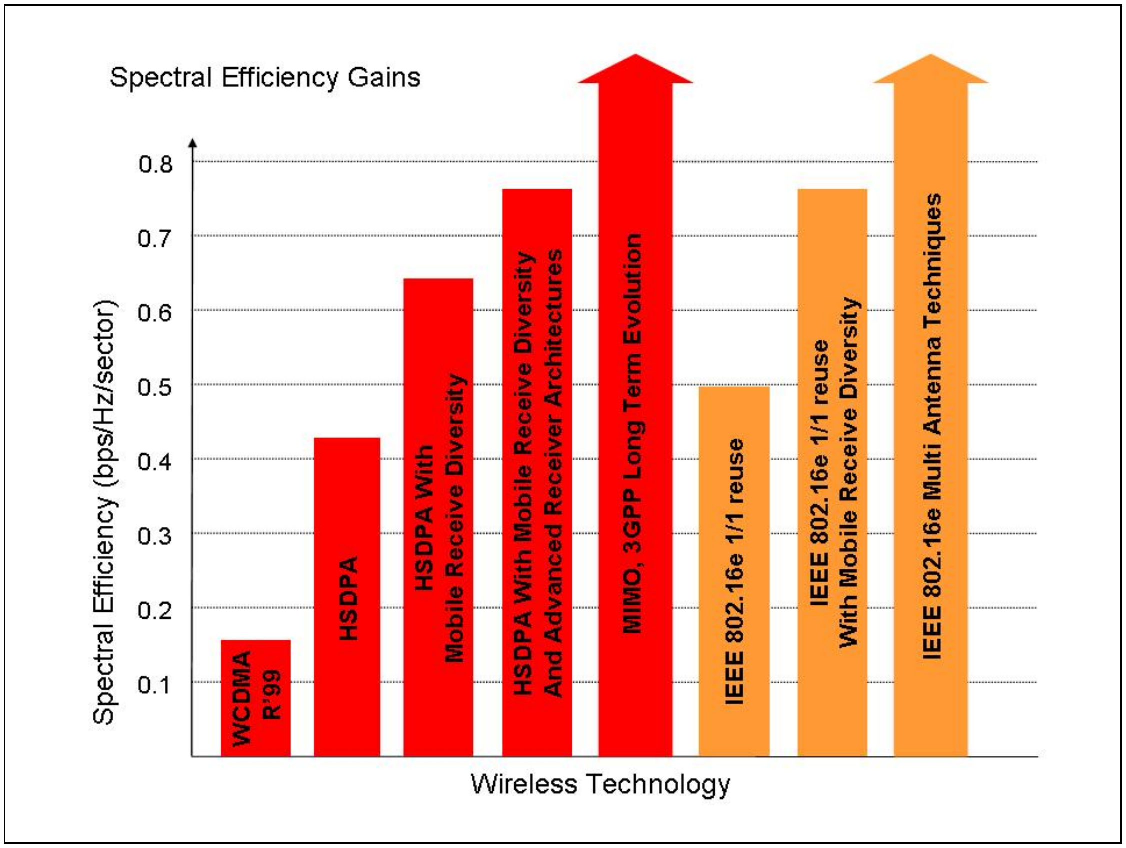
Figure 16: Performance Relative to Theoretical Limits[45]



Longer term, advanced receiver architectures will provide gains of 20% or higher for downlink spectral efficiency. IEEE 802.16e also will become more spectrally efficient as various optimizations are applied. Gains will be available for HSDPA and IEEE 802.16e through the use of technologies such as Space Division Multiple Access (SDMA) and Multiple Input Multiple Output (MIMO). The 3GPP is studying SDMA and MIMO for 3GPP Release 7. Beyond HSDPA, increasing spectral efficiency even further is an important goal for 3GPP Long Term Evolution. See Figure 17.

[45] Source: 3G Americas' member company.

Figure 17: Enhancements in Spectral Efficiency of 3GPP Systems and WiMAX[46]



Another development that may affect capacity is VoIP over HSDPA/E-DCH channels. Preliminary analysis indicates potential voice capacity gains relative to WCDMA bearer channels, but it is too early to tell exactly what the gains may be. However, VoIP will bring other benefits, such as a consolidated IP core network for operators and sophisticated multimedia voice applications for users.

Conclusion

This paper has described the data capabilities of GPRS to HSDPA. HSDPA has one of the highest spectral efficiencies and lowest latency of any wireless technology available today or in the near future. The GSM evolution to HSDPA and beyond 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 control 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. Today, there are already more than 80 commercial UMTS networks in operation. UMTS also has support from nearly all major regional standardization bodies.

[46] Source: Joint analysis by 3G Americas' members.

UMTS offers an excellent migration path for GSM operators and as well as an effective technology solution for Greenfield operators.

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 added 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 220-320 kbps (six to eight times wireline dial-up), which bring an entirely 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 efficient for wideband services. EDGE and WCDMA provide the capabilities to make entire cities and countries "broadband hotspots." Unlike some 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 HSDPA, an extremely fast data service with anticipated average speeds of about 550 kbps to 1.1 Mbps, and peak theoretical speeds of up to 14 Mbps, the highest rate defined 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 a software-based upgrade and is currently being trialed with commercial availability expected in late 2005. HSDPA and its advanced evolution can compete against any other technology in the world and it is widely expected that most all UMTS operators will eventually upgrade to HSDPA. While HSDPA improves throughput speeds and spectral efficiency for the downlink, the uplink Enhanced Dedicated Channel will improve these for the uplink. Other innovations will be deployed over the next several years, including terminals that can operate at higher peak speeds, new antenna systems and advanced receiver architectures.

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. The GPRS to HSDPA evolution path followed by 3GPP Long Term Evolution provides one of the most robust portfolios of technologies and an optimum framework for realizing this potential.

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

References

3G Americas, “The Evolution of UMTS, 3GPP Release 5 and Beyond”, June 2004.

3G Americas, “The Global Evolution of UMTS/HSDPA - 3GPP Release 6 and Beyond”, July 2005.

AT&T Wireless, research data, July 2002, November 2003, June 2004, submission to 3G Americas.

