SDR Market Studies Overview

Over the past several years, the SDR Forum has asked Dr. James E. Gunn, a market research and technology consultant specializing in digital wireless communications and multimedia communication systems, to evaluate the marketplace for reconfigurable radios. This year, Jim has delivered four reports addressing cognitive radio, public safety radios, WiFi/WiMax, and telematics.

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

A summary of this year's market reports is provided below, the complete documents are available to Forum members on the members-only section of the Forum's website.

Telematics

"The Telematics Market" provides a comprehensive look at initiatives by the automotive industry and government transportation organizations to utilize computer and communications technology to enhance the public's automobile travel experiences. The highways of the world are becoming increasingly congested. Adding new roads and highways to relieve overcrowding is becoming a less attractive option and alternate approaches are needed. Telematics offers solutions by applying and integrating geolocation, communications, and information technologies into vehicle architecture and highway and road infrastructure. The promise of telematics is convenience, safety, and increased highway capacity without new construction.

A key trend in the automotive industry is the evolution to a more international market. Traditionally, the market has been dominated by the high tier, mature economies such as the United States, Western Europe, Japan, and Korea. Figure 1.1 shows vehicles per 1,000 population for the world and its regions. North America, dominated by the U.S. has had for many years by far the highest vehicle registrations and yearly new vehicle sales. However, over the next 5 years emerging economies, especially in Asia, are anticipated to create a very high percentage of Year-over-Year (YoY) growth. China and India are especially attracting significant industry interest.

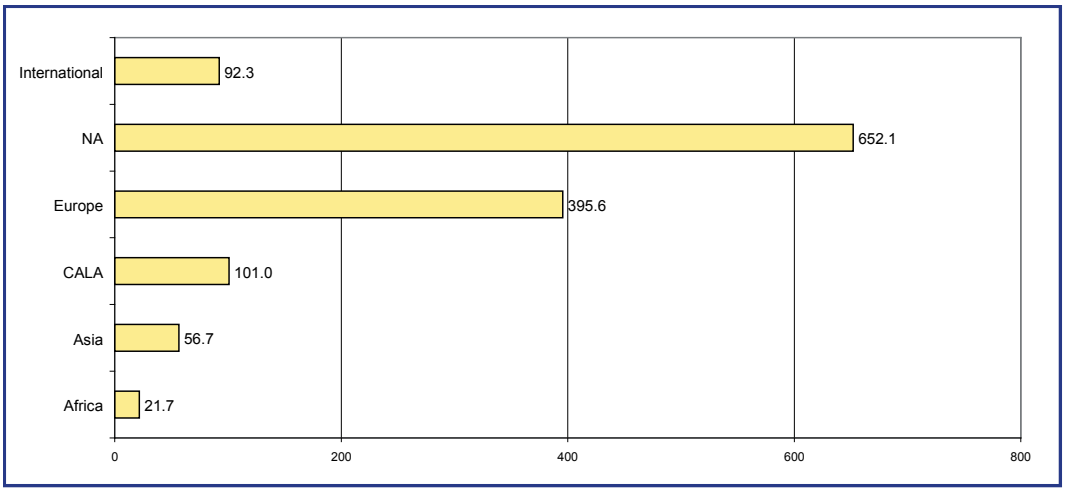

Figure 1.1 Vehicles in 2006 per 1000 Population by Region
(International = World, NA = North America, CALA = Central and Latin America)

In the past, U.S. automotive manufacturers dominated international vehicle production and sales, supported by a strong domestic market. However, for the first time in the first quarter of 2007, Toyota, headquartered in Japan, surpassed General Motors (GM) in market share of the international automobile and light vehicles sales. This was significantly impacted by the recent surge in gas prices, resulting in increased demand for more fuel efficient smaller passenger cars.

GM's OnStar is the recognized leading Telematics service provider, with services focused largely in US and Canadian markets. GM has indicated that all of the 2008 model year vehicles it sells in these markets will have OnStar devices as standard equipment. GM provides free OnStar service for one year for purchasers of OnStar equipped vehicles.

