"Advanced Data Description Exchange Services For Heterogeneous Systems "

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Abstract. CCT is conducting NASA sponsored research to provide an advanced data description exchange approach for space/spaceport systems that will provide a generic platform independent software capability for exchange of semantic control and monitoring information. This new strategy will reduce development, operations, and support costs for legacy and future systems that are part of ground and space based distributed control systems. It will also establish a space systems information exchange model that can support future highly interoperable and mobile software systems. The concept leverages the emerging OMG XML Telemetry and Telecommand Data Specification to provide a generic solution that will ease the adoption of a common data definition and exchange standard for legacy and future systems by minimizing or eliminating the need for custom semantic description software in new and legacy ground systems.

Introduction: Identification and Significance of the Innovation

The proposed innovations discussed in the paper are as follows:

1) Provide a generic cross-platform software capability for exchange of telemetry and command description language between spacecraft and spaceport systems.
2) Develop a program generator for creating cross-platform control and monitor exchange application programs from high level languages or specifications.

These services are significant because control and monitor data exchange middleware will:

1) Enable legacy and future space systems to exchange common control and monitor (command and telemetry) format descriptions,
2) Reduce operations and support costs associated with sharing descriptions of control and monitor definitions for launch systems and ranges,
3) Reduce the up-front cost of transition to a common extensible data exchange standard for legacy and future systems.
4) Prolong the life of existing systems by providing a standards-based infrastructure that enables interoperability and transition to new technologies without requiring a major redesign or system replacement.
5) Build an initial information exchange model to support future mobile software by demonstrating technologies that provide interoperable control and monitor capabilities.

The current lack of standardization requires custom ingestion of telemetry and commanding information across a variety of systems and organizations throughout a mission lifecycle. Additionally, many of these organizations must support multiple heterogeneous missions using a common ground segment infrastructure. This is made difficult and costly because standardized and automated methods are not used for communicating this information. The current lack of adequate standardization for general control and monitor data exchange results in a proliferation of custom ingestion application programs. This customization is inherently error-prone, resulting in the need to revalidate the data representation at each transition in the lifecycle. Mission operations would be more efficient if consistent telemetry and command definitions could be easily exchanged among all of the lifecycle phases, systems, and organizations. The emerging OMG XTCE[1] standard is based on XML technology that has the potential to fill the standardization void; however, successful interoperability requires adaptation of a variety of legacy systems. Without supporting tools that ease the burden of adopting a new standard it may be cost prohibitive for the US space systems infrastructure to take advantage of it.

Background

Future space systems (spaceport, spacecraft, launch vehicles, ranges) will need to be able to operate adaptively, with more autonomy than systems do today. In the future, concepts of ubiquitous communications infrastructure, dynamic service discovery, and mobile agents will enable loosely coupled systems to collaborate to establish objectives and achieve broad mission goals. A critical stepping-stone in realizing this future is establishing a vocabulary and mechanisms for exchange of a wide range of configuration, control, and instrumentation information. This potential stepping-stone to the future is a very real challenge for our space systems infrastructure today.

Spacecraft design is performed today through the use of a number of desperate tools and techniques. Interface design for space systems is manual and time consuming. Data design, both telemetry and commanding, is performed multiple times by multiple contractors during the vehicle lifecycle, well before the systems are deployed for mission operations.

Similarly, mission operations require the exchange of telemetry and command information across multiple heterogeneous missions using a common ground segment infrastructure. Information must be exchanged among all of the operational phases, systems and organizations. This is made difficult and costly because there is no standard method for exchanging this data definition information. The lack of standardization currently requires custom ingestion of the telemetry and commanding information. This customization is inherently error-prone, resulting in the need to compare and revalidate at each step in the lifecycle.

