Software-Defined Radio

White Paper

A Technology Overview

August 2002

Wipro Technologies

Innovative Solutions, Quality Leadership

Executive Summary

Software-Defined Radio (SDR) is a rapidly evolving technology that is receiving enormous recognition and generating widespread interest in the telecommunication industry. Over the last few years, analog radio systems are being replaced by digital radio systems for various radio applications in military, civilian and commercial spaces. In addition to this, programmable hardware modules are increasingly being used in digital radio systems at different functional levels. SDR technology aims to take advantage of these programmable hardware modules to build an open-architecture based radio system software.

SDR technology facilitates implementation of some of the functional modules in a radio system such as modulation/demodulation, signal generation, coding and link-layer protocols in software. This helps in building reconfigurable software radio systems where dynamic selection of parameters for each of the above-mentioned functional modules is possible. A complete hardware based radio system has limited utility since parameters for each of the functional modules are fixed. A radio system built using SDR technology extends the utility of the system for a wide range of applications that use different link-layer protocols and modulation/demodulation techniques.

Commercial wireless communication industry is currently facing problems due to constant evolution of link-layer protocol standards (2.5G, 3G, and 4G), existence of incompatible wireless network technologies in different countries inhibiting deployment of global roaming facilities and problems in rolling-out new services/features due to wide-spread presence of legacy subscriber handsets.

SDR technology promises to solve these problems by implementing the radio functionality as software modules running on a generic hardware platform. Further, multiple software modules implementing different standards can be present in the radio system. The system can take up different personalities depending on the software module being used. Also, the software modules that implement new services/features can be downloaded over-the-air onto the handsets. This kind of flexibility offered by SDR systems helps in dealing with problems due to differing standards and issues related to deployment of new services/features.

Introduction

Software-Defined Radio (SDR) Forum [www.sdrforum.org] defines SDR technology as "radios that 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 & evolving standards over a broad frequency range."

In a nutshell, Software-Defined Radio (SDR) refers to the technology wherein software modules running on a generic hardware platform consisting of DSPs and general purpose microprocessors are used to implement radio functions such as generation of transmitted signal (modulation) at transmitter and tuning/detection of received radio signal (demodulation) at receiver.

SDR technology can be used to implement military, commercial and civilian radio applications. A wide range of radio applications like Bluetooth, WLAN, GPS, Radar, WCDMA, GPRS, etc. can be implemented using SDR technology. This whitepaper provides an overview of generic SDR features and its architecture with a special focus on the benefits it offers in commercial wireless communication domain.

Motivation

SDR has generated tremendous interest in the wireless communication industry for the wide-ranging economic and deployment benefits it offers. Following are some of the problems faced by the wireless communication industry due to implementation of wireless networking infrastructure equipment and terminals completely in hardware:

- Commercial wireless network standards are continuously evolving from 2G to 2.5G/3G and then further onto 4G. Each generation of networks differ significantly in link-layer protocol standards causing problems to subscribers, wireless network operators and equipment vendors. Subscribers are forced to buy new handsets whenever a new generation of network standards is deployed. Wireless network operators face problems during migration of the network from one generation to next due to presence of large number of subscribers using legacy handsets that may be incompatible with newer generation network.

The network operators also need to incur high equipment costs when migrating from one generation to next. Equipment vendors face problems in rolling out newer generation equipment due to short time-to-market requirements.

- The air interface and link-layer protocols differ across various geographies (for e.g., European wireless networks are predominantly GSM/TDMA based while in USA the wireless networks are predominantly IS94/CDMA based). This problem has inhibited the deployment of global roaming facilities causing great inconvenience to subscribers who travel frequently from one continent to another. Handset vendors face problems in building viable multi-mode handsets due to high cost and bulky nature of such handsets.

- Wireless network operators face deployment issues while rolling-out new services/features to realize new revenue-streams since this may require large-scale customizations on subscribers' handsets.

SDR technology enables implementation of radio functions in networking infrastructure equipment and subscriber terminals as software modules running on a generic hardware platform. This significantly eases migration of networks from one generation to another since the migration would involve only a software upgrade. Further, since the radio functions are implemented as software modules, multiple software modules that implement different standards can co-exist in the equipment and handsets. An appropriate software module can be chosen to run (either explicitly by the user or implicitly by the network) depending on the network requirements. This helps in building multi-mode handsets and equipment resulting in ubiquitous connectivity irrespective of underlying network technology used.

