SOFTWARE DEFINED RADIO SOLUTIONS
"Taking JTRS to the Field" with Current and Future Capabilities

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ABSTRACT

Despite encountering some significant programmatic and technical issues, the Joint Tactical Radio System (JTRS) Program continues to be a key U.S. DoD transformational program. The JTRS Program is intended to provide foundational support for the U.S. DoD objective of information superiority on the battlefield, meeting the growing demand of War-fighters' communications needs. The transformational efforts of DoD's architecture depends on the information infrastructure called the Global Information Grid (GIG). Without a capability like JTRS, the GIG's transformational networking would halt at the command center level, unable to extend to actual War-fighters (the so-called last tactical mile). JTRS remains a significant force in the evolution of military Software Defined Radio (SDR) solutions and associated technology.

The JTRS Software Communications Architecture (SCA) continues to mature with the release of the SCA v2.2.2 specification [2] and as evidenced by the first fielding of certified SCA implementations. This paper will offer insight and recommendations for continued evolution of the SCA towards broader applicability and acceptance, including: API development and scalability.

As indicated in a September 2006 report [1], the U.S. General Accounting Office (GAO) stated the "Restructured JTRS Program reduces risk, but significant challenges remain". The JTRS Program has encountered a number of problems, resulting in significant delays and cost increases. Harris has demonstrated a complimentary approach to the development of JTRS solutions through large Government funded programs. Harris is developing a family of JTRS capable radios through private investment, following a commercial development model. This paper discusses pertinent experience with the development, integration, waveform porting, testing, certification, and fielding of the Harris Falcon® III AN/PRC-152 (C) Hand-held radio, a commercially developed JTRS capable radio with thousands of deployed units. Relevant data, lessons learned and recommendations are presented in this paper regarding this AN/PC-152 (C) Hand-held radio development experience.

As part of recent restructuring, the JTRS Program has evolved from a legacy radio replacement program to a network centric radio program. JTRS radio systems are expected to provide network-centric capabilities that enable mission flexibility for the DoD Joint Vision 2020. The proliferation of situational data on the battlefield and the development of networking waveforms to support these capabilities is a significant area of technological investment and a focus of the JTRS Program. This paper offers recommendations for heterogeneous, high assurance, EIP (Everything IP) networking waveform solutions, with scalable capabilities including: true multi-talker voice communications and coalition solutions.

1. INTRODUCTION

"A broad background of JTRS and SDR experience"

Harris Corporation is an active participant in multiple aspects of the JTRS Program, with diverse experience across several U.S. Government contracts. Harris has leveraged this Government Program experience with an unprecedented military SDR background to develop and deploy the first privately funded JTRS capable radios to the War-fighters. The Harris AN/PRC-152 hand-held radio was first delivered to the U.S. Army in October 2005 and is widely deployed in U.S. DoD areas of operation around the world.

Harris has been involved with the JTRS Program since its inception, participating in the following elements of the overall Program:

- Step 1 Program - member of the Boeing Team.
- Step 2B Program - validation of the SCA for battery-powered, Man-pack radio platforms using Harris Sierra™ II security technology in accordance with the SCA Security Supplement.
- Ground Mobile Radio (GMR) Program – hardware developer including the Cryptographic Subsystem (CSS) and other Line Replaceable Units (LRUs), software developer for the VULOS and HAVEQUICK waveform applications, and security architecture developer.
- Airborne, Maritime, Fixed (AMF) Program -major player on the Boeing Team as a hardware developer for key elements of the Joint Tactical Radio (JTR), including the Secure Network Processor, and RF distribution system for Maritime platforms.
- CEA Program - developer of software applications, which implement required modes of various cryptographic equipments. The Harris developed

CEAs are targeted for Sierra™ II based cryptographic systems (i.e., the GMR radio set).

- Other - Harris also supports the JTRS Joint Program Executive Office (JPEO) through active participation with the JTRS Standards and Information Assurance organizations.

