SDR Market Study

Task 2: The Cellular Industry—
Terminals and Infrastructure

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by

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About the Author

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Dr. Gunn is currently developing a series of Software Defined Radio (SDR) market and technology studies for the SDR Forum. The first report was *SDR Market Study, Task 1: Market Segmentation and Sizing*. He is author of market research reports entitled *Wireless Infrastructure: Technology and Markets* that have been published by Forward Concepts. He served as principal investigator on a DARPA Small Unit Operations (SUO) project to develop advanced software radio architectures for military and commercial waveforms. He is co-author of "Communication Mediums for Intelligent Transportation Systems" (TRB/National Academy Press), which is a multi-media/multi-medium communication system design guide.

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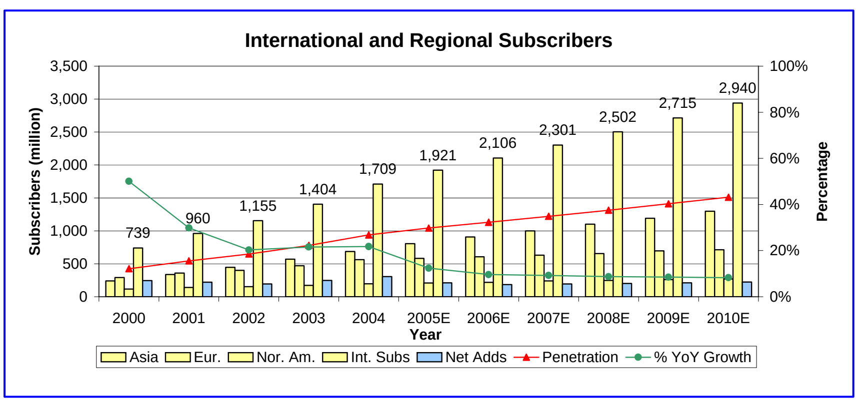
Executive Summary and Conclusions

This report, *The Cellular Industry—Terminals and Infrastructure*, provides a comprehensive look at the largest potential market segment for SDR technologies. This report is the second of a series of studies commissioned by the SDR Forum. Other segments to be addressed in subsequent reports include WLAN/WiFi/WiMax; Military, Public Sector, Aviation, and Telematics.

The growth of the cellular industry in the past two decades has been remarkable. In the first 15 years of the industry, until 2000, the number of international subscribers grew at a rate of more than 50% year-over-year (YoY). From the original analog first-generation (1G) systems, to the digital 2G systems of the early 1990s, the industry has now advanced past 2.5G and into 3G systems, adding wireless data, video, and Internet services and providing enhanced voice-capacity along the way.

The first report of this SDR Market Study series, *Market Segmentation and Sizing*, presented summary data on worldwide market segments of the wireless industry. Cellular, unlike the other segments, is not dominated by the United States; rather, international requirements are driving an international market. The industry at year-end 2004 had achieved more than 1.7 billion subscribers and a penetration (subscribers/ population) of 26.8% worldwide. As shown in this report, projections are for steady growth, and put these numbers at almost 3 billion subscribers and 40% penetration by 2010.



(***Sources:*** **ITU, operator reports, technology associations, and author research)**

The market segments for the cellular industry can be divided into two types: mature markets and emerging markets. As the name implies, penetration in the mature markets (for example, Western Europe, Japan, Korea, and the United States) is typically more than 60%, and even exceeds 100% in places where individuals may have multiple subscriptions. Interest in this market centers on new 3G data services such as pictures, short message system (SMS), streaming video, and wireless web capabilities, among other enhancements. In contrast, penetration in the emerging markets (for example, China, India, Russia, Eastern Europe, Africa, and Latin America) is low, but these markets represent more than half of international net subscriber additions (Net Adds). Interest in this market centers on subscriber plans with a low average revenue per unit (ARPU). This restricts operators to low capital expenses (CAPEX) and operating expenses (OPEX).

Therefore, the significant drivers for the cellular industry are (1) to develop winning 3G data services for the mature markets to facilitate revenue growth opportunities and (2) to develop low-cost business models for emerging markets with appropriately priced service plans, terminals, and infrastructure (OPEX and CAPEX).

This report includes comprehensive estimates of the international wireless market addressing subscriber numbers and the terminal and infrastructure markets.

The cellular industry is clearly the largest wireless market from several perspectives, including:

1. Forecast to surpass 2 billion international subscribers at year-end 2005 or early 2006 and to approach 3 billion international subscribers in late 2010.
2. Forecast cumulative terminal market of more than $1,000 billion during the decade 2000-2010.
3. Forecast cumulative infrastructure market of more than $500 billion during the decade 2000-2010.

A goal of the SDR Forum in these studies has been to develop business models for each market segment. This report develops the cellular business model with examples and data from many sources, including international operators, various terminal and infrastructure vendors, and others, with the following principles:

1. Total cost of ownership (TCO) is a combination of both CAPEX and OPEX. The lowest initial equipment costs do not typically provide the lowest TCO.
2. Reducing the number of total cell sites generally provides the lowest TCO. Thus, SDR technologies offer much potential to enhance coverage and capacity with flexible technologies, including diversity, smart antennas, and interference mitigation (multiuser detection, or MUD).

The operator community is clearly in a discovery mode. Cellular has significant time-to-market pressures related to the desire of cellular carriers to not only increase revenues with new data services that are attractive to subscribers, but also to price these services appropriately.

In addition to lower cost as an important consideration for the cellular industry, common platforms to provide for flexibility and economies of scale have been consistently identified as key goals. Ideally, a single box (i.e., system platform) could be provided for all applications. However, each cellular standard and each market has unique requirements, drivers, and priorities that encompass services, costs, integration, power consumption, modes of operation, bands of operation, applications, network interfaces, and so forth. Thus, a highly valued SDR benefit for the cellular industry includes component and technology reuse in multiple product families that reduce costs as well as time-to-market, and enable enhanced cost-effective, flexible, and market-driven feature sets. This reuse includes components, modules, subsystems, and intellectual property as well as systems, hardware, software, manufacturing, logistics, testing, and so on.

Voice is expected to be the “killer application” for the foreseeable future—a part of the “triple play” of voice, data (e.g., Internet/web), and TV on Internet Protocol (IP) Multimedia Systems. This was evidenced at two important shows early in 2005 (3GSM in Cannes, France, and CTIA in New Orleans), at which several terminal and infrastructure vendors indicated that their technical staffs consist of approximately 75% software personnel. Software flexibility and cost reduction appear to be very essential to the cellular industry.

As discussed in the first SDR Market Study, which was based on industry input, 90 nanometers (nm) and below complementary metal-oxide semiconductor (CMOS) digital technologies appear well positioned to support aggressive SDR capabilities (i.e., highly flexible mode and band selection via software) in the cellular industry. Radio frequency (RF) and data acquisition, however, do not appear to be on track to cost effectively support aggressive SDR capabilities for the foreseeable future. Many valuable solutions through reuse of components, chips, subsystems, and, of course, software are achievable with substantial benefits. Many SDR capabilities are currently viable and provide valued benefits to the cellular industry.

• *SDR Forum Study Series Overview*

This report is the second of a series of Software Defined Radio (SDR) market studies commissioned by the SDR Forum. The work to create these SDR market reports is divided into two phases and multiple tasks. The SDR Market Study for Task 1, *Market Segmentation and Sizing*, provided an overview of the most promising market segments with rough order of magnitude (ROM) estimates and general segment discussions. This second study provides a comprehensive look at the cellular industry. Follow-on tasks will provide more detailed segmentation and sizing for each segment and more detailed analyses of requirements, drivers, issues, and business models. An overview of the phases and tasks for these studies is presented in the following table.

Phase 1 (Completed) Task 1 – Segment and Size – Rough Order of Magnitude Task 2 – The Cellular Industry – Terminals and Infrastructure
Phase 2 – Follow-on Tasks – Ongoing Task 3 – WiFi, WiMAX and Beyond 3G/4G Task 4 – Public Safety (Law Enforcement, Fire, Emergency Management, etc.) Task 5 – Military Task 6 – Telematics Task 7 – Avionics Task n – Further tasks to be determined

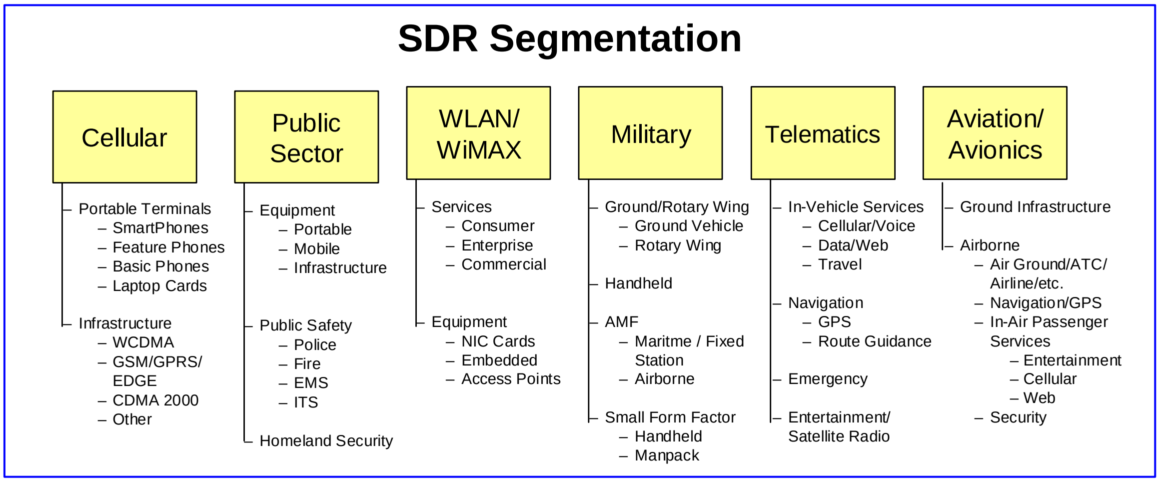
For many years, most wireless industry segments have utilized programmable digital signal processors (DSPs) and/or microprocessors for the less throughput-intensive algorithms (i.e., essentially baseband functions) deployed in their terminals and infrastructure. Recent advances in semiconductor technologies, including 90 nm and below digital technologies, RF technologies, and data acquisition technologies, provide imminent market opportunities for software defined radios to extend programmability for more transceiver algorithms and more extensively achieve the long-verified software benefits presented in the next table.

1. Incur lower development costs
2. Provide enhanced mass customization flexibility in development, deployment, and fielded products
3. Provide critical time-to-market enhancements
4. Facilitate better reuse of intellectual property (IP)
5. Support multiband and multimode RF operations
6. Enable the SDR vision of field software-enabled waveform, protocol, and application selection and update.

A fundamental goal of this work is to provide clarity and guidance for the SDR community on "Where are we, where do we need to be, and how do we get there?" based on market opportunities and requirements. These are not static conclusions and positions with final end points, however, but ongoing opportunities that will be enhanced and improved as we progress through these studies, as well as afterwards, based on lessons learned and technology advancements.

- ***Segmentation Overview***

The following figure presents the SDR market segmentation developed for these SDR studies. The first report developed market size estimates for the first level for total units and total revenues. In subsequent reports, more detailed subsegmentation and market sizing data will be developed as appropriate for each segment.



1 Introduction

1.1 Report Overview

This report, entitled *The Cellular Industry—Terminals and Infrastructure*, provides a comprehensive look at the largest market segment providing opportunities for SDR technologies. This report is organized as follows:

Executive Summary
1. Introduction
2. Cellular Industry Trends, Issues, and Drivers
3. Cellular Industry Market Forecasts
4. Cellular Industry Business Models
5. Update on SDR Platforms and Technology Roadmaps

The best way to begin discussions of the cellular industry is to review the spectacular growth of international subscribers since initial cellular launches in the early 1980s, as presented in Figure 1-1, which shows more than 1.7 billion subscribers at year-end 2004. During its first 15 plus years until 2000, the industry consistently achieved at least 50% year-over-year (YoY) subscriber growth. In the 1980s, the first-generation (1G) systems were analog. Starting in the early 1990s, the transition to 2G digital systems commenced, with the primary drivers being increased capacity, improved functionality, and lower costs. Since the early 2000s, the cellular industry has been evolving from the original 2G digital standards, which provided voice-centric services, to 2.5G and 3G, which add wireless data, video, and Internet services and provide additional voice-capacity enhancements.

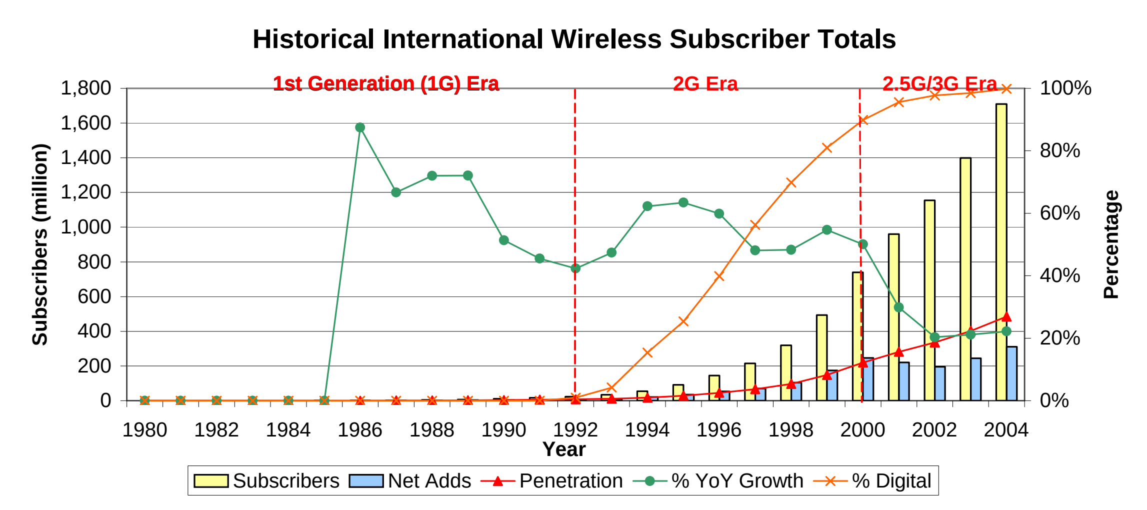
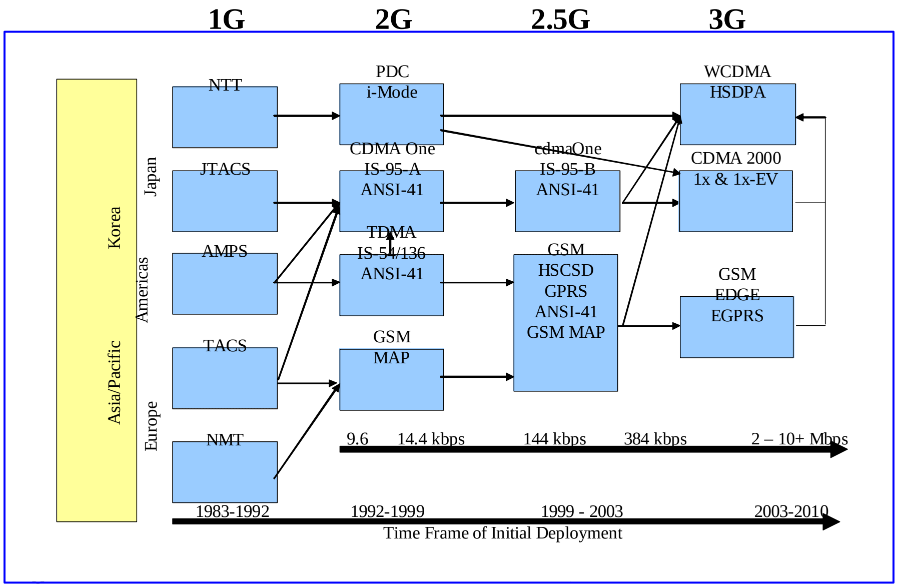


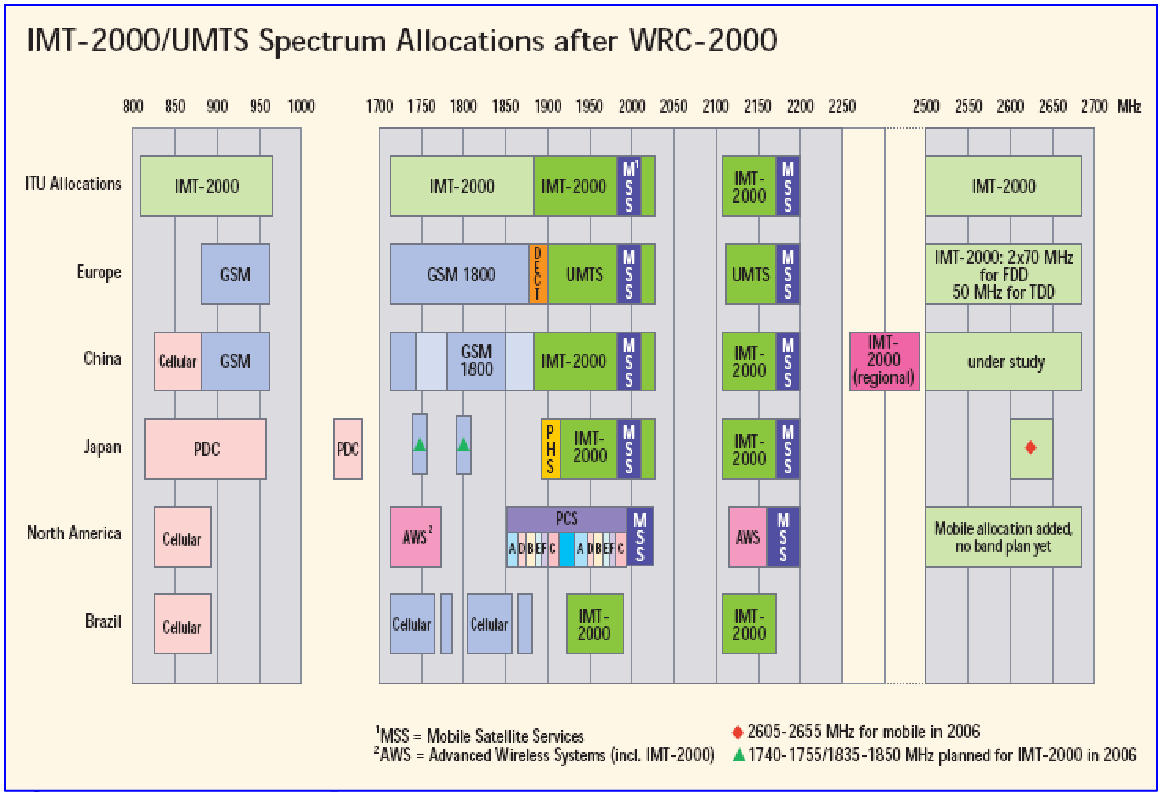
Figure 1-1 Historical International Wireless Subscribers
(*Sources:* ITU, US Census Bureau, company reports, and author research)

An overview of this evolution from 1G to 2G and ongoing to 2.5G and 3G standards is presented in Figure 1-2. Figure 1-3 provides a summary of international frequency allocations for cellular.



(*Source*: Jim Gunn)
Notes: AMPS = Advanced Mobile Phone Service; ANSI = American National Standards Institute; CDMA = Code Division Multiple Access; EDGE = enhanced data rate for GSM evolution; EGPRS = enhanced GPRS; GPRS = general packet radio service; GSM = global system for mobile communications, HSCSD = high-speed circuit switched data; HSPDA = high-speed downlink packet access; JTACS = Japanese Total Access Communications System; MAP = Mobile Application Part; NMT = Nordic Mobile Telephone; PDC = personal digital cellular; TACS = Total Access Communication Service; TDMA = Time Division Multiple Access; WCDMA = wideband CDMA

The key 3G cellular standards are GSM/EDGE/GPRS, CDMA 2000 1x/1x-EV-DO, WCDMA/HSDPA, and TD-SCDMA (Time Division-Synchronous Code Division Multiple Access; China-led technology). In 2000, two international standards organizations assumed lead responsibility from many regional standards organizations for 3G standards and for future evolutions of 2G, 2.5G, and 3G standards. The 3rd Generation Partnership Project (3GPP) assumed responsibility for GSM/EDGE/GPRS, WCDMA/HSDPA, TD-SCDMA, and related standards. Traditionally, these standards have been European centric, but have increasingly achieved international successes, such as in China. The 3GPP2 assumed responsibility for CDMA One, CDMA 2000, and related standards. These standards have been US centric, led by Qualcomm, and have also achieved international successes.



(WRC-2000)
(*Source*: UMTS Forum White Paper, February 2005)
Note: IMT = International Mobile Telecommunications; UMTS = Universal Mobile Telecommunications System

1.2 SDR Cellular Market Opportunity

This report presents many SDR opportunities from the perspective of cellular industry drivers, markets, and business models. The cellular industry is clearly the most significant wireless segment for SDR in terms of numbers of subscribers, wireless terminals and infrastructure, and the revenues generated. This section summarizes the many key cellular SDR opportunities that are identified throughout this report.

A recurring question is "What are the SDR market numbers?". A seemingly preferred method of estimating these numbers would be to use the SDR Forum's "SDR Definition: Tiers of Capability and Flexibility" that is presented in Table 5-1. Using the Tier 2 definition, a reasonable conclusion is that Tier 2 SDR technologies are deployed in all (100%) cellular terminals and infrastructure. A summary of historical and forecast revenues for terminals and infrastructure, extracted from Sections 3.1 and 3.2, is presented in Figure 1-4. As the figure indicates, the cumulative total SDR cellular opportunity between 2000 and 2010 is US$1,656 billion, consisting of the terminal opportunity at $1,034 billion and the infrastructure opportunity at $622 billion.

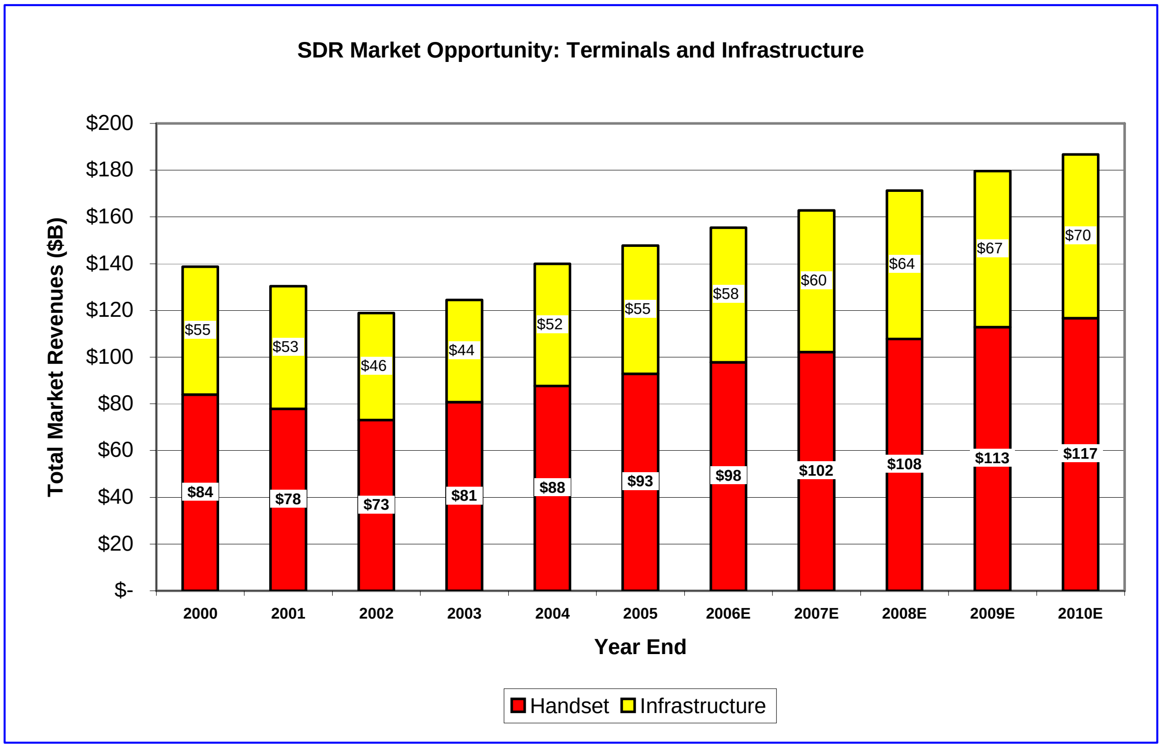


Figure 1-4 SDR Cellular Market Opportunity: Terminals and Infrastructure

However, the percentage would be 0% if Tier 3, Ideal Software Defined Radio, is the assumed criteria, and the current and foreseeable future unit and revenue numbers for SDR would be zero. This assumption does not seem reasonable, as virtually every terminal and infrastructure vendor reviewed for this report has indicated that they implement all possible functions in software providing that other key goals, such as performance, power, cost, form factor, and time-to-market, are not compromised. An often-articulated fact by many vendors has been that their development staffs typically consist of ~75% software personnel. The key conclusion is that all vendors are evolving to SDR capabilities to the maximum extent possible with available technologies to achieve the SDR platform benefits that are presented in Table 1-1. Furthermore, although with some variability in approach and goals, vendors consistently indicate active R&D programs to continually enhance flexibility by incorporating SDR technologies and concepts in their products.

