Sharing Telemetry across Organizations and Systems

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***Abstract*— The XTCE (XML Telemetric and Command Exchange) standard provides a way to describe space mission telemetry and command "databases" (or dictionaries) to be exchanged across centers and space agencies. Having a standard format for describing the telemetry and command formats allows for the development or adoption of compatible tools and significantly reduces the amount of custom software development often needed to ensure all system components have access to consistent format definitions. The main objective of this paper is to show how powerful XTCE is in terms of interoperability across organizations. This paper summarizes work which entailed converting the mission telemetry database for a current NASA mission, in XTCE format, into several target mission operation databases associated with different telemetry and command toolchains, and then, comparing the results of the telemetry processing and display. The target toolchains selected were Ball Aerospace/COSMOS, NASA-GSFC/ITOS (Goddard Space Flight Center/Integrated Test and Operations System), and NASA-AMMOS/AMPCS (Advanced Multi-Mission Operations System/Mission Data Processing and Control System) – all real-time telemetry and command processing systems.**

Keywords—XTCE, telemetry, standards

I. Introduction

At NASA, we have investigated approaches to address the rising need to share and interpret information across centers and space agencies. We performed an examination of XTCE's applicability to the NASA Advanced Multi-Mission Operations System (AMMOS) to meet our mission needs. AMMOS is NASA's recommended provider of multimission products and services for NASA space science missions, particularly missions exploring our solar system and beyond [1]. This recommendation is based on the high quality, low risk, and cost effectiveness of AMMOS products and services. AMMOS is managed by the Multimission Ground System and Services (MGSS) Program Office within the Interplanetary Network Directorate (IND) at the NASA's Jet Propulsion Laboratory (JPL).

II. Why XTCE?

XTCE is a possible solution to the challenges of telemetry and command sharing across systems and organizations, which currently depend on proprietary formats, incompatible among GOTs (government off-the-shelf) and vendor tools. Given that XTCE is a standard for command and telemetry definitions using an information model defined as an XML schema, it can be used to create common command and telemetry descriptions shared among XTCE-compatible components increasing interoperability.

Information within a mission setting held in XTCE can be shared between spacecraft and instrument manufacturers, instrument, simulators, trending, real-time telemetry and command processing, among others. The stakeholders may be internal and/or external to an organization. For example, a JPL mission may contain an instrument from another national space organization. In effect, XTCE may serve as the exchange format used between different organizations both within and eternal to them -- and may allow for common telemetry processing or commanding across various systems and processes.

A. What is XTCE?

XTCE [2] is a standard XML Schema published by the Object Management Group (OMG), jointly with Consultative Committee for Space Data Systems (CCSDS).

Mission operations description (i.e. "database") formats for telemetry and command are typically file based. These files are used to configure software for particular telemetry and commanding toolchains. The common idiom "mission operations database" is regularly used in the industry for these file formats, and will be used throughout the remainder of the paper.

Traditionally, the descriptions are written in a proprietary format and tied to the specific toolchain in question and organization. Usually, the formats are custom languages, XMLs, text tables or other readily processable forms. All over the world, most organizations that run space missions have gravitated to this "model" to support the telemetry and commanding of the spacecraft.

XTCE contains the typical information related to telemetry and command descriptions found in these existing proprietary mission databases. That information includes items such as packet and mnemonic descriptions, calibrators, limits, and commands. An important advantage is that XTCE is an open standard in the public domain – this means any organization or vendor can support it – and many do at this time.

III. XTCE INFUSION PROGRAM AT NASA

We have developed processes [3] that allowed us to assess the suitability of XTCE to support our missions. We quantified the ability for XTCE to capture the telemetry and command definitions of our current missions and the steps taken to help move towards total compatibility between XTCE with minimal augmentations and our existing capabilities at JPL.

Our team has worked on a set of support tools (Conversion, Validation, Compliance measurement) that has been able to quantify usability of XTCE and demonstrate round-trip capability for some sample missions such as the Juno mission to Jupiter and the Mars Odyssey mission.

The adoption of XTCE may reduce software maintenance costs by reducing or eliminating the need to support multiple formats between our existing mission dictionaries and toolchains that all have their own formats – which is all too common today even within the same organization.

Tools have been developed to convert between XTCE files and AMMOS Multi-Mission Dictionaries (MMDs) at NASA. The "MMD dictionaries" represent the mission operations database for AMMOS.

