SDR Market Study

Task 1: Market Segmentation and Sizing

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by

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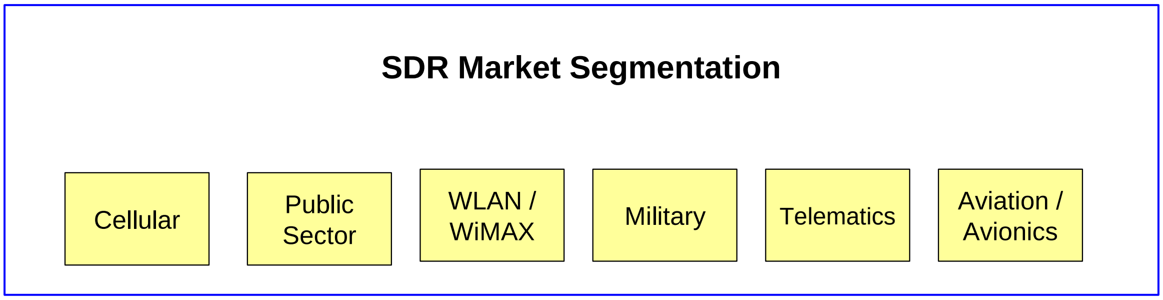
Table of Contents

List of Figures

List of Tables

Executive Summary

Significant software defined radio (SDR) opportunities, requirements, and benefits are emerging in many market segments. This report provides an overview of the market segments generally considered to offer the most significant potential for SDR technologies. The segments covered are presented in the following figure.

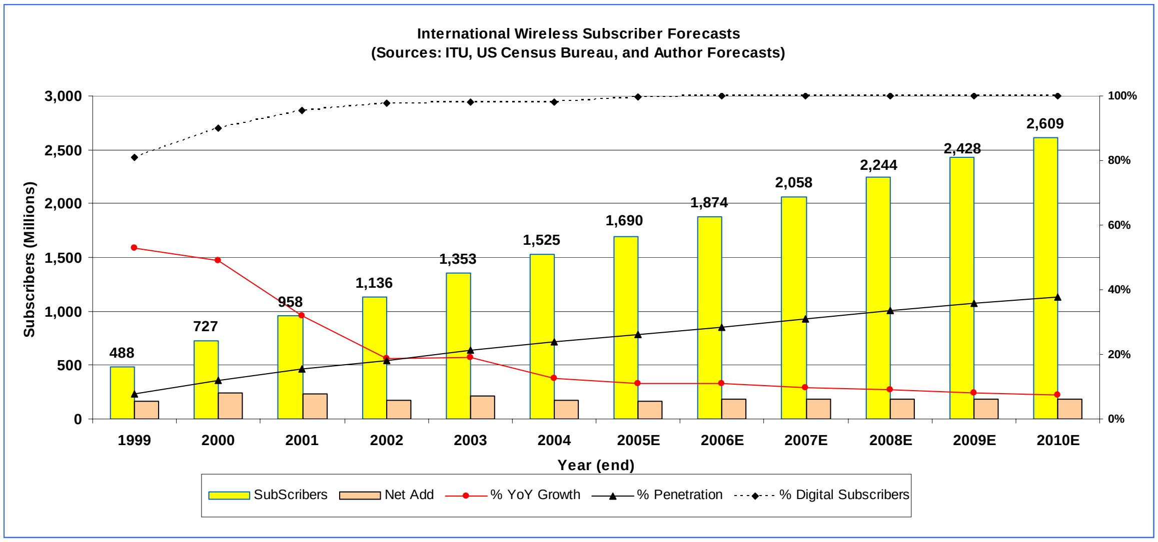


This report is the first of a series of studies commissioned by the SDR Forum. This report provides rough order of magnitude (ROM) estimates of the units and revenue market number for each segment as well as general discussions of requirements and drivers. Subsequent reports will address each of these segments in more detail.

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 infrastructures. Recent advances in semiconductor technologies, including 90 nanometers (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 as presented in the following table.

- 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.
- Support multiband and multimode radio frequency operations
- Enable the SDR vision of field software-enabled waveform, protocol, and application selection and update.

As illustrated in the following figure, cellular appears to be the clear “big” opportunity with an international subscriber base of more than 1.5 billion at year end 2004. The cumulative 10-year (2000-2010) terminal market (e.g., cellular phones) is estimated to approach $1 trillion and the infrastructure market (e.g. base station and core network) is estimated at more than $500 million.



(***Source:*** Wireless Infrastructure Technology and Markets: The Challenge of 3G; by Jim Gunn with updates)

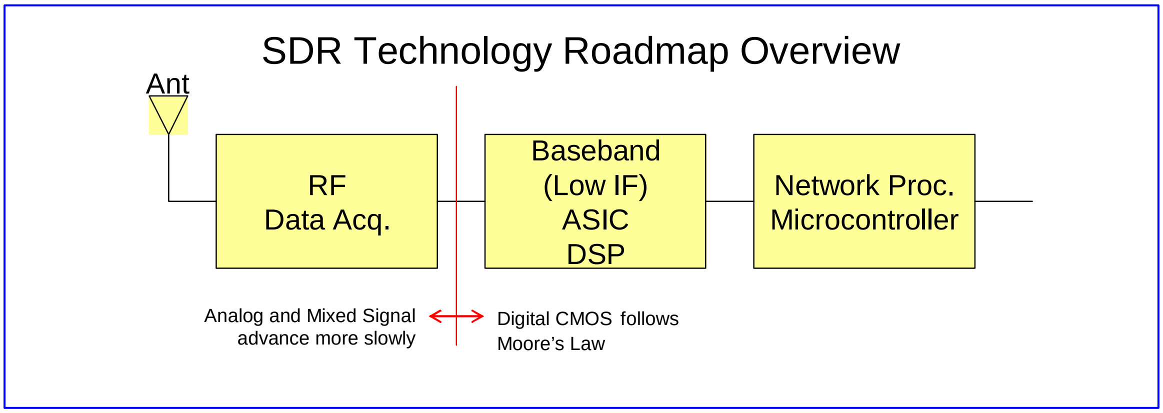
The military appears to be the SDR technology leader, with the US Joint Tactical Radio System (JTRS) which has significant international partners and interests. The JTRS program has invested significantly in SDR R&D.

Public safety has attracted much international attention due to problems of first responders in the 9/11/2001 terrorist attacks in the United States due to lack of interoperable and adequate communication resources. SDR technologies offer significant benefits to address technology issues and provide enhanced solutions. Public safety includes law enforcement, fire fighters, and emergency medical technicians.

Software flexibility and cost reduction are essential to all segments. Additionally, to varying degrees, all segments seem to have significant time-to-market pressures. Virtually all segments are in the process of standards migration. Most are still migrating from analog to digital (e.g., public safety, military, telematics, and avionics). The cellular industry is largely in transition from 2nd generation (2G) digital technologies to enhanced 3rd generation (3G) digital technologies to add wireless data capabilities. The WLAN market segments are essentially new segments that are digital in initial deployments.

Lower cost is an important consideration for all market segments, and a common platform to provide for economies of scale has been consistently identified as a key enabler. Ideally, a single box (i.e., system platform) could be provided for all applications. A first-level SDR segmentation has been portable, mobile, and infrastructure, with the goal that common system platforms be achievable for multiple segments. However, each market segment has unique requirements, drivers, and priorities that include cost, integration, power consumption, modes of operation, bands of operation, applications, and network interfaces. Thus, industry seems focused on technology reuse to reduce costs. Technology reuse includes components, modules, subsystems, and intellectual property (IP), as well as systems, hardware, software, manufacturing, logistics, testing, etc. Thus, highly valued SDR benefits by industry include component and technology reuse. Reuse targets multiple evolving product families that reduce costs and time-to-market (TTM), and enable enhanced cost-effective, flexible, and market-driven feature sets.

Technology roadmaps of requirements to enable SDR have been somewhat neglected by industry. Input to date from industry representatives on their opinions and plans indicates that 90 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). Radio frequency (RF) and data acquisition, however, do not appear to be on track to support aggressive SDR capabilities cost-effectively in the foreseeable future. Nevertheless, many valuable solutions through reuse of components, chips, subsystems, and, of course, software are achievable with substantial benefits.



Enhanced R&D planning for RF and data acquisition would be beneficial to highlight problems and to identify the most promising alternatives and roadmaps. The SDR community should provide enhanced value propositions and analyses for each market segment that addresses current and emerging SDR capabilities and benefits as technologies increasingly achieve SDR visions. Each market segment has unique priorities, drivers, and value propositions, so the SDR community needs to better scope each segment's requirements and provide tailored technology roadmaps for each segment.

1 Introduction

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 infrastructures. Recent advances in semiconductor technologies including 90 nanometers 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 as presented in Table 1-1.

1. 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.
5. Support multiband and multimode radio frequency operations
6. Enable the SDR vision of field software-enabled waveform, protocol, and application selection and update.

Table 1-1 SDR Benefits / Value Propositions

This report is the first of a series of SDR market studies commissioned by the SDR Forum. The work to create these SDR market study reports is divided into two phases and multiple tasks. This first task of the current work phase is to “segment and size” the most promising market segments with rough order of magnitude (ROM) estimates and general segment discussions. Follow-on tasks will provide more detailed segmentation and sizing for each segment and more detailed analysis of requirements, drivers, issues, and business models. An overview of the phases and tasks for these studies is presented inTable 1-2.

Phase 1 (Current Work) **Task 1 – Segment and Size – Rough Order of Magnitude** **Task 2 – Cellular – Terminals and Infrastructure**
Phase 2 – Follow-on Tasks – Order of completion TBD (to be determined) **Task 3 – Military** **Task 4 – Public Safety (Law Enforcement, Fire, Emergency Management, etc.)** **Task 5 – Wireless Local Area Networks** **Task 6 – Telematics** **Task 7 – Avionics** **Task n – TBD**

Table 1-2 SDRF Market Study Phase and Tasks

A fundamental goal of this work is to provide clarity and guidance for the SDR community on “where we are, where we need to be, and how we get there” based on market opportunities and requirements. These are not static goals with final end points, but ongoing opportunities that will be enhanced and improved not only as we progress through these studies, but also afterward, based on lessons learned and technology advancements.

This first report, on SDR segmentation and sizing identifies the most promising market segments for SDR technologies, provide 1st level ROM segment market estimates and forecasts, and provide general segment discussions. The report is organized as follows:

1. Executive Summary
2. Introduction
3. Segmentation Overview
4. Technology Roadmaps and Platforms
5. SDR Market Segments

Increasingly, platforms are being adapted by industry where similarity of requirements is suitable. One example of platform categorizations is that of portable, mobile, and infrastructure. Effective platform concepts provide many benefits, including IP reuse, reduced time to market, economies of scale, and almost always lower cost. General platform-based concepts and benefits are identified in this report. More detailed and segment-specific platform-based opportunities, examples, and benefits will be identified in tasks 2 through n.

Some forms of SDR have been deployed for many years via programmable digital DSP and microprocessor technologies for less throughput-intensive baseband functions. These capabilities need to be expanded to the more throughput-intensive digital functions as well as RF and data acquisition. This report develops an overview of the anticipated technology roadmap.

As SDR addresses emerging markets and technologies, the focus will be on targeted key SDR stakeholders with technology and market knowledge and opinions as opposed to surveys soliciting broad trends, statistics, and consensus information.

A key activity of Task 1 has been developing contacts and information sources for follow-on tasks. The SDR Forum consists of many individuals from organizations with SDR interests, capabilities, knowledge, and technologies; anyone with interest in providing input or opinions for these reports is encouraged to contact the author (see the title page for contact information).

2 Segmentation Overview

Figure 2-1 presents the SDR market segmentation developed for these SDR studies. This report develops market size estimates for the first level for total units and total revenues. As appropriate, further estimates for each segment are developed for the general SDR segmentation of portable, mobile, and infrastructure. In subsequent reports, more detailed subsegmentation and market sizing data will be developed as appropriate for each segment.

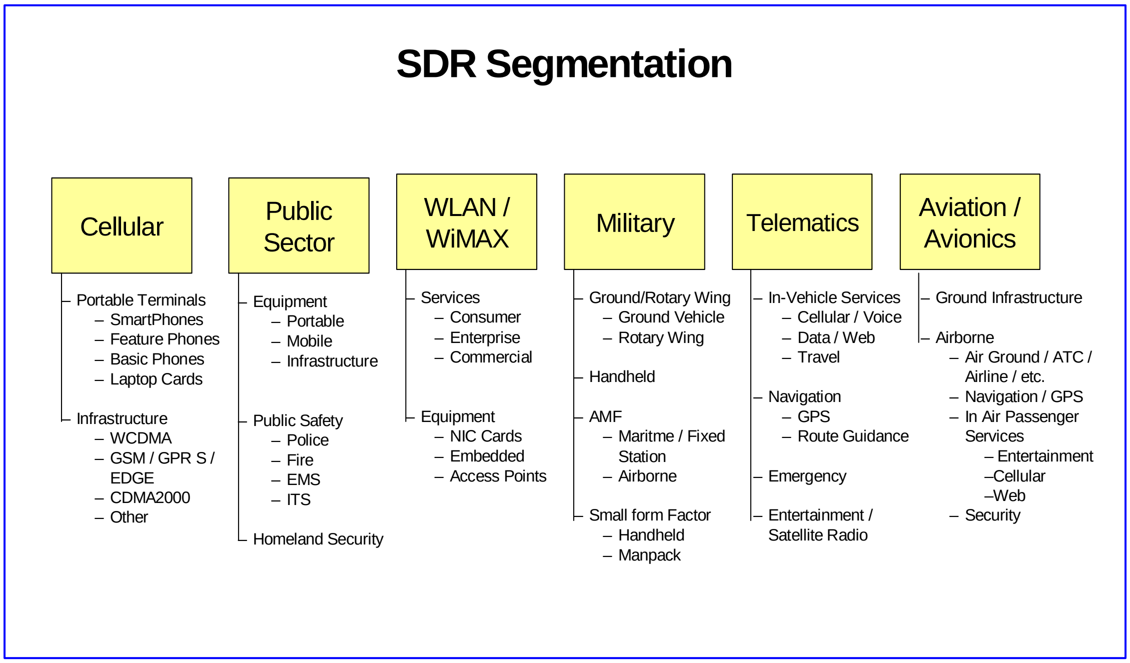


Figure 2-1 SDR Market Segmentation

3 Platforms and Technology Roadmaps

Critical to SDR market successes are platforms and enabling technologies for SDR implementations. This section will present current findings. As these studies continue through later tasks on individual market segments, this information will be updated as appropriate.

Figure 3-1 presents a recent front-page headline from the *Wall Street Journal* documenting an increasing market requirement for Software Defined Radio capabilities. Historically, cellphone manufacturers have dominated cellphone features, user interfaces, branding presence, etc. in the legacy voice-centric 2G market. The 3G evolution adds a multitude of additional data, video, and voice services. Cellular operators are in a discovery mode with many differing market segments, requirements, opportunities, and possible operator responses. Emerging technologies include 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 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 3-1 Emerging markets for Smartphones require SDR capabilities
(*Source:WSJ, 11/12/2004, p*1)

A consistent early question in engagements to obtain input for this study has been "What is the definition of SDR?" As a good starting point, the SDR Forum's definition, presented in Table 3-1, is offered in terms of "Tiers of Capabilities and Flexibility." In the mid 1990s, the first exposure to SDR positioned it as a means to help the US military community address its need to replace aging communication systems and equipment that consisted largely of incompatible point solutions for each service and many subordinate commands and applications. The original key goals were defined in terms of "common platforms" to achieve "economies of scale" and "interoperability." With many legacy waveforms, many bands of desired operation, and many desired new bands and broadband waveforms, these original military SDR goals quickly became synonymous with the popular expression of "2 MHz to 2+ GHz" flexible waveform selection with software. Industry engagements related to this report indicate that "2 MHz to 2+GHz" goals are being indirectly positioned (i.e., not directly stated) as secondary to the primary goals expressed in Table 1-1. The SDR community can more effectively address broad commercial, military, government, business models and value propositions by better prioritization of these more general goals.

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 by 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 a 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 global positioning systems (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 3-1 SDR Definition: Tiers of Capability and Flexibility
(*Source:* www.sdrforum.org/tech_comm/definitions.html)

3.1. SDR Platforms

Various definitions and motivations for platforms have been offered in the industry. The most general definition is at the system level and includes categorization, such as portable, mobile, infrastructure, and perhaps others, with each category having sufficiently similar requirements and feature sets. Specific examples include boxes such as cellular basestation transceivers (BTS), or portable handsets such as cellular phones. The ultimate goal is a common platform that can be personalized via software for a wide range of market segments, applications, and business models as required for cellular, public safety, WLAN, avionics, telematics, and so on.

In reality, each market segment (and often subsegments) has unique 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 portability, often articulated as in the graphic representation of Figure 3-2. Thus, platforms become subsystems, modules, chips, etc. that can be integrated into winning products with reusable hardware, software, and related IP that provide time to market, lower cost, and flexible customization benefits.

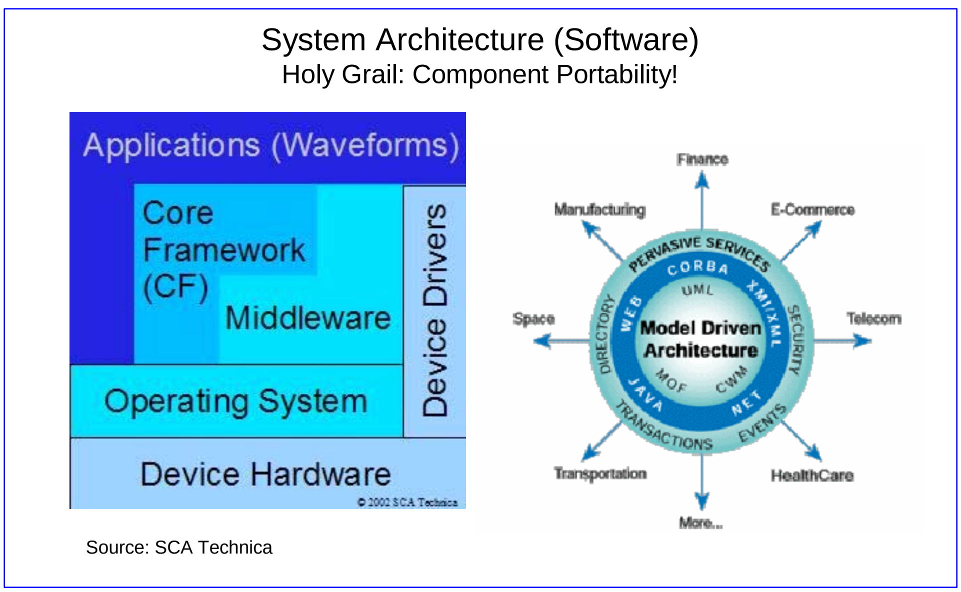


Figure 3-2 Component Portability

General industry platform requirements and drivers are presented in Table 3-2. A key ingredient for emerging platform successes results from economies of scale and lower cost of software versus hardware Very High-level Design Language (VHDL) developments.

- **Low Cost**
- **Low Power**
- **Power Amplifier (PA) – trend to multicarrier power amplifier (MCPA)**
- **Power Efficiency – e.g., Constant Amplitude GSM to EDGE: Efficiency – 50+% to 10+%**
- **Integration – Box, Module, Packaging, or Chip**
    - **Technologies: RF, Data Acquisition, Baseband**
    - **Segments: Cellular, WLAN, Bluetooth, Military, etc.**
    - **Many simultaneous RF link applications are emerging**
- **Multimode – Multistandard 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 3-2 Platform Requirements and Drivers

Historically, most wireless market segments have 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, PA, 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 wireless “food chain” (see Figure 3-3) and is being developed by third-party subsystem, module, and semiconductor suppliers. The industry downturn of the early 2000s has required many system product vendors to reduce resources and become more amenable to outside third-party products and IP. This food chain trend will most likely be an important SDR opportunity, but will necessitate broader responsive business model goals for SDR.

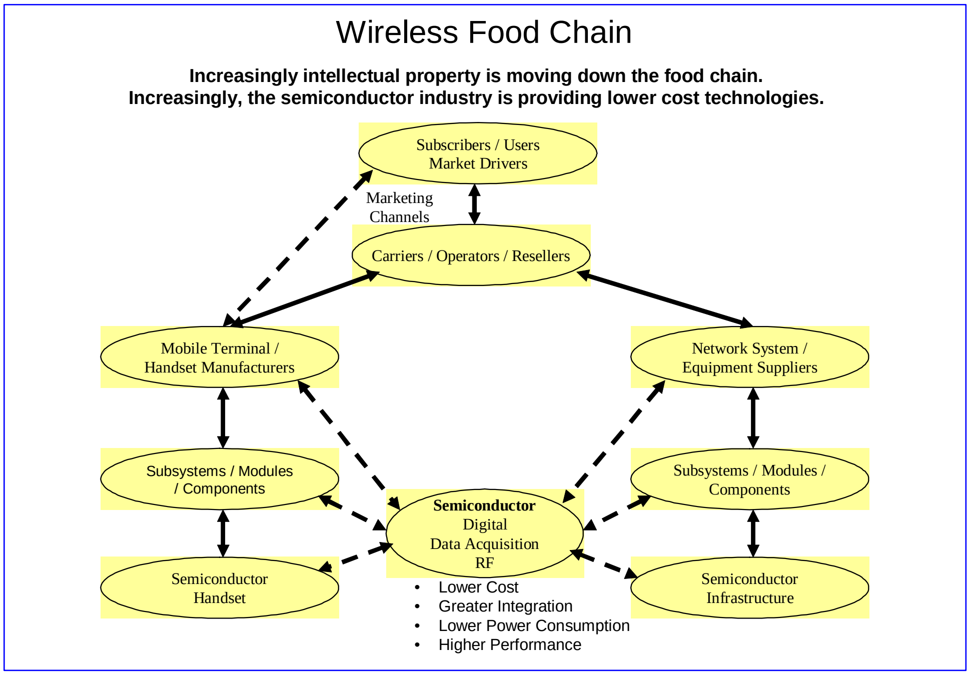


Figure 3-3 Wireless Food Chain
(*Source*: Adapted from *Wireless Infrastructure Technologies and Markets*)

Clear indications of platform opportunities are the emerging platform interface standards. Several examples are presented in Figure 3-4. Historically, cellular handset and infrastructure vendors utilized proprietary interfaces between the various subsystems in their products. 3rd 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 multivendor sourcing at the module and subsystem level. The standards presented in Figure 3-4 are for interfaces between the antenna, baseband, and/or the RF transceiver subsystems. These standards reflect an emerging opportune trend, as these interfaces are generally evolving from legacy analog interfaces to digital interfaces.

