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Application of Model-Based Systems Engineering to VICTORY-Enable Tactical Radios

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ABSTRACT

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Tactical Radio Systems such as the Mid-Tier Networking Vehicular Radio (MNVR) and the Handheld, Manpack, and Small Form Fit (HMS) Radio provide common functions that can be componentized with standardized interfaces. In the Army's acquisition and testing processes, next generation radios are being fielded with related systems and components as capabilities. Model-Based Systems Engineering (MBSE) is an ideal methodology to develop a Reference Architecture using a common development process. MBSE uses a formal model of a system of systems to represent all systems engineering information. Key benefits of MBSE include traceability, communication, configuration management and common languages and notations. This paper evaluates implementation experiences in applying MBSE to develop a Reference Architecture (RA) that provides VICTORY interfaces for radio, computing systems, and Satellite Communications (SATCOM) terminals. The information representation of the Hardware/Software (HW/SW) RA is especially suited for interface constructs provided by the Unified Modeling Language (UML) and Systems Modeling Language (SysML) including blocks, ports and associations. This paper also presents an architecture development process that can realize a reference architecture that represents VICTORY applications such as health monitoring of components, status and actionable data collection and transmission.

INTRODUCTION

Recent initiatives in vehicular communications in the Army have focused on developing open architectures to take advantage of reuse and to support changing mission requirements [1], [2], [3]. The Army's Capability Set fielding process presents a challenge of translating overarching end-to-end requirements to specific system product lines. In the Army's acquisition and testing processes, next generation radios are being fielded with related systems and components as capabilities. Tactical Radio Systems such as the Mid-Tier Networking Vehicular Radio (MNVR) and the Handheld, Manpack, and Small Form Fit (HMS) Radio provide common functions that can be componentized with standardized interfaces.

The mapping from capabilities to reusable modules and system components presents unknown problems, risks and issues that may not be known at design time. As an example, the Modular Open RF Architecture (MORA) extension [4], [5] to the Vehicular Integration for Command, Control, Communications Computers, Intelligence, Surveillance, and Reconnaissance (C4ISR)/Electronic Warfare (EW) Interoperability (VICTORY) standard [4] uses shared Radiohead antennas to provide a common air-interface for multiple types of software defined radios [2]. The control logic and device management of radio components needs to be mapped to and from existing product requirements, including the MNVR and Manpack (MP) radio systems. HW/SW interface specifications can be mapped to a platform-specific tactical radio architecture.

The purpose of this paper is to explore how a reference architecture developed using a Model-Based Systems Engineering (MBSE) approach can realize of existing tactical radio capabilities in an open modular architecture. This paper evaluates past implementation experiences in applying MBSE to develop Reference Architectures (RAs) for realizing Common Operating Environment services in ground-based platforms. Therefore, the paper seeks to determine how well MBSE can meet the tenets of an open standards approach called for in the DoD Open Systems Architecture (OSA) initiative [6]. DoD OSA prefers solutions with open data models and standards that enable interoperability and modularity.

The process for developing reference architectures should consider the project environment and product requirements. An open question addressed by this paper is whether architecture development processes (ADPs) can develop open, common, feasible, implementable, and testable interface requirements that realize the tenets of the MORA while also enabling product line engineering (PLE) of tactical radios.

BACKGROUND

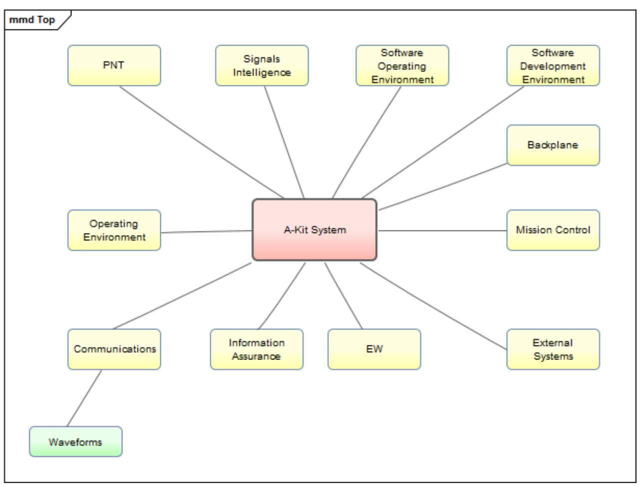

Figure 1. Conceptual Organization of Open Radio Architecture Elements Derived From [3]