IV. MISSIONS USING XTCE

The following are a sample of missions that use XTCE:

- GOES 16 & 17
- NASA Orion
- NASA SLS
- Iridium NEXT
- WorldView-4 (DG)
- Orbital Express (ASTRO & NextSAT)

V. USE CASES PERFORMED AT NASA

We performed some use case tests with the Juno mission, Soil Moisture Active Passive (SMAP), Odyssey, and Lunar Reconnaissance Orbiter (LRO) to showcase the advantages of using XTCE across systems and organizations. In this paper, we are showing the latest results with the LRO mission.

VI. MOST RECENT RESULTS WITH THE LRO MISSION

A. Testing XTCE in a Realistic Scenario

Our main goal was to convert the LRO database to XTCE and then identify several "target" toolchains that would accept this file so that they could be configured to process LRO telemetry data. For us, this represented both multiple vendors and multiple organizations.

These toolchains represent recipients of mission telemetry that are not within the operating organization or new software products not part of the original operations architecture.

This model is one of the key goals of XTCE – to allow the easy support of a wider variety of toolchains outside the "four walls" of the user's organization – a one to many relationships between XTCE and possible toolchains – inside or outside the mission's organization.

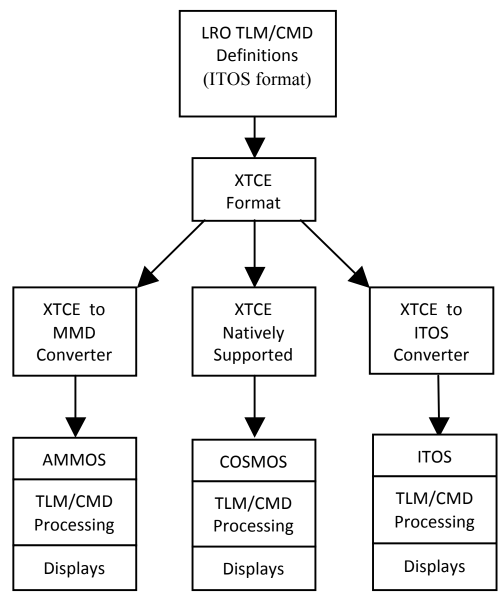

Fig. 1. Block diagram of the processing performed with different toolchains

B. The LRO Mission

LRO [4] is a robotic mission that was launched in 2009 to map the moon's surface and, after a year of exploration, was extended with a unique set of science objectives. LRO observations have enabled numerous groundbreaking discoveries, creating a new picture of the moon as a dynamic and complex body. LRO mission operations area is located at NASA GSFC.

C. The Original Mission Database

LRO mission operations provided the spacecraft database and telemetry samples to use in our XTCE tests.

The contents of the LRO telemetry database include descriptions for all the telemetered packets that the LRO satellite sends to mission operations. The telemetered packets follow the CCSDS format.

Each telemetry packet has a header and time stamp – and an identifier. The identifier has a range of 0-2047 and is called the "application identifier" or "APID".

The overall LRO packet "map" consists of 143 packet descriptions (telemetered directly), which include over 500 conditional packet fragments, giving at least 11,000 mnemonics.

The database is in ITOS format – one of two GSFC ground system toolchains. The LRO mission also supplied a report of the database contents and several telemetry files from recent operations that were also used in our tests.

D. Telemetry Datasets

LRO delivered several telemetry binary data packet files containing a snapshot of telemetry packets from several passes – already assembled from the traditional CCSDS frame telemetry stream and in time order.

E. Target Toolchains

With the example real mission database, we focused our attention on the toolchain targets. That is -- assuming we successfully converted the LRO telemetry database to XTCE – then what we would do with it?

We identified several possible target toolchains for various reasons as follows:

1. *ITOS Target – a quick check for conversion correctness.*
2. *Ball Aerospace COSMOS – Ball Aerospace COSMOS is a freely available telemetry and command tool from the web, and it can support XTCE as its database, directly.*
3. *NASA AMPCS – NASA AMPCS is part of the NASA AMMOS tool suite for ground telemetry and command processing that can support XTCE through conversion tools.*

Several of these had existing XTCE software support making our job easier, COSMOS has both an importer and supports XTCE natively as its database.

TABLE I. TOOLSCHAINS AND EXISTING XTCE SUPPORT

	Import XTCE TLM Definitions	Export XTCE TLM Definitions	Import XTCE CMD Definitions	Export XTCE CMD Definitions
ITOS	Existing	No	No	No
Ball Aerospace COSMOS	Existing (&Native)	Existing	Existing (&Native)	Existing
NASA AMPCS	Existing	Existing	Existing	Existing

F. XTCE Tools Created for the Project

Conversion to XTCE involved several steps and creation of new tools and modifying existing XTCE tools:

Step 1

- *Convert new ITOS database information to XTCE*
- *Validate definitions (if appropriate)*

The resulting file after step 1 became the "Root LRO XTCE File" and would be further manipulated as needed per the toolchain feature support without changing its fundamental descriptions [Table II].

