RYSAVY RESEARCH

DATA CAPABILITIES FOR GSM EVOLUTION TO UMTS

November 19, 2002

White Paper developed for

3G americas

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1-541-386-7475

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Introduction

Wireless data has the potential to produce significant new revenues for cellular operators. Applications include short message service, multimedia messaging, wireless application protocol (WAP) applications, streaming media, mobile office, e-mail, and workforce automation. The widespread launch of next-generation cellular-data services in 2002 has set the stage for broad adoption, especially with user awareness increasing, choices of terminal equipment expanding, coverage becoming ubiquitous, and application and content becoming optimized for wireless access. Use of wireless data, which constituted 500 million dollars of revenue in the United States in 2001[1], is expected to grow tenfold over the next five years. In Europe, leading operators are reporting fifteen percent of revenues from data, with strong growth momentum. In Japan, NTT DoCoMo's popular I-mode service using a relatively slow packet data network is used by 76% of its customers and generated 18.5% of the company's overall revenues in early 2002. For this year, the GSM Association predicts over 360 billion SMS messages will be sent. For the future, the UMTS Forum Report 17 of February 2002 predicts service revenue from 3G networks of $320 billion in 2010, $233 billion of which will be generated by new mobile data services.

Success of wireless data has thus far been limited to specific areas, including SMS, I-mode in Japan, and wireless LANs in the US. However, a number of important trends will ultimately make wireless data as significant as wireless voice. First, computing itself is becoming ever more mobile, and notebooks and PDAs are prevalent. With the miniaturization of electronics, mobile telephones are becoming powerful computing platforms. Second, lifestyles and work styles are becoming increasingly mobile, with a mounting percentage of the population traveling for work, pleasure, or in retirement. Third, the Internet is becoming progressively more intertwined in the

[1] Source: CTIA.

fabric of people's lives, providing communications, information, service enhancements for memberships and subscriptions, community involvements, and commerce. In this mix, wireless data is a powerful catalyst for the creation of new services and new business opportunities for operators as well as third-party businesses.

In this new world of Internet anywhere, services like GPRS are just the first step, but a very important step. As the benefits of these services become apparent, as the services themselves become more powerful thanks to higher throughput rates and quality-of-service mechanisms, and as service costs drop due to increased spectral efficiency, use will constantly grow. Data will soon account for an increasing percentage of cellular traffic. Already, data represents more than fifty percent of traffic of worldwide telecom networks, and the trends cited above will create similar usage rates for wireless data.

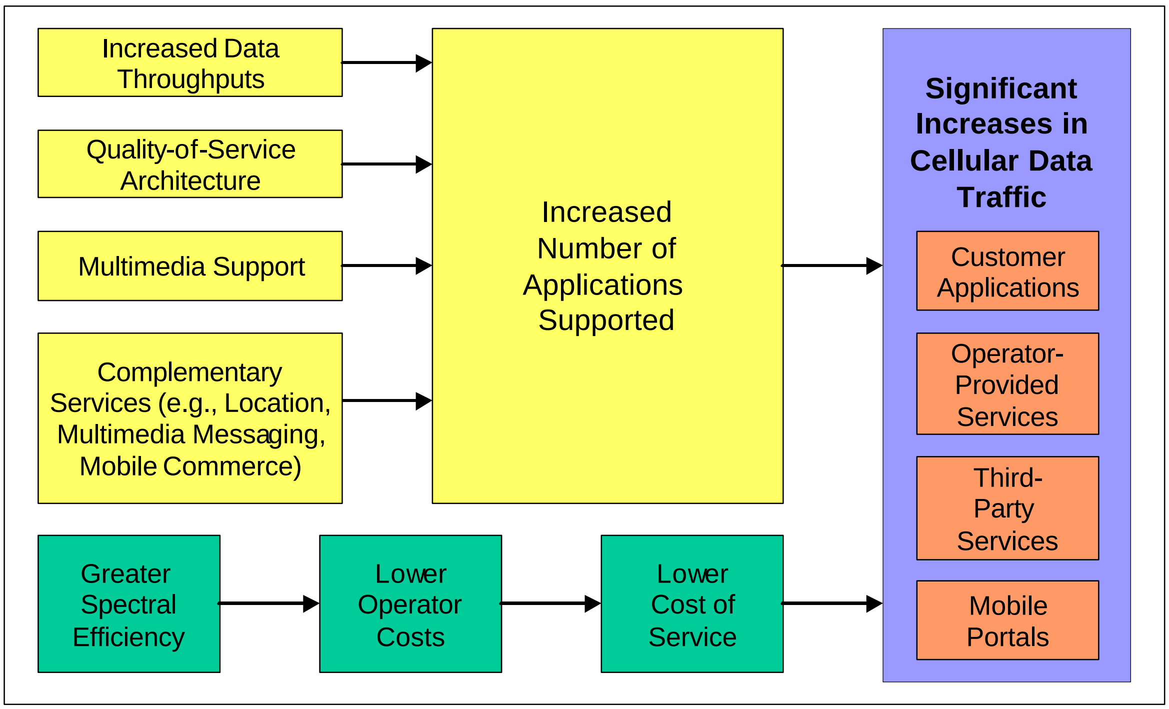

Figure 1: Growth Factors for Wireless Data

With data constituting a rising percentage of total cellular traffic, it is essential that operators deploy data technologies that meet customer requirements for performance and that are spectrally efficient, especially as data applications can demand significant network resources. Operators have a huge investment in spectrum and in their networks—data services must leverage these investments. It is only a matter of time before 711 million GSM, 129 million CDMA, and 104 million TDMA second-generation customers[2] migrate to the new generation of wireless data networks. This presents tremendous opportunities and risks to operators as they choose the most commercially viable evolution path for migrating their customers.

The GSM evolution to the Universal Mobile Telecommunications System (UMTS) not only supports a broad range of data services, but it does so with minimum new investment and in a

[2] June 2002 subscriber estimates.

spectrally efficient fashion that maximizes revenue and profit potential. As the wireless data market evolves, users will demand increased capabilities, such as higher throughputs, quality-of-service controls, and multimedia support. The GSM evolution to UMTS satisfies this need through a series of continual enhancements.

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

- General Packet Radio Service (GPRS) offers a sophisticated always-on IP service for GSM networks and supports a wide range of enterprise and consumer applications.
- EDGE doubles GPRS capacity and triples data throughputs.
- As one of the first cellular technologies to feature adaptive modulation and coding schemes and incremental redundancy, EDGE is spectrally more efficient for lower data rates (below 100 Kbit/s) than GPRS, WCDMA, and CDMA2000 1XRTT.
- EDGE can readily be deployed in spectrum that operators are using for GSM and GPRS, and in many cases it requires no additional hardware. EDGE traffic can share both spectrum and the transceiver timeslot resources with speech and GPRS traffic.
- WCDMA is spectrally more efficient for high-data throughput services than EDGE and CDMA2000 1XRTT. It offers high peak rates, multimedia support, (e.g., conversational video) and advanced quality of service, and is also cost-efficient for high-traffic deployments.
- EDGE and WCDMA radio access networks can be combined in one seamless network to provide efficient narrowband and wideband data capabilities, using the same quality-of-service architecture.
- High Speed Downlink Packet Access (HSDPA) offers the highest data-throughput rates of any cellular-data technology specified, with peak rates of 10 Mbit/s.
- With the UMTS Multi-radio network, a common core network supports GSM, GPRS, EDGE, WCDMA, and HSDPA, 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, improved multimedia support, and integration with wireless LAN technology.

