Heterogeneous Middleware for Advanced Interoperable Communications

J. Smith, T. Demirbilek, M. Bicer
Mercury Computer Systems, Chelmsford, MA
978-967-1760 / jesmith@mc.com

Abstract

The Software Communications Architecture (SCA), a mandatory speciation for Software Radio implementations by the Joint Tactical Radio System (JTRS), defines a Common Object Request Broker Architecture (CORBA) based component model for building portable applications in a heterogeneous environment. The Object Management Group's (OMG) CORBA is an accepted architecture for distributed systems that recently added a component model to its suite of standards. Leveraging the strength of CORBA by reusing OMG standards within the SCA, and improving OMG standards to match JTRS expectations, will ease implementations and improve scalability within the SCA framework. The Streaming Component Environment (SCE), a Mercury endeavor that provides this kind of flexibility within our current high-performance embedded systems, is being extended to comply with the OMG and SCA specifications.

1. INTRODUCTION

To keep up with today's rapid pace of technological advances, telecommunication systems must maximize the transparent insertion of new technologies at every phase of their lifecycles. Given the computational complexity of the algorithms involved in the transfer and receive cycles of waveform processing, and rapidly changing wireless technologies, a scalable and reconfigurable radio approach is desired. Software defined radios provide the means to overcome these problems. We also discuss how software can be deployed on a multiple processor distributed hardware platform with associated performance trade-offs.

In order to maintain interoperability, the radio systems must be built upon a well defined, standardized, open architecture. Defining architecture also enhances scalability and provides plug-and-play behavior for the components of a radio.

The Software Communications Architecture is an open architecture defined by the Joint Tactical Radio System Joint Program Office (JPO). The SCA has been published to provide a common open architecture that can be used to build a family of radios across multiple domains. Radios built upon SCA are interoperable, can use a wide range of frequencies, employ reusable components and enable technology insertion.

2. Current Research Activities

In this section we give a brief overview of the current status of the SDR standards and on-going SDR research and development efforts among different standardization bodies.

2.1 OMG Specifications

The Object Management Group is an international non-profit consortium that is setting standards in the area of distributed object computing software. It is a vendor-neutral membership-driven organization and has hundreds of members from the industry and academia who are working towards developing and refining these standards.

CORBA [2], the OMG's flagship specification, is an open, vendor-independent infrastructure for distributed computing where services are accessed in a location-independent manner. Later, the OMG adopted the CORBA Component Model (CCM) [3]. In combination with the ability to assemble components into an application, the CCM better promotes code and component reuse: the smaller components are, the more likely they can be reused.

The authors played a leading role in the submission and adoption of the recent Deployment and Configuration of Component Based Distributed Applications (D&C) [4] specification that addresses the limitation of there being no standard interfaces to deploy (i.e. run) applications into a distributed system. The specification allows the packaging of alternative implementations to be chosen based on the target environment and user preferences (e.g. a Linux vs. a Windows vs. a Java version of the same component). Software requirements are defined using XML metadata and automatically matched against hardware requirements. Vendor-specific software is responsible for executing implementations, allowing for a wide range of concepts, from on-demand compilation to scripted implementations to DSP code to FPGA-targeted VHDL code.

At the OMG Software Radio Domain SIG, Mercury is helping to specify an updated set of waveform APIs that will contribute to the next generation SCA. The new set of APIs provides standard interfaces for military, government and commercial waveforms. The API possesses attributes or parameters and provides the coordination, but it is not the implementation of the agreement. This allows waveforms to be developed independent of hardware and to be easily ported to diverse radio sets.

2.2 Next Generation SCA

The SCA builds on CORBA, but predates some of the other OMG specifications, mentioned in section 2.1. Its model of Resources interconnected via ports is comparable to the CCM. The SCA also defines other services and profiles of existing services that are relevant to any embedded system.

Tighter integration of heterogeneous hardware in the same embedded system created a demand for vendor-independent standards, versus proprietary protocols, in the embedded domain. The OMG addressed the issue with the Minimum CORBA specification. The same approach of removing redundancy and features that are not relevant to embedded systems was then applied to other parts of the standards suite, This JPO sponsored process has already resulted in "lightweight" versions of various OMG specifications, such as logging and services.

The authors are involved in a JPO-sponsored effort to build a next generation SCA using related OMG specifications. The updated SCA specification will simply include pointers to the new commercial OMG standards. By making effective use of these various standards, approximately 80% of the SCA specification can be commercialized. As a result, the SCA specification will become smaller, as will SCA implementations as they are built with COTS software. When supported by the OMG Waveform APIs, the next generation SCA will provide interoperability and scalability in a wider domain.

