The Software Communications Architecture: Two Decades of Software Radio Technology Innovation

Claude Belisle, Vince Kovarik, Lee Pucker, and Mark Turner

ABSTRACT

What began more than 20 years ago as a U.S. Department of Defense project aimed at implementing a radio system that could be reprogrammed on the fly to support multiple waveforms has evolved to become a widely adopted, versatile, and industry-changing architecture. The resulting Software Communication Architecture has now been deployed in more than 400,000 radios worldwide. This article explores the evolution of the SCA starting with its origins back in the SPEAKEasy Program to the upcoming release of SCA 4.1.

INTRODUCTION

The Software Communications Architecture (SCA) is an implementation-independent architectural framework that specifies a standardized infrastructure for a software defined radio (SDR). Initially developed and published by the U.S. Department of Defense (DoD), the SCA is maintained by the Joint Tactical Networking Center (JTNC) in collaboration with various industry partners and organizations, such as the Wireless Innovation Forum [1]. The specification has significantly influenced the evolution of the SDR domain, and its concepts have been used within multiple industries, products, and countries worldwide as depicted in Fig. 1 [2].

Advances in digital processor technology, increases in analog-to-digital sampling rates, and other technological developments have enabled the continuing growth of complex signal processing in the digital domain. This increase in digital processing has appreciably altered the architecture and design of radio systems. Recent generations of SDRs evolved to become highly software-intensive complex systems facilitating further advancement of communications capabilities. SDRs have enabled more cost-effective radio platform life cycles by providing for the update and addition of system functions and features without requiring hardware modifications. Prior to the establishment of the SCA as an open standard, SDRs were developed using proprietary software architectures that tightly coupled hardware platforms and waveform applications in a manner that was unique to each SDR manufacturer. The SCA has built on the capabilities of these preceding generations of SDRs, moving today's radios substantial steps further forward by leveraging large-scale commercial software industry investments in technology and promoting open standardization. The SCA specification and associated technologies facilitate broad software reuse and application portability across SDR platforms, while enabling achievement of the key industry-wide objectives:

- Enhanced interoperability between SDRs and across entire radio communications systems, especially important for mission-critical communications
- Reduction of the time and cost required to develop and deploy SDRs and associated systems, including the incremental rollout of new SDR and radio system features and functions

The SCA provides a set of rules and constraints that define the interactions between software applications (i.e., waveforms) and radio hardware platforms, leveraging an object oriented (OO) software paradigm and employing component-based development (CBD) technologies. CBD technologies are sometimes referred to as the "industrial revolution" of software, fostering the advent of interchangeable software parts built to predefined specifications [3]. With CBD technologies, software components can be thought of as software integrated circuits with a set of defined functionality, performance, and input/output. Components can be assembled together to create entire applications, such as waveform applications for an SDR. The SCA specification also defines a core set of open system interfaces and profiles that provide for the configuration, assembly, deployment, and management of components, which ultimately comprise the software waveform applications. The components of these software waveform applications can be distributed across various SDR hardware processing elements in a manner determined by the particular radio developers that