Internationally, the focus of Telematics markets and governments has differed. In the US and North America, the concern has been on safety and security. In Europe, the emphasis has been navigation and traffic information to address traffic congestion. In Asia, especially region leader Japan, the interest has been navigation and infotainment (information and entertainment). Nowhere, to date, have revenue producing Telematics services achieved significant commercial success. However, traffic information services, often free and sometimes with companion revenue services have been popular in some areas. An example is the Traffic Message Channel using FM sub-carriers service that has achieved wide spread deployment in Europe. On-board navigation units with map data bases and display are achieving popularity as an extra cost vehicle option in all markets.

Another Telematics initiative is Ford's "Sync" optional factory-installed communication and entertainment system that will be available in the fall of 2007. Ford collaborated with Microsoft and will use Microsoft software. Sync will provide drivers hands-free voice-activated control over their mobile phones and digital music players (e.g. iPod) via USB or Bluetooth interfaces. Initially, Sync will be available on various Ford, Lincoln, and Mercury models in North America. It conveniently connects drivers' phones and music players with their vehicle's in-car microphone and sound system. Using "brought-in" devices

offers interesting new and enhanced Telematics service opportunities, in more cost effective scenarios, as opposed to the historical preference for built-in devices.

Automobiles employ ECUs (Electronic Control Units) to more effectively and cost efficiently implement features for a variety of traditional mechanical, hydraulic, and electrical/electronic functions. A modern automobile typically has 20 to 80 ECUs. An emerging trend is to consolidate to fewer, more powerful ECUs and enhance functionality with inter-unit communication via vehicle buses. FlexRay is an emerging international automotive bus standard for this purpose.

Many automotive industry initiatives, collectively referred to as Intelligent Transportation Systems (ITS), are synergistic with Software Defined Radio. One is the AUTOSAR (AUTomotive Open System ARchitecture) initiative that targets open and standardized automotive software architecture. AUTOSAR is being jointly developed by automobile manufacturers, suppliers and tool developers. Another program is Vehicle Infrastructure Integration (VII). which involves collaboration between the automotive industry and governmental transportation organizations. The goal is to provide enhanced transportation information to the traveling public. A key component of VII is Digital Short Range Communication (DSRC). DSRC equipment and standards will provide Vehicle-to-Vehicle (V2V) and Vehicle-to-Infrastructure (V2I or sometimes V2R for road) communication. DSRC is an enhancement of the popular 802.11 WLAN standards to accommodate transportation applications and emerging licensed spectrum.

Many feel that Telematics has historically not achieved anticipated successes. However, the need for improved safety and security, improved travel information and navigation, coupled with synergies with the emerging "Any Where," "Any Time," and "Any Service" telecommunication initiatives appear poised to help enable and create a more favorable environment for Telematics successes.

Cognitive Radio

"The Cognitive Radio (CR) Market" provides a comprehensive look at an emerging technology that many industry stakeholders are identifying as an essential enabling technology to achieve future goals in key wireless industry market segments. These include commercial, public safety, and military segments. The key near-term goals are spectrum efficiency and spectrum availability to support emerging requirements and market opportunities. The longer-term goal is cognitive capability not only for spectrum efficiency, enhanced regulatory effectiveness, licensing, and spectrum management purposes, but to adaptively anticipate and accomodate user needs and efficiency. Most standards organizations regard CR and Software Defined Radio (SDR) as distinct but complementary, and mutually enabling, technologies.

Regulatory authorities focus on spectrum efficiency, availability, and management. A key issue for them is to provide supporting CR regulatory initiatives without favoring or impeding any particular approach. They largely support the idea that the competitive marketplace is the most appropriate venue to evolve CR technologies and initiatives, unencumbered by excessive unnecessarily constraining regulations. CR visionaries appear to have broader goals for CR that including cognitive or intelligent support

for market, regulatory, user application needs, as well as enabling the benefits of improved spectrum management and efficiencies.