A typical example of this process is between spacecraft or vehicle and the operating organization. The manufacturer defines the telemetry and command data in a format that is much different than the one used in the ground, or spaceport, segment. This creates the

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[1] Object Management Group, XML Telemetry, and Telecommand Data Specification – Draft Adopted, http://www.omg.org/docs/dtc/03-05-07.pdf, May 2003

need for database translation, increased testing, software customization, and increases probability of error. Standardization of the telemetry and command definition format will streamline the process allowing dissimilar systems to communicate without the need for the development of mission specific database import/export software.

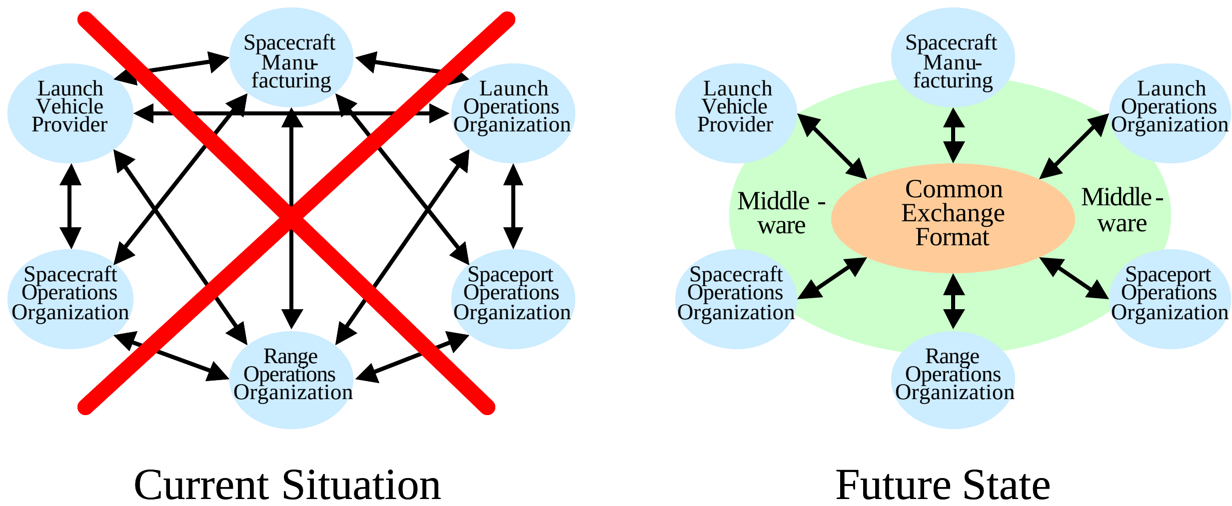

Figure 1 Research results

Ideally, a space system operator should be able to transition from one ground system to another by simply moving an already existing command and telemetry database that is compliant with the standard control and monitor specification. As illustrated in Figure 1, there currently is a need for N(N-1) number of interfaces between producers and consumers of telemetry and command description information. The proposed approach seeks to produce a more manageable strategy that requires 2N potential interfaces. This means a smaller number of interfaces to develop and maintain, and increased flexibility and utility in between the producers and consumers.

A concrete example of the problems facing current space systems infrastructure can be seen through the NASA ELV telemetry operations at Cape Canaveral Air Force Station and Vandenberg Air Force Base. The NASA telemetry organization deals with a broad range of telemetry users and producers. Launch vehicle providers, payload organizations, the Eastern and Western Ranges all have a myriad of unique telemetry ground systems and unique strategies for describing telemetry format, and content. Exchange of format and content information is a standard part of everyday business. The NASA telemetry organization is faced with creating custom software for each unique organization and mission that supports exchange of information as well as binding mission databases to NASA legacy telemetry infrastructure. As a middleman in the exchange process, NASA would benefit tremendously if all of producers and consumers would standardize on how they exchange telemetry databases. However, adopting a standard is a non-trivial exercise, especially considering the various organizations involved, already have a significant investment in their current methods, and changing to a new strategy will require new software and processes. The problem, and possible price for a solution, is exacerbated by the diversity of systems, software, operating systems, etc. in use. It makes a single, monolithic solution/tool unpractical.