Step 2

- *Import to the current version of ITOS using existing conversion tools into AMPCS*
- *Use XTCE as the database file in Ball Aerospace COSMOS.*

We generated one single LRO XTCE file from the original LRO database information that is being distributed to the various tools. Normally each tool team would be responsible for adapting any feature support issues, but we performed that task here.

TABLE II. TARGET TOOL FEATURE ISSUES

Issue	ITOS	Ball Aerospace COSMOS	AMPCS
Byte Order	All	Big/Little	Big as of V7.3
Arrays	Yes	Yes	No
Forced Naming Convention	No	No	JPL Specific
LimitSet	Yes	No	Yes
Time Formats	Yes	No	1
CCSDS Knowledge	Yes	No	Yes
Plots	Limited	Yes	Yes

After this process was completed, we were able to capture mnemonics values and generate plots to compare results, some of which are shown in the next section.

G. Checking XTCE Validity using File Comparison

In order to validate that the XTCE conversion was performed correctly, we develop concise text based report files from the original toolchain of the database, as well as similar concise reports from the converted XTCE file and one target toolchain that contains the key aspects of the database.

Once these concise reports are generated, simple scripts and tool like "diff" can be used to determine that the databases in each toolchain have identical information by comparing these text records.

Validation should not be overlooked, and should be included in the project development plan.

H. LRO Database Feature Set

After the conversion of the LRO telemetry database to XTCE, the following statistics were produced concerning its contents:

TABLE III. LRO DATA STATISTICS

Feature	Items
Total Telemetered Packet Descriptions (APID=11 bits)	143 (not counting conditionals)
Total Mnemonics Defined in Packets	~11k
Total Simple Limits	700
Total Set Limits	1116
Total Poly Cals	664
Total Linear Cals	0
Total General Expression Cals	66
Total Mnemonics Big Endian	11333
Total Mnemonics Little Endian	36
Total Mnemonics Other Endian	43
Total Flat Named Mnemonics (e.g. BatVolt1)	~11k
Total Array Named Mnemonics (e.g. BatVolt[1])	290
Total Hierarchically Named Mnemonics (e.g. Bat.Volt1)	0
Total Time Formats	6

All of these features were considered for XTCE – but there were some exceptions such as "range enumerations" which associate a numeric range with a label. We were satisfied that most of these issues will be addressed in XTCE 1.2.

I. Checking XTCE Validity using Telemetry Processing

We used LRO telemetry data samples files that contain packets assembled from the raw telemetry stream in time order. The packets have a CCSDS header.

In theory, each packet APID should match a description with the same APID in the database so that it can be fully decommutated per the description in the selected toolchain (e.g. first 4 bytes: unsigned integer, next 4 bytes: IEEE-785 float). The following table [Table IV] describes their basic contents:

TABLE IV. DATA FILES EXAMPLES

File name	Total Packets	Approx. Time Span in Seconds
SC_2016222_0029351.hk	813670	6800
SC_2016222_0029352.hk	825978	6900
SC_2016222_0029353.hk	823421	6900
SC_2016222_0029354.hk	825876	6900
SC_2016222_0029355.hk	828968	6900
SC_2016222_0029356.hk	839121	7000
SC_2016222_0029357.hk	824379	6900
SC_2016222_0029358.hk	830829	6950
SC_2016222_0029359.hk	830496	6950
SC_2016222_0029360.hk	826277	6900
SC_2016222_0029361.hk	821202	6800
SC_2016222_0029362.hk	802852	6700

We processed the same packet files through our target toolchains using the same XTCE file and comparing results. We decided to compare data samples of representative set of mnemonic values and to plot them as well for a visual confirmation.

J. Decommuted Data Samples:

TABLE V. SAMPLE 1: ACRW1P28SWV RW 1 +28V SWITCHED VOLTAGE – CALIBRATED VOLTAGE

LRO Packet 70	
Cosmos	*AMPCS*
ACRW1P28SWV	*ACRW1P28SWV*
32.02792969	32.02793055
31.97285157	31.97285243
32.00039063	32.00039149
32.00039063	32.00039149
31.91777344	31.9177743
31.89023438	31.89023524
31.9453125	31.94531336
31.9453125	31.94531336
31.9453125	31.94531336
31.9453125	31.94531336
31.89023438	31.89023524
31.91777344	31.9177743
…	…

The data aligns, except minor differences in the lower order values due to implementation differences (Ruby vs C/Java).