This white paper first describes the data capabilities and data mechanisms of GPRS, EDGE, and UMTS, including the efficiency of the data services. Topics include radio technology, the core network, and key features. The paper then quantifies performance and capacity of these services. Finally, the paper describes how operators can evolve their networks from GSM to UMTS. This paper also contrasts capabilities with those of other cellular technologies.

Technology Capabilities

The GSM migration from second-generation to third-generation technology incorporates constant enhancement in capability and efficiency. This progression enables an increasing number of applications, both due to performance and lower usage costs. Second-generation cellular data support is limited to basic data applications, such as messaging, text-based e-mail, and download of ring tones, and it lacks adequate connectivity for efficient Internet access. The addition of GPRS makes a new world of applications feasible, including enterprise applications, web browsing, consumer applications, and some multimedia applications. EDGE expands the capability of GPRS, enabling richer Internet browsing, streaming applications, a greater scope of enterprise applications, and more multimedia applications. With UMTS and HSDPA, users can look forward to video phones, high-fidelity music, rich multimedia applications, and extremely effective access to their organizations. The broadening scope of supported applications will stimulate higher customer demand and usage, and thus higher revenue for operators.

In assessing the potential applications of cellular-data services, it is helpful to note the approximate throughput requirements for different applications. These are as follows:

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

In looking at these, one can see that GPRS already meets the requirements of many applications. 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 developers will develop more mobile content and new mobile 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.

It should be noted that it is challenging to predict just what applications will drive the wireless data market, and what their exact bandwidth requirements are. Note the wide range of bandwidths suggested in the bulleted list above for different applications. It is also not clear whether consumer applications will have greater bandwidth requirements than business applications, though this could well be the case if streaming entertainment becomes popular. Given this uncertainty, it is imperative that data services be flexible, have high spectral efficiency, and support a wide variety of applications. The data services in GSM evolution to UMTS provide exactly this capability, as summarized in the following table.

Technology	Benefits
GPRS with coding schemes 1 to 2	IP packet data service delivers effective throughputs of up to 40 Kbit/s.
GPRS with coding schemes 1 to 4	Includes an option for operators to boost speeds of GPRS service by 33%.
EDGE	Third-generation technology effectively triples GPRS data rates and doubles its spectral efficiency.
UMTS	WCDMA radio link supports flexible, integrated voice/data services with peak rates of 2 Mbit/s.
HSDPA	An enhancement to WCDMA and fully backwards compatible, HSDPA will offer peak data rates of 10 Mbit/s, higher than any other cellular-data service.
Quality-of-service	Available for both EDGE and WCDMA, QoS mechanisms support multiple classes of applications.
Multimedia support	A comprehensive multimedia framework enables voice-over-IP and video applications.
WLAN integration	Future networks will integrate cellular networks with WLAN hot spots.

Table 1: Summary of Data Capabilities for GSM to UMTS

This section describes both the capabilities and the inner workings of each of these technologies, while the later section "Evolution Paths from GPRS to UMTS" describes how operators will evolve their networks to enhance data capabilities.

GPRS

GPRS is now available worldwide in over 65 countries, with service from 141 operators with a choice of over 85 handsets[3]. Various analysts predict unit sales of over one hundred million GSM/GPRS devices in 2003, making GPRS the leading next-generation, packet-based 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 throughput rates of up to 48 Kbit/s (80 Kbit/s with GPRS CS3-4)[4] 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.

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[3] As of July, 2002.

[4] Throughput at the radio link control (RLC) layer as delivered to the application. User perceived throughputs depend on file/page size, and are at least 10% lower due to protocol and application effects.

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

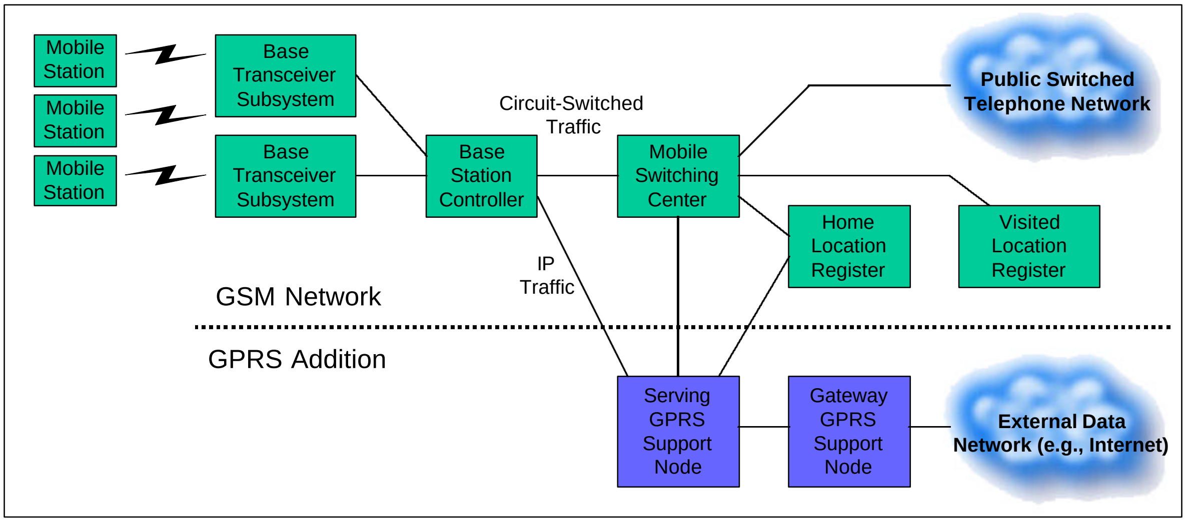

Figure 2: GSM/GPRS Architecture

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

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

Another important element is the home location register (HLR), which stores users' account information for both voice and data service. What is significant is that this same packet infrastructure can be used to support data services in EDGE and WCDMA networks, simplifying operator network upgrades in the future.

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 more voice traffic when data traffic is low, and maximizes the overall use of the network.