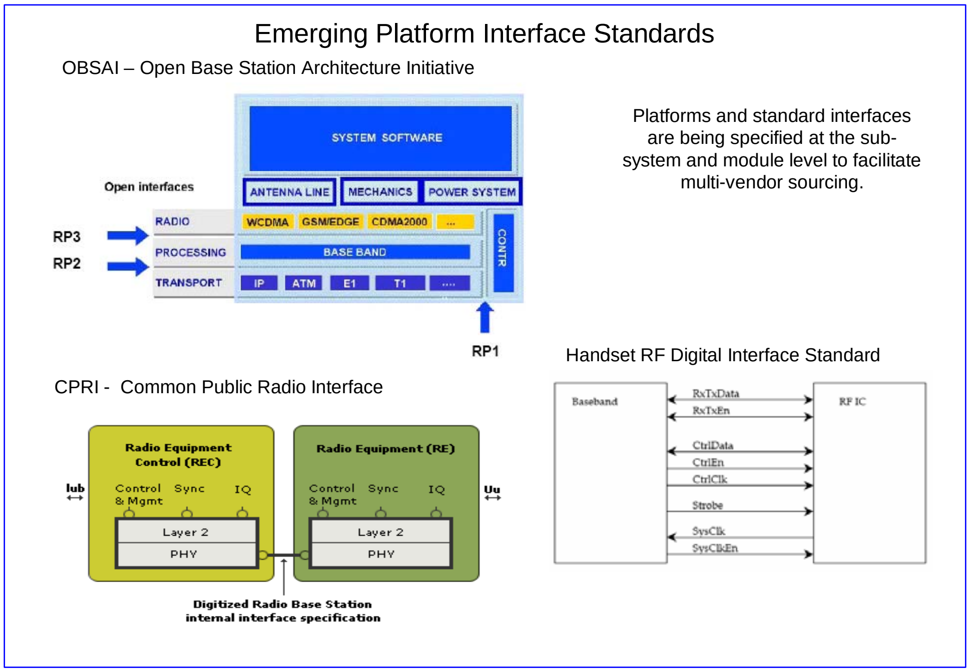


Figure 3-4 Emerging Platform Interface Standards
(*Sources:* OBSAI: www.obsai.org; CPRI: www.cpri.info; Handset RF Digital Interface Standard: DigRF Baseband/RF Digital Interface Specification, EGPRS Version; Digital Interface Working Group; Version 1.12, 2/2/2004.)

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.

Table 3-3 presents a preliminary matrix of platforms (columns) and SDR market segments (rows). Common key drivers and priorities for each market segment for all platforms are identified in the first column. Unique key drivers and priorities for market segments and platforms are identified in the cells of the matrix.

The entries in Table 3-3 are based on preliminary broad (not in-depth) industry engagements for this initial "Segment and Size" task. As more in-depth engagements are accomplished in following tasks that develop more detailed information, these entries will be updated to reflect these requirements and drivers for each segment.

Platforms / Segments	Wearable / Manpack	Portable	Mobile / Vehicle	Fixed Station / Infrastructure	Embedded
Cellular WAN Standards Migration 3G Data Services		Low Cost Low Power Integration Multimode Multiband Mass Customization		Cost Power efficiency Common box platforms ASSP trend	
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 requirements 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 3-3 General Platform Matrix: Key Drivers and Priorities

3.2. Technology Roadmap

The original statement of work (SOW) for these studies stated that "recent advancements in semiconductor technologies including .13 micron and below digital technologies, RF technologies, and data acquisition technologies create imminent market opportunities to extend programmability to virtually all aspects of transceiver algorithms. This extends the long verified software benefits to achieve lower cost, more flexible transceiver developments, and enable the SDR vision of field software-enabled waveform selection and update."

In the early planning for these market studies, judgments may have been overly influenced by the highly visible "Moore's Law" for digital CMOS technologies, which indicates that chip integration, gate speeds, and power consumption improve by a factor of two approximately every two years. Ongoing market and technology research engagements have included many impressive briefings, input, and data on emerging and enhanced digital technologies that will enable SDR, including DSP, microprocessors, co-processors/accelerators, array processors, reconfigurable logic, etc. Based on this input, a reasonably near-term aggressive SDR vision is deemed to be achievable. We now believe that this statement should identify baseband technologies as appearing capable of supporting aggressive SDR goals.

The RF and data acquisition (mixed signal) challenges for SDR are well known, and assumptions that these challenges have near-term solutions are not well founded. In developing "an overview of the technology roadmap critical to SDR commercial successes that addresses digital baseband, data acquisition, and RF," industry representatives consulted for this report agree, without exception, that "DSP and related digital technologies appear on-track to support near-term aggressive SDR goals, but that RF and data acquisition technologies appear challenging." . In discussions to clarify opinions, many offered supplemental comments that generally conclude that completely flexible "2 MHz to 2+ GHz" SDR capabilities do not appear commercially achievable in the next 5- to 10-year timeframe for RF and data acquisition. This is based on current input and visibility to current RF and data acquisition technologies and challenges. Companies consulted include Texas Instruments (TI), Freescale, Analog Devices, TelAsic, Ericsson, plus many more.

Figure 3-5 presents a typical transceiver algorithm block diagram that illustrates algorithms partitioning into baseband, data acquisition, and RF/IF functions. The diagram is representative of a heterodyne architecture employing intermediate frequency (IF) conversion(s). Direct conversion technologies are emerging that convert directly to (x,y) baseband without an IF conversion. Direct conversion offers potential advantages that include reduced parts count, lower cost, and more flexible baseband channelization digital filtering. Data acquisition alternatives are represented by dotted lines. As signal digitization moves to the left as envisioned for future all-digital transceivers, RF and/or data acquisition technical challenges increase. The ultimate SDR target is to digitize the entire spectrum of interest and to digitally perform all channelizing /filtering, baseband RF translation, modulation, and error coding functions, as well as network/control functions.

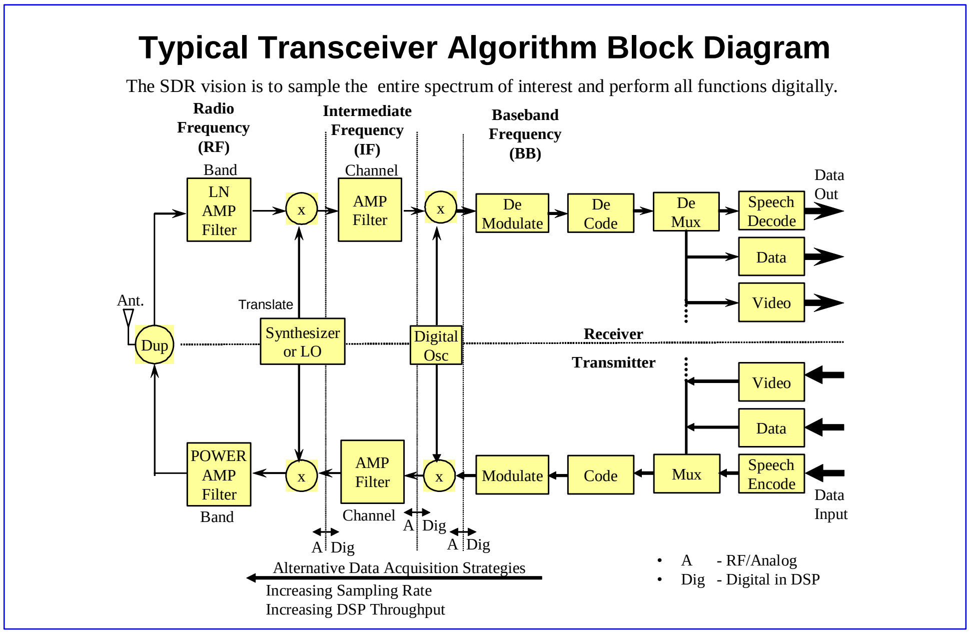


Figure 3-5 Typical Transceiver Algorithm Block Diagram

A generic radio architecture block diagram from a technology perspective is presented in the SDR Technology Roadmap Overview, Figure 3-6, which is partitioned by technology into (1) RF and Data Acquisition, (2) Baseband, and (3) Network Processing. This figure provides an overview of assessments of technology challenges.

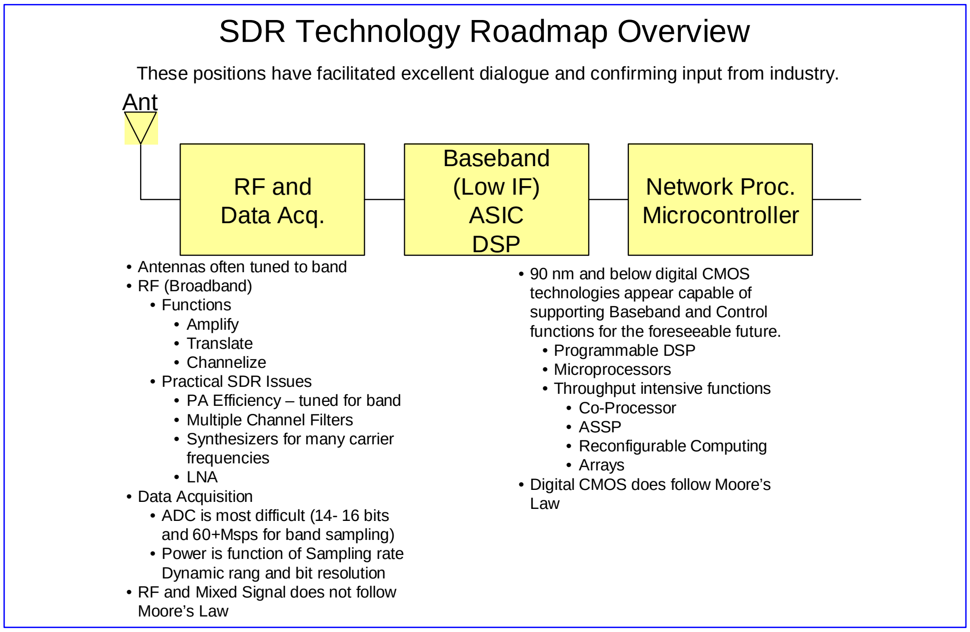


Figure 3-6 SDR Technology Roadmap Overview

Digital baseband technologies, supported by 90 nm and below digital CMOS semiconductor technologies, appear on track to support aggressive SDR goals. The specific products include DSP, microprocessors, and special-purpose circuits that can be stand-alone products or integrated enhancements for traditional advancing DSP and microprocessor technologies. These special-purpose circuits include co-processors, application-specific standard products (ASSPs), reconfigurable logic, arrays, and other technologies that support throughput-intensive functions. These functions have been historically addressed in proprietary application-specific integrated circuits (ASICs), field-programmable gate arrays (FPGAs), and other implementations. Many examples exist, such as the TI block diagram (Figure 3-7) of their highly integrated TCS4105 chipset and reference design targeting wideband code division multiple access (WCDMA) and global system for mobile communications/general packet radio service (GSM/GPRS) multimode, multiband cellular phones.

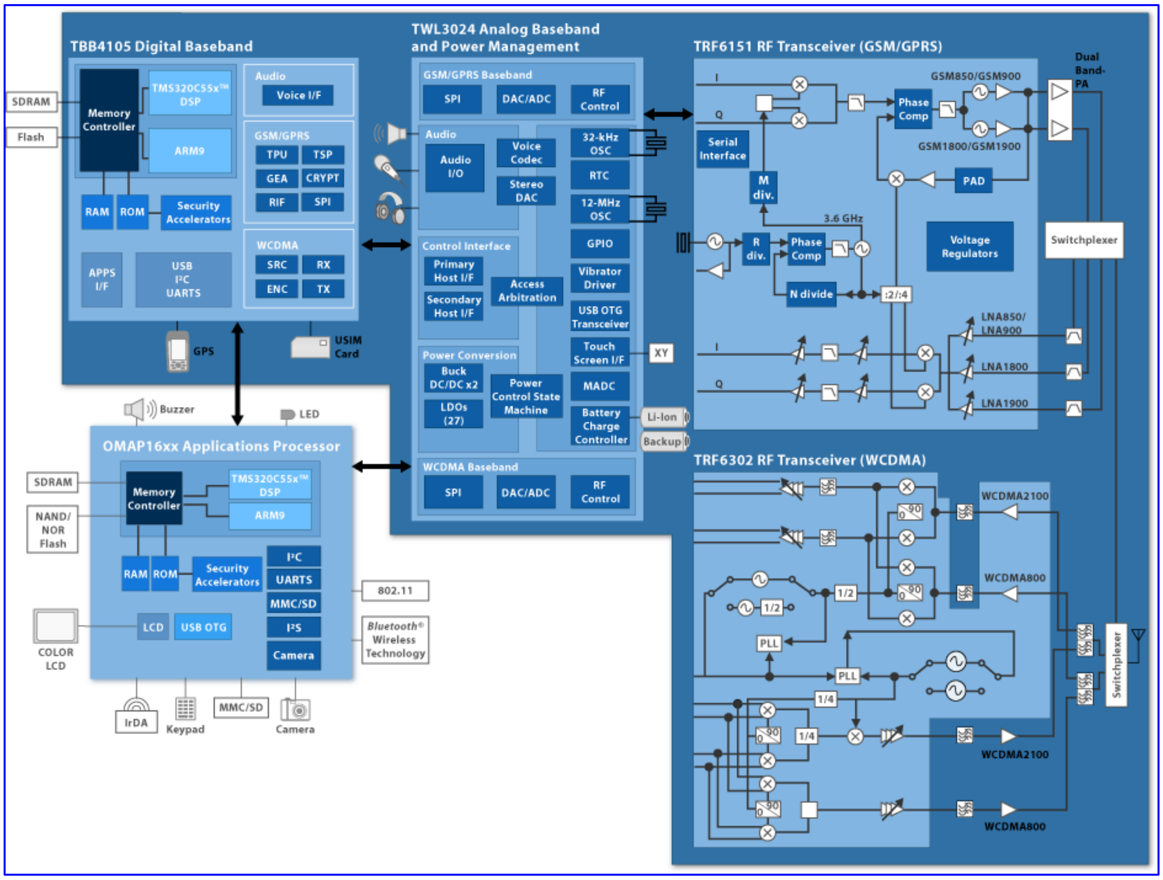


Figure 3-7 TI's Highly Integrated TCS4105 Chipset and Reference Design
(*Source:* Texas Instruments)

RF/IF circuits do not enjoy as rapid a pace of technological advancement that digital technologies do (Moore's Law). Simplistically, RF/IF circuits amplify, translate, and channelize analog signals.

Silicon Laboratories (Silab) is a company that focuses on high-performance mixed signal CMOS integrated circuits (ICs). Silab's Aero EDGE (Enhanced Data for Global Evolution) radio chip set and reference design, Figure 3-8, provides an excellent and successful example of the value propositions of advanced current RF technologies for a quad-band GSM/GPRS/EDGE radio. (Consider also the RF architecture of Figure 3-7.) The value propositions articulated by Silabs include:

- Small footprint and fewer components
- High data rates
- Small form factors
- Digital low-IF architecture that supports both Gaussian minimum shift keying (GMSK) and 8-phase shift keying (8-PSK) modulation
- Mainstream CMOS semiconductor process
- 8-PSK transmitter formed with a companion chip that includes a direct up-conversion mixer and a variable gain amplifier (VGA)

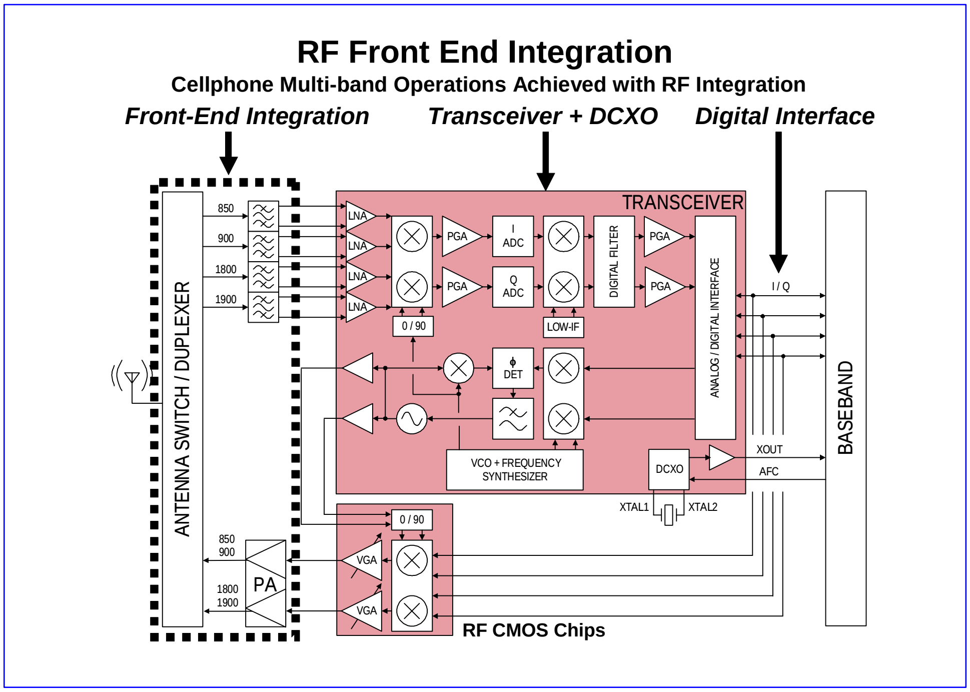


Figure 3-8 Silicon Laboratories RF Front End Integration
(*Source:* Silicon Laboratories)

Broadband RF provides many practical technology challenges for SDR, including:

- Power amplifier (PA) efficiency requires PAs tuned for band of operation.
- Advanced waveforms (e.g., WCDMA, EDGE) are not of constant amplitude and require linear PAs that are less efficient.
- Multiple band and/or channel filters are required.
- Synthesizers must accommodate each desired carrier frequency.
- Low-noise amplifiers (LNAs) are tuned for band of operation.
- Antennas are tuned for band of operation.

Data acquisition refers to both analog-to-digital (ADC) conversion and digital-to-analog (DAC) conversion. The challenges to data acquisition in supporting the broadband signals that are desired for SDR include:

- ADC is more difficult than DAC.
- Digitization of a band followed by digital channelization substantially increases the required dynamic range and required bits of resolution (expressed as spurious free dynamic range (SFDR)).
- The ADC in the receiver requires a more dynamic range.
- Current industry ADCs for infrastructure support:
  - 14–16 bits at 60–110+ Msps (megasamples per second)are required for band sampling.
  - Power is a function of sampling rate dynamic range and bits of resolution.

A representative advanced ADC specification is presented in Table 3-4 for the Analog Devices AD6645 converter. This converter can digitize 15–20 MHz bands that will address three or four carriers for 3.84 MHz WCDMA signals.

Analog Devices AD6645 **– 14-Bit, 80 /105 Msps A/D Converter**	
Resolution (Bits)	**14bit**
Throughput Rate	**105Msps**
# of ADC Inputs	**1**
Supply V	**Multi(+3.3, +5)**
Power Dissipation (max)	**1.75W**
Ain Range	**2.2 V p-p**
SNR	**75 dB, Fin = 15 MHz up to 105 Msps** **72 dB, Fin = 200 MHz up to 105 Msps**
SFDR	**89 dBc, Fin = 70 MHz up to 105 Msps** **100 dB Multitone**
IF Sampling	**to 200 MHz**
Sampling Jitter	**0.1 ps**

Table 3-4 Representative High-Performance AD Converter for Wireless Infrastructure

Data acquisition circuits capable of digitizing “2 MHz to 2+ GHz” at reasonable power do not appear feasible in the next 5 to 10 years. The current trend for infrastructure is to digitize bands (e.g., cellular, PCS, WCDMA band in the 800/900, 1800/1900, and 2100 MHz ranges) that are typically 15–20 MHz and then perform channelization digitally. For cellular phones with very low power constrains, the trend is to continue to provide RF/IF channelization (i.e., analog) and to digitize only the required modulated RF carrier.

Although some may view these technology roadmap conclusions as disappointing, near-term RF and data acquisition technologies 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, more flexible transceiver developments, as well as to enable the SDR vision of field software-enabled waveform selection and update. Albeit that band and waveform flexibility goals will be prioritized appropriately with other goals, such as cost, time to market, and more general flexibility opportunities, future SDR studies will update these platform and technology roadmap conclusions.

4 SDR Market Segments

This section provides rough order of magnitude (ROM) market estimates and forecasts and general discussion for the following segments:

1. Cellular
2. Military
3. Public Safety
4. WLAN/WiMAX,
5. Automotive/Telematics
6. Aviation / Avionics

Some would classify intelligent transportation systems (ITS) with automotive/telematics. However, ITS is addressed here as part of public safety because it is largely government funded and driven and is an important Homeland Security asset.

The market estimates herein generally cover the time period from 2000 to 2006, and beyond as appropriate. This report provides representative historical data as well as forecast data. In some segments, such as public safety and military, the requested forecasts are generally presented as replacement costs because these segments can vary significantly depending on government budgets. This work strives to provide fundamental data such as world populations, cellular subscribers, and penetration so that these forecasts can be updated and enhanced easily to accommodate such situations as multiple devices per subscriber, changing market conditions, and so forth.

4.1. Cellular

The cellular industry has evolved to become one of the largest international industries with an international subscriber count of approximately 1.6 billion at year end 2004. Cellular is overtaking traditional wireline in both 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, WLAN, cable TV, voice-over-Internet-Protocol (VoIP), and related technologies and services to ensure future growth.

Since the late 1990s, the cellular industry has been evolving from the original 2G digital standards that provide voice-centric services to 2.5G and 3G standards that provide voice capacity enhancements and add wireless data, video, and Internet services. Figure 4-1 presents an overview of this evolution. Table 4-1 provides a summary of international frequency allocations for these standards.

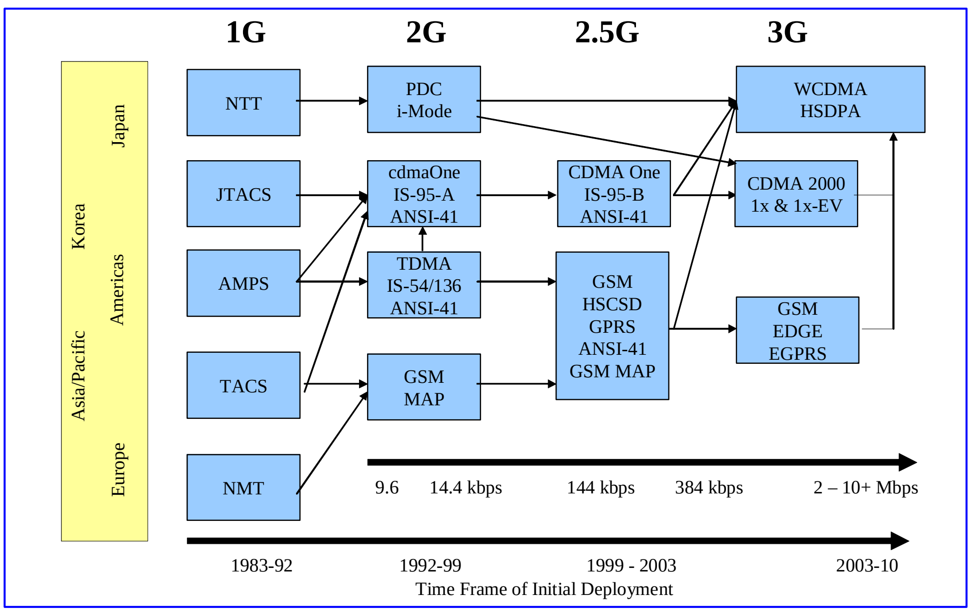


Figure 4-1 2G/2.5G/3G Standards Evolutions

Region	Standard / Band	Uplink	Downlink	Comment
Americas	Cellular	824 - 840 MHz	869 - 894 MHz	
	PCS	1850 - 1910 MHz	1939 - 1990 MHz	
	WCDMA	1850 - 1910 MHz	1939 - 1990 MHz	New FCC bands under consideration
Europe, most of rest of world	Cellular	880 - 915 MHz	925 - 960 MHz	
	DCS	1710 - 1785 MHz	1805 - 1880 MHz	
	WCDMA	1920 - 1980 MHz	2110 - 2370 MHz	Same as Asia
Asia	Cellular	824 - 840 MHz	869 - 894 MHz	
	KPCS	1750 - 1785 MHz	1840 - 1970 MHz	
	WCDMA	1920 - 1980 MHz	2110 - 2370 MHz	Same as Europe

Table 4-1 International Cellular Frequency Band Allocations

The key 3G cellular standards are GSM/EDGE/GPRS, CDMA 2000 1x/1x-EV-DO, WCDMA/HSDPA, and TD-SCDMA (China-led technology). In the late 1990s 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 Euro-centric, but have increasingly achieved international successes. The 3GPP2 assumed responsibility for CDMA One, CDMA 2000, and related standards. These standards have been US-centric, led by Qualcomm, but have also achieved international successes. Figure 4-2 presents estimated 2004 year-end subscriber counts by technology. Of significance, GSM dominates the international market with more than 70% of total subscribers.