The commercial markets for wireless technologies are clearly the largest markets for SDR and CR in terms of both units shipped and revenues. These commercial markets include: 1) The cellular market including Beyond 3G and Long Term Evolution (LTE), 2) The Wireless Local Area Network Market (WLAN, e.g., WiFi Market), and 3) The Broadband Wireless Access Market, (BWA, e.g. WiMAX). The key SDR and CR opportunities in the commercial sector are improved spectrum efficiency and availability and cognitive support for network and terminal configurations to support the emerging triple/quadruple play, multimedia, and multi-radio initiatives. SDR-centric and CR-centric features appear essential to success of these commercial wireless market goals. The key SDR and CR stakeholder opportunities, and issues, are technology insertion consistent with overall industry goals and initiatives. It should be noted that many commercial sector stakeholders have expressed opposition to involuntary spectrum sharing (i.e., involuntary unlicensed operations in cellular bands). Industry prefers secondary market initiatives, where access is under operator business and technical parameters and control. Secondary market initiatives provide significant CR opportunities.

The SDR Forum's Public Safety SIG (Special Interest Group) has initiated ongoing activities to develop use cases for cognitive radio applications in public safety. The key public safety application for SDR and CR is interoperability. In many disaster events communication may not be available due to infrastructure damage. A key requirement for CR technologies is to reconfigure responders' radios as an ad hoc extension to the existing network to allow transmissions relayed from a disaster site along a network of individual responder radios providing access to the main radio network.

The defense community has been the leader of SDR and CR initiatives. Although international interests and initiatives exist, the military leader of SDR and CR initiatives has been the U.S. Department of Defense in its DARPA XG (neXt Generation) program, and in other related programs. Military programs have a focus on Mobile Adhoc NETworks (MANETs) that require no supporting infrastructure. The Tactical Edge has various types of MANETs that are formed to support tactical operations using waveforms appropriate to units and missions. MANETs are deployed to support fluid wireless tactical networking operational requirements for voice and data waveforms based on Internet Protocol (IP) network technologies.

Two regulatory leaders of SDR and CR initiatives have been the U.S. Federal Communications Commission (FCC) and the United Kingdom Office of Communication (Ofcom). Some of the key recent releases by the FCC concerning CR and SDR initiatives include new SDR rules/regulations facilitating CR, unlicensed operations in TV bands, a CR spectrum sharing test-bed, and secondary licensing. Ofcom representatives have stated that "Research suggests that if licenses were more flexible this could increase the value the UK generates from the radio spectrum by nearly €1bn". In pursuit of this Ofcom has funded several studies on SDR and CR over the last several years. In a study report on CR released in February 2007 by Ofcom, it is stated that "two problems are identified to achieving full CR. The first is making a truly cognitive device with the ability to intelligently make decision based on its own situational awareness. The second is the evolution of SDR technologies to enable reconfigurability."

A European CR program is the End-to-End Reconfigurability (E2R) project sponsored by the European Commission. The program goals are to realize the full benefits of the diversity within the radio eco-space, composed of wide range of systems such as cellular, fixed, wireless local area and broadcast. The key objective of the E2R project is to devise, develop, trial and showcase architectural design of reconfigurable devices and supporting system functions to offer an extensive set of operational choices to the users, application and service providers, operators, and regulators in the context of heterogeneous systems. The program is a CR project for commercial operator initiatives with extensive business model analyses.

Public Safety

A number of recent events, including 9/11 and Hurricane Katrina, have brought considerable attention to the need for enhanced Public Safety (PS) communications.

It is a very fragmented market, consisting of a multitude of federal, state, and local agencies, city, county, and regional jurisdictions, and police, fire, and emergency medical functions.

Communications interoperability, the ability for public safety officials of independent organizations to communicate in real-time, has received increased recent attention. The National Task Force on Interoperability identified five issues that are challenges for interoperability of public safety communication systems:

1. Incompatible and aging communication equipment
2. Limited and fragmented budget cycles and funding
3. Limited and fragmented planning and coordination
4. Limited and fragmented spectrum
5. Limited equipments standards.

Many public safety stakeholders indicate that they experience operability problems in use of their communication systems even for intended organic organizational uses, due largely to functional inadequacies and these five issues, especially aging equipment.