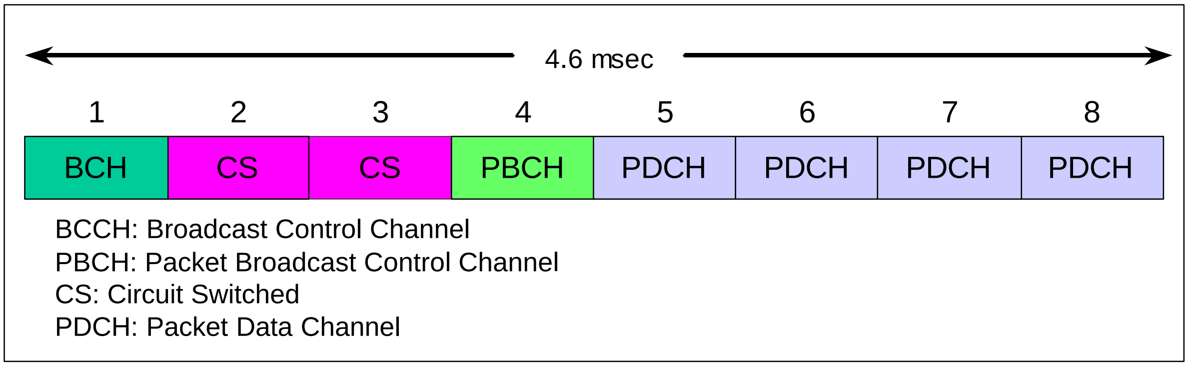

Figure 3: Example of GSM/GPRS Time Slot Structure

With respect to data performance, each data time slot can deliver user data rates of about 10 Kbit/s using coding schemes 1 and 2, and the network can aggregate up to four of these on the downlink with current devices to deliver users perceived data throughputs of up to 40 Kbit/s. 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%[5]. Coding schemes 3 and 4 are an option for operators. To boost GPRS performance and capacity even further, operators can deploy EDGE technology.

EDGE

Enhanced Data Rates for GSM Evolution (or its alternative name Enhanced Data Rates for Global Evolution) is an official 3G cellular technology that can be deployed in 450, 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. It does so by enhancing the radio interface while allowing all the other network elements, including BSC, SGSN, GGSN, and HLR to remain the same. In fact, with new GSM/GPRS deployments, EDGE[6] is a software-only upgrade to the network. A GPRS network using the EDGE radio interface is technically called an Enhanced GPRS (EGPRS) network, and the combination of GSM and EDGE radio access networks is referred to as GERAN. EDGE is fully backwards compatible with GPRS and any application developed for GPRS will work with EDGE.

EDGE employs three advanced techniques in the radio link that allow EDGE to achieve extremely high spectral efficiency for narrowband cellular-data[7] services. The first technique

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

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

[7] *Narrowband data* refers to rates of up to about 100 Kbit/s.

is the addition of a new modulation scheme called Octonary Phase Shift Keying (8-PSK) that allows the radio signal to transmit three bits of information in each radio symbol[8]. In contrast, GSM/GPRS modulation uses Gaussian Minimum Shift Keying (GMSK), which transmits one bit of information per radio symbol. The second technique is multiple coding schemes, where the network can adjust the number of bits dedicated to error control based on the radio environment. EDGE has five coding schemes available for 8-PSK and four coding schemes for GMSK, providing up to nine different modulation and coding schemes. See Table 2. EDGE dynamically selects the optimum modulation and coding scheme for the current radio environment. In the third technique, if blocks of data are received in error, EDGE sends an incremental amount of error-correcting data in each retransmission, making each retransmission more likely to succeed than the prior one. This extremely effective mechanism, which provides an effective link gain of around 2 dB, assures the fastest possible receipt of correct data and is called *incremental redundancy*.

Modulation and Coding Scheme	Modulation	Throughput per Time Slot (Kbit/s)
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

Table 2: EDGE Modulation and Coding Schemes[9]

The resulting throughput per time slot with EDGE can vary from 8.8 Kbit/s under adverse conditions to 59.2 Kbit/s with a very good carrier-to-interference (C/I) ratio. In comparison, GPRS delivers 12 Kbit/s with coding scheme 2 (the most commonly used scheme today) and 20 Kbit/s with the optional coding scheme 4[10]. Though EDGE can theoretically provide 59.2 Kbit/s in each of eight time slots, adding up to a peak network rate of 473.6 Kbit/s in eight time slots, actual user data rates are typically in the 130 to 170 Kbit/s (RLC payload) range with four time-slot devices, more than three times higher than GPRS (using CS1-2).

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

[9] RLC throughputs.

[10] RLC throughputs. Layer 1 throughputs are 13.4 Kbit/s per time slot for CS2 and 21.4 Kbit/s per time slot for CS4.

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

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

Since EDGE benefits from higher C/I, an obvious question is whether the higher rates are available throughout the entire coverage area. The answer is that 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 (Kbit/s 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.

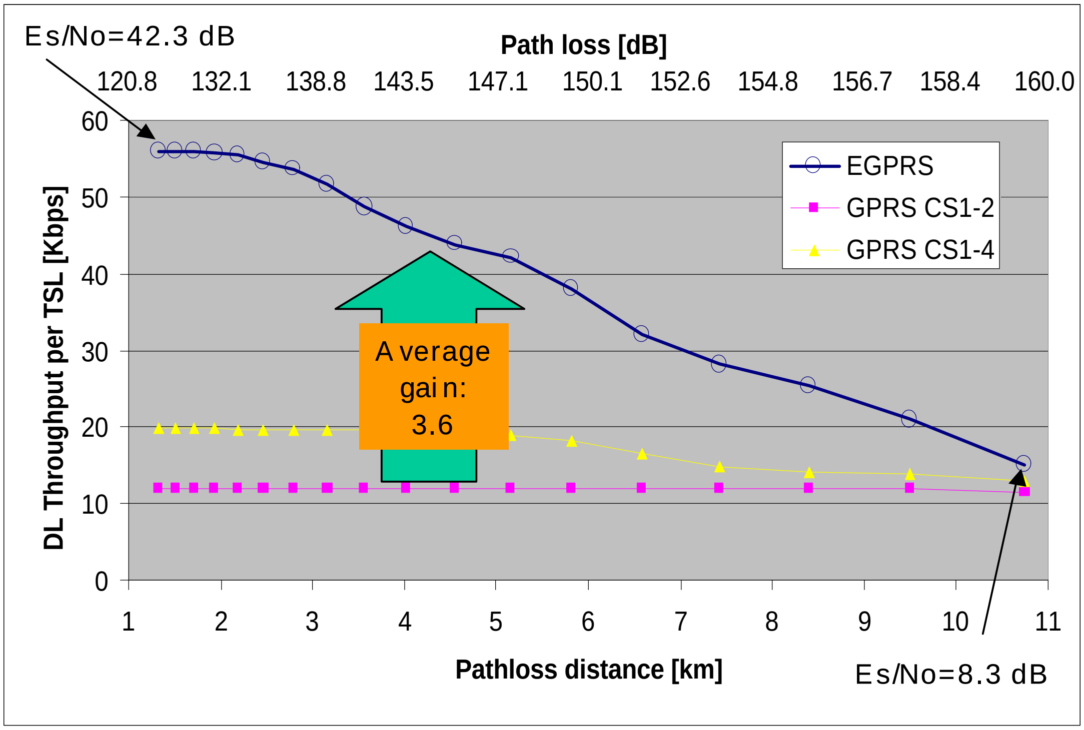

Figure 4: Throughput Versus Distance for EGPRS/EDGE[11]

The second set of curves, as shown in Figure 5, depict throughput per time slot versus C/I:

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

[11] Source Nokia. Coverage limited scenario.