Figure 4-3 presents data and forecasts from 2000 to 2010 of international wireless subscribers, yearly net subscriber additions, penetration (subscribers/population), percentage year-to-year growth, and percentage of digital subscribers.

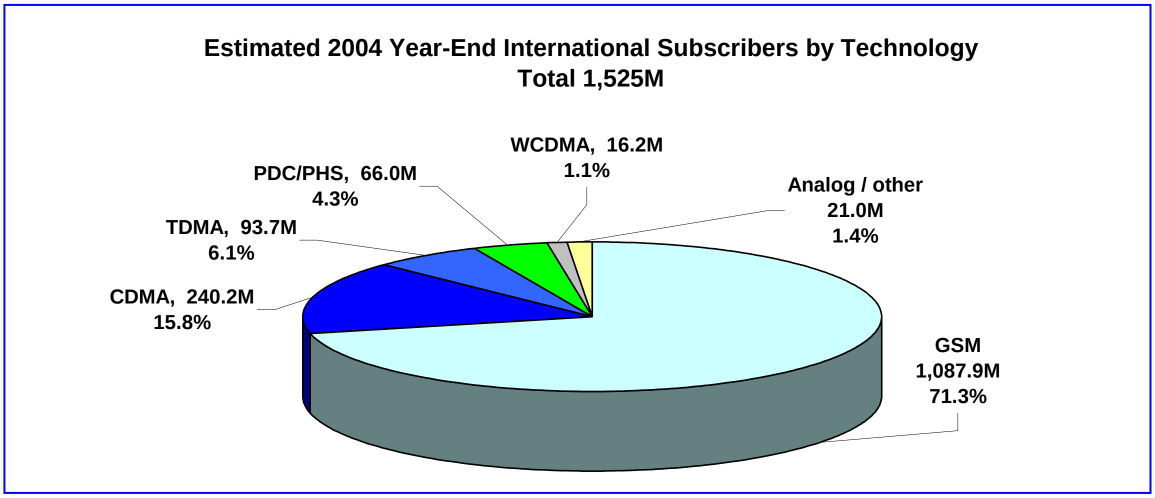


Figure 4-2 Estimated 2004 Year End International Subscribers by Technology
(*Sources:* Technology associations and author research.)

Several key cellular trends are emerging. First, two major market segments are emerging. The mature markets, which include Western Europe, United States, Japan, and Korea, are becoming saturated at high penetration (~ 60%–80%), and future growth opportunities are for new 3G data services such as pictures, SMS, streaming video, ringtones, and wireless web. The emerging markets, which include China, India, Russia, Eastern Europe, Africa, Latin America, and others that have low penetration are now providing more than 50% of international net subscriber additions (NET Adds). However, in these emerging markets, operators must offer subscribers plans at a low average revenue per unit (ARPU) that requires commensurate capital expenses (CAPEX) and operating expenses (OPEX) budgets.

Second, the transition from 2G to 2.5G and 3G is progressing at an uneven pace.

Figure 4-4 presents international subscriber counts by technology for 2000 to 2010. In the first quarter of 2004, GSM achieved one million subscribers, and the GSM/GPRS/EDGE family will continue to be the leading international technology for many years. The general industry consensus has been that initial WCDMA deployments will generally be in highly populated, generally urban/suburban areas, and that GSM/GPRS/EDGE will continue to provide desired wide-area coverage.

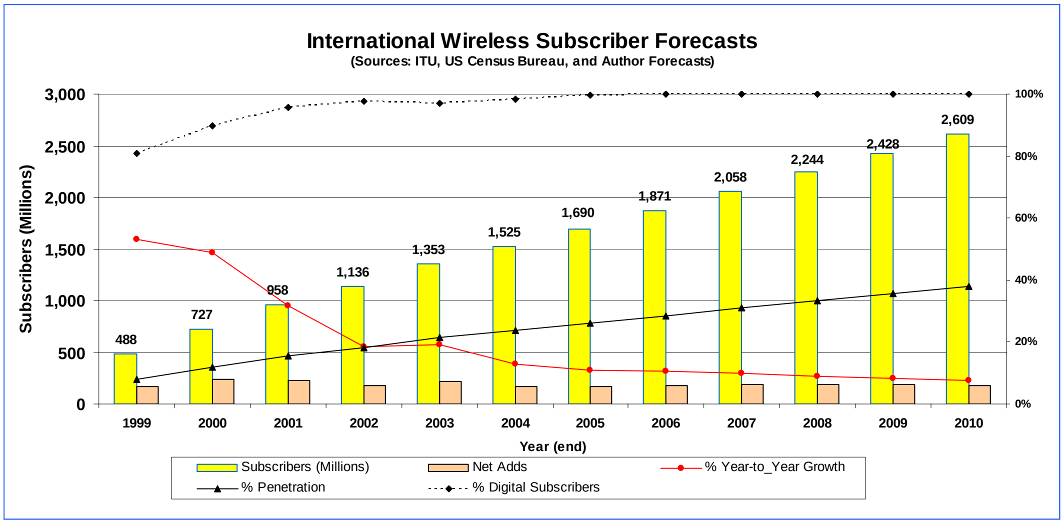


Figure 4-3 International Subscriber Data and Forecasts
(*Source:Wireless Infrastructure Technology and Markets: The Challenge of 3G*, with updates)

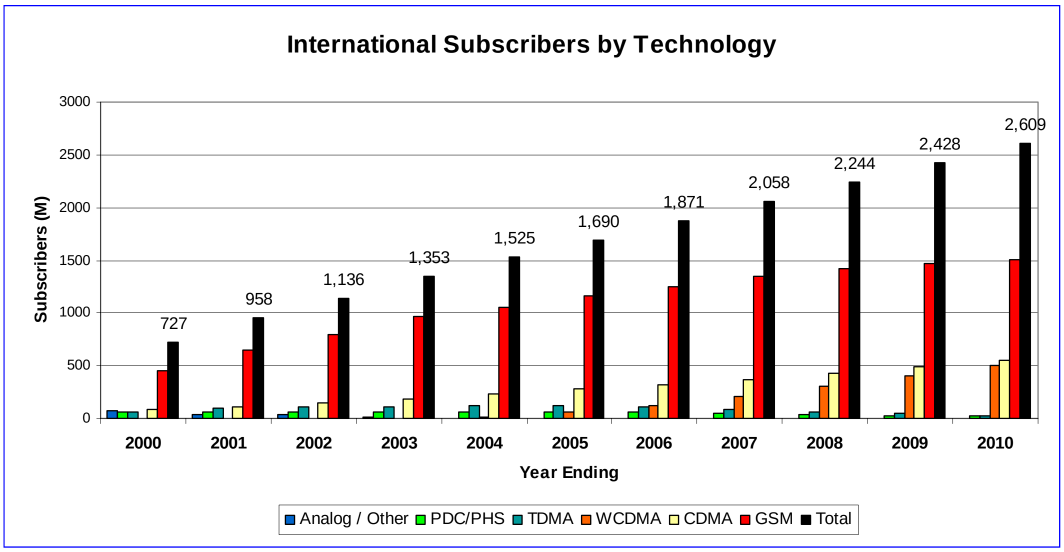


Figure 4-4 International Cellular Subscriber by Technology
(*Source:* Technology associations and author research.)

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. DoCoMo initiated the first WCDMA system in Japan in September 2001 and experienced limited early successes, but has been achieving greater successes in 2004. DoCoMo's original WCDMA deployment was a pre-release 1999 implementation, but now it appears on track to achieve full standard compatibility. WCDMA has experienced many startup problems, including:

- Inadequate and immature WCDMA standards have been an early challenge.

- Cellphone vendors have had difficulty bringing to market multimode, multiband handsets that support handoff with 2G/2.5G standards (e.g., PDC in Japan, GSM in Europe and elsewhere). Multimode, multiband handsets are 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 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.

These problems appear to be stabilizing and a significant number of 3G WCDMA launches have occurred in 2004. A significant ramp is expected in 2005 followed by significant growth in 2006 and following years. WCDMA is anticipated to eventually (probably post-2010) overtake GSM as the dominant cellular technology because it has significant international critical mass; over time, it appears that it will be on track to achieve superior cost efficiencies.

The CDMA 2000 community appears to have executed well, benefiting from being a smaller community for coordination and from the technical creativity of its inventor, 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 the WCDMA problems 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, and India, plus many others. 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 (e.g., Ericsson and Nokia).

There is little doubt that cellular is the largest SDR market opportunity. The cellular handset market is anticipated to be a $1 trillion cumulative market between 2000 and 2010. The cellular infrastructure is anticipated to be a $572 billion market between 2000 and 2010. Data and forecasts (based on company reports and various financial analyses as well as author forecasts) for 2000–2010 handsets and infrastructure are shown in the following figures:

Figure 4-5 Wireless Handset Unit Data and Forecasts (2000–2010),
Figure 4-6 Cellular Handset Revenue Data and Forecasts (2000–2010) ,
Figure 4-7 Cellular Infrastructure Cell Site Data and Forecast (2000–2010), and
Figure 4-8 Cellular Infrastructure Electronic Equipment Revenue Forecast (2000–2010).

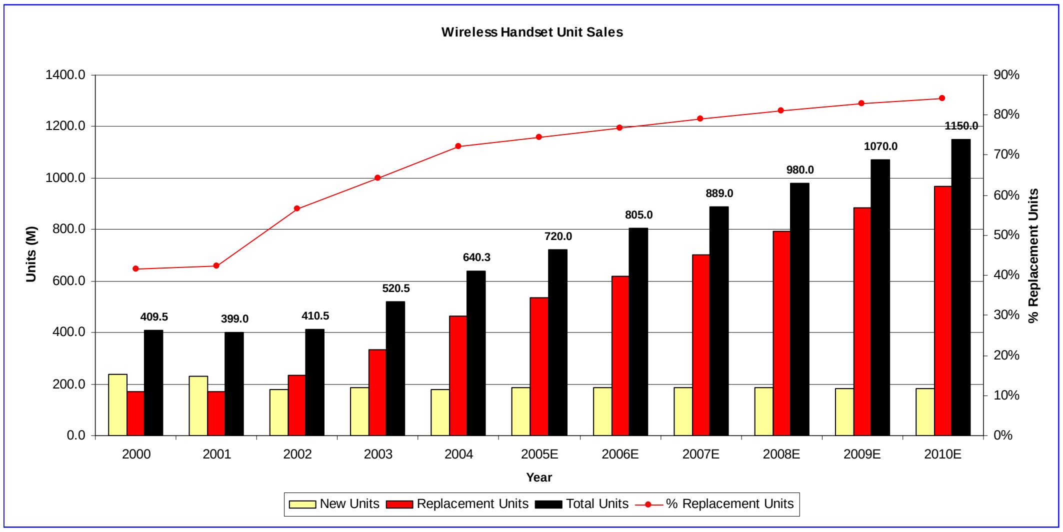


Figure 4-5 Wireless Handset Unit Data and Forecasts (2000–2010)
***(Source*: Company Reports, Various Analysis Reports, Author Research and Estimates)**

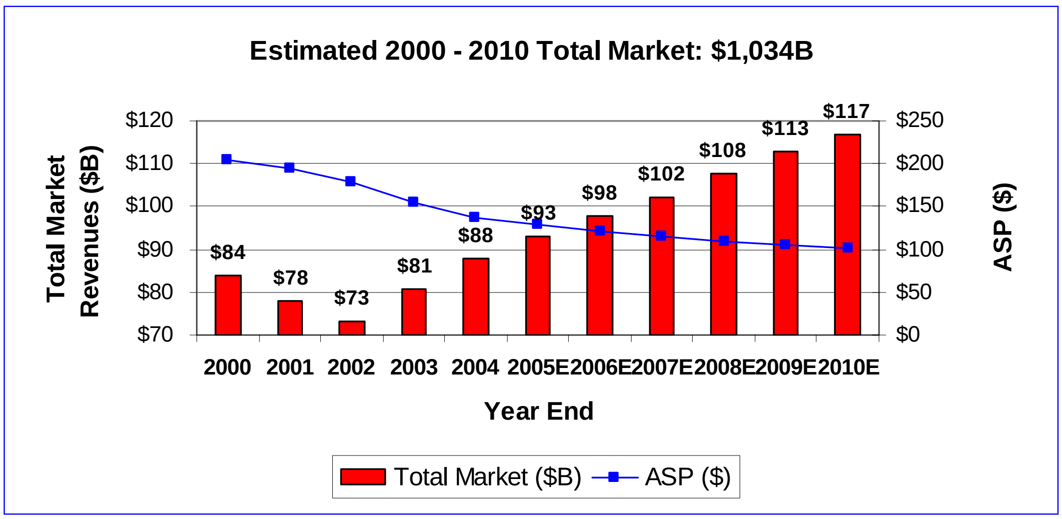


Figure 4-6 Cellular Handset Revenue Data and Forecasts (2000–2010)
***(Source*: Company Reports, Various Analysis Reports, Author Research and Estimates)**

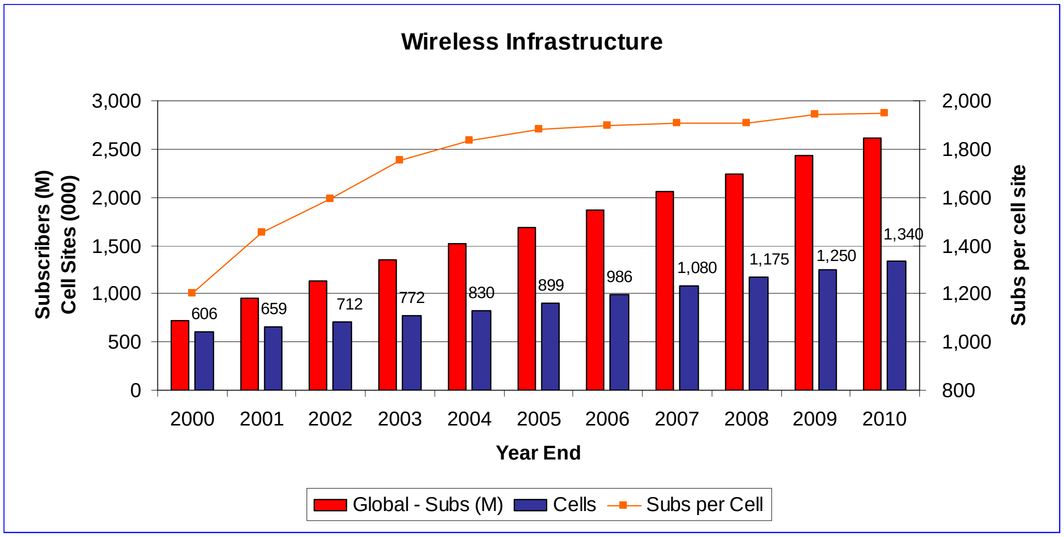


Figure 4-7 Cellular Infrastructure Cell Site Data and Forecast (2000–2010)

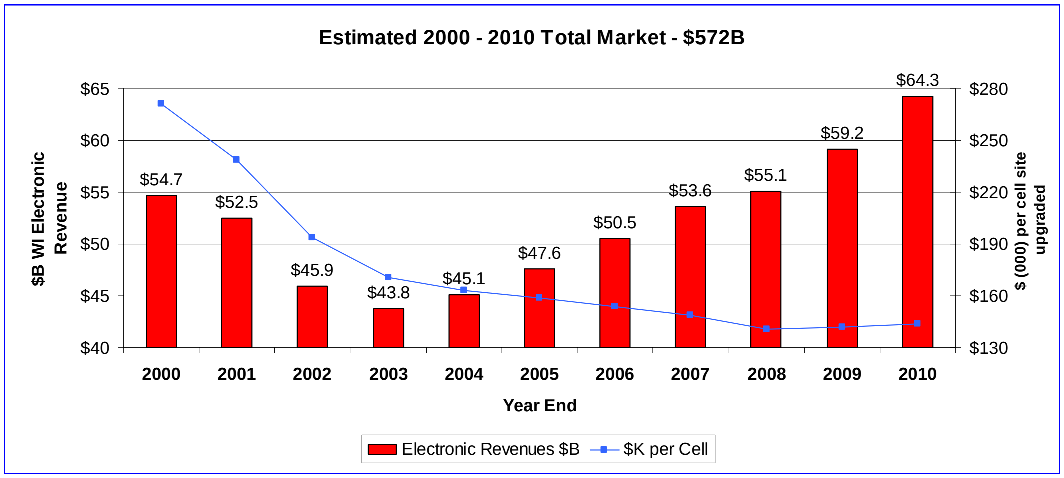


Figure 4-8 Cellular Infrastructure Electronic Equipment Revenue Forecast (2000–2010)

As Figures 4-5 through 4-8 indicate, the cellular industry is in a recovery mode from the economic recessionary environment from the 2000 to 2003 time frame. Interestingly, the handset market flattened first and recovered first and achieved 640 million units in 2004. The infrastructure lagged but operators appear to have spent approximately $45 billion with network equipment vendors in 2004 and achieved the first growth year since 2000. This growth is anticipated to continue through 2010 as operators in emerging markets deploy Greenfield infrastructure and operators in mature markets upgrade their infrastructure to support emerging 3G standards, services, and revenue opportunities.

The cellular industry is clearly in a “discovery mode.” Traditional cellular voice services provided operators with a single and comparatively simple business model. We anticipate that voice will continue to be the “killer application” (“Killer App”) at least for the next several years, and perhaps always. 3G adds a multitude of data, 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 based 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.

In observing the pioneering 3G “early adopter” markets of Korea and Japan, 3G subscribers do demonstrate 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. Most likely, 3G deployments will 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.

4.2. Military

The United States budgets approximately $370 trillion, or 3.3% of its gross domestic product (GDP) for yearly military purposes, as shown in Table 4-2. Based on the CIA's *World Factbook, 2004* data, this is approximately 42.5% of the world's total yearly military budgets.

The US Department of Defense (DOD) Joint Tactical Radio System (JTRS) program appears to be providing technical leadership for SDR for not only the military community, but also the entire wireless industry. In reviewing available data, the international military community is following the US lead for SDR technologies including many partners in eventual deployments of JTRS-compatible communication equipment and systems. The military SDR market research discussed here focuses on the JTRS program and will include international information and data as they become sufficiently available in the future.

A top-level overview of JTRS interoperability requirements with other current and known future systems is presented in Figure 4-9. JTRS addresses communication requirements and systems for Army, Air Force, Navy, Marine, National Guard, and other military-related organizations. A goal is to insert JTRS technologies in public sector and other potential SDR market sectors.

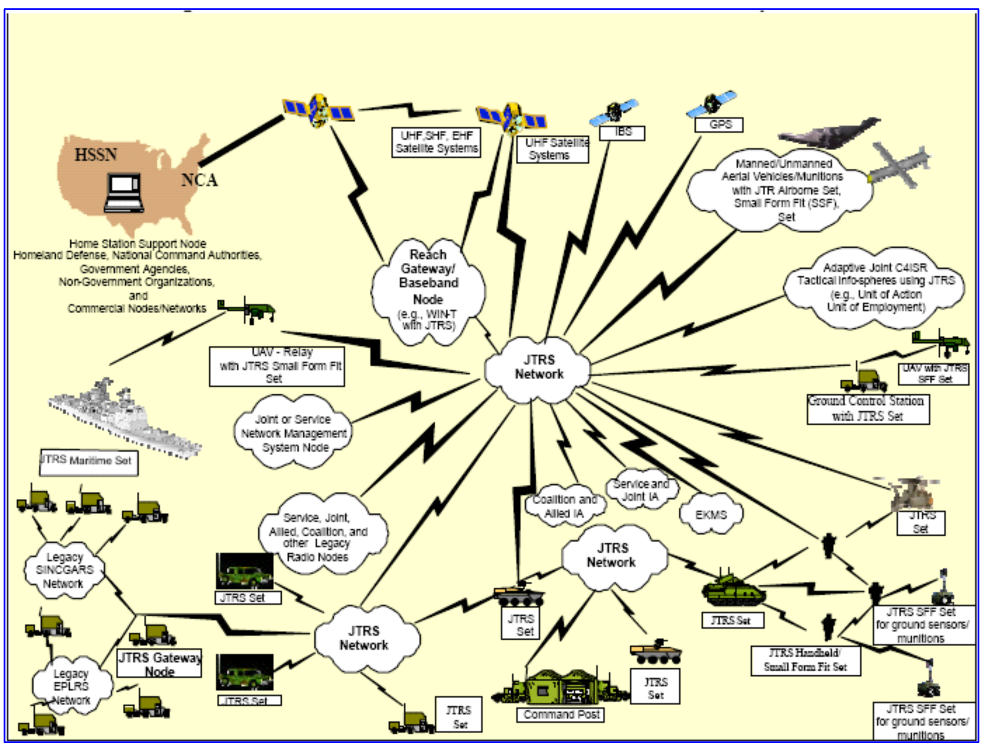


Figure 4-9 JTRS Operational Overview
(*Source:* CIA, *World Factbook*, 2004 edition)

Rank	Country	Military Expenditures (US$)	Military Expenditures as Percent of GDP (%)	Date of Information
	World	$870,887,000,000	2.00%	
1	United States	$370,700,000,000	3.30%	March 2003
2	China	$60,000,000,000	NA	2003 est.
3	France	$45,238,100,000	2.60%	2003
4	United Kingdom	$42,836,500,000	2.40%	2003
5	Japan	$42,488,100,000	1.00%	2003
6	Germany	$35,063,000,000	1.50%	2003
7	Italy	$28,182,800,000	1.90%	2003
8	Saudi Arabia	$18,000,000,000	10.00%	2002
9	Korea, South	$14,522,000,000	2.70%	FY03
10	Australia	$14,120,100,000	2.80%	2003
11	India	$14,018,800,000	2.40%	2003
12	Turkey	$12,155,000,000	5.30%	2003
13	Brazil	$10,439,400,000	2.10%	2003
14	Spain	$9,906,500,000	1.20%	2003
15	Canada	$9,801,700,000	1.10%	2003
16	Israel	$9,110,000,000	8.70%	FY03
17	Netherlands	$8,044,400,000	1.60%	2003
18	Taiwan	$7,611,700,000	2.70%	2003
19	Greece	$7,288,900,000	4.30%	2003
20	Korea, North	$5,217,400,000	22.90%	FY02
21	Mexico	$5,168,300,000	0.90%	2003
22	Singapore	$4,470,000,000	4.90%	
23	Sweden	$4,395,000,000	2.10%	FY01
24	Argentina	$4,300,000,000	1.30%	
25	Iran	$4,300,000,000	3.30%	2003 est.
26	Norway	$4,033,500,000	1.90%	2003
27	Belgium	$3,999,000,000	1.30%	2003
28	Poland	$3,500,000,000	1.71%	2002
29	Portugal	$3,497,800,000	2.30%	2003
30	Colombia	$3,300,000,000	3.40%	
31	Denmark	$3,271,600,000	1.60%	2003
32	Chile	$2,839,600,000	4.00%	2003
33	Pakistan	$2,700,000,000	3.90%	FY02/03
34	South Africa	$2,653,400,000	1.70%	2003
35	Switzerland	$2,548,000,000	1.00%	FY01
36	Kuwait	$2,500,400,000	5.80%	2003
37	Egypt	$2,443,200,000	3.60%	2003
38	Morocco	$2,297,200,000	4.80%	2003
39	Algeria	$2,196,600,000	3.50%	2003
40	Jordan	$2,043,200,000	20.20%	2003
41	Finland	$1,800,000,000	2.00%	FY98/99
42	Thailand	$1,775,000,000	1.80%	
43	Malaysia	$1,690,000,000	2.03%	
44	United Arab Emirates	$1,600,000,000	3.10%	
45	Austria	$1,497,000,000	0.85%	FY01/02
46	Iraq	$1,300,000,000	NA	FY00
47	Libya	$1,300,000,000	3.90%	
48	Czech Republic	$1,190,200,000	2.10%	FY01
49	New Zealand	$1,147,000,000	1.00%	FY03/04
50	Venezuela	$1,125,600,000	1.30%	2003

Table 4-2 Top 50 International Countries Yearly Military Expenditures
(*Source:* CIA, *World Factbook*, 2004 edition)

The JTRS program elements as well as responsibilities for various elements are presented in Figure 4-10 These elements include, among others, the Software Communication Architecture (SCA). Interviews with commercial market segment stakeholders indicated a consistent input that the SCA has excessive overhead for deployment in commercial applications. More detailed specifics on this input will be solicited in later study tasks.