To realize interoperable radio components, while encouraging competitive product lines, it is important to define a Reference Architecture that can guide their implementation. A HW/SW CVG RA identifies common hardware and software interfaces for a new product ecosystem of reusable plug-and-play tactical radio modules. A HW/SW Convergence (CVG) RA provides data, control and management interfaces of VICTORY-compliant products that implement the OpenVPX backplane [3], [7], VICTORY In-Vehicle Network (IVN) [4] and the MORA specifications [4], [5].

Requirements of a Reference Architecture

There are a number key requirements for a RA. First, the reference architecture should define a framework that defines core capabilities for a derived tactical radio architecture or implementation. Second, the RA also should provide the principles, rules and models that can be used to develop solution architectures [8]. Since Software Defined Radios that follow the Software Communications Architecture are component-based [9], the HW/SW CVG RA should adopt a similar modeling philosophy. The functional decomposition method used for realizing Tactical Radio architectures should be translated into component-based design methods.

A RA provides a common technology-independent model that can drive the definition of specific radio architectures tailored for particular mission scenarios. A key requirement of the RA is to decompose radio systems into high-level components with well-defined functions and interfaces. RA interfaces should also enable decoupled hardware to support a diverse set of waveforms in a tactical environment. Plug-and-play modules form a tradespace of components that can be inserted into the architecture while meeting system interface requirements. Component interfaces enable better interoperability and can also be used to improve the interworking between among vendor solutions that build to the specification. The value added by a RA is the alignment of existing product functionality with open standards such as the OpenVPX backplane standard [7].

MBSE ARCHITECTURE DEVELOPMENT PROCESS

MBSE is a promising methodology that can effectively develop the RA elements and interfaces. Since MBSE leverages the benefits provided by a formal model of a system of systems (SoS), the RA interfaces can be documented using use cases and sequence diagrams as suggested by [10]. The HW/SW CVG RA use cases, requirements and component interfaces can then be validated against the top-level use cases derived from the MORA [5] and VICTORY specifications [4]

MBSE represents systems with modeling elements that are enhanced with formal semantics [11], [12]. Key benefits of MBSE include traceability, communication, configuration management and common languages and notations [13] [12] [10]. MBSE can improve the traceability of requirements to designs which have flexible combinations of resource types such as hardware, software and people. MBSE can also improve the communications of complex concepts. MBSE makes configuration management of an architecture easier since changes are applied directly to the model. MBSE can also specify an ecosystem of interoperable and pluggable