Incur lower development costs Provide enhanced mass customization flexibility in development, deployment, and fielded products Provide critical time-to-market enhancements Facilitate better reuse of intellectual property (IP) Support multiband and multimode RF operations Enable the SDR vision of field software-enabled waveform, protocol, and application selection and update.

Table 1-1 SDR Platform Benefits

As discussed in this report as well as the Task 1 report, DSP/digital technologies at emerging 90 nm and below CMOS technology nodes appear capable of supporting highly flexible SDR functionality and still achieve required market goals for power, cost, multimode, targeted multi-band, etc, However, RF and data acquisition technologies are progressing at a slower pace and do not appear on track over the next 5 to perhaps 10 years to achieve the often-articulated utopian goal of highly flexible 2 MHz to 2+ GHz multiband and multimode functionality. However, these technologies are progressing and constantly improving, and more flexible multiband solutions are emerging. Thus, careful engineering, business, market segment, and cost trade-offs will be the norm for the foreseeable future to insert an expanding suite of SDR capabilities and technologies.

Specific, SDR cellular opportunities presented in this report include:

- Infrastructure
    - Common platforms and technology reuse in multiple products are an increasingly goal to increase flexibility at reduced costs.
    - Typically, each band requires targeted RF and data acquisition designs, but increasingly baseband/DSP subsystems can be extensively reused.
    - Total cost of ownership appears best achieved by reducing the number of base station sites to achieve coverage and capacity goals. Thus, smart antennas, MIMO, MUD, and other technologies that enhance link performance and reduce the required number of sites offer significant SDR opportunities. Careful performance and TCO trades must be proven.
- Terminals
    - The evolution to WCDMA requires multband and multimode terminals to successfully and cost effectively transition subscribers to 3G services. Cost-effective point solutions are required with the emerging trend to integrate WiFi, WiMAX, and other local area links will expand this requirement.
    - 3G adds high-speed broadband wireless links. Inherently, higher speed requires higher performance links (or reduced cell coverage reach), thus MIMO and MUD technologies are targeted in emerging terminal designs.

A repeatedly articulated goal by cellular stakeholders is to “future proof” terminals and infrastructure. By this, they are referring to cost-effective software with the flexibility to accommodate discovery processes by operators for emerging 3G services that attract expanded subscriptions and enhanced revenue opportunities. In this regard, SDR opportunities are significant.

2 Cellular Industry Trends, Issues, and Drivers

The cellular industry has evolved to become one of the largest international industries with a subscriber count of approximately 1.7 billion at year-end 2004. Note that the estimates and forecasts for this report were raised based on current data and clearly indicate improving trends. Cellular has overtaken traditional wireline in subscriber numbers and penetration. Many legacy telecommunication operators are recognizing that wireline is a mature market with flat (or declining) opportunities, and they are aggressively embracing cellular as well as emerging broadband, Internet, wireless local area network (WLAN), cable television, voice over IP (VoIP), and related technologies and services to ensure future growth. At both 3GSM in Cannes, France, in February 2005 and CTIA in New Orleans in March 2005, the buzzwords (focuses) were “triple play,” consisting of voice, data (e.g., Internet/web), and television on “converged” (All) IP multimedia broadband networks (IMS) that encompass wireless as well as wireline services. These emerging goals envision converged transport, core networks, and services that are agnostic to the utilized access technology.

A first consideration of drivers for cellular industry opportunities is the general economic environment. Percentage annual international gross domestic product (GDP) growth based on historical data from a 2003 Citigroup report and on 2004-2006 data from International Monetary Fund (IMF) reports is presented in Figure 2-1. It is a widely held consensus opinion that GDP growth of 3% is a desired goal. In the 2000-2003 timeframe, the international GDP growth was below 3% and the industry’s performance declined. In 2004, a 3.4% growth was achieved, and the industry achieved very good performance. Note that the IMF is forecasting GDP for 2005 growth at less than 3% and improving in 2006. Supplementary information for selected countries and regions is presented in Table 2-1. As the table indicates, the European area is experiencing comparatively slower growth, the emerging Asian economies are experiencing spectacular growth in excess of desirable long-term goals, and the United States is experiencing good growth. Note that many regard continuing growth substantially in excess of 3% as unsustainable due to the potential for undesirable issues, such as inflation, to arise. Thus, a key driver and issue for the industry is that the economic environment remains favorable.

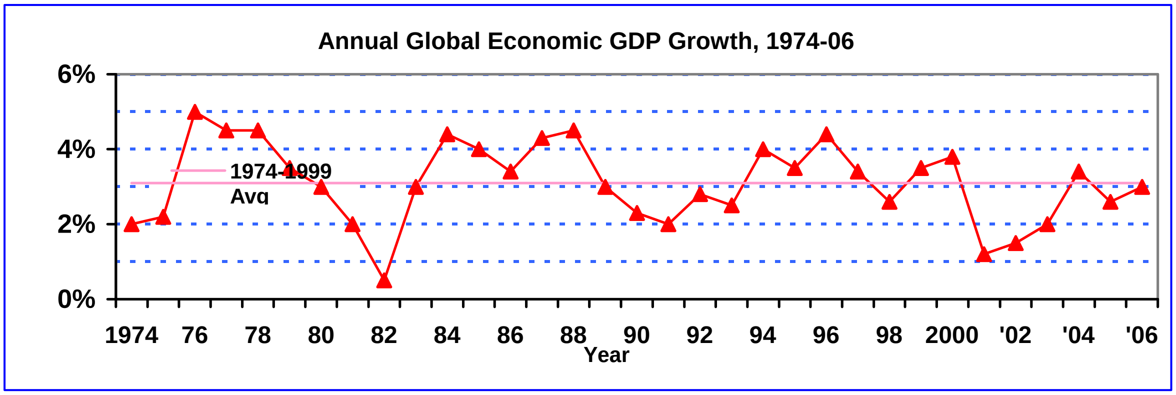


Figure 2-1 Global – Annual Economic Gross Domestic Product (GDP) Growth, 1974 – 2006
(*Sources*: "Global Economic Outlook and Strategy" Report, Citigroup, April 23, 2003, and IMF web site (www.imf.org), April 2005)

Select Regions / Countries	GDP % Growth		
	2004	2005F	2006F
Advanced Economies	3.4%	2.6%	3.0%
United States	4.4%	3.6%	3.6%
European Area	2.0%	1.6%	2.3%
Germany	1.7%	0.8%	1.9%
France	2.3%	2.0%	2.2%
Italy	1.2%	1.2%	230.0%
Spain	2.7%	2.8%	3.0%
UK	3.1%	2.6%	2.6%
Japan	2.6%	0.8%	1.9%
Korea	4.6%	4.0%	5.2%
Newly Industrialized Asian Economies	5.5%	4.0%	4.8%
China	9.5%	8.5%	8.0%
India	7.3%	6.7%	6.4%

Table 2-1 Selected International Percentage GDP Growth Indications
(*Source*: IMF web site (www.imf.org), April 2005)

Two major cellular market segments are emerging. The first includes mature markets, such as Western Europe, Japan, Korea, the United States, that are becoming saturated at high penetration (~ 60% to 100+%). Future revenue growth opportunities for this segment include new 3G data services such as pictures, SMS, streaming video, ringtones, and wireless web. A very clear illustration of the importance of new data revenue opportunities to operators in the mature Western Europe market is illustrated in the information in Figure 2-2, which was presented by Siemens at the 3GSM in February 2005. In 2004, data revenues achieved approximately 20% of total revenues.

The second market segment includes emerging markets such as China, India, Russia, Eastern Europe, Africa, Latin America, and others that have low penetration and are now providing more than 50% of international net subscriber additions (Net Adds). In these emerging markets, however, operators must offer subscribers plans at a low average revenue per unit (ARPU) that require commensurate capital expenses (CAPEX) and operating expenses (OPEX) budgets.

Figure 2-3 presents data on the top 10 international cellular markets based on mobile subscribers at year-end 2004. The graph for each country presents the number of subscribers, percentage YoY subscriber growth, and percentage penetration (mobile subscribers/population) by year from 1994 to 2004. This top 10 includes mature market countries with high penetration as well as emerging market countries with comparatively lower penetration. Note that a few countries (e.g., Italy) are reporting subscriber penetration of more than 100%. Reasons for this may be that some subscribers have multiple accounts (e.g., for voice/data, for traveling to avoid high roaming costs), and/or more than one phone (e.g., Smartphones, personal digital assistants (PDAs), and lower-cost phones for personal activities). Many travelers purchase prepaid system interface module (SIM) cards in local markets because this is cheaper than roaming charges from their home operators. Finally, it has been widely reported that prepaid customers (estimated at approximately50% to 60% of international subscribers) often “churn” (take service with another operator) without terminating their current accounts. Prepaid account balances can expire or be consumed prior to a subscriber being deleted from an operator’s reported subscriber count. Subscribers typically have varying periods to recharge their accounts before losing their cell number and being deleted from an operator’s subscriber count. Thus, there is some double counting of subscribers. In recent years, the accounting requirements for reporting subscriber counts have been tightened over previous years.

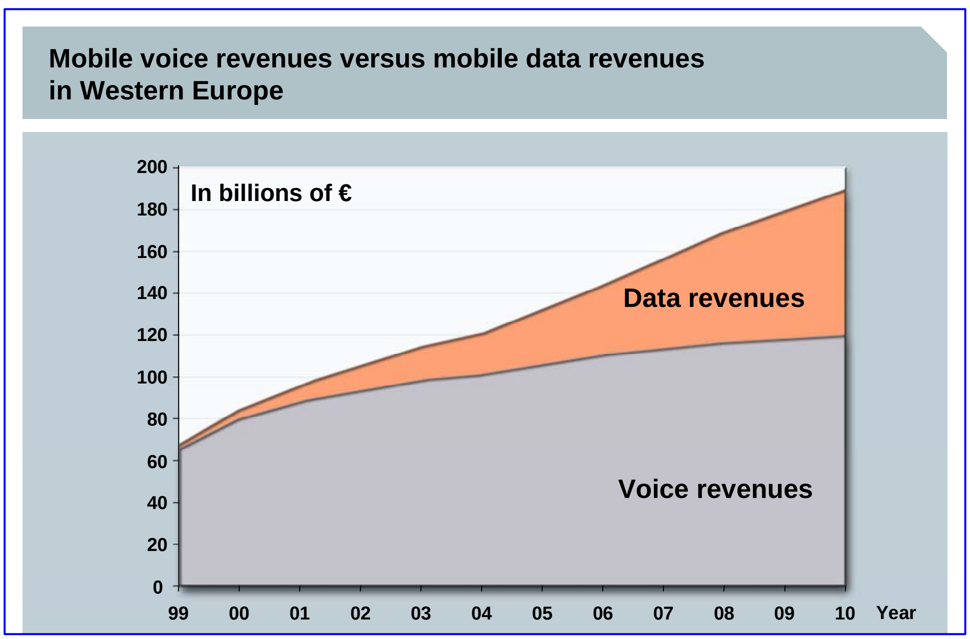
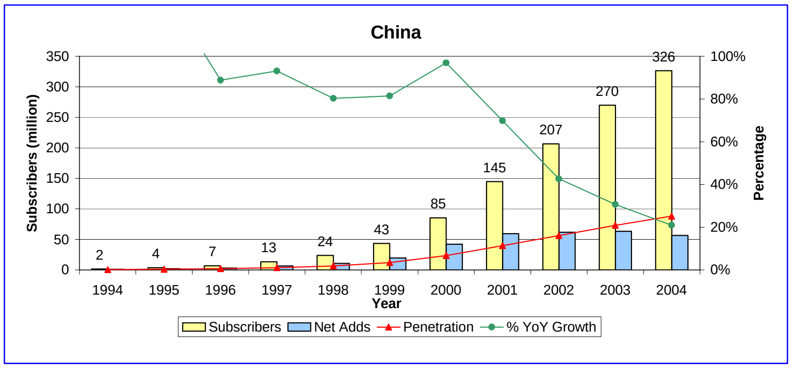
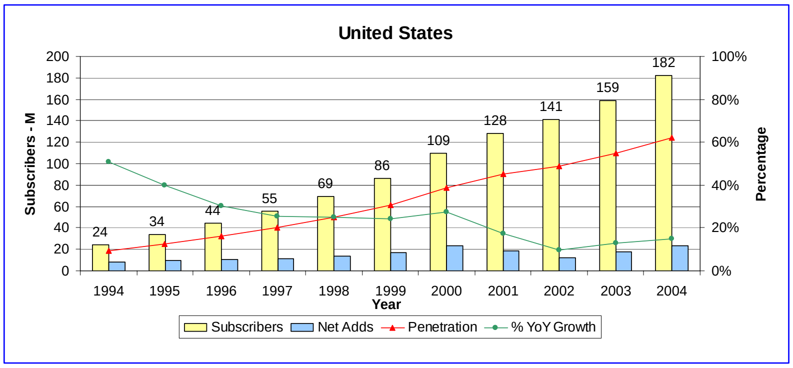
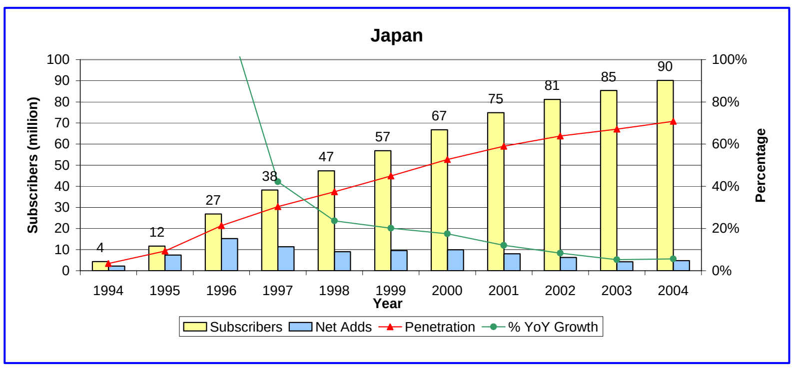
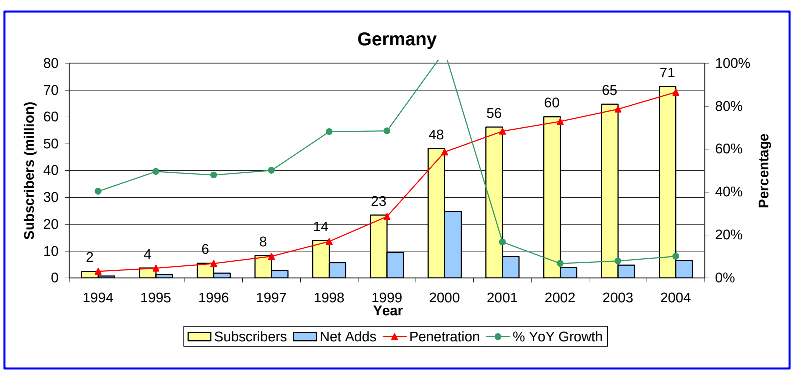


Figure 2-2 Mobile Voice Revenues versus Mobile Data Revenues in Western Europe
(*Source:* Siemens Com Mobile Network, August 2004, cited in Siemens 3GSM presentation by Lothar Pauly, CEO of Siemens’ Communications, February 2005)

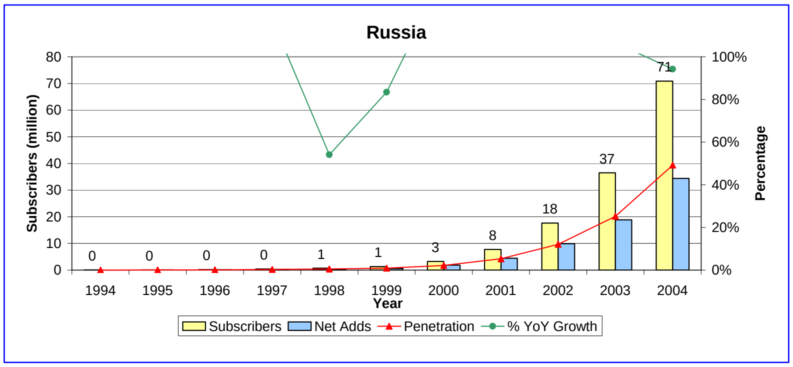

China
Subscribers (million)
Percentage
Year
Subscribers
Net Adds
Penetration
% YoY Growth
2
4
7
13
24
43
85
145
207
270
326

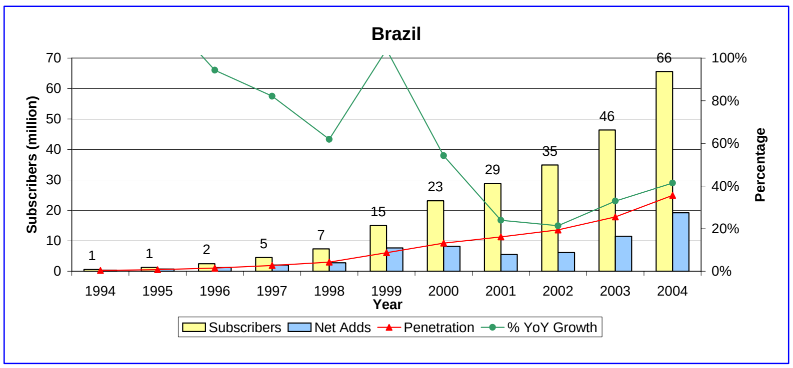

United States
Subscribers - M
Percentage
Year
Subscribers
Net Adds
Penetration
% YoY Growth
24
34
44
55
69
86
109
128
141
159
182

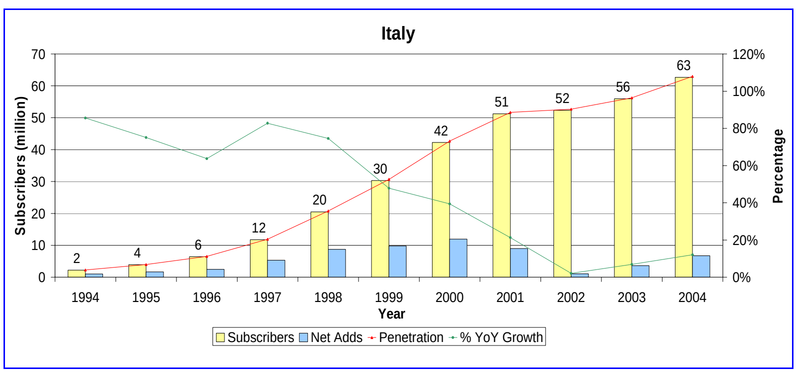

Japan
Subscribers (million)
Percentage
Year
Subscribers
Net Adds
Penetration
% YoY Growth
4
12
27
38
47
57
67
75
81
85
90

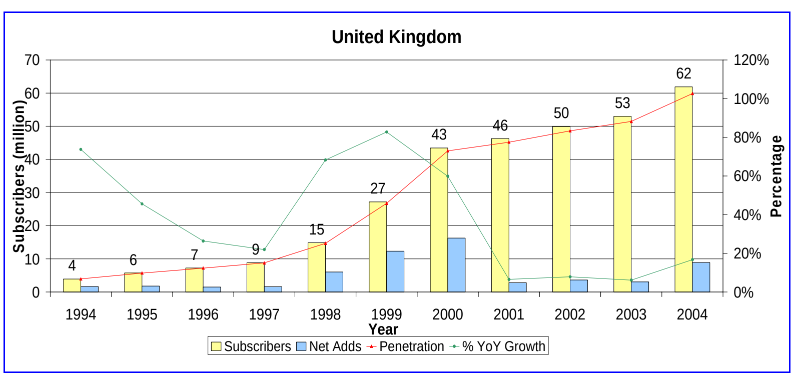

Germany
Subscribers (million)
Percentage
Year
Subscribers
Net Adds
Penetration
% YoY Growth
2
4
6
8
14
23
48
56
60
65
71

(continues)

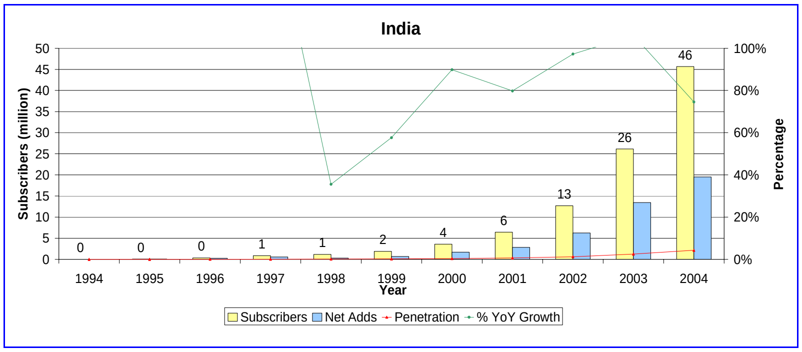

Russia
Subscribers (million)
Percentage
Year
0 0 0 0 1 1 3 8 18 37 71
1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004
Subscribers Net Adds Penetration % YoY Growth


Brazil
Subscribers (million)
Percentage
Year
1 1 2 5 7 15 23 29 35 46 66
1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004
Subscribers Net Adds Penetration % YoY Growth


Italy
Subscribers (million)
Percentage
Year
2 4 6 12 20 30 42 51 52 56 63
1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004
Subscribers Net Adds Penetration % YoY Growth


United Kingdom
Subscribers (million)
Percentage
Year
4 6 7 9 15 27 43 46 50 53 62
1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004
Subscribers Net Adds Penetration % YoY Growth

(continues)



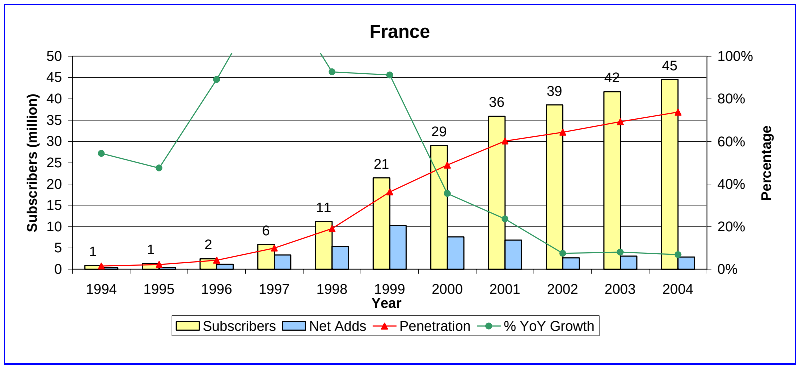
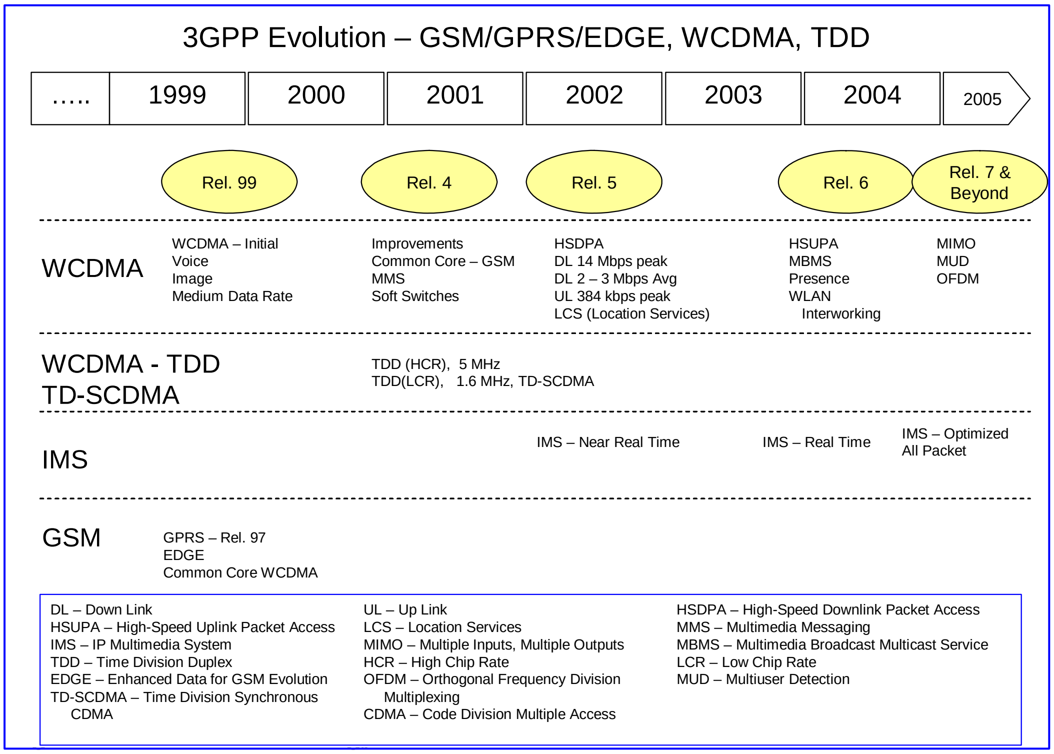


Figure 2-3 Top 10 International Markets: Subscribers, Net Adds, Penetration, and %YoY Growth
(*Sources*: ITU and author research)

In the first quarter of 2004, GSM achieved one billion subscribers, and the GSM/GPRS/ EDGE family is forecast to be the leading international technology for many years. At year-end 2004, GSM achieved 1.266 billion subscribers, which represented close to 75% of all international subscribers. This has created significant economies of scale for GSM and has provided the GSM community with much influence, not only for GSM, but also for its planned evolution to UMTS/WCDMA.