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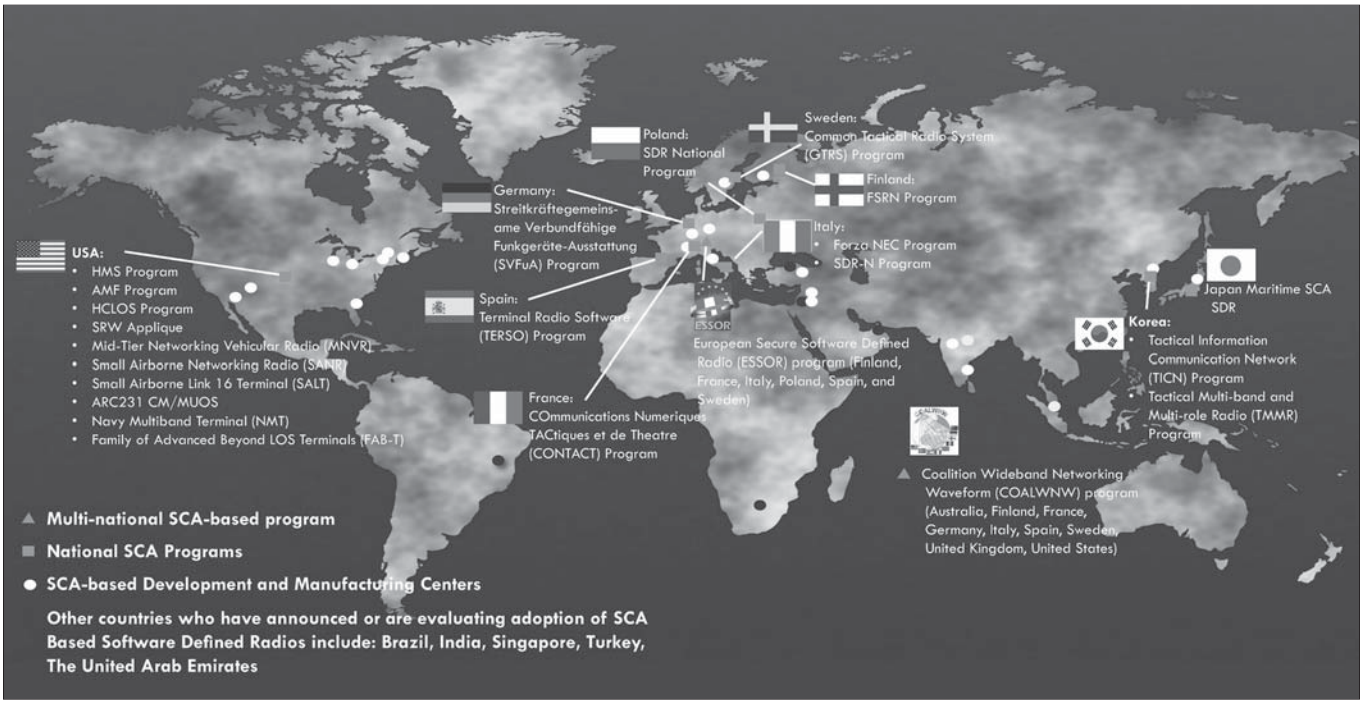

Figure 1. SCA utilization worldwide.

support the overall SDR requirements, radio hardware platform capabilities, and design, in conjunction with the SDR software design and configuration.

Origins of the SCA

Early development of the SCA began under the U.S. DoD SPEAKeasy project. SPEAKeasy began in 1991 with a goal of implementing an SDR system capable of being reprogrammed while in operation to support multiple air interface standards, referred to as waveforms [4]. This capability was very attractive to the military community as a means to reduce the long-term operations and maintenance costs associated with hardware-based radio systems. The SPEAKeasy platform consisted of an array of TMS320C40 processors from Texas Instruments as well as other special-purpose processors mapped onto an industry standard backplane. The platform also included a separate transceiver subsystem and programmable information security (INFOSEC) module. In moving beyond SPEAKeasy, funding was provided for some proof of concept systems such as the Joint Combat Information Terminal (JCIT) and Digital Modular Radio (DMR). These systems further established the feasibility of implementing and deploying an SDR.

Based on the experience and lessons learned in creating the SPEAKeasy and follow-on systems, it became clear that a common radio management system was required to deploy, configure, and manage the signal processing software and other components of the waveform. This management system was developed as a custom software module for each of the early projects, which limited the reuse of application code across platforms. The push toward a common application framework and operating environment to future-proof the system and allow multiple teams to develop waveforms for the platform in parallel started in the SPEAKeasy Phase II program [5], which began in 1995.

