Reconfiguring to Meet Demands: Software-Defined Radio

Dean Nathans
Office of Secretary of Defense

Dr. Donald R. Stephens
Joint Program Executive Office

A Software Defined Radio (SDR) allows a single hardware platform to be reconfigurable so that it can accommodate multiple radio waveforms and be easily upgraded with software changes. The Joint Tactical Radio System (JTRS) is the Department of Defense's (DoD) solution for a family of tactical SDRs based on common open standards and architectures. JTRS accommodates legacy and new mobile ad hoc networking waveforms. Additionally, military Satellite Communication, and Intelligence, Surveillance, and Reconnaissance (ISR) terminals are migrating to SDRs to enable consolidation of multiple legacy systems into single multi-band configurations. This article describes current military SDR programs, their challenges, and the way ahead for the DoD.

Current communications systems have evolved to meet service specific and mission specific requirements. Specialized functionality has resulted in limitations in communicating from one system to another resulting in interoperability issues. More recent DoD systems such as Link-16[1] have made large strides in providing more capable and interoperable data links; however, the DoD must now evolve to acquire a family of high capacity, interoperable, networked, and affordable radio systems as part of the transport layer of the Global Information Grid (GIG).

The appeal of SDRs is the ability to handle multiple radio communication protocols on a single hardware platform by means of programmable hardware controlled by software. From a DoD perspective, the reprogrammable radio can store and run multiple waveforms. Rather than developing many different radio systems operating to different standards, SDRs enable the DoD to have a family of interoperable radios based on common waveforms, standards, and interfaces.

For the DoD, the impetus for SDRs is to significantly reduce the number of different radios and waveforms in the inventory. Hand in hand with these reductions is the elimination of proprietary or unique implementations, eliminating interoperability issues. Costs to the DoD for radio systems are also significantly reduced, and SDRs contribute to net-centricity by enabling newer high-rate, networked waveforms.

DoD SDR Programs

Trying to develop a reduced set of radios and waveforms for the DoD generates challenges in itself as the family must accommodate numerous requirements from each service. Software flexibility provides the ability for operation of many waveforms on single hardware platforms; however, there are still many additional unique military challenges. The radios must be useful in air, sea, and ground applications with different size, weight, power, environmental, and threat needs.

To develop a family of radios useful to all services, the Joint Tactical Radio System (JTRS) Program was initiated in 1997. Initially, waveforms and cryptographic applications were controlled by the JTRS Joint Program Office, and JTRS hardware development was assigned to service leads. The DoD recently restructured the program so that all JTRS products would be under the control of the Joint Program Executive Office JTRS (JPEO JTRS). JTRS programs currently include Ground; Airborne, Maritime, and Fixed Site (AMF); and Network Enterprise Domains (NED). The ground domain includes ground vehicular, Manpack radio, handheld, and special applications. The AMF domain includes standard airborne, Multifunctional Information Distribution System – JTRS, and 19-inch rack applications. The NED includes the waveforms, gateways, and common networking services products used by the other domains. Included within the NED programs are new networking waveforms based on Internet Protocol (IP) standards that allow interoperability and include Mobile Ad-Hoc Network (MANET) protocols for operation over bandwidth constrained and potentially intermittent wireless links.

> *"The JPEO is developing and implementing a common infrastructure across all domains to define a host environment that ensures a waveform porting among JTR sets."*

The JPEO is developing and implementing a common infrastructure across all domains to define a host environment that ensures waveform porting among JTR sets. The hardware domains have been partitioned to allow common core hardware and software in each domain, which is then tailored with additional modules to apply to its unique applications. To ensure waveforms are portable and perform as intended, they go through a rigorous certification process under the auspices of the JPEO.

The foundation for the JTRS family of radios is the Software Communications Architecture (SCA), Figure 1 [1]. It is simultaneously an architecture framework, specification, and guidance document for software defined radios allowing convenient reuse, update, or replacement of software. The JPEO JTRS currently has over 3.5 million source lines of SCA compliant code in its Information Repository (IR) [2] developed by the JTRS community. When a new JTRS program requires software, the program developers download it from the IR, which enhances interoperability of JTR sets, since all instantiations are based upon the same software.