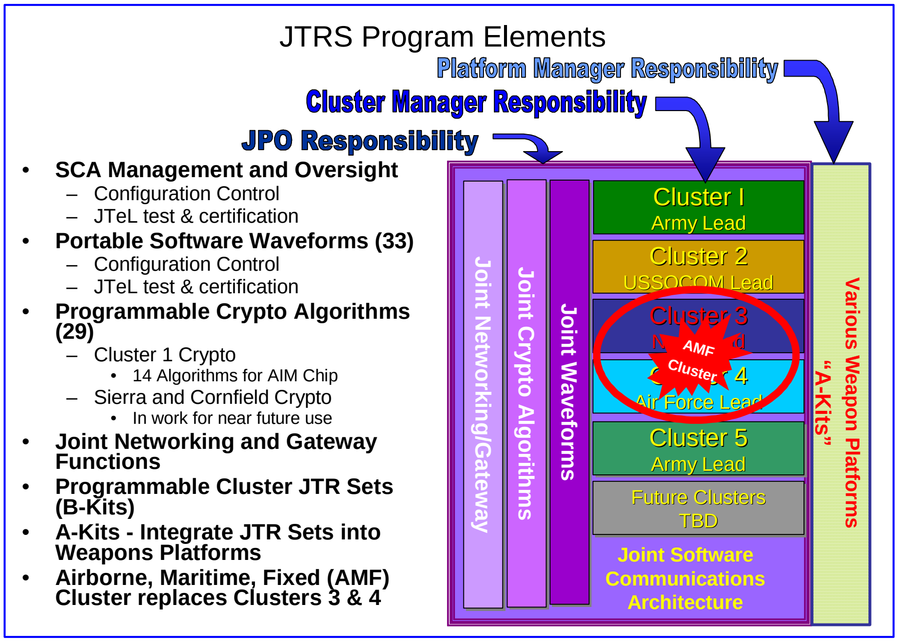


Figure 4-10 JTRS Program Elements
(*Source:* JTRS-JPO)

As Figure 4-10 indicates, JTRS platforms are grouped into clusters based on similarity of requirements and required fielding schedules. An overview of these clusters is presented in Table 4-3. The benefits of the cluster approach are:

- Reduces overlapping research, development, test, and evaluation efforts
- Leverages the DOD investment in JTRS
- Provides for acquisition of sufficient quantities of joint tactical radio (JTR) sets to promote competition and innovation
- Reduces logistics requirements across the services
- Promotes interoperability among services

	Cluster 1	Cluster 2	Cluster AMF Combines Clusters 3 & 4	Cluster 5
Description	Ground Mobile & Helicopter	Handheld (30 – 512 MHz) APCO25	Airborne & Maritime/Fixed Station	Embedded and Small Form Factor
Manager	CECOM	Special Operations Command	Joint AF & Navy	Army, CECOM
Contractor (Current)	Boeing, Northrop Grumman, Rockwell Collins	Thames Communications	General Dynamics (Motorola DMR)	General Dynamics

Table 4-3 JTRS Overview and Clusters
(*Source:* JTRS web site, JTRS.army.mil)

JTRS has both hardware and software components (i.e., intellectual property). The Joint Waveform Acquisition Schedule for this software is presented in Figure 4-11. Interestingly, the planned waveforms include legacy narrowband military waveforms, advanced broadband military waveforms, public safety waveforms, aviation waveforms, and cellular waveforms, anticipated to be of value in future military operations.

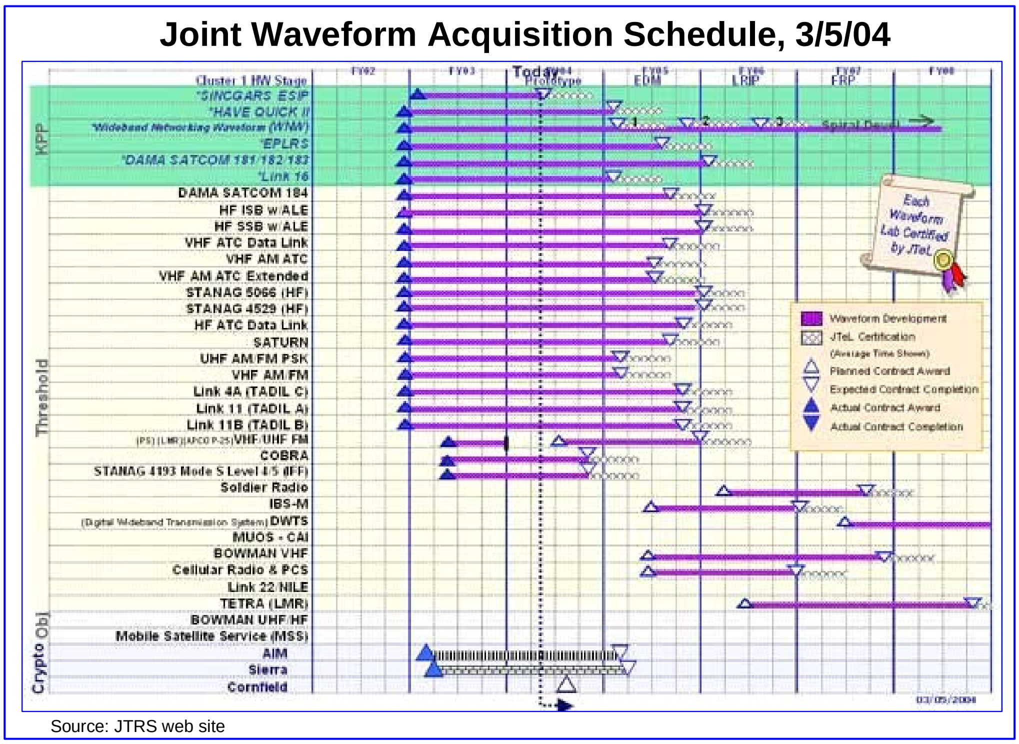


Figure 4-11 JTRS Joint Waveform Acquisition Schedule
(*Source:* JTRS web site, JTRS.army.mil)

JTRS has a Virtual Lab Team, the JTRS Technical Lab (JTeL), for certification, test, and support for the SDR waveforms. An overview of this is presented in Figure 4-12 as well as an overview of JTeL's missions. The overall JTRS program schedule is presented in Figure 4-13This schedule shows the early development and deployment schedules. Overall procurements and deployments are anticipated to extend over the next 20 to 25 years.

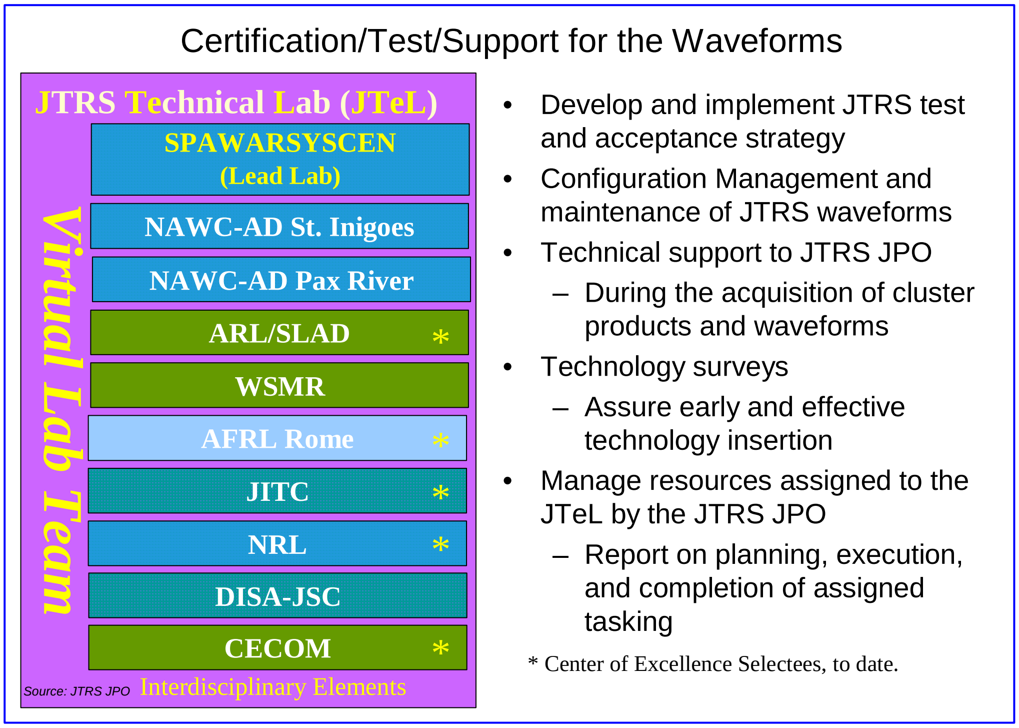


Figure 4-12 JTel Certification, Test, and Support and mission
(*Source:* JTRS-JPO.)

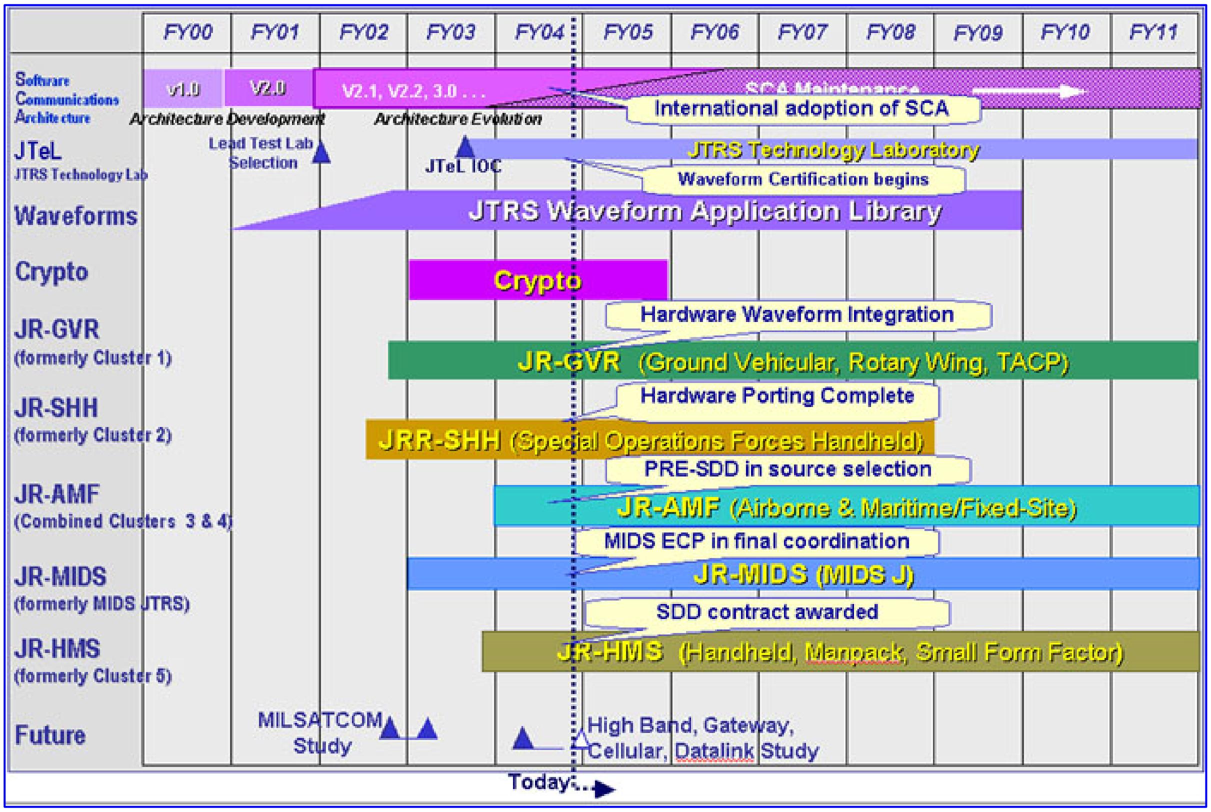


Figure 4-13 JTRS Program Schedule

Currently and through 2009, JTRS will continue to experience significant develop costs in its budgets and then transition over time to more significant procurement budgets as presented in Figure 4-14.

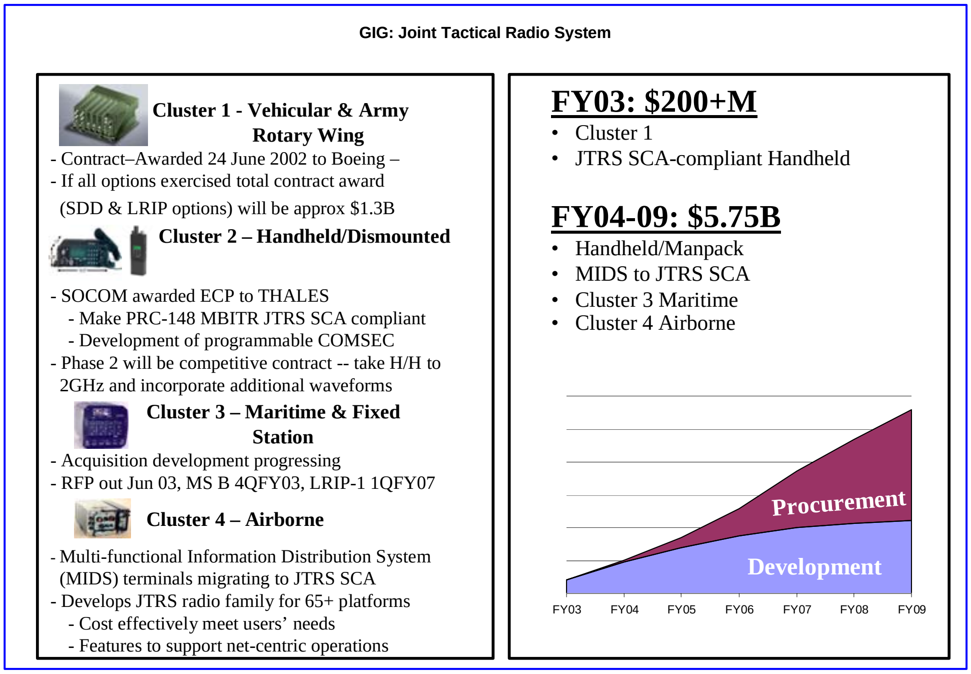


Figure 4-14 JTRS FY03 - FY09 Budgets
(*Source:* JTRS Industry Day presentation, February 24, 2005; slide 19, Dr. Michael S. Frankel)

Table 4-4 presents a detailed budget analysis since the last Defense Acquisition Board (DAB) review.

JTRS Program Buy-in Since Last DAB ($M)

FY 02 Presidents Budget — FY 03 Presidents Budget Total $1052.2M — Total $ 3203.2M — Total $ 5,909.0M (562%)

Source: FY 04 Presidents Budget

	FY02 & prior	FY03	FY04	FY05	FY06	FY07	FY08	FY09	Totals
JTRS JPO RDTE	1925	62.9	134.7	91.6	62.8	55.9	28.8	27.3	656.7
Army RDTE	110.9	95.6	270.8	194.1	122.5	82.6	57.0	31.4	964.8
Army Procurement	0	0	1.9	159.2	165.6	194.4	185.1	189.8	896.1
Air Force RDTE	4.0	18.3	54.0	52.1	112.8	77.9	52.6	37.0	409.7
Air Force Procurement	0	0	0	6.8	134.8	486.0	537.5	567.6	1,732.8
Air Force O&M	0	0	0	0	0	11.5	11.7	11.8	35.0
Navy RDTE	8.8	19.9	87.9	84.1	57.7	11.0	9.7	7.1	286.3
Navy Procurement	0	0	26.0	40.6	127.2	123.2	112.7	117.4	547.0
Navy O&M	0	2.6	2.8	3.0	3.1	3.2	3.3	3.4	21.3
USMC RDTE	0	.6	8.1	8.7	4.1	3.7	1.6	1.6	28.4
USMC Procurement	0	0	13.9	33.1	32.5	90.9	80.7	73.2	324.3
USSOCOM	5.0	0	0	0	0	0	0	0	5.0
OSD CWP	.6	.6	0	0	0	0	0	0	1.2
Nunn Funding	.6	0	0	0	0	0	0	0	.6
TOTALS	322.4	200.5	600.1	673.3	823.0	1,140.4	1,080.7	1,068.5	5,909.0

Totals may include rounding differences *Source: JTRS JPO*

Table 4-4 JTRS Program Buy-in since Last DAB ($M)
(*Sources:* JTRS-JPO and FY04 President's Budget.)

Market estimates for potential JTRS communication equipment procurements are based on information in the JTRS Operational Requirements Document (ORD, vol. 3.2; 4/9/03 unclassified), and are presented in Tables 4-5 through 4-7. Table 4-5 presents the current DOD inventory of radio sets. Table 4-6 contains affordability unit cost targets from the ORD. Applying these costs to quantities from Table 4-5, Table 4-7 provides an estimate for ;the total value of JTRS for US forces that totals approximately $21.3 billion over an approximately 25 year time period. International opportunities will undoubtedly increase this value.

Current DOD Inventory 200 Radio Types

a. US Army.

JTR SET	CHANNELS	OPERATIONAL	SPARES	TRAINING	TOTAL
SMALL FORM FIT	GPS +1	TBD	TBD	TBD	TBD
SMALL FORM FIT	GPS +2	44,001	2,200	880	47,081
HAND-HELD	GPS +1	7,222	361	144	7,727
HAND-HELD	GPS +2	18,565	928	371	19,864
MAN PACK	GPS +2	23,091	1,155	462	24,708
VEHICULAR	GPS +6	121,854	6,093	2,437	130,384
AIRBORNE	GPS +8	2,990	150	60	3200
MARITIME/FIXED	GPS +4	124	7	3	134
TOTAL		217,846	10,894	4,357	233,097

b. US Air Force.

JTR SET	CHANNELS	OPERATIONAL	SPARES	TRAINING	TOTAL
SMALL FORM FIT	GPS +1	TBD	TBD	TBD	TBD
SMALL FORM FIT	GPS +2	TBD	TBD	TBD	TBD
HAND-HELD	GPS +1	17,250	690	173	18,113
HAND-HELD	GPS +2	5,750	230	58	6,038
MAN PACK	GPS +2	1,262	60	20	1,342
VEHICULAR	GPS +6	4,107	165	45	4,317
AIRBORNE	GPS +8	4,600	184	46	4,830
MARITIME/FIXED	GPS +4	2,933	120	30	3,083
TOTAL		35,902	1,449	372	37,723

c. US Navy.

JTR SET	CHANNELS	OPERATIONAL	SPARES	TRAINING	TOTAL
SMALL FORM FIT	GPS +1	TBD	TBD	TBD	TBD
SMALL FORM FIT	GPS +2	TBD	TBD	TBD	TBD
HAND-HELD	GPS +1	1,755	195	0	1,950
HAND-HELD	GPS +2	0	0	0	0
MAN PACK	GPS +2	2,745	305	0	3,050
VEHICULAR	GPS +6	1,874	208	0	2,082
AIRBORNE	GPS +8	1,370	120	20	1,510
MARITIME/FIXED	GPS +4	4,000	200	50	4,250
TOTAL		11,744	1,028	70	12,842

d. US Marine Corps.