Cingular Wireless, “Spectrum Efficiency Comparison, GSM vs. UMTS vs. 1XRTT” - research material, March 14, 2002, submission to 3G Americas.

Ericsson, “Delay Versus Capacity Trade Off”, July 2005, submission to 3G Americas.

Ericsson, “HSDPA Performance”, July 2005, submission to 3G Americas.

Ericsson, “Measurement TCP Throughput over HSDPA”, July 2005, submission to 3G Americas.

Ericsson, “Technology Comparison”, July 2005, submission to 3G Americas.

Ericsson, “Uplink Capacity Evaluations”, July 2005, submission to 3G Americas.

Ericsson, “WCDMA, EDGE and cdma2000 - Capacity for Packet Data Services”, July 2002, submission to 3G Americas.

Ericsson. Johan Skold, Magnus Lundevall, Stefan Parkvall and Magnus Sundelin. “Broadband Data Performance of Third-Generation Mobile Systems”, White Paper, Ericsson, White Paper, “GSM to WCDMA the Global Choice”, 2002.

Ericsson, White Paper, “WCDMA Evolved, The first step – HSDPA”, May 2004.

Ericsson, Nokia, Siemens. “Agreed Data Performance Characterization for EGPRS, WCDMA and CDMA2000 1XRTT”, September 20, 2002, submission to 3G Americas.

Timo Halonen, Javier Romero, Juan Melero, “GSM, GPRS and EDGE Performance - GSM Evolution towards 3G/UMTS”, May 13, 2002.

Harri Holma and Antti Toskala, “WCDMA for UMTS”, 3rd edition, John Wiley & Sons, July 2004.

Informa Telecoms & Media, WCIS, “Global UMTS Network Status”, July 26, 2005.

Lucent, “3GPP Rel’7 Enhancement Concepts”, July 2005, submission to 3G Americas.

Lucent, “Benefits of MIMO: BLAST vs. SDMA”, July 2005, submission to 3G Americas.

Lucent, “Comparative Spectral Efficiency”, July 2005, submission to 3G Americas.

Lucent, “HSDPA Test Results”, July 2005, submission to 3G Americas.

Lucent, “Link Capacity for Various Rate-Controlled Technologies”, July 2005, submission to 3G Americas.

Lucent, “Performance of VoIP on Dynamic Shared Channels”, July 2005, submission to 3G Americas.

Lucent, “UMTS Data Performance from Simulations and Field Data Measurements”, submission to 3G Americas.

Motorola, “Performance of 3GPP High Speed Downlink Packet Access (HSDPA)”, Robert Love, Amitava Ghosh, Weimin Xiao and Rapeepat Ratasuk, 2004.

Nokia, “A comparison between EDGE and Alternative Technologies”, June 5, 2001, www.3Gamericas.org.

Nokia, Datasheet, “Nokia High Speed Packet Access Solution”, 2004.

Nokia, “HSDPA and the Shannon Limit”, July 2005, submission to 3G Americas.

Nokia, Performance data for HSDPA and E-DCH, July 2005, submission to 3G Americas.

Nokia, Performance analysis of WCDMA and HSDPA, July 2004, submission to 3G Americas.

Nokia, “EGPRS Throughput versus Path Loss”, October 5, 2002, submission to 3G Americas.

Nortel, Christian Dubuc, David Starks, Tim Creasy, and Yong Hou, Nortel Networks, “A MIMO-OFDM Prototype for Next-Generation Wireless WANs”, December 2004, IEEE Communications.

Nortel, IEEE 802.16e and HSDPA performance analysis, July 2005, submission to 3G Americas.

Nortel, MIMO-OFDM performance analysis, July 2005, submission to 3G Americas.

Nortel, WiMAX: Untethering the Internet User”, Bill Gage, Charlie Martin, Ed Sich, and Wen Tong, Nortel Technical Journal, Issue 2.

Nortel, “What 3G Applications & Services to Launch?”, June 2004, submission to 3G Americas.

Rysavy Research, “Hard Numbers and Experts' Insights on Migration to 4G Wireless Technology”, published by Datacomm Research, Feb 2005.

Acronyms

The following are the acronyms used in this paper. Acronyms are defined the first time they are used in the paper.

1XRTT – One Carrier Radio Transmission Technology

3G – Third Generation

3GPP – Third Generation Partnership Project

3GPP2 – Third Generation Partnership Project 2

8-PSK – Octagonal Phase Shift Keying

AAS – Adaptive Antenna Systems

AMR – Adaptive Multi Rate

ARQ – Automatic Repeat Request

ARPU – Average Revenue Per User

BCCH – Broadcast Control Channel

BSC – Base Station Controller

C/I – Carrier to Interference Ratio

CDMA – Code Division Multiple Access

CS – Coding Scheme; Circuit Switched

DTM – Dual Transfer Mode

DVB-H – Digital Video Broadcasting-H

E–DCH – (Uplink) Enhanced Dedicated Channel

EBCMCS – Enhanced Broadcast Multicast Services

EDGE – Enhanced Data Rates for GSM Evolution

EGPRS – Enhanced GPRS (EDGE)