- 15% (in the pink section) experiences a five times performance improvement.

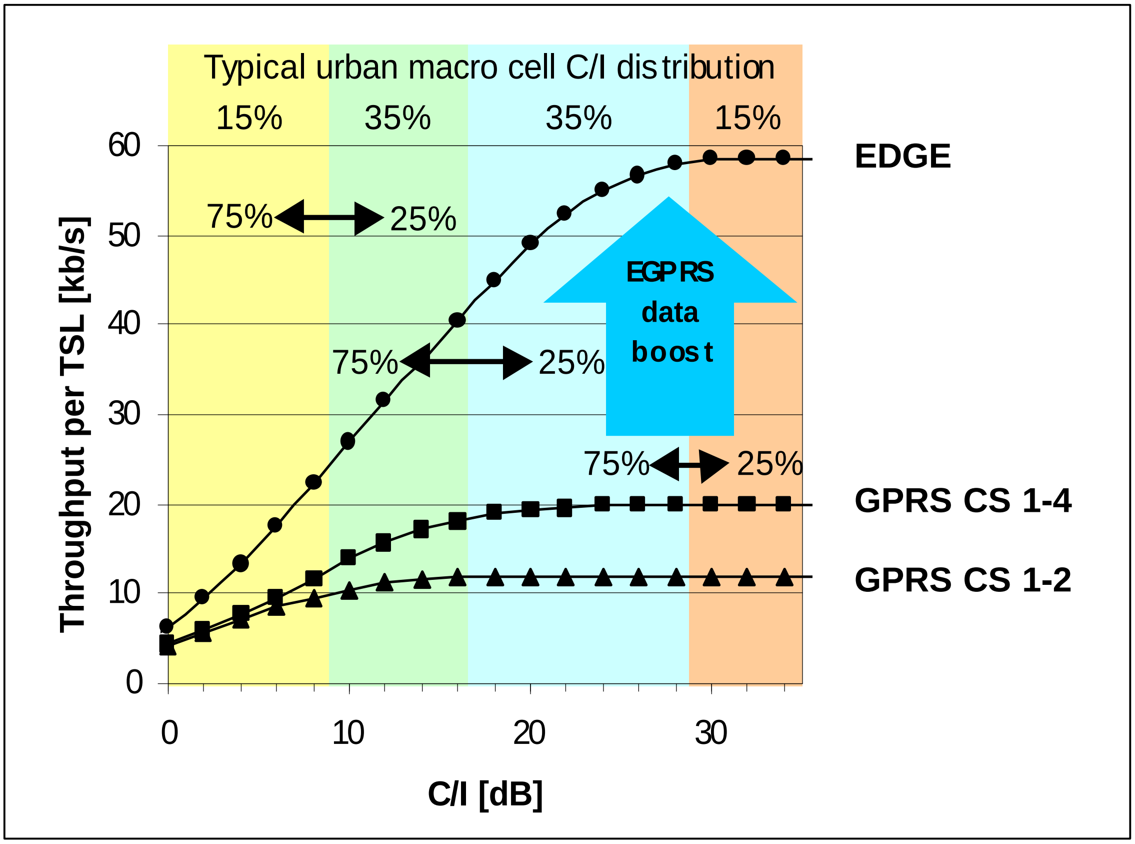

Figure 5: EDGE Performance Improvement over Coverage Area[12]

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

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[12] Source Nokia. 7 Km cell site distance, 1/3 reuse.

[13] 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.

With respect to deployment, the GSM network can allocate GPRS and EDGE time slots in the 5/15 or 4/12 reuse layer[14] (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.

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

UMTS/WCDMA

UMTS has garnered the overwhelming majority of new 3G spectrum licenses, with over 100 carriers worldwide planning on deploying UMTS networks. UMTS employs a wideband CDMA radio-access technology. The primary benefits of UMTS include high spectral efficiency, high user densities, and support for high-bandwidth data applications. Additionally, operators can use a common core network that supports multiple radio access networks, including GSM, GPRS, EDGE, and WCDMA. This common core network uses 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.

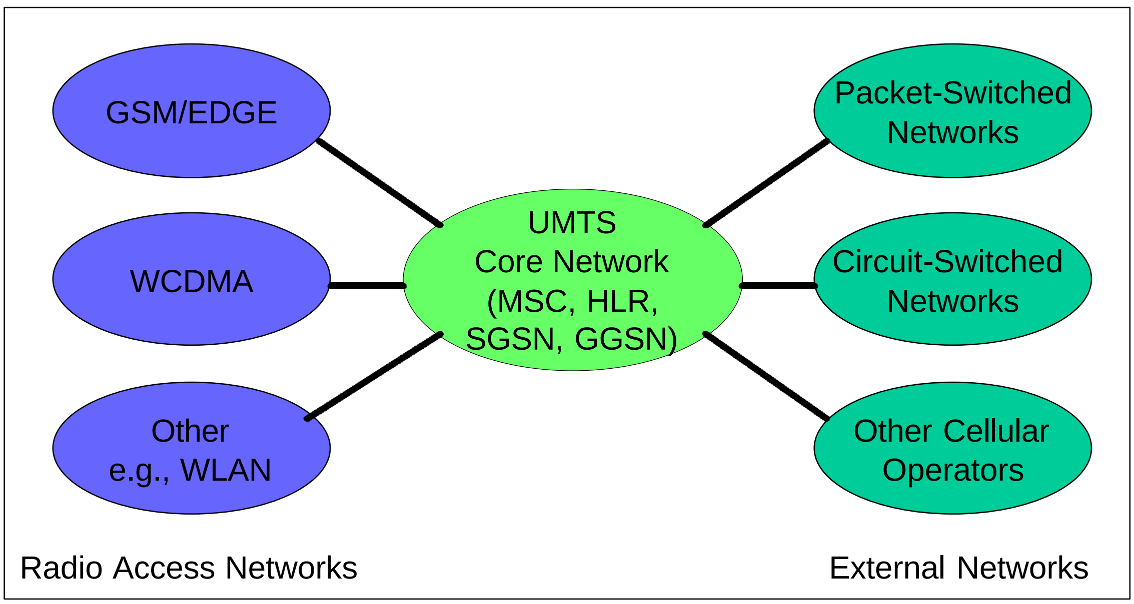

Figure 6: UMTS Multi-Radio Network

The UMTS radio access network consists of radio base stations (corresponding to GSM base transceiver systems) that connect to radio network controllers (corresponding to GSM base

[14] *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.

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

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

In WCDMA, data channels can support up to 2 Mbit/s of data throughput. Though exact throughput depends on what size channels the operator chooses to make available and the number of users active in the network, users can expect throughputs of up to 384 Kbit/s, which will satisfy almost any communications-oriented application.

Whereas EDGE is an extremely efficient technology for supporting low-bandwidth users, WCDMA is extremely efficient for supporting high-bandwidth users (e.g., 100 Kbit/s 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, and maximizing the number of user applications that can be supported.