Bringing essential radio communications capabilities to the field in the form of JTRS technology is a measurable success for the key tenants and principles behind the JTRS Program. The Harris AN/PRC-152 (C) Hand-held radio embodies these JTRS key tenants and principles while maintaining focus on the needs and perspective of the War-fighter, where the emphasis is on capability, not technology. For example, the ability to communicate using multiple waveform applications provides mission flexibility as opposed to single dedicated capability legacy solutions. Interoperability, communications range and battery life performance are each viewed as significantly more important by the user community than abstract technical detail (i.e., JTRS software certification) and data rights (i.e., Government Purpose Rights).

2. SCA EVOLUTION

"The path to becoming a true open standard"

The SCA consists of a set of rules and protocols, which define a Common Open Standards Architecture for SCA applications. The JTRS SCA utilizes Component Based Development (CBD) technology, which promotes the advent of interchangeable software parts, built to predefined specifications. With respect to SDR solutions, the ability to reuse existing software components across multiple radio applications in an open framework, and the encapsulation of hardware specific capabilities and platform services through well-defined APIs are the lynchpins for facilitating true waveform portability, from practical application, affordability and time-to-market perspectives.

The software components which provide for the management and execution of SCA applications and devices comprise the SCA Operating Environment (OE). The SCA supports implementation of waveform application software that can be re-used or "ported" across multiple radio sets (platforms and/or form factors). A Board Support Package (BSP) binds the OE to specific radio set hardware. The OE and BSP can be considered "platform software", collectively providing an appropriate abstraction of the underlying radio set hardware implementation. Refer to Figure 2.0-1 for a high level block diagram of the SCA.

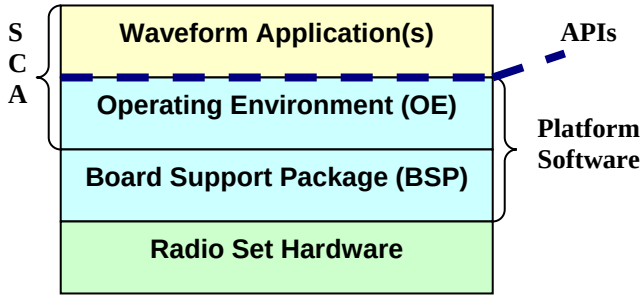

Figure 2.0-1 SCA High Level Block Diagram

The JTRS Information Repository maintains configuration control and access for JTRS work products and artifacts. The contents include: Reference Model implementations, software design document and specifications (base waveforms), and all ported implementations (target waveforms). The waveform applications stored in the JTRS Information Repository are intended to be used as the basis for all JTRS radio set implementations into the future.

Portability is an underlying tenet of the JTRS Program and is intended to help reduce the life-cycle cost of the Program (since each waveform application is built only once), and to increase interoperability among JTRS radio sets built by different vendors. The SCA is also intended to facilitate technology insertion into JTRS radio sets over the platform life cycle and leverage advances in commercial radio markets (i.e., cognitive radio technology).

During the development of the SCA, Government has identified the objective to promulgate the SCA throughout industry as an open SDR standard. For the Government to realize the full impact and benefit of broad industry acceptance, there needs to be movement towards satisfying the open standard objective. There are several tangible benefits for the development and application of open SDR standards:

- Enables interoperability between radio sets developed by multiple manufacturers.
- Can reduce the cost and risk associated with innovation through knowledge sharing (standards can reflect the collective brainpower of industry, Government and academia).
- Facilitates software reuse, reducing development costs and time to market. To meet the pace of changing War-fighter needs it is essential to build less new software, reusing proven, existing applications.
- Facilitates technology insertion and third party participation, increasing market competitiveness.
- Enables the development and integration of advanced capabilities (i.e., Cognitive Radio).

- Aids in coordination with a myriad of radio related regulatory concerns around the globe.