EV–DO – Evolved Data Optimized

Flash OFDM – Fast Low-Latency Access with Seamless Handoff OFDM

FLO – Forward Link Only

Gbps – Gigabits per second

GERAN – GSM EDGE Radio Access Network

GGSN – Gateway GPRS Support Node

GMSK – Gaussian Minimum Shift Keying

GPRS – General Packet Radio Service

GSM – Global System for Mobile communications

HARQ – Hybrid Automatic Repeat Request

HLR – Home Location Register

HME – HSDPA Mobility Enhancement

HSDPA – High Speed Downlink Packet Access

HS-DSCH – High Speed Downlink Shared Channels

HTML – Hypertext Markup Language

IMS – IP Multimedia Subsystem

IP – Internet Protocol
ITU – International Telecommunications Union
kbps – Thousand Bits Per Second
LAN – Local Area Network
LTE – Long Term Evolution
MBMS - Multimedia Broadcast/Multicast Service
Mbps – Million Bits Per Second
MIMO – Multiple Input Multiple Output
MSC – Mobile Switching Center
OFDM – Orthogonal Frequency Division Multiplexing
PBCH – Packet Broadcast Control Channel
PDCH – Packet Data Channel
PoC – Push-to-talk over Cellular
QAM – Quadrature Amplitude Modulation
QoS – Quality of Service
QPSK – Quadrature Phase Shift Keying
SDMA – Space Division Multiple Access
SGSN – Serving GPRS Support Node
SIP – Session Initiation Protocol
SMS – Short Message Service
SNR – Signal to Noise Ratio
TDD – Time Division Duplex
TDMA – Time Division Multiple Access
TD-SCDMA – Time Division Synchronous CDMA
TTI – Transmission Time Interval
UMTS – Universal Mobile Telecommunications System
UTRAN – UMTS Terrestrial Radio Access Network
VoIP – Voice over IP
VPN – Virtual Private Network
WAN – Wide Area Network
WAP – Wireless Application Protocol
WCDMA – Wideband CDMA
Wi-Fi – Wireless Fidelity
WiMAX – Worldwide Interoperability for Microwave Access
WLAN – Wireless LAN

Appendix A: Global HSDPA Status

Data as of September 6, 2005:

OPERATOR	COUNTRY	STATUS
3	UK	Evaluating
Bouygues Telecom	France	Planned/In deployment
Cellcom	Israel	Planned/In deployment
China Mobile	China	Planned/In deployment
Cingular Wireless	USA	Planned
Connect Austria (ONE)	Austria	Planned
Elisa	Finland, Estonia	In Deployment / Trial
Finnet / Finnish 2G	Finland	In deployment
HI3G	Sweden	Planned
Hutchison 3G	Australia	Planned
KPN	Netherlands	Planned/In deployment
KTF	South Korea	Planned/In deployment
Manx Telecom (o2)	Isle of Man	In deployment
Maxis Communications	Malaysia	Planned/In deployment
Mobilkom Austria	Austria	Planned/In deployment
Mobitel	Slovenia	In Deployment
MTN	South Africa	Planned/In deployment
NTT DoCoMo	Japan	Planned/In deployment
O2	UK, Germany, Ireland	Planned/In deployment
Orange	France, UK	Planned
Optimus	Portugal	Trial
Partner Communications (Orange)	Israel	Planned/In deployment
Q-TEL	Qatar	Planned
SFR	France	Planned
SK Telecom	South Korea	Planned/In deployment
SmarTone	Hong Kong (China)	Trial
Sunday	Hong Kong (China)	Planned/In deployment
T-Mobile	Austria, Czech Republic, Germany, Netherlands, UK, USA	Planned/In deployment
Tele.ring	Austria	In Deployment
Telefonica Moviles	Spain	Planned/In deployment
Telfort	Netherlands	In deployment
Telstra	Australia	Planned
TIM	Italy	Planned/In deployment
VIBO Telecom	Taiwan	In deployment
Vodacom	South Africa	In deployment
Vodafone	Germany, Japan, Italy, New Zealand	Planned/In deployment

Source: Informa Telecoms & Media's world Cellular Information Service and public announcements - September 2005

Appendix B: Global UMTS Network Status

GLOBAL UMTS NETWORK STATUS	NETWORKS IN SERVICE	82
Informa Telecoms & Media, WCIS	PRE-COMMERCIAL	9
Updated: September 6, 2005	PLANNED/IN DEPLOYMENT	61
	LICENSE AWARDED	7
Source:	TRIAL	18
Informa Telecoms & Media	POTENTIAL LICENSE	38
World Cellular Information Service	LICENSE REVOKED/SOLD	11

Networks In Service as of September 2005

	Country	Operator	Network	Status	Start Date	Opening
1	Australia	Hutchison 3G	3	In Service	Apr 2003	
2	Australia	Telstra		In Service	Sep 2005	
3	Austria	Connect Austria	ONE	In Service	Dec 2003	
4	Austria	Hutchison 3G	3	In Service	May 2003	
5	Austria	mobilkom		In Service	Apr 2003	
6	Austria	T-Mobile Austria		In Service	Dec 2003	
7	Austria	tele.ring		In Service	Dec 2003	
8	Bahrain	MTC Vodafone Bahrain		In Service	Dec 2003	
9	Denmark	HI3G Denmark	3	In Service	Oct 2003	
10	Finland	Elisa		In Service	Nov 2004	
11	Finland	TeliaSonera	Sonera	In Service	Oct 2004	
12	France	Orange France	Orange	In Service	Dec 2004	
13	France	SFR		In Service	Nov 2004	
14	Germany	E-Plus		In Service	Aug 2004	
15	Germany	O2		In Service	Jul 2004	
16	Germany	T-Mobile		In Service	May 2004	
17	Germany	Vodafone D2		In Service	May 2004	
18	Greece	Cosmote		In Service	May 2004	
19	Greece	Panafon	Vodafone	In Service	Aug 2004	
20	Greece	STET Hellas	TIM	In Service	Jan 2004	
21	Guernsey	Wave Telecom		In Service	Jul 2004	
22	Hong Kong	Hong Kong CSL		In Service	Dec 2004	
23	Hong Kong	Hutchison		In Service	Jan 2004	
24	Hong Kong	SmarTone		In Service	Dec 2004	
25	Hong Kong	Sunday		In Service	Jun 2005	
26	Hungary	T-Mobile		In Service	Aug 2005	
27	Ireland	Hutchison Whampoa		In Service	Jul 2005	
28	Ireland	O2		In Service	Mar 2005	
29	Ireland	Vodafone Ireland		In Service	Nov 2004	
30	Israel	Cellcom Israel		In Service	Jun 2004	
31	Israel	Partner Communications	Orange	In Service	Nov 2004	
32	Italy	H3G	3	In Service	Mar 2003	
33	Italy	TIM		In Service	May 2004	
34	Italy	Vodafone Omnitel		In Service	May 2004	
35	Italy	Wind		In Service	Oct 2004	
36	Japan	NTT DoCoMo	FOMA	In Service	Oct 2001	
37	Japan	Vodafone		In Service	Dec 2002	