Elements of this software architecture were introduced to the Modular Multifunction Information Transfer Systems (MMITS) Forum, which was created at the request of the U.S. Air Force as an industry association focused on advancing the development of software radio technology. In 1997, the MMITS Forum published its Technical Report 1.0, defining "Architecture and Elements of Software Radio Systems" [6, 7]. In 1998, the MMITS Forum rebranded as the Software Defined Radio (SDR) Forum, and continued to mature this architecture through its Mobile Working Group, resulting in the "Software Radio Architecture" (SRA) published in Technical Report 2.1 as an industry standard in 1999 [8].

The SRA was designed to support the functional interfaces outlined in Fig. 2. Key requirements for the architecture included scalability, allowing the architecture to be implemented across as wide a range of radio platforms as possible, and upgradability, to allow new capabilities and waveforms to be added to a radio without replacing the underlying hardware. To achieve these goals, the SRA adopted an OO core framework consisting of a domain manager, file manager, resource manager, and devices necessary to set up, tear down, and control waveform applications. The Common Object Request Broker Architecture (CORBA) was selected as the middleware layer or "software bus" in this architecture, and a common operating environment was also defined based the POSIX specification. Applications utilizing this core framework are created based on the Object Management Group's component model, and were instantiated on the radio platform through the use of an "application factory."

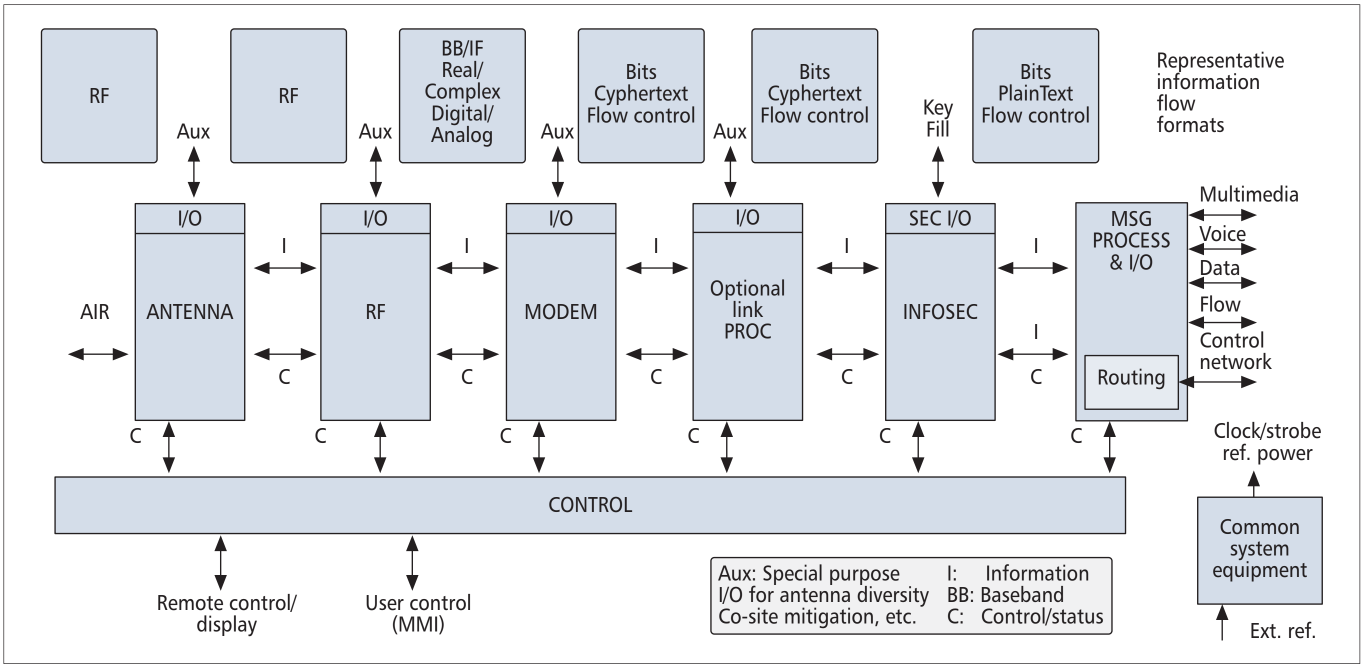

Figure 2. SDR Forum functional interface diagram.