In 2000, the responsibility for standards transitioned from regional standards bodies (e.g., the European Telecommunications Standardisation Institute [ETSI] in Europe, Telecommunication Industry Association [TIA] in the United States). The Third-Generation Partnership Project (3GPP) assumed responsibility for the GSM/WCDMA. A companion 3GPP2 body assumed responsibility for standards for the CDMA 2000 family of standards. Evolution path overviews for 3GPP are presented in Figure 2-4 and those for 3GPP2 are discussed later in this section and shown in Figure 2-8. Note that the regional standards bodies still usually have responsibilities to adapt these standards for their local markets.



(Source: 3GPP web site and author research)

3GPP plans address evolution for GSM/GPRS/EDGE, UMTS/WCDMA, the Time Division Duplex (TDD) technologies, and the IMS core network standards. With more than 1.3 billion subscribers and continuing growth, GSM still has significant standards development activities. EDGE provides advance modulation formats for GSM that increase the data rates. The legacy circuit-switched (CS) core network for both the GSM and WCDMA standards are on common evolution paths, which facilitates cost-effective common core network strategies for operators planning dual GSM and WCDMA networks. The current core network standards provide separate packet-switched (PS) core and evolution of the legacy GSM MAP CS core. IMS provides an evolution path to an eventual "all-IP" core network for converged multimedia core networks (and including VoIP voice services). This is not anticipated to be achieved until Release 7 (Rel. 7) or later. The IMS functionality in Release 6 (near real-time) and Release 7 (real-time) start the transition with parallel CS and PS core network elements.

In addition to the current widely deployed Frequency Division Duplex (FDD), 3GPP standards provide a TDD evolution path. The TDD HCR is the 5 MHz (3.84 Mcps) that is the evolution of the legacy ETSI standards. TDD LCR is the 3GPP standards for the China-led TD-SCDMA technologies that has carrier spacing of 1.6 MHz (1.28 Mcps). General opinions are that the Chinese government's Ministry of Information Industry (MII) will award 3G spectrum in late 2005 or 2006 and that TD-SCDMA will be required in portions of the awarded bands. Many also question the near-term value propositions of

3G in China (as well as in other emerging markets) and believe that 3G deployments may be delayed longer than expected.

Operators have been slow to offer commercial WCDMA services, although many operators have ongoing trial, or even limited initial, services. Many European operators have 3G service deployment schedule requirements as a condition of their spectrum allocations by government regulators. NTT DoCoMo initiated the first WCDMA in Japan in September 2001, and after experiencing limited early successes has been achieving greater successes in 2004 and into 2005. DoCoMo's original WCDMA deployment was a pre-release 1999 implementation, but the company now appears on track to achieve full standard compatibility. WCDMA has experienced many startup problems, including the following:

- Inadequate and immature WCDMA standards have been an early challenge.
- Cellphone vendors have had difficulty bringing multimode, multiband handsets to market that support handoff with 2G/2.5G standards (e.g., PDC in Japan, GSM in Europe and elsewhere). This handoff is very desirable because WCDMA coverage has been focused in more densely populated, urban areas, and 2G capability is essential for wide-area coverage.
- WCDMA is a complex and broadband technology, and low power for longer battery life in handsets has been a problem.
- Operators have required more time than anticipated for testing and certification of handsets from multiple vendors, often including multiple models and with infrastructure equipment from multiple vendors.

A key business model consideration for 3G deployments is coverage for a significant percentage of the target population of subscribers and areas of usage. NTT DoCoMo of Japan is the first international operator to deploy their FOMA (DoCoMo brand name for WCDMA). It has been well documented in the press, however, that DoCoMo has experienced many problems in their FOMA launch, including lack of a dual-mode handset (FOMA and legacy PDC) with competitive feature sets and battery life as well as early lack of sufficient coverage. Figure 2-5 provides DoCoMo's report of coverage progress since its initial launch. DoCoMo is reporting 99.9% population coverage at calendar year-end 2004 with approximately 14,900 base station transceiver (BTS) sites and 17,300 BTS sites at fiscal year-end March 31, 2005. Interestingly, review of year-end data indicates that DoCoMo had 11.5 million FOMA subscribers and that non-voice data revenues were approximately 39.9% of total revenues. This compares with their legacy PDC service with 46.5 million subscribers and 89.9% iMode (data) subscribers, and non-voice revenues of 25.9% of total revenues. DoCoMo, other Japanese operators, and Korean operators are clear pioneering leaders of 3G deployments and services.

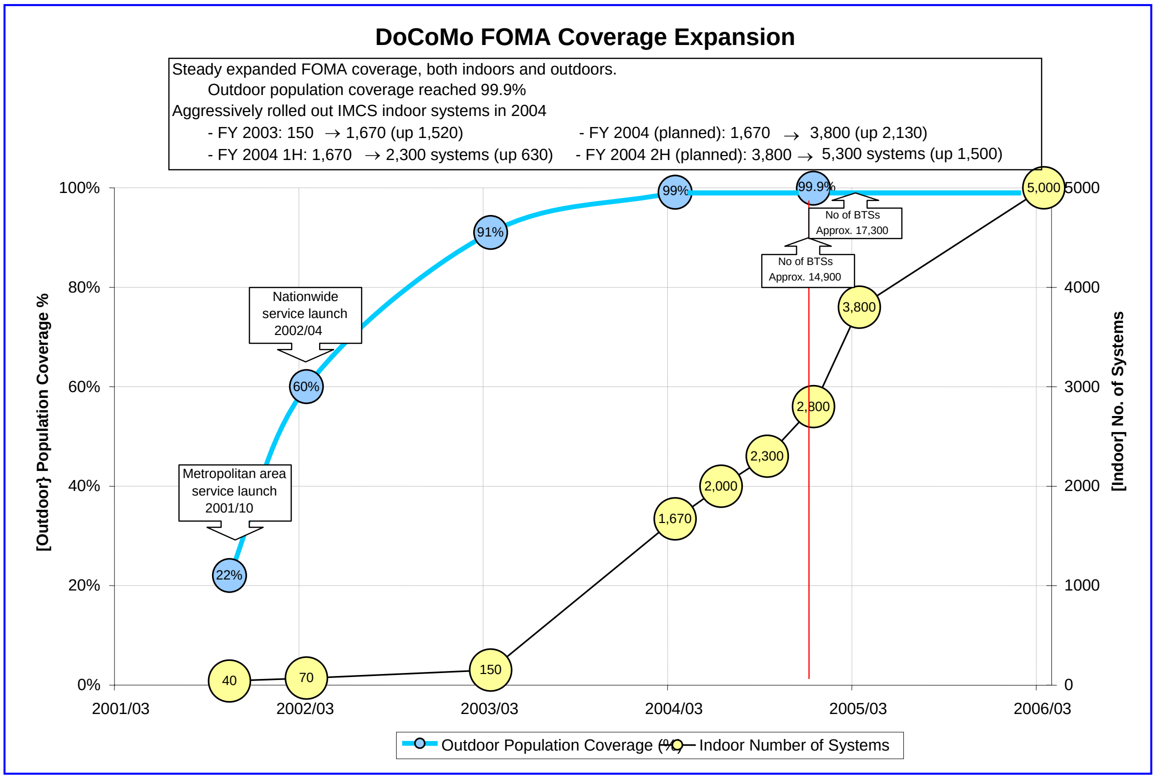


Figure 2-5 DoMoCo FOMA Coverage Expansion
(*Source:* Recreated and adapted from NTT DoCoMo Financial Report, 3rd Qtr FY2004 (ending 12/2004), 1/2005)

Most other international WCDMA operators are currently estimated at approximately 60% population coverage, which DoCoMo achieved on its nationwide launch in April 2002, as indicated in Figure 2-5. We believe that there will be substantial international WCDMA growth throughout the decade as operators deploy for coverage, first in urban and suburban areas, and then upgrade for capacity to address increasing voice and emerging 3G data services capacity requirements.

Although historically receiving less attention, the core network of cellular networks consumes approximately 30% of operator CAPEX in deployments. Over the last several years, the industry has been planning an evolution from the legacy CS (Time Division Multiplexed, or TDM) core networks to converged "all IP" core networks. The heart of this environment is the IP Multimedia Subsystem that provides control layer functionality (including billing). IP transport (generally including backhaul) is provided by the connectivity layer.

Historically, legacy CS core networks have used vertical architectures, as indicated on the left of Figure 2-6, with, for example, cellular, wireless, Internet, and WiFi having incompatible "stove-pipe" core networks. IMS evolves this to converged common applications and core network elements, as presented on the right of the figure, regardless of the access technology (e.g., cellular, Wireline, ISP, WiFi). Wireline, cable, and ISP operators have shown significant interest, indicating intentions to evolve to this converged IMS core. IMS essentially encompasses what has been referred to as Next Generation Network (NGN) initiatives in wireline.

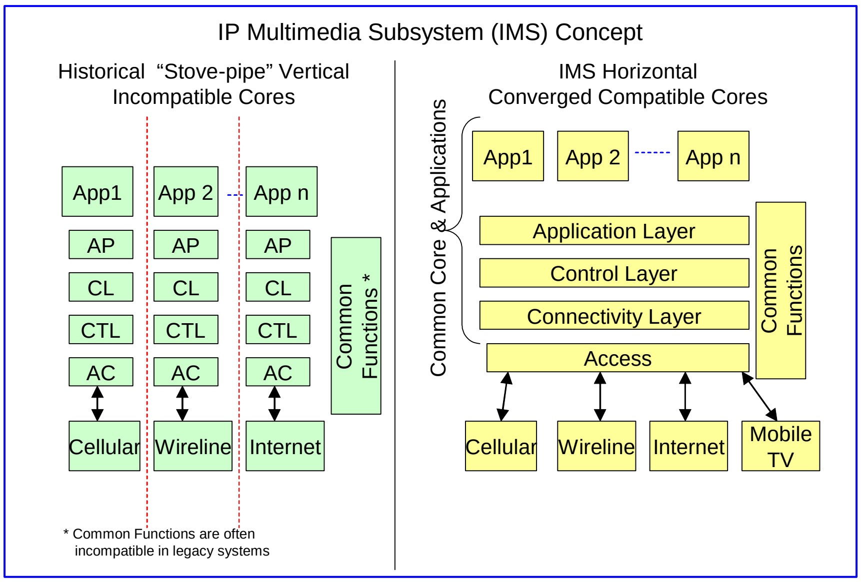


Figure 2-6 IP Multimedia Subsystem Concept
(*Source*: Author research)

A key selection by 3GPP has been the use of the Internet Engineering Task Force's (IETF) Session Initiation Protocol (SIP) to enable peer-to-peer sessions (e.g., voice calls) as opposed to the more typical client-to-server sessions (e.g., web access, email) employed on most legacy Internet networks.

IMS first appeared in 3GPP Release 5, which is generally described as near real-time, and a planned update in Release 6, which is generally described as real-time. Interestingly, 3GPP (GSM/GPRS/EDGE/WCDMA) and 3GPP2 (CDMA 2000) have highly harmonized IMS standards, with the reported major divergence being GPRS versus Mobile IP mobility concepts for IP routing. Note also that the evolution must accommodate compatibility in transition with legacy circuit switched technologies and legacy Internet technologies. This requirement has slowed both the standards process as well as deployments. Most reports indicate that major IMS deployments will most likely begin in 2006 and then evolve and mature in later years.

Lucent Technologies has provided a simplified IMS block diagram (Figure 2-7) that illustrates the emerging IMS architecture. The horizontal layers in this architecture include: the access layer, the transport layer, the session control layer, and the applications layer. Note that the converged network also initiates a common management capability that has been notoriously fragmented, even in legacy individual vertical service networks.

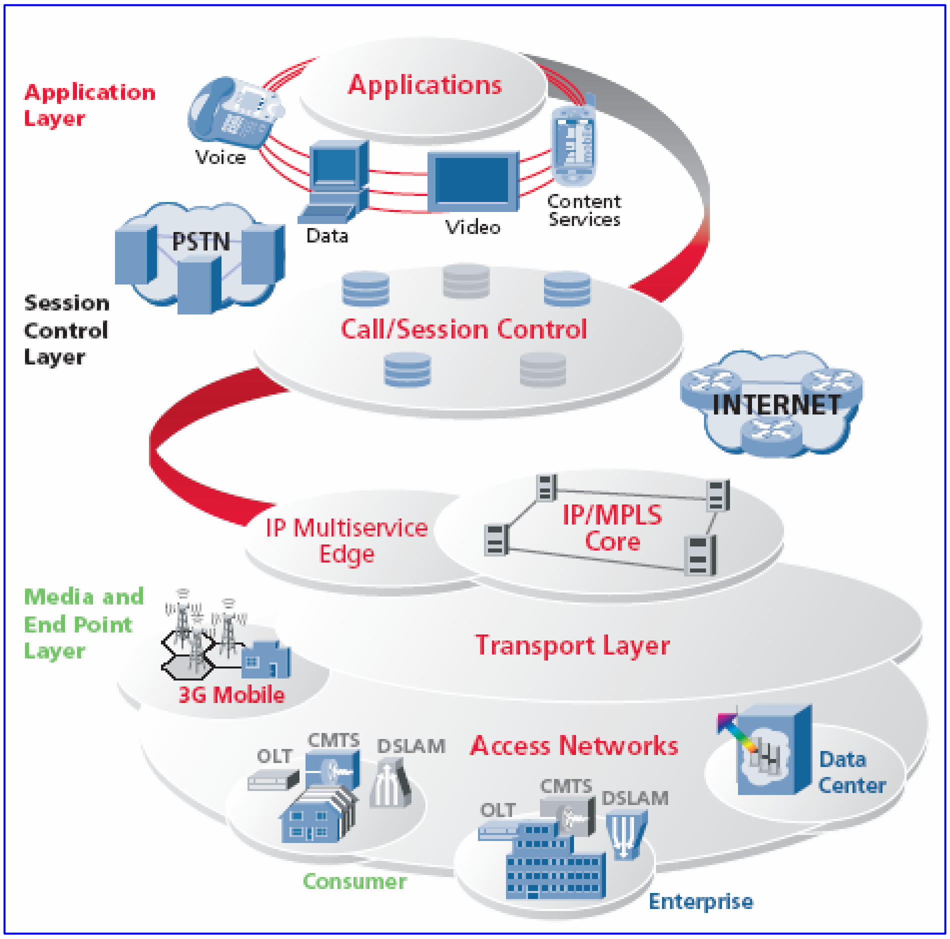


Figure 2-7 Simplified IMS Network Architecture
(*Source*: "Making IMS Simple" white paper by Lucent Technologies, 2005, with permission)

The CDMA 2000 community appears to have executed well, benefiting from being a smaller community for coordination and from the technical creativity of its creator, Qualcomm. Inspection of the 3GToday.com web site has revealed for many months a wide range of available CDMA 2000 3G handsets with popular features. Additionally, the CDMA 2000 community has been able to define and deliver both infrastructure and valued 3G services. CDMA 2000 has not experienced problems comparable to those of the WCDMA with standards maturity. CDMA 2000 is an accredited ITU 3G standard. It has achieved significant successes in many countries, including the United States, Korea, China, India, and Russia. Although GSM and (eventually) WCDMA are anticipated to be the dominant cellular technologies, CDMA 2000 has achieved significant successes sufficient to attract the attention of many GSM/WCDMA vendors.

In the Japanese market for the last several years, KDDI, the CDMA 2000 operator, has attracted more subscribers to its 3G CDMA 2000 1x service than had the earlier deployed

DoCoMo FOMA (WCDMA). (Note that this probably will change in late 2005 or 2006.) KDDI has clearly had the benefit of more mature standards, a greater variety of attractive handsets, a more mature family of 3GPP2 standards, and better coverage.

As presented in the Task 1 report on *Market Segmentation and Sizing*, the CDMA 2000 community has long promoted its technology advantage of common 1.25-MHz-band plans that facilitate more cost-effective transition paths for operators. Interestingly, the Wireless Infrastructure report[1] based on input from operators and network equipment vendors concluded that CDMA 2000 1x has greater voice capacity that GSM/EDGE and even slightly greater voice capacity than WCDMA in 10 MHz of spectrum. No new information has been identified since that report to change these conclusions. Note that WCDMA deployments, except perhaps in Japan, are still in the early phases of service and subscriber ramps and that not much operational experience with loaded networks is currently available.

Figure 2-8 presents the CDMA2 000 community evolution plan overview. For data, CDMA 2000 has two data paths: CDMA 2000 1x-EV-DO (EVolution Data Only) and CDMA 2000 1x-EV-DV (EVolution Data Voice) (Rev. C adding high-speed downlink and Rev. D adding high-speed uplink). Notice that the EV-DO path in the figure is identified by Korean Operator LG Telecom as an overlay to CDMA 2000 1x. Results of industry interviews consistently state that this requires a dedicated reallocation of a 1.25 MHz carrier from 1x voice to 1x-EV-DO data and that an operator cannot reconfigure DO equipment for 1x operations. CDMA 2000 1x-EV-DV provides for voice and data operations on a single carrier. Many operators (e.g., Sprint PCS in the United States) had for many months indicated that they would not deploy EV technology until EV-DV technology was available. However, it appears that competitive pressures, resulting from Verizon Wireless in the United States aggressively deploying 1x-EV-DO nationwide, have motivated many operators, including Sprint PCS, to accelerate 1x-EV-DO deployments. In fact, many attendees at the September 2004 CDG Americas conference in Miami, Florida, and again at CTIA2005 in March in New Orleans, Louisiana, speculated that 1x-EV-DV might never be commercially deployed. Interestingly, several discussions at these conferences concerning analyses of VoIP over 1x-EV-DO indicated 1x-EV-DO could have higher voice capacity than the CDMA 2000 1x voice air interface. However, not much detail was available. The 1x-EV-DO/1x-EV-DV and related VoIP trends should prove very interesting. The focused CDMA 2000 community might lead the industry.

[1] *Wireless Infrastructure Technology and Markets: The Challenge of 3G*, Jim Gunn, published by Forward Concepts, November 2002

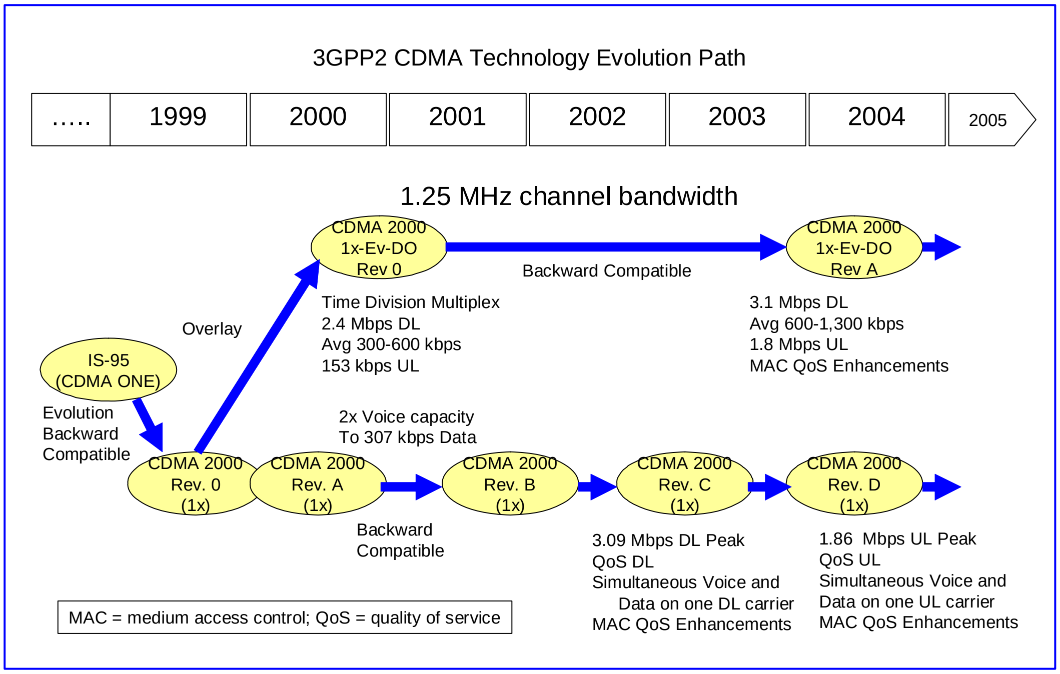


Figure 2-8 3GPP2 Technology Evolution Plan Overview
(*Source*: Adapted from "3G Wireless and cdma2000 1x Evolution in Korea," Kim et al., LG Telecom, *IEEE Communication Magazine*, April 2005, with permission)

Increasingly, the 3GPP and 3GPP2 communities are harmonizing many of their future technology evolution plans. The high-speed links (e.g., HSDPA/HSUPA, CDMA 2000 1x-EV-DO (and -DV)) are largely harmonized (or similar) in their use of enhanced technologies to achieve high speed, such as Adaptive Modulation and Coding (AMC), fast transmission with incremental redundancy, Hybrid Automatic Repeat Request (HARQ), and fast scheduling by moving medium access control (MAC) functionality from base station/radio network control (BSC/RNC) to BTS/NodeB. Additionally, the IMS is a harmonized activity with reports that the major divergence was the 3GPP2's use of IETF's Mobile IP to provide mobility functionality and 3GPP's use of GPRS mobility functionality. Perhaps of most interest are longer range technology evolution plans that include significant harmonization for:

1. Multiuser Detection (MUD or Interference Mitigation)
2. Multiple Inputs, Multiple Outputs (MIMO) Wireless Antenna System
3. Orthogonal Frequency Division Multiplexing (OFDM)
4. Digital Video Broadcast – Mobile

The cellular industry is clearly in a "discovery mode." Traditional cellular voice services provide operators with an essentially single and comparatively simple business model. Voice should continue to be the "killer application" at least for the next several years, perhaps always. 3G adds a multitude of data, enhanced voice, and video service options, and no clear "killer app" is apparent. A more likely scenario is that no single or small number of killer apps will emerge. Each operator will likely be in a discovery mode to provide a winning suite of 3G services base on local demographics, subscriber preferences, differentiating opportunities, and successes. Flexibility to adapt and evolve with market opportunities and requirements will be essential. In mature markets, the goal will undoubtedly be to develop business models to increase ARPU with 3G data services. In emerging markets, the challenge will to be to develop profitable CAPEX and OPEX business models for the available low ARPU opportunities.

As the pioneering 3G “early adopter” markets of Korea and Japan show, 3G subscribers find that these services provide value. Operators in these markets are reporting that 3G subscribers are willing to pay higher ARPU for both voice and data services. 3G deployments will likely continue to achieve increasing international successes. A key requirement will be to provide flexibility for operators to offer winning services responsive to their local market opportunities and requirements. SDR technologies provide substantial benefits to promote successes for 3G.

As presented in the Task 1 report on *Market Segmentation and Sizing*, Figure 2-9 presents a November 2004 front page headline from the *Wall Street Journal* documenting an increasing market requirement for software defined radio capabilities. Historically, cellphone manufacturers have dominated cell phone features, user interfaces, branding presence, and so forth in the legacy voice-centric 2G market. An exception has been DoMoCo in Japan, which has long commanded a strong presence in handset features and branding. The 3G evolution adds a multitude of additional data, video, and voice services. As stated earlier, cellular operators are faced with many differing market segments, requirements, opportunities, and possible operator responses. Emerging are Smartphones with software mass customization capabilities in manufacture, delivery, and field. Multiband and multimode capabilities are proving critical for market success in the 2.5G/3G evolution from voice-centric 2G services and technologies. Subscribers value the superior coverage and familiar look and feel of longer-deployed 2G networks and respond more favorably to multimode, multiband phones. The dominant multimode requirement is for GSM/WCDMA, but PDC/WCDMA is a requirement for Japan. The emerging WLAN/WiFi represents another multimode opportunity.

The Blackberry prominently features Vodafone's branding, one of Vodafone's many demands.

Wall Street Journal, Nov. 12, 2004, p1 article
Headline
"After Long Peace, Wireless Operator Stirs Up Industry. U.K.'s Vodafone Is Dictating Handsets' Look and Feel"
Extract
"Its profit growth is likely to come from selling add-on services and the most effective way to market them is to embed Vodafone's software inside customers' phones."

Figure 2-9 Emerging Markets for Smartphones Require SDR Capabilities

At the 3GSM Congress in Cannes, France, in February 2005, the GSM Association announced that Motorola had been selected to supply the first handsets for the Emerging Market Handset (EMH) program to provide low-cost (under $40) handsets for the emerging markets. Table 2-2 includes an extract from Motorola's press release on this. This low-cost handset represents the antithesis to the Smartphone for the mature high-end market. Although high-end phones should be available at evolving lower costs, there will be a continuing requirement for even cheaper low end phones for emerging markets with low ARPU requirements.