3. Multi Computer Technology

Several goals can be achieved with multicomputing including:

1) An SCA Framework for a pool of heterogeneous processors performing scaleable waveform processing,
2) SCA-compatible Multi Level Security (MLS) pool of processing and
3) Dynamic reconfiguration of waveform components.

The pool of processing software radio approach, shown in Figure

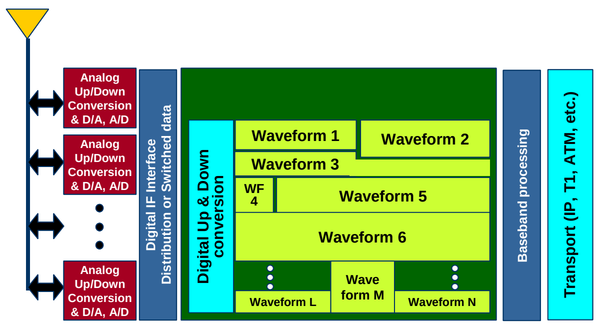

Figure 1. Multicomputer Waveform Architecture

1, affords several key features that are not found in JTRS software radio approaches today. In contrast to the ’slice’ based board and channel architecture (Figure 2); the flexible reconfigurable pool

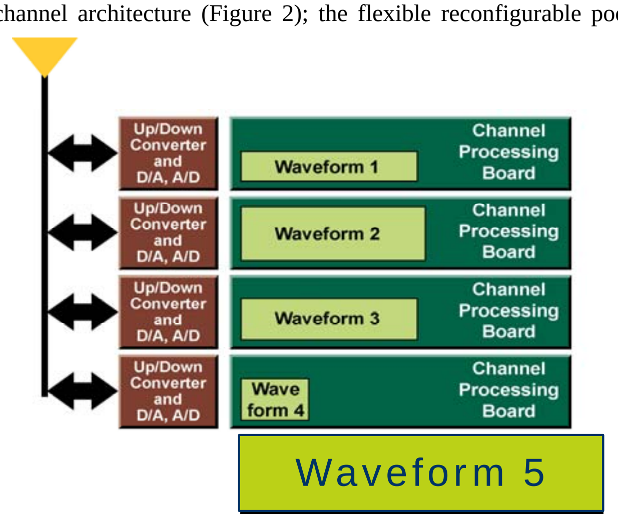

Figure 2. "Slice-Based" Architecture

of processing software radio approach provides equal access to all processing elements. All processing elements of a radio system – FPGAs and RISCs – are equally embedded in the densely interconnected interprocessor wideband switch network.

Following the A/D conversion in the receive chain, down conversion can be accomplished in the pool of processing. Similar considerations apply to the transmit signal stream.

A digital I/O interface will provide a wideband distribution of multiple paths of data between the analog RF modules and the switch fabric-based pool of processing. Mercury is currently engaged with the tuner suppliers and A/D suppliers to displace existing proprietary solutions with a common digital I/O standard.

3.1 Streaming Component Environment

An enabling technology called Streaming Component Environment (SCE) is being developed at Mercury based on a combination of software and hardware component architectures.

The SCE is a component based middleware that utilizes CORBA for the control plane and an in-house developed data plane. Any given SCA implementation, running on SCE middleware, exploits the multiprocessing architecture in many ways providing 1) support for low-level streaming data-flow architectures e.g. data reorganization and high speed message transfer, 2) “future-proofing” compatibility with the current SCA and burgeoning SCA specifications (e.g. lightweight logging, D&C, etc.), 3) heterogeneous processing support, etc.

The key requirements for the SCE technology are reuse, portability and scalability. The SCE provides isolation between the component and the underlying hardware platform by performing trampolining of functions from the components and providing a dynamic loading and linking.

The SCE supports a signaling mechanism that is common between all of the supported devices, including microprocessors, FPGAs and DSPs. All data and signals are transferred concurrent with processing; hence very high processor utilization can be achieved.

The design of the SCE predates both SCA and CCM. We are making the SCE compatible with these standards so that the SCE can be used to build both SCA and CCM compatible applications.

3.2 Multicomputer/Timing Issues

Timing issues associated with multiprocessing waveforms fall into 3 classes. These issues and solutions are described in this section (an expanded form is given in [5], [9]).

3.2.1 Waveform Synchronization

In radio communications, it is important to ensure system clocks synchronization involves both timing and carrier recovery.

In an environment with multipath propagation, one has to mitigate the effects of multipath propagation, so that multiple received symbols with different delays can be effectively merged together.