JTR SET	CHANNELS	OPERATIONAL	SPARES	TRAINING	TOTAL
SMALL FORM FIT	GPS +1	189	0	0	189
SMALL FORM FIT	GPS +2	TBD	TBD	TBD	TBD
HAND-HELD	GPS +1	18,050	740	210	19,000
HANDHELD	GPS +2	0	0	0	0
MAN PACK	GPS +2	14,320	600	155	15,075
VEHICULAR	GPS +6	1,390	590	150	2,130
AIRBORNE	GPS +8	see AF	see AF	see AF	see AF
MARITIME/FIXED	GPS +4	0	0	0	0
TOTAL		33,949	1930	515	36,394

Table 4-5 Force Structure – JTRS Quantity of Sets Requirements
(*Source:* JTRS ORD V3.2; 4/9/03 (Unclassified))

ORD Affordability Targets

Affordabilility Targets		Threshold	Objective
Handheld	GPS + 1 Channel	$9,000	$4,000
	GPS + 2 Channel	$10,000	$5,000
Man Pack	GPS + 2 Channel	TBD	TBD
Small Form Fit	1 Channel w/Type III Encryption	TBD	TBD
Vehicular	GPS + 2 Channel	$47,000	$23,500
	GPS + 3 Channel	$60,000	$30,000
	GPS + 4 Channel	$69,000	$34,500
	GPS + 5 Channel	$97,000	$48,500
	GPS + 6 Channel	$105,000	$52,500
Rotary Wind	GPS + 8 Channel	$149,000	$74,500
Fixed Wing	GPS + 8 Channel	TBD	TBD
Maritime/Fixed	GPS + 2 Channel	$250,000	$200,000
	GPS + 3 Channel	$375,000	$300,000
	GPS + 4 Channel	$500,000	$400,000

Table 4-6 JTRS ORD Affordability Cost Targets
(*Source:* JTRS ORD V3.2; 4/9/03 (Unclassified))

Estimated JTR Total Unit and Market Value

Author calculation from ORD Unit Estimates and Affordabilility Targets
Procurement could be over 25 year time period

Totals Units All Services

JTR SET	CHANNELS	OPERATIONAL	SPARES	TRAINING	TOTAL
SMALL FORM FIT	GPS +1	189	-	-	189
SMALL FORM FIT	GPS +2	44,001	2,200	880	47,081
HAND-HELD	GPS +1	44,277	1,986	527	46,790
HAND-HELD	GPS +2	24,315	1,158	429	25,902
MAN PACK	GPS +2	41,418	2,120	637	44,175
VEHICULAR	GPS +6	129,225	7,056	2,632	138,913
AIRBORNE	GPS +8	8,960	454	126	9,540
MARITIME/FIXED	GPS +4	7,057	327	83	7,467
TOTAL		299,441	15,301	5,314	320,056

Estimated Total JTR Set Cost

JTR SET	CHANNELS	OPERATIONAL	SPARES	TRAINING	TOTAL
SMALL FORM FIT	GPS +1	$1,701,000	$0	$0	$1,701,000
SMALL FORM FIT	GPS +2	$440,010,000	$22,000,000	$8,800,000	$470,810,000
HAND-HELD	GPS +1	$398,493,000	$17,874,000	$4,743,000	$421,110,000
HAND-HELD	GPS +2	$243,150,000	$11,580,000	$4,290,000	$259,020,000
MAN PACK	GPS +2	$414,180,000	$21,200,000	$6,370,000	$441,750,000
VEHICULAR	GPS +6	$13,568,625,000	$740,880,000	$276,360,000	$14,585,865,000
AIRBORNE	GPS +8	$1,335,040,000	$67,646,000	$18,774,000	$1,421,460,000
MARITIME/FIXED	GPS +4	$3,528,500,000	$163,500,000	$41,500,000	$3,733,500,000
TOTAL		$19,929,699,000	$1,044,680,000	$360,837,000	$21,335,216,000

Assumptions: Costs for Small Form Fit and Man Pack are assumed same as handheld
Costs for Airborne are assumed same as Rotary Wing

Table 4-7 Estimated JTRS Total Units and Market Value
(*Source*: Author estimates based on data in Tables 4-5 and 4-6)

4.3. Public Safety

Public safety has attracted much attention as a result of September 11, 2001 (9/11) experiences, for which communication was a major problem for first responders due to the lack of interoperable and adequate communication resources. SDR offers significant potential to provide solutions for these problems.

Although public safety is the focus here, it is considered by many to be part of a broader segment, often referred to as the public sector or even land mobile radio (LMR) as per the US FCC regulations. Table 4-8 provides an overview of this public sector segment. This section generally uses interchangeably the terms public sector, public safety, and public land mobile radio (PLMR). Included in general LMR are several non-public sector segments that have similar market requirements (e.g., dispatch and coordination) and are usually addressed by common regulatory organizations and suppliers.

Public Sector Segments
Land Mobile Radio (LMR)

• **Public Safety**	Police Emergency Medical Services	Fire
• **Government**	Municipal Services National Ministries	Federal Agencies Education
• **Utilities**	Gas Water	Electric Telephone
• **Transportation**	Airlines Transit	Railroad Courier
• **Manufacturing**	Automotive Industrial	High-Tech Aerospace
• **Other Verticals**	Construction Petrochemical	Retail Corporate

Table 4-8 Public Sector Segments
(*Source:* Motrola CGISS 4Q 2003 Presentation)

Motivated by 9/11, the United States, as well as the international community, has increased focus on terrorism. The US government has created a Department of Homeland Security (DHS) to provide a single authority for planning, execution, and evaluation, as well as accountability. The general key goals for US homeland security include:

1. First Responder Organization, Staffing, and Planning;
2. Interoperable Communications;
3. Inter-Jurisdictional Coordination – Local, State, Federal;
4. Interagency Coordination – Police, Fire, Emergency Medical Services, etc.; and
5. Standards-based Communications that Provides Voice and Data Services.

The US DHS strategic goals as articulated at www.DHS.gov are presented in Table 4-9.

US Department of Homeland Security Strategic Goals • Prevention – Detect, deter and mitigate threats to our homeland. • Protection – Safeguard our people and their freedoms, critical infrastructure, property and the economy of our Nation from acts of terrorism, natural disasters, or other emergencies. • Response – Lead, manage and coordinate the national response to acts of terrorism, natural disasters, or other emergencies. • Recovery – Lead national, state, local and private sector efforts to restore services and rebuild communities after acts of terrorism, natural disasters, or other emergencies. • Service – Serve the public effectively by facilitating lawful trade, travel and immigration.

Table 4-9 US Department of Homeland Security Strategic Goalshttp:///
(*Source:* www.DHS.gov)

Several trends are very apparent in the public sector. These public and private organizations typically have budgeting problems. The public organizations must complete for public funds. The private organizations are often fragmented (e.g., taxis) or often assign lower priority to their LMR requirements.

LMR is in slow evolution from legacy analogy LMR to emerging digital LMR standards. APCO25 is the North American standard being developed by the Miami-headquartered Association of Public-Safety Communications Officials, International (APCO), which provides recommended voluntary standards of uniform digital two-way radio technology for public safety organizations. TErrestrial Trunked RAdio (TETRA) is an open digital trunked radio standard being developed by the European Telecommunications Standardisation Institute (ETSI) that is focused in Europe and most of the rest of the world.

Spectrum issues are major considerations in public safety. In 2001, the US FCC issued new Part 90 rules to require refarming in the PLMR band under 512 MHz to improve channel spacing and spectral efficiency. An overview of the FCC's 10-year refarming plan is presented in Figure 4-15. Recently, much activity and controversy have centered on (re)allocation of the 700, 800, and 900 MHz spectra to better provide for public safety needs. The upcoming public safety report will provide details on these important spectrum allocation activities.

Increasingly the public sector is using cellular for administrative and routine coordination communication (e.g., Nextel and emerging Push-to-Talk, PTT). Critical Command & Control, dispatch, and other communications are still usually accomplished on dedicated PLMR systems. Some ITS organizations have indicated that they might transition to exclusive commercial PTT services, such as cellular, and decommission their PLMR systems. However, no exclusive transitions have been observed to date.

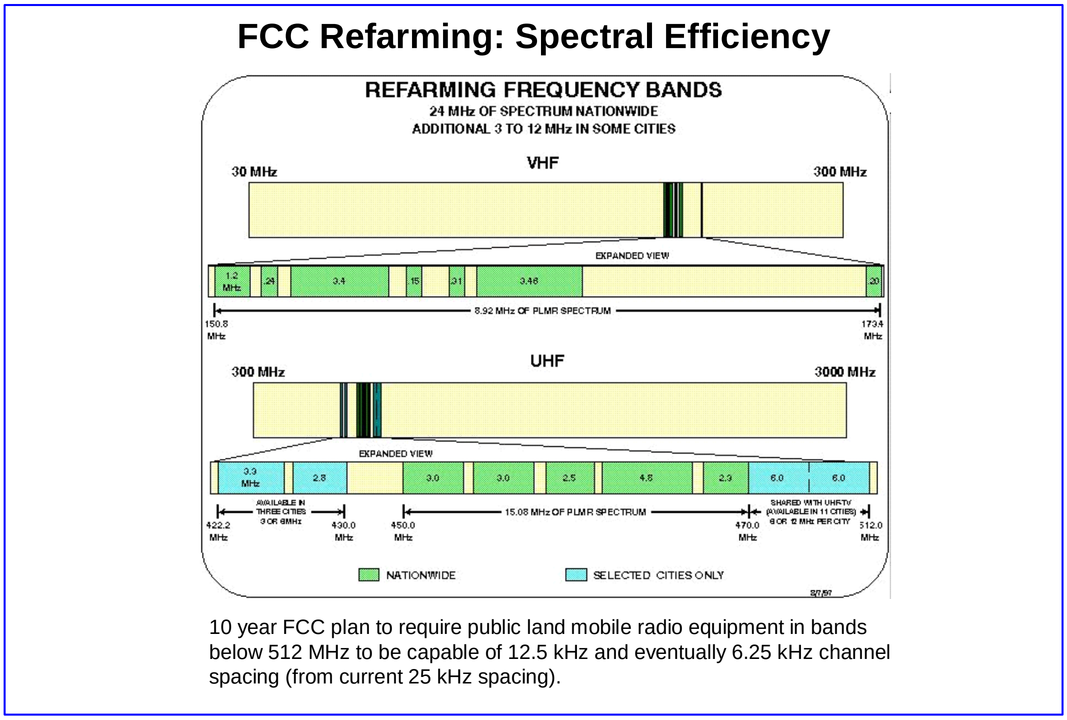


Figure 4-15 US FCC Refarming Plans

Commercial cellular service problems and inadequacies in emergency situations have been well documented in post-9/11 reports and other emergencies, such as hurricanes. Commercial cellular systems are not designed for five-9s reliability or increased capacity requirements that emergency situations create. Cellular is particularly vulnerable compared to legacy wireline systems because cellular access is by shared RF links, whereas wireline has dedicated copper access links. One public safety communications official indicated that he designs his PLMR communication systems for about 33% capacity operation under anticipated routine operations so that sufficient capacity is available in much higher load emergency situations. Additionally, although the legacy (100+ years) wireline systems have five-9s reliability in their network deployments (perhaps excluding the copper access link), the young wireless industry has not yet consistently evolved its networks.

The key technical goals for public safety that have been consistently identified by stakeholders are presented in Table 4-10.

Key Public Safety Communication Goals

- Interoperability with supporting agencies in emergency operations (by adding interoperability frequencies, gateways, multimode/multiband radios, and/or SDR)
- Life-cycle cost reductions
- Adequate capacity and reliability for emergency situations
- Data with sufficient speed, coverage, and capacity
- Encryption capabilities and standards
- Sufficient standards for digital voice and data (many report that APCO still lacks trunking standards)
- Coordinated emergency planning with commercial communication service providers supported by reasonable laws and regulations

Table 4-10 Key Public Safety Communication Goals

The public sector market is a very fragmented market consisting of a multitude of federal, state, and even more numerous local jurisdictions (e.g., city, county, regional as well as numerous agencies such as police, fire, emergency (medical) management, etc.). Although each operates from public funds and has operational coordination, PLMR communication system coordination, management, and procurement have historically not usually been a focus for senior public officials who have other professional experiences and priorities. PLMR is usually delegated and thus has generally good local coordination and information, but less than desirable state, national, and international coordination, visibility, and general market information. Of course, 9/11 and Homeland Security create new priorities.

Public safety stakeholders tasked to collect market data for this report verified repeatedly that very little comprehensive market data appears available. A very succinct input was offered by Chief Harlin R. McEwen, Chairman of the Communication and Technology Committee for the International Association of Chiefs of Police (IACP), who stated that he is not aware of satisfactory market data in government, professional association, or other sources. Further, he indicated that he believes that this has created problems in justifying desired and needed public budgets. He also offered a very good suggestion for a methodology for developing market estimates and forecast using FBI data, which is generally followed here (see Table 4-11).

The relationship between public sector headcount and the general population density is presented in

Figure 4-16 for law enforcement, firefighter, and emergency medical service (EMS). The headcount refers to the number of law, firefighter, and EMS employees, and is expressed as a percentage of the general population (or in per 1,000 by multiplying the percentage by 10; thus, 15% translates into 150 per 1,000). It should be noted that the x-axis is population density and that it is logarithmic (as is the y-axis) and care must be exercised in extrapolating to various sizes of geographic area and to various population densities.

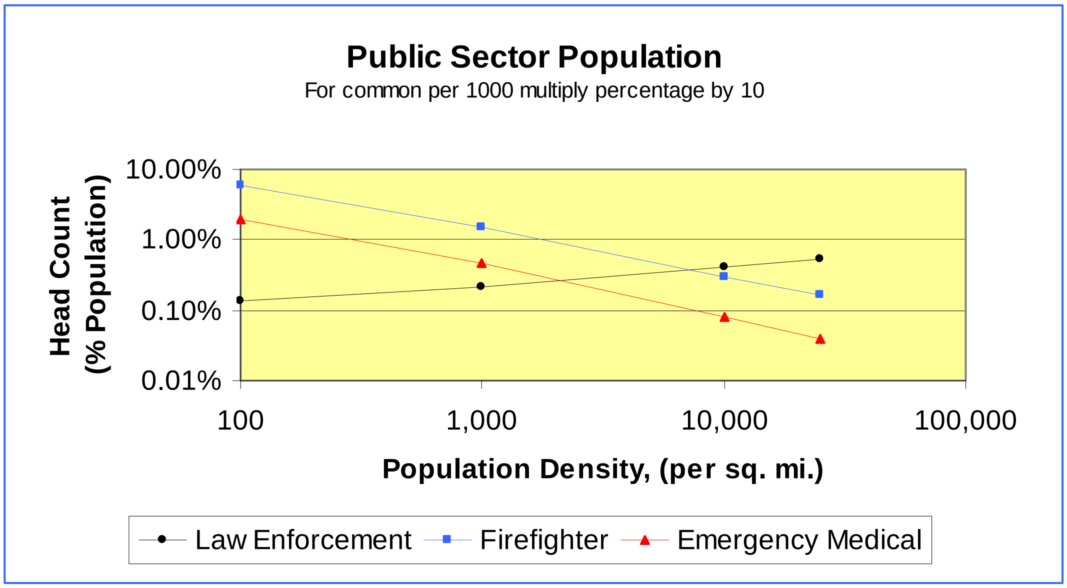


Figure 4-16 Public Sector Population Statistics
(*Source:* Recreated from PSWAC, ORSC Report, 9/11/96)

For example, according to the FBI's *Crime in United States*, 2003 report, the number of total US law enforcement employees per 1,000 was approximately 3.5, and the number of officers was 2.5. Table 4-11 presents extractions from this report and lists by state the number of law enforcement agencies, total law enforcement employees, total (sworn) officers, and total law enforcement civilians. Total population and total area in square miles are also included in this table. The US averages are calculated from this data.

With significant budgeting problems and uncertain digital migration schedules, the most requested market numbers for the public sector are replacement costs of communication equipment to address Homeland Security requirements and digital migration. Table 4-12 presents these estimates by utilizing the FBI law enforcement data of Table 4-11. Based on various interview inputs, this table assumes one portable terminal per officer and one per 10 civilians. Similarly, the numbers of basestations were estimated by input from sources indicated in the tables. Unit cost estimates are based on interviews as indicated in the table.

Full-time Law Enforcement Employees as of October 31, 2003, by State (2002 Population)						
State	**Area (sq mi)**	**Population**	**Agencies**	**Total Law Enforcement Employees**	**Total Law Enforcement Officers**	**Total Law Enforcement Civilians**
Alabama	**50,744**	**3,930,746**	**297**	**13,613**	**9,351**	**4,262**
Alaska	**571,951**	**642,955**	**41**	**1,857**	**1,161**	**696**
Arizona	**113,635**	**5,443,984**	**101**	**18,731**	**10,964**	**7,767**
Arkansas	**52,068**	**2,710,079**	**206**	**7,638**	**5,064**	**2,574**
California	**155,959**	**30,685,929**	**462**	**113,827**	**74,174**	**39,653**
Colorado	**103,717**	**4,403,008**	**233**	**15,489**	**10,704**	**4,785**
Connecticut	**4,844**	**3,374,179**	**97**	**9,741**	**7,788**	**1,953**
Delaware	**1,954**	**807,385**	**51**	**3,101**	**2,206**	**895**
District ofColumbia	**61**	**570,898**	**3**	**4,923**	**4,023**	**900**
Florida	**53,927**	**16,401,547**	**407**	**69,762**	**41,511**	**28,251**
Georgia	**57,906**	**7,226,657**	**431**	**26,651**	**18,753**	**7,898**
Hawaii	**6,423**	**1,244,898**	**4**	**3,553**	**2,799**	**754**
Idaho	**82,747**	**1,311,796**	**114**	**3,502**	**2,358**	**1,144**
Illinois	**55,584**	**12,542,030**	**751**	**50,441**	**36,389**	**14,052**
Indiana	**35,867**	**6,049,242**	**253**	**17,292**	**10,742**	**6,550**
Iowa	**55,869**	**2,916,660**	**231**	**7,529**	**5,053**	**2,476**
Kansas	**81,815**	**2,691,202**	**343**	**9,980**	**6,787**	**3,193**
Kentucky	**39,728**	**4,068,895**	**383**	**10,035**	**7,719**	**2,316**
Louisiana	**43,562**	**4,356,611**	**207**	**22,539**	**16,957**	**5,582**
Maine	**30,862**	**1,291,698**	**134**	**2,927**	**2,195**	**732**
Maryland	**9,774**	**5,291,592**	**123**	**19,516**	**14,827**	**4,689**
Massachusetts	**7,840**	**6,268,238**	**328**	**19,749**	**16,425**	**3,324**
Michigan	**56,804**	**9,976,197**	**606**	**28,080**	**21,006**	**7,074**
Minnesota	**79,610**	**4,859,720**	**285**	**12,583**	**8,104**	**4,479**
Mississippi	**46,907**	**2,426,944**	**170**	**8,381**	**5,277**	**3,104**
Missouri	**68,886**	**5,604,305**	**536**	**18,838**	**13,202**	**5,636**

Table 4-11 US Law Enforcement Employees and Officers
(*Source:* FBI, Crime in United States, 2003 report.)

Full-time Law Enforcement Employees as of October 31, 2003; by State (2002 Population)						
State	**Area(sq mi)**	**Population**	**Agencies**	**Total Law Enforcement Employees**	**Total Law Enforcement Officers**	**Total Law Enforcement Civilians**
Montana	**145,552**	**909,453**	**106**	**2,707**	**1,581**	**1,126**
Nebraska	**76,872**	**1,719,618**	**164**	**4,649**	**3,386**	**1,263**
Nevada	**109,826**	**2,173,491**	**36**	**8,312**	**4,907**	**3,405**
New Hampshire	**8,968**	**925,055**	**131**	**2,523**	**1,917**	**606**
New Jersey	**7,417**	**8,331,239**	**530**	**38,931**	**30,483**	**8,448**
New Mexico	**121,356**	**1,851,009**	**110**	**5,660**	**4,142**	**1,518**
New York	**47,214**	**16,675,972**	**425**	**80,990**	**59,654**	**21,336**
North Carolina	**48,711**	**8,313,727**	**513**	**27,852**	**19,691**	**8,161**
North Dakota	**68,976**	**608,703**	**89**	**1,542**	**1,104**	**438**
Ohio	**40,948**	**10,878,422**	**555**	**33,621**	**23,664**	**9,957**
Oklahoma	**68,667**	**3,493,714**	**302**	**10,585**	**7,108**	**3,477**
Oregon	**95,997**	**3,492,816**	**164**	**7,679**	**5,617**	**2,062**
Pennsylvania	**44,817**	**8,590,601**	**779**	**28,183**	**23,713**	**4,470**
Rhode Island	**1,045**	**1,063,557**	**43**	**3,122**	**2,485**	**637**
South Carolina	**30,109**	**3,735,856**	**260**	**12,128**	**8,787**	**3,341**
South Dakota	**75,885**	**747,844**	**130**	**2,016**	**1,267**	**749**
Tennessee	**41,217**	**5,787,364**	**437**	**23,962**	**15,174**	**8,788**
Texas	**261,797**	**21,670,261**	**965**	**77,464**	**47,710**	**29,754**
Utah	**82,144**	**2,315,689**	**124**	**6,872**	**4,636**	**2,236**
Vermont	**9,250**	**364,545**	**58**	**1,343**	**956**	**387**
Virginia	**39,594**	**7,292,028**	**278**	**21,540**	**16,552**	**4,988**
Washington	**66,544**	**6,064,698**	**251**	**13,747**	**9,868**	**3,879**
West Virginia	**24,077**	**1,790,599**	**352**	**3,959**	**3,028**	**931**
Wisconsin	**54,310**	**4,849,982**	**316**	**15,848**	**11,347**	**4,501**
Wyoming	**97,100**	**496,899**	**66**	**1,989**	**1,239**	**750**
Total US	**3,537,437**	**271,240,537**	**13,981**	**957,502**	**665,555**	**291,947**

Table **4-11 US Law Enforcement Employees and Officers (Continued)**
(*Source:* FBI, Crime in United States, 2003 report.)