SDR technology supports over-the-air upload of software modules to subscriber handsets. This helps both network operators as well as handset manufacturers. Network operators can perform mass customizations on subscriber's handsets by just uploading appropriate software modules resulting in faster deployment of new services. Manufacturers can perform remote diagnostics and provide defect fixes by just uploading a newer version of the software module to consumers' handsets as well as network infrastructure equipment.

However, SDR technology has some drawbacks like higher power consumption, higher processing power (MIPS) requirement and higher initial costs. SDR technology may not be suitable for all kinds of radio equipment due to these factors.

Hence these factors should be carefully considered before using SDR technology in place of a complete hardware solution. For e.g., SDR technology may not be appropriate in pagers while it may offer great benefits when used to implement base-stations.

Features

Following are the key features of SDR technology:

- **Reconfigurability:** SDR allows co-existence of multiple software modules implementing different standards on the same system allowing dynamic configuration of the system by just selecting the appropriate software module to run. This dynamic configuration is possible both in handsets as well as infrastructure equipment. The wireless network infrastructure can reconfigure itself to subscriber's handset type or the subscriber's handset can reconfigure itself to network type. SDR technology facilitates implementation of future-proof, multi-service, multi-mode, multi-band, multi-standard terminals and infrastructure equipment.

- **Ubiquitous Connectivity:** SDR enables implementation of air interface standards as software modules and multiple instances of such modules that implement different standards can co-exist in infrastructure equipment and handsets. This helps in realizing global roaming facility. If the terminal is incompatible with the network technology in a particular region, an appropriate software module needs to be installed onto the handset (possibly over-the-air) resulting in seamless network access across various geographies. Further, if the handset used by the subscriber is a legacy handset, the infrastructure equipment can use a software module implementing the older standard to communicate with the handset.

- **Interoperability**: SDR facilitates implementation of open architecture radio systems. End-users can seamlessly use innovative third-party applications on their handsets as in a PC system. This enhances the appeal and utility of the handsets.

Architecture

This section gives a brief overview of a basic conventional digital radio system and then explains how SDR technology can be used to implement radio functions in software. It then explains the software architecture of SDR.

The various functional blocks in a generic digital radio transceiver (transmitter/receiver) system is depicted in figure 1.

The digital radio system consists of three main functional blocks: RF section, IF section and baseband section. The RF section consists of essentially analog hardware modules while IF and baseband sections contain digital hardware modules.