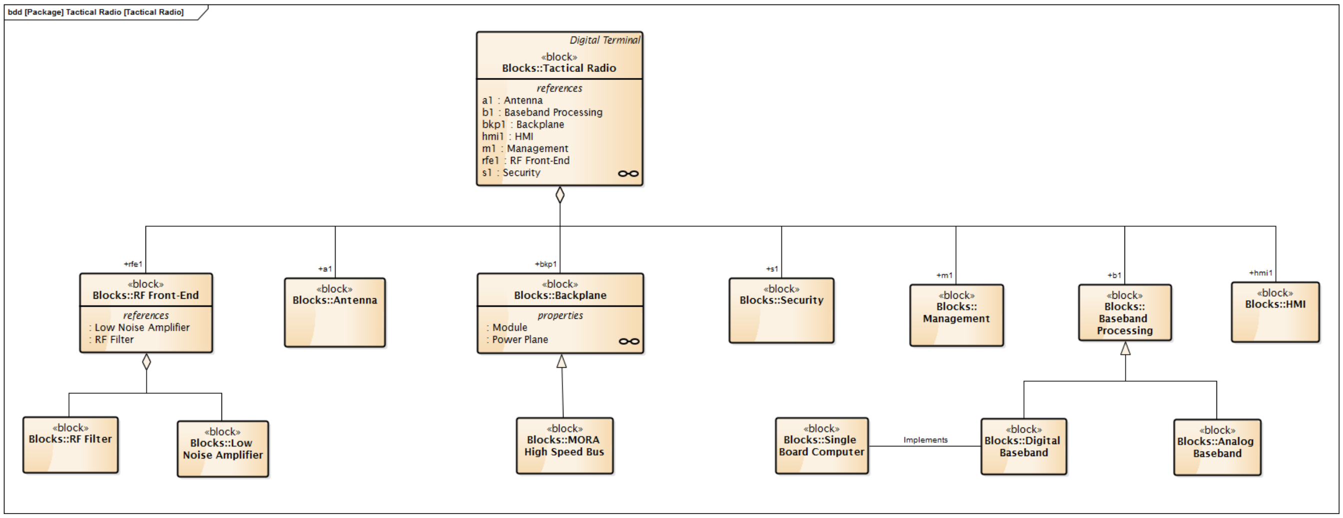

Figure 2. Representative Block Definition Diagram of Radio Components. This diagram depicts the key System Elements which are interconnected through Port classes.

modules that can be developed by more than one manufacturer.

Hause [14] suggests that a standards-based approach using modeling paradigms such as MBSE, UPDM (Unified Profile for DoDAF [Department of Defense Architecture Framework] and MODAF [Ministry of Defense Architecture Framework]), and SysML support development of reusable models that can realize capabilities. SysML supports behavior, structure and parametric relationships which can include algebraic equations. The UPDM / MBSE style of DoDAF development which incorporates SysML as the modeling language has become increasingly popular [14].

Architecture Development Process Workflow

The HW/SW CVG MBSE Architecture Development

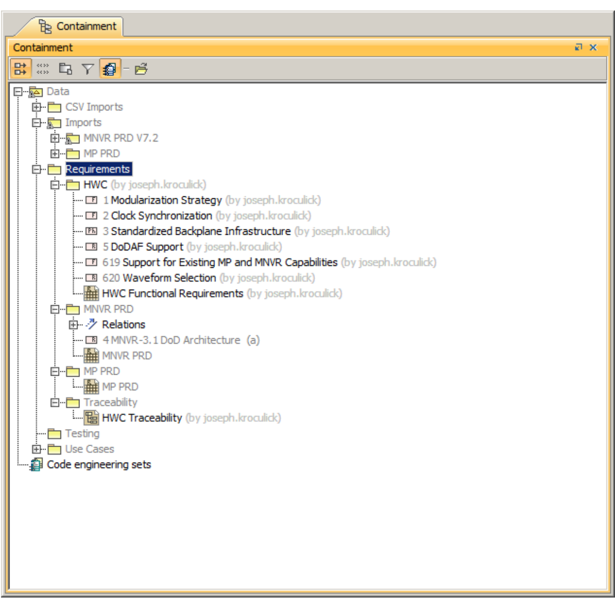

Figure 3. MagicDraw Containment Window Depicting the Data Organization of a UML/SysML project

Process (HADP) should ensure that best practices would be used to develop the RA. A unique contribution of the HADP is the alignment of the functional decomposition of tactical radio architecture development with the component-based architectures of Software-Defined Radios (SDRs) and VICTORY. A capabilities analysis was performed on MNVR and MP Capability Development Documents (CDDs) to select common functions which were allocated to the HW/SW CVG components. HW/SW CVG components were developed in each of the following domains in Figure 1.

With an MBSE approach that refers to a shared architecture, the system under study can be directly aligned with other initiatives such as the Joint Open Architecture Spectrum Infrastructure (JOASI) [15], the Common Operating Environment (COE) [16] and the Open Systems Architecture for Condition Based Maintenance (OSA CBM) v3.2 [17]. The consequence is that spectrum concepts in these research initiatives do not need to be recreated; they can simply be plugged in. As a result, the investments are better used since there is less rework and redesign. Also a System of Systems Engineering (SOSE) approach to implementation of Future Advanced SATCOM Technologies [1] and HW/SW CVG allows for more advanced field testing and integration with the Army's Agile process [18].