To further support waveform portability and code reuse, the SCA specifies operating system Application Programming Interfaces (APIs) that must be provided by the JTR set's Real Time Operating System (RTOS). Labeled the Application Environment Profile (AEP) in Figure 1, the SCA specifies a subset of

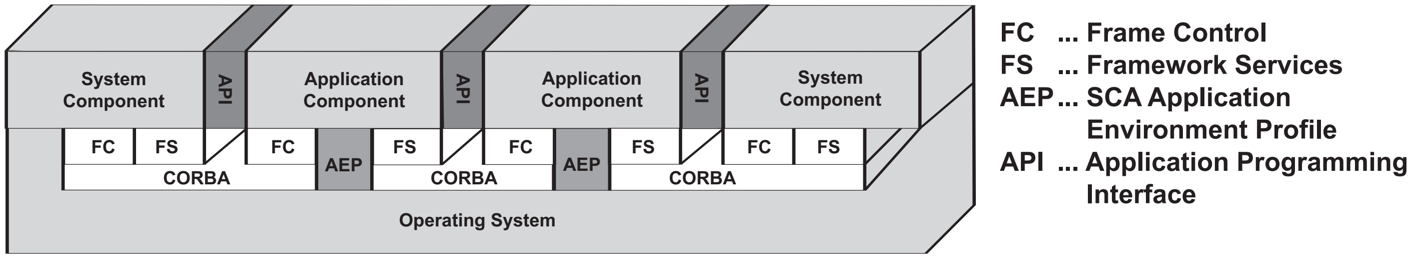


Figure 1: *SCA Component Architecture*

the Portable Operating System Interface that every JTR set must support and to which each waveform is limited. In combination with the defined Common Object Request Broker Architecture middleware, the SCA guarantees that every SCA-compliant object can be executed upon any JTR set.

Originally, JTRS was envisioned to cover the entire radio spectrum. However, during the JTRS restructure, the DoD determined that satellite communications and line-of-sight radios operating in the Super High Frequency (SHF) and the Extremely High Frequency (EHF) spectrum have a large enough set of distinct features and requirements to keep them separate from the JTRS Program. One of the largest differences is the high throughput demands of some of the SHF and EHF waveforms. In addition to JTRS, the DoD has continued with a set of multiband SHF/EHF terminal SDR programs led by the services. These SHF/EHF programs invoke the JTRS SCA; additional collaborative possibilities, including a common reference architecture, are being pursued.

SHF/EHF Programs include the following:

- Air Force Family of Advanced Beyond Line-of-Sight Terminals.
- Army High Capacity Communications Capability.
- Army Joint Command, Control, Computers ISR (JC4ISR).
- Multi-Role Tactical Common Data Link Demonstration Program.
- Navy Multi-band Terminal.