Motorola Chosen by GSM Association to "Connect the Unconnected"

Bringing the promise of mobile technology to everyone

Cannes, France – February 14, 2005 – Motorola, Inc. (NYSE: MOT) has been selected by the GSM Association (GSMA) to supply the first handsets for the Emerging Market Handset (EMH) programme – a programme critical to the social and economic development of many emerging markets.

Motorola will be offering a family of products built on its new, Ultra-Low Cost C114 platform that is optimised for the durability, long talk time and design preferences of emerging markets. Motorola has committed to start delivering these products during the second quarter of 2005 at a price point below US$40 (ex-factory) and has a strategic intent to work with GSMA members to develop follow-on products at sub US$30 price points.

The initial unit volume target for the first six months once shipments begin is six million handsets. This equates to approximately one per cent of the global handset market. As the programme expands, this new market segment has the potential to add more than a 100 million new connections per year.

The GSM Association estimates that despite 80 per cent of the world's population having wireless access, only 25 percent are able to use it, with cost identified as the single biggest barrier to mobile communications usage in emerging markets.

Table 2-2 GSMA selects Emerging Market Handset (EHM) supplier
(*Source*: Motorola press release, February 2005)

Validating the need for SDR technologies is Figure 2-5, which provides data on DoCoMo's deployment of 5000 indoor systems at fiscal year-end 2004. Although an early identified goal of the 3G, less than expected deployment of micro and pico cells has been observed. Yet continual talk of poor coverage abounds, lately more related to specific areas or in-building problem areas. As cellular service has a competitive goal to displace many wireline subscribers to cellular as their only voice services, a requirement exists to provide comparable quality of service in terms of coverage, capacity, voice quality, drop calls, and so on. An obvious solution would be to add more sites, but cell sites are expensive. It is much less expensive to have fewer cell sites with improved coverage, capacity, and quality of service (QoS). Coverage is more that just cell radii, however, because intervening terrain, buildings, and other obstacles can cause poor coverage even inside conservatively designed cell radii. A contributing solution is better RF link performance achieved with advanced technologies such as smart antennas, MIMO antenna systems, and interference mitigation (i.e., MUD). As higher speed is deployed for 3G services, micro, pico, and in-building cells enhanced with advanced technologies such as MIMO and MUD appear essential to total cost of ownership (TCO) cost-effectiveness and minimizing deployments of more costly additional cell sites.

These advanced technologies are key ingredients of the SDR value proposition. The SDR community should position them as key SDR components and values.

3 Cellular Industry Market Forecasts

The cellular industry has had spectacular growth since its initial launches in the early 1980s, as was illustrated in Figure 1-1. Unlike many of the other market segments discussed in the first SDR Market Study report[2], the cellular industry is not dominated (in terms of market numbers/revenues) by the United States. Rather, it is a market that is increasingly being driven by international requirements. Figure 3-1 presents estimates and forecasts of international and selected region subscribers for the decade 2000 to 2010. The subscriber numbers by region used in this figure are presented in Table 3-1. At year-end 2004, the industry achieved more than 1.7 billion subscribers and a penetration of 26.8% (subscribers/population).

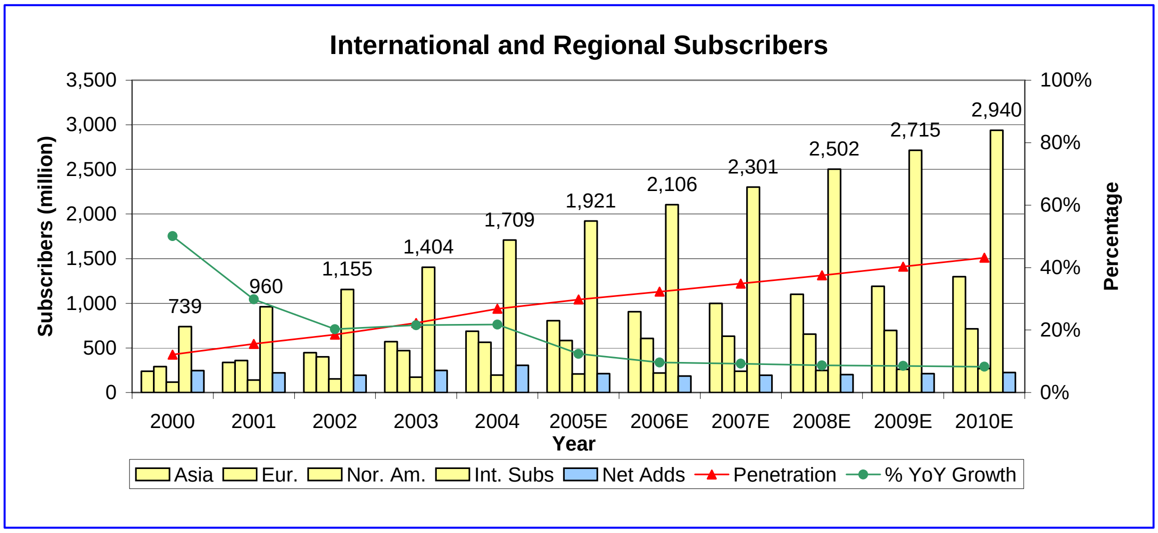


Figure 3-1 International and Regional Subscriber Forecasts
(*Source:* ITU, operator reports, technology associations, and author research)
***Note:* E indicates estimate.**

	2000	2001	2002	2003	2004	2005E	2006E	2007E	2008E	2009E	2010E
Total	739.4	960.0	1,154.8	1,403.8	1,709.3	1,920.8	2,106.0	2,301.3	2,502.4	2,715.2	2,939.7
Africa	15.8	25.7	36.6	51.0	75.5	100.4	123.4	151.2	184.6	219.4	264.8
North America	118.2	139.2	152.6	172.0	197.1	208.6	220.3	239.5	248.9	259.0	269.5
CALA	63.3	85.1	100.7	123.4	167.0	203.3	229.1	257.4	287.0	322.5	363.4
Asia	240.6	337.7	448.5	569.3	688.0	805.9	905.7	999.6	1,101.1	1,192.1	1,298.9
Europe	291.2	358.5	401.2	470.9	562.8	582.6	606.4	630.8	656.4	695.5	714.5
Oceania	10.3	13.7	15.3	17.3	18.8	19.9	21.1	22.8	24.5	26.6	28.5

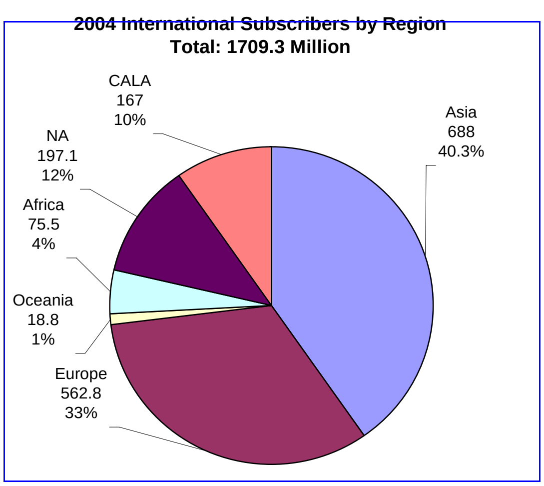
Table 3-1 International Subscribers by Region (in millions)
(*Source:* ITU, operator reports, technology associations, and author research)
***Note:* E indicates estimate.**

[2] *SDR Market Study: Task 1: Market Segmentation and Sizing*, by Jim Gunn, January 2005.

As Figure 3-1 shows, YoY percentage growth in 2004 was 21.8% and is anticipated to decline to 8.3% in 2010. This is in contrast to the consistent approximately 50% YoY growth number in the 1990s, but it is to be expected as a market matures. The industry achieved 1 billion subscribers in 2002. A popular industry expression has been that the second billion anticipated in early 2006 will be more difficult, and the third billion, anticipated around year-end 2010, will be even more difficult. Net subscriber additions (Net Adds) are becoming more difficult because additions increasingly are in lower-tier economies, with subscribers requiring lower rate plans and lower costs. Net Adds were more than 300 million in 2004, the peak year for Net Adds. Virtually all markets have achieved approximately 100% digital subscriber bases at year-end 2004 and the very few remaining legacy analog networks are rapidly being decommissioned.

As the data in Table 3-1 show, Asia has become the leading regional market, followed by Europe. The fastest growing markets in terms of subscriber growth are the emerging markets generally in Asia, Eastern Europe, Africa, and the Caribbean and Latin American (CALA). The leading emerging growth market countries include China, India, Russia, and Brazil.

Figure 3-2 presents the international subscriber numbers by region and technology at year-end 2004. The regional subscriber numbers are presented in Table 3-1, and the subscriber numbers for technologies are presented in Table 3-2. These tables provide estimates and forecasts for the decade 2000 to 2010.



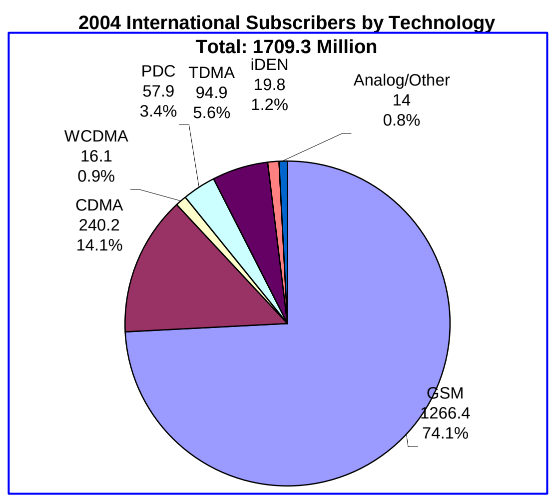


Figure 3-2 2004 International Subscribers by Region and Technology
(*Sources:* ITU, GAMA, CDG, 3G Americas, ITU and author research)

Millions	2000	2001	2002	2003	2004	2005F	2006F	2007F	2008F	2009F	2010F
Total	739.4	960.0	1,154.8	1403.8	1,709.3	1,920.8	2,106.0	2,301.3	2,502.4	2,715.2	2,939.7
GSM	456.0	626.3	790.5	991.6	1,266.4	1,441.7	1,565.6	1,689.5	1,816.9	1,920.9	2,009.5
CDMA	80.4	111.4	146.7	188.6	240.2	305.4	371.2	431.2	481.6	535.3	588.3
WCDMA	0.0	0.0	0.2	2.8	16.1	33.5	57.9	89.3	125.6	189.5	275.3
PDC	51.0	57.1	60.3	62.2	57.9	52.9	46.5	38.3	31.1	23.5	19.6
TDMA	61.3	94.7	107.4	109.0	94.9	55.9	33.7	19.9	11.9	7.1	4.2
iDEN	9.0	11.1	13.6	16.5	19.8	23.9	27.5	31.6	35.3	38.9	42.8
Analog / Other	81.6	59.4	36.1	33.1	14.0	7.5	3.6	1.5	0.0	0.0	0.0

Table 3-2 International Subscribers by Technology (in millions)
(*Sources:* GSMA, CDG, Operator Reports, 3G America, and author research)
Note: F indicates forecast.

Inspections of these figures and tables confirm that the market is growing and that Asia and Europe are the leading international markets. Additionally, the dominant technology is clearly GSM (inclusively GSM/EDGE/GPRS). Whereas the emerging markets are focused on Net Adds, the more mature markets are saturated with relatively high penetration and are focusing on emerging 3G technologies and data services as their future revenue growth opportunities.

Table 3-3 presents the 2004 year-end top 25 international markets by subscribers. As the table illustrates, emerging markets, currently at low penetration, are rapidly increasing subscribers. China, India, and Brazil, with high populations, comparatively lower GDPs, and lower cellular penetrations, and are attracting much current international attention as the hot growth markets. Assuming sufficiently low-cost rate plans (and operator business models) for less economically able subscribers, these economies will be the dominant Net Adds growth markets for the future. In the last year or two, India, the second largest country by population at more than 1 billion persons, has gained momentum in cellular subscriber penetration.

Rank	Country	Region	Subscribers	Penetration
	World Total		1,709.7	26.8%
1	China	Asia	326.5	25.1%
2	United States	North America	182.1	62.2%
3	Japan	Asia	90.2	70.8%
4	Germany	Europe	71.3	86.5%
5	Russia	Europe	70.9	49.2%
6	Brazil	CALA	65.6	35.6%
7	Italy	Europe	62.7	107.9%
8	United Kingdom	Europe	61.9	102.6%
9	India	Asia	45.7	4.3%
10	France	Europe	44.6	73.7%
11	Spain	Europe	39.1	97.1%
12	Mexico	CALA	38.5	36.7%
13	Korea (Rep. of)	Asia	36.6	75.9%
14	Turkey	Europe	36.0	52.3%
15	Philippines	Asia	33.0	38.3%
16	Thailand	Asia	31.5	48.5%
17	Indonesia	Asia	28.3	11.9%
18	Taiwan, China	Asia	21.5	94.6%
19	South Africa	Africa	21.5	48.4%
20	Poland	Europe	20.7	53.6%
21	Australia	Asia	17.9	88.9%
22	Netherlands	Europe	16.0	99.5%
23	Canada	North America	15.1	47.1%
24	Malaysia	Asia	14.6	56.5%
25	Argentina	CALA	12.9	33.0%
	Top 25 Total		1,404.7	

Table 3-3 Top 25 International Cellular Markets by 2004 Subscribers (in millions)
(*Sources*: Company reports, country government statistics, industry associations, and author research)

Table 3-4 presents the 2004 top 11 cellular operators by number of subscribers. The subscriber numbers in this table are proportionate subscribers based on percent ownership of subsidiaries and affiliates. Not surprisingly, China Mobile and China Unicom are ranked 1 and 3. Excluding Verizon Wireless and Cingular (United States), the Chinese operators, and NTT DoCoMo (Japan), most of the other top-ranked operators have operations in multiple countries.

Rank	Operator	Corporate Headquarters	Subscribers (million)
1	China Mobile	China/Hong Kong	204.3
2	Vodafone	United Kingdom	151.8
3	China Unicom	China/Hong Kong	84.3
4	T-Mobile (Deutsch Telekom)	Germany	69.2
5	America Movil	Mexico	60.6
6	Orange (France Telecom)	France/United Kingdom	57.3
7	Telefonica	Spain	49.6
8	Cingular	United States	49.1
9	NTT DoCoMo	Japan	47.9
10	Verizon Wireless	United States	43.8
11	Telecom Italia Mobile (TIM)	Italy	42.0

Table 3-4 Top 11 International Wireless Operators Ranked by Proportional Subscribers
(*Sources:* Operator reports and author research)

3.1 Cellular Phone Forecasts

The cellular phone (cellphone) market, after experiencing down or flat years in the early 2000s, has been on a steady growth ramp that appears sustainable for the decade, as the forecasts presented in Figure 3-3 indicate. The key trend is that an increasing percentage of cellphone sales are replacement sales to existing customers. In many cases, these replacement customers are new customers to the acquiring operators resulting from churn (i.e., terminations) from other operators.

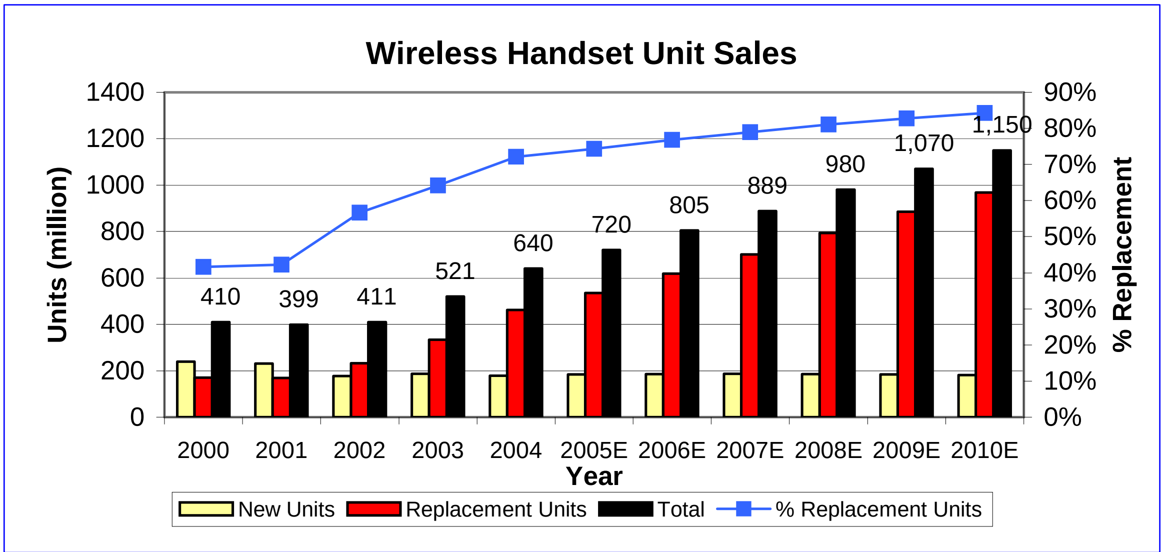


Figure 3-3 Wireless Handset Unit Forecast
(*Sources:* Company reports, financial analyst reports, and author estimates)
Note: E indicates estimate.

Net Adds refers to the net increase of subscribers from one reporting period (e.g., month, quarter, year) to another, and Gross Adds are total new subscribers to an operator including Net Adds and additions that replace subscribers lost through churn. As operators generally subsidize cellphone purchases to attract new subscribers, reduction of churn is a key goal of operators. Operators generally allocate marketing budgets for both subscriber acquisition and retention. Retention is almost always more cost effective than new subscriber acquisition. Churn reduction is a consistently identified operator priority.

In general, yearly handset unit sales by industry are estimated from company reports and verified as follows:

Sales Out = Net Adds + Churn + Handset Upgrades or Replacements – Refurbished Units

Sales In = Sales Out ± Inventory Adjustment = Handset Industry Sales

where Net Adds = new subscribers

Churn = additional new subscribers replacing lost subscribers)

Table 3-5 presents details of the wireless handset estimates and forecasts, including new units, replacement units, and total units. Percentages of year-over-year growth and percentage of previous year subscribers are also presented.

Handset / Terminals (M)	2000	2001	2002	2003	2004	2005E	2006E	2007E	2008E	2009E	2010E
New Units	239.1	230.4	177.9	186.5	178.2	184.5	186.3	187.1	185.9	184.1	181.3
Replacement Units	170.4	168.6	232.6	334.0	462.1	535.5	618.7	701.9	794.1	885.9	968.7
Total Units	409.5	399.0	410.5	520.5	640.3	720.0	805.0	889.0	980.0	1070.0	1150.0
% New Units	58.4%	57.7%	43.3%	35.8%	27.8%	25.6%	23.1%	21.0%	19.0%	17.2%	15.8%
% Replacement Units	41.6%	42.3%	56.7%	64.2%	72.2%	74.4%	76.9%	79.0%	81.0%	82.8%	84.2%
Year-over-Year % Growth	2000	2001	2002	2003	2004	2005E	2006E	2007E	2008E	2009E	2010E
New Units	41.3%	-3.6%	-22.8%	4.8%	-4.5%	3.6%	0.9%	0.4%	-0.6%	-1.0%	-1.5%
ReplacementUnits	39.1%	-1.1%	38.0%	43.6%	38.4%	15.9%	15.5%	13.4%	13.1%	11.6%	9.3%
Total	40.4%	-2.6%	2.9%	26.8%	23.0%	12.4%	11.8%	10.4%	10.2%	9.2%	7.5%
% Previous year subscribers	2000	2001	2002	2003	2004	2005E	2006E	2007E	2008E	2009E	2010E
New Units	49.0%	31.7%	18.6%	16.4%	13.5%	12.3%	11.1%	10.0%	9.0%	8.2%	7.5%
Replacements Units	34.9%	23.2%	24.3%	29.4%	35.0%	35.7%	36.7%	37.5%	38.6%	39.5%	39.9%
Total Units	83.9%	54.9%	42.9%	45.8%	48.4%	48.0%	47.8%	47.5%	47.6%	47.7%	47.4%

Table 3-5 Wireless Handset Forecast
(*Sources:* Company reports, financial analyst reports, and author estimates)
***Note:* E indicates estimate.**

Table 3-6 presents forecasts for wireless handsets by technology. The table also presents percentage of total units and percent year-over-year growth. The clear take-away from the information in this table is that GSM dominates the units throughout the decade.

Handsets (000,000)	2000	2001	2002	2003	2004	2005E	2006E	2007E	2008E	2009E	2010E
Total	409.5	399.0	410.5	520.5	640.3	720.0	805.0	889.0	980.0	1,070.0	1,150.0
GSM	275.7	266.6	289.7	384.9	484.8	514.7	564.7	621.7	687.0	717.4	738.6
CDMA	45.5	47.9	57.7	76.0	91.5	129.6	159.2	178.0	193.2	216.3	234.1
WCDMA	0.0	0.0	0.2	2.7	13.9	21.7	34.6	49.8	65.9	106.3	149.9
PDC	17.2	16.8	14.7	15.9	13.2	15.5	16.2	14.8	12.7	10.5	8.0
TDMA	36.8	46.4	31.7	26.6	23.1	25.4	17.1	10.7	6.6	4.0	2.4
iDEN	5.5	4.0	4.7	6.1	6.8	9.4	10.9	12.8	14.2	15.5	17.1
Analog / Other	28.9	17.3	11.9	8.4	7.0	3.8	2.3	1.1	0.5	0.0	0.0
% Total	2000	2001	2002	2003	2004	2005E	2006E	2007E	2008E	2009E	2010E
Total	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
GSM	67.3%	66.8%	70.6%	74.0%	75.7%	71.5%	70.2%	69.9%	70.1%	67.0%	64.2%
CDMA	11.1%	12.0%	14.1%	14.6%	14.3%	18.0%	19.8%	20.0%	19.7%	20.2%	20.4%
TDMA	0.0%	0.0%	0.0%	0.5%	2.2%	3.0%	4.3%	5.6%	6.7%	9.9%	13.0%
PDC/PHS	4.2%	4.2%	3.6%	3.1%	2.1%	2.2%	2.0%	1.7%	1.3%	1.0%	0.7%
WCDMA	9.0%	11.6%	7.7%	5.1%	3.6%	3.5%	2.1%	1.2%	0.7%	0.4%	0.2%
Analog / Other	1.3%	1.0%	1.2%	1.2%	1.1%	1.3%	1.4%	1.4%	1.5%	1.5%	1.5%
% Growth	2000	2001	2002	2003	2004	2005E	2006E	2007E	2008E	2009E	2010E
Total	40.4%	-2.6%	2.9%	26.8%	23.0%	12.4%	11.8%	10.4%	10.2%	9.2%	7.5%
GSM	61.6%	-3.3%	8.6%	32.9%	26.0%	6.2%	9.7%	10.1%	10.5%	4.4%	3.0%
CDMA	28.0%	5.3%	20.4%	31.8%	20.4%	41.5%	22.9%	11.8%	8.5%	11.9%	8.2%
TDMA			560.8%	1383.4%	425.0%	56.3%	59.5%	43.8%	32.3%	61.4%	41.0%
PDC/PHS	-27.8%	-1.8%	-12.8%	8.2%	-17.2%	17.7%	4.3%	-8.6%	-14.3%	-17.1%	-24.3%
WCDMA	57.9%	25.9%	-31.7%	-16.1%	-13.1%	10.1%	-32.8%	-37.2%	-38.5%	-39.0%	-40.2%
Analog / Other	74.2%	-27.0%	18.5%	28.3%	12.1%	38.4%	16.0%	17.7%	10.3%	9.5%	10.0%

Table 3-6 Wireless Handset Unit Forecast by Technology
(*Sources:* Company reports, financial analyst reports, and author estimates)
***Note:* E indicates estimate.**

As previously stated, WCDMA appears to be on track to eventually become the dominant international standard. Increasingly, wireless phones will be dual-mode (perhaps multimode), generally having WCDMA and at least one local legacy technology (e.g., GSM in Europe, PDC in Japan). The opportunities for SDR are abundant. Dual-mode phones in these unit estimates are considered as one unit and counted in the most advanced technology category (e.g., WCDMA when GSM is also included). If WCDMA transitions occur faster (or slower) than anticipated, then the WCDMA, GSM, and other unit forecasts would change because more units would be WCDMA capable with multimode capabilities.

Figure 3-4 presents a breakout of the units for the anticipated dominant technologies. As the figure indicates, the dominant technologies are anticipated to be GSM/GPRS and GSM/GPRS/EDGE and CDMA 2000 1x-RTT and CDMA2000 1x-EV-DO. The estimates for WCDMA and WCDMA/HSDPA assume a ramp similar to the initial early 1990s ramp of GSM.