It is very easy to see how this same example scenario can play out in any number of possible current and future space systems infrastructures where heterogeneous systems need to interact. Hence, a fundamental requirement for the interoperability of current and future space systems is to establish a common language for describing how systems communicate. An information model is needed that facilitates common understanding of structure and content for control and monitoring systems. Emerging standards, such as XTCE, offer a part of the potential solution by identifying common mechanisms for representing form and content. However, standards alone will not be sufficient to solve the problem. Software required to accommodate these new and complex standards will be expensive, especially if the standards are to be adopted by the myriad of legacy systems owned and operated by the government and industry. Adopters of these standards could be faced with spending hundreds of thousands of dollars per system, which will aggregate to many millions of dollars across the space operations enterprise. Robust, adaptive software tools and/or services are needed to reduce the cost and complexity of adopting the new standards.

General Goals

The major goals for this research proposal are identified in Table 1 below.

Table 1 Major Research Goals

Goal	Priorities
Provide interoperable systems, tools, and data products to simplify operations and increases affordability	Affordability is primary focus. Need to reduce costs, decrease schedule impacts, become faster and more efficient. Legacy approaches need to be supported ▪ Owners of existing infrastructures often consider them to be de facto 'standards' ▪ System configurations and initializations are custom and unique, but dependent on external control and monitor definitions that need to be standardized
Provide standardized data definition, exchange, and communication	Common control and monitor description language. XML is an enabling technology
Need better validation	Built-in, more automated capability. Need reusable solutions, less recurring customization. Control and monitor format dependencies as well as simple data entries. Reduces data entry errors, minimizes troubleshooting and rework.
Need extensible/variable solutions	Provide interoperability to support multiple carriers NASA, LV providers, spaceports, & spacecraft have different needs ▪ Organizations like NASA deal with multiple contractors, users and LV providers and need to consolidate variations ▪ LV providers have working systems and want to minimize impacts driven by external changes

XML – An Enabling Technology

XML is a key enabling technology for information exchange problems. It has existed since 1996, and was established as a standard[2] by the World Wide Web Consortium in 1998. XML is a structural and semantic markup language. The power of XML lies in its simplicity, its support in the commercial community, and its relationship to the Internet. XML has its root in other markup languages (e.g., Hypertext Markup Language (HTML) and Standard Generalized Markup Language (SGML)) that deal with data format. XML allows a user, or community of users, to define a set of markup tags that capture the inherent structure of the data. The components of the structure are called elements, and these elements are constructed in a hierarchical form. Unlike HTML, which uses tags to define data presentation, XML uses tags to describe data content. This provides a mechanism for coupling the meaning of the data with the data itself, and makes that meaning available to software.

XML consists of an *extensible* set of rules for designing text formats to structure data. It is an incredibly simple, well-documented, straightforward data format. It allows users to define a new document format by combining and reusing other formats. XML elements can be embedded and layered in complicated patterns.

Since XML is portable and license-free, there is no cost to use it, but you still have to build your own database and your own programs and procedures that manipulate it.

Some of the major benefits of using XML for application to this research include:

- The structured document format enables essential data and structural meaning of information to be captured in a human readable form, rather than embedded in software
- XML provides database structure with capability for OO design concepts such as abstraction, inheritance, and encapsulation, without having to adopt expensive OO database management systems. These features promote reuse and scalability, minimizing redundancy and reducing maintenance
- It is standardized and extensible, providing users and developers with the capability to adapt databases for custom and/or domain specific applications. XML is a controlled standard that is open and designed to be extended.
- XML database information can be formally defined yet loosely coupled to software application. XML does not specify or restrict how data is processed or used, only how it is described. It ensures a standard method for exchanging data and data definitions is always available
- Open source software tools and libraries are numerous, readily available, and free (or inexpensive), providing such features as: parsing, editing, networking, validation, import/export, and display. Tool support is readily available in all major programming languages and environments.

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[2] W3C Recommendation - Extensible Markup Language (XML) 1.0 (Second Edition)", www.w3.org/TR/REC-xml, Oct. 2000.