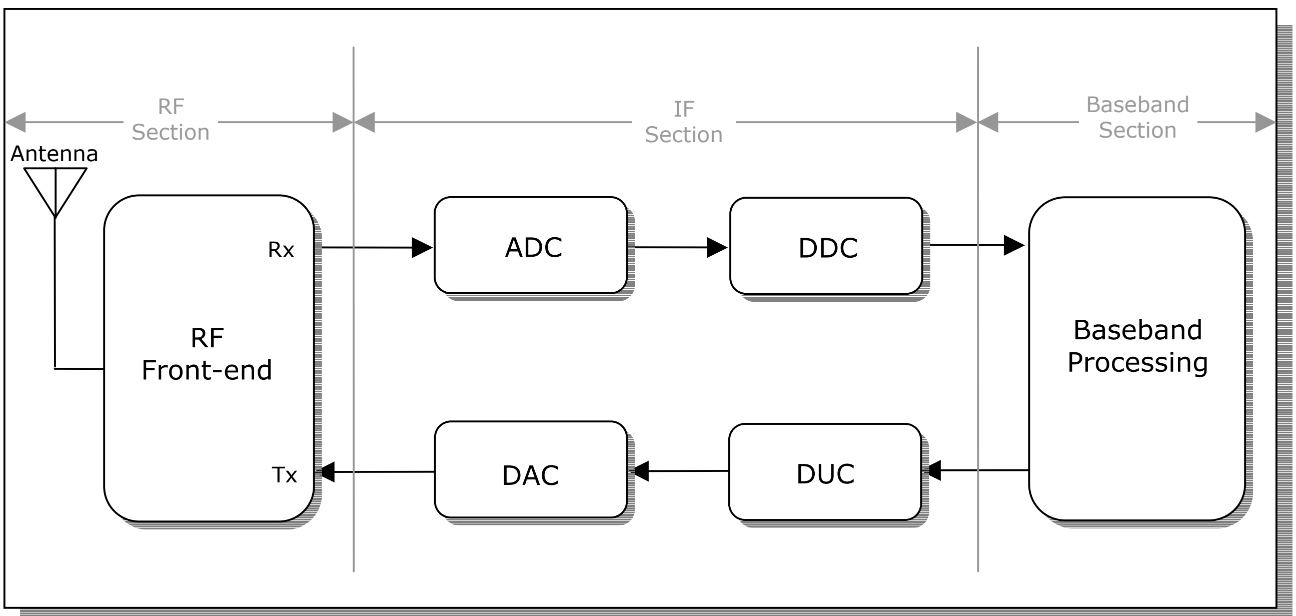

Figure 1: Block diagram of a generic digital transceiver

The RF section (also called as RF front-end) is responsible for transmitting/receiving the radio frequency (RF) signal from the antenna via a coupler and converting the RF signal to an intermediate frequency (IF) signal. The RF front-end on the receive path performs RF amplification and analog down conversion from RF to IF. On the transmit path, RF front-end performs analog up conversion and RF power amplification.

The ADC/DAC blocks perform analog-to-digital conversion (on receive path) and digital-to-analog conversion (on transmit path), respectively. ADC/DAC blocks interface between the analog and digital sections of the radio system. DDC/DUC blocks perform digital-down-conversion (on receive path) and digital-up-conversion (on transmit path), respectively. DUC/DDC blocks essentially perform *modem* operations, i.e., modulation of the signal on transmit path and demodulation (also called digital tuning) of the signal on receive path.

The baseband section performs baseband operations (connection setup, equalization, frequency hopping, timing recovery, correlation) and also implements the link layer protocol (layer 2 protocol in OSI protocol model).

The DDC/DUC and baseband processing operations require large computing power and these modules are generally implemented using ASICs or stock DSPs. Implementation of the digital sections using ASICs results in fixed-function digital radio systems. If DSPs are used for baseband processing, a programmable digital radio (PDR) system can be realized. In other words, in a PDR system baseband operations and link layer protocols are implemented in software. The DDC/DUC functionality in a PDR system is implemented using ASICs. The limitation of this system is that any change made to the RF section of the system will impact the DDC/DUC operations and will require non-trivial changes to be made in DDC/DUC ASICs.

A software-defined radio (SDR) system is one in which the baseband processing as well as DDC/DUC modules are programmable. Availability of smart antennas, wideband RF front-end, wideband ADC/DAC technologies and ever increasing processing capacity (MIPS) of DSPs and general-purpose microprocessors have fostered the development of multi-band, multi-standard, multi-mode radio systems using SDR technology. In an SDR system, the link-layer protocols and modulation/demodulation operations are implemented in software.

If the programmability is further extended to the RF section (i.e., performing analog-to-digital conversion and vice-versa right at the antenna) an ideal software radio systems that support programmable RF bands can be implemented. However, the current state-of-the-art ADC/DAC devices cannot support the digital bandwidth, dynamic range and sampling rate required to implement this in a commercially viable manner.

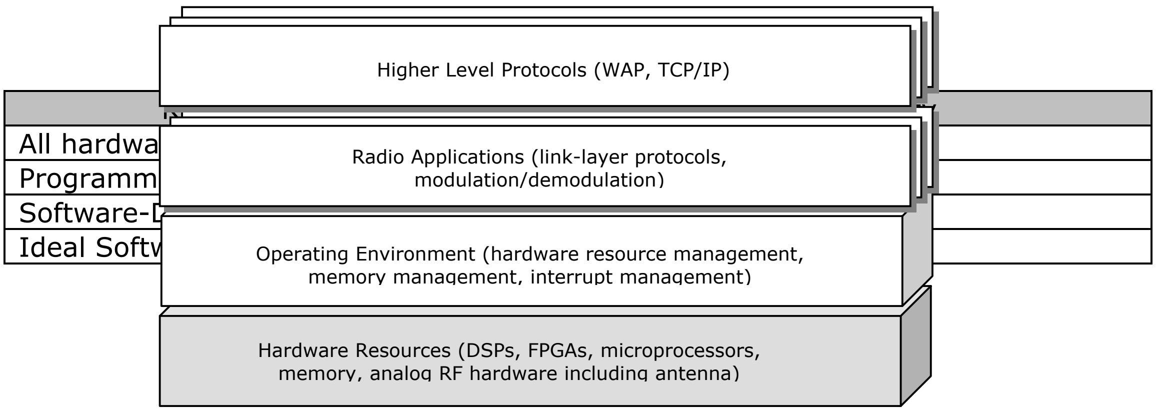

Figure 2: Software Architecture of SDR

Table 1 summarizes programmability levels of different digital radio systems.