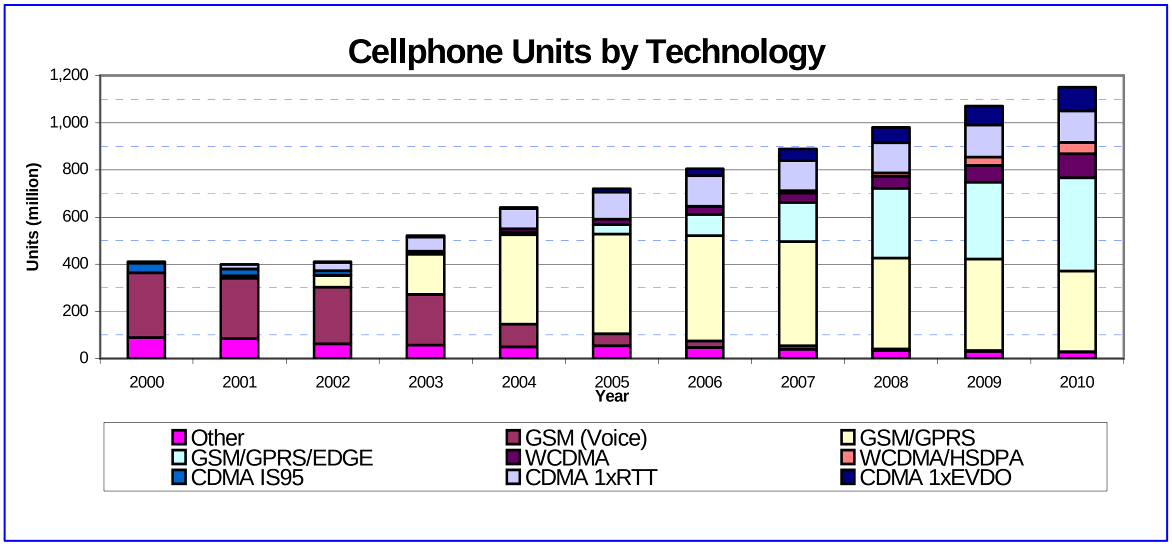


Figure 3-4 Cellular Phone Market Forecast by Technology
(*Sources:* Cellphone manufacturers, financial analyst reports, and author estimates)
***Note:* Years 2005-2010 are estimates.**

Table 3-7 presents estimates and forecasts of unit sales by region.

Handsets Units (million)	2000	2,001	2002	2,003	2004	2005E	2006E	2007E	2008E	2009E	2010E
Total	409.5	399.0	410.5	520.5	640.3	720.0	805.0	889.0	980.0	1070.0	1150.0
Africa	10.7	13.7	16.7	23.0	36.6	47.4	55.4	68.5	84.6	98.1	120.2
North America	69.2	70.5	77.5	82.5	85.0	87.5	89.1	90.8	92.4	94.0	95.7
Caribbean and Latin America	39.5	38.0	34.7	43.0	49.0	55.0	61.5	67.9	74.9	78.1	79.5
Asia	128.5	136.8	145.1	172.5	192.9	214.1	232.0	237.4	247.7	255.0	260.0
Europe	160.5	137.6	134.2	149.0	162.5	175.2	187.8	202.5	212.0	220.5	225.5
Oceana	5.1	5.9	4.7	5.6	5.6	6.8	5.6	8.6	9.4	10.5	11.0
Handsets Units % Total	2000	2001	2002	2003	2004	2005E	2006E	2007E	2008E	2009E	2010E
Total	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
Africa	2.6%	3.4%	4.1%	4.4%	5.7%	6.6%	6.9%	7.7%	8.6%	9.2%	10.5%
North America	16.9%	17.7%	18.9%	15.9%	13.3%	12.2%	11.1%	10.2%	9.4%	8.8%	8.3%
Caribbean and Latin America	9.7%	9.5%	8.4%	8.3%	7.7%	7.6%	7.6%	7.6%	7.6%	7.3%	6.9%
Asia	31.4%	34.3%	35.4%	33.1%	30.1%	29.7%	28.8%	26.7%	25.3%	23.8%	22.6%
Europe	39.2%	34.5%	32.7%	28.6%	25.4%	24.3%	23.3%	22.8%	21.6%	20.6%	19.6%
Oceana	1.2%	1.5%	1.1%	1.1%	0.9%	0.9%	0.7%	1.0%	1.0%	1.0%	1.0%
Handsets Units % YoY Growth	2000	2001	2002	2003	2004	2005E	2006E	2007E	2008E	2009E	2010E
Total	40.4%	-2.6%	2.9%	26.8%	23.0%	12.5%	11.8%	10.4%	10.2%	9.2%	7.5%
Africa	117.2%	28.2%	21.7%	37.7%	59.2%	29.4%	16.9%	23.6%	23.5%	16.0%	22.5%
North America	29.4%	1.9%	9.9%	6.5%	3.0%	2.9%	1.8%	1.9%	1.8%	1.7%	1.8%
Caribbean and Latin America	68.1%	-3.8%	-8.8%	24.1%	14.0%	12.2%	11.8%	10.4%	10.3%	4.3%	1.8%
Asia	36.0%	6.5%	6.1%	18.9%	11.8%	11.0%	8.4%	2.3%	4.3%	3.0%	2.0%
Europe	44.3%	-14.3%	-2.5%	11.0%	9.1%	7.8%	7.2%	7.8%	4.7%	4.0%	2.3%
Oceana	21.1%	16.1%	-20.4%	19.4%	0.3%	20.5%	-17.0%	53.3%	9.8%	11.6%	4.5%

Table 3-7 Wireless Handset Unit Forecast by Region
(*Sources:* Company reports, financial analyst reports, and author estimates)
***Note:* E indicates estimate.**

Table 3-8 provides estimates of vendor market units and percentage market share from 2000 through 2004. Not surprisingly, Nokia and Motorola are the leading vendors. Samsung and LG, both Korean vendors, are consistently increasing market share, and LG is anticipated to achieve the fourth market position in 2005.

Vendor	2000		2001		2002		2003		2004	
	Units	% Share	Units	% Share	Units	% Share	Units	% Share	Units	% Share
Nokia	128.4	]	140.0	35.1%	150.0	36.5%	179.3	34.4%	207.7	32.4%
Motorola	67.6	16.5%	63.0	15.8%	67.9	16.5%	74.9	14.4%	104.4	16.3%
Samsung	21.4	5.2%	28.7	7.2%	41.0	10.0%	55.9	10.7%	86.8	13.6%
Siemens	28.9	7.1%	29.5	7.4%	34.2	8.3%	42.7	8.2%	49.1	7.7%
LG	13.5	3.3%	9.9	2.5%	15.0	3.7%	27.9	5.4%	44.3	6.9%
Sony/Ericsson	43.5	10.6%	28.3	7.1%	22.0	5.4%	26.9	5.2%	42.9	6.7%
Panasonic	21.6	5.3%	12.2	3.1%	13.7	3.3%	18.2	3.5%	21.8	3.4%
NEC	18.8	4.6%	12.9	3.2%	11.7	2.9%	13.8	2.7%	17.9	2.8%
Kyocera	5.4	1.3%	7.4	1.9%	8.3	2.0%	9.9	1.9%	12.8	2.0%
TLC/Alcatel	19.1	4.7%	10.9	2.7%	13.0	3.2%	8.1	1.6%	9.1	1.4%
Audiovox	1.0	0.2%	7.0	1.8%	5.3	1.3%	4.3	0.8%	5.1	0.8%
Other	41.3	10.1%	56.2	14.1%	33.7	8.2%	62.9	12.1%	43.5	6.8%
Total	409.5	100.0%	399.0	100.0%	410.5	100.0%	520.5	100.0%	640.3	100.0%

Table 3-8 Cellular Phone Vendor Market Share
(*Sources:* Company reports, financial analyst reports, and author estimates)

Figure 3-5 presents a forecast of revenues for the cellphone industry during the decade 2000–2010. The industry is forecast to be more than $1,000 billion dollar market opportunity during the decade. It is possible that the total market opportunity could be reduced with less than anticipated subscriber growth and if competitive pressures reduce the average selling price (ASP), which could be possible, especially in emerging markets where higher prices could influence subscribers not to purchase.

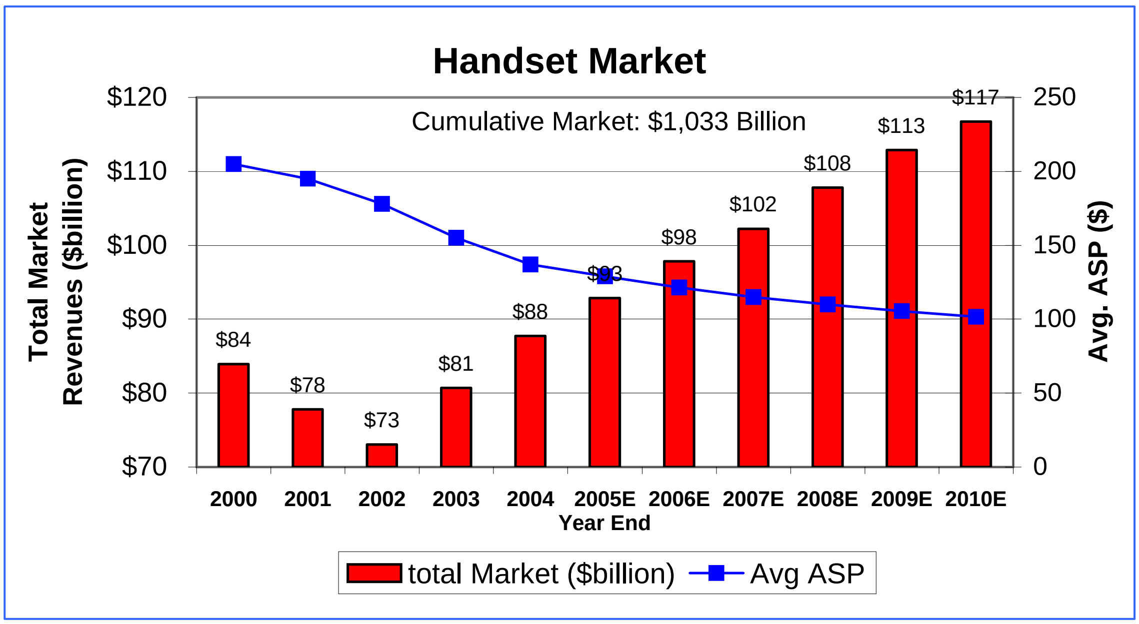


Figure 3-5 Cellular Handset RevenueEstimates and Forecasts
(*Sources:* Company reports, financial analyst reports, and author estimates)
Note: E indicates estimate.

3.2 Cellular Infrastructure Forecasts

Deployed infrastructure is a function of the number of subscribers, the amount of traffic that they place on the infrastructure, and the coverage requirements. In Greenfield deployments, infrastructure is typically dimensioned to provide coverage. As subscribers and their offered traffic grow, dimensioning evolves to a capacity focus. Much of the world now has cellular service, so the infrastructure market is increasingly evolving to a replacement market with capacity focus.

Many industry representatives and many published papers indicate that cellular networks are dimensioned using the 100-year-old Erlang technique[3]. Basically, this targets a typical blocking probability of 2%, which theoretically requires that offered subscriber voice traffic load typically be less than 90% of sector (or cell) voice capacity. Figure 3-6 extrapolates this concept to international composite capacity load as a function of average subscriber monthly minutes of use (MOU).

Increasingly, operators are offering more monthly minutes (often in flat-rate bucket plans) at lower costs. Thus, even with decreasing subscriber growth and even if 3G data services emerge more slowly than envisioned, the demand for infrastructure equipment should increase to support growing voice capacity requirements. As 3G data usage increases, enhanced infrastructure deployments will be required to provide for the increased capacity for wireless multimedia capacity for Internet, streaming video, streaming music, and similar modes.

[3] *Wireless Infrastructure Technology and Markets: The Challenge of 3G*, Jim Gunn, Published by Forward Concepts, November 2002

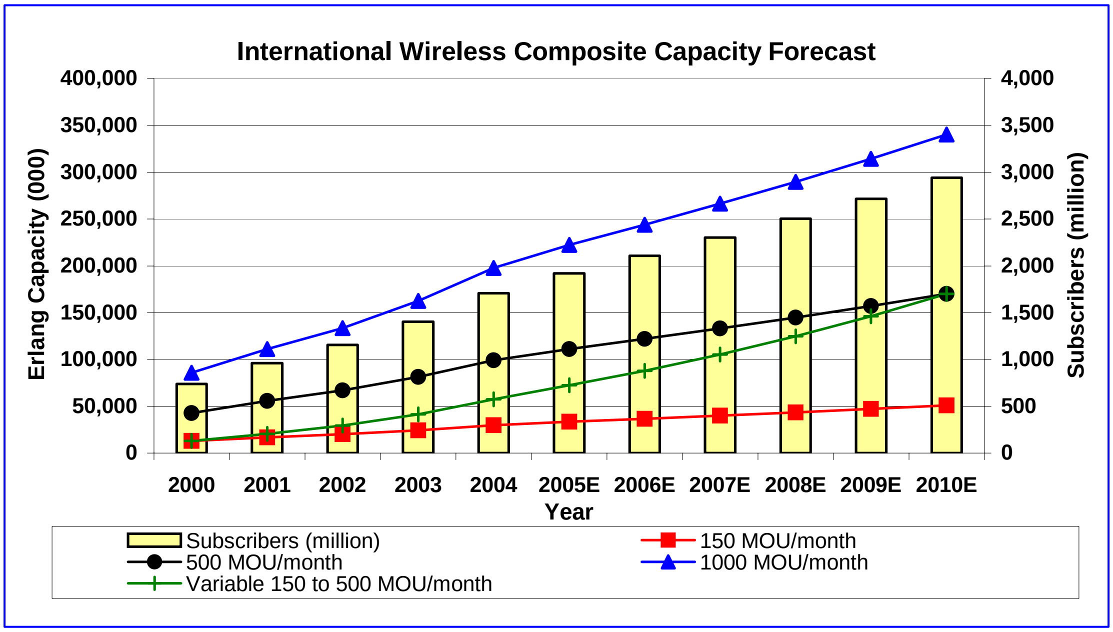


Figure 3-6 International Wireless Voice Capacity Estimates and Forecasts
(*Sources:* Company reports, financial analyst reports, and author estimates)
***Note:* E indicates estimate.**

While emerging nonvoice multimedia traffic will reduce voice capacity, the consensus industry opinion indicates that voice will be the killer app for the foreseeable future and that capacity for voice will be carefully planned and deployed to maintain—in fact, enhance—capacity as well as performance (e.g., Erlang, dropped calls).

Table 3-9 presents the international operator CAPEX forecast for infrastructure. The term CAPEX is used in a very fuzzy manner in many industry analyses. Often CAPEX is used as composite international wireless infrastructure vendor revenues. In actuality, operators do not spend all their CAPEX budgets with their network equipment vendor(s). In a Greenfield deployment, an estimated 50% of an operator's CAPEX budget is allocated for network equipment vendor purchases. In mature market upgrades, this estimate increases to typically 66.6% or more. Nonvendor (other) CAPEX allocation includes site planning and construction, towers, buildings, backup power, and so on. In Table 3-9, the data for Base Station and Switch represents CAPEX expenses generally allocated to network equipment vendor purchases.

	2000	2001	2002	2003	2004	2005E	2006E	2007E	2008E	2009E	2010E
Operator Infrastructure Investments	$98.5	$87.2	$76.1	$70.0	$81.0	$82.3	$86.4	$90.7	$95.3	$100.0	$105.0
Base Station & Switch	$54.7	$52.5	$45.9	$43.8	$52.3	$54.9	$57.6	$60.5	$63.5	$66.7	$70.0
Base Station	$38.3	$36.8	$32.1	$30.6	$36.6	$38.4	$40.3	$42.3	$44.5	$46.7	$49.0
MSC Switch	$16.4	$15.8	$13.8	$13.1	$15.7	$16.5	$17.3	$18.1	$19.1	$20.0	$21.0
Other	$43.8	$34.7	$30.3	$26.3	$28.7	$27.4	$28.8	$30.2	$31.8	$33.3	$35.0

Table 3-9 Forecast Operator Infrastructure Capital Expense (CAPEX) Investments ($billion)
(*Sources*: Vendor reports, Various financial analyst reports, ITU, and author estimates)
***Note:* E indicates estimate.**

The market for infrastructure equipment—similar to the cellphone market—is increasingly for replacement equipment for existing cell sites. This reduces operator CAPEX for cell site construction and related expenses. Table 3-10 presents estimates for international cell sites, average yearly investment per subscriber, and average yearly investment per cell site.

	2000	2001	2002	2003	2004	2005E	2006E	2007E	2008E	2009E	2010E
Global - Subs (million)	739.4	960.0	1,154.8	1,403.9	1,709.3	1,919.8	2,104.1	2,297.9	2,498.0	2,709.9	2,932.0
Delta Subs	246.6	220.6	194.9	249.0	305.4	210.6	184.2	193.8	200.2	211.9	222.1
Cell Sites	616,135	662,048	699,297	759,769	879,184	946,050	1,037,987	1,097,461	1,179,796	1,266,863	1,354,719
Delta Cell Sites	146,838	45,913	37,249	60,473	119,415	66,866	91,937	59,475	82,335	87,066	87,857
Avg $ Investment per Subscriber	$74	$55	$40	$31	$31	$29	$27	$26	$25	$25	$24
Avg $ Investment per Cell Site	$88,828	$79,330	$65,594	$57,596	$59,430	$57,991	$55,497	$55,114	$53,831	$52,638	$51,686
Existing Site % Investment	47.0%	55.0%	58.0%	68.0%	74.0%	76.0%	80.0%	81.0%	82.0%	83.0%	84.0%

Table 3-10 Estimated and Forecast Wireless Network Equipment Electronic Equipment and Service CAPEX
(*Source*: Update from *Wireless Infrastructure Technology and Markets: The Challenge of 3G*, by Jim Gunn, published by Forward Concepts, November 2002)
***Note:* E indicates estimate.**

The predominant drivers of infrastructure deployments are (1) capacity to achieve performance (e.g., blocked, dropped calls) and (2) geographic coverage. Table 3-11 and Table 3-12 provide international forecasts by technology and region, respectively, of the number of channels, RF carriers, and cell sites. Fundamentally, wireless infrastructure demand is determined by, among other factors, number of subscribers, MOU, and data traffic, which is addressed by deployed channels, RF carriers, cell sites, and so forth.

	2000	2001	2002	2003	2004	2005E	2006E	2007E	2008E	2009E
	International Total									
Global - Subs (million)	739.4	960.0	1,154.8	1,403.9	1,709.3	1,919.8	2,104.1	2,297.9	2,498.0	2,709.9
Erlangs (000)	40,572.0	54,116.0	65,816.6	79,397.1	95,216.3	105,723.6	114,397.3	123,492.8	132,249.1	140,405.3
Channels (000)	53,475.2	70,952.1	86,149.8	104,551.6	128,018.9	144,186.7	158,563.8	165,576.1	173,207.7	183,793.5
RF Carriers (000)	13,678.6	15,031.6	15,819.6	17,777.3	18,576.3	19,050.5	19,607.7	20,526.4	21,414.6	22,354.5
Cells	616,135	662,048	699,297	759,769	879,184	946,050	1,037,987	1,097,461	1,179,796	1,266,863
	GSM/GPRS/EDGE									
Global - Subs (million)	456	626.3	790.5	991.6	1266.4	1441.74	1565.6	1689.5	1816.9	1920.9
Erlangs (000)	21,825.2	30,540.1	39,095.1	49,860.1	64,552.1	73,745.8	80,270.0	86,683.8	93,028.4	98,137.4
Channels (000)	29,100.3	40,720.1	52,126.8	66,480.2	86,069.4	98,327.7	107,026.7	115,578.3	124,037.8	130,849.9
RF Carriers (000)	3,880.0	5,429.4	6,950.2	8,864.0	11,475.9	13,110.4	14,270.2	15,410.4	16,538.4	17,446.7
Cells	380,000	431,931	471,592	524,200	633,156	691,063	754,574	879,948	936,546	985,077
	CDMA IS-95/CDMA2000-1x/CDMA2000-1x-EV-DO									
Global - Subs (million)	80.4	111.4	146.7	188.6	240.2	305.4	371.2	431.2	481.6	535.3
Erlangs (000)	6,088.0	9,012.2	11,767.7	14,840.3	18,633.7	22,489.8	25,989.4	29,128.0	31,849.6	34,701.0
Channels (000)	7,610.0	11,265.3	14,709.6	18,550.4	23,292.1	28,112.2	32,486.7	36,410.0	39,812.0	43,376.2
RF Carriers (000)	447.7	662.7	865.3	1,091.2	1,370.1	1,653.7	1,911.0	2,141.8	2,341.9	2,551.5
Cells	67,033	76,794	91,688	107,771	133,444	162,880	195,368	154,000	172,000	191,179
	UMTS/WCDMA/HSDPA									
Global - Subs (million)	0.0	0.027	0.2	2.8	16.1	33.5	57.9	89.3	125.6	189.5
Erlangs (000)	0.0	0.3	2.2	28.9	161.0	364.0	677.1	1,092.1	1,491.7	2,123.7
Channels (000)	0.0	7.2	48.0	614.4	3,434.7	6,034.2	9,479.3	5,162.4	1,864.6	2,654.6
RF Carriers (000)	0.0	0.060	0.4	4.8	26.8	48.3	77.5	101.2	36.6	52.1
Cells	-	19	125	1,600	8,944	17,867	30,474	31,893	44,857	67,679
	Other - including TDMA/PDC/iDEN/Analog									
Global - Subs (million)	202.9	222.3	217.4	220.9	186.6	139.2	105.6	86.5	74.0	64.3
Erlangs (000)	12,658.7	14,563.4	14,951.6	14,667.8	11,869.5	9,124.1	7,460.9	6,589.0	5,879.5	5,443.1
Channels (000)	16,764.9	18,959.6	19,265.4	18,906.7	15,222.7	11,712.6	9,571.1	8,425.4	7,493.3	6,912.7
RF Carriers (000)	9,350.9	8,939.5	8,003.7	7,817.3	5,703.4	4,238.2	3,349.0	2,873.0	2,497.8	2,304.2
Cells	169,102	153,304	135,892	126,198	103,640	74,240	57,571	31,621	26,393	22,929

Table 3-11 International Wireless Infrastructure Electronic Equipment Estimates and Forecasts of Channels, RF Carriers, and Cell Sites by Technology

(*Source*: Update from *Wireless Infrastructure Technology and Markets: The Challenge of 3G*, by Jim Gunn, published by Forward Concepts, November 2002)

***Note:* E indicates estimate.**

	2000	2001	2002	2003	2004	2005E	2006E	2007E	2008E	2009E
Global - Subs (million)	739.4	960.0	1,154.8	1,403.9	1,709.3	1,919.8	2,104.1	2,297.9	2,498.0	2,709.9
Erlangs (000)	40,572.0	54,116.0	65,816.6	79,397.1	95,216.3	105,723.6	114,397.3	123,492.8	132,249.1	140,405.3
Channels (000)	53,475.2	70,952.1	86,149.8	104,551.6	128,018.9	144,186.7	158,563.8	165,576.1	173,207.7	183,793.5
RF Carriers (000)	13,678.6	15,031.6	15,819.6	17,777.3	18,576.3	19,050.5	19,607.7	20,526.4	21,414.6	22,354.5
Cells	616,135	662,048	699,297	759,769	879,184	946,050	1,037,987	1,097,461	1,179,796	1,266,863
North America - Subs (million)	118.2	139.2	152.6	172.0	197.1	207.8	218.6	236.6	245.1	254.5
Erlangs (000)	11,425.2	15,335.2	17,974.9	20,468.0	23,618.1	24,815.3	25,650.0	27,031.0	27,651.4	28,333.5
Channels (000)	14,772.5	19,518.1	22,735.6	25,980.7	30,148.1	31,722.0	32,818.7	34,591.9	35,380.3	36,248.4
RF Carriers (000)	5,516.2	5,182.1	4,771.7	4,756.8	4,592.9	4,230.5	4,093.3	4,260.2	4,272.1	4,368.6
Cells	98,504.0	96,025.0	95,385.0	98,293.0	109,511.0	110,820.0	115,073.0	97,482.0	100,299.0	103,682.0
CALA Subs (million)	63.3	85.1	100.7	123.4	167.0	203.2	228.9	257.1	286.5	322.0
Erlangs (000)	2,417.7	3,252.0	3,844.7	4,713.3	6,379.3	7,708.9	8,621.2	9,575.6	10,587.2	11,638.8
Channels (000)	3,145.6	4,171.3	4,910.5	5,995.3	8,168.0	9,942.5	11,126.9	12,368.2	13,685.4	15,052.0
RF Carriers (000)	1,465.3	1,599.1	1,645.2	1,553.1	1,745.0	1,592.9	1,482.7	1,430.0	1,485.5	1,587.1
Cells	52,750	58,719	62,914	70,516	92,790	108,392	120,457	112,219	124,789	139,628
Asia/Oceania - Subs (million)	250.9	351.4	463.8	586.6	706.8	825.8	926.8	1,022.1	1,125.4	1,218.5
Erlangs (000)	13,939.8	19,520.5	25,756.4	32,497.7	38,837.3	45,190.8	50,468.3	55,416.1	60,643.7	65,118.5
Channels (000)	18,469.5	25,858.0	34,155.8	43,420.4	53,234.0	62,567.2	70,800.2	76,718.2	79,742.3	85,537.7
RF Carriers (000)	3,916.2	4,545.9	5,764.4	7,101.1	7,387.5	8,172.4	8,752.2	9,312.1	9,856.1	10,317.5
Cells	209,098	242,338	277,850	313,171	352,667	400,415	457,775	487,832	531,644	570,698
Europe/Africa Subs (million)	306.9	384.2	437.8	521.9	638.3	683.1	729.8	782.1	841.0	914.9
Erlangs (000)	12,789.2	16,008.4	18,240.5	21,718.0	26,381.6	28,008.7	29,657.8	31,470.1	33,366.7	35,314.4
Channels (000)	17,087.6	21,404.7	24,347.9	29,155.2	36,468.9	39,955.0	43,818.0	41,897.8	44,399.6	46,955.4
RF Carriers (000)	2,780.9	3,704.5	3,638.3	4,366.3	4,850.8	5,054.7	5,279.4	5,524.1	5,800.9	6,081.3
Cells	255,784	264,966	263,148	277,789	324,217	326,424	344,682	399,929	423,064	452,855

Table 3-12 International Wireless Infrastructure Electronic Equipment Forecast of Channels, RF Carriers, and Cell Sites by Region

(*Source*: Update from *Wireless Infrastructure Technology and Markets: The Challenge of 3G*, by Jim Gunn, published by Forward Concepts, November 2002)

***Note:* E indicates estimate.**

The reports of wireless infrastructure vendors are tracked with much interest. In recent years, the historical revenues of these vendors and international totals have been more difficult to track due to the changing valuation of the US dollar (US$) versus other international currencies, such as: the Euro (€) and Sweden's Krona (SEK). As the US dollar has devalued, the YoY comparisons are altered by changing conversion rates between the currencies. This is illustrated in Table 3-13, which sows the 2000 to 2004 exchange rates. As the table shows, the US$ has appreciated during this time period, and vendor revenues in US$ provide a more optimistic market picture than in Euros. Note that essentially all of the major infrastructure vendors have international operations and usually claim sales in many local currencies. Their financial reports, however, typically present bookings and sales in the currency of their corporate headquarters and give very minimal information by country on currency conversions.