The Emerging XTCE Standard

The Object Management Group[3] and a number of major US and international industry and government aerospace organizations have collaborated to produce the XML Telemetry and Telecommand Data (XTCE) Specification. The XTCE specification is intended as a way to describe telemetry and command "databases" as used in space and ground telemetry systems, packet, and TDM based systems. The XTCE is only a specification, not a service. The intent is to allow the easy interchange of these databases between systems and organizations.

OMG's vision for the XTCE is that it will one day be the "native" format for ground systems. Until that time, companies and organizations can use converters to go from one system to another, or can convert an existing database into this format for exchange with other parties.

Currently in 2nd draft release, the XTCE standard is projected for approval in 2004. The scope of the specification includes:

- Telemetry data definition including support for CCSDS packets as well as TDM frames
- Data manipulation algorithms to support packaging and unpackaging of individual data items
- Commanding data definition including command identification, argument specification, and validation criteria
- Data representation definitions
- Data properties including such things as it default value, validity criteria, and data dependencies
- The definition of extensible formats such that blocks of information can be portrayed in this architecture

The XTCE uses *XML Schema* to describe TM/TC information. The XTCE schema is organized in to seven separate schemas: 1) Space System, 2) Parameter, 3) Common Types, 4) Packaging, 5) Algorithm, 6) Stream Definition, and 7) Command Definition.

The XTCE schema is a hierarchical structure, mimicking the organization of space systems, which are typically systems within systems. The hierarchical approach is useful for minimizing name space collisions, more manageable organization, and implicit inheritance of features from higher levels to lower levels. It consists of a collection of space systems including space assets, ground assets, multi-satellite systems and subsystems.

Other Related Standards

TMATS

The Telemetry Group of the Range Commanders Council (RCC) introduced the Telemetry Attributes Transfer Standard (TMATS) in 1993, presented as Chapter 9 of the IRIG Standard 106. The purpose of TMATS is to provide a common definition and format to facilitate the transfer of information between the user and the test range and between ranges.

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[3] Object Management Group (OMG), www.omg.org

"The format, while not necessarily compatible with any receiving/ processing system, will allow test ranges or other receiving systems to develop a computer conversion program to extract the information and to set up data required for their unique equipment configuration."[4]

The telemetry attributes are defined such that the information required to set-up (configure) the telemetry receiving and processing equipment is provided. The TMATS description of the mission configuration includes attributes categorized into general information, transmission, tape source, multiplex/modulation, digital data (PCM/1553), PAM, data conversion, and airborne hardware.

ASN.1

Abstract Syntax Notation One (ASN.1) is a formal notation used for describing data transmitted by telecommunications protocols[5]. ASN.1 was first standardized in 1984 by the International Telegraph and Telephone Consultative Committee (CCITT). ASN.1 is a data-definition language for defining protocol syntax and the information that an application exchanges between systems. It provides the ability to describe the information that will be exchanged independent of the way that information is represented on each of the communicating systems. Several ANS.1 areas are planned for XML work, notably the provision of ASN.1 XML Value Notation, and XML Encoding Rules (XER).

Standardization Issues

There is a proliferation of data representation standards, often making it difficult to determine exactly what is the 'standard' for a given domain. Instead of determining a path that ensures compatibility, organizations must either adopt a set of related standards or try to choose the one that seems to be more 'preferred' within their domain. This non-deterministic approach introduces inherent risk when investing in a new system built around a specific standard that may become obsolete or rarely used. Once a standard is adopted, it tends to become tightly integrated into systems and processes. Users and operators become familiar with specific keywords and syntax, and special tools are purchased. Eventually, organizations become financially committed to maintaining legacy compliance and tend to resist migrating their systems to adopt new standards.

Although standardization enables interoperability, the standards themselves continue to evolve. In the long-term, adaptability is the key to survival for large-scale systems that rely on standardization. These systems need an approach that abstracts external standardization details from internal components and operations. Systems and organizations that are insulated from, or loosely coupled to, the intricacies of standards compliance can take a more practical approach in the near-term, and have a cost effective means to adapt and evolve in the future.