In each time domain partition, any number of processors can be allocated per partition. The same synchronization issues exist in a pool of processors based multicomputer except advanced middleware can defer these issues until allocation of components to processing element time, permitting real-time operation through scalability and deployment to the appropriate heterogeneous processor on the fabric. The multicomputer does nothing to exacerbate this type of timing problem.

3.2.2 Intercomponent/Interprocessor Communication Timing Issues

When a component-based waveform is running in a fabric-based muilticomputer, the components are assigned to various processing resources in the radio. This assignment can be dynamic or predefined. Timing in the processing of waveform components, other than throughput of the specific processor for the specific function, depends on buffering, processor multiplexing rate, processor multiplexing overhead and context switching overhead.

Timing problems such as synchronization of a number of threads to signal completion of a task are inherent to any real-time, multi-component, multi-computer application. The SCE middleware eliminates those synchronization issues and promotes real-time operation through multi-buffering. Other traditional multi-component timing issues include race conditions and meeting real-time and latency waveform requirements. Fabric-based multicomputers promote real-time performance through non-blocking DMA-transfers and fabric routing priorities.

3.2.3 Security-Related Timing Issues

A covert channel is a communication channel that is a side effect of the primary communication intent. The bandwidth of covert timing channels is usually significantly less than the primary communication media, but any such leak can be devastating.

A big issue with implementing LPI/LPD signals is preventing timing leaks. By suppressing the carrier information (via pulse shaping, decreasing ISI, etc.) one can get rid of certain signatures in the frequency spectrum and make the waveform's spectral signature look like noise.

The foundational objective of the MILS architecture is the suppression of covert timing channels through careful management of processor time allocation in fixed increments. Accordingly, a MILS operating system would be extremely difficult, if not impossible, to implement on a non-real-time operating system since typically only real-time operating systems have the prerequisite precise time management capabilities [6, 7].

The hardware architecture underlining the MILS operating system also plays an important role in allowing the MILS operating system to achieve its timeliness objectives in support of the suppression of covert timing channels.

4. Future Work

With each of the growing SDR research and development efforts has a set of new issues. We've selected a partial list of advances/issues related to our topic of heterogeneous middleware for advanced communications, with associated recommendations.

4.1 FM^{3}TR Extensions

FM^{3}TR waveform [8] is an international open specification, used for interoperability tests in multi-vendor radio systems and proof-of-concept of a radio platform. FM^{3}TR specification was developed by Rome Labs (AFRL). Following that, several companies, including Mercury, implemented and demonstrated FM^{3}TR capabilities on their own SDR platforms. This interest and success in demonstrating FM^{3}TR waveform capabilities has proven the FM^{3}TR waveform is an important test tool for SDR systems.

The FM^{3}TR waveform only consists of physical layer and limited MAC layer functionality. This was believed to be sufficient since any vendor implementing this waveform could have used their proprietary waveform stack on top FM^{3}TR by giving some thought into capabilities of the physical layer. With the latest advances in the SDR community, there has been increased interest in standardizing software application interfaces for adapting radio functions through software control so that component interoperability for JTR sets can be achieved. The OMG Software Radio DSIG extended the waveform APIs, originally published as the waveform API supplement for SCA, to have a complete coverage across different waveforms. We are defining waveform layer extensions for the FM^{3}TR waveform that would use standard APIs defined by the OMG Software Radio spec. This extended waveform specification can be used as a test waveform for demonstrating compliance to the standard.

4.2 Public Safety Using SDR Sets

Interoperability is the ability of public safety service and support providers to communicate with other responding agencies, to exchange voice and data communications on demand and in real time. Communicating through communication centers or commercial cellular networks is neither efficient nor reliable in times of crisis.

Currently, Public Safety agencies focus on using the same waveform, viz. Project 25 (P25), to solve their interoperability problems. P25 is a user-driven effort to create a digital standard for public safety wireless communications users. It enables systems to be scalable from single channel conventional to regional trunking. The systems can be configured in voting, multicast or simulcast designs, while still including the public safety agencies required talk-around capability.

Interoperability can be defined at the waveform, infrastructure and component levels. Interoperability at waveform level means using the same communications protocol in all radio sets e.g. in using two VHF radios. Interoperability at infrastructure level takes this concept a step further. By standardizing the architecture used to implement these communications protocols (i.e. waveforms), radios can "borrow" each other's waveforms. Interoperability at component level is achieved by establishing well-defined sub-system interfaces. This is a similar concept to plug-and-play computer components. When interoperability at component level is achieved, different waveform services can be implemented by different vendors and used in the same radio set. The P25 standards suite aims to solve the waveform level interoperability problem.