Currency Exchange Rates	2000	2001	2002	2003	2004
US$/€	0.92	0.90	0.95	1.10	1.30
SEK/US$	9.17	10.36	9.72	8.08	6.93
SEK % Increase	-15.73%	-3.01%	6.04%	15.85%	18.18%
Euro % Increase	-9.50%	-11.47%	6.59%	20.30%	16.59%

Table 3-13 Selected Currency Exchange rates
(Source: *Wall Street Journal*, various issues)

Figure 3-7 presents the effect of the changing currency exchange rates by showing the total international vendor revenues by year in both US dollars and Euros. As the figure illustrates, the industry results are not as favorable when viewed from a Euro perspective. Table 3-14 presents yearly vendor-reported revenue numbers for 2000–2010. Note that Ericsson reports its financial numbers in SEK; Nortel, Lucent, and Motorola report theirs' in US$; and Nokia, Siemens, and Alcatel report their numbers in Euros. The forecast numbers herein are presented in US$ at the yearly exchange rate in Table 3-13. Also note that these numbers represent the "Base Station and Switch" operator CAPEX expenditures shown in Table 3-9.

Figure 3-8 presents graphic information on international subscribers, forecast cell sites, and average subscribers per cell site.

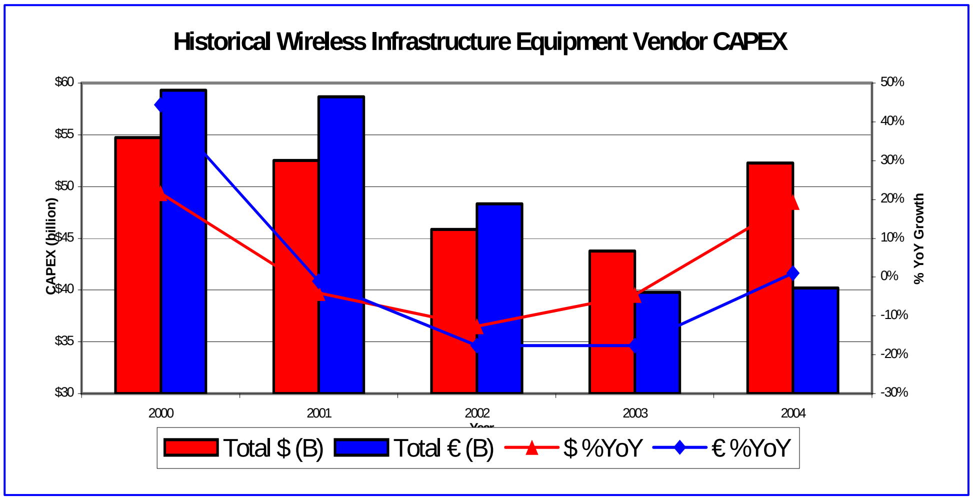


Figure 3-7 Historical Wireless Infrastructure Equipment Vendor CAPEX
(*Sources:* Company reports and author research)

	2000	2001	2002	2003	2004
Ericsson	$17.24	$14.89	$12.39	$12.46	$14.18
Nokia	$7.12	$6.75	$6.21	$6.18	$8.28
Siemens	$3.89	$5.23	$4.94	$4.70	$6.63
Motorola	$7.79	$6.55	$4.61	$4.42	$5.35
Nortel	$5.44	$5.71	$4.22	$4.39	$4.57
Alcatel	$1.54	$2.13	$4.31	$3.89	$4.29
Lucent	$6.74	$6.48	$5.03	$3.74	$4.20
Other	$4.98	$4.77	$4.17	$3.98	$4.75
Total	$54.73	$52.52	$45.87	$43.76	$52.25
%YoY	21.66%	-4.04%	-12.66%	-4.60%	19.40%

Table 3-14 Wireless Infrastructure Vendor Revenues (billion)
(*Sources*: Company reports and author research)

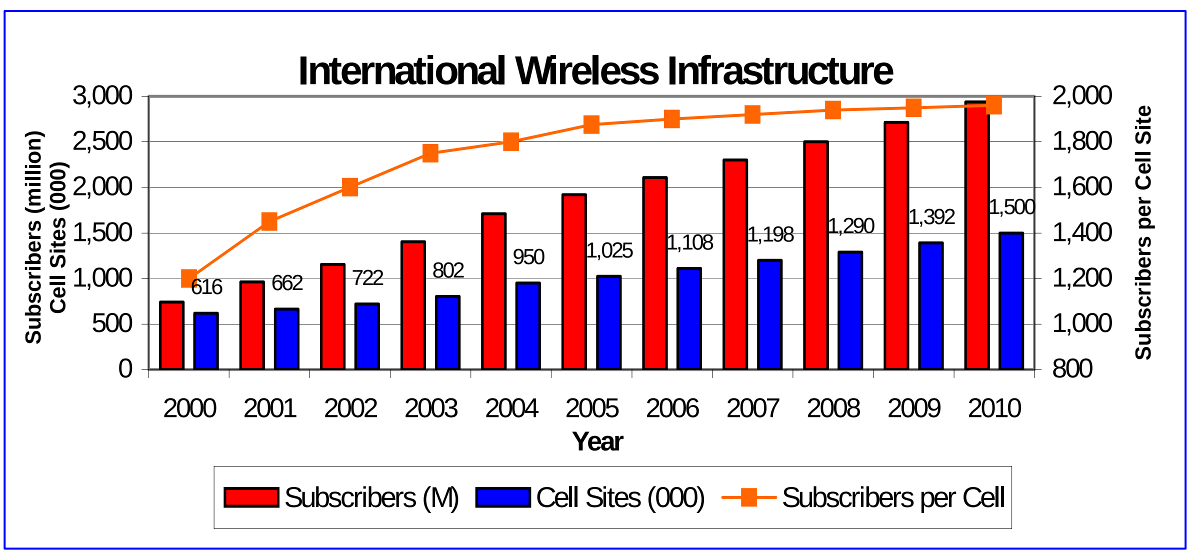


Figure 3-8 Cellular Infrastructure Cell Site Forecast (2000–2010)
(*Source*: Update from *Wireless Infrastructure Technology and Markets: The Challenge of 3G*, by Jim Gunn, published by Forward Concepts, November 2002)
***Note:* Data for 2005-2010 are estimates.**

Table 3-15 presents the forecast of the international wireless infrastructure market by technology. Not surprisingly, GSM/GPRS/EDGE, with more than a billion subscribers, will be the largest market throughout the decade. As shown, WCDMA/HSDPA should grow to exceed CDMA sometime in the 2005-2006 timeframe.

	2000	2001	2002	2003	2004	2005E	2006E	2007E	2008E	2009E	2010E
Total	$54.7	$52.5	$45.9	$43.8	$52.3	$54.9	$57.6	$60.5	$63.5	$66.7	$70.0
GSM/GPRS/EDGE	$31.7	$31.1	$27.6	$26.5	$31.1	$29.4	$27.4	$23.7	$25.4	$26.0	$26.6
WCDMA/HSDPA	$0.0	$0.0	$1.5	$3.1	$8.1	$12.5	$16.2	$18.9	$20.1	$22.3	$23.5
CDMA IS95/CDMA 2000 1x	$8.0	$8.9	$8.3	$8.0	$9.7	$11.8	$13.0	$17.4	$17.3	$17.1	$18.4
Other, including TDMA/PDC/ iDEN /Analog	$15.1	$12.6	$8.4	$6.2	$3.3	$1.2	$1.1	$0.5	$0.7	$1.3	$1.5

Table 3-15 International Wireless Infrastructure Electronic Equipment Investment Forecast by Technology (billion)
(*Source*: Update from *Wireless Infrastructure Technology and Markets: The Challenge of 3G*, by Jim Gunn, published by Forward Concepts, November 2002)
***Note:* E indicates estimate.**

Note that GSM and WCDMA are viewed to be an essentially unified market and assume that WCDMA growth will take market share from GSM as various countries deploy 3G infrastructure to enable 3G data services and to more cost-effectively add voice capacity. If this materializes less than anticipated, then substantial portions of the indicated WCDMA expenditures should be allocated back to GSM/GPRS/EDGE because this technology is forecast to achieve 2 billion subscribers in 2010. It would not be unreasonable to forecast that WCDMA could achieve more rapid subscriber uptake in 2006 -2010 than can be forecast based on current data.

Table 3-16 presents the forecast for international wireless infrastructure market forecast by region. As would be anticipated due to its large population and rapidly increasing cellular subscriber uptake, Asia is the leading market. Table 3-16 also contains forecast wireless equipment CAPEX for China and India, both countries with populations of more than 1 billion. Rapid cellular growth in China has been ongoing for several years, whereas India has achieved more recent significant growth successes. These two countries have slightly less than one-third of the total world population. North America (largely the United States, but also Canada) has a surprisingly high equipment CAPEX, which can be attributed to a much higher monthly ARPU as well as a much higher post-paid subscriber base and much higher monthly MOU, resulting in higher capacity requirements.

	2000	2001	2002	2003	2004	2005E	2006E	2007E	2008E	2009E	2010E
Total	$54.73	$52.52	$45.87	$43.76	$52.25	$54.86	$57.61	$60.49	$63.51	$66.69	$70.02
North America	$14.70	$14.41	$11.63	$10.24	$11.70	$10.72	$10.42	$13.17	$11.69	$11.62	$11.63
CALA	$3.22	$3.09	$2.54	$2.52	$3.63	$4.23	$4.18	$5.76	$6.21	$6.09	$6.66
Asia/Oceania Total	$18.80	$19.75	$19.56	$18.95	$21.75	$25.38	$27.17	$32.63	$28.42	$32.13	$35.10
China	$7.09	$9.00	$9.28	$8.93	$9.76	$10.45	$11.52	$15.74	$15.95	$15.34	$16.22
India	$0.29	$0.41	$0.68	$1.12	$1.75	$2.69	$3.69	$6.37	$6.32	$4.93	$5.15
Europe/Africa	$18.01	$15.27	$12.14	$12.05	$15.17	$14.53	$15.84	$8.93	$17.19	$16.85	$16.63

Table 3-16 International Wireless Infrastructure Electronic Equipment Investment Forecast by Region (billion)
(*Source*: Update from *Wireless Infrastructure Technology and Markets: The Challenge of 3G*, by Jim Gunn, published by Forward Concepts, November 2002)
***Note:* E indicates estimate.**

There is little doubt that cellular is the largest SDR market opportunity. The cellular handset market is anticipated to be a trillion dollar cumulative market between 2000 and 2010. Cellular infrastructure is anticipated to be a more than $600 billion market between 2000 and 2010. The opportunities for SDR are abundant.

4 Cellular Industry Business Models

Software defined radio technologies must be inserted into deployed systems because of superior value propositions and not just because of "high technology" features and related hype. Thus, the SDR Forum has set a goal to develop business models in its market studies and to develop input on how SDR technologies can help improve these business models. Cellular is the largest segment in terms of subscribers and revenues, including terminal and infrastructure equipment revenues, and thus clearly appears to be the most significant opportunity and driver for SDR.

Several concepts must be discussed to introduce the cellular business models. An excellent starting point is the total cost of ownership (TOC) model by Ericsson, shown in Figure 4-1. This figure presents a generic cost component model for cellular operators, which is representative of many operator financial reports that have been reviewed for this study. Operator financial reports generally report capital expenditures (CAPEX) and depreciation, OPEX, and subscriber acquisition costs (SAC). The box and line heights in Figure 4-1 are roughly representative of the percentage of the total cost of each item. This model suggests that CAPEX (which includes electronic equipment purchases) is not the dominant operator cost and that other costs more significantly drive the business model and provide SDR opportunities.

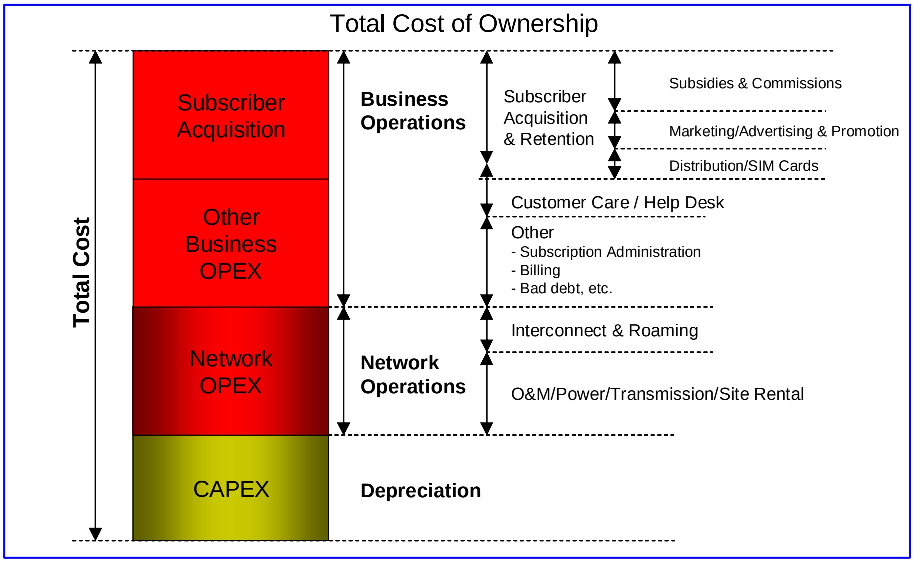


Figure 4-1 Cellular Total Cost of Ownership
(*Source:* Adopted from Ericsson Presentation at 3GSM 2004, by J. Bergendahl & C. Hedelin, Feb 2004)

With a few appropriate modifications, this model should apply to all market segments (e.g., Public Safety, Avionics, Telematics). These modifications will be developed in future segment reports.

The industry has much marketing and product data from most vendors on their products and benefits and high-level potential business model improvements. Detailed information is generally considered proprietary; thus, information available for this report often lacked desired details. Ericsson, the leading infrastructure vendor, and Nokia, the leading handset vendor and second leading infrastructure vendor, were willing to discuss their various presentations, papers, and so forth with appropriate limitations. From such information from various vendors on business models, a reasonably representative model that sufficiently addresses issues to accurately guide SDR technology insertion could be developed. Future input should provide verification, clarification, and more details.

Cellular operator income statements are generally structured as in Table 4-1. The typical sources of income for an operator include: (1) services revenues, including monthly fees, MOU fees, data service fees, and other service fees; (2) cellphone and accessory sales (cellphones sales are often subsidized by operators); (3) interconnecton fees with other telecommunication operators; and (4) roaming fees from other operators. Note that operators also incur interconnection and roaming expenses from other operators. The various expenses are presented in Figure 4-1.

Revenues
- Direct cost of services or goods
Gross Income (Gross Margin)
- General and administrative (includes subscriber acquisition costs (SAC) subscriber retention costs (SRC), and related sales and marketing)
EBITDA (**E**arnings **B**efore **I**nterest, **T**axes, **D**epreciation and **A**mortization) Income
- Depreciation and amortization
Operating Income (Operating Margin)
- Interest expenses and taxes and any special items not included above
Net Income (Net Margin or Profit Margin)

Table 4-1 Summary of Typical Cellular Operator Income Statement

In reviewing many financial reports of operators and industry financial analysts, various margin calculations are frequently used as indicators. Generically, margin is a percentage calculated as follows:

$$\text{Margin} = \left(\frac{\text{Revenue} - \text{Cost}}{\text{Revenue}} \right)$$

The financial community uses several different margins, such as gross margin, operating margin, EBITDA margin, profit margin, and net margin, generally reflecting which income statement costs are included, as indicated in Table 4-1.

In a white paper[4], Nokia presents very informative and insightful information in a chart on margins, recreated in Figure 4-2. In this figure, the typical gross margin (total excluding OPEX) is 55%, EBITDA margin (total excluding OPEX and subscriber acquisition and retention) is 40%, and operating margin (profit) is 25%. The percentages in this chart are of total revenues. Note that net margin would be after taxes and all special items, which are often dependent on local operations and government requirements.

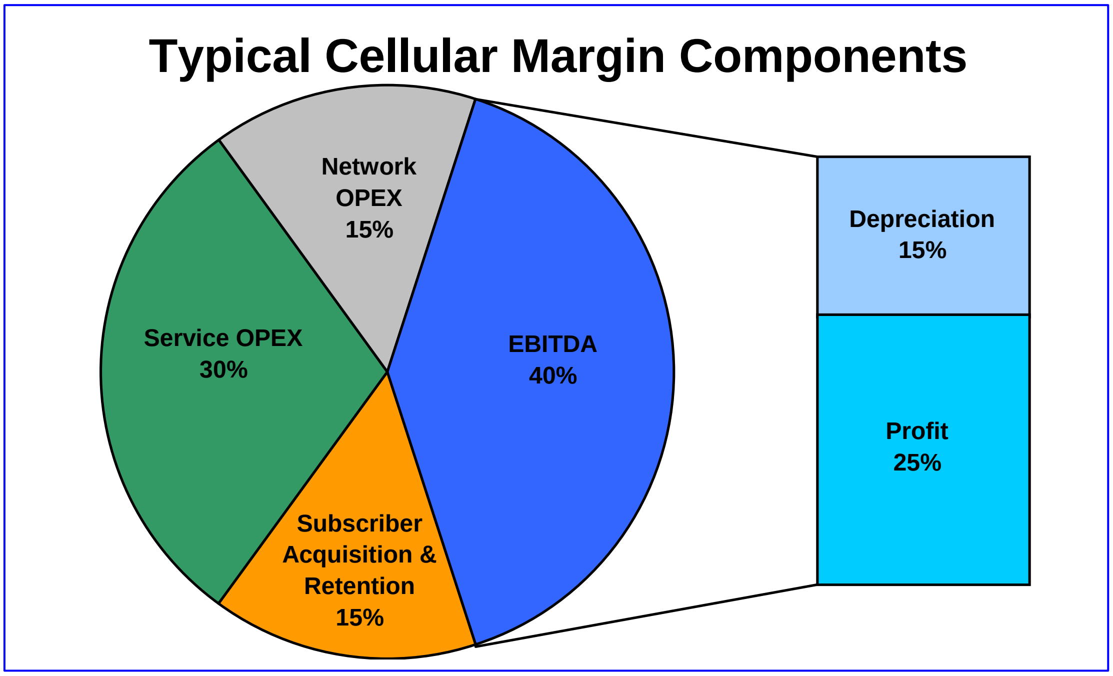
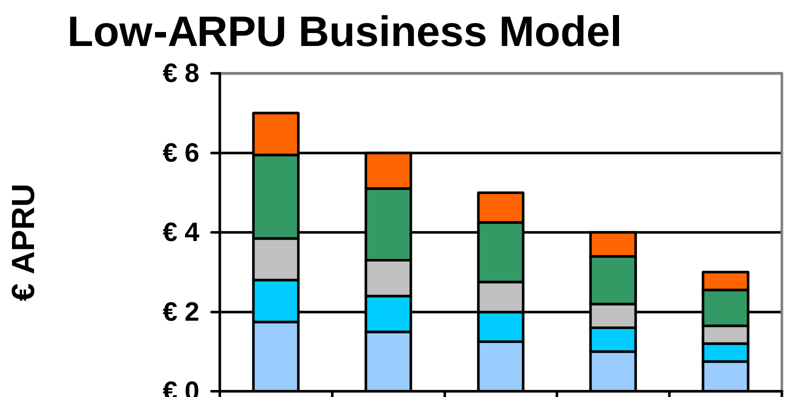


Figure 4-2 Typical Cellular Margin Components
(*Source*: Recreated from Nokia, "The Prerequisites for Profitable Entry Business," April 2004, www.nokia.com)

Nokia presents an interesting summarization of "the potential and profitability challenges" of operators in targeting the second and third billion subscribers with a high percentage of low-ARPU customers requiring a low TCO. An analysis that was developed for low-ARPU emerging markets is presented in Figure 4-3. The figure applies the percentages from Figure 4-2 to arrive at target budgets for various operator expenses. Note that various industry sources have indicated that many operator costs are based on local payroll, site costs, and so forth, and these are typically reduced in low-ARPU markets.

[4] "The Prerequisites for Profitable Entry Business," by Nokia, 4/2004, www.nokia.com.

For comparison, Nokia states, “The ARPU in Europe varies between EUR 15 and EUR 25 per month. In most new growth low penetration countries it is between EUR 10 and EUR 15 per month. In some markets the industry average is even under EUR 10 per subscriber per month.” Note that the average US ARPU is approximately $50 per month.



	€7.00	€ 6.00	€ 5.00	€ 4.00	€ 3.00
Subscriber Acquisition	€ 1.05	€ 0.90	€ 0.75	€ 0.60	€ 0.45
Service OPEX	€ 2.10	€ 1.80	€ 1.50	€ 1.20	€ 0.90
Network OPEX	€ 1.05	€ 0.90	€ 0.75	€ 0.60	€ 0.45
Depreciation	€ 1.05	€ 0.90	€ 0.75	€ 0.60	€ 0.45
Profit	€ 1.75	€ 1.50	€ 1.25	€ 1.00	€ 0.75

Figure 4-3 Low ARPU Business Model for Emerging Markets
(*Source*: Recreated from Nokia, “The Prerequisites for Profitable Entry Business,” April 2004, www.nokia.com)

More details on cell site CAPEX and OPEX are discussed in a very interesting paper by Ericsson[5] that elaborates its product and service differentiating strategies of its Expander Base Station family to address operator TCO goals. In Figure 4-4, TCO is defined as network OPEX plus reporting period depreciation allocations.

Note that most operator financial reports provide both depreciation and CAPEX. CAPEX includes the actual expenditures during the year that will be depreciated over an identified reporting life for electronic equipment (typically seven years). Note also that CAPEX and depreciation, although closely related, are not the same. CAPEX is typically a cash flow item, and depreciation is typically a balance sheet and income statement item. A widely offered consensus opinion is that yearly CAPEX of mature telecommunication operators is typically approximately 15% of yearly revenues (or sales). Operator reports issued prior to the economic downturn of the early 2000s had CAPEX/sales ratios generally in the 20% to 30% range. This is probably not out of line because the cellular industry’s revenue growth was largely the result of impressive international 50% YoY subscriber growth until 2000. Since the economic downturn, observed CAPEX ratios

[5] Ericsson, “Expander – Cost-Effective Expansion into New Geographical Areas,” Ericsson Review No. 2, 2004

have tended down to around 15% because percentage subscriber growth has slowed substantially and many operators now regard emerging 3G data services as important new revenue growth opportunities.