Joint Tactical Radio System

In the late 1990s the Joint Tactical Radio System (JTRS) Joint Program Office (JPO) was formed to develop a new family of software-based reconfigurable radio systems. One of the first activities was to define a common software infrastructure that would be applied to this new family of radio systems. Initial project funding was provided to address the development of a radio framework, and the Modular Software Radio Research Consortium (MSRC) was formed to develop a common radio framework. The concepts in the SRA were further matured by the members of the MSRC working in cooperation with the Forum's Mobile Working Group, and this resulted in what became the JTRS Software Communications Architecture (JTRS SCA)[9].

Early SCA Versions

The timeline in Fig. 3 illustrates several key milestones in the evolution of the SCA specification. In the late 1990s there were several preliminary versions prior to v. 1.0, which was released in early 2000. Although portions of the SCA were implemented as prototypes, the specification was not sufficiently mature and complete to implement a complete software framework for radio applications. Version 1.0 was the first version considered to be sufficiently complete for a full prototype, and several prototypes were implemented by members of the MSRC.

An incremental release, v. 1.1, was used for a proof of concept demonstration that the SCA could be used to configure and manage an existing radio system. One of these demonstrations, performed in 2000 as part of step 2B of the JTRS program, was a collaborative demonstration by Harris Corporation and Exigent. In this demonstration, a Harris Corporation tactical radio was interfaced to a PC running the SCA core framework (CF) developed by Exigent. It was successfully demonstrated that deployment and configuration of the waveform on the Harris radio system could be performed and managed by the Exigent SCA CF running on the PC.

The demonstration identified several shortcomings in the specification with regard to the control interfaces and the specification and configuration of devices. Another iteration of review and modification of the specification was performed, resulting in v. 2.0. Another round of preliminary implementations resulted in further incremental iterations, and in November 2011 v. 2.2 was released. Version 2.2 was generally considered to be sufficiently mature to use as the basis for the development and deployment of a tactical SDR system.

With the release of SCA 2.2, the U.S. government initiated the procurement process for the first set of SCA-compliant radio systems to be developed. In June 2002, the first major program to apply the SCA was awarded. The Cluster 1 program, later renamed the Ground Mobile Radio (GMR) program, was the inaugural project using v. 2.2 of the SCA. Other JTRS Cluster programs were later awarded. In April 2004, almost three years after the 2.2 specification, v. 2.2.1 was released. This version corrected several errors in the 2.2 specification, and incorporated several clarifications and enhancements.

SCA 3.0

At the same time, issues with waveform portability were being raised through the ongoing JTRS Cluster programs. The basic problem was that the code developed for a general-purpose processor (GPP) was reasonably portable between platforms. However, the code developed for a digital signal processor (DSP) and field programmable gate array (FPGA) generally remained specific to the particular processor and architecture of the radio.