Sufficient spectrum has been an ongoing issue for public safety for many years. APCO International, has provided information on spectrum availability and deployments that is presented in Figure 3.1. The left pie chart depicts total spectrum deployments by band and illustrates that VHF high band is by far the most deployed public safety band in the US. The right pie chart depicts allocated spectrum by band. Historically, the total amount of spectrum for public safety in the U.S. has been 26.1 MHz in the VHF, UHF, and the 800 MHz bands plus a few other little used bands. The 800 MHz band has experienced significant interference problems and is being re-banded to move public safety users from fragmented assignments to frequencies better separated from other users. Sprint Nextel will be paying for the relocation costs. New public safety 700 MHz band allocations (not shown in Figure 3.1) that total 24 MHz will almost double public safety allocations. The 700 MHz frequencies will become available nationwide in February 2009.

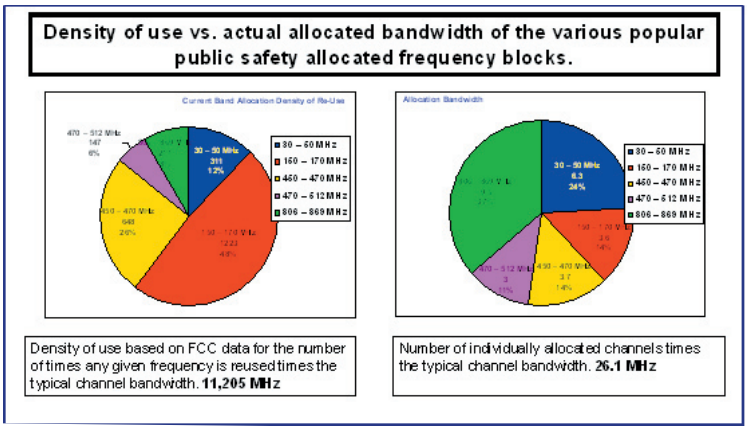

Figure 3.1 Public Safety Spectrum Allocation Bandwidth and Density of Re-Use
(Source: Ron Haraseth, Director, Automated Frequency Coordination, APCO International)

To address the standards problems the first Project 25 (P25) standard was published in 1995 and was the Common Air Interface (CAI). Although other standards have been needed, the CAI has been the only available standard through early 2006. In the first half of 2006, announcements have been made that additional needed standards have been ratified that include the Inter-RF Subsystem Interface (ISSI), the Fixed/Base Station System Interface (FSSI), and the Console Subsystem Interface (CSSI). The current P25 standard, referred to as phase 1, provides a FDMA (single channel per carrier) that provides both analog and digital voice in 12.5 kHz, trunking, encryption, Over-The-Air Rekeying (OTAR), and P25 data standards. A key U.S. broadband activity is the Mobility for Emergency and Safety Applications (MESA) initiative, which is an international partnership between the U.S.-led TIA and the European Telecommunication Standards Institute (ETSI). In the US the targeted spectrum is in the recently allocated 4.9 GHz band.

Public safety officials from several states were interviewed to get their views on the market for SDRs in the public safety community. The summary conclusions from these interviews are:

- Many states are planning, or deploying, state-wide shared communication systems. Local or federal users can use a shared system, typically paying a fee, buying their own terminals, and funding any special infrastructure requirements.
- The slowness of P25 and related standards development has been an issue.
- There have been continuing problems achieving multi-vendor interoperability in public safety communications. P25 is viewed as a positive emerging solution for interoperability as well as re-farming and narrowband requirements, and potentially lower costs due to a more competitive market.
- Funding is a significant problem for most states to upgrade their public safety communication systems. The economic downturn of the early 2000's exacerbated the problem, although the current situation is improving. Many states have completed planning projects, but are unable to fund deployments.
- The FCC mandated transition to 12.5 kHz (and eventually 6.25 kHz) channel width is an issue, with pushed out dates.

- VHF is the most used public safety band in the U.S., and most of those interviewed would like to continue its use in low density rural population areas where better propagation supports lower cost deployments. 700 MHz and 800 MHz are needed for more densely populated urban areas requiring more capacity and less range and coverage per site.

Due to the fragmented nature of the market, market estimates for the U.S. public safety market have been elusive. Table 3.1 presents a summary estimate of U.S. public safety personnel, department, and agencies.