Relative to CDMA2000, WCDMA has some inherent advantages due to its wider radio channel (5 MHz versus 1.25 MHz.) The higher chip rate (3.84 Mcps versus 1.22 Mcps) can support higher peak data rates and has better statistical traffic averaging, referred to as trunking 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, available for both EDGE and WCDMA radio access networks, 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. To belabor a point, increasing the range of applications drives demand and revenue potential.

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

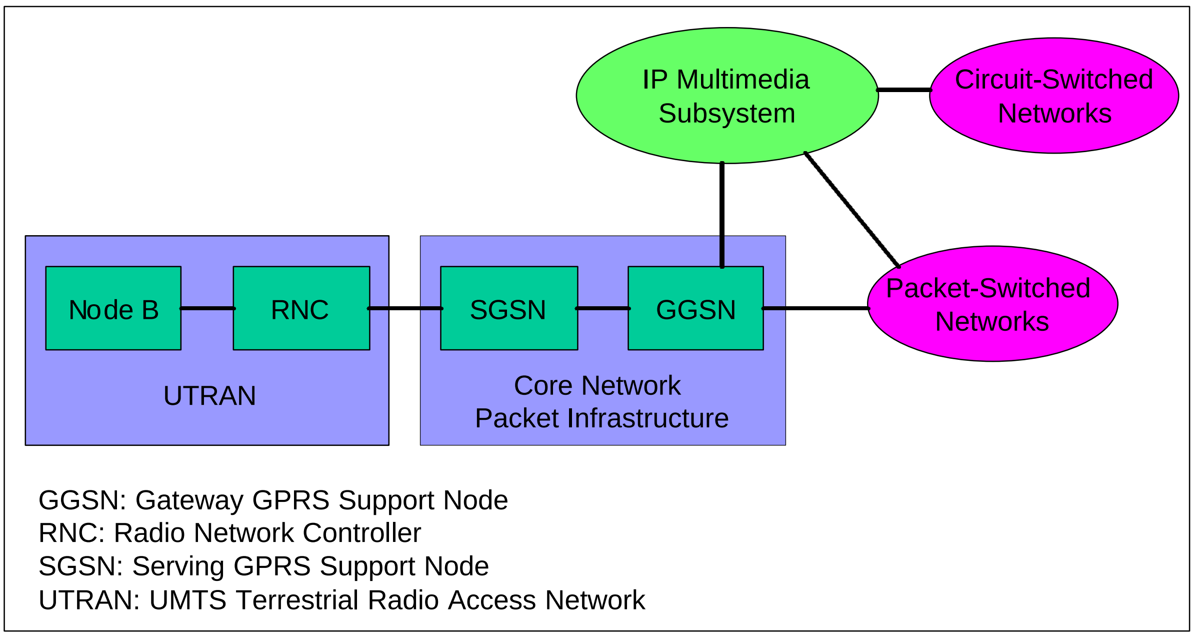

Figure 7: IP Multimedia Subsystem

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

HSDPA

High Speed Downlink Packet Access is an enhancement to WCDMA that delivers a high-performance cellular-data capability with peak rates of about 10 Mbit/s. HSDPA is fully backwards compatible with WCDMA, and any application developed for WCDMA will work with HSDPA. HSDPA is a feature of release 5 of 3GPP specifications.

HSDPA achieves its high speeds through the same techniques that amplify EDGE performance past GPRS. These include the addition of higher order modulation such as 16-QAM, variable error coding, and fast adaptation of the link to current radio conditions, adjusting modulation and coding as necessary. In addition, HSDPA uses an efficient scheduling mechanism to determine which user obtains resources. Finally, HSDPA shares its high-speed channels among users in the time domain, which is the most efficient approach.

HSDPA takes WCDMA to its fullest potential for providing broadband services, and is the highest-throughput cellular-data capability defined. In the same way that EDGE increases spectral efficiency compared to GPRS, so does HSDPA increase spectral efficiency compared to WCDMA. 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, with HSDPA providing over twice the capacity of WCDMA.

Technology Comparisons

Having described the workings of the various technologies, we now turn to a quantitative comparison. There are two fundamental items to examine. One is end-user performance. The other is spectral efficiency, namely the aggregate throughput of the network.

Performance Comparisons

This section quantifies the performance of the different networking technologies. Referring to Table 3, the peak network speed refers to the maximum specified throughput that the network technology can theoretically deliver per carrier, per sector[15], and the average user throughput refers to the typical expected data rates that users will experience with these services. The first important observation is the significant increase in performance going from GPRS to EDGE to UMTS to HSDPA. As shown in Figure 4, EDGE more than triples GPRS (CS 1-2) speeds to yield average perceived throughputs of 110 to 130 Kbit/s. There are further gains with UMTS and HSDPA. The second observation is that though CDMA2000 1XRTT has a temporary throughput advantage over GPRS, EDGE will more than nullify this advantage.

	Peak Network Speed	Average Expected User Throughputs (File Download of 256 Kbytes)
GPRS CS1-2	115 Kbit/s	35 to 40 Kbit/s

[15] Note that the required bandwidth to achieve the maximum throughput is different for each technology.

EDGE	473 Kbit/s	110 to 130 Kbit/s
UMTS	2Mbps	200 to 300 Kbit/s
HSDPA	10 Mbit/s	See footnote [16]
CDMA2000 1XRTT	153 Kbit/s	50-70 Kbit/s
CDMA2000 1XEV-Data Only (DO)[17]	2.4 Mbit/s	See footnote [18]
CDMA2000 1XEV-DV	5 Mbit/s	See footnote [18]

Table 3: Data Performance Comparison of Different Technologies[19]

Spectral Efficiency Comparisons

This section compares the spectral efficiencies of the different technologies discussed in this paper. Figure 8 shows the spectral efficiency in Kbit/s per MHz per sector versus average user throughput in Kbit/s. The Y axis of the graph shows the maximum load that the network can support for the throughput requirement that is expressed in the X axis. The figure compares EDGE (or EGPRS) versus WCDMA and CDMA2000. This paper chooses these technologies for comparison, as they are the ones that major mobile operators in the Americas have publicly committed to deploy.

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

Relative to WCDMA, simulations show that HSDPA will increase capacity by a further 60% based on a simple “round robin” scheduling scheme. By using a more advanced scheduling scheme such as “proportional-fair scheduling”[20], HSDPA can realize further capacity gains, averaging 40%. In total, the simulations show that relative to WCDMA, HSDPA will increase capacity by at least a factor of two. Similar gains are available for the CDMA2000

[16] User throughputs will depend on many variables, including options chosen by operators and network loading. Any estimates are highly speculative. HSDPA with its increased spectral efficiency will be able to more than double typical WCDMA data rates.

[17] Note that DO is a data-only technology, whereas all the other cellular technologies listed support both data and voice service.

[18] As with HSDPA, user throughputs will depend on many variables, including options chosen by operators and network loading. Any estimates are highly speculative but increased spectral efficiency will allow at least a doubling of typica1 1XRTT data rates.

[19] Source: Rysavy Research. These are expected perceived user throughputs and include protocol overhead.