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[4] Range Commanders Council (RCC), IRIG Standard 106-01, http://jcs.mil/RCC

[5] Abstract Syntax Notation One (ASN.1), http://asn1.elibel.tm.fr/en/index.htm

Relevant CCT Experience

Control and monitoring of spacecraft systems is CCT's core competency. In addition, CCT has significant experience applying XML technology to solving typical control and monitoring data definition problems. We rely on XML for virtually all our data definition chores.

CCT's flagship product, The Command and Control Toolkit™ (CCTK), incorporates an XML database for all stream and data definitions, including telemetry interfaces for PCM data acquisition, simulation and data transmission. However, when CCT decided to significantly leverage XML technology a few years ago, it had nothing to do with standards, and everything to do with using a great technology for describing and exchanging information that provided our product line with ease of reconfiguration, decoupled our core software from proprietary database management systems, and enhanced extensibility and flexibility to new applications. In fact, at the time we transitioned to using XML, there were no standards like XTCE even on the drawing board.

The CCTK product line employs exclusive use of XML for all data description. This includes:

- Measurement data definitions and properties including default value, validity and exception criteria
- Data manipulation algorithms including commutation/decommutation of individual data items and EU conversion
- Commanding data definitions including argument specification
- Notification definitions including user-defined and system error messages
- Extended to telemetry data definitions for TDM frames (digital PCM signals)
- Extended to HW I/F configuration parameters including device drivers and I/O cards

CCT has collected a number of lessons learned from our experience using XML that are directly applicable to this research proposal. The following is a summary of those lessons learned:

Software architecture, design, and implementation Lessons Learned

Long-term success is directly related to the overall software architecture and the corresponding database analysis and design effort.

- Domain analysis identifies requirements and determines appropriate architecture and database approach
- Technology forecasting decisions have both short and long-term implications. Example: Schema verses (Data Translation Document) DTD[6]. The original DTDs allow for simplistic content definition, but use a somewhat arcane/awkward syntax with limited built-in text-based data types. The newer Schemas are more complex, but allow syntax and schemata defined using XML format, include simple and complex data typing, support for namespaces, and inheritance
- Extending XML can lead to a proliferation of unique and non-standard languages

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[6] There are two document formats supported by XML for data description. One is schema; the other is data translation document (DTD). Schema evolved after DTD.

Adopting XML and integrating it into a legacy system is a non-trivial commitment that can initially require a substantial software implementation effort.

- Legacy approach will be a significant decision driver and can be a design constraint. XML is open but programming language, operating system or hardware platform can still be significant factors. System configuration and initialization, both hardware and software, will impose database requirements
- Open source approach deserves careful consideration. The Potential for long-term cost savings are substantial, but some research is needed to avoid common pitfalls. It requires fewer software developers, but a more sophisticated and knowledgeable development team. It also allows greater flexibility, portability, and interoperability when used properly

Data management Lessons Learned

Ingest and exchange of raw/bulk data is application dependent

- XML enables simplified data ingest and exchange, but does not do it for you. A common solution will usually not be appropriate for multiple different applications. Almost any solution will require some software development effort.
- Methods used depend on data type, source, quantity, stability, availability, etc.

The user interface approach for interacting with XML databases needs to be addressed

- Manual data entry will not be eliminated, plan for editing of XML documents
- GUI solutions are not always the most appropriate, but users will almost always want one anyway. You should attempt to use standard text editors, but if a custom GUI is required, try to keep it simple.

The Concept

The proposed concept is to introduce technology that will ease the adoption of a common data definition and exchange standard across a heterogeneous space operations domain. The solution requires identification and development of an interoperable set of domain-specific services and middleware that can help the current legacy infrastructure adapt and evolve towards a generic control and monitor capability.