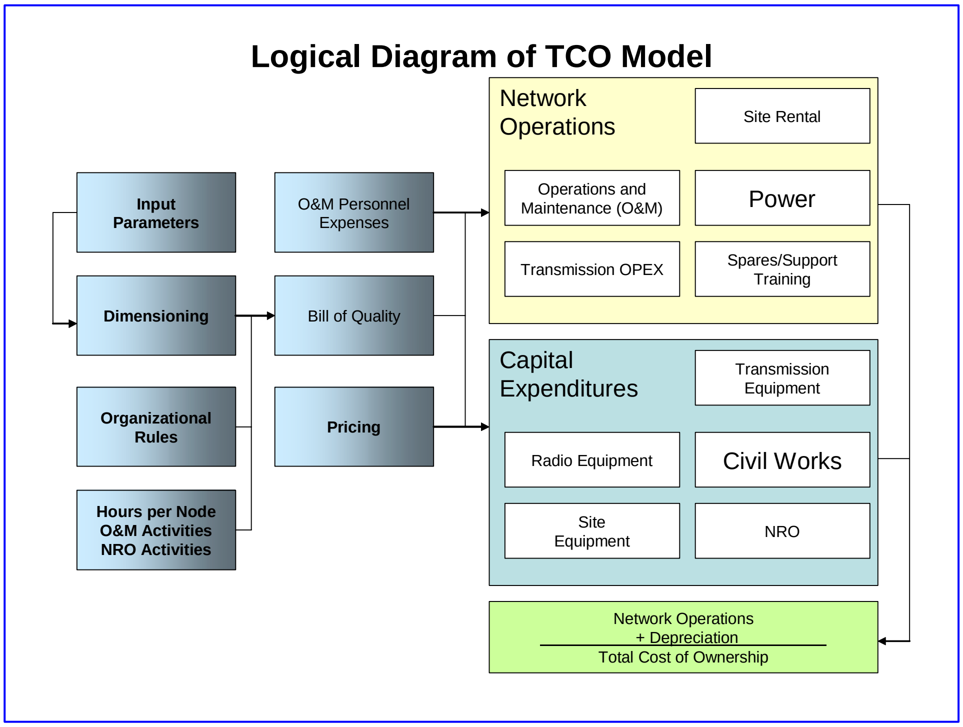


Figure 4-4 Logical Diagram of TCO Model
(*Source:* Adapted from Ericsson, "Expander – Cost-Effective Expansion into New Geographical Areas," Ericsson Review No. 2, 2004)

Ericsson states that the Expander Family is "both a concept and a set of mobile solutions for the core network, radio access network (RAN), service layer, and transmission, and telecommunication services." The central theme of Ericsson's Expander strategy is flexibility and ability to reduce the number of cell sites. Ericsson makes a seemingly very reasonable claim that "OPEX and CAPEX have many interdependencies" and that better-quality base stations and flexible base station subsystem (BSS) features can reduce TCO by: (1) "optimized entry-level investments" and "flexible growth in capacity, as needed"; (2) providing better coverage; (3) reducing the number of sites, site rentals, and other site costs; (4) reducing power consumption; and (5) improving reliability, thus reducing required site visit and maintenance costs. In discussing RAN cost structure, Ericsson indicates that the radio base station (RBS—same as RAN here) CAPEX expenditures are approximately two-thirds of total operator CAPEX and that radio, transmission, and BSC hardware/software equipment costs are less than half of the RBS site CAPEX cost. This is very much in line with long-reported estimates of allocations of 70% for RAN and 30% for core network; as well as estimates that operators, particularly in Greenfield deployments, typically spend approximately 50% of CAPEX with network equipment vendors. The Ericcson paper also contains one of the more complete lists of examples of CAPEX items for an RBS site, which is recreated in Table 4-2.

The Expander has a transceiver (TRX) capability that can be viewed as a precursor to eventual SDR and arrays capabilities (author's opinion, not an Ericsson input). In the downlink, the Expander TRX has an interesting flexibility to support capacity or coverage configurations. In one configuration, a power amplifier (PA) can be used independently for a RF carrier at lower power to provide more capacity at reduced range. In a second configuration, two PAs can be combined for an RF carrier to provide approximately double power and reduced capacity. In a third configuration, two PA outputs can be phase controlled for transmit diversity and better multipath mitigation performance but also at reduced capacity. These features are claimed to provide entry-level coverage capability and flexible capacity enhancement as subscriber load grows.

In its paper, Ericsson presents an interesting example of an African operator analysis and claims that its Expander solutions can reduce the number of required sites from 53 to 41 and reduce TCO by 22%.

Site Equipment	Site Services
RBS Electronics	Site acquisition
Base Frame Backup	Site Inspection
Batteries	Site Engineering
Air Conditioning	Site Investigation
Alarm	Design and Documentation
Light	Installation
Installation material	Product Configuration
Transmission	Product Integration
Power	Civil Works
Antenna System	Tower & Shelter Foundation
RBS Antennas	Foundation rooftop
Antenna Support	Shelter
Feeder support	Tower
Antenna system installation material	Forklift
Tower Mount Antenna (TMA)	Fence
Control module	Lightning protection
Current injectors	Grounding system
TMA installation	Generator power

Table 4-2 Typical Base Station Site CAPEX Items
(*Source*: Adapted from Ericsson, "Expander – Cost-Effective Expansion into New Geographical Areas," Ericsson Review No. 2, 2004)

Many financial reports from international operators revealed increasing consistency over time of reported key performance indicators (KPIs). However, financial reporting requirements are not uniform throughout the world. As a further illustration of cellular business models and KPIs, Table 4-3 presents an income statement for SK Telecom of Korea from their 2004 year-end report. Note that it does not explicitly break out costs by operations, sales, general, and administration (SG&A), as was identified by Nokia in

Figure 4-2 (as SAR, subscriber acquisition and retention). Based on Table 4-3, SK Telecom achieved the following margins:

EBITDA Margin: 41.8%

Operating Margin: 24.3%

Profit Margin: 15.4%

Income Statement	2004 Revenues Billion of KRW	2004 Revenues Million of US$ 1$ = KRW 997	% of 2004 Revenues
REVENUE	KRW 9,703.70	$9,732.90	100.00%
OPERATING EXPENSES	KRW 7,344.10	$7,366.20	75.70%
Labor cost[a]	KRW 448.10	$449.45	4.60%
Commissions Paid[b]	KRW 2,827.20	$2,835.71	29.10%
Depreciation and amortization[c]	KRW 1,577.40	$1,582.15	16.30%
Network interconnection	KRW 858.80	$861.38	8.90%
Leased line	KRW 365.40	$366.50	3.80%
Advertising	KRW 328.60	$329.59	3.40%
Others	KRW 938.60	$941.42	9.70%
OPERATING INCOME	KRW 2,359.60	$2,366.70	24.30%
Other Income	KRW 237.10	$237.81	2.40%
Other expenses	KRW 480.90	$482.35	5.00%
ORDINARY INCOME	KRW 2,115.80	$2,122.17	21.80%
Income taxes	KRW 620.90	$622.77	6.40%
NET INCOME	KRW 1,494.90	$1,499.40	15.40%
EBITDA[d]	KRW 4,059.10	$4,071.31	41.80%

Table 4-3 SK Telecom 2004FY Income Statement (US$ = KRW 997)
(*Source*: abbreviated from SK Telecom's 2004 Annual Report)
Notes:

a. Labor cost = Salaries + Provisions for severance benefit
b. Commissions paid include marketing commissions and other commissions
c. Deprecation excludes research-and-development (R&D)-related depreciation
d. EBITDA = Earnings before Income Taxes, Depreciation, and Amortization

Vodafone is the second leading international operator (behind China Mobile) and has significant operations in Europe, the United States, Japan, and other countries. At calendar year-end 2004, Vodafone claimed 151.8 million proportionate subscribers (based on percent ownership of their cellular properties). Figure 4-5 presents an operating cost analysis by Vodafone UK. Vodafone's fiscal year-end is March 31, so H1 04/05 represents the interim 6-month report ending September 30, 2004, for example. As this figure indicates, Vodafone UK achieved margins as follows:

Gross Margin: 50.1%

EBITDA Margin: 33.2

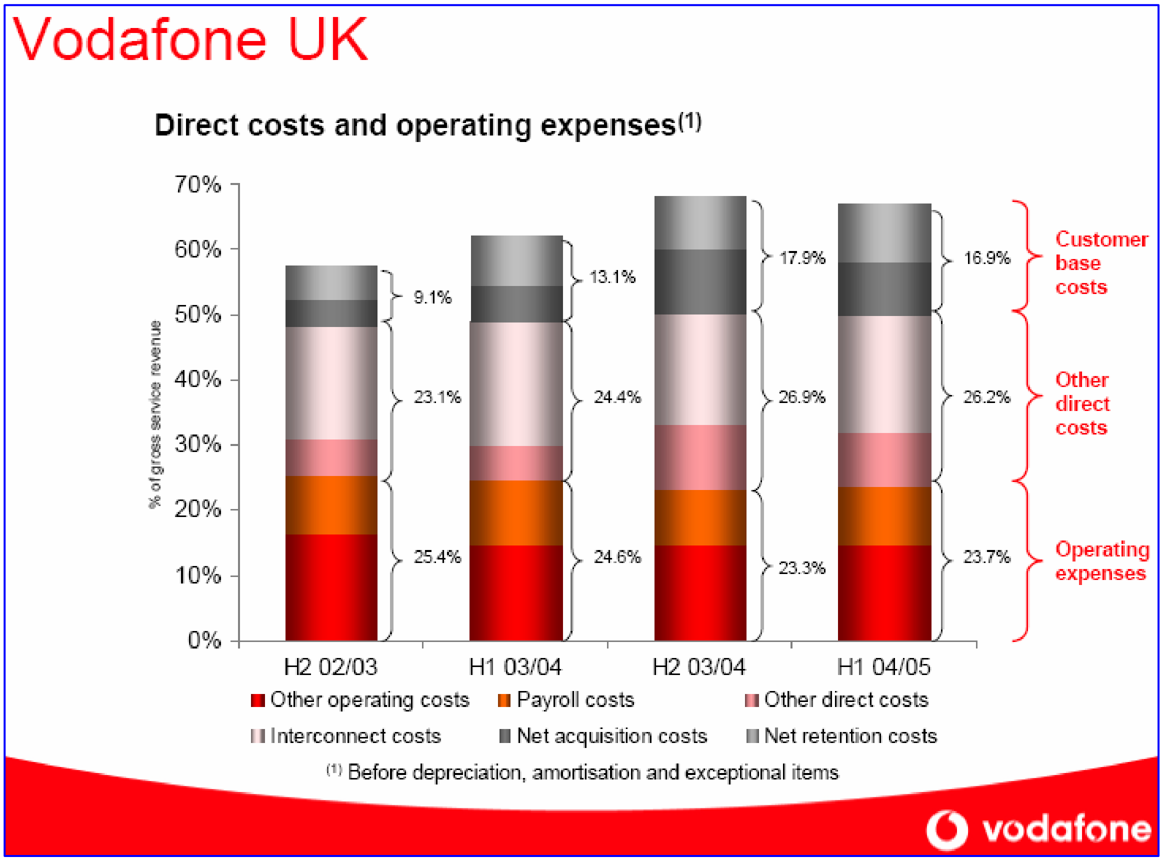


Figure 4-5 Vodafone UK Operating Cost Analysis
(*Source*: Vodafone 2004/5 1H Presentation, October 2004)

Table 4-4 provides a compilation of key performance indicators for 10 international operators. Fiscal year-end 2004 financial reports of each operator were reviewed to extract KPIs that include revenues; various operating costs; SG&A; various income (e.g., gross, EBITDA, operating, net); and other key indicators, including subscribers, percent prepaid, ARPU, and MOU. Note that financial reporting requirements are not uniform across the world, and each local operator (or operation of a multination) has local requirements and some local latitude on what is reported. European and Asian operators typically do not report SG&A as an easily identifiable cost item.

Table 4-4 includes date for three US operators, three European operators, three Asian operators, and one CALA operator, representing a very good cross section of international operators. Vodafone, Germany's Deutsche Telekom's T-Mobile unit, and Mexico's America Movil have cellular operations in multiple countries and provide consolidated financial results as well as individual results by country. However, they typically do not (perhaps cannot) provide complete reporting for consolidated operations and individual country operations because some costs involve corporate-level allocations and differing country tax and reporting methodologies. Table 4-4 provides individual country operations for Vodafone (Germany) and America Movil (Mexico), but consolidated international operations information for T-Mobile.

	Verizon Wireless	Cingular	Sprint	China Mobile	DoCoMo	SK Telecom	TIM S.P.A. Domestic	Vodafone	T-Mobile Consolidated	America Movil Consolidated
Country of Operation	US	US	US	China	Japan	Korea	Italy	Germany	Europe / US	CALA
Technology	CDMA	GSM / WCMDA / TDMA	CDMA	GSM	WCDMA / PDC	CDMA / WCDMA	GSM / WCDMA	GSM / WCDMA	GSM / WCDMA	GSM / TDMA
Reporting Period	2004YE Dec	2004YE Dec	2004YE Dec	2004YE Dec	2005FE Mar	2004YE	2004YE Dec	2005H1 SEP	2004FY Dec	2004FY Dec
Revenue (M), (B, Japan, Korea)	$27,662	$19,436	$14,647	$24,637	$46,967	$9,733	$12,926	$4,734	$32,494	$12,250
Service Rev.	$24,400	$17,473	$12,529	$23,549				$4,613	$27,608	$10,066
SG&A	$9,591	$5,428	$3,406	$8,056		$1,869		$565	$10,447	$2,477
Depreciation	$4,486	$2,089	$2,563	$5,804	$7,071	$1,582	$1,482	$774	$6,614	$1,690
operating Income	$5,838	$2,254	$1,552	$7,445	$7,540	$2,367	$5,391	$1,482	$6,027	$2,136
Net Income	$1,645	$977		$5,218	$7,188	$1,499	$3,669			
CAPEX	$5,633	$3,449	$2,559	$7,800	$8,284	$1,611	$1,910		$3,134	$2,036
Gross Margin	87.4%	81.1%	51.6%	86.5%			53.8%	61.2%		
EBITDA Margin	52.7%	53.1%	28.3%	53.8%	33.6%	41.8%	53.2%	48.9%	42.4%	31.2%
Operating Margin	36.5%	42.4%	10.8%	30.2%	16.1%	24.3%	41.7%	33.2%	18.6%	17.4%
Net Margin	6.0%	5.0%		21.2%	15.3%	15.4%	28.4%	0.0%	0.0%	12.3%
Subscribers (M)	43.82	49.10	24.76	204.29	46.33	18.78	26.26	26.09	69.20	61.10
% Pre-Paid Subscribers	3.0%	7.0%		70.7%		0.0%	0.0%	51.0%	49.5%	93.0%
% Non-Voice Service Rev.	5.6%	5.6%		7.5%		20.6%	10.7%	17.1%		
Churn	1.5%	2.7%	2.6%	1.3%	1.0%	1.4%	0.0%	1.5%	1.5%	2.9% (03)
ARPU	$50.2	$49.3	$62.0	$12/$7/$20*	$69.2	$44.6	$37.7	$45.0	$37.7	$17.4
MOU (month)	est 500	est 450	est 600	297/517/194*	151	319	129.8	0	0	0
Currency	US $	US $	US $	China ¥ RMB/$	Japan ¥ Yen/$	Korea KRW/$	$/€ EURO	$/British £	$/€ EURO	Mex Peso/$
Conversion Currency to $	1	1	1	8.28	104	997	1.3	1.75	1.3	11

Table 4-4 International Operator Business Model Indicators

(*Sources*: 2004 Fiscal year end company reports (if available) and author research)

***Composite, prepaid, and postpaid are coded in table as composite (prepaid, postpaid)/prepaid/postpaid**

In general, in Table 4-4, when information on desired indicators was not available or could not confidently be calculated with available data, the indicator was simply left blank. Some operators have fiscal years that do not coincide with the calendar year—many ending on March 31, 2005. Thus, several 2004 final annual reports and 20F reports were not available for review for this report. These reports often have interesting details, not available in quarterly presentations and reports. Finally, operators report in the currency of their local operations (or their corporate headquarters). All data are converted to US dollars at the estimated average yearly exchange rates indicated in the table.

Table 4-4 provides interesting conclusions. First, although there is variability, the table provides verification that the generic margin components of Figure 4-2 are representative. Some of the more significant variations may be the result of differing governmental reporting requirements and perhaps the author's interpretations.

Another key take-away for the table is that China Mobile, with 204 million subscribers, a 70% prepaid subscriber base, and a $12/month ARPU is indicating profitable 2004 operations.

Total RAN (or RBS) OPEX allocations, as illustrated in Figure 4-2, are approximately equal to total RAN depreciation allocations. A generic example of OPEX allocations is presented in Figure 4-6. The percentages in this figure are of network OPEX (see Figure 4-2, not total revenues) and do not include depreciation or CAPEX expenses, nor customer care and related expenses. Note that site rental comprises approximately 40% of OPEX costs. Additionally, Ericsson indicates that CAPEX generally consists of 67% (2/3) equipment and 33% (1/3) nonequipment. As this and other inputs have indicated, the number of RAN sites is the most important driver of RAN TCO. Even though equipment costs might be somewhat higher with fewer sites, the TCO is generally less. Additionally, note that site rental, labor costs, power, and other factors are undoubtedly different in all markets, and these costs are generally cheaper in emerging second-tier markets. This would help facilitate lower ARPU business models.

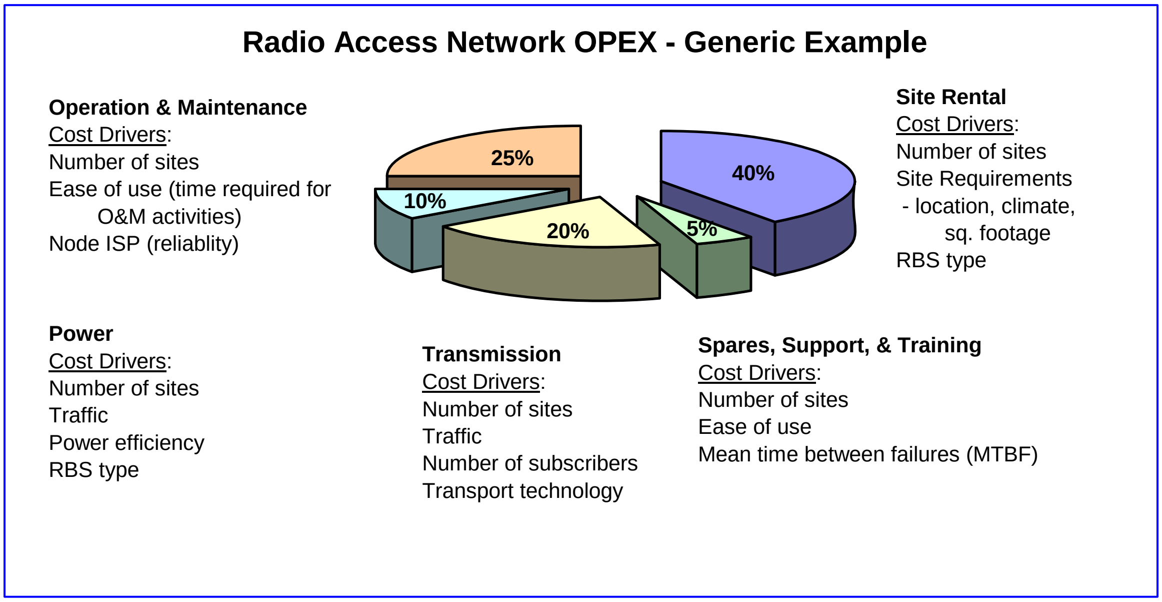


Figure 4-6 RAN OPEX – Generic Example
(*Sources*: Ericsson web site (www.ericsson.com); and telephone and email exchanges, May 2005)

For comparison, a major European operator, in a very interesting telephone interview (anonymity requested), provided information on network OPEX budget allocations, as presented in Figure 4-7. Noted that leased line pricing in Europe is not the same as in other markets, such as the United States, and reports indicate that the vast majority of backhaul links in Europe are microwave because leased line from telecommunication operators are much more expensive. Thus, backhaul in Europe is reported predominately as a capital expense with a comparatively much smaller operating expense. Conversely, reports in the United States indicate that most backhaul circuits are leased T1 circuits and thus would predominately be an operating expense in the United States.

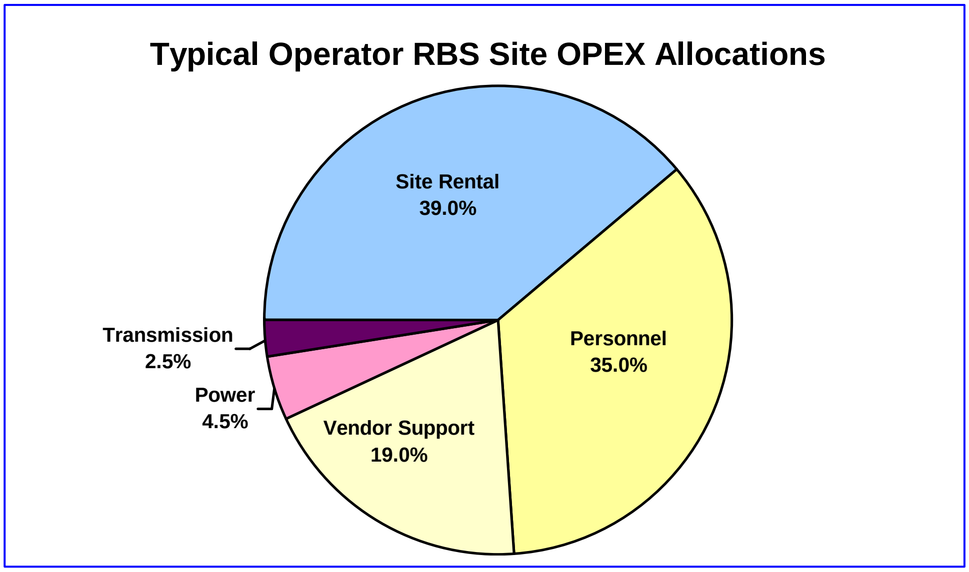


Figure 4-7 Typical RBS Site Network OPEX Allocations
(*Source*: Major European operator, May 2005, anonymity requested)

In conclusion, RAN TCO is dependent on many factors, including site rental costs, labor rates, power availability and costs, backhaul costs, and others. Additionally, the lowest cost radio equipment does not necessarily provide the lowest TCO.

5 Update on SDR Platforms and Technology Roadmaps

The section on Platforms and Technology Roadmaps in the SDR Market Study for Task 1, *Market Segmentation and Sizing*, was initiated with the goal to update it in subsequent reports with specific information for the market focus of that report. This section provides this update for the cellular industry. Some material from the Task 1 report may be repeated here, as appropriate, and the first report should be reviewed for supporting discussions.

Increasingly, platforms are being adapted by the cellular industry with the primary goals of reducing costs; reusing hardware, software and other intellectual property assets; and achieving time-to-market goals.

As background, the SDR Forum's definition of SDR "Tiers of Capabilities and Flexibility" is presented in Table 5-1. The cellular industry is essentially at Tier 2 for both handset and infrastructure equipment.

Tier Name	**Description**
Tier 0 Hardware Radio (HR)	The radio is implemented using hardware components only and cannot be modified except through physical intervention.
Tier 1 Software Controlled Radio (SCR)	Only the control functions of an SCR are implemented in software – thus only limited functions are changeable using software. Typically this extends to inter-connects, power levels, etc. but not to frequency bands and/or modulation types, etc.
Tier 2 Software Defined Radio (SDR)	SDRs provide software control of a variety of modulation techniques, wide-band or narrow-band operation, communications security functions (such as hopping), and waveform requirements of current and evolving standards over a broad frequency range. The frequency bands covered may still be constrained at the front-end, requiring a switch in the antenna system.
Tier 3 Ideal Software Radio (ISR)	ISRs provide dramatic improvement over an SDR by eliminating the analog amplification or heterodyne mixing prior to digital-analog conversion. Programmability extends to the entire system with analog conversion only at the antenna, speaker, and microphones.
Tier 4 Ultimate Software Radio (USR)	USRs are defined for comparison purposes only. A USR accepts fully programmable traffic and control information and supports a broad range of frequencies, air-interfaces, and applications software. It can switch from one air interface format to another in milliseconds, use GPS to track the user location, store money using smartcard technology, or provide video so that the user can watch a local broadcast station or receive a satellite transmission.

Table 5-1 SDR Definition: Tiers of Capability and Flexibility
(*Source*: www.sdrforum.org**)**

The multimode, multiband functionality in handsets as well as infrastructure equipment is less than desired. In discussions with industry, the problem areas consistently identified have been cost effectiveness, appropriate (low) power consumption, and performance for RF and data acquisition components. Although the popular “2 MHz to 2+GHz” flexible waveform selection with software is desirable, its priority is lower than other goals presented in Table 5-2. Figure 1-3 presented international cellular frequency allocations, and the cellular industry has high priority for target bands of operations that must be met. Greater SDR band flexibility, however, has lower priority.