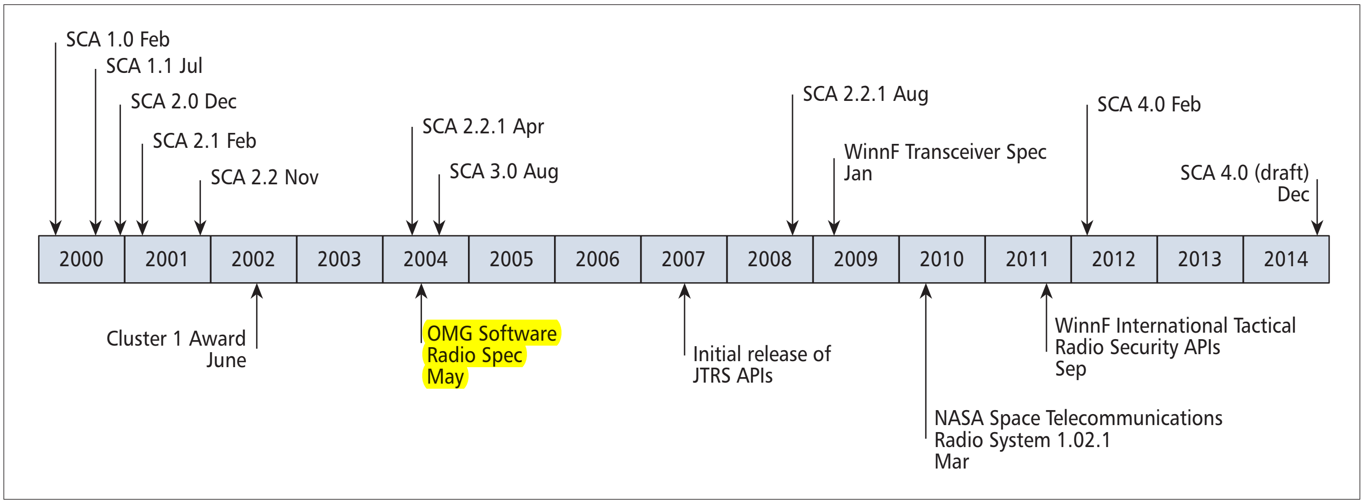

Figure 3. SCA specification timeline.

The DSP and FPGA portability issue came to a head in late 2004, resulting in several special workshops called by the JPO to address the topic. The subsequent result was the SCA 3.0 specification in 2004. This version of the SCA changed few of the core requirements describing the SCA. It did, however, define additional constraints on DSP software related to what system calls could be used by DSP code, proposed a set of waveform components and a high-level data transport design (called HAL-C), and also included an antenna application programming interface (API) section. The general reaction in the community was that the specification required additional work, and, while the concepts and approaches were potentially useful, more detail and analysis were required to achieve a set of descriptions that could be implemented efficiently.

JTRS APIs and SCA 2.2.2

In late 2005 and early 2006, the JPO was reorganized as a Joint Program Executive Office (JTRS JPEO), and undertook a task to revisit some of the waveform portability issues raised by the JTRS program and evaluate alternatives to address the problem. The consensus was that there were insufficient specifications for common APIs to the underlying hardware elements. This resulted in the formation of an API working group to analyze and specify a set of interfaces for the radio system hardware. The initial work drew heavily from the Cluster 1 program and resulted in the specification of several key APIs for common hardware elements. With the release of SCA 2.2.2 in 2006 and the ongoing API work, SCA 3.0 was deprecated and shown on the JPEO website as "not supported." SCA 2.2.2, as the number implies, is an incremental version from the 2.2.1 version of the SCA.

SDR Forum Contributions

With the initial ramp up of the JTRS program, the MSRC was dissolved. Most of the MSRC participants were also founding members of the SDR Forum, which consequently acted as a catalyst for the SCA and SCA related activities. An early activity of the Forum was sponsorship of a project to implement an open source implementation of the SCA. This project resulted in the SCA reference implementation (SCARI) project developed by the Communications Research Centre (CRC). SCARI-OPEN is an open source implementation of the SCA in the Java language and is still available for download [10]. Another project was to develop a reference implementation of the FM3TR waveform. The FM3TR waveform is a multi-mode waveform supporting voice and data. This was developed in the mid-2000s and is available to the community for experimentation.

In 2004, member representatives from Harris Corporation and CRC gave an interoperability demonstration of two independently developed implementations of the SCA specification. This demonstration underscored the power of having a common set of interfaces and definitions across multiple radio systems.