[20] Scheduling refers to how radio resources are assigned to different users based on total number of users, their demands, and factors such as the quality of their radio signal. Round-robin scheduling gives each user equal time to resources. Proportional-fair scheduling gives priority to devices with a better radio signal. The algorithm takes advantage of short-term variations in the radio channel, while maintaining equivalent long-term throughput for all devices.

evolution. Assuming proportional-fair scheduling, 1XEV-DO (a data-only cellular technology) more than doubles capacity relative to 1XRTT. 1XEV-DV (1X evolution data and voice) increases capacity up to an additional 20%. HSDPA and 1XEV-DV have comparable spectral efficiency.

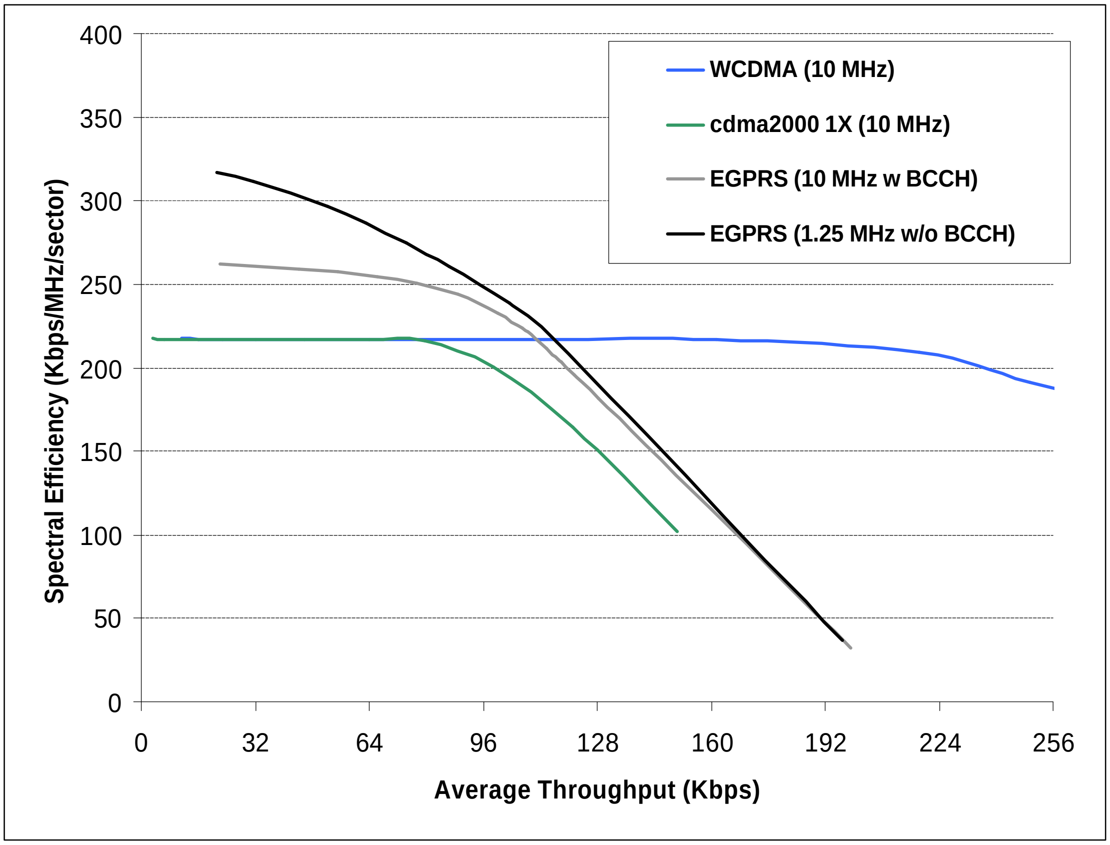

Figure 8: Spectral Efficiency Comparison Based on Average Throughput[21]

The next figure shows the spectral efficiency in Kbit/s per MHz per sector versus tenth-percentile throughput in Kbit/s, and compares EDGE (or EGPRS) versus WCDMA and CDMA2000. The significance of using tenth-percentile data is that ninety percent of users obtain data rates greater than that amount. This approach avoids scenarios where a subset of users, due to good radio conditions, account for a disproportionate amount of aggregate throughput. In this comparison, EDGE is the most spectrally efficient technology below 72 Kbit/s.

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

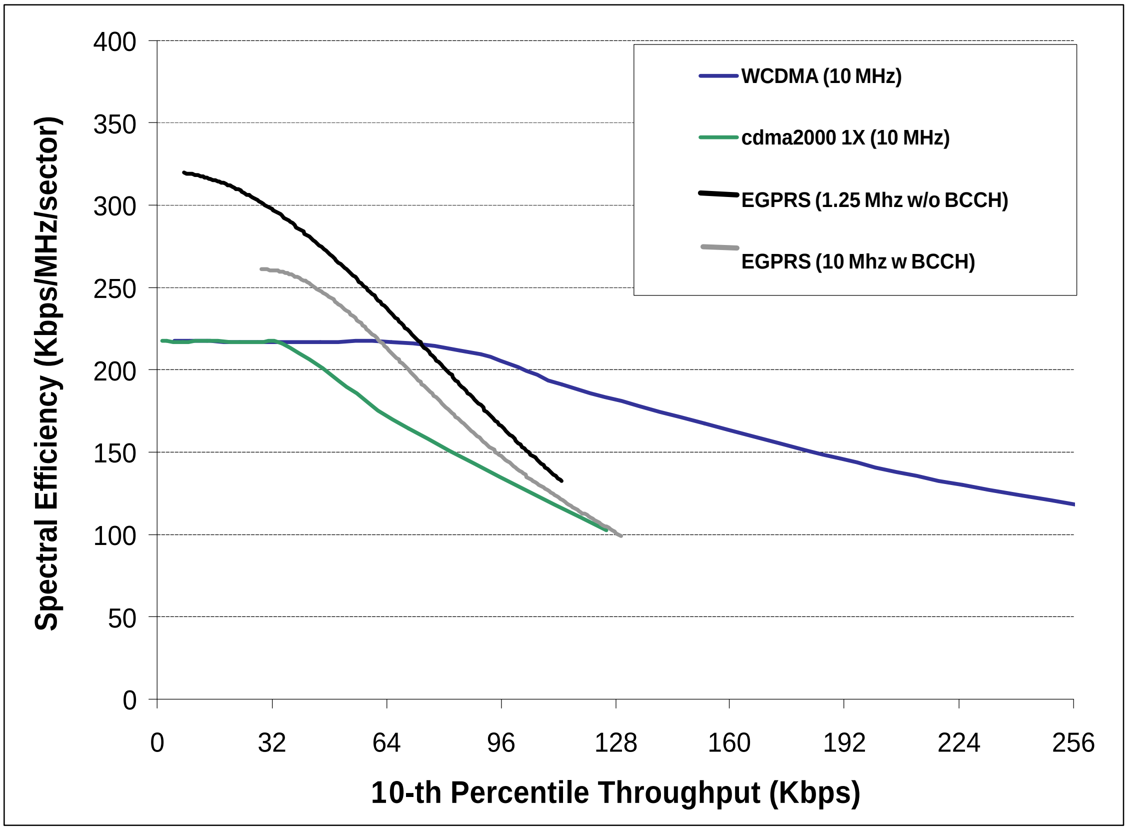

Figure 9: Spectral Efficiency Comparison Based on 10-th Percentile Throughput[22]

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

The final comparison is to show the number of users that can be supported per sector in 10 MHz versus average throughput. This is based on the same assumptions as in Figure 8 and Figure 9, though using a different data-traffic model, and provides an alternate comparison of spectral efficiency. Clearly, these networks can support the greatest number of users at lower data rates. Once again, EDGE performs extremely well for lower data rates, supporting one hundred and sixty users per sector in 10 MHz at 32 Kbit/s of throughput and ninety users per sector at 64 Kbit/s.