Establishing the MBSE Requirements Development Process

The MBSE HADP provides traceability through an iterative, workflow-driven process. The traceability of requirements is realized using SysML requirement relationships. Consequently, design decisions on radios and their components are integrated with other systems can be managed. Architecture data can be integrated using

MagicDraw's rich set of traceability relationships in order to trace to product CPDs and Performance Requirements Documents (PRDs). The HADP Requirements Development process and its constituent activities is represented as a Business Process Model and Notation Diagram (BPMN) in **Error! Reference source not found.**.

Managing the MBSE Environment

To apply MBSE to an architecture development project, a data management approach that manages the data produced by systems engineering practices is needed. An effective MBSE process depends on an enterprise architecture repository (EAR) to represent the RA data. The EAR provides the focal point where information can be accessed and reused by the project stakeholders so they both use and create project data [13]. The enterprise repository also provides automated architecture model support for simulation, specialty analysis, and application development. It also enables integration to be performed. MagicDraw Teamwork Server (TWS) [19] was selected as the repository and structured to support the engineering design process. TWS facilitated configuration management of model data enabling stakeholders reviews in real-time. A notional schema for MBSE data is represented in **Error! Reference source not found.**.

Reporting MBSE Data from the EA Repository

To provide actionable architecture data, it is necessary to develop a reporting process that leverages the Army's available tools. A lightweight MagicDraw publishing process that pushes data onto a SharePoint site from Excel provides a candidate approach with minimal resources.

Managing the Project Backlog and Retrospectives

The HADP included a lessons learned retrospective activity that reviews issues and uncovers assumptions. A running project issues list may be updated with proposed changes and corrections to the HW/SW CVG RA. The HADP also developed a Project Lessons Learned database and adds proposed resolutions. An updated issues can be posted on the project SharePoint Site.

CASE STUDY EXAMPLE ILLUSTRATING HOW MBSE CAN BE USED TO DEVELOP A VICTORY REFERENCE ARCHITECTURE

The HW/SW CVG RA in this case study represents VICTORY interfaces, which provide Health Publishing, Information Assurance, and Positioning, Navigation and Timing (PNT) services over the VICTORY Data Bus (VDB). The VDB is the core concept that enables integration of C4ISR/EW systems using services and an infrastructure. The VDB provides the middleware that enables applications to be explored as VICTORY services. The VDB depends on an underlying IVN based on the Ethernet standards [20].

The HW/SW RA can be documented using the Object Management Group (OMG) Unified Modeling Language (UML) [21] and Systems Modeling Language (SysML) [22] and provided automated translation of design requirements into an architecture. Structural and behavioral views were modeled using SysML models. UML Composite Structure Diagrams and Class Diagrams are analogous to the SysML Block Definition Diagrams (BDDs) and Internal Block Diagrams (IBDs).

Key systems that were detailed include the Radiohead, the Software Defined Radios, and the Radio-Frequency Distribution Device. The RA can also be translated into UPDM [23] fit-for-purpose diagrams, which include the Capability Viewpoint diagrams based on merged capabilities derived from Joint Tactical Radio System (JTRS) Manpack and MNVR Capability Production Documents (CPDs). A notional tactical radio BDD and a UML Composite Structure Diagram (CSD) (which is similar to a SysML Internal Block Diagram (IBD)) are depicted in Figure 2 and Figure 3, respectively.

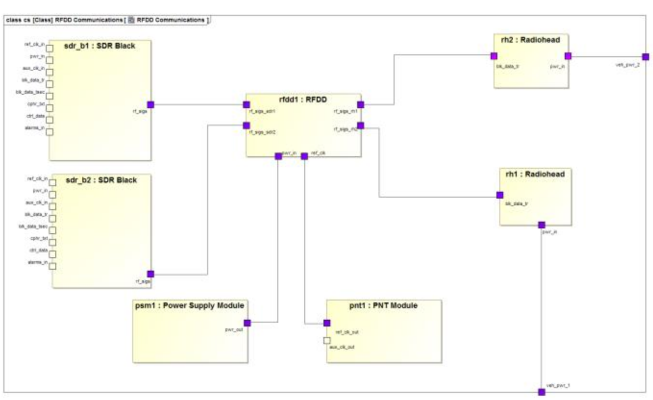

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Figure 4. Notional UML Composite Structure Diagram of Software Defined Radio-to-Radio Frequency Distribution Device-to-Radiohead Communications