Numerous other contributions were made through the Forum supporting the advancement of the SCA worldwide:

- API Position Paper (SDRF-03-R-0005-V1.0.0)
- Submission to JTRS JPO from SDR Forum regarding DSP and FPGA portability standardization effort (SDRF-04-R-0003-V1.0.0)
- SDRF Change Proposals and Comments on JTRS SCA 3.0 Specialized Hardware Supplement (SDRF-05-R-0001-V1.0.0)
- Comments on Software Communications Architecture Specification Version 2.2.2 (SDRF-06-R-0012-V1.0.0)
- Endorsement of JTRS SCA 2.2.2 (SDRF-08-R-0006-V1.0.0)
- Test and Certification Guide for SDRs based on SCA — Part 1: SCA (SDRF-08-P-0007-V1.0.0)

SCA Variants

From 2000 to 2009, a number of variations of the SCA were introduced, the most significant of which follow.

OMG Software-Based Communications Standard

One of the original goals of the MSRC and government sponsors was to evolve the SCA into an industry standard rather than a military-only specification, with a long-term goal to deprecate the government SCA specification. Many organizations participating in the MSRC and JTRS Program were already members of the Object Management Group (OMG), so the U.S. government sponsored some of these organizations to facilitate the introduction, adoption, and release of the SCA as an OMG standard. However, as the SCA went through the OMG standards process, the impact of multiple organizations and individual perspectives resulted in a specification that diverged from the SCA specification. When the OMG specification was finally released in 2004 [11], the JTRS program was already heavily invested in its radio acquisition programs, so consequently, the specification was never formally adopted by the SCA community. However, a number of the concepts and interfaces of the OMG specifications later found their way into both the SCA 4.0 and Space Telecommunications Radio System (STRS) specifications.

Space Telecommunications Radio System

In the mid-2000s, NASA kicked off an effort to explore the feasibility of deploying software radio systems in space. NASA became a member of the Wireless Innovation Forum and initiated the STRS project. STRS drew on concepts and capabilities of the OMG specification and the SCA. The STRS specification [12] interface definitions and functionality show significant similarity in interface signatures and logical behaviors. STRS was implemented on radio systems provided by General Dynamics, NASA Jet Propulsion Lab, and Harris Corporation. These radio systems were integrated onto a pallet with a common avionics control system. The pallet was flown to the International Space Station on a shuttle mission and installed on the space station. It has since been in use for SDR experiments in the space environment.

The ESSOR Architecture

The European Secure Software Defined Radio (ESSOR) program was launched in 2009 under the umbrella of the European Defence Agency (EDA) and sponsored by the governments of Finland, France, Italy, Poland, Spain, and Sweden. The program was awarded by the Organisation Conjointe de Coopération en Matire d'Armement (OCCAR) to the dedicated joint venture Alliance for ESSOR (a4ESSOR S.A.S.) in charge of managing the industrial consortium composed of the following respective national champions: Elektrobit, Indra, Radmor, Saab, Selex Elsag, and Thales Communications and Security. The main scope of this project was to provide the normative referential required for development and production of software radios in Europe through the use of:

- The ESSOR architecture of SDR for military purposes
- A military high data rate waveform (HDR WF) compliant with such architecture.

The ESSOR architecture is an SDR architecture relying on the already published JTRS SCA and APIs. The ESSOR architecture is a complete and consistent secure SDR architecture addressing the European military radio communications market, and fostering waveform portability among heterogeneous SDR platforms.

The SVFuA Program

Also in 2009, Germany launched an SDR program known as SVFuA (Armed Forces Joint Network Radio Equipment in German). The SVFuA program includes the development of a multi-channel SDR platform together with WF development and porting onto the platform using a national variant of the SCA and APIs.

Wireless Innovation Forum Specifications

The members of the Wireless Innovation Forum have also been active in the development of multiple specifications extending the SCA including the International Radio Security Services (IRSS) API, transceiver facility specification, PIM IDL specification, and lightweight and ultra-lightweight AEP specification.