TABLE VI. SAMPLE 2 -- SWACISAANGLE1 - SOLAR ARRAY GIMBLE ANGLE IN RADIANS

LRO Packet 244	
Cosmos	*AMPCS*
SWACISAANGLE1	*SWACISAANGLE1*
…	
-1.265014642	-1.265014642
-1.265145542	-1.265145542
-1.265276441	-1.265276441
-1.265538241	-1.265538241
-1.26566914	-1.26566914
-1.26580004	-1.26580004
-1.266061839	-1.266061839
-1.266192739	-1.266192739
-1.266323639	-1.266323639
-1.266454538	-1.266454538
-1.266716338	-1.266716338
-1.266847238	-1.266847238
-1.266978137	-1.266978137
-1.267239937	-1.267239937
-1.267370836	-1.267370836
-1.267501736	-1.267501736

A few of the initial samples were missing from the AMPCS files but then the data aligned perfectly for the remainder of the 20,000 values extracted. This issue is due to the fact that the mission telemetry files start with malformed packets and each toolchain handles these differently before "syncing up" on the real packet data.

TABLE VII. SAMPLE 3 -- ACST1STARNUM - STAR TRACKER STARS TRACKED

LRO Packet 89	
Cosmos	*AMPCS*
ACST1STARNUM	*ACST1STARNUM*
9	9
9	9
9	9
9	9
9	9
9	9
9	9
…	…

The data continues and aligns perfectly.

K. Comparison of the Processed Telemetry by Plotting

The selected systems supported plotting of the telemetered data, which we used as a visual correctness check. There are some variations due to implementation issues. One major issue is that the COSMOS plot tool is not using the packet time stamps for the x-axis. Up to this time, we have not found a way for it to support it.

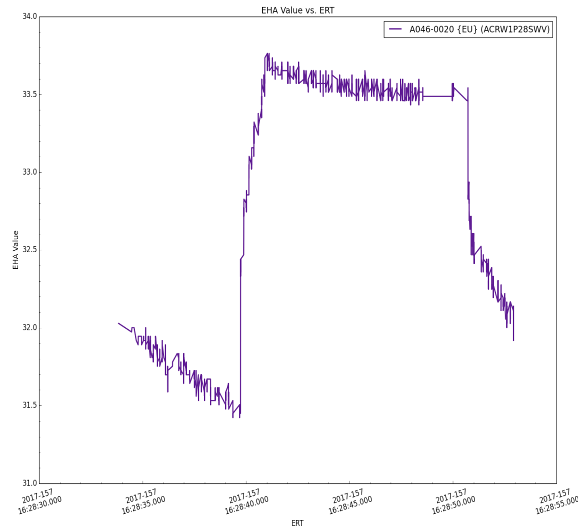

Fig. 2. NASA AMPCS. The first plot shows the telemetry processed by AMPCS (packet 70)

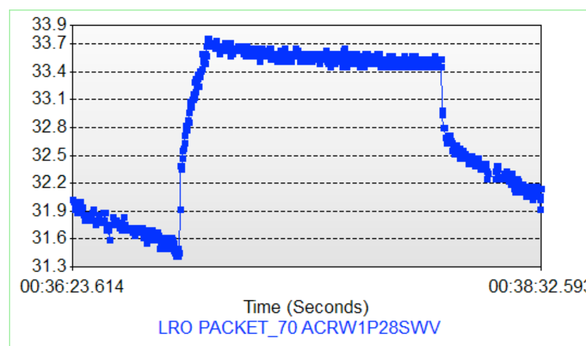

Fig. 3. Telemetry processed by Ball Aerospace COSMOS (packet 70)

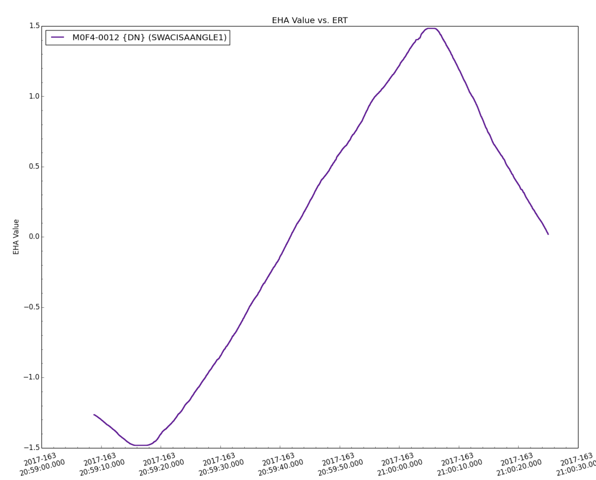

Fig. 4. .NASA AMPCS processed telemetry (packet 244)