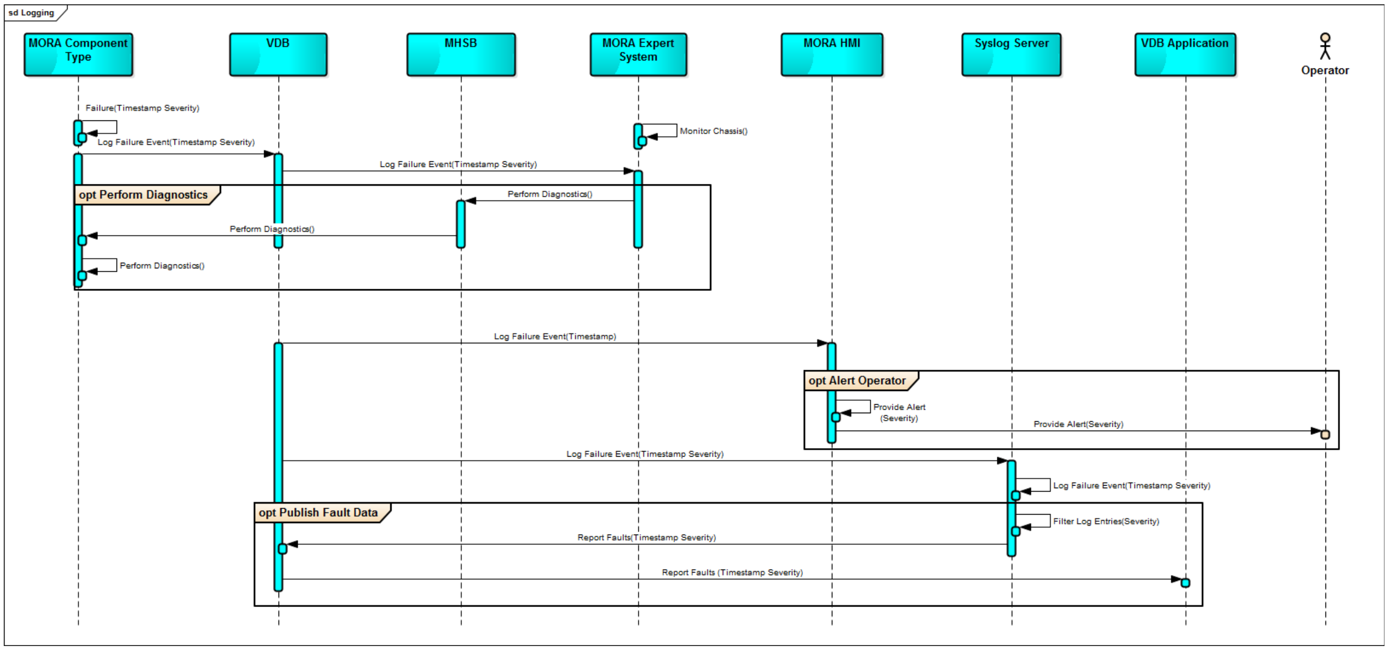

Figure 5. Notional Health Status Reporting Scenarios and Sequence Diagrams. Three optional sequences are depicted which include performing diagnostics on a MORA component type, alerting a radio operator of a failure, and publishing fault data to a VICTORY logging application. All communications is over the VDB.

Defining the MORA API through System-Level Use Cases

The project initially developed use cases between actors and subsystems to represent the interface contracts. Since SysML supports textual pre- and post-conditions, underlying system rules were added as text-based constraints. The HW/SW CVG RA interfaces are specified using UML Use Case Specifications. These specifications are derived from the MORA, VICTORY and OpenVPX standards and documented in MagicDraw architecture development tool. Software-Defined Radio (SDR) use cases were derived from military radio requirements including the JTRS CPDs and added key functions which act on the SDR interfaces for a RA-enabled radio. Such SDR use cases encompass voice and data transmission, radio security services, formation of networks at the media access layer (MAC), routing on the red side, routing on the black side, and management of the radio. Key Software-Defined Radio (SDR) interfaces such as the SDR to management, source SDR to destination SDR, and the SDR red/black side separation may also be represented. Representative use cases were limited to the MORA interfaces [5] required by a Tactical Radio.