A domain analysis will be performed to identify data definition exchange features that are common across all systems and those that are different for specific systems. The common capabilities, such as accessing and validating data descriptors, will define the basic features of the exchange services. The differences such as system-specific configuration parameters, legacy software interfaces, custom data structures and file formats, will be handled by incorporating variation points into the software architecture design. These variation points will allow for a controlled customization of the exchange services package for a particular application instance.

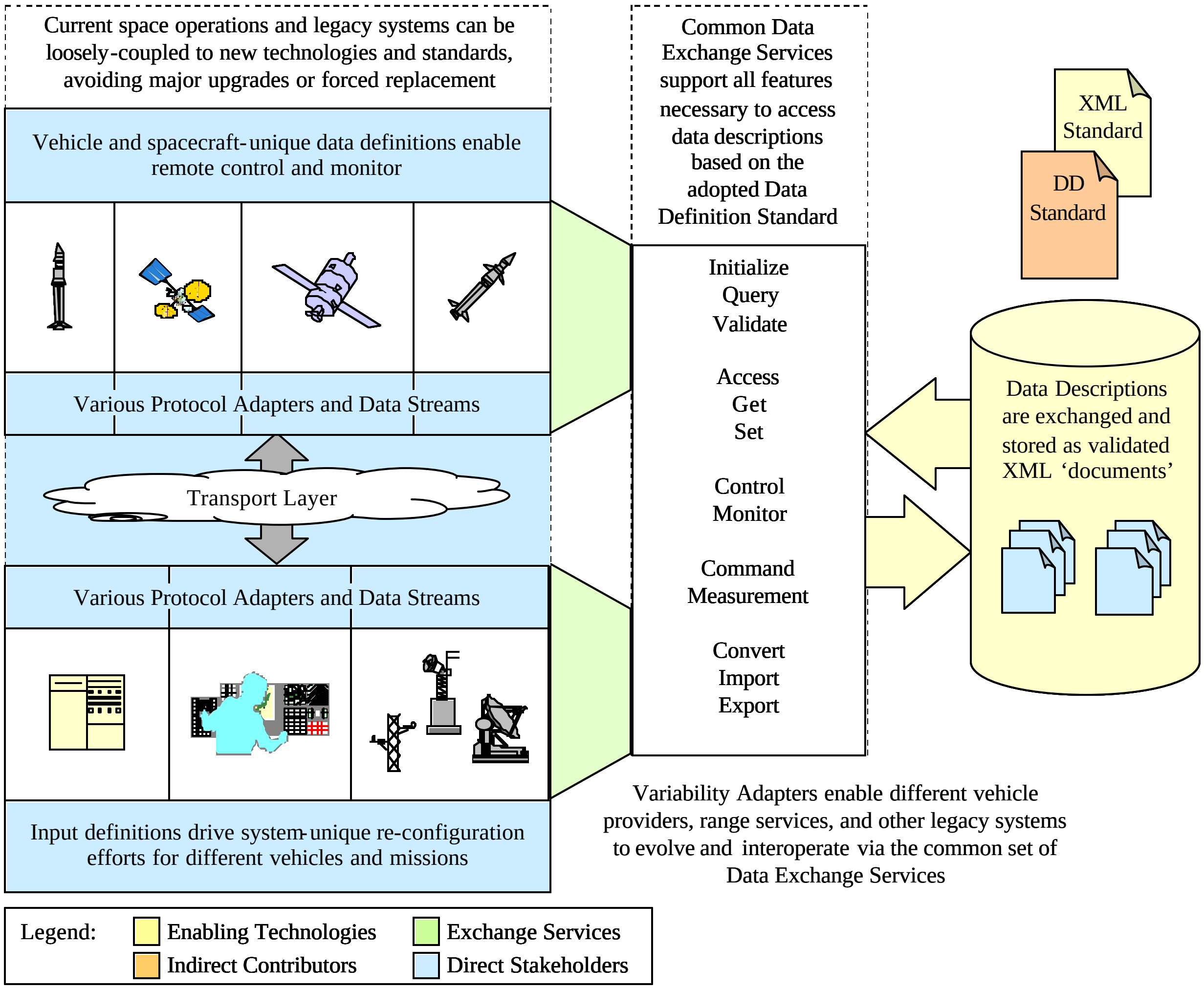

Figure 2 General concept

The approach, illustrated in Figure 2 above, seeks to prove the viability of using a standard communications exchange and data definition language to enable heterogeneous systems to interoperate on a platform independent basis. The advanced data description exchange services will provide a reusable framework of loosely coupled software components that can be configured in different ways to produce solutions optimized for a particular system.