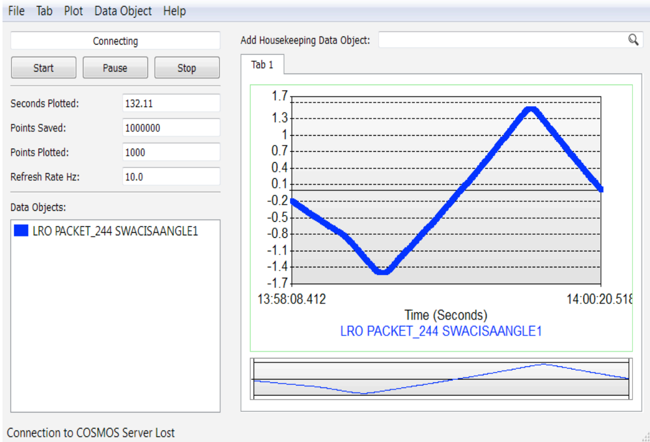

Fig. 5. Ball Aerospace COSMOS processed telemetry (packet 244)

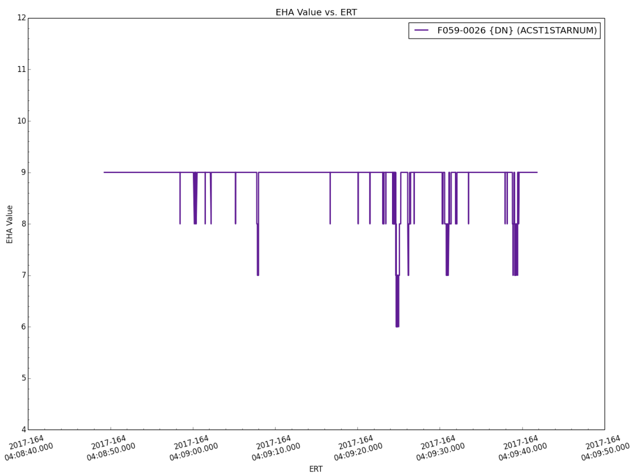

Fig. 6. NASA AMPCS processed telemetry (packet 89)

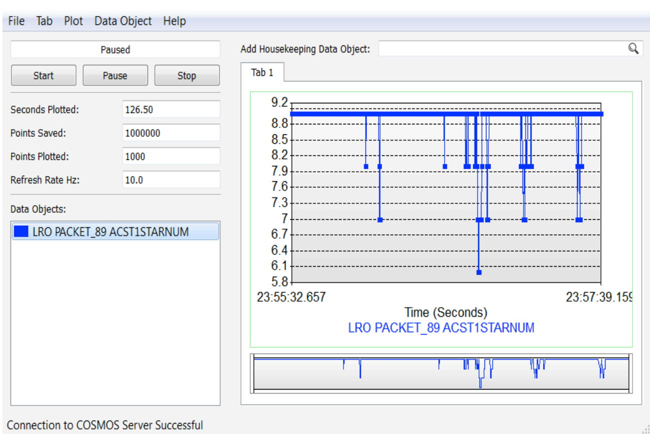

Fig. 7. Ball Aerospace COSMOS processed telemetry (packet 89)

L. Overall Results

We were able to successfully run three telemetry and command tools and process the telemetered engineering packets from one XTCE file and obtain similar results. We were able to compare telemetered values easily – sampled data values and telemetry plots.

VII. Benefits of Using XTCE Based on Our Results

Our results show the potential of XTCE to offer new levels of interoperability, because we were readily able to share the XTCE database among different toolchains and process the mission telemetry with minimal issues – which illustrates our vision of how XTCE can increase interoperability for an organization. In our use case, we have first quantified the ability for XTCE to capture the telemetry definitions of the Lunar Reconnaissance Orbiter (LRO) mission by use of our suite of support tools (Conversion, Validation, Compliance measurement). The next step was to show processing and monitoring of the same telemetry in two NASA centers (JPL and GSFC). The ability to take a real mission database and real mission telemetry (LRO) and display them on various tools from two centers (NASA GSFC and NASA JPL) by conversions, as well as using a commercially free tool from Ball Aerospace COSMOS that natively supports XTCE, shows that potential of using a standard as XTCE across systems.

VIII. Future Plans

Future plans include supporting NASA missions that use the XTCE standard with our tool suites in their collaboration with other space agencies or among NASA centers. Finally, the XTCE tools developed for this work will be incorporated into the NASA AMMOS catalog [5] so that NASA missions will be able to use it with XTCE support.

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