Figure 2 illustrates the architecture of software components in a typical SDR system. The system uses a generic hardware platform with programmable modules (DSPs, FPGAs, microprocessors) and analog RF modules. The operating environment performs hardware resource management activities like allocation of hardware resources to different applications, memory management, interrupt servicing and providing a consistent interface to hardware modules for use by applications. In SDR system, the software modules that implement link-layer protocols and modulation/demodulation operations are called radio applications and these applications provide link-layer services to higher layer communication protocols such as WAP and TCP/IP.

Conclusion

Current market drivers such as future-proof equipment, seamless integration of new services, multi-mode equipment and over-the-air feature insertion in commercial wireless networking industry have resulted in widespread interest in SDR technology. The technology can be used to implement wireless network infrastructure equipment as well as wireless handsets, PDAs, wireless modems and other end-user devices. However, factors like higher power consumption, increased complexity of software and possibly higher initial cost of equipment vis-à-vis the benefits offered by the technology should be carefully considered before using SDR technology to build a radio system.

Summarizing, SDR is a promising technology that facilitates development of multi-band, multi-service, multi-standard, multi-feature consumer handsets and future-proof network infrastructure equipment.

Acronyms

ADC	Analog-to-Digital Conversion
ASIC	Application Specific Integrated Circuit
CDMA	Code-Division Multiple Access
DAC	Digital-to-Analog Conversion
DDC	Digital Down Conversion
DSP	Digital Signal Processor
DUC	Digital Up Conversion
FPGA	Field Programmable Gate Array
GPRS	General Packet Radio Services
GPS	Global Positioning System
GSM	Global System for Mobile communication
IP	Internet Protocol
MIPS	Million Instructions Per Second
PC	Personal Computer
PDA	Personal Digital Assistant
PDR	Programmable Digital Radio
RF	Radio Frequency
Rx	Receive
SDR	Software Defined Radio
TCP	Transmission Control Protocol
TDMA	Time Division Multiple Access
Tx	Transmit
WAP	Wireless Application Protocol
WCDMA	Wideband Code-Division Multiple Access
WLAN	Wireless Local Area Network

About Wipro

Wipro is the first PCMM Level 5 and SEI CMMi Level 5 certified IT Services Company globally. Wipro provides comprehensive IT solutions and services (including systems integration, IS outsourcing, package implementation, software application development and maintenance) and Research & Development services (hardware and software design, development and implementation) to corporations globally.

Wipro's unique value proposition is further delivered through our pioneering Offshore Outsourcing Model and stringent Quality Processes of SEI and Six Sigma.

Wipro and SDR Technology

Development of a complete SDR system requires multi-disciplinary skill-sets in areas such as RF design, firmware, ASIC design, DSP software, Operating Systems, security algorithms, data communication protocols and more. Wipro has domain-expertise in each of these areas and can provide design and implementation services for development of SDR systems. Further, Wipro is in the process of developing re-usable IP blocks for use in SDR systems.

For further information and more details about our Services, e-mail us at info@wipro.com or visit us at http://www.wipro.com/dsp.

America

Wipro Technologies
1995 El Camino Real, Suite 200
Santa Clara, CA 95050, USA
Phone: +1 (408) 2496345
Fax: +1 (408) 6157174

Europe

Wipro Technologies
European Headquarters
137, Euston Road,
London NW12AA, UK
Phone: + (44) 020 73870606
Fax: + (44) 020 73870605

Japan

Wipro Japan K. K.
Saint Paul Bldg, 5-14-11
Higashi-Oi, Shinagawa-Ku,
Tokyo 140-0011, Japan
Phone: +(81) 354627921
Fax: +(81) 354627922

India - Worldwide Headquarters

Wipro Technologies
Doddakannelli, Sarjapur Road
Bangalore-560 035, India
Phone: + (91) 808440011 -15
Fax: +(91) 808440254

Web: www.wipro.com
E-mail: info@wipro.com
To access more white-papers, please visit http://www.wipro.com/shortcuts/downloads.htm