SCA Next and SCA 4.1: Driving toward Market Harmonization

The proliferation of SCA variants required SDR manufacturers and technology vendors to fork their development efforts in supporting the international community. The result was a gradual increase in cost that was the natural result of a loss of economies of scale. Recognizing this issue, the members of the SDR Forum, now rebranded as the Wireless Innovation Forum, formed the Coordinating Committee on International SCA Standards in 2010, with a mandate to support "the harmonization of SCA based standards at the international level for the mutual benefits of all stakeholders." Early work of this committee defined a "Coordination Model for International SCA Standards" (Document WINNF-10-R-0018) and endorsement of a three-level model for SCA standardization:

1. Areas of open standards with unlimited public access, which are managed in the best interest of all stakeholders (U.S. DoD, EDA, radio providers, waveform applications developers and others) by an independent international organization like the Wireless Innovation Forum
2. Areas of limited distribution for sensitive multi-national needs, such as for coalition interoperability, which are managed by a relevant multi-national body such as NATO or EDA
3. Areas of highly restricted access for specific national and sovereign interests, which are managed by national bodies

In parallel with this activity, the Joint Tactical Networking Center (JTNC) began work on the SCA Next initiative to develop the next major version of the SCA: SCA 4.0. Building on the lessons learned from the deployment of more than 400,000 SCA-enabled radios worldwide, the goal of this initiative was to improve performance of the SCA and expand its applicability in

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To complete the radio development framework, enabling a truly interoperable standard, it is now important that a set of APIs, on which interoperable platforms and applications can be developed and agreed upon. A number of those APIs have already been published but many are still to be defined.

the SDR market. Key features added in this version of the specification included:

- Removing dependencies on CORBA by providing a baseline specification that was technology-neutral with appendices providing the necessary definition of the implementation technologies, thereby allowing radio and waveform providers to select the most appropriate technology for a particular radio and waveform combination
- Adding profiles, called units of functionality, allowing the SCA to be tailored for an individual radio such that only those features needed by the radio and waveforms were implemented, thus reducing overhead
- Reducing the processing overhead, and thus reducing the time required to load and start a new waveform

Elements of the ESSOR architecture and other international variants were introduced into SCA 4.0 through recommendations made by the Wireless Innovation Forum [13]. SCA 4.0 was formally released on 28 February 2012. After some experimental development by several organizations, a number of items were identified that required further refinement in order to better meet the objectives of the new specification. Thus, the SCA 4.1 initiative was kicked off with the SCA 4.1 Working Group of the Wireless Innovation Forum serving to coordinate across all the stakeholders and as a liaison with the JTNC. Finalizing SCA 4.1 is well underway, with six recommendations and two new specifications provided by the Wireless Innovation Forum to the JTNC for evaluation to be included in the revised standard. The SCA 4.1 draft was released on 26 January 2015, and the final approved specification is anticipated to be released later in the year. Although ongoing radio programs remain based on SCA 2.2.2, it is anticipated that future programs and internal projects will evolve toward the SCA 4.x version.

What's Next?

The SCA has now proven its value as a framework of reference for the design and development of military tactical radios. It has been deployed and is in use on the battlefield by soldiers worldwide. With its component-based design approach, it has considerably changed the way radios are built, enabling a higher degree of design flexibility and leading to manufacturing cost reduction. From an original U.S. DoD vision of a standard military radio development architecture, the SCA, with v. 4.1, has now moved toward becoming an international specification, thanks in part to the Wireless Innovation Forum, which spearheaded a process of gathering contributions from worldwide government agencies and industry to improve on the earlier SCA 2.2.2 version.

The future of the SCA will reside in the capability of the community to expand the reach of the SCA to break the adoption barriers that new technologies face. On the technology adoption curve, within the tactical military radio market, the SCA has no doubt passed the "early adoption" stage and is ramping up into the "early majority" phase. To ensure that it continues on this rising path, a few more things are being put in place by the community to ensure wider adoption and sustainability of the technology.