960,000 Firefighters 830,000 EMS Personnel 710,000 Law Enforcement Officers	28,495 Fire Departments[1] 5,841 EMS Departments[1] 27,496 Law Enforcement Agencies[1]	25,763 Local Agencies [1] 6,396 State Agencies[1] 2,967 Federal Agencies[1]

[1] Source: www.SafetySource.com

Table 3.1 U.S. Summary of Public Safety personnel, departments, and agencies
(Source: 'Interoperability Standards" Presentation, by Dereck Orr (NIST) and Nyla Houser (SAFECOM Support), at Project MESA Meeting, October 25, 2005)

Our market forecast for the U.S. public safety market is based on a top down analysis on a state-by-state basis to estimate the number of sites per state for infrastructure. The FBI's "Crime in United States" report was used to develop estimates by state for personnel counts, and the number of portable and mobile terminals deployed. We developed estimates of loaded costs for a representative state-wide shared public sector communication system gleaned from information and sources obtained in state public safety communication official interviews. We then applied these results to estimate costs to deploy a public sector communication system intended to serve all public safety agencies in each of the 50 states. U.S. totals are:

- $46.5 billion, approximately half for terminals and half for infrastructure
- The estimate is total replacement cost that would be adjusted for current or planned usable deployments and would undoubtedly be spread over many years.

State agency only estimates reviewed were skewed with much higher infrastructure costs than terminal costs, which illustrate potential savings with shared infrastructure as opposed to current frequent practice of independent agency deployments.

WiFi, WiMax, and Beyond 3G

Broadband, including wireline and wireless initiatives, appears poised to provide the next significant telecom growth opportunities. Users, in order to competitively participate in society, want seamless access to emerging triple play (voice, data/web, and video) services in all their wireline and wireless subscriptions.

Figure 4.1 presents historical key telecommunication indicators including telephone line subscriptions, cellular subscriptions, Internet users and subscriptions, and broadband subscriptions. The figure illustrates that historical telephone (voice) subscriptions are relatively flat and future growth will focus on cellular and broadband. Broadband includes digital subscriber link (DSL), cable, FTTx (e.g., fiber-to-the-node, premise, etc.), and broadband wireless access (BWA). Internationally, wireline and wireless operators are indicating intentions to evolve their legacy circuit-switched networks to converged "all IP" multimedia networks. Many already have evolutions in progress.

Review of international broadband data, press reports, industry reports, and industry interviews indicates that BWA is an emerging opportunity with essentially insignificant legacy deployment numbers. Wi-Fi® is the significant exception. In reality, cost-effective technologies are only beginning to emerge to support most BWA opportunities. The BWA opportunity appears as if it will experience interesting growth in the 2007–2010 time frame, and have most significant growth ramps beyond 2010. The BWA segments addressed in this report are Wireless Fidelity (Wi-Fi, or wireless local area network (WLAN)); Worldwide Interoperability for Microwave Access (WiMAX, or wireless metropolitan area network (WMAN)); and Beyond 3G/4G (or wireless wide area network, WWAN).

Table 4.1 presents an overview of BWA market segments including Wi-Fi, WiMAX, and cellular's Beyond 3G/4G initiatives. The table identifies each segments current status and anticipated segment evolution.