- Low Cost
- Low Power
- PA – trend to MCPA
- Power Efficiency – e.g. Constant Amplitude GSM to EDGE: Efficiency – 50+% to 10+%
- Integration – Box, Module, Packaging, or Chip
    - Technologies: RF, Data Acquisition, Base Band
    - Segments: Cellular, WLAN, Bluetooth, Military, etc.
    - Many simultaneous RF link applications are emerging
- Multimode – Multi-Standard functionality
- Multiband – Vision 2 MHz to 2.0+ GHz – Practically, targeted bands are implemented.
- Software Flexibility for:
    - Efficient Reuse
    - Mass customization: manufacture, distribution, field
    - Lower development costs
    - Time to market requirements

Table 5-2 Platform Requirements and Drivers
(*Source: SDR Market Report, Task 1: Market Segmentation and Sizing*, SDR Forum)

In infrastructure, multiple bands of operation generally require multiple RF transceiver subsystems. An apparent trend is toward baseband channel card farms and increasing indications and interest (e.g., Alcatel) in complete baseband waveform selection through software. Industry, in general, is providing infrastructure that is advertised as “future proof” through software upgrade. An example is the legacy GSM evolution to EDGE by baseband software upgrade. Similarly, the evolution path from WCDMA to the next emerging HSDPA/HSUPA is advertised as a (baseband) software upgrade. In both cases, the power amplifier must meet more stringent linearity requirements and PA power efficiency goals. Data acquisition components are increasingly more capable of digitizing entire uplink and downlink bands, and channelization is being performed digitally. This generally requires that the more difficult analog-to-digital (ADC, as compared to digital-to-analog, or DAC) digitize approximately 30 MHz bandwidths, requiring sampling rates of 100+ MHz at 14–16 bits of resolution. In infrastructure, digitization of entire bands provides benefits because infrastructure must modulate and demodulate all the RF carriers and their payload channels. As we transition to more complete SDR flexibility, wireless equipment vendors widely indicate that their products are “future proof” via reuse of common boxes and cabinets, power supplies, modules, and other components that can be updated with less costly board or even module replacement.

In addition, in handsets, to achieve low power, baseband SDR functionality is being maintained for single-carrier waveforms. Single-carrier digitization has smaller bandwidths and can be digitized at less power—a very important goal for battery-powered handsets. Thus, the handset market still utilizes RF/IF (or analog) channelization to achieve low-power goals. However, within a carrier, significant SDR baseband waveform flexibility is achievable today. One problem area in SDR waveform flexibility is that more advanced waveforms (i.e., higher bits/sec/Hz) are not constant amplitude (such as GSM) and require linear PAs with significantly less power efficiency. Thus, EDGE, CDMA 2000, WCDMA, HSDPA, and other advanced 3G waveforms have required advances in handset power amplifier (PA) technologies and products. Figure 5-1, an illustration of the state of the art in cellular handset architectures, presents an example from Texas Instruments (TI). Notice that multiple low-noise amplifiers (LNAs) are employed for cellular bands. Also, multiple PAs are employed: one for the 800/900 MHz band, one for the 1,800/1,900 MHz band, and one for the emerging 2,100 MHz WCDMA band. Note also that GSM/EDGE, being TDM, employs a Switchplexer to select the uplink or downlink connection to antenna (no duplexer). Conversely, the WCDMA transceiver, being continuous CDMA, requires a duplexer for simultaneous uplink and downlink operation. This adds complexity and cost pressures to WCDMA terminals compared to legacy low-cost GSM handsets (dual-mode requires both).

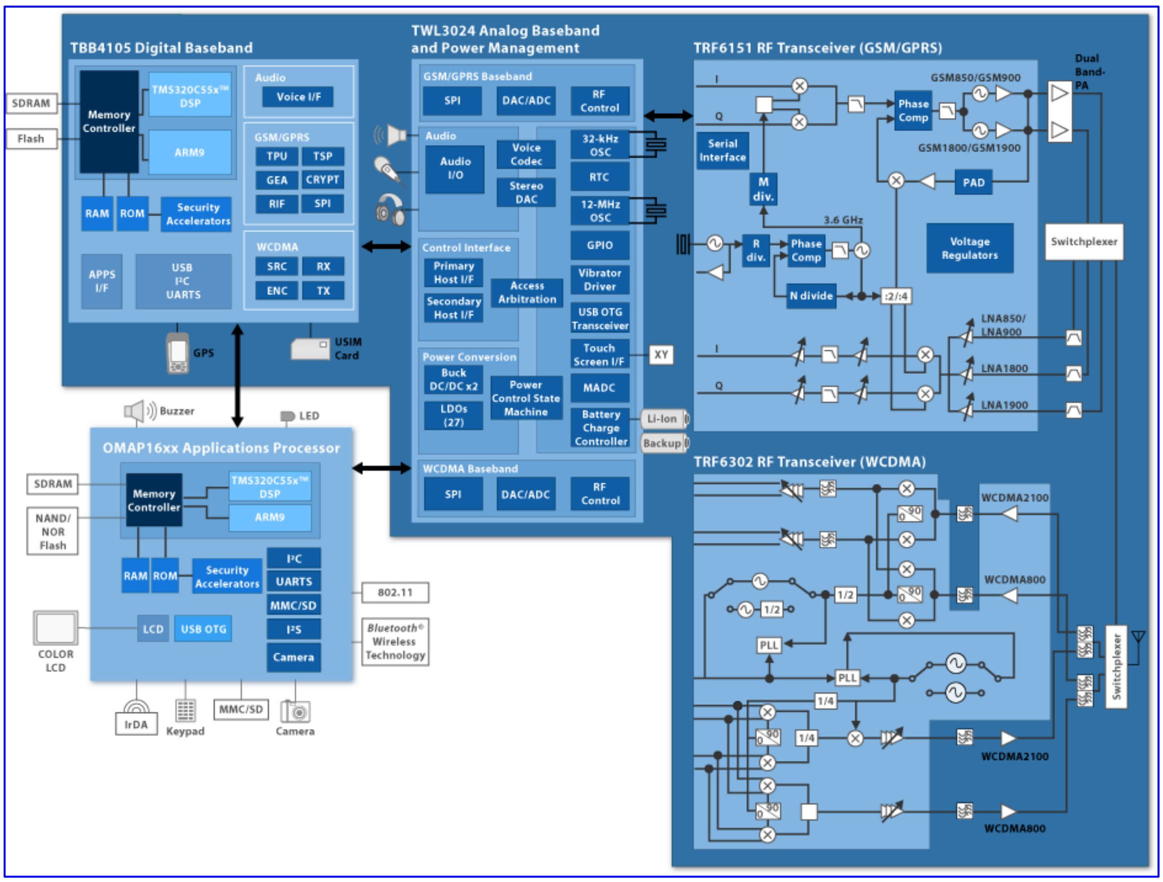


Figure 5-1 TI's Highly Integrated TCS4105 Chipset and Reference Design
(*Source*: TI web site)

Although point multiband and/or multimode capabilities are often desirable, more aggressive SDR capabilities are often not a high priority requirement or driver. For example, cellular handsets have key goals for low power (talk and standby time), cost, integration, targeted multiband/multimode, and emerging mass customization (e.g., Smartphone). More aggressive SDR RF flexibility goals are typically of lower priority.

It is well documented in the press that many operators have either delayed WCDMA service launches (e.g., in China and much of Europe) or experienced ramp problems in their WCDMA launches (e.g., Japan's DoCoMo). The European market needs multimode and multiband GSM/EDGE and WCDMA/HSDPA/HSUPA terminals. Japan requires terminals with WCDMA and its local PDC technologies. As Figure 5-1 illustrates, current RF technologies require multiple PAs and LNAs, and the current solutions generally target integration. Note that industry sources indicate that multiple LNAs are inexpensive (cost, power, and die area) and are a smaller issue. PAs are a more significant issue.

Future technology reports will provide more details on baseband, RF, and data acquisition technologies; present industry current state of the practice; and anticipate future evolution. Based on significant industry input, semiconductor technologies are available to provide highly flexible SDR baseband functionality. However, the exact winning architectures to achieve this are still open for industry innovation and market competition to establish value propositions. The RF and data acquisition technologies do not appear on track to provide highly flexible multimode and multiband SDR functionality and will require appropriate functional, cost, and performance trades to best match evolving technology capabilities and market requirements.

The Task 1 report was based on significant industry input, indicating that RF and data acquisition technologies will not for the foreseeable future be adequate for the Tier 4 or 5 SDR vision. Since that first report was issued, new input from several sources has indicated that they have technologies in development to better address these problems. Future technology studies will profile these technologies.

Each market segment (and often subsegments) is unique in its requirements, drivers, vendor differentiation goals; differing frequency band and mode requirements; and cost targets that require personalized platforms. The most prevalent expressed high-priority platform goal is component or intellectual property (IP) portability, often articulated as in the graphic representation of Figure 5-2. Thus, platforms become subsystems, modules, chips, and so forth that can be integrated into winning products with reusable hardware, software, and related IP that provide less time to market, lower cost, and flexible customization benefits. Reuse and platforms have been consistently expressed as cellular goals for both terminals and infrastructure.

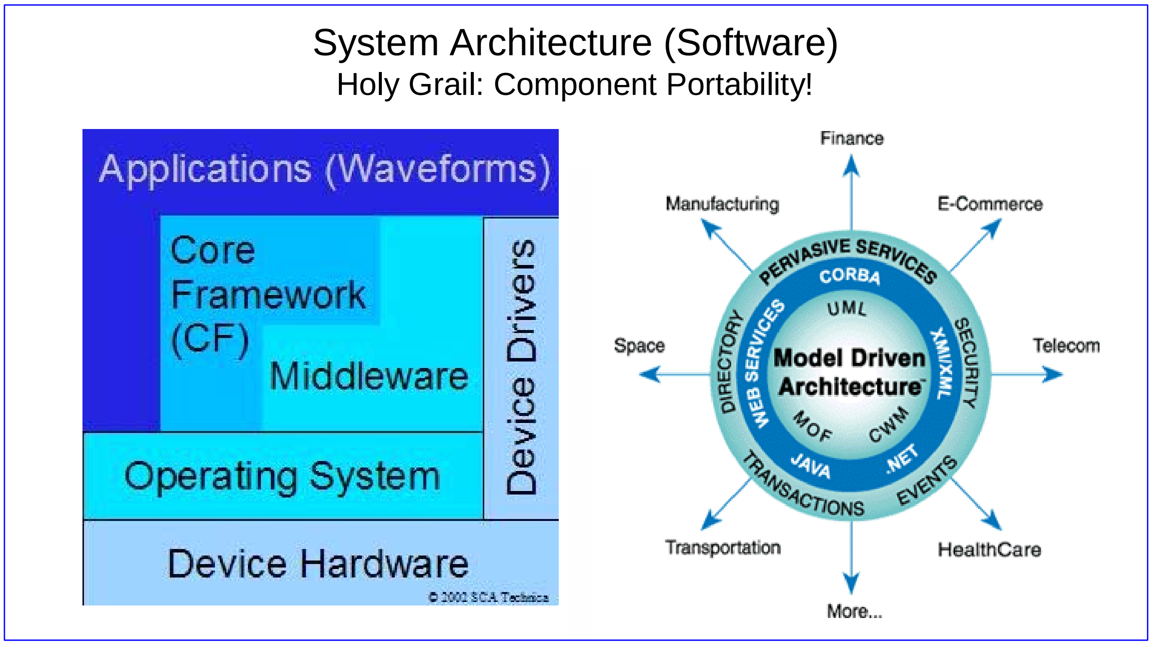


Figure 5-2 Component Portability
(*Sources*: SCA Technica and OMG (www.omg.org))

Historically, the cellular market segment has been vertically integrated, with terminal and infrastructure vendors providing a high percentage of critical differentiating IP in chips, modules, software, and systems that address baseband, RF, PAs, and software technologies. In response to the cellular industry becoming the leading market segment for DSP as well as many other semiconductor segments, IP is increasingly moving down the "food chain" (see Figure 5-3) and being developed by third-party subsystem, module, and semiconductor suppliers. The industry downturn of the early 2000s has required many network equipment vendors to reduce resources and become more amenable to outside third-party products and IP. We believe this food chain trend will be an important SDR opportunity.

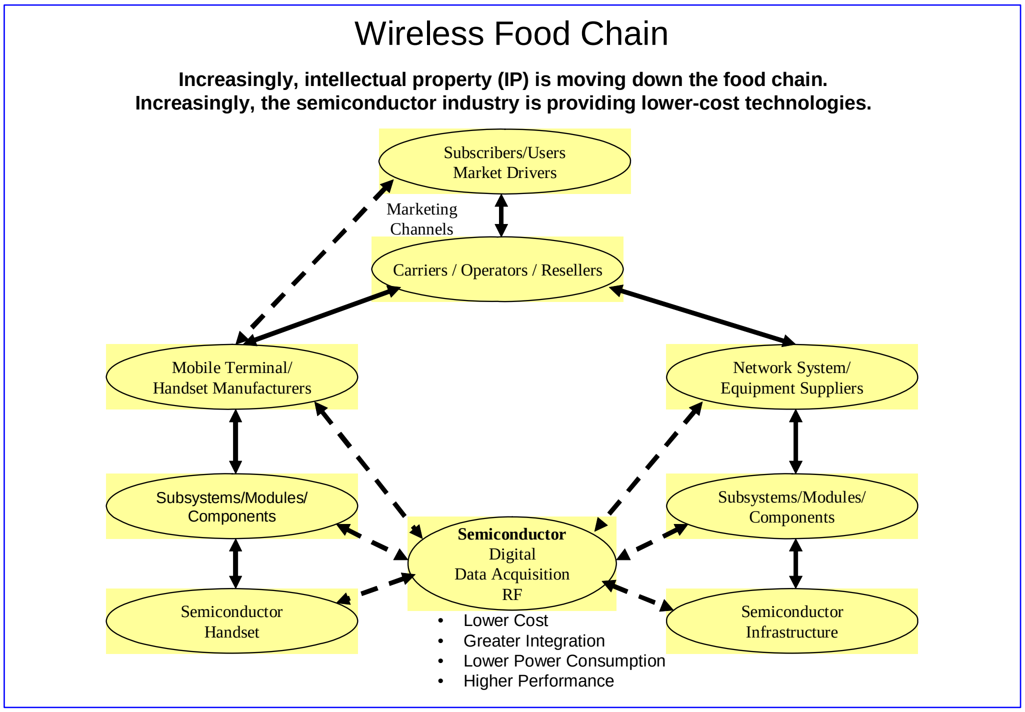


Figure 5-3 Wireless Food Chain
(*Source*: Update from *Wireless Infrastructure Technology and Markets: The Challenge of 3G*, by Jim Gunn, published by Forward Concepts, November 2002)

Clear indications of platform opportunities are the emerging platform interface standards. Several examples are presented in Figure 5-4. Historically, cellular handset and infrastructure vendors utilized proprietary interfaces between the various sub-systems in their products. Third-party vendors, such as multicarrier power amplifier (MCPA) vendors have had the difficult task of reverse engineering or contracting with network equipment vendors to penetrate the opportunities. The emerging standards define open interfaces that facilitate multi-vendor sourcing at the module and subsystem level. The standards presented in Figure 5-4 are for interfaces between the antenna, baseband, and/or the RF transceiver sub-systems. These standards are an emerging opportune trend because these interfaces are generally evolving from legacy analog interfaces to digital interfaces.

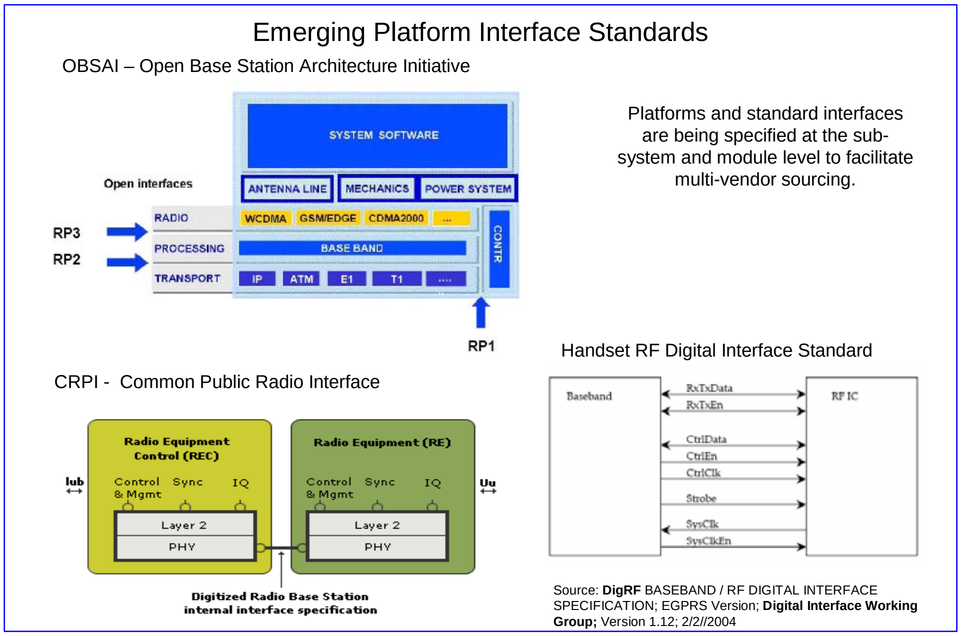


Figure 5-4 Emerging Platform Interface Standards
(*Sources*: OBSAI and CPRI web sites www.obsai.info and www.cpri.info, respectively)

In the Task 1 report, a preliminary matrix of platforms (columns) and SDR market segments (rows) was developed. Table 5-3 presents that matrix with updates for the cellular industry. Unique key drivers and priorities for market segments and platforms are identified in Table 5-3. Common key drivers and priorities for each market segment for all platforms are identified in the first column. Other segments will be updated in upcoming task reports for each segment.

The updates for cellular handsets address the clear emergence of two market segments. The first, the low-cost segment, is the emerging market segment of second-tier economies with low ARPU and requiring very low cost terminals. The second segment is the legacy first-tier economies that are approaching saturation and require terminals with enhanced feature sets (e.g., Smartphones) to address emerging 3G data services. Historically, operator revenue growth has been fueled by subscriber growth. These markets must now fuel their growth though new services.

The updates for infrastructure include improved coverage and capacity at lower TCO. As the industry evolves 3G services, greater capacity is required for the load of these new 3G services. Additionally, voice service is widely regarded as the key "killer app." Increasingly, operators are offering bundled or lower-cost MOU in rate plans as competitive incentives to attract customers. If either subscribers or MOU double, capacity requirements also approximately double.

Platforms / Segments	Wearable / Manpack	Portable	Mobile / Vehicle	Fixed Station / Infrastructure	Embedded
Cellular WAN Standards Migration 3G data Services		Low cost Segment Feature Segment Low Power Integration Multimode Multiband Mass Customization		Lower TCO Power Efficiency Common Box Platforms Baseband Farms ASSP Trend Improved Coverage Improve Capacity	
WLAN / WiMAX Short range High speed		Low Power Low Cost Integration		Short range Low Cost Integration	Cellular Computer Game Platforms
Public Sector Interoperability Digital Migration Refarming		Shift Battery Life Point to Point Point to Network	Point to Point Point to Network	Trunked Req. Significant Repeater Deployments	
Aviation / Avionics Digital Migration Refarming			Integration Add Passenger Services Security	Digital Migration Integration	
Automotive / Telematics			GPS Integration Services Zero defects		
Military (Significant R&D) Legacy waveforms Economies of Scale 2 MHz to 2.5 GHz	Integration GPS	Integration GPS	Integration GPS	Ad hoc Networks GPS	

Table 5-3 Platform Matrix: Key Drivers and Priorities
(*Source*: Update from *SDR Market Study: Task 1: Market Segmentation and Sizing*, by Jim Gunn, January 2005)

Lower TCO has been a consistent input in these studies. Press reports have positioned this as lower cost of CAPEX for purchase of wireless infrastructure equipment. Although CAPEX is an important consideration, OPEX costs are equally, usually more, significant to TCO. OPEX expenses typically include operation and maintenance; site rental; space, support, and training; power, transmission (i.e., backhaul); among other expenses. CAPEX includes, but is not limited to, wireless equipment, site construction and/or preparation, and planning. TCO is most effectively reduced by reducing the number of sites to provide required coverage and capacity. Thus, TCO, capacity, and coverage are added in Table 5-3.

In the Task 1 report, a generic radio architecture block diagram from a technology perspective was developed; this diagram is presented in Figure 5-5. The technologies are partitioned into (1) RF and data acquisition, (2) baseband, and (3) network processing. This figure provides an SDR technology roadmap overview as well as an overview of assessments of technology challenges.

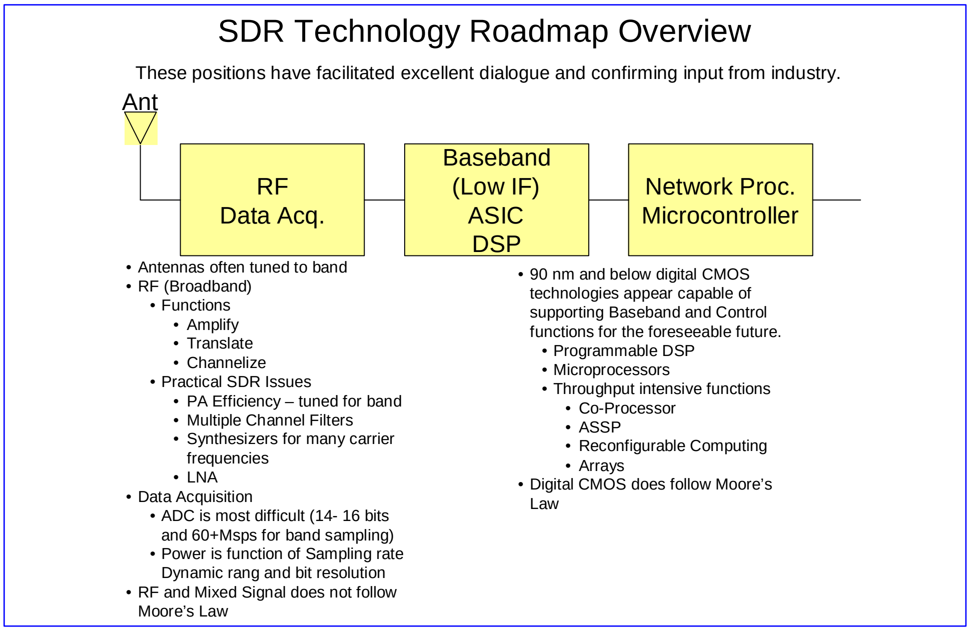


Figure 5-5 SDR Technology Roadmap Overview
(*Source*: Update from *SDR Market Study: Task 1: Market Segmentation and Sizing*, by Jim Gunn, January 2005)

Some may view these technology roadmap conclusions as disappointing. Near-term RF and data acquisition technologies, however, do provide needed and improving capabilities and feature sets to enable very valuable SDR benefits. This includes the long-verified software benefits to achieve lower cost, to provide more flexible transceiver developments, and to enable the SDR vision of field software-enabled waveform selection and update. The band and waveform flexibility goals presented here must be prioritized appropriately with other goals, such as cost, time to market, and more general flexibility opportunities. Information to update our platform and technology roadmap conclusions is always welcome.

Acronyms

1G, 2G, ...	first generation, second generation, etc.
3GPP(2)	3rd Generation Partnership Project
ADC	analog-to-digital
AMC	Adaptive Modulation and Coding
AMPS	Advanced Mobile Phone Service
ANSI	American National Standards Institute
ARPU	average revenue per unit
ASP	average selling price
BSC	base station control
BSS	base station subsystem
BTS	base station transceiver
CALA	Caribbean and Latin American
CAPEX	capital expenses
CDMA	Code Division Multiple Access
CMOS	complementary metal-oxide semiconductor
CS	circuit-switched (core network)
DAC	digital-to-analog
DSP	digital signal processor
EBITDA	Earnings Before Interest, Taxes, Depreciation, and Amortization
EDGE	enhanced data rate for GSM evolution
EGPRS	enhanced GPRS
EMH	Emerging Market Handset
ETSI	European Telecommunications Standardisation Institute
EV-DO	EVolution Data Only
EV-DV	EVolution Data Voice
FDD	Frequency Division Duplex
GDP	gross domestic product
GPRS	general packet radio service
GSM	global system for mobile communications
HARQ	Hybrid Automatic Repeat Request
HSCSD	high-speed circuit switched data
HSPDA	high-speed downlink packet access
IETF	Internet Engineering Task Force
IMS	Internet Multimedia Systems
IMT	International Mobile Telecommunications
IP	Internet Protocol; intellectual property
ISR	ideal software radio
JTACS	Japanese Total Access Communications System
KPI	key performance indicators
LNA	low-noise amplifier
MAC	medium access control
MAP	mobile application part
MII	Ministry of Information Industry (China)
MIMO	multiple inputs, multiple outputs
MOU	minutes of use (usually monthly)
MUD	multiuser detection
Net Adds	net subscriber additions
NGN	Next Generation Network
nm	nanometer
NMT	Nordic Mobile Telephone
OFDM	orthogonal frequency division multiplexing
OPEX	operating expenses
PA	power amplifier
PDC	personal digital cellular
PS	packet-switched (core network)
QoS	quality of service
RAN	radio access network
RBS	radio base station
RF	radio frequency
RNC	radio network control
ROM	rough order of magnitude
SAC	subscriber acquisition costs
SAR	subscriber acquisition and retention
SCR	software controlled radio
SG&A	sales, general, and administration
SIM	system interface module
SIP	Session Initiation Protocol
SMS	short message systems
SUO	Small Unit Operations
TACS	Total Access Communication Service
TCO	total cost of ownership
TDD	Time Division Duplex
TDMA	Time Division Multiple Access
TFDM	Time Division Multiplexed
TIA	Telecommunication Industry Association
TRX	transceiver
UMTS	Universal Mobile Telecommunications System
USR	ultimate software radio
VoIP	voice over IP
WCDMA	wideband CDMA
WLAN	wireless local area networks
YoY	year-over-year