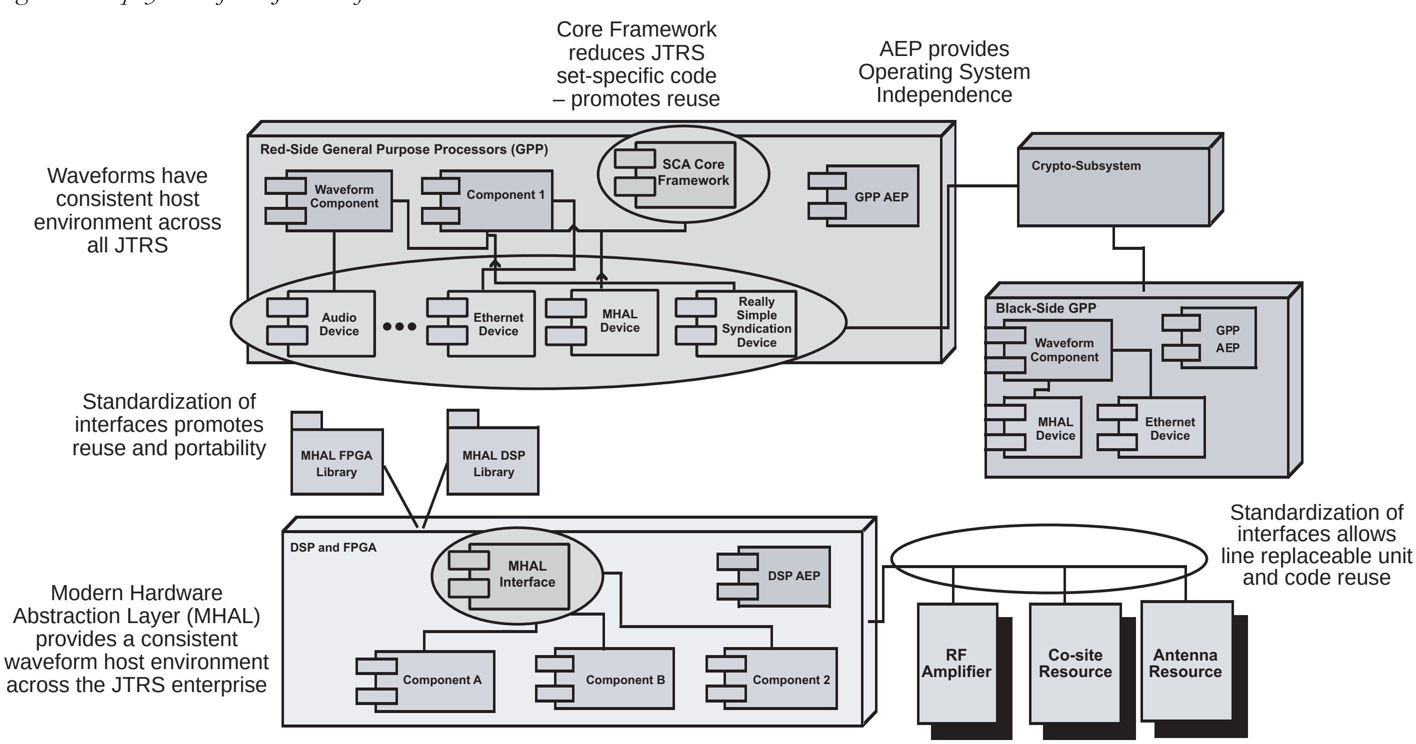
JTRS Enterprise Architecture

JTRS is a family of radios which spans across multi-channel, vehicle-mounted radios to disposable, unattended ground sensors. Although early expectations might have been for one software suite that could be installed into any radio, it is not practical to deploy radios with capabilities exceeding their missions. Individual JTR sets are expected to reuse as much host environment software as possible from the JTRS information repository, but are permitted to integrate unique implementations of devices and services as long as the JTRS APIs are supported. The set provider's primary responsibility is to meet mission requirements. Waveform software is expected to be largely consistent across all JTR sets.

To achieve interoperability and software reuse, the JTR set providers are required to provide set-to-waveform interfaces that are consistent across the JTRS enterprise [3]. The JTR set implementations of components may be unique, but the exposed interfaces to the waveforms are standardized. Figure 2 shows the deployment of the JTRS infrastructure.

The infrastructure defines the host environment for all JTRS software components. A software component in an unattended ground sensor has exactly the same operating system functions, the same middleware communication, and the same hardware interfaces as a software component deployed in a multi-

Figure 2: *Deployment of the JTRS Infrastructure*



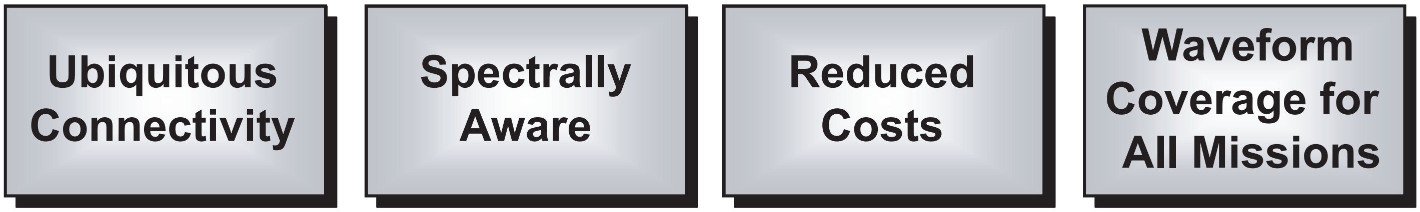


Figure 3: *Evolution of SDRs*

channel vehicle-mounted radio. Regardless of whether the software component is a general purpose processor, Digital Signal Processor (DSP), or Field Programmable Gate Array (FPGA) component, the JTRS infrastructure further defines a host environment that is consistent across the enterprise. Implementations may vary due to the mission or size, weight, and power requirements, but the host environment and the exposed radio services and hardware interfaces are the same.