The following provides a list of key characteristics associated with an open standard:

- An open standard does not contain proprietary data or information (proprietary data inevitably restricts competition and breadth of acceptance).
- An open standard is readily available in published specifications and is employed with an effective change management strategy (i.e., backwards compatibility). This characteristic promotes both the development and availability of associated tool suites.
- An open standard has a formal validation process which is accessible to all who develop deployable implementations.
- An open standard is proven to be implementable through the existence of one or more certified implementations.
- An open standard is extensible, with the ability to evolve to support future demands (proven to stand the "test of time").
- An open standard has broad acceptance across industry, Government and other user space (i.e., beyond the U.S. DoD).

There are several challenges which need to be overcome for the SCA to meet this broad objective and acceptance beyond the military radio domain. The following list highlights some of these most significant challenges:

- Published specifications are not all readily available (the API supplement is a CRITICAL element of SCA).
- There is currently very limited participation in the continued evolution of the SCA.
- Access to the JTRS Information Repository is limited to JTRS JPEO and JTRS contractors. Almost all content is currently U.S. export controlled. Broad exportability is essential for broader usage, even coalition level interoperability (i.e., MIDS JTRS Program, NATO, Partners-for-Peace).
- SCA compliance testing has limited capacity and the peripheral processes (i.e., contracts, approval) have to date had slow engagement. SCA compliance testing is an intrusive process including source code level evaluation. Large OE requirements are NOT defined or validated (i.e., API supplement).
- SCA requires more scalability for broader acceptance (both for very large systems and very small systems).

APIs are of critical importance to the true standardization of the SCA. APIs provide encapsulation of hardware specific capabilities and platform services, facilitating the programmability and portability of waveform applications. However, today the API definitions being developed for the SCA OE as part of the JTRS Program are not readily available due to U.S. export restrictions. Waveform application porting experience performed to date, clearly indicates there is a significant cost and time-to-market impact attributable to the lack of standard API definitions. Porting costs of the JTRS VULOS and HAVEQUICK waveform applications to a radio set with different APIs than the waveform applications were designed for more than doubled the porting cost and amount of modified software. For the AN/PRC-152 (C) Hand-held radio, approximately 10% of the VULOS and HAVEQUICK waveform application software required modification specifically due to the difference in API definitions.

The SDR Forum SCA Working Group is pursing the development of APIs that are not constrained with U.S. export restrictions, with the intent of facilitating broad acceptance of these APIs and ultimately international standardization. In order to provide compatibility with the APIs being developed as part of the JTRS Program, the SCA WG is considering the concept of an API convergence layer which would serve as an API mapping function (refer to Figure 2.0-2). For implementations that do not require JTRS API definitions, there would be no need to include these or the API convergence layer.

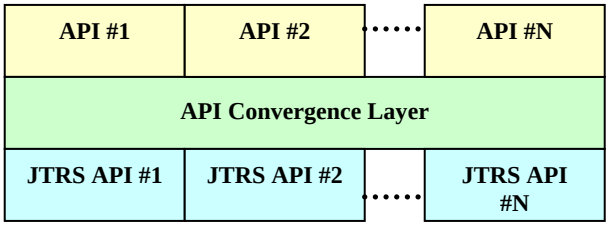

Figure 2.0-2 API Convergence Layer

The scalability of the SCA also needs to be addressed to enable broader applicability. For example, key sets of SCA requirements are not inherently pertinent to small form factor radios, such as dynamic device discovery. Small radio form factors such as Hand-held radios have static hardware configurations, therefore the utilization of devices and the associated deployment of resources is constant. There are several other examples of the need for increased SCA scalability for small radio form factors and also very large radio system form factors. A concept being discussed by the SDR Forum WG is the application of form factor profiles across SCA requirements, where a core set of SCA requirements would be common for all form factors and the remaining requirements would be applied dependent on specific type of radio form factor.