38	Korea	KTF		In Service	Dec 2003	
39	Korea	SK Telecom		In Service	Dec 2003	
40	Latvia	LMT		In Service	Dec 2004	
41	Latvia	Tele2		In Service	Dec 2004	
42	Luxembourg	LUX Communications	VOX.mobile	In Service	May 2005	
43	Luxembourg	P&T Luxembourg	LUXGSM	In Service	Jun 2003	
44	Luxembourg	Tele2	Tango	In Service	Jul 2004	
45	Malaysia	Maxis Communications		In Service	Jul 2005	
46	Malaysia	Telekom Malaysia	Celcom 3G	In Service	May 2005	
47	Maldives	Wataniya Telecom		In Service	Aug 2005	
48	Mauritius	Emtel		In Service	Nov 2004	
49	Netherlands	KPN Mobile		In Service	Oct 2004	
50	Netherlands	Vodafone Libertel		In Service	Jun 2004	
51	New Zealand	Vodafone New Zealand		In Service	Aug 2005	
52	Norway	Telenor Mobil		In Service	Dec 2004	
53	Norway	Netcom		In Service	Jun 2005	
54	Poland	Polkomtel		In Service	Sep 204	
55	Portugal	Optimus		In Service	Jun 2004	
56	Portugal	TMN		In Service	Apr 2004	
57	Portugal	Vodafone Telecel		In Service	May 2004	
58	Romania	MobiFon		In Service	Apr 2005	
59	Singapore	MobileOne		In Service	Feb 2005	
60	Singapore	SingTel Mobile	3loGy Live	In Service	Feb 2005	
61	Singapore	StarHub		In Service	Apr 2005	
62	Slovenia	Mobitel		In Service	Dec 2003	
63	South Africa	MTN		In Service	Jun 2005	
64	South Africa	Vodacom		In Service	Dec 2004	
65	Spain	Amena		In Service	Oct 2004	
66	Spain	Telefónica Móviles	MoviStar	In Service	May 2004	
67	Spain	Vodafone España		In Service	May 2004	
68	Sweden	HI3G	3	In Service	May 2003	
69	Sweden	Svenska UMTS-Nät		In Service	Mar 2004	
70	Sweden	Vodafone Sweden		In Service	Jul 2004	
71	Switzerland	Swisscom Mobile		In Service	Dec 2004	
72	Switzerland	Orange		In Service	Sep 2005	
73	Taiwan	Chunghwa Telecom		In Service	Jul 2005	
74	Taiwan	FarEasTone		In Service	Jul 2005	
75	Tadjikistan	Babilon Mobile OAO		In Service	Jun 2005	
76	Tadjikistan	TT Mobile		In Service	Jun 2005	
77	UAE	Etisalat		In Service	Jan 2004	
78	UK	Hutchison 3G	3	In Service	Mar 2003	
79	UK	O2		In Service	Mar 2005	
80	UK	Orange		In Service	Dec 2004	
81	UK	Vodafone		In Service	Nov 2004	
82	USA	Cingular Wireless		In Service	Jul 2004	

Pre-commercial Networks						
1	Australia	Optus		Pre-commercial	Oct 2005	
2	Belgium	Belgacom Mobile	Proximus	Pre-commercial		Q3 2005
3	Croatia	VIPnet		Pre-commercial		Q3 2005
4	Hungary	Pannon		Pre-commercial		Q4 2005
5	Monaco	Monaco Telecom		Pre-commercial		Q4 2005
6	Poland	Polska Telefonia Cyfrowa		Pre-commercial		Q4 2005
7	Switzerland	TDC Switzerland	sunrise	Pre-commercial		Q3 2005
8	Taiwan	Taiwan Mobile Comp.		Pre-commercial		Q3 2005
9	UK	T-Mobile		Pre-commercial		Q4 2005
Networks Planned/In Deployment						
1	Andorra	STA		Planned/In Deployment		Dec 2005
2	Australia	Vodafone		Planned/In Deployment		Oct 2005
3	Belgium	BASE	Orange	Planned/In Deployment		Q3 2005
4	Belgium	Mobistar		Planned/In Deployment		Q2 2005
5	Bulgaria	BTC		Planned/In Deployment		Q4 2005
6	Bulgaria	Cosmo Bulgaria Mobile		Planned/In Deployment		Q4 2006
7	Bulgaria	MobilTel		Planned/In Deployment		Q4 2006
8	Croatia	T-Mobile		Planned/In Deployment		Q1 2006
9	Croatia	Tele2		Planned/In Deployment		Q4 2005
10	Cyprus	Areeba		Planned/In Deployment		Q4 2005
11	Cyprus	CYTA		Planned/In Deployment		Q4 2005
12	Czech Republic	Eurotel Praha		Planned/In Deployment		Q1 2007
13	Czech Republic	Oskar Mobil		Planned/In Deployment		Q3 2007
14	Czech Republic	T-Mobile		Planned/In Deployment		Q1 2007
15	Denmark	TDC Mobil		Planned/In Deployment		Q3 2005
16	Denmark	Telia Denmark		Planned/In Deployment		Q2 2005
17	Estonia	Elisa		Planned/In Deployment		Q4 2006
18	Estonia	EMT		Planned/In Deployment		Q1 2006
19	Estonia	Tele2		Planned/In Deployment		Q4 2006
20	Fiji	Vodafone Fiji		Planned/In Deployment		Q1 2007
21	Finland	Finnish 2G	DNA Finland	Planned/In Deployment		Dec 2005
22	Finland - Republic of Åland	Alands Mobiltelefon		Planned/In Deployment		Q3 2005
23	Finland - Republic of Åland	Song Networks		Planned/In Deployment		Q3 2005
24	France	Bouygues Telecom		Planned/In Deployment		Q2 2006
25	Hungary	Vodafone		Planned/In Deployment		Jan 2006
26	India	Aircel		Planned/In Deployment		Sep 2006
27	India	Bharti Cellular		Planned/In Deployment		Sep 2006
28	India	BPL Cellular		Planned/In Deployment		Sep 2006
29	India	BSNL		Planned/In Deployment		Sep 2006
30	India	Dishnet Wireless		Planned/In Deployment		Dec 2006
31	India	Essar Spacetel		Planned/In Deployment		Sep 2007
32	India	Hutchison Max		Planned/In Deployment		Sep 2006
33	India	Idea Cellular		Planned/In Deployment		Sep 2006
34	India	MTNL		Planned/In Deployment		Sep 2006