JTRS SCA and Enterprise Architecture Future Increments

The JTRS infrastructure of Figure 2 has resulted in an executable and sustainable deployment model for the JTRS family of radios. The requirements for the next increment of JTRS are still in development, so it is early to conjecture about the feature set of the next-generation JTRS infrastructure. Because the information repository will have approximately four million lines of source code from JTRS Increment 1, it is probable that the future infrastructure must be backward compatible with today's infrastructure.

As additional form factors are developed, there may be minor revisions to the SCA to extend the current architecture. To better support battery-powered missions, there may be specific changes to the RTOS and middleware specifications. In addition, System on Chip (SOC) interconnection is becoming increasingly important and standardization may be required because FPGAs have become capable of hosting increased functionality of the SDR.

SDR Challenges

Because of the complexity of SDRs, systems and software engineering is more important now than for the previous generation of radios. Developers in both the commercial and DoD sectors must ensure sufficient training and experience necessary for SDR development including engineering disciplines of communications systems, radio frequency, digital/analog hardware, software, and digital signal processing. Complementing a need for developer training is the requirement for improved development and test tools. Recognizing the need and potential marketplace, several companies have emerged specifically targeting SDR development tools. A key item in achieving waveform reuse is the use of compatible tools with thoroughly documented code.

An additional challenge for the SDR developer is to design the architecture such that interfaces may be replaced with a different standard at a future date. The selection of a set of open standards among many competing standards is also a challenge for DoD in achieving more reuse of hardware and software among programs.

"SDRs will be able to handle new networking waveforms, while also being able to operate prior legacy waveforms so that interoperability can be maintained as the older waveforms are phased out."

Hardware innovations and improvements are required for SDRs to achieve their full potential. Greater performance can be achieved with improved analog to digital (A/D) and digital to analog (D/A) converters; reduced power parts, especially FPGAs; wider bandwidth and more linear amplifiers; and radio frequency (RF) technology allowing wider bandwidth operation. For SHF/EHF systems, improvements are needed to reduce the high costs of the steerable, directional, antenna systems.

A unique challenge for DoD is that radio life cycles are three to 10 times longer than commercial products. The life cycle was less problematic with hardware defined radios, but SDRs utilize commercial products such as operating systems, middleware, and software development tools. DoD platforms such as aircraft carriers, aircraft, submarines, etc., have very long life cycles. SDRs represent an opportunity to update the communications capabilities in these platforms for relatively low cost.

Evolution of DoD SDRs Into the Future

SDRs will continue to play a larger role in allowing military users to seamlessly interoperate and provide the wireless interface to the GIG. In addition, SDRs will help reduce the total number of radios in the DoD inventory, allow fielded systems to be more easily refreshed and upgraded, and help with the drive towards a reduced number of waveforms and protocols. SDRs will be able to handle new networking waveforms, while also being able to operate prior legacy waveforms so that interoperability can be maintained as the older waveforms are phased out. The evolution of SDRs is shown in Figure 3.

Ubiquitous Connectivity

The next increment of SDRs must continue the paradigm shift from a communications model of disparate, service-owned and operated radio communications to net-centric warfare by unifying communications resources that are shared across cooperating services. The current increment of JTRS is evolving the radio and networking technologies necessary to realize this vision. Net-centric warfare integrates mobile/tactical users via networked IP and meets frontline demands for bandwidth. The next generation transport architecture will include routers and translation services to enable meaningful and seamless connectivity between multiple, diverse tactical and theater networks and satellite resources. SDRs must incorporate frequency reuse mechanisms to maximize use of available spectrum.

Spectrally Aware

Frequency bandwidth is required to supply the warfighter with the information needed for tomorrow's battlefield. Unfortunately there is a dearth of unassigned frequency spectrum and without simultaneous regulatory and technology breakthroughs, radio spectrum will become a limiting resource for the DoD. A potential reuse mechanism is a spectrally aware radio that is trusted by regulatory agencies to monitor the frequency spectrum and only transmit in unused frequencies.