3. JTRS CAPABLE RADIOS GO TO THE FIELD

"Commercial model moves radios to the War-fighters"

The JTRS program has a renewed focus on the use of an evolutionary acquisition approach, providing for multiple procurements with increasing capability and functionality over time. Through increasing degrees of interoperability, military communications will evolve from the current state of single-function legacy systems, to full integration of tactical radio communications across joint and coalition operations. Evolutionary acquisition is intended to allow the JTRS Program to keep pace with developing commercial technology, maintain required interoperability with existing communications networks and ultimately with the GIG. The open architecture nature of the SCA is intended to facilitate the development of JTRS capable radios through commercial innovation and investment. The development of JTRS capable radios through private industry investment can directly lower the Government System Design & Development (SD&D) costs, facilitate price competitiveness throughout the product life-cycle and stimulate continual technological advancement.

3.1. Harris funded JTRS Hand-held Radio

Harris has strongly embraced the vision of JTRS, coupling broad technical knowledge and experience with significant private investment to develop highly capable and cost effective military SDR solutions for JTRS applications. The AN/PRC-152 (C) Hand-held radio is a leading example of a commercially developed JTRS capable product through private investment. The AN/PRC-152 (C) has been developed by Harris as part of the Falcon® III radio family, a suite of JTRS capable tactical radios. The AN/PRC-152 (C) is a Type 1 secure military radio that initially operates in the 30 – 512 MHz frequency range and has both 5W and 50W transmit power out configurations. **Harris has delivered more than 10,000 AN/PRC-152 Hand-held radios since initial shipments began in October 2005**. The AN/PRC-152 (C) Hand-held radio supports several key JTRS waveform applications, including:

- VHF/UHF LOS (AM/FM)
- HAVEQUICK
- SINCGARS ESIP
- Mil-Std-188-181B
- High Performance Waveform (HPW) - SATCOM
- COBRA and APCO P-25 (June 2007)

The AN/PRC-152 (C) Hand-held radio as depicted in Figure 3.1-1 has a fully capable JTRS hardware architecture, including a Harris Sierra™ II based Cryptographic Subsystem (CSS) that ensures the portability of JTRS Information Repository waveform applications. The AN/PRC-152 (C) Hand-held radio completed certification by the National Security Agency (NSA) in August 2005, executed through a Commercial COMSEC Evaluation Program (CCEP) agreement. All high assurance Type 1 security requirements specified by the NSA for JTRS were met by the AN/PRC-152 (C) Hand-held radio as well as the re-programmability security objectives of the NSA Cryptographic Modernization program.

Figure 3.1-1 AN/PRC-152

Harris continues to develop new waveform applications for the AN/PRC-152 (C) hand-held radio. An SCA version of the APCO P25 waveform has been developed by Harris and was demonstrated operating on the AN/PRC-152 (C) Hand-held radio in early October 2006.

3.2. SCA Operating Environment Certification

The AN/PRC-152 (C) Hand-held radio successfully completed SCA Compliance testing by the JTeL and received formal notification on 28-June-2006 from the JTRS JPEO, that the AN/PRC-152 Operating Environment is certified as "SCA Compliant with waivers" to SCA v2.2. Of the 735 defined requirements in SCA V2.2, Harris requested and received waivers for 14 specific requirements, 12 of which are related to the same topic area of SCA device launching. The Harris alternative SCA device launching implementation is a performance saving optimization and provides exactly the same results as usage of the standard implementation in a more direct and efficient manner. Note that device launching is only applicable at system startup time and has no impact on waveform application portability or operation, as confirmed in the JTeL test report. The remaining 2 waived requirements are considered extremely minor. One waiver item relates to the handling of a specific file handling error case that the AN/PRC-152 (C) Hand-held radio OE avoids through an optimized implementation. The remaining waiver item will become overcome by events as the associated SCA requirement has been removed in SCA v2.2.2 (although it continues to be included in the standard SCA v2.2 testing).