The Development of Internationally Adopted APIs

To complete the radio development framework enabling a truly interoperable standard, it is now important to have a set of APIs on which interoperable platforms and applications can be developed and agreed. A number of those APIs have already been published [14], but many are still to be defined, such as the transceiver and security APIs. Here again, it will be important that those APIs receive international recognition and be mandated by military acquisition programs. The Wireless Innovation Forum is playing a vital role here.

Expansion into Other Military Markets

The military tactical radio domain has been the leader in the development and adoption of this technology. By design, however, the SCA is not specific to military radio environments. Its component-based design (CBD) approach to software development can certainly be applied to many other domains, particularly those based on complex heterogeneous and distributed embedded systems that other commercial CBD approaches are not efficient at supporting. By simply modifying the domain APIs, many other military systems could benefit from the component-based standardized process brought by this technology. Electronic warfare systems, radar, avionics, signal intelligence, and armament systems are very complex systems nowadays, heavily dependent on signal processing and heterogeneous embedded computing for their operations. Advocacy to military organizations worldwide, outside of the radio domain, now needs to be done to expand the adoption of this technology. This is especially true as cognitive RF systems are beginning to be studied. Standardization on a proven technology should certainly be easier than in the early days of the U.S. JTRS radio program, when the leaders were truly visionary to bank on such a new revolutionary technology.

It will be important, especially within the military family, to ensure global adoption of this standard to avoid costly duplication of effort in parallel programs that would result in similar but non-compatible architectures.

Expansion to Commercial Markets

The commercial sector is also an important market where the SCA could be of great benefit, maybe not so much in the consumer domain but certainly in the industrial domain, such as backbone telecommunications systems, test and instrumentation, robotics, transportation, and more. In Japan, for example, part of the train telecommunications system is built on the SCA specification [15]. Moving the SCA to those sectors will give it additional visibility for it to become a standard for embedded system software development and deployment environments.

The larger the adoption cloud becomes, the stronger the development ecosystem will be, providing manufacturers with more choices and even greater integrated software tools, hardware platforms and signal processing components to be used by manufacturers to facilitate the development of embedded systems, lowering development time and cost.

The Wireless Innovation Forum, as an international organization, will continue to have a significant role in bringing together the technical forces to continue to evolve the specification, including the definition of standard APIs. It will also play a vital advocacy role to promote the use of the specification into domains other than military radios.

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Biographies

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VINCE KOVARIK has more than 30 years in systems and software development. He has been involved in software defined radio technology development for the last decade. As a member of the Modular Software Radio Consortium, he worked on the initial version of the Software Communications Architecture. He was the product manager for the Domain Management ToolKit (dmTK), a commercial off-the-shelf product that implemented the SCA, first available in 2000.

LEE PUCKER (lee.pucker@wirelessinnovation.org) is chief executive officer of the Wireless Innovation Forum. He has more than 25 years of experience in the development, management, marketing, and production of embedded signal processing and advanced wireless systems in organizations that include spectrum signal Processing, ITT industries, and Computer Sciences Corporation. He is the named inventor on multiple patents and holds a Bachelor of Science degree in electrical engineering from the University of Illinois, a Master of Science degree from Johns Hopkins University and is Pragmatic Marketing Certified.

MARK TURNER has more than 33 years of experience in the software engineering and radio communications industries. He has been responsible for the design and engineering of multiple military radio and high-grade security products for U.S. domestic and international markets, including development and delivery of solutions for SCA-based requirements. He has been the author and presenter of more than 40 technical papers and presentations on embedded software development, software defined radio, cognitive radio, the SCA, and programmable security.

The Wireless Innovation Forum, as an international organization, will continue to have a significant role in bringing together the technical forces to continue to evolve the specification, including the definition of standard APIs. It will also play a vital advocacy role to promote the use of the specification into domains other than military radios.