State	Portable Terminals	Mobile Terminals	Basestation Installations (at 584.6 sq. mi. per cell)	Cost of Portable Terminals (at $2,000 per terminal)	Cost of Mobile Terminals (at $3,000 per terminal)	Cost of Basestation Equipment (at $12,000 per cell equipment cost)	Total Cost: Terminals & Basestations
Alabama	9,777	5,109	83	$19,554,000	$15,327,000	$996,000	$35,877,000
Alaska	1,231	633	100	$2,462,000	$1,899,000	$1,200,000	$5,561,000
Arizona	11,741	5,971	186	$23,482,000	$17,913,000	$2,232,000	$43,627,000
Arkansas	5,321	2,758	86	$10,642,000	$8,274,000	$1,032,000	$19,948,000
California	78,139	40,338	254	$156,278,000	$121,014,000	$3,048,000	$280,340,000
Colorado	11,183	5,821	170	$22,366,000	$17,463,000	$2,040,000	$41,869,000
Connecticut	7,983	4,250	9	$15,966,000	$12,750,000	$108,000	$28,824,000
Delaware	2,296	1,200	4	$4,592,000	$3,600,000	$48,000	$8,240,000
District of Columbia	4,113	2,166	1	$8,226,000	$6,498,000	$12,000	$14,736,000
Florida	44,336	22,563	89	$88,672,000	$67,689,000	$1,068,000	$157,429,000
Georgia	19,543	10,193	95	$39,086,000	$30,579,000	$1,140,000	$70,805,000
Hawaii	2,874	1,526	11	$5,748,000	$4,578,000	$132,000	$10,458,000
Idaho	2,472	1,290	135	$4,944,000	$3,870,000	$1,620,000	$10,434,000
Illinois	37,794	19,750	91	$75,588,000	$59,250,000	$1,092,000	$135,930,000
Indiana	11,397	5,868	59	$22,794,000	$17,604,000	$708,000	$41,106,000
Iowa	5,301	2,762	92	$10,602,000	$8,286,000	$1,104,000	$19,992,000
Kansas	7,106	3,707	134	$14,212,000	$11,121,000	$1,608,000	$26,941,000
Kentucky	7,951	4,215	66	$15,902,000	$12,645,000	$792,000	$29,339,000
Louisiana	17,515	9,156	72	$35,030,000	$27,468,000	$864,000	$63,362,000
Maine	2,268	1,201	51	$4,536,000	$3,603,000	$612,000	$8,751,000
Maryland	15,296	8,052	17	$30,592,000	$24,156,000	$204,000	$54,952,000
Massachusetts	16,757	8,969	14	$33,514,000	$26,907,000	$168,000	$60,589,000
Michigan	21,713	11,412	93	$43,426,000	$34,236,000	$1,116,000	$78,778,000
Minnesota	8,552	4,413	130	$17,104,000	$13,239,000	$1,560,000	$31,903,000
Mississippi	5,587	2,882	77	$11,174,000	$8,646,000	$924,000	$20,744,000

Table 4-12 Estimated US Law Enforcement Radio Equipment Replacement Costs
(*Cost Data Sources:* Robert Pletcher, Texas DPS; Terry Miller, Washington DOT; Pat Worsham, Texas DOT)

State	Portable Terminals	Mobile Terminals	Basestation Installations (at 584.6 sq. mi. per cell)	Cost Portable Terminals at $2,000 per terminal)	Cost Mobile Terminals (at $3,000 per terminal)	Cost Basestation Equipment (at $12,000 per cell equipment cost)	Total Cost: Terminals & Basestations
Missouri	**13,766**	**7,199**	**113**	**$27,532,000**	**$21,597,000**	**$1,356,000**	**$50,485,000**
Montana	**1,694**	**865**	**238**	**$3,388,000**	**$2,595,000**	**$2,856,000**	**$8,839,000**
Nebraska	**3,512**	**1,845**	**126**	**$7,024,000**	**$5,535,000**	**$1,512,000**	**$14,071,000**
Nevada	**5,248**	**2,673**	**179**	**$10,496,000**	**$8,019,000**	**$2,148,000**	**$20,663,000**
New Hampshire	**1,978**	**1,048**	**16**	**$3,956,000**	**$3,144,000**	**$192,000**	**$7,292,000**
New Jersey	**31,328**	**16,658**	**13**	**$62,656,000**	**$49,974,000**	**$156,000**	**$112,786,000**
New Mexico	**4,294**	**2,260**	**198**	**$8,588,000**	**$6,780,000**	**$2,376,000**	**$17,744,000**
New York	**61,788**	**32,422**	**78**	**$123,576,000**	**$97,266,000**	**$936,000**	**$221,778,000**
North Carolina	**20,507**	**10,721**	**80**	**$41,014,000**	**$32,163,000**	**$960,000**	**$74,137,000**
North Dakota	**1,148**	**603**	**113**	**$2,296,000**	**$1,809,000**	**$1,356,000**	**$5,461,000**
Ohio	**24,660**	**12,887**	**68**	**$49,320,000**	**$38,661,000**	**$816,000**	**$88,797,000**
Oklahoma	**7,456**	**3,884**	**113**	**$14,912,000**	**$11,652,000**	**$1,356,000**	**$27,920,000**
Oregon	**5,823**	**3,062**	**157**	**$11,646,000**	**$9,186,000**	**$1,884,000**	**$22,716,000**
Pennsylvania	**24,160**	**12,907**	**74**	**$48,320,000**	**$38,721,000**	**$888,000**	**$87,929,000**
Rhode Island	**2,549**	**1,359**	**3**	**$5,098,000**	**$4,077,000**	**$36,000**	**$9,211,000**
South Carolina	**9,121**	**4,783**	**50**	**$18,242,000**	**$14,349,000**	**$600,000**	**$33,191,000**
South Dakota	**1,342**	**693**	**124**	**$2,684,000**	**$2,079,000**	**$1,488,000**	**$6,251,000**
Tennessee	**16,053**	**8,268**	**68**	**$32,106,000**	**$24,804,000**	**$816,000**	**$57,726,000**
Texas	**50,685**	**25,995**	**426**	**$101,370,000**	**$77,985,000**	**$5,112,000**	**$184,467,000**
Utah	**4,860**	**2,531**	**134**	**$9,720,000**	**$7,593,000**	**$1,608,000**	**$18,921,000**
Vermont	**995**	**522**	**16**	**$1,990,000**	**$1,566,000**	**$192,000**	**$3,748,000**
Virginia	**17,051**	**9,015**	**65**	**$34,102,000**	**$27,045,000**	**$780,000**	**$61,927,000**
Washington	**10,256**	**5,380**	**109**	**$20,512,000**	**$16,140,000**	**$1,308,000**	**$37,960,000**
West Virginia	**3,121**	**1,661**	**40**	**$6,242,000**	**$4,983,000**	**$480,000**	**$11,705,000**
Wisconsin	**11,797**	**6,163**	**89**	**$23,594,000**	**$18,489,000**	**$1,068,000**	**$43,151,000**
Wyoming	**1,314**	**677**	**159**	**$2,628,000**	**$2,031,000**	**$1,908,000**	**$6,567,000**
Total US	**694,752**	**362,286**	**4,968**	**$1,389,504,000**	**$1,086,858,000**	**$59,616,000**	**$2,535,978,000**

Table 4-12 Estimated US Law Enforcement Radio Equipment Replacement Costs (Continued)
(*Cost Data Sources:* Robert Pletcher, Texas DPS; Terry Miller, Washington DOT; Pat Worsham, Texas DOT)

Data on the population for the US firefighter force are presented in Table 4-13. The key take-away from these data is that there is a significant volunteer component in the US fire fighter community. Several knowledgeable stakeholders in the EMS community advised that the only available data are fragmented from individual local government organizations, and there is no identified source of compiled national data.

Intelligent transportation systems have attracted considerable interest in recent years. Significant communication infrastructure has been deployed to integrate traffic control for area-wide traffic light coordination and, more recently, to deploy freeway management systems with cameras for video freeway surveillance and incident management. Most state departments of transportation (DOT) in the United States have highway maintenance LMR systems for dispatch and coordination.

	Fire Departments	**Career Firefighters**	**Volunteer Firefighters**	**Total Firefighters**
1998	**31,114**	**278,300**	**804,200**	**1,082,500**
1999	**3 0,436**	**279,900**	**785,250**	**1,065,150**
2000	**3 0,339**	**286,800**	**777,350**	**1,064,150**
2001	**3 0,020**	**293,600**	**784,700**	**1,078,300**
2002	**3 0,310**	**291,650**	**816,600**	**1,108,250**
2002, Per 1000 population		**0.990**	**2.773**	**3.763**

Table 4-13 US Firefighter Population
(*Source:* National Fire Protection Association; August 2004.)

The estimate of the ITS market presented here was developed based on support by Larry Miller of the American Association of State Highway and Transportation Officials (AASHTO). AASHTO is the FCC's frequency coordinator for ITS. Table 4-14 presents the results of an email survey to state DOT communication officials who have responsibility for DOT LMR radio systems. Table 4-15 presents an estimate of the total cost to replace this ITS communication equipment. Note that these estimates are for equipment only, and that total installed system costs would be significantly greater.

State	Area (sq. mi.)	Population	Portables	Mobiles	Infrastructure Cell Sites	Portable per 1,000 population	Mobiles per 1,000 population	Sq. Miles per Cell Site (95% coverage)
Arkansas	52,068	2,710,079	1000	1000	151	0.37	0.37	327.58
Colorado	103,717	4,403,008	868	868	165	0.20	0.20	597.16
Connecticut	4,844	3,374,179	275	1675	6	0.08	0.50	766.97
Idaho	82,747	1,311,796	763	1662	102	0.58	1.27	770.68
Illinois	55,584	12,542,030	600	4500	146	0.05	0.36	361.68
Kentucky	39,728	4,068,895	1000	1000	200	0.25	0.25	188.71
Ohio	40,948	10,878,422	1100	5000	140	0.10	0.46	277.86
Tennessee	41,217	5,787,364	1209	1997	129	0.21	0.35	303.54
Texas	261,797	21,670,261	3146	9707	383	0.15	0.45	649.37
Virginia	39,594	7,292,028	1500	5000	342	0.21	0.69	109.98
Washington	66,544	6,064,698	600	3500	125	0.10	0.58	505.73
Total	788,788	80,102,760	12,061	35,909	1,889	0.15	0.45	396.69
							Average Range	7.67 mi.

Table 4-14 ITS US DOT Communication Survey
(*Source:* Email Survey of US State DOT Representatives.)

Extrapolation to US				Estimated Total Cost ($M) of Equipment Replacement					
	Area (sq. mi.)	Population	Portables	Mobiles	Cell Sites	Portables	Mobile	Basestation Equipment Infrastructure	Total
United States	3,794,000	294,500,000	44,343	132,020	7,651	$88.7	$396.1	$91.8	$576.6
	6.2% of world total	4.6% of world total			Per unit Cost:	$2,000	$3,000	$12,000	

(*Cost data sources:* Terry Miller, Washington DOT; Pat Worsham, Texas DOT.)
Table 4-15 ITS Estimated Total Radio Equipment Replacement Cost

Table 4-16 presents the US and international replacement estimates for the public sector markets. As before, these estimates are total replacement costs for radio equipment; the total systems costs would be much greater.

Unit Estimates	Area (sq. mi.)	Population	Portable Terminals	Mobile Terminals	Basestation Installations
US Law Enforcement	3,537,437	294,700,000	694,752	362,286	4,968
US Public Sector	3,537,437	294,700,000	2,779,008	1,449,144	12,420
World	57,393,000	6,399,000,000	60,342,288	31,466,143	201,508
Cost Estimates		**Cost of Portable Terminals**	**Cost of Mobile Terminals**	**Cost of Basestation Equipment**	**Total Cost: Terminals & Basestations**
US Law Enforcement		$1,389,504,000	$1,086,858,000	$59,616,000	$2,535,978,000
US Public Sector		$5,558,016,000	$4,347,432,000	$149,040,000	$10,054,488,000
World		$120,684,575,000	$94,398,430,000	$2,418,096,000	$217,501,101,000

Table 4-16 US and International Public Sector Replacement Estimates

The assumptions for these estimates are:

- US law enforcement data are from FBI Crime in United States, 2003 report, per previous data in Table 4-11 and Table 4-12.
- US public sector portable and mobile terminal counts are four times US law enforcement count.
- US public sector basestation count estimate is 2.5 times US law enforce count
- International estimates are based on the ratio to US population for terminals and the ratio to US land area for infrastructure.
- Cost would undoubtedly be spread out over multiple years (~ 5–10 years).

4.4. WLAN/WiMAX

WLAN and WiMAX are part of a broader family of emerging wireless technologies that include wireless personal area networks (PAN), local area networks (LAN), metropolitan area networks (MAN), and wide area networks (WAN). Unlike cellular, the technologies and standards are more extensively driven by the semiconductor industry. An overview of these technologies is presented in Figure 4-17 which also includes cellular for comparison.

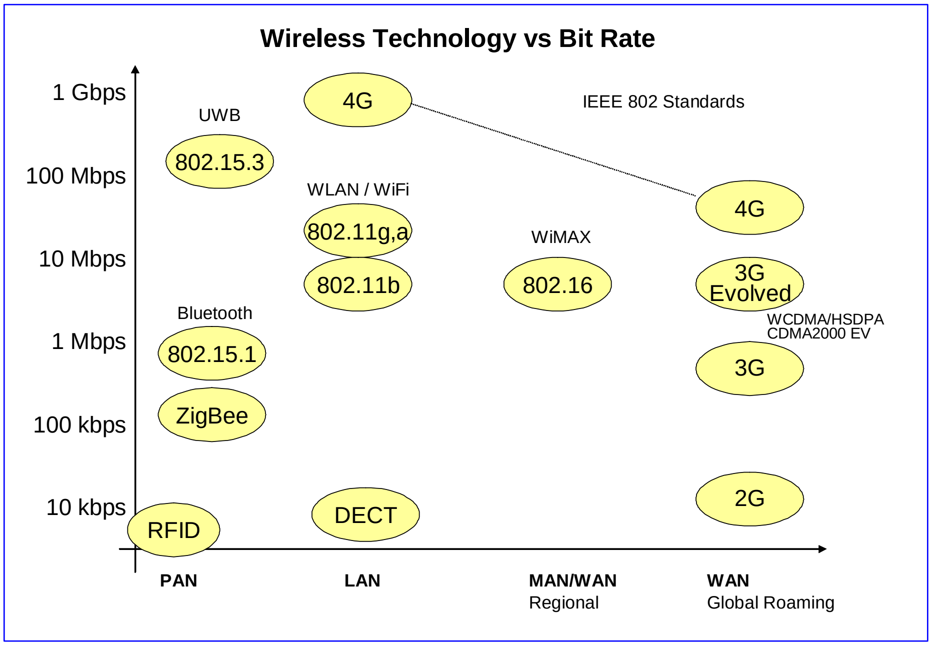


Figure 4-17 Wireless LAN, MAN, WAN, PAN Wireless Technologies

The WLAN/WiFi technologies have achieved substantial successes. However, as indicated in Table 4-17, several key emerging technologies have anticipated initial commercialization time frames in 2005 or 2006. During 2004 WiMAX has achieved significant industry interest for broadband wireless access applications to provide wireless alternatives to wireline DSL and cable modem broadband access. The WLAN market study (phase 2) will cover WiMAX technologies with market analysis commensurate to its emerging status.

The PAN segments include such technologies as the already deployed Bluetooth, ZigBee, and the emerging ultra-wideband (UWB) technologies. These are generally intended for very short range, low-power, and low-cost embedded applications. PAN requirements create substantially different SDR opportunities that must address very low cost and generally greater integration requirements. These technologies will undoubtedly be deployed in many converged devices, such as cellular phones and PDAs, and will provide simultaneous services with cellular. Thus, for these applications SDR technologies must provide for simultaneous waveforms as opposed to waveform selection.

Technology	Abbreviation	Anticipated Commercialization
Ultra Wideband	UWB / WPAN	2005/6 Commercialization
Wireless Personal Area Network	WPAN	Bluetooth Commercialized
Wireless Local Area Networks	WLAN / WiFi	WiFi Commercialized
Wireless Metropolitan Area Networks	WMAN / WiMAX	2005/6 Commercialization

Table 4-17 Anticipated Wireless LAN, PAN, MAN Technology Commercializations

Voice-over-Internet-Protocol (VoIP) is achieving increasing successes in wireline. Converged cellular, PDA, and other wireless devices with integrated WiFi capabilities are emerging to provide WLAN VoIP. For example, cellular subscribers may switch to VoIP service to reduce cellular airtime usage when within WLAN coverage.

Many of the standards in Figure 4-17 are IEEE 802 standards. These include:

- WPAN 802.15
  - Bluetooth 802.15.1
  - Ultra-Wideband (UWB) 802.15.3
- ZigBee 802.15.4
- WLAN (WiFi) 802.11a,b, and g
- WMAN (WiMAX) 802.16 a and e (mobile)

The frequency bands for these technologies are largely in unlicensed bands. Although some variability does exist in international frequency allocations, most of the world generally follows US allocations specified in FCC Part 15 rules. These include the industrial, scientific, and medical (ISM) bands as follows (bandwidths in parentheses):

- 902 – 928 MHz (26 MHz)
- 2.4000 – 2.4835 GHz (83.5 MHz)
- 5.725 – 5.875 GHz (150 MHz)

WMAN / WiMAX will have both licensed and unlicensed bands.

The IEEE 802 standards generally define physical layer standards. However, market experiences have clearly demonstrated that additional standards organizations are desirable to provide for technology insertion and marketing, and interoperability testing and certification. Examples of these organizations include, among many more:

- Bluetooth SIG – a Personal Area Network (PAN)
- WiFi – Wireless Fidelity for Wireless LANs
- WiMAX – Broadband Wireless Access
- UWB Forum – Ultra-Wideband Forum

Bluetooth is a short-range, open-standard for voice and data. Table 4-18 presents an overview of the Bluetooth standard. The Bluetooth SIG is a trade association that was founded in September 1998. An overview of the Bluetooth SIG is presented in

Table 4-19, which includes the intended market segments and a recently announced specification.

- Short-range wireless open-standard for voice and data
  - Low cost, royalty-free
  - Low power (1mW - 100mW)
  - Small physical size
- Enables electronic products to unconsciously and automatically communicate
  - Compelling specifications – link layer and application layer
  - 10m range (100m with amplifier)
  - 1 Mbps gross bit rate
  - Uses globally available 2.45 GHz ISM band
  - Frequency hopping protocol provides good immunity from interference
    - 1,600 hops per second
    - 79 frequencies at 1 MHz Intervals
- Standardized platform for eliminating cables between mobile devices
- Ad hoc Networking
- Data and Voice
  - Up to 7 simultaneous connections
  - Data Rates of up to 723kbps (v1.1), 10Mbps (v2.0)
  - SCO links for voice
  - ACL links for data

Table 4-18 Bluetooth Overview
(*Source:* Bluetooth SIG)

- Bluetooth Special Interest Group (SIG) is a trade association
- The Bluetooth SIG was founded in September 1998.
- The Bluetooth SIG includes:
  - Promoter member companies, such as Agere, Ericsson, IBM, Intel, Microsoft, Motorola, Nokia, and Toshiba
  - Thousands of Associate and Adopter member companies
- Market
  - Automotive
  - Consumer
  - Core Technology
  - Computer
  - Telephony
- Announced November 8, 2004: Bluetooth Core Specification Version 2.0 + EDR are:
  - Three times faster transmission speed (up to 10 times in certain cases)
  - Lower power consumption through reduced duty cycle
  - Simplification of multi-link scenarios due to more available bandwidth
  - Backwards compatible to earlier versions
  - Further improved BER (Bit Error Rate) performance

Table 4-19 Bluetooth SIG Overview, Market Segments, and Announced Specification
(*Source:* Bluetooth SIG)

UWB is an emerging wireless technology that is generally being led by United States proponents. The general market segments targeted include mobile devices, home entertainment equipment, automotive, and computers and peripherals.

On February 14, 2002, the US FCC issued a report and order to amend Part 15 rules to allow operation of devices incorporating UWB technologies. The maximum allowed transmit power was specified to be below the FCC's intentional radiation limit of –41.25 dBm/MHz. The frequency band for UWB communication measurement systems employing indoor and handheld devices was specified as 3.1 – 10.6 GHz. An overview of FCC Part 15.501 rules for UWB is presented in Table 4-20. The physical layer standards for UWB are defined by IEEE standards 802.15 and 802.15a. An overview of UWB data rates, features, and addressed market segments are presented in Table 4-21.

Interestingly, two competing technology/standards are being proposed. One is based on orthogonal frequency division multiplexing (OFDM), and the other is based on direct sequence (DS) spread spectrum access.

- FCC Part 15.501-525 UWB Rules Highlights
  - UWB Applications (some restrictions on organizations authorized to use imaging apps)
    - Imaging
      - Ground Penetration Radar Systems — below 960 MHz or 3.1 – 10.6 GHz
      - Through Wall Systems — below 960 MHz or 1.99 – 10.6 GHz
      - Surveillance Systems — 1.99 – 10.6 GHz
      - Medical Imaging — 3.1 – 10.6 GHz
    - Vehicle Radar Systems — 22 – 20 GHz
    - Communications & Measurement Systems — 3.1 – 10.6 GHz
    - Bandwidth – 500 MHZ or 0.2 of Carrier Frequency
- IEEE Standards – 802.15 and 802.15a
- Competing Standard Organizations
  - Multiband OFDM Alliance (MBOA) - OFDM-UWB
  - DS-UWB Forum

Table 4-20 Ultra-Wideband FCC Rules and Standards

- Data Rates: Short-Range Applications
  - Scalable data rates from 55 Mbps to 480 Mbps
  - 110 Mbps at 10 meters in realistic multi-path environments
  - 200 Mbps at greater than 4 meters in realistic multi-path environments
  - 480 Mbps at 2 meters in realistic multi-path environments
- Features
  - Short distance wireless
  - Low-cost solutions
  - Low-power physical layer (PHY) solutions
  - Integrated CMOS solutions, Single chip solutions
  - Small form factors
  - Coexistence with current and future devices
- General Market Segments
  - Mobile CE and communications
  - Consumer electronics
  - Computers and peripherals

Table 4-21 UWB Data Rates, Features, and General Market Segments

The WLAN or Wi-Fi market has experienced spectacular success in the past several years. WLAN is intended to provide untethered nomadic wireless access to the Internet. The consumer market has been the largest segment allowing consumers to connect easily to their home networks without the hassle and expense of connecting wires. The Enterprise segment has also been a strong adopter. More problematic has been the commercial "hot spot" segment that has experienced problems developing profitable business models to date.

The standards for WLAN are under the responsibility of the IEEE 802 standards organizations. The IEEE WLAN standards are presented in Table 4-22.

Standard	Frequency	Bit Rate	Modulation	Channel Spacing	MAC
802.11b	2.4 MHz Unlicensed Part 15, ISM (same as Bluetooth)	1, 2, 5.5, and 11 Mbps	DSSS, BPSK, CCK	5 MHz 25 MHz (No Interference)	Distributed, adapted from 802 LAN/WAN Standards
802.11g	2.4 MHz Unlicensed Part 15, ISM (same as Bluetooth)	Same as 802.11b plus Up to 54 Mbps	Same as 802.11b plus OFDM	Same as 802.11b	Distributed, adapted from 802 LAN/WAN Standards
802.11a	5 GHz Part 15 ISM, NII	6, 9, 12, 18, 27, 36, 54 Mbps	OFDM, (64 FFT), BPSK, QPSK, 16/64 QAM	20 MHz	Distributed, adapted from 802 LAN/WAN Standards

Table 4-22 IEEE 802.11 WLAN Standards

The Wi-Fi Alliance is a non-profit international association that was formed in 1999 to certify interoperability of IEEE 802.11 products. Additionally, the Wi-Fi Alliance serves as a technology marketing organization to "promote Wi-Fi as the global wireless LAN brand across all market segments, including the home, small office, large enterprise, and public access areas." The Alliance has more than 200 member companies and 1,500 products certified. The WiFi™ Ccrtification program consists of (1) published compliance testing procedures, (2) independent lab tests, and (3) Wi-Fi seal of certified interoperability. Prior to the Wi-Fi certification program, IEEE 802.11 market penetration had been languishing.

The WLAN market has been characterized by rapid unit growth and declining year-over-year (YOY) average sale price (ASP) decline. The WLAN market is driven by semiconductor chips, and thus can accommodate higher volumes, greater integration, and lower prices. WLAN market numbers are presented in Table 4-23.

	2002	2003	2004	2005	2006	2007
802.11 Shipments (M)	18.8	44.0	78.9	122.2	176.7	248.3
All Revenue ($Mil)	$2,580	$4,118	$5,399	$6,735	$7,556	$8,534
ASP Average ($)	$137.42	$76.24	$68.43	$55.09	$42.75	$34.37
Unit Growth %	119%	188%	46%	55%	45%	40%
Sales Growth %	210%	60%	37%	25%	12%	13%
ASP Change %	42%	-45%	-10%	-19%	-22%	-20%

Table 4-23 WLAN Market Numbers (Actual and Forecast)
(*Source:* Forward Concepts)

The WLAN market segments include network interface card (NIC), embedded (e.g., cellular phones, PDAs), multimedia, wireless residential gateway (WRG), and access points (AP). WLAN market segment numbers are presented in Table 4-24.