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

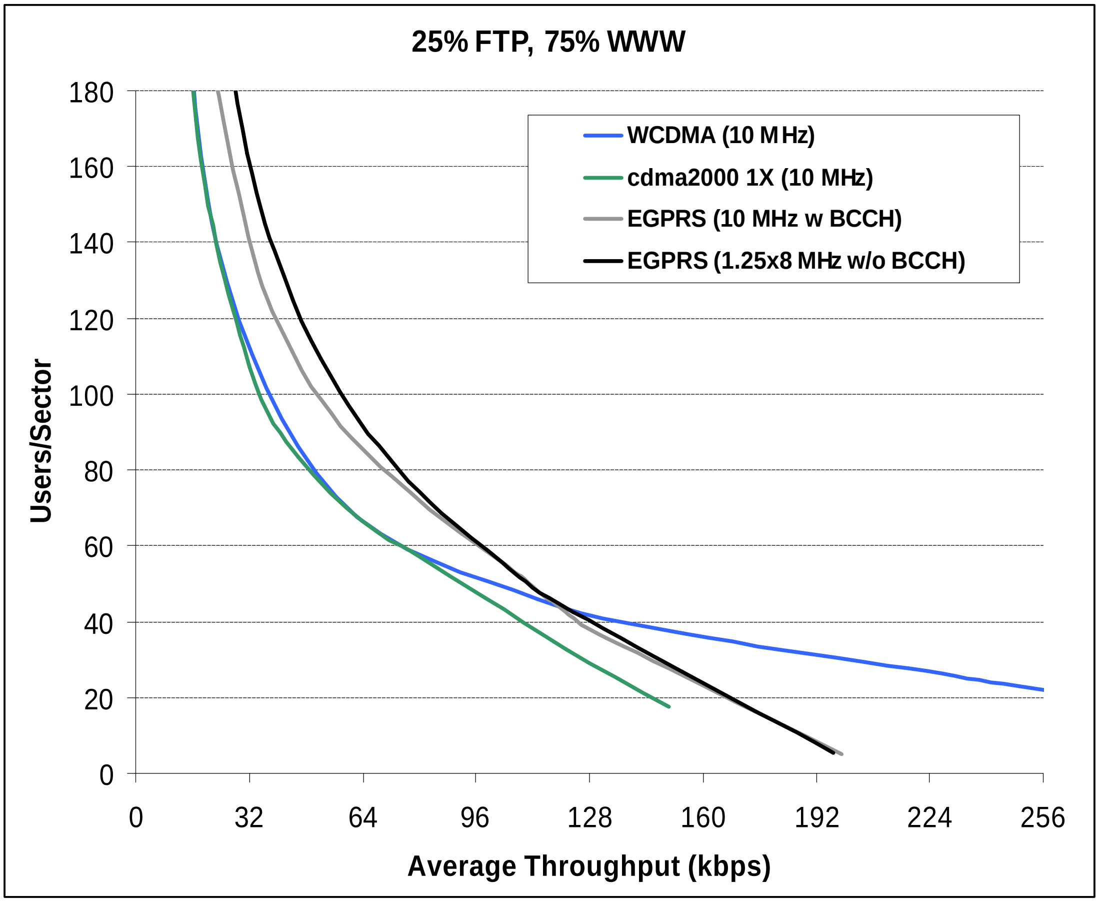

Figure 10: Users per Sector in 10 MHz versus Average Throughput[23]

In conclusion, of the technologies compared in these curves, EDGE promises to be the most spectrally efficient technology for lower data throughputs and WCDMA the most spectrally efficient technology for higher data throughputs, and the UMTS Multi-radio network, which combines EDGE and WCDMA radio access networks, will deliver the highest and most efficient data performance.

Evolution Paths from GPRS to UMTS

This section discusses the evolution of data capability from GPRS to UMTS and the stages that operators will go through in evolving their networks. This progression, as shown in Figure 11, happens in multiple phases, first with the addition of GPRS, next the first phase of 3G capability

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

using EDGE and UMTS radio access networks, followed by evolved 3G capability through enhancements such as all IP networks.

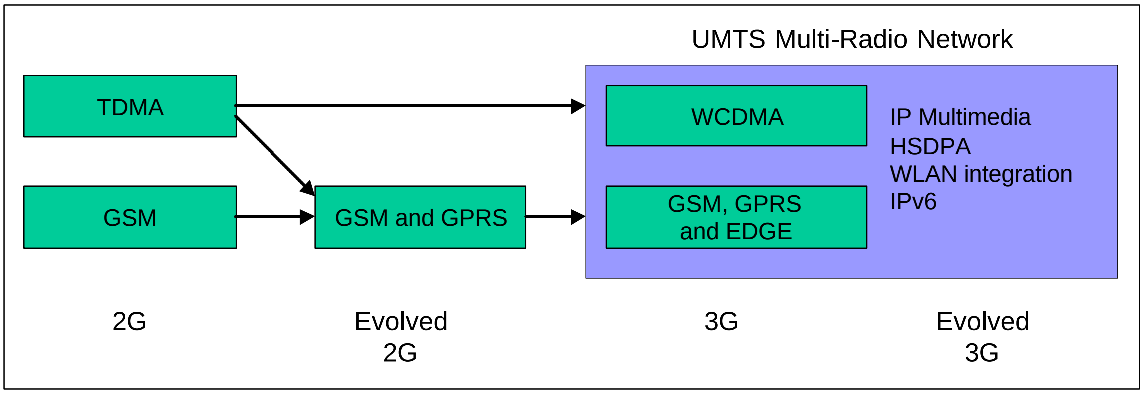

Figure 11: Evolution of Cellular Technologies

Operators with existing GSM networks have enhanced their networks to support GPRS through the addition of the GPRS infrastructure discussed above in the section “Technology Capabilities.” They have been able to do this using existing cell sites, transceivers and interconnection infrastructures. Meanwhile, operators deploying new GSM networks (e.g., AT&T Wireless, Cingular Wireless, Rogers Wireless, Telecom Personal) have deployed GSM and GPRS simultaneously.

TDMA operators who have chosen the GSM evolution path are deploying overlay networks that largely function independently of the TDMA network. These deployments have leveraged existing cell-site facilities, networking transports, and central site resources. Operators are offering multi-mode devices that support both GSM and TDMA as an interim step before their GSM networks are fully deployed. CDMA operators also have the option of evolving their networks to GSM/UMTS.