35	India	Reliance Telecom		Planned/In Deployment		Dec 2006
36	India	Spice Telecom		Planned/In Deployment		Sep 2006
37	Indonesia	Cyber Access		Planned/In Deployment		Q1 2006
38	Isle of Man	Manx Telecom		Planned/In Deployment		Nov 2005
39	Latvia	Bité		Planned/In Deployment		Q1 2006
40	Libya	El Madar Tel. Company		Planned/In Deployment		Q1 2005
41	Libya	Libyana		Planned/In Deployment		Q1 2006
42	Liechtenstein	Orange		Planned/In Deployment		Q4 2005
43	Liechtenstein	Tele2	Tango	Planned/In Deployment		Q2 2005
44	Malta	TBA		Planned/In Deployment		Q4 2006
45	Malta	MobIsle Communications	go mobile	Planned/In Deployment		Q4 2006
46	Malta	Vodafone		Planned/In Deployment		Q1 2006
47	Mauritius	Cellplus Mobile Communications		Planned/In Deployment		Q4 2005
48	Netherlands	Orange		Planned/In Deployment		Q3 2005
49	Netherlands	T-Mobile Netherlands		Planned/In Deployment		Q2 2005
50	Netherlands	Telfort		Planned/In Deployment		Q4 2005
51	New Zealand	TelstraClear		Planned/In Deployment		Q4 2005
52	Norway	Hi3G Access Norway		Planned/In Deployment		Q4 2005
53	Poland	Centertel		Planned/In Deployment		Q4 2005
54	Poland	Netia		Planned/In Deployment		Q2 2006
55	Qatar	Q-TEL		Planned/In Deployment		Q3 2005
56	Romania	Orange Romania		Planned/In Deployment		Q2 2006
57	Saudi Arabia	Etisalat		Planned/In Deployment		Q1 2006
58	Slovak Republic	Orange		Planned/In Deployment		Q1 2006
59	Slovak Republic	T-Mobile		Planned/In Deployment		Q1 2006
60	Sudan	Bashair Telecom		Planned/In Deployment		Q4 2005
61	Taiwan	VIBO		Planned/In Deployment		Q2 2005
Licenses Awarded						
1	Georgia	Magticom		License Awarded		Q4 2009
2	Italy	Ipse 2000		License Awarded		
3	Saudia Arabia	Saudi Telecom Comp.		License Awarded		Q4 2006
4	Spain	Xfera		License Awarded		Q3 2005
5	Switzerland	Team 3G		License Awarded		
6	Thailand	CAT		License Awarded		Q4 2006
7	Thailand	TOT		License Awarded		Q4 2006
Networks in Trial						
1	Algeria	Algérie Télécom		Trial		
2	Brunei	B-mobile Communicaitons		Trial		Q1 2006
3	China - Beijing	Beijing Mobile		Trial		
4	China - Beijing	Beijing Netcom		Trial		
5	China - Beijing	CATT		Trial	Dec 2000	
6	China - Beijing	China Tietong		Trial		
7	China - Guangdong	Guangdong Mobile		Trial		
8	China - Guangdong	Guangdong Telecom		Trial		
9	China - Guangdong	Guangdong Unicom		Trial		
10	China - Shanghai	China Tietong		Trial		
11	China - Shanghai	Shanghai Netcom		Trial		
12	China - Shanghai	Shanghai Telecom		Trial		

13	China - Shanghai	Shanghai Unicom		Trial		
14	French Polynesia	Tikiphone		Trial	Sep 2005	
15	Indonesia	Telkomsel		Trial		Jun 2006
16	Kuwait	MTC		Trial		
17	Vietnam	MobiFone		Trial		
18	Vietnam	VinaPhone		Trial		
Potential License						
1	Belgium	-tba-		Potential License		Q4 2008
2	Bulgaria	-tba-		Potential License		Q4 2009
3	Egypt	-tba-		Potential License		Q4 2007
4	Estonia	-tba-		Potential License		Q4 2008
5	France	-tba-		Potential License		Q4 2008
6	Hungary	-tba-		Potential License		Q1 2007
7	Lithuania	-tba-		Potential License		Q2 2007
8	Lithuania	-tba-		Potential License		Q2 2007
9	Lithuania	Omnitel		Potential License		Q2 2007
10	Montenegro	-tba-		Potential License		Q1 2007
11	Montenegro	-tba-		Potential License		Q1 2007
12	Montenegro	-tba-		Potential License		Q1 2007
13	Morocco	-tba-		Potential License		Q4 2007
14	Morocco	Tba		Potential License		Q4 2007
15	Pakistan	Paktel		Potential License		Dec 2007
16	Pakistan	PMCL		Potential License		Dec 2007
17	Pakistan	PTML		Potential License		Dec 2007
18	Pakistan	Telenor		Potential License		Dec 2007
19	Pakistan	Warid Telecom		Potential License		Dec 2007
20	Philippines	-tba-		Potential License		Mar 2007
21	Philippines	Globe Telecom		Potential License		Mar 2007
22	Philippines	Smart Communications		Potential License		Mar 2007
23	Romania	-tba-		Potential License		Q3 2007
24	Romania	-tba-		Potential License		Q3 2007
25	Russia	-tba-		Potential License		Q1 2007
26	Russia	-tba-		Potential License		Q1 2007
27	Russia	-tba-		Potential License		Q1 2007
28	Saudi Arabia	-tba-		Potential License		Q2 2007
29	Serbia	-tba-		Potential License		Q4 2006
30	Singapore	-tba-		Potential License		Q1 2009
31	Slovenia	-tba-		Potential License		Q2 2007
32	Slovenia	-tba-		Potential License		Q2 2007
33	Turkey	-tba-		Potential License		Q4 2006
34	Turkey	-tba-		Potential License		Q4 2006
35	Turkey	-tba-		Potential License		Q4 2006
36	Turkey	-tba-		Potential License		Q4 2006
37	UAE	-tba-		Potential License		Q3 2006
38	Ukraine	-tba-		Potential License		Q4 2008
Licenses Revoked/Sold						
1	Austria	3G Mobile		License Revoked/Sold		Q4 2003
2	Denmark	Telia Denmark		License Revoked/Sold		Q4 2004