The incorporation of generative programming techniques will provide a means for future evolution so that systems can continue to adapt and maintain compliance with minimal software development effort. The program generation for a particular system instance is facilitated by a standardized procedure, or checklist of decisions, for specifying the options and variations that will cause an optimized solution to be generated. The focus of the optimization will be to maximize interoperability within the domain in the most cost effective manner. For many legacy systems, the solution that requires the least amount of change to the existing infrastructure and causes the least operational impact is the most cost effective.

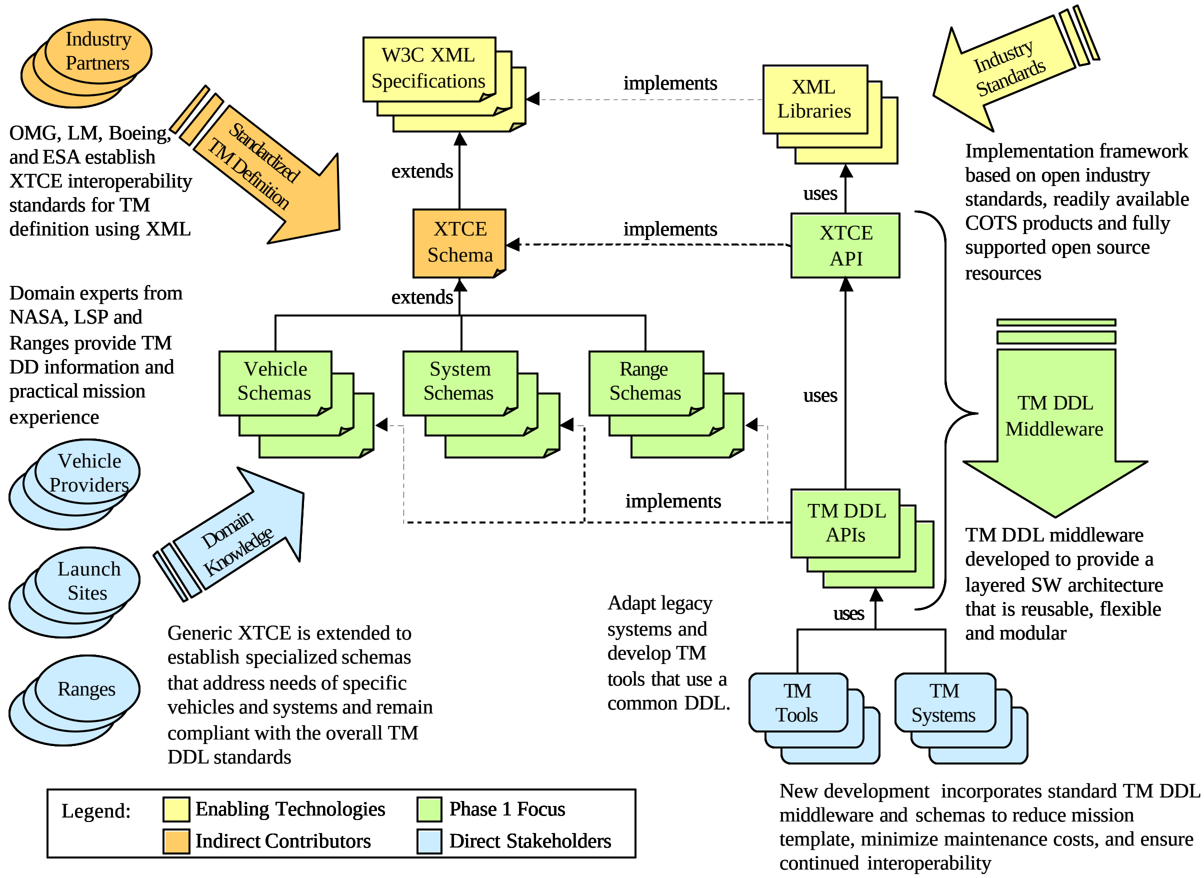

Figure 3 Phase 1 focus concepts - telemetry exchange

Figure 3 depicts an instance of this concept specific for telemetry data definition exchange, using XTCE as the telemetry and command description standard.

Directly Related Outside Work

Directly related published work includes:

- W3C Recommendation - Extensible Markup Language (XML) 1.0 (Second Edition)", www.w3.org/TR/REC-xml, Oct. 2000
- Object Management Group, XML Telemetry, and Telecommand Data Specification – Draft Adopted, http://www.omg.org/docs/dtc/03-05-07.pdf, May 2003
- Range Commanders Council (RCC), IRIG Standard 106-01, http://jcs.mil/RCC
- Abstract Syntax Notation One (ASN.1), http://asn1.elibel.tm.fr/en/index.htm
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- J. C. Cleaveland, "Program Generators Using XML and Java", Prentice-Hall, XML Book Series, 2001, http://craigc.com/pg/

Relevant CCT R/R&D

CCT's primary interest in this research is the potential for incorporating the resulting technology into our command and control product line. CCT engineers have participated in many projects that required the use of data and command description languages similar to what has been discussed earlier in this proposal. In addition, as discussed in section 3, CCT's core product line heavily leverages technologies that are directly applicable to this proposed research. CCT has invested heavily in R&D in the last 2.5 years in information exchange technologies that directly support our products and our customers.

The Command and Control Toolkit™ (CCTK) is a commercial CCT product used to develop turnkey vehicle control systems. The CCTK provides a framework for command and control systems including real time messaging, archival and retrieval functions, and multiple plug and play data interface support. CCTK is easily customized with COTS tools and custom software to readily fit varying applications. The CCTK is based on a commercialized NASA technology developed for Space Station ground operations. This SBIR project is designed to augment ongoing design and development work in this area to the mutual benefit of NASA and CCT.