Revenues	2002	2003	2004	2005	2006	2007
Revenue NICs ($Mil)	$1,129	$1,495	$1,531	$1,419	$1,184	$918
Revenue Embedded	$75	$129	$568	$852	$832	$1,076
Revenue Multimedia	$0	$245	$673	$1,540	$2,223	$2,745
Revenue WRG ($Mil)	$567	$1,068	$1,245	$1,649	$2,133	$2,734
Revenue AP ($M)	$809	$1,181	$1,383	$1,275	$1,185	$1,060
Units	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**
802.11 Clients (M)	11.86	20.30	27.70	27.90	29.10	27.20
802.11 Embedded (M)	1.50	3.50	18.90	35.30	53.70	81.90
802.11 Multimedia (M)	0.00	2.40	7.80	22.50	42.60	64.60
802.11 WRG (M)	3.24	13.80	19.20	31.00	45.30	68.20
802.11 AP (M)	2.18	4.00	5.20	5.60	6.10	6.40
ASP	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**
ASP Client ($)	$95.24	$73.50	$55.19	$50.94	$40.73	$33.73
ASP Embedded ($)	$49.95	$36.50	$30.10	$24.12	$15.50	$13.15
ASP Multimedia ($)	$110.00	$102.81	$85.90	$68.51	$52.13	$42.50
ASP WRG ($)	$175.25	$77.40	$64.75	$53.18	$47.08	$40.10
ASP AP ($)	$370.60	$294.82	$264.50	$229.00	$194.65	$165.45

Table 4-24 WLAN Market Segment Numbers
(*Source:* Forward Concepts)

In 2004, much attention was devoted WiMAX to serve broadband wireless access applications. WiMAX can also serve other applications, as presented in Figure 4-18. These applications include fixed access and portability with simple mobility that is addressed in the current IEEE 802.16-2004 standard. Full mobility is to be added in IEEE 802.16e, which is scheduled for 2005.

The properties of WiMAX are presented in Table 4-25. WiMAX, like the higher speed versions of Wi-Fi, employs OFDM. Based on IEEE and WiMAX Forum standards and interoperability certification, WiMAX potentially could have a more streamlined and open standards process than the often slow-moving cellular standards. The OFDM will scale to varying bandwidths and bit rates with conceptually compatible physical layers.

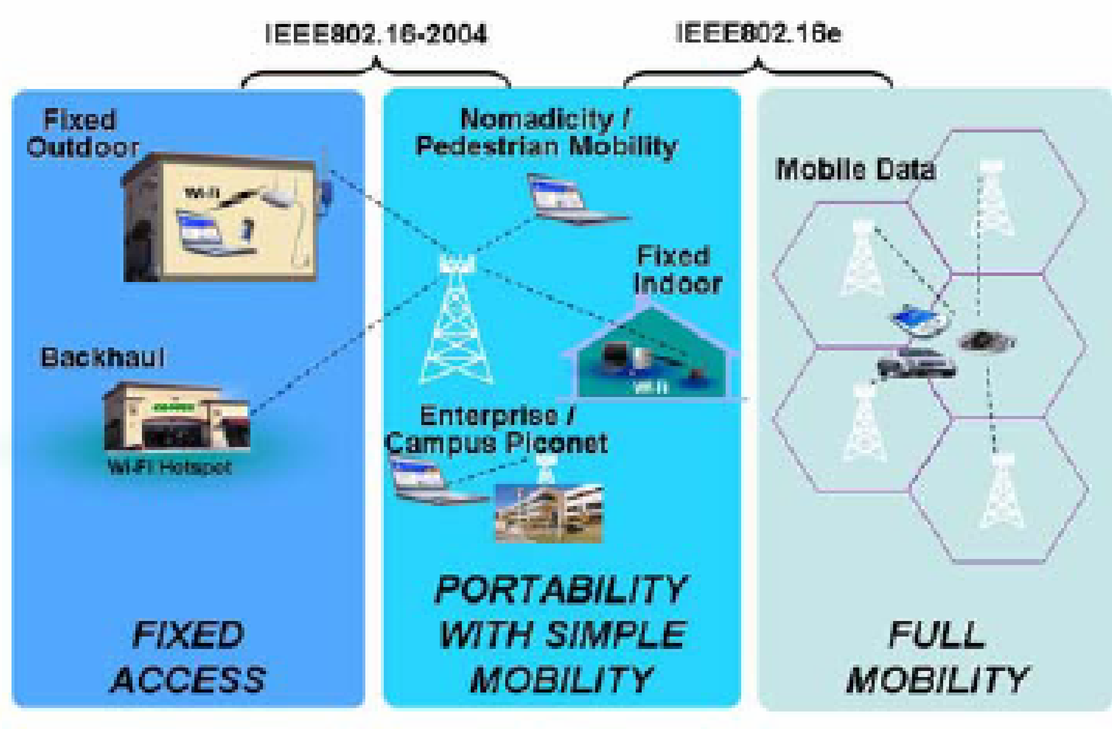


Figure 4-18 WiMax – Broadband Wireless Access Application
(*Source: Intel Technology Journal*, Vol. 8, #3, 2004.)

WiMAX – 802.16 Properties

- Up to 134 Mb in 28 MHz channel (in 10-66 GHz)
- Supports multiple services with quality of service (QoS)
- IPv4, IPv6, ATM, etc.
- Frame-by-frame bandwidth on demand
- Adaptive modulation and coding
- Comprehensive and extensible security (3 DES, AES)
- Support for multiple frequency allocations
- OFDM for NLOS
- Point-to-multipoint with mesh extensions
- Support for adaptive antennas, MIMO, etc.
- Extensions to mobility

Table 4-25 WiMAX – Properties of 802.16x
(*Source:* Fujitsu, WiMAX IEEE Dallas CVT presentation, September 2004.)

The market opportunities for WiMAX are presented in Table 4-26. The end result of all these goals is that there are likely to be multiple ubiquitous coverage WiMAX networks in the same key metropolitan markets.

The potential spectra for WiMAX applications are presented in Figure 4-19. Interoperability standards and certification are anticipated for equipment in each band and bandwidth, as necessary.

- **RBOCs are looking to WiMAX to**
  - Reach customers outside of their serving areas
  - Provide the out-of-region access to in region-based customers
  - Fill in the gaps in DSL coverage
- **MSOs are looking to WiMAX to**
  - Limit service opportunities lost to 3G wireless
  - Access out-of-franchise customers
  - Provide value-added services to existing customers
- **Wireless service providers are looking to WiMAX to**
  - Provide a less costly method for providing high capacity services
  - Provide 3G type data services in the public spectrum
- **IXCs are looking to WiMAX to**
  - Rapidly reach off-network customers
  - De-risk expensive last-mile builds by spreading the cost over multiple customers
  - Reach customers in other countries
- **State and local governments are looking to WiMAX to**
  - Provide data services to public safety offices
  - Provide emergency backup for wireline services
  - Provide public data services

Table 4-26 WiMAX Market Opportunities
(*Source:* Fujitsu, IEEE Dallas CVT Presentation, September 2004.)

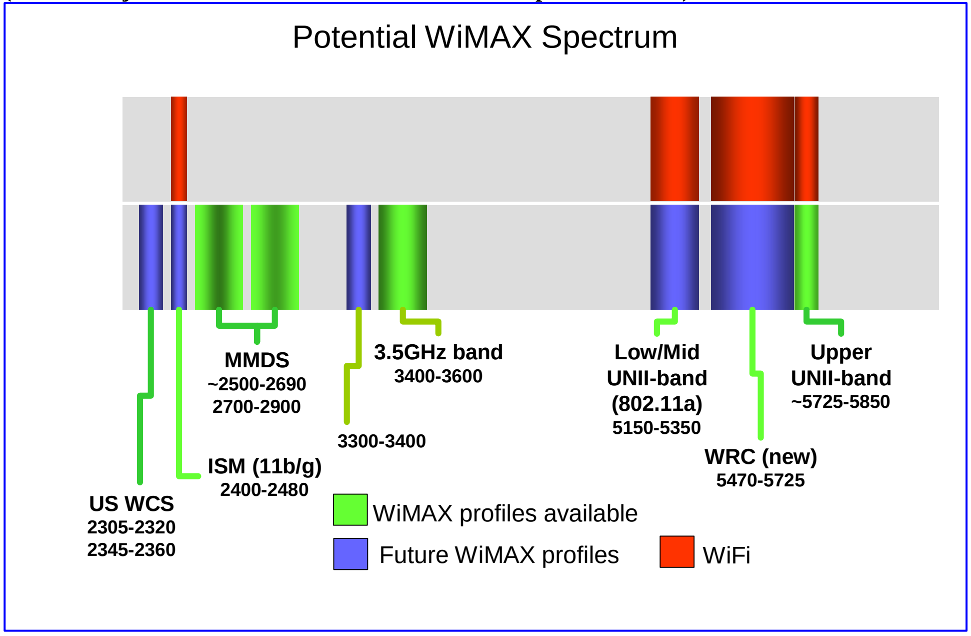


Figure 4-19 Potential WiMAX Spectrum
(*Source:* Fujitsu, Wireless System Design Symposium, March 2004.)

4.5. Automotive / Telematics

Telematics service providers are seeking to provide driver conveniences and to promote transportation system efficiencies. Telematics focuses on providing drivers a variety of services that include emergency services, stolen vehicle tracking, remote diagnostics, and navigation, plus many other potential services. Although many consider intelligent transportation systems (ITS) and telematics as a common market segment, ITS was better represented in the public safety market segment, due to its public funding.

Figure 4-20 presents a telematics overview, which includes typical services. The figure also includes a picture of a Cadillac Deville equipped with OnStar equipment. GM offers OnStar service free for one year on all equipped new vehicles. Reports indicate that approximately 50% renew the service after the first year for approximately $200 to $300 per year or more depending actual services selected. Figure 4-20 also shows the simple, easy-to-use OnStar control panel that consists of three buttons located on the rearview mirror.

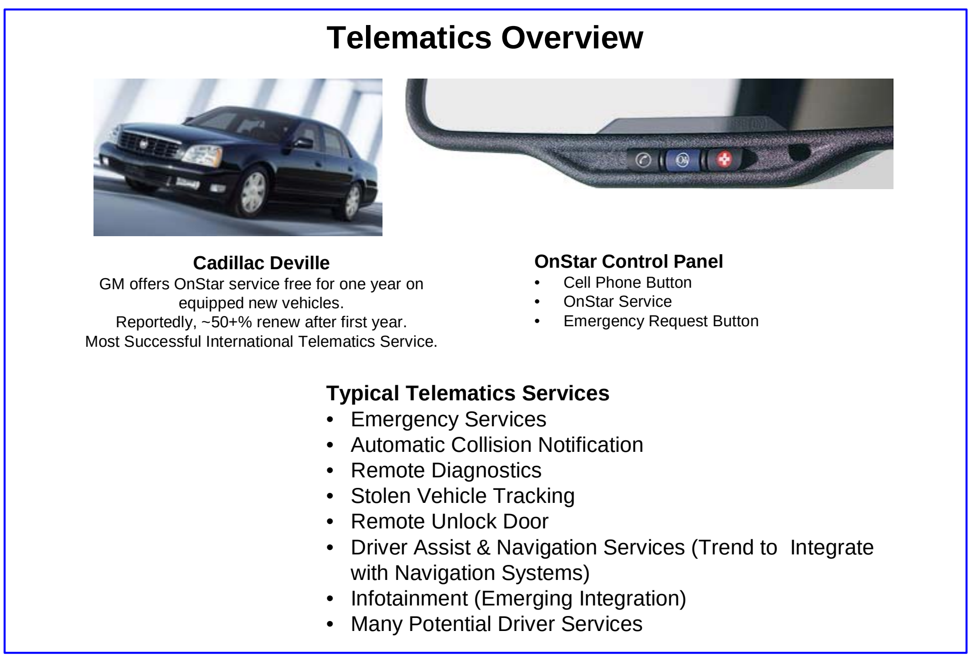


Figure 4-20 Telematics Overview with Typical Services
(*Source*: OnStar web site and author research)

An overview of key telematics players is presented in Table 4-27. To date, telematics services have been largely promoted by vehicle manufacturers. GM's OnStar is clearly the most successful international telematics service provider with an estimated 80% market share in terms of subscribers. Surprisingly, many optimistic telematics plans and discussions exist, but indications of current successful business models are few. This lack of success should be only temporary and future successful international telematics business models are expected to emerge.

While they will always have a large stake in telematics, third-party partnerships appear essential to successes. Potential emerging players include third-party telematics service providers (TSPs), cellular operators, and perhaps even public or private ITS organizations. OnStar provides voice services using Verizon Wireless's (VZW's)cellular network in the United States. This service currently uses the legacy analog network, but is evolving to VZW's CDMA 2000 network as GM equips automobiles.

- Current Players
  - United States
    - OnStar/GM – appears to have 80+% of market
    - ATX – Irving, TX, claims to be second biggest player
  - Europe
    - BMW & Mercedes Benz – use ATX in US
  - Japan
    - Nissan
    - Honda
    - Toyota
- Emerging Potential Players
  - Third Party Telematics Service Providers (TSPs; e.g., ATX)
  - Cellular Operators
  - Intelligent Transportation System (ITS) Organizations, public and private

Table 4-27 Key Telematics Players
(*Source*: Author research)

Several automotive and telematics trends are emerging. Significant general automotives trends include an expected evolution from the current approximately 20% of automotive costs being for electronics to perhaps about 40% by 2010. Open standards are considered essential to support this evolution. Interestingly, at the 2004 Convergence Automotive Electronics Conference, presentations indicated an intent to evolve from current 100+ 16-individual platforms (one for each subsystem) to more integrated 25 to 30 32-bit microcontrollers. This will reduce component count, interconnecting communication equipment, and costs.

Typical current telematics equipment includes the telematics control unit, the user interface, a GPS receiver, and analog cellular (OnStar). Telematics will also experience future integration to include emerging vehicle infotainment, navigation, and other electronics systems. Bluetooth interface options to cellular phones will be integrated that, in addition to hands-free voice options, could provide telematics services via cellular. Eventually, vehicle web access will be available for telematics and other services.

As a high-level calibration on the potential for telematics, Table 4-28 provides estimates by year of the total international vehicles on the road by region. These estimates are based on World Bank data on vehicles per 1,000 by country with gaps supplemented by author research, estimates, and calculations. The gaps were generally for lower-tier counties and latest yearly data.

Estimates for 2003 international vehicle sales and 2003 telematics-equipped vehicle sales are presented in Figure 4-21 and Figure 4-22, respectively. As the figures indicate, North America (NA) and Europe dominate automotive sales, and North America dominates telematics sales.

World Auto on the Road								
	2001	2002	2003	2004	2005	2006	2007	2008
NA	240,976,645	243,419,014	245,876,168	248,350,453	250,844,942	253,345,802	255,839,509	258,329,051
CALA	51,695,315	52,867,116	54,048,364	55,240,361	56,442,419	57,657,531	58,888,319	60,131,108
Europe	288,283,603	291,893,847	295,507,219	299,121,863	302,734,408	306,347,047	309,964,882	313,585,350
Asia	171,936,249	174,989,289	178,044,825	181,122,459	184,219,395	187,336,278	190,468,087	193,607,149
Total	752,891,812	763,169,266	773,476,576	783,835,136	794,241,164	804,686,658	815,160,797	825,652,658

Table 4-28 International Vehicles on the Road by Region
(*Source:* World Bank, Vehicles per 1000 by Country, author calculations.)
NA = North America; CALA = Central America/Latin America

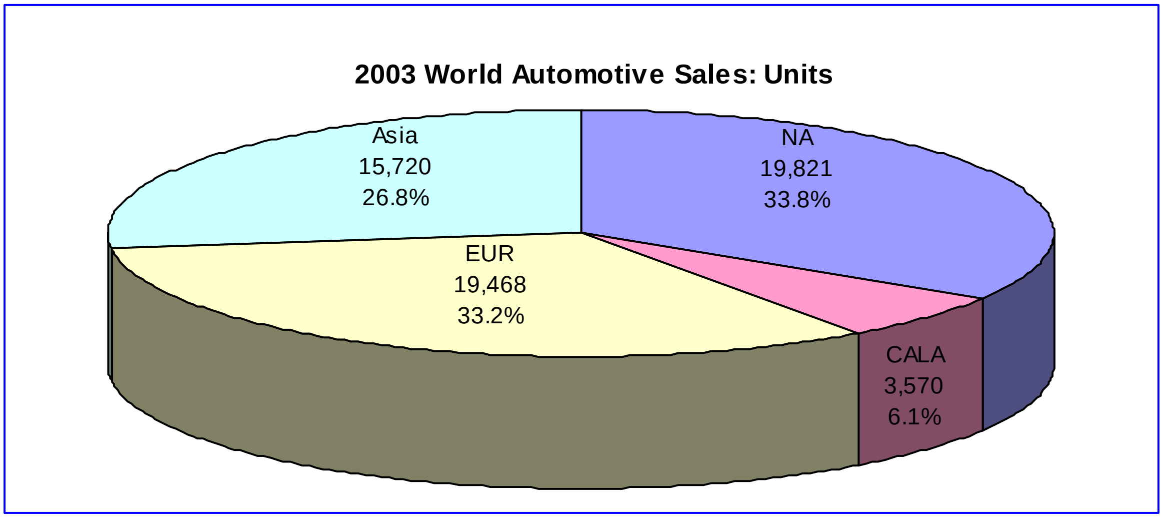


Figure 4-21 2003 International Automotive Sales by Regions

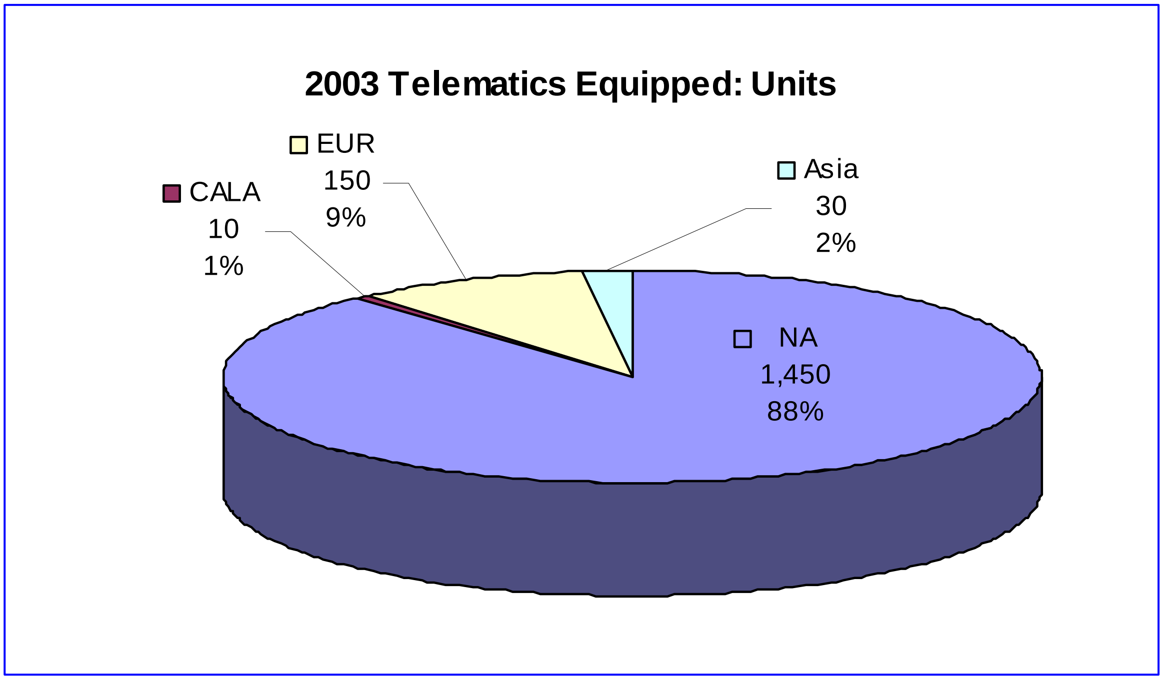


Figure 4-22 2003 International Telematics-Equipped Vehicle Sales by Regions

Forecasts for international vehicle sales are presented in Table 4-29, and forecasts for international telematics-equipped vehicle sales are presented in Table 4-30. Although these forecasts indicate North American dominance of telematics based on current trends, significant international telematics markets are expected to emerge. However, at this time this market share cannot be forecast based on current trends. The forecasting methodology used here provides an easily revised framework as trends and supporting data emerge to justify revisions.

New Vehicle Sales, Units (000)

	1998	1999	2000	2001	2002	2003	2004E	2005E	2006E	2007E	2008E
NA	19,041	20,040	20,455	20,250	20,118	19,821	19,841	19,940	20,088	20,169	20,377
CALA	4,061	4,274	4,297	4,009	3,673	3,570	3,534	3,569	3,578	3,586	3,592
Europe	18,672	19,540	20,054	19,705	19,172	19,468	19,760	19,878	20,088	20,297	20,442
Asia	10,971	11,658	12,491	13,101	14,373	15,720	17,198	18,155	19,021	19,977	20,899
Total	52,745	55,512	57,297	57,065	57,336	58,579	60,336	61,543	62,774	64,029	65,310

New Vehicle Sales, % Total Worldwide

	1998	1999	2000	2001	2002	2003	2004E	2005E	2006E	2007E	2008E
NA	36.1%	36.1%	35.7%	35.5%	35.1%	33.8%	32.9%	32.4%	32.0%	31.5%	31.2%
CALA	7.7%	7.7%	7.5%	7.0%	6.4%	6.1%	5.9%	5.8%	5.7%	5.6%	5.5%
Europe	35.4%	35.2%	35.0%	34.5%	33.4%	33.2%	32.7%	32.3%	32.0%	31.7%	31.3%
Asia	20.8%	21.0%	21.8%	23.0%	25.1%	26.8%	28.5%	29.5%	30.3%	31.2%	32.0%
Total	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

% YOY Growth

	1998	1999	2000	2001	2002	2003	2004E	2005E	2006E	2007E	2008E
NA		5.2%	2.1%	-1.0%	-0.7%	-1.5%	0.1%	0.5%	0.7%	0.4%	1.0%
CALA		5.2%	0.5%	-6.7%	-8.4%	-2.8%	-1.0%	1.0%	0.2%	0.2%	0.2%
Europe		4.7%	2.6%	-1.7%	-2.7%	1.5%	1.5%	0.6%	1.1%	1.0%	0.7%
Asia		6.3%	7.1%	4.9%	9.7%	9.4%	9.4%	5.6%	4.8%	5.0%	4.6%
Total		5.2%	3.2%	-0.4%	0.5%	2.2%	3.0%	2.0%	2.0%	2.0%	2.0%

Table 4-29 International Vehicle Sales by Region

(*Source:* Historical data from GM annual reports, 1999–2003, validated other annual reports; forecasts are author estimates.)

NA	1.14%	3.22%	7.32%	12.35%	16.55%	20.41%	24.29%	27.97%
CALA	0.00%	0.05%	0.28%	0.34%	0.67%	1.40%	2.09%	3.48%
Europe	0.18%	0.39%	0.77%	0.77%	1.51%	2.64%	4.19%	5.03%
Asia	0.08%	0.14%	0.19%	0.24%	0.38%	0.47%	0.83%	0.96%
Total	0.50%	1.30%	2.80%	4.40%	6.00%	7.60%	9.20%	10.80%

Telematics: New Vehicles Equipped, Units (000)

	2001	2002	2003	2004E	2005E	2006E	2007E	2008E
NA	230	648	1,450	2,450	3,300	4,100	4,900	5,700
CALA	-	2	10	12	24	50	75	125
Europe	35	75	150	152	300	531	850	1,028
Asia	10	20	30	41	69	90	166	200
Total	285	745	1,640	2,655	3,693	4,771	5,891	7,053

Telematics Equipment Revenues (assume ASP $400 per unit)

	2001	2002	2003	2004E	2005E	2006E	2007E	2008E
NA	$92,000	$259,200	$580,000	$980,000	$1,320,000	$1,640,000	$1,960,000	$2,280,000
CALA	$0	$800	$4,000	$4,800	$9,600	$20,000	$30,000	$50,000
Europe	$14,000	$30,000	$60,000	$60,800	$120,000	$212,400	$340,000	$411,200
Asia	$4,000	$8,000	$12,000	$16,400	$27,600	$36,000	$66,400	$80,000
Total	$114,000	$298,000	$656,000	$1,062,000	$1,477,200	$1,908,400	$2,356,400	$2,821,200

Table 4-30 International Telematics-Equipped Vehicle Sales

(*Source*: Author estimates.)