3	Finland	Finnish 3G		License Revoked/Sold		Q3 2005
4	Germany	Group 3G	Quam	License Revoked/Sold		
5	Germany	MobilCom Multimedia		License Revoked/Sold		
6	Luxembourg	Orange		License Revoked/Sold		Q1 2005
7	Norway	Broadband Mobile		License Revoked/Sold		
8	Norway	Tele2 Norway		License Revoked/Sold		
9	Portugal	OniWay		License Revoked/Sold		
10	Slovak Republic	Profinet		License Revoked/Sold		
11	Sweden	Orange Sweden		License Revoked/Sold		Dec 2004

In Service: Operator has commercially launched its network to both consumer and enterprise market, with handsets available in retail outlets.
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.
Planned/in deployment: Licensee is in planning stages of deploying network or is actually building the network.
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.
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.
License Revoked/Surrendered: Licensee/operator involuntarily/voluntarily hands back license.
Potential License: Small level of speculation. Government policy or privatization process indicates that licensing opportunity may become available.

Appendix C: Global EDGE Network Status

Data as of September 6, 2005:

Region	Country	Operator	Commercial	Frequency	Status
Outside	Algeria	Orascom Télécom Algérie		900	In Deployment
Americas	Anguilla	Cingular Wireless Anguilla / Digicel		900/1900	Planned
Americas	Anguilla	Cable & Wireless		850	Planned
Americas	Antigua & Barbuda	Cable & Wireless		850	Planned
Americas	**Argentina**	**CTI Movil**	**Mar-04**	**1900**	**In Service**
Americas	**Argentina**	**Telecom Personal**	**Dec-04**	**1900**	**In Service**
Americas	**Argentina**	**Telefonica Movistar**	**Mar-05**	**1900**	**In Service**
Americas	Argentina	Unifon		1900	Planned
Outside	Australia	Telstra		900/1800	Planned
Outside	**Austria**	**Mobilkom Austria**	**May-05**	**900/1800**	**In Service**
Americas	Bahamas	Bahamas Telecommunications Company (BTC)		1900	In Deployment
Outside	Bahrain	Batelco		900/1800	In Deployment
Outside	**Bahrain**	**MTC Vodafone**	**Jan-04**	**900**	**In Service**
Outside	Bangladesh	GrameenPhone		900	In Deployment
Americas	**Barbados**	**Cingular Wireless Barbados / Digicel** (Cellular Communications Barbados)	**Sep-04**	**900/1900**	**In Service**
Americas	Barbados	Cable & Wireless		850	Planned
Outside	Belgium	BASE		1800	Planned
Outside	Belgium	Mobistar		900/1800	Planned
Americas	**Bermuda**	**Cingular Wireless Bermuda / Digicel** [Telecommunications Ltd. (Bermuda & West Indies)]	**Nov-03**	**1900**	**In Service**
Americas	Bermuda	BTC Mobility		1900	Planned
Americas	**Bolivia**	**Movil de Entel**	**Aug-04**	**1900**	**In Service**
Americas	Bolivia	Nuevatel (Viva PCS)		1900	In Deployment
Outside	**Bosnia Herzegovina**	**Mobilna Srpska**	**Aug 05**	**900**	**In Service**
Outside	Botswana	Mascom		900	Planned
Americas	Brazil	Amazonia Celular		900/1800	EDGE-Capable
Americas	**Brazil**	**Brasil Telecom GSM**	**Apr-05**	**900/1800**	**In Service**
Americas	**Brazil**	**Claro/Telecom Americas**	**Mar-04**	**1800**	**In Service**
Americas	Brazil	CTBC		1800	EDGE-Capable
Americas	Brazil	Oi		1800	In Deployment
Americas	**Brazil**	**Telemig Celular**	**Nov-04**	**900/1800**	**In Service**
Americas	**Brazil**	**TIM Brasil**	**Jun-04**	**1800**	**In Service**
Americas	British Virgin Islands	CCT Boatphone		800/1900	Planned
Outside	**Brunei**	**DataStream Technology**	**Dec-04**	**900**	**In Service**
Outside	Bulgaria	BTC Bulgaria	*Apr-05*	900/1800	In Deployment
Outside	**Bulgaria**	**MobilTel**	**Mar-05**	**900**	**In Service**
Americas	**Canada**	**Rogers Wireless/Microcell**	**Jun-04**	**850/1900**	**In Service**
Americas	**Cayman Islands**	**Cingular Wireless Cayman /Digicel**	**1Q-04**	**850/1900**	**In Service**
Americas	Cayman Islands	Cable & Wireless		1900	Planned
Americas	**Chile**	**Entel Movil (Entel PCS)**	**Aug-04**	**1900**	**In Service**
Americas	**Chile**	**Telefonica Movil**	**Oct-03**	**1900**	**In Service**