Summary

The current lack of standardization for exchange of telemetry and commanding information is clearly a problem in search of a solution. The emerging OMG XTCE standard is a step in the right direction; however, successful interoperability requires adaptation of a variety of legacy systems. Without supporting tools, like we have proposed in this paper, that ease the burden of standards adoption a new standard may not be affordable for most.

CCT's experience with XML in telemetry and command applications over the last three years has proven that there are tremendous benefits in using XML as a semantic description language both for exchange and native configuration description. Our experience has also taught us that adopting XML is not necessarily a simple undertaking. In fact, it can be tedious and software intensive requiring a significant engineering effort; however, we see this as an opportunity rather than a problem. We plan to leverage our in-depth XML skills, the new XTCE standard, and R&D support from organizations with a need to improve the state of semantic knowledge exchange, to create a generic cross platform suite of tools that significantly ease the adoption of XML and XTCE as a telemetry and command description language.

We are currently in the design phase of this process and are seeking collaborators and contributors to this effort. Success will require a broad cross section of input from the ground systems domain. We currently have limited financial support from NASA under the SBIR program, and some additional matching funds contributed from the Expendable Launch Vehicle community for an application specific pathfinder. We have received technical support from the NRO, and the Air Force. Other participants are welcome and desirable.

We plan to complete the 1st prototype that focuses primarily on telemetry in the 3rd quarter of 2004. Somewhat concurrent with completing the prototype, we are seeking phase 2 NASA SBIR funding in addition to funding from other stakeholders that will allow us to produce a fully functional tool suite for telemetry and commanding. Organizations interested in participating, contributing to the effort, or simply interested in obtaining more information should contact Rodney Davis, 321-264-1193 x120, davisrd@cctcorp.com.