VICTORY Health Management Applications

The Army and US Marine Corps have both recommended the use of the VICTORY standard for the management and configuration of their networked ground platforms [3]. Since VICTORY allows health status and faults to be collected for systems on the network, the platform will now allow improve

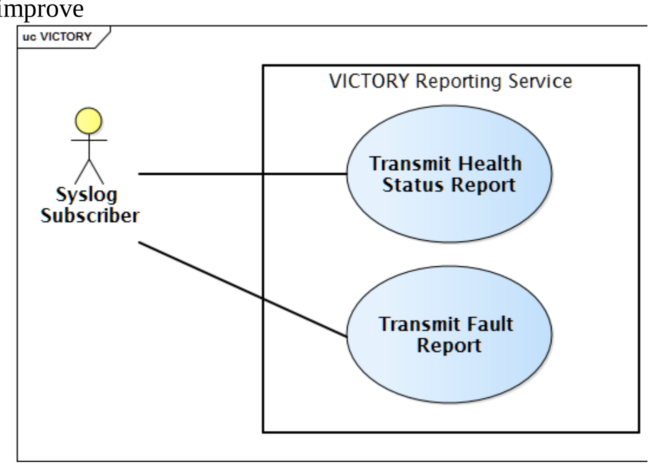

Figure 6. Notional Use Case Diagram for Health Status Reporting. The primary initiating Actor that requests a health status report using a VICTORY service depicted on the left-side of the use case diagram.

d data integration with VICTORY components. The standardized network integration afforded by VICTORY is driving a new eco-system of enterprise applications including prognostics and health management (PHM), improved cyber and kinetic situational awareness (SA) and faster mission command (MC) decisions.

Maintenance Systems can connect to a platform's VICTORY In-Vehicle Network in an on-platform in order to collect the health management needed to accomplish their missions. The existing "off-platform" approach of connecting to a motor port and offloading the data to the Maintenance Support Device (MSD) is still supported. The VICTORY component types for logistics exchange health management data and configuration management information bi-directionally. A notional use case and sequence diagram that represents a VICTORY component publishing the Syslog health status data over the VDB to a VICTORY application is depicted in **Error! Reference source not found.** and **Error! Reference source not found.**. File converter software can be developed to extract logged health data from a vehicle data logger application. This data could then be transformed into existing Army Bulk CBM+ Data (ABCD) formatted files, which are transmitted over a radio network or through a SATCOM interface.

CONCLUSION

Tactical radios such as MNVR and MP must provide, voice and data communications, route and relay and high availability capabilities enabling lower-tier and mid-tier communications. The promise of modular open suite of standards provided by initiatives such as VICTORY is an ecosystem of applications running over an In-Vehicle Network [3], which include Condition-Based Maintenance Plus (CBM+), Mission Command (MC) and advanced provisioning of the radio.

This paper presented specific MBSE practices that enable plug-and-play functionality through the sharing of common functions such as smart displays using standardized interfaces. The architecture development process using MBSE improves the communications of complex concepts with the HW/SW CVG Working Integrated Project Team (WIPT). An MBSE approach to realizing VICTORY-compliant products allows system block diagrams to be generalized into modular and open systems and assesses whether the associated capability can be implemented.

A challenge in developing a RA is collaboration with communities of interest (CoIs) responsible for developing RA systems and system elements. Operational processes and mission threads should drive the underlying models. Successfully implementing MORA and VICTORY depends on communicating feedback on implementation issues with the standard the CoIs.

The HW/SW CVG MBSE project resulted in major improvements to the VICTORY standard. These changes include the development of an application programming interface (API) to remotely manage the radio through an OpenVPX chassis and the VICTORY IVN. The architecture analysis identified conflicts with the evolving standards and resulted in several Engineering Change Proposals (ECPs). The VICTORY standards were also improved through the identification of operational interfaces, data transport protocol configurations, configuration and initialization procedures, and specific training requirements.

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