Outside	**China**	**China Mobile**	**May-05**	**900/1800**	**In Service**
Outside	China	China Unicom		900	Trial
Americas	Colombia	Colombia Movil (OLA)		850/1900	In Deployment
Americas	**Colombia**	**Comcel**	**Apr-05**	**850/1900**	**In Service**
Outside	**Croatia**	**VIPNet**	**Apr-04**	**900**	**In Service**
Outside	**Croatia**	**T-Mobile – Cronet**	**Jun-04**	**900**	**In Service**
Outside	Cyprus	Investcom (Scancom)		900	In Deployment
Outside	**Czech Republic**	**EuroTel Praha**	**Mar-05**	**900/1800**	**In Service**
Outside	**Czech Republic**	**T-Mobile**	**Nov-04**	**900/1800**	**In Service**
Outside	**Czech Republic**	**Oskar Mobil (Cesky Mobil)**	**Mar-05**	**900/1800**	**In Service**
Outside	Denmark	Sonofon		900	Planned
Americas	Dominica	Cable & Wireless		850	Planned
Americas	Ecuador	America Movil (Conecel dba Porta)		850	In Deployment
Outside	**Estonia**	**EMT**	**Jun-04**	**900/1800**	**In Service**
Outside	**Faroe Islands**	**Faroese Telecom Ltd.**	**Dec-04**	**900**	**In Service**
Outside	**Finland**	**Ålands Mobiltelefon AB**	**Mar-05**	**900/1800**	**In Service**
Outside	**Finland**	**Elisa**	**Jul-05**	**900/1800**	**In Service**
Outside	Finland	Finnet/DNA Finland		900/1800	Trial
Outside	**Finland**	**TeliaSonera**	**Dec-03**	**900/1800**	**In Service**
Outside	**France**	**Bouygues Telecom**	**May-05**	**900/1800**	**In Service**
Outside	**France**	**Orange**	**Apr-05**	**900/1800**	**In Service**
Americas	French West Indies	Cingular Wireless FWI / Digicel		1800	Planned
Outside	Ghana	Scancom		900	In Deployment
Outside	Greece	TIM Hellas		900	EDGE-Capable
Americas	Grenada	Cable & Wireless		850	Planned
Americas	Guatemala	Sercom		1900	Planned
Americas	Guyana	Cel Star		900	Planned
Outside	**Hong Kong (China)**	**New World Mobility**	**Sep-04**	**1800**	**In Service**
Outside	**Hong Kong (China)**	**CSL**	**Sep-03**	**900/1800**	**In Service**
Outside	**Hong Kong (China)**	**Peoples**	**Aug-04**	**1800**	**In Service**
Outside	Hong Kong (China)	Sunday		1800	Trial
Outside	**Hungary**	**Pannon**	**Feb-05**	**900/1800**	**In Service**
Outside	**Hungary**	**T-Mobile (Westel)**	**Oct-03**	**900/1800**	**In Service**
Outside	**India**	**AirTel (Bharti Tele-Ventures)**	**Jul-04**	**900/1800**	**In Service**
Outside	India	BSNL (Bharat Sanchar Nigam Ltd.		900/1800	Planned
Outside	India	Dishnet Wireless Limited		1800	Planned
Outside	**India**	**Hutchinson Max**	**Jul-04**	**900/1800**	**In Service**
Outside	**India**	**IDEA Cellular**	**Jul-04**	**900/1800**	**In Service**
Outside	Indonesia	Indosat		900/1800	In Deployment
Outside	**Indonesia**	**Telkomsel**	**Feb-04**	**900/1800**	**In Service**
Outside	Ireland	Meteor		900/1800	Planned
Outside	**Israel**	**CellCom Israel**	**Jun-04**	**1800**	**In Service**
Outside	**Italy**	**TIM Italy**	**May-04**	**1800**	**In Service**
Outside	Italy	WIND		900/1800	Planned
Americas	Jamaica	Cingular Wireless Jamaica / Digicel		1900	Planned
Americas	Jamaica	Cable & Wireless		1900	Planned
Outside	**Jordan**	**Mobilcom**	**Jun-04**	**900**	**In Service**
Outside	**Jordan**	**Umniah**	**Jun-05**	**1800**	**In Service**

Outside	**Kazakhstan**	**GSM Kazakhstan**	**Dec-04**	**900**	**In Service**
Outside	Kazakhstan	Kar-Tel		900	EDGE-Capable
Outside	**Kuwait**	**MTC-Vodafone**	**Sep-04**	**900/1800**	**In Service**
Outside	Kuwait	Wataniya Telecom		900/1800	In Deployment
Outside	Latvia	Bité		1800	In Deployment
Outside	Libya	El Madar Telephone Comp. (Orbit, GPTC)		900	Planned
Outside	**Lithuania**	**Bite GSM**	**Dec-03**	**900/1800**	**In Service**
Outside	**Lithuania**	**Omnitel**	**Aug-04**	**900/1800**	**In Service**
Outside	**Malaysia**	**DiGi**	**May-04**	**1800**	**In Service**
Outside	Malaysia	Maxis Communications Bhd		900/1800	EDGE-Capable
Outside	**Maldives**	**Wataniya Telecom**	**Aug-05**	**900**	**In Service**
Americas	**Mexico**	**Telcel**	**Oct-04**	**1900**	**In Service**
Americas	**Mexico**	**Telefonica Moviles (TMM)**	**Jun-04**	**1900**	**In Service**
Outside	**Moldova**	**Moldcell**	**Jun-05**	**900**	**In Service**
Outside	Montenegro	ProMonte		900	In Deployment
Americas	Montserrat	Cable & Wireless		850	Planned
Outside	**Netherlands**	**Telfort**	**Apr-05**	**1800**	**In Service**
Americas	Netherlands Antilles – Curaçao	Cingular Wireless Curaçao / Digicel		1900	Planned
Outside	**Norway**	**Netcom (TeliaSonera)**	**Dec-04**	**900/1800**	**In Service**
Outside	**Norway**	**Telenor Mobile**	**Sept-04**	**900/1800**	**In Service**
Outside	Pakistan	PTML (Ufone)		900	In Deployment
Outside	Pakistan	Telenor		900/1800	Planned
Americas	**Paraguay**	**Personal / Núcleo**	**Oct-04**	**850**	**In Service**
Americas	**Paraguay**	**Telecel (Tigo)**	**Jun-04**	**850**	**In Service**
Americas	Peru	TIM Peru		1900	In Deployment
Outside	Philippines	Digitel/ Sun Cellular		1800	In Deployment
Outside	**Philippines**	**GLOBE**	**Mar-04**	**900/1800**	**In Service**
Outside	**Philippines**	**SMART (Gold GSM)**	**Feb-04**	**900/1800**	**In Service**
Outside	**Poland**	**Centertel (Idea)**	**Oct-04**	**900/1800**	**In Service**
Outside	**Poland**	**Polkomtel/ Plus GSM**	**Jan-05**	**900/1800**	**In Service**
Outside	**Poland**	**PTC** (Polska Telefonia Cyfrowa -- Era)	**Apr-05**	**900/1800**	**In Service**
Americas	**Puerto Rico**	**Cingular Wireless Puerto Rico**	**Nov-03**	**1900**	**In Service**
Outside	**Réunion**	**SFR Réunion**	**Dec-04**	**900**	**In Service**
Outside	**Romania**	**Orange Romania**	**Oct-04**	**900**	**In Service**
Outside	**Russia**	**Mobikom Kavkaz**	**Jul-05**	**900/1800**	**In Service**
Outside	**Russia**	**Mobile Communications Systems Povolzhie**	**Feb-5**	**900/1800**	**In Service**
Outside	Russia	Mobile TeleSystems (MTS)		900/1800	In Deployment
Outside	Russia	SMARTS		900/1800	EDGE-Capable
Outside	Russia	STeK		900	In Deployment
Outside	Russia	Uralsvyazinform		900/1800	In Deployment
Outside	**Russia**	**Vimpelcom (Bee Line GSM)**	**Dec-04**	**900/1800**	**In Service**
Outside	Russia (Siberia)	CTeK GSM		900	Planned
Outside	**Saudi Arabia**	**Etisalat**	**Apr-05**	**900**	**In Service**
Outside	**Serbia**	**Mobtel Srbija**	**Sep-04**	**900**	**In Service**
Outside	Serbia	Telekom Srbija/YUG 03		900	In Deployment