As indicated in the JTRS JPEO SCA certification letter, because of the maintenance considerations of the

waived requirements, this certification with waivers is conditional for a one year period. Harris has already completed implementation and preliminary testing of software updates for the AN/PRC-152 (C) Hand-held radio OE to fulfill the SCA requirements indicated in these waivers (while maintaining comparable startup time performance through other non-SCA specific optimizations). These software modifications will be tested by the JTeL for the purpose of receiving an updated SCA certification with no waivers in the near future.

3.3. Waveform Design, Porting and Performance

Harris is a highly experienced JTRS waveform application developer. **The VHF/UHF LOS and HAVEQUICK waveform applications developed by Harris are the first and only JTRS Information Repository waveforms to be ported and fielded.** These waveform applications were originally designed and developed by Harris in accordance with the waveform and radio form factor requirements established under the JTRS Ground Mobile Radio (GMR) Program. Harris subsequently ported these two waveform applications to the AN/PRC-152 (C) Hand-held radio. Most of the scope of work to port these waveform applications to the AN/PRC-152 (C) Hand-held radio was due to the implementation of different APIs (as previously discussed). The AN/PRC-152 (C) Hand-held radio APIs were optimized to support specific radio form factor performance requirements (i.e., power-on time, waveform switching time, battery life).

Harris also employed a "right size" waveform design concept to target the performance and memory footprint requirements of the smallest, and most processing disadvantaged radio form factor (in this case a Hand-held radio form factor). "Right size" waveform design is intended to ensure that the waveform application will be readily portable to the smallest common denominator platform and can be easily "scaled up" to more capable platforms. "Right size" waveform design includes a combination of multiple design and analysis techniques, including: component granularity, performance and data flow allocation. Without the use a "right size" waveform application design concept it could be extremely difficult and costly to port a developed waveform application to a small platform ("scaling- down").

It is essential that waveform application implementations are capable of meeting all waveform performance specifications and real-life expectations (i.e., range, jamming, co-site interference). War-fighters don't care about waveform application software design, they care about the ability to communicate in real world environments. Harris carefully developed and tested all SCA waveform applications for the Falcon III family. Measurements were captured and reviewed throughout the development process to ensure key performance standards were achievable. The AN/PRC-152 (C) Hand-held radio was tested in real-life conditions against standard Combat Net Radio performance parameters (i.e., jamming scenarios, co-site interference, and battery life) with very favorable results as depicted in Figure 3.2-1.

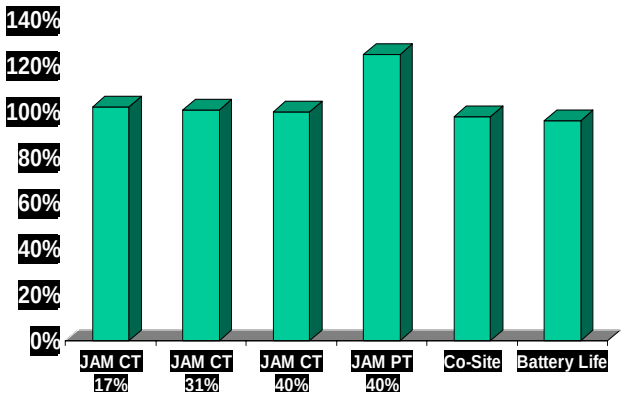

Figure 3.2.1 AN/PRC-152 Performance

In addition, the AN/PRC-152 (C) Hand-held radio powers up to a usable state (able to communicate) within 30 seconds and is able to switch between installed waveform applications (i.e., VULOS to HAVEQUICK) within 5 seconds.

4. FUTURE CAPABILITIES – NETWORKING

"The last tactical mile through wideband networking"

As stated in [1] "JTRS is to contribute to DOD's goal of network centric warfare operations by introducing new wideband networking waveforms that dramatically increase the amount of data and speed at which data can be transmitted. As such, the waveforms would facilitate the use of maps, imagery and video to support the decision making of tactical commanders at all echelons."