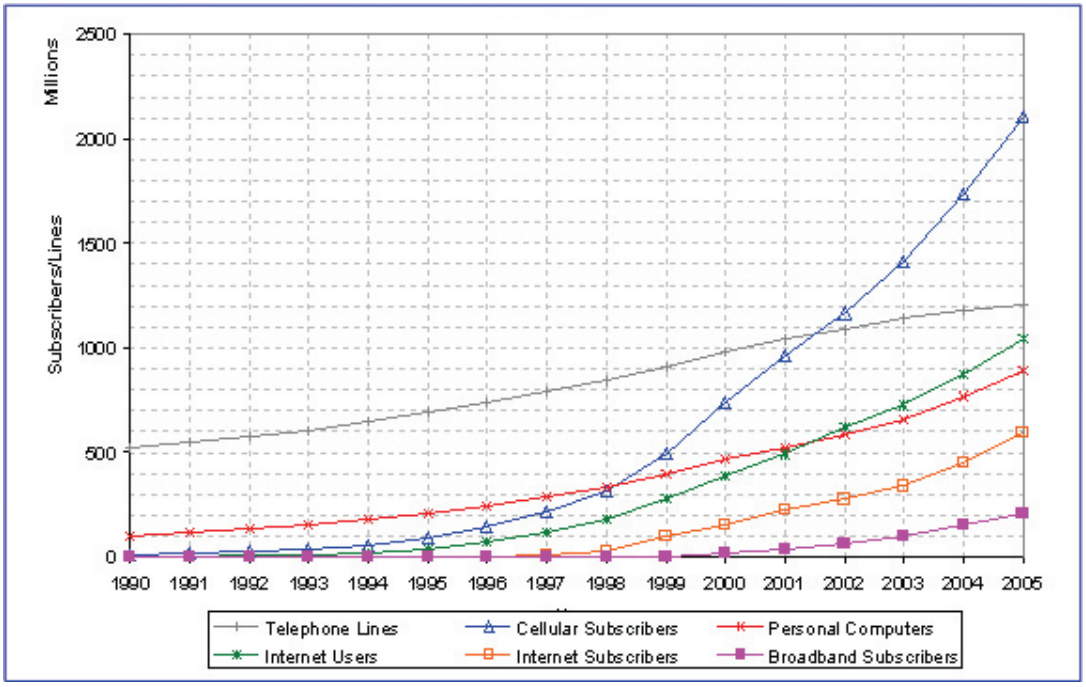

Figure 4.1 Historical Telecommunication Indicators (Source: ITU, DSL Forum, and Author research)

Table 4.1 BWA Market Segments and Status

BWA Segment	Segment Status	Anticipated Segment Evolution
WLAN, 802.11, Wi-Fi	Current notebook computer successes. personal digital assistant (PDA) and cell phone applications are emerging.	Anticipate consumer (digital television (DTV), games, home network), health care, and other emerging successes.
WMAN, 802.16, WiMAX	Some current pre-standard deployments, expect in 2008 some initial WiMAX fixed wireless compliant deployments	Poised to potentially become international BWA standard. Mobile standard compliant deployments anticipated in 2008–2010
Cellular, Beyond 3G/4G, Third Generation Partnership Programs (3GPP and 3GPP2)	High-Speed Downlink Packet Access (HSDPA), High-Speed Uplink Packet Access (HSUPA) in 5 MHz Wideband Code Division Multiple Access (WCDMA) bands	Orthogonal Frequency Division Multiplexing (OFDM) standards in up to 20 MHz anticipated in 2008-2010 time frame.

(Source: Author research)

Multiradio is a hot industry trend in cellular and BWA segments. It will be important in many segments, perhaps also beneficially impacting military, public safety, telematics, avionics, and other segments. Multiradio refers to inclusion of multiple radio standards (or waveforms) on a single mobile, portable, or infrastructure platform. Multiradio envisions that two or more radio links will operate simultaneously. An example would be a wide area (WWAN) broadband cellular link to a cell phone and a simultaneous WLAN Wi-Fi link to an Internet Protocol television (IPTV) display or a notebook or desktop computer. Global positioning system (GPS) links for location services will typically operate in parallel with other waveforms. Thus, software defined radio (SDR) needs to address both waveform selection (traditional SDR focus) as well as simultaneous operations. Although some variability of opinion exists, commercial industry sources indicate that up to 11 radios might emerge in future cell phones.

Wi-Fi, WiMAX, and Beyond 3G all have initiatives to utilize OFDM in their evolving standards. OFDM appears to be the modulation technology offering superior broadband high signal-to-noise ratio (SNR) performance.

Key emerging market requirements in all BWA include: (1) higher bit rates; (2) quality of service – enabling real-time and multimedia services such as voice over Internet Protocol (VoIP), video over IP (VioIP), multi-player gaming; (3) security; and (4) mobility. Cellular-like mobility in Wi-Fi and WiMAX standards and deployments will require time to evolve competitive functionality.

SDR opportunities appear significant in emerging BWA and ongoing cellular initiatives. SDR should be a key enabler to achieve multiradio, OFDM, and legacy waveform capabilities, as well as to address key emerging market requirements.

This report provides a comprehensive look at BWA which appears to potentially be the next significant

commercial wireless growth market opportunity. Subscription forecasts as well as terminal, consumer premise equipment (CPE), and infrastructure data are addressed in this report.