The first major upgrade to GPRS is EDGE, a relatively straightforward upgrade to GPRS for GSM carriers. 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. In fact, 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[24]. The same packet infrastructure supports both GPRS and EDGE. Once operators have deployed EDGE, they can enhance its applications capabilities by deploying the IP Multimedia Subsystem in their core networks, which will also support a WCDMA radio access network.

All networks will be able to take advantage of EDGE because the majority of terminals will support EDGE, facilitating a natural and smooth evolution.

To expand capability and capacity further, operators can deploy UMTS, which is a complementary technology for EDGE, or an alternative. Worldwide, GSM and new 3G operators

[24] *POP* refers to population.

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

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

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

Deployment Stage	**Characteristics**
Initial UMTS deployment	Only a portion of coverage area has UMTS. GSM 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. Access network chosen based on service and load demands.
Full Multi-radio network capability	Dense deployment of UMTS, including micro cells. Integration of GERAN and UTRAN core equipment. Seamless quality-of-service integration. Addition of new radio technologies, such as WLANs.

Table 4: Deployment Progression of UMTS

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 12. This will lower total network cost and improve integrated operation of the separate access networks.

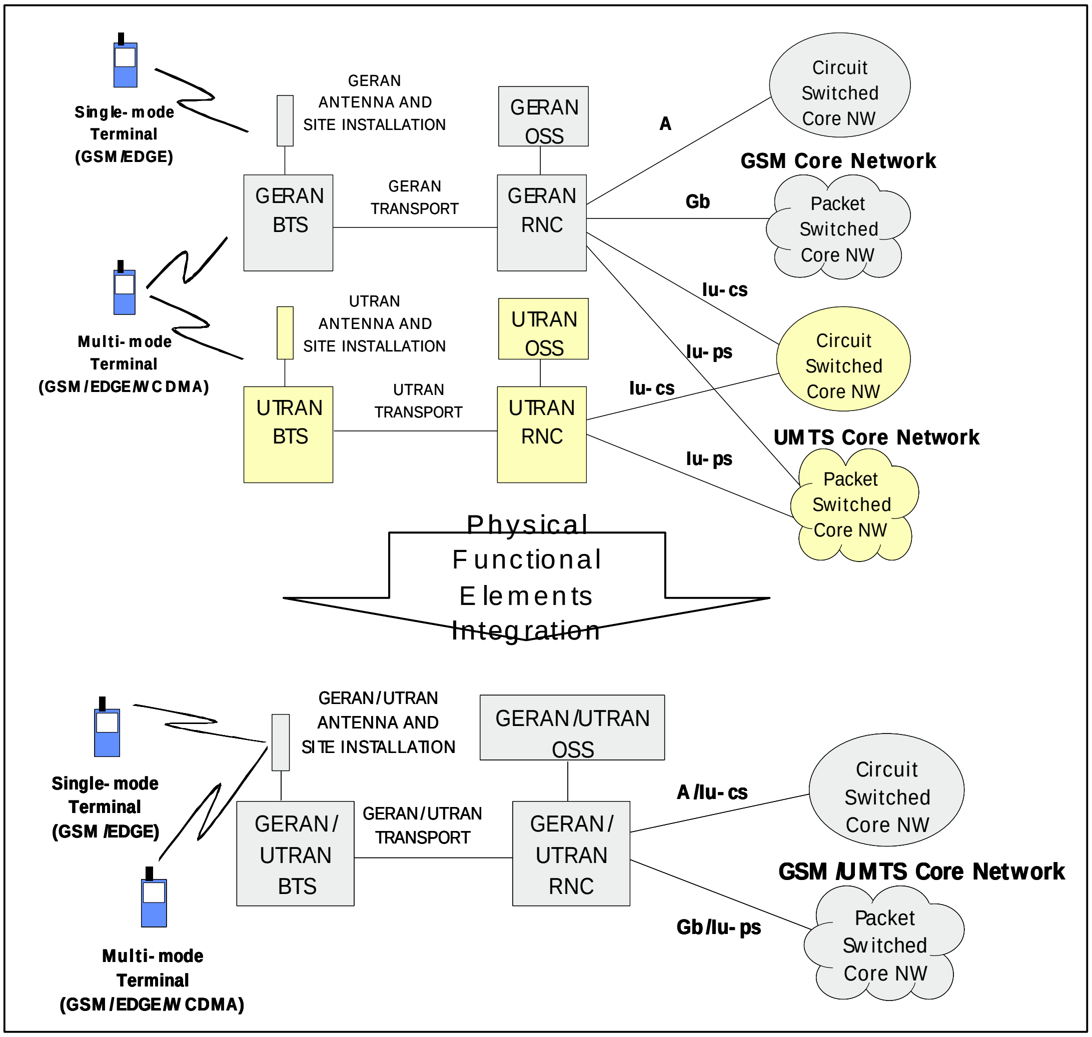

Figure 12: Integration of UMTS and GSM/EDGE Core Network Equipment[25]

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. Support for GSM/EDGE/GPRS/WCDMA radio access networks.
- **Release 4:**[26] Completed. Multi-media messaging support.
- **Release 5:** Being finalized. HSDPA and first phase of IP-based Multimedia Services (IMS).

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

- **Release 6**: Under development. Second phase of IMS, WCDMA/WLAN interworking, common radio resource management (GERAN/UTRAN), Multiple Input Multiple Output (MIMO) antenna systems for higher user data rates and high-speed uplink packet access (HSUPA.)

Conclusion

This paper has described the data capabilities in the GSM evolution to UMTS. This evolution occurs in successive stages, with each stage increasing data throughputs and spectral efficiency, and adding new features such as quality-of-service and multimedia support. The migration and benefits of the evolution from GSM to UMTS 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 for both users and operators. UMTS is already the world's most selected third-generation technology, with support from nearly all major regional standardization bodies. It offers an excellent migration path for existing TDMA and GSM operators and a path also available to CDMA operators.

Specific benefits and features of the GSM evolution to UMTS begin with GPRS, an IP-based packet-data capability for GSM networks with average user-perceived throughputs of up to 40 Kbit/s, and the option to increase these with coding schemes 1-4. GPRS support for a wide range of business and consumer applications will drive demand for data service and will generate new revenue for operators.

Beyond GPRS, EDGE provides a cost-effective 3G solution for operators to upgrade to an ITU-approved 3G technology. EDGE provides operators significantly higher data rates and improved efficiency. Using advanced radio networks, EDGE promises to be one of the most spectrally efficient technologies available for cellular-data services. The risk of implementing EDGE into a network is minimal as it is an incremental investment that leverages the existing GPRS network.

As demand for data services grows, operators can deploy UMTS networks, which bring an entire new set of capabilities, particularly the support for high-bandwidth applications. Whereas EDGE is extremely efficient for narrowband data services, the WCDMA radio link is extremely efficient for wideband services. 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. This solution is further enhanced by the deployment of High Speed Downlink Packet Access, an extremely fast data service with peak speeds of up to 10 Mbit/s, the highest rate available for any cellular technology.

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

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