Battlefield networks of increasing complexity will be formed dynamically to meet the above objectives, consisting of multiple wideband networking waveforms connecting via discrete sub-networks in a heterogeneous manner. Over-the-air interoperability will be restricted to sub-networks operating a specific wideband networking waveform, with various gateway elements employed to transfer information across sub-network boundaries. The common element of the networking waveforms will be the ability to pass Internet Protocol (IP) traffic, both in secure and un-secure environments.

4.1. Advanced Networking Wideband Waveform

Harris has developed the Advanced Networking Wideband Waveform (ANW2) that is targeted as a potential solution for NATO, coalition and other international markets. The ANW2 is a self-synchronizing, Time Division Multiple Access (TDMA) waveform that does not require GPS to achieve synchronization. Full ad-hoc networking capabilities are utilized in ANW2, including: passive, pro-active and reactive protocols. An important feature of ANW2 is the incorporation of a dedicated digital voice interval for traditional Combat Net Radio and multi-talker voice capability (true party line).

Even though military communications are moving more and more towards the use of data, there will still be a significant need for on-demand, high-priority voice communications. Voice-over-IP (VOIP) solutions may someday accommodate this demand, however War-fighters need Push-to-Talk (PTT) solutions today and ANW2 ensures timely voice communications which meet current mission operations (in addition to IP data communications). The ANW2 utilizes a robust set of Signals in Space (SiS) to accommodate real-world conditions, with bandwidths ranging between 500 KHz to 5 MHz, and on air rates of 20 Kbps to 10 Mbps. The current instantiation of the ANW2 implementation consists of approximately 180,000 Source Lines of Code, excluding the higher layers of the network stacks which are employed using COTS technology. ANW2 has been designed to support secure communications using IPSEC or HAIPE (for high assurance) dependent on mission security requirements.

4.2. Wideband Networking Man-pack Radio

Harris is currently developing a Falcon® III Man-pack Radio (RF-300D-MP) on private investment which supports a similar set of capabilities and narrowband waveforms as described for the AN/PRC-152 (C) Hand-held radio, as well as hardware and software architectures that support high-speed, wideband networking waveforms such as the ANW2 described above.

The RF-300D-MP is a single channel, secure military radio that initially operates in frequency up to 2000 MHz with both 20W and 50W transmit power out configurations (refer to Figure 4.2-1). The RF-300D-MP radio can support all of the same narrowband waveform applications as deployed on the AN/PRC-152 (C) Hand-held radio, plus ANW2 and other wideband waveforms when they become available.

Figure 4.2.1 RF-300D-MP Radio

Harris has implemented an SCA version of the ANW2 on the RF-300D-MP, demonstrating wideband networking capabilities since October 2005, culminating with a field demonstration at the Pentagon in April 2006.

5. CONCLUSIONS

"Take Away Messages"

- Harris is a prominent player in the military SDR industry world-wide and a significant contributor to the JTRS Program, fielding JTRS capable radios through a commercial development model.
- Harris has shipped more than 10,000 Falcon® III AN/PRC-152 (C) Hand-held radios, the **FIRST AND ONLY** JTRS capable radios to have completed full NSA type 1 certification, received certification of "SCA Compliance with waivers" from the JTRS JPEO and is deployed with ported JTRS Information Repository waveform applications.
- Harris has developed the Advanced Networking Wideband Waveform (ANW2) in conjunction with the RF-300M man-pack radio capable of wideband networking communications.
- As the SCA continues to evolve and mature, there are some significant issues to overcome to facilitate true standardization. The SDR Forum SCA WG is working to help address API standardization and SCA scalability issues.
- War-fighters are focused on capability, interoperability and communicating in real-world environments, not technology, acquisition models, the SCA or waveform application portability.

6. REFERENCES

[1] General Accounting Office, Defense Acquisitions, "Restructured JTRS Program Reduces Risk, but Significant Challenges Remain", September 2006.

[2] JTRS Joint Program Office, "Software Communications Architecture Specification", Version 2.2.2, 15-May-2006