Reduce Costs

The JTRS program has consolidated multiple radio domains under a single program executive office. Through the use of a common infrastructure, the JTRS JPEO is maximizing reuse of products through its enterprise and correspondingly reducing development and procurement costs. Additionally, a core set of interoperable networking waveforms is being developed. Currently, the DoD is continuing with individually managed service multi-band SHF/EHF programs; however, future collaborative possibilities are being examined. Reuse of the SCA and some of the JTRS enterprise architecture is anticipated, with additions as needed to establish an SHF/EHF reference architecture.

Waveform Coverage for All Missions

Communications for DoD missions vary from dismounted soldiers in the canyons of Afghanistan, supersonic aircraft, unattended ground sensors in the tropics, to conventional office environments. Although one waveform for all communications would be desirable, it is as impractical as expecting that all DoD transportation needs can be served with a single vehicle. The next increment of SDRs will provide coverage of all DoD communication needs with fewer waveforms.

Outlook

The development and use of SDRs is a key enabler for DoD in achieving a family of interoperable radios based on common waveforms, standards, and interfaces, with enhanced portability and reusability. While there have been significant developmental challenges, the DoD SDR programs have made good progress, with prototypes available and being tested in the field for several JTRS and SHF/EHF programs. As users gain familiarity and experience with these radios, their transformational communications capabilities will become evident. The reprogrammable SDR will allow further evolution to additional advanced capabilities building upon the current programs.◆

References

1. JTRS-5000SCA. "Software Communications Architecture Specification (SCA)." V2.2.2. 15 May 2006.
2. North, R., N. Browne, and L. Schiavone. "Joint Tactical Radio System – Connecting the GIG to the Tactical Edge." Military Communications (MILCOM), 2006.
3. Stephens, D.R., B. Salisbury, and K. Richards. "JTRS Infrastructure Architecture and Standards." MILCOM, 2006.

Note

1. Link-16 is a secure near real-time situational awareness and command/control data link used on the Joint Tactical Information Distribution System and Multifunctional Information Distribution System Terminals of the United States and North Atlantic Treaty Organization allies.

About the Authors

Dean Nathans is the senior staff assistant for Military Satellite Communications (MILSATCOM) Terminals in the Communications Directorate, Office of the Assistant Secretary of Defense for Networks and Information Integration (OASD [NII]) where he is responsible for oversight of microwave communications satellite terminal programs and for providing technical advice for MILSATCOM, JTRS, and Mobile Ad-Hoc networking programs. He has been involved with the development of military communications and navigation systems for more than 25 years. Prior to assignment at OASD (NII), Nathans was a deputy program manager in the ground-based midcourse Command, Control, and Communications (C3) Program Management Office at the Missile Defense Agency. Nathans has a masters degree in electronics engineering from Villanova University, and a bachelor's degree in electrical engineering from Rutgers College of Engineering. He has received several awards for his service, including the Navy Meritorious Civilian Service Award, and is a registered Professional Engineer.

OASD (NII), DASD
(C3, Space and Spectrum)
Communications Directorate
6000 Defense Pentagon
Washington, D.C. 20301
Phone: (703) 607-0263
Fax: (215) 607-0276
E-mail: dean.nathans@osd.mil

Donald R. Stephens, Ph.D., is JTRS standards manager at the JPEO JTRS, San Diego, CA. His team is responsible for the establishment and standardization of the JTRS infrastructure. Stephens has development experience with three software radios: the Digital Modular Radio, the Joint Tactical Terminal, and the Airborne Integrated Terminal Group. He has extensive experience in multiple communications and radar receiver systems including satellite communications, spread spectrum waveforms, and multi-spectral signal processing with companies such as Raytheon E-Systems, McDonnell Douglas, Emerson Electric, and Scientific Atlanta. Stephens has participated in all technology facets of software radio design such as RF, DSP, distributed computing, security, and networking. He authored *Phase-Locked Loops for Wireless Communications: Digital, Analog, and Optical Implementations* and several other publications and patents. Stephens has bachelor's and master's degrees in electrical engineering from Georgia Tech, and a doctorate in electrical engineering from the University of Missouri – Rolla.

JPEO JTRS
33000 Nixie WY
San Diego, CA 92147
Phone: (727) 642-9669
Fax: (619) 524-4522
E-mail: donald.stephens1.ctr@navy.mil