The benefits of SDR for telematics are significant. Automotive manufacturers sell their products in many international markets. Each market has unique consumer preferences, telematics service requirements, spectral allocations, and so forth, and SDR offers opportunities to provide a common platform that can be personalized via software. Additionally, most manufacturers provide bumper-to-bumper warranties for several years and/or mileage limits. High reliability, as well as customization, to minimize warranty costs is a very important goal that provides significant SDR technology benefits.

Telematics' business models are very much a "work in progress." From its 1996 origins, telematics has not provided many clear successes, other than perhaps modest OnStar successes. As integration progresses to include navigation services (more than stand-alone GPS boxes), infotainment services (e.g., satellite radio), ITS travel guidance services, cellular, and web access, the potential of telematics to provide successful business models in the future is very optimistic. Significant consumer and commercial fleet opportunities should also emerge.

4.6. Aviation/Avionics

The aviation industry provides air transportation to the traveling public. Avionics equipment and systems provide communication services to enable efficient and safe operations. In recent years, communication services such as cellular and Internet access have emerged as passenger services. Industry interviews (e.g., from Bruce Eckstein FAA, System Engineering Office) have provided consistent input that the United States represents approximately 50% of the international market for aircraft. Thus, the discussions in this section have a US focus, but also will provide international aviation fleet market numbers.

The "pieces and players" for the aviation community are presented in Figure 4-23. An overview of the US National Airspace System (NAS) is presented in

Figure 4-24, which depicts satellites, various types of aircraft, and ground systems such as radars and traffic control facilities, airports, control towers, and runways.

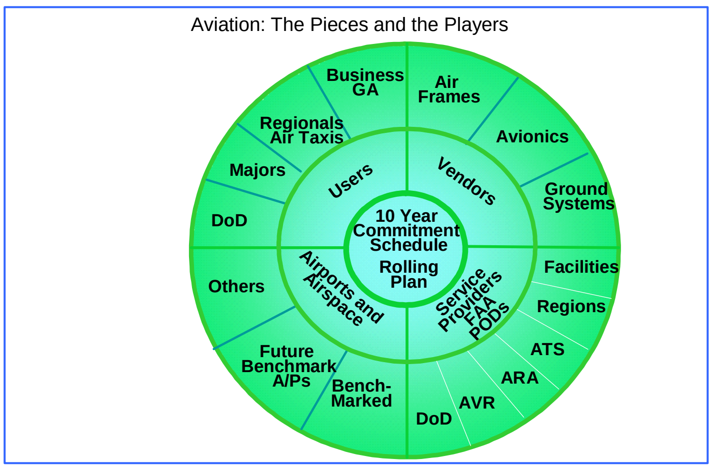


Figure 4-23 Aviation: The Pieces and Players
(*Source:* FAA 2003 Industry Day Presentation, July 2, 2003.)

The US NAS consists of the following (see the MITRE CAASD web site, www.caasd.org):

- 18,000 Airports
- 460 Airport Control Towers
- 20 ARTCC
- 173 Terminal Radar Approach Control Faculties
- Oceanic Centers
- 4,500 Air Navigation Facilities
- 75 Flight Service Stations

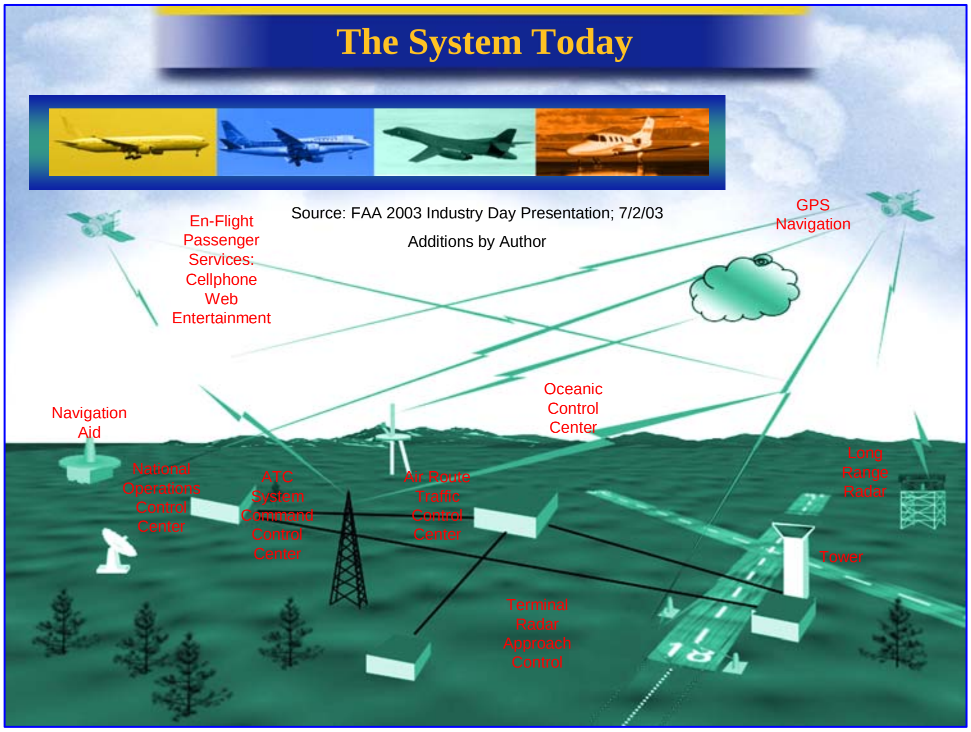


Figure 4-24 NAS: The System Today
(*Source*: FAA presentations at www.FAA.gov)

The goal of the Federal Aviation Administration's 10-year Operational Evolution Plan (OEP) is to increase the capacity and efficiency of NAS while enhancing safety and security. The FAA's web site (www.faa.gov/programs/oep) identifies four key problem areas:

- Arrival/Departure Rate
- Airport Weather Conditions
- En Route Congestion
- En Route Severe Weather

A key supporting goal, according to the web site, is the upgrade of current analog (25 kHz) avionic/communication systems to include:

- Digital Voice (6.25 kHz per voice channel); Voice Data Link 3 (VDL3)
- Controller Pilot Data Link (CPDLC)
- Domestic Reduced Vertical Separation Minima (DPDCL)
- Required Navigation Procedures (RNP)

OEP envisions modernizing the current, largely analog, equipment in all US NAS facilities with updated VDL3 digital equipment. Figure 4-25 is a slide extracted from an FAA presentation that provides an overview of NEXCOM's planned schedule of evolution from current analog equipment to the VDL3 equipment.

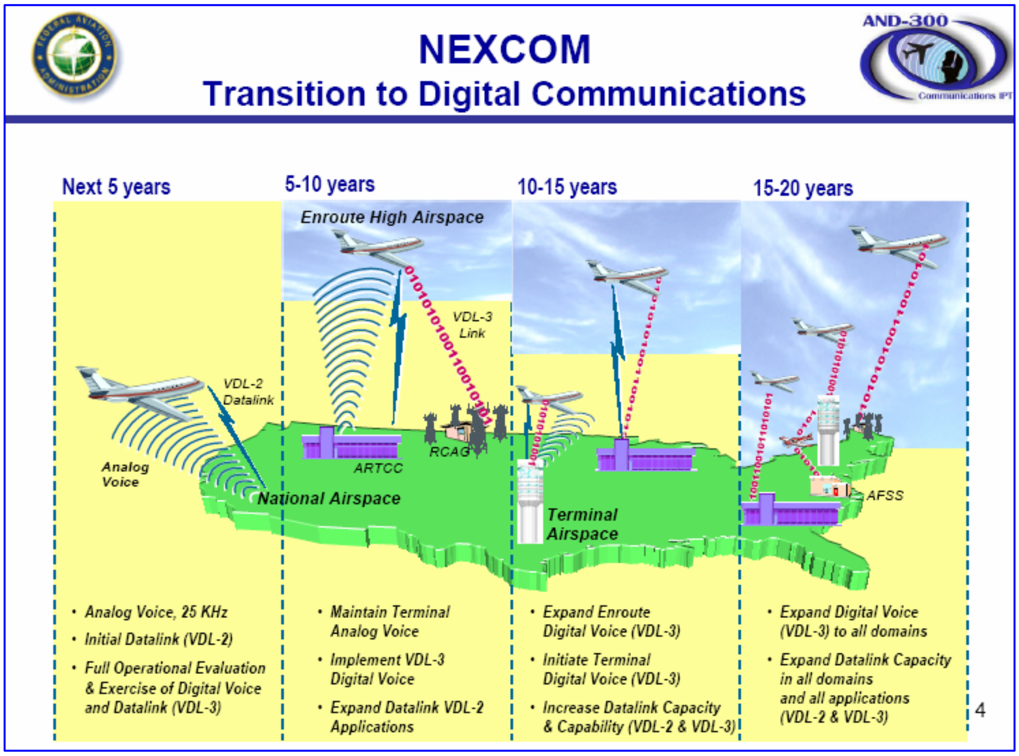


Figure 4-25 FAA NEXCOM Program; Transition to Digital Communications
(*Source:* Next Generation Air/Ground Com; Program Status Briefing; presented to AEEC Committee, October 2003; Bruce Eckstein; Communications Integrated Product Team; Federal Aviation Administration.)

Estimates for the number of US NAS facilities and costs to upgrade to OEP-compliant radio equipment are presented in Table 4-31.

Facilities	Number *	Estimated Radios per Organization	Total Radios	Total Radio Cost *
Airports	18,000	2	36,000	$ 900,000,000
Airport Controls Towers	460	25	11,500	$ 287,500,000
Air Route Traffic Control Centers	20	50	1,000	$ 25,000,000
Terminal Radar Approach Control Center	173	4	692	$ 17,300,000
Oceanic Centers	3	50	150	$ 3,750,000
Air Navigation Facilities	4,500	2	9,000	$ 225,000,000
Flight Service Stations	75	10	750	$ 18,750,000
Total	23,231		59,092	$ 1,477,300,000

* Assumes $25,000 per radio cost (anonymous industry source)

- Above are Total Installed-Base Cost of Radios.
- Upgrade of Fleet and Infrastructure to digital Avionics would accelerate the replacement cycles and cost. Also significant additional costs for planning, system engineering, installation, commissioning, testing, certification, etc. will be required.

Table 4-31 US NAS Facilities and OEP Radio Equipment Update Cost Estimates
(*Source:* FAA web site, www.FAA.gov supplemented with author research)

In a November 2004 telecom, Tom Jewel, Senior Program Manager for ITT's ATC Communication Business Unit, stated that ITT was awarded a $600 million contract by the FAA in 2001 to develop and deploy their Multimode Digital Radio (MDR) as part of the FAA's NEXCOM program. (*Note:* ITT requested that ITT authorization be obtained for any distribution of this information outside the SDR Forum.) The MDR is SDR capable and provides for software-enabled evolution during the analog-to-digital transition.

The international aviation fleet population numbers are presented in Table 4-32, which includes the sources and assumptions for the forecasts.

International Aviation Fleet

Aviation Fleet	2000	2001	2002	2003	2004	2005	2006
Commericial Aviation (T.O.>20,000LB)(1)	19,741	20,330	20,936	21,561	22,208	22,874	23,560
Jet Aircraft (e.g. Business) (1)	15,926	16,389	16,865	17,355	17,876	18,412	18,964
Turbo Prop (1)	3,635	3,767	3,903	4,045	4,166	4,291	4,420
General Aviation (2)	357,177	360,749	364,356	368,000	371,680	375,397	379,151
Total	396,479	401,235	406,061	410,961	415,930	420,974	426,095

(1) ICAO, 1993 & 2003, interpreted
(2) ICAO 2003, used AOPA US growth to estimate International growth
(3) Author Forecasts; Assume 3% Growth, GA 1%

Table 4-32 International Aviation Fleet
(*Sources: ICAO Journal*, #6, 2004, AOPA, and author estimates.)

Forecasts for the avionics equipment market for units and revenue are presented in Table 4-33 and Table 4-34, respectively. The assumptions for the forecasts are contained in the tables. Although the units for general aviation (GA) are significantly higher than commercial aviation, the cost per unit for commercial aviation is significantly higher and thus dominates the segment.

Avionics Equipment Market - Units

Avionics Equipment Market - Units	2000	2001	2002	2003	2004	2005	2006
Commericial Aviation (T.O.>20,000 lb)	7,466	7,689	7,918	8,155	8,409	8,661	8,921
Jet Aircraft (e.g. Business)	3,995	4,111	4,230	4,353	4,512	4,648	4,787
Turbo Prop	956	991	1,027	1,064	1,052	1,083	1,116
General Aviation	21,218	21,431	21,645	21,861	22,080	22,301	22,524
Total	33,635	34,221	34,820	35,433	36,053	36,693	37,348

Commercial aviation figures assume a 10% replacement rate; general aviation figures assume a 5% replacement rate.

Table 4-33 Aviation Avionics Equipment Market – Units

Avionics Equipment Market - $ (000)

Market - $ (000)	2000	2001	2002	2003	2004	2005	2006
Commericial Aviation (T.O.>20,000 lb)	186,650	192,225	197,950	203,875	210,225	216,525	223,025
Jet Aircraft (e.g. Business)	99,875	102,775	105,750	108,825	112,800	116,200	119,675
Turbo Prop	23,900	24,775	25,675	26,600	26,300	27,075	27,900
General Aviation	31,827	32,147	32,468	32,792	33,120	33,452	33,786
Total	342,252	351,922	361,843	372,092	382,445	393,252	404,386

Assumptions: Commercial fleet unit avionics cost: $25,000 per unit
General aviation unit aviation cost: $1,500 [range $700-$2,000] per unit

Table 4-34 Aviation Avionics Equipment Market – Revenue
(*Source:* Aviation industry, anonymity requested.)

Revenues for the above forecasts are for communication equipment only. Aviation, like other public sector applications, has significant costs associated with planning, system design, installation and test, training, and so forth; thus, our forecasts are much lower than the total cost.

Kent V. Hollinger of MITRE's CAASD organization, in a presentation at the FAA's Industry Day on July 2, 2003, included an estimate of avionics costs by airlines to modernize their fleet for OEP. His table is presented in

Table 4-35 for selected US airlines.

The aviation segment has a critical requirement for SDR technologies in the transition from legacy analog to enhanced digital technologies. In terms of units and equipment revenues, aviation is comparatively smaller than most other segments. However, aviation is a critical world asset to the traveling public and economic vitality. For baseband and data acquisition components, we conclude that emerging SDR technologies seem well positioned to serve requirements. However, the dedicated Aviation RF bands appear to present niche opportunities for RF components.

Total Selected Avionics Costs by Airline ($M)
(Preliminary)

OR

	RNP-1,1,0.11	RNP-2,2,0.3	DRVSM	CPDLC	VDL-M3	Total w/RNP 0.11	Total w/RNP 0.3
Alaska	$26	$6	$8	$8	$10	$52	$33
American	$179	$45	$58	$70	$88	$394	$260
America West	$90	$10	$11	$14	$10	$125	$45
Continental	$91	$23	$18	$22	$22	$153	$85
Delta	$239	$60	$37	$43	$52	$371	$192
FedEx	$95	$16	$25	$14	$20	$155	$76
Northwest	$132	$9	$33	$23	$12	$201	$78
Southwest	$140	$35	$29	$32	$32	$232	$127
United	$323	$50	$42	$56	$51	$472	$199
UPS	$89	$22	$19	$13	$19	$139	$72
US Airways	$164	$23	$20	$26	$22	$232	$92
RJs, and HEGA*	**	**	$225	$533	$144	900+	900+
Total	$1,600+	$300+	$525	$854	$482	3300+	2200+

* High-end GA; ** No information

Table 4-35 Total Select Avionics Costs by Airline
(*Source:* Kent V. Hollinger, MITRE FAA 2003 Industry Day, July 2, 2003.)

5 List of Acronyms

2G	second-generation
3G	third-generation
3GPP	Third-Generation Partnership Program
3GPP2	Third-Generation Partnership Program 2 (CDMA)
AASHTO	American Association of State Highway and Transportation Officials
ADC	analog-to-digital
AEEC	Airlines Electronic Engineering Committee
AES	advanced encryption standard
AFRL	Air Force Research Lab
AMF	airborne, maritime fixed
AMPS	Advanced Mobile Phone Service
AN	access network
ANSI	American National Standards Institute
AOPA	Aircraft Owners and Pilots Association
AP	access points
APCO	Association of Public-Safety Communications Officials
ARA	Associate Administration for Research and Acquisition (FAA)
ARL/SLAD	Army Research Lab/Survivability/Lethality
ARPU	average revenue per unit
ARTCC	Air Route Traffic Control Center
ASIC	application-specific integrated circuit
ASP	average sale price
ASSP	application-specific standard products
ATM	Asynchronous Transfer Mode
ATS	Air Traffic Services
ATX	Company Name and ATX Communications
AVR	(FAA) Aviation Regulation, www.faa.gov/avr
BPSK	binary phase shift key
BTS	basestation transceivers
CAASD	Centre for Advanced System Development
CALA	Central America/Latin America
CAPEX	capital expenses
CCK	complementary code keying
CDMA	Code Division Multiple Access
CE	consumer electronics
CECOM	Communications Electronics Command
CIA	Central Intelligence Agency
CMOS	complementary metal-oxide semiconductor
COMSEC	Communications Security
CPDLC	Controller Pilot Data Link
CPDLS	controller pilot data link
CWP	Coalition Warfare Initiative

DAB	Defense Acquisition Board
DAC	digital-to-analog
dBm	decibels milliwatt
DCS	Digital Cellular System
DES	data encryption standard
DHS	Department of Homeland Security
DISA-JSC	Defense Information Systems Agency
DOD	Department of Defense
DOT	Department of Transportation
DPDCL	Domestic Reduced Vertical Separation Minima
DRVSM	domestic reduced vertical separation minima
DS	direct sequence
DSP	digital signal processors
DSSS	direct sequence spread spectrum
DXCO	Digitally Controlled Oscillator
ECP	engineering change proposal
EDGE	enhanced data for GSM evolution
EGPRS	Enhanced General Packet Radio Service
EMS	emergency medical service
Enterprise	Business (as opposed to consumer)
ETSI	European Telecommunications Standardisation Institute
FAA	Federal Aviation Administration
FCC	Federal Communications Commission
FFT	Fast Fourier Transform
FPGA	field-programmable gate-array
GA	general aviation
GDP	gross domestic product
GM	General Motors
GMSK	Gaussian minimum shift keying
GPRS	general packet radio service
GPS	global positioning system
GSM	global system for mobile communications
HEGA	high-end general aviation
HR	hardware radio
HSCSD	high-speed circuit switched data
HSDPA	high-speed packet data access
IACP	International Association of Chiefs of Police
IC	integrated circuit
ICAO	International Civil Aviation Organization
IF	intermediate frequency
IP	intellectual property
ISM	industrial, scientific, and medical
ISR	ideal software radio
ITS	intelligent transportation systems
JITC	Joint Interoperability Test Command
JPO	Joint Program Office

JR-AMF	Joint Radio-Airborne, Maritime, Fixed
JR-GVR	Joint Radio-Ground, Vehicle, Rotary
JR-HMS	Joint Radio-Handheld, ManPack, Small form
JR-MIDS	Joint Radio-Multifunction Information Dist. Sys.
JRR-SHH	Joint Radio-Special Operation Forces Hanheld
JTACS	Japanese Total Access Communications System
JTeL	JTRS Technical Lab
JTR	Joint Tactical Radio
JTRS	Joint Tactical Radio System
kHz	kilohertz
KPCS	Korean PCS
LAN	local area network
LMR	land mobile radio
LNA	low noise amplifier
LRIP	low rate initial production
MAC	medium access control
MAN	metropolitan area network
MAP	Mobile Access Protocol
MBOA	Multibank OFDM Alliance
MCPA	multi-carrier power amplifier
MDR	Multimode Digital Radio
MHz	megahertz
MIDS	Multifunctional Information Distribution System
MIMO	multiple inputs, multiple outputs
MMDS	Multipoint Microwave Distribution System
NA	North America
NAS	National Aerospace System
NAWC-AD	Naval Air Warfare Center0 Aircraft Division
NDL3	Voice Data Link 3
NET Adds	net subscriber additions
NEXCOM	Navy Exchange Service Command
NIC	network interface card
NLOS	non-line of sight
NMT	Nordic Mobile Telephone
NRL	Naval Research Lab
O&M	operations and maintenance
OEP	Operational Evolution Plan
OFDM	orthogonal frequency division multiplexing
OPEX	operating expenses
ORD	Operational Requirements Document
ORSC	Operational Requirements Subcommittee
PA	power amplifier
PAN	personal area network
PCS	personal communication services
PDA	personal digital assistant
PDC	Personal Digital Cellular

PHY	physical layer
PLMR	public land mobile radio
PODs	Point of Delivery
PSK	phase shift keying
PSWAC	Public Safety Wireless Advisory Committee
PTT	push-to-talk
QAM	quadrature amplitude modulation
QoS	quality of service
QPSK	quadrature phase shift key
R&D	research and development
RDTE	research, development, test, and evaluation
RF	radio frequency
RJ	regional jet
RNP	required navigation procedure
ROM	rough order of magnitude
SCA	Software Communication Architecture
SCR	software controlled radio
SDD	system development and demonstration
SDR	Software Defined Radio
SFDR	spurious free dynamic range
SIG	special interest group
Silab	Silicon Laboratories
SMS	short message system
SOCOM	Special Operations Command
SOW	statement of work
SPAWAR	Space and Naval Warfare Systems Command
SPAWARSYSCEN	SPAWAR System Center
T.O.	take-off (weight)
TACS	Total Access Communication Service
TDMA	Time Division Multiple Access
TETRA	TErrestrial Trunked RAdio
TI	Texas Instruments
TSP	telematics service providers
U-NII	Unlicensed National Information Infrastructure
USMC	United States Marine Corps
USR	ultimate software radio
UWB	ultra-wideband
VDL	voice data link
VGA	variable gain amplifier
VHDL	Very High-level Design Language
VoIP	voice-over-Internet-Protocol
VZW	Verizon Wireless
WAN	wide area network
WCDMA	wideband code division multiple access
WCS	wireless communication service
WiFi	wireless fidelity

WLAN	wireless local area network
WMAN	wireless metropolitan area network
WPAN	wireless personal area network
WRC	World Radio Conference (ITU)
WRG	wireless residential gateway
WSMR	White Sands Missile Range (NM)
YE	year-end
YOY	year-over-year