A common architecture tailored for the needs of public safety communications facilitate interoperability at all levels by providing the ability to share waveforms across platforms. Coalition waveforms can be used on any radio that is compliant with the architecture, regardless of the underlying hardware. In addition, public safety agencies can communicate with military units, as the proposed architecture is based on SCA.

Public safety has the same scalability issues as the military. In the past, Mercury worked with the Office of the Secretary of Defense (OSD - C3I branch) to help define a coalition waveform that would permit communication among defense, disaster recovery (using the Incident Control System integration), C4I and provide automatic link establishment. The number of public safety related radio types and subscribers far outnumber military requirements. It would be prudent to include a coordination task with OSD to align public safety radio infrastructure goals. The phrase used in the military is that the next generation SCA must scale to zero. This means that the same system that runs on a host with no embedded targets (for functional execution) must easily scale from the same host to up to hundreds of targets for real-time execution and to satisfy future requirements. The proposed architecture must also scale to zero with even more targets on both the base-station and the client computer / radio sides.

4.3 Scalable Waveform Bridging

Waveform interoperability is an important aspect that needs to be addressed when building reliable SDR systems. SDR sets can act as a waveform bridge between legacy radio sets that use different waveforms and cannot communicate without a bridge. Special care must be taken when using a SDR set as a bridge.

In order to utilize the system resources efficiently, a waveform bridge should be able to scale to zero when the there is no bridging to be done. Waveform bridging can be performed by reusing components in the waveform repository. The bridge can be intelligently implemented such that only the required steps in the demodulation chain are done. The waveform does not need to be demodulated all the way to the baseband raw voice or data. The assembly controller can decide which components are necessary to carry out the bridging functionality with the given quality of service constraints. Those constraints indirectly imply the scaling requirements on the waveform bridge. With a pool of processors approach, those requirements can be met without changing the system configuration.

4.4 Secure Radios

Existing software radio architectures have been driven to the inefficient "slice"-based design described in section 3 due to MILS constraints - the need for independent levels of security. Between computers, splitting applications at the same level of security affects scalability and performance. Within a multicomputer, the problem grows adding the need to separate red/black processing. The desire is to enforce security within a processor and run anywhere at any level. LM (with Green Hills and OIS) has been working on an NSA-approved software approach to MILS for the JSF and YF-22 Programs. Mercury has been working with Green Hills (in the area of partitioned secure kernels) and OIS (for an Mercury optimized ORB and related CORBA specs). It would make sense to initiate a project to join Green Hills, OIS, Mercury and NSA to map the work done thus far for a secure MILS/JTRS compliant multicomputer to improve the scalability and efficiency of future software radio design. Mercury has "primed" this process with a self-funded investigation to explore this architectural trade-off space to recommend approaches that will be reported on in future papers.

4.5 FPGAs As Components

With the increasing adoption of component models for multi processing applications, the need for supporting unconventional processing resources such as FPGA and adaptive logic devices increases. Mercury has demonstrated seamless integration of FPGA-based hardware components into SCE applications. Software component architectures provide interfaces that facilitate communications between components.

The benefits of a standard set of interfaces for internal FPGA facilities are significant from a technical point of view. The ability to purchase off the shelf FPGA components that comply with standard interfaces permits the development of products with reduced in-house skill sets.

To achieve a truly flexible component based infrastructure, it is necessary to provide a scheme that allows the transfer of data payloads and state signaling. With this additional functionality, it is possible to integrate software and hardware components together in a heterogeneous system. It is necessary to provide interfaces to an FPGA component that indicates the availability of data payloads, and allows the FPGA component to indicate that data payloads have been processed and new output payloads have been created.

5. Conclusion

We have described JPO-sponsored middleware for next generation radio standards. This newly enabled class of advanced interoperable communications will depend on scalable multicomputer technologies. Our thesis is that a heterogeneous multicomputer is required to implement complex waveforms and system-level or adaptive algorithms (e.g. co-site/channel interference, adaptive equalization, etc.) in a scalable fashion. We have expanded this thesis with the premise that a platform provider, security expert and ORB vendor must work together to provide a MILS/SCA compatible existence proof/testbed in the required multicomputer environment. In particular, we have described improvements to waveform synchronization, intercomponent/interprocessor communication and security-related timing issues through algorithmic, partitioning and hardware/software architectural techniques. The Mercury infrastructure does not exacerbate waveform timing issues and has an inherent advantages with features supporting multi-cast, deterministic OS, time-tagging with component and CPU monitoring with associated repartitioning and reparameterization.

6. References

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