Outside	**Slovak Republic**	**EuroTel Bratislava (T-Mobile)**	**Jun-04**	**900/1800**	**In Service**
Outside	**Slovak Republic**	**Orange Slovensko (Orange SK)**	**Jan-05**	**900/1800**	**In Service**
Outside	**Slovenia**	**Si.Mobil – Vodafone**	**Mar-04**	**900/1800**	**In Service**
Outside	South Africa	Cell C		1800	In deployment
Outside	**South Africa**	**MTN**	**Apr-05**	**900**	**In Service**
Outside	**Sri Lanka**	**Dialog GSM / MTN Networks**	**Mar-04**	**1800**	**In Service**
Outside	**Sri Lanka**	**Mobitel**	**Jan-04**	**1800**	**In Service**
Americas	St. Kitts & Nevis	Cingular Wireless St. Kitts & Nevis / Digicel		900/1900	Planned
Americas	St. Kitts & Nevis	Cable & Wireless		850	Planned
Americas	St. Lucia	Cingular Wireless St. Lucia / Digicel		900/1900	Planned
Americas	St. Lucia	Cable & Wireless		850	Planned
Americas	St. Vincent & Grenadines	Cable & Wireless		850	Planned
Outside	**Sweden**	**TeliaSonera Sweden**	**Jan-05**	**900/1800**	**In Service**
Outside	**Switzerland**	**Swisscom Mobile**	**Mar-05**	**900/1800**	**In Service**
Outside	Switzerland	TDC Switzerland (sunrise)		900/1800	In deployment
Outside	**Thailand**	**AIS**	**Oct-03**	**900**	**In Service**
Outside	Thailand	DTAC		1800	In Deployment
Outside	Thailand	TA Orange		1800	In Deployment
Americas	Trinidad & Tobago	TSTT		1800	Planned
Outside	Turkey	Avea		1800	In Deployment
Outside	**Turkey**	**Turkcell**	**Mar-05**	**900**	**In Service**
Americas	Turks & Caicos	Cable & Wireless		850	Planned
Outside	UK	Orange		900-1800	Planned
Outside	**Ukraine**	**DCC/Astelit**	**Mar-05**	**1800**	**In Service**
Outside	Ukraine	Kyivstar GSM		900/1800	In Deployment
Americas	**Uruguay**	**ANTEL/ANCEL**	**Jan-05**	**1800**	**In Service**
Americas	**US Virgin Islands**	**Cingular Wireless Virgin Islands / Digicel**	**2Q-04**	**1900**	**In Service**
Americas	USA	Cellular One of Amarillo		850	Planned
Americas	USA	Cellular One of NE Arizona		1900	In Deployment
Americas	USA	Centennial Wireless		800	Planned
Americas	**USA**	**Cincinnati Bell Wireless**	**Feb-05**	**1900**	**In Service**
Americas	**USA**	**Cingular Wireless**	**Jun-03**	**850/1900**	**In Service**
Americas	USA	Corr Wireless Communications		800/1900	Planned
Americas	**USA**	**Dobson Communications**	**Oct-04**	**850/1900**	**In Service**
Americas	**USA**	**EDGE Wireless**	**Oct-04**	**1900**	**In Service**
Americas	**USA**	**PSC Wireless**	**Feb-05**	**850**	**In Service**
Americas	**USA**	**Rural Cellular Corporation**	**Feb-05**	**1900**	**In Service**
Americas	**USA**	**T-Mobile USA**	**Sep-05**	**1900**	**In Service**
Americas	**USA**	**Triton PCS**	**Sep-04**	**1900**	**In Service**
Americas	**USA**	**Viaero (NECCI)**		**800/1900**	**In Service**
Americas	USA	Western Wireless		800/1900	Planned
Americas	USA	Westlink (Kansas)		1900	In Deployment
Americas	**Venezuela**	**Digitel**	**Oct-04**	**900**	**In Service**

Outside	Vietnam	MobiFone (VMS/Vietnam Posts & Telecommunications Corp.)	*(Dec-05)*	900	Planned
Outside	Vietnam	Vinaphone (GPC - Vietnam Telecom Services Company/VNPT)		900	Planned
Outside	Vietnam	Viettel		900	EDGE-Capable
Outside	Yemen	SabaFon		900	Planned

Source: Information compiled by 3G Americas from Informa Telecoms & Media, WCIS and public company announcements - September 2005

Status:
In Service: Operator has commercially launched EDGE in its network to consumer/enterprise market, with handsets/data cards available in retail outlets.
In Deployment: Operator has deployed EDGE in its GSM network but has not commercially launched EDGE.
Planned: Operator is in the planning stages of deploying EDGE.
Trial: Operator is conducting a network trial for EDGE.
EDGE-capable: Operator's GSM network is currently equipped to enable EDGE technology through an upgrade.