XTCE Tailoring for the European Space Agency

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XML Telemetric and Command Exchange (XTCE) is a CCSDS standard that defines a model for describing spacecraft telemetry and commanding data. The adoption of XTCE by an organization involves the definition of a tailoring guide that describes how to adapt the standard to the organization needs. This paper describes the tailoring defined for the European Space Agency, and the tailoring approach followed, which has been defined in collaboration with NASA, and could also be adopted by other organizations.

I. Introduction

XML Telemetric and Command Exchange (XTCE)[1] is a CCSDS standard that defines a model for describing spacecraft telemetry (TM) and commanding (TC) data. Its goal is to facilitate the exchange of TM and TC data across the different organizations and systems involved in the lifecycle of a space mission.

Figure 1 illustrates some typical usage scenarios for XTCE, during the Assembly, Integration and Validation (AIV) and Operations phases of a mission.

During AIV, TM/TC data are typically managed both at spacecraft subsystem/payload level and at spacecraft level; ultimately the TM/TC data of all the spacecraft subsystems are integrated into the Spacecraft Database (SDB), which contains the whole spacecraft TM/TC. Several systems make use of the SDB for spacecraft testing, including the EGSE (Electrical Ground Support Equipment), database editors, procedure generators, etc.

In the Operations phase, the SDB is taken as input to generate the Operational Database (ODB) which is used for spacecraft monitoring and control by a number of ground systems, including the major MCS (Mission Control System), MPS (Mission Planning System) and FDS

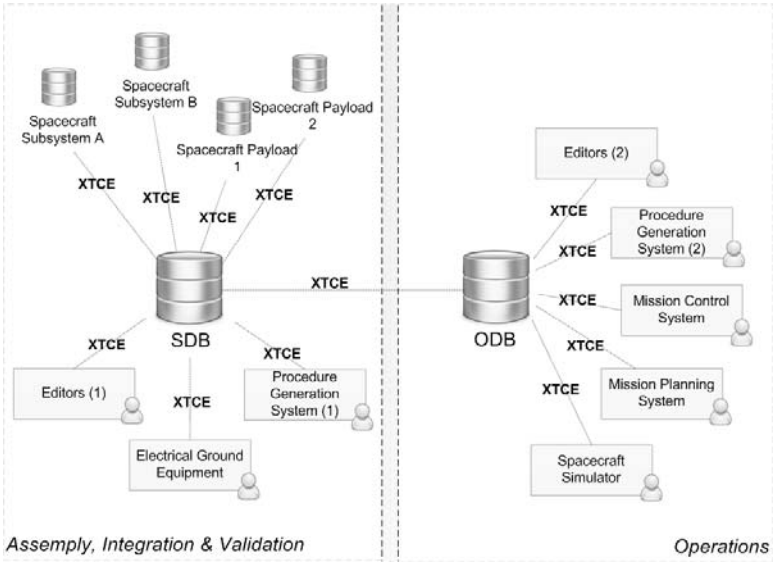

Figure 1. XTCE Usage Scenarios

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(Flight Dynamic System), and also simpler tools like database editors or procedure generators which have clear similarities with their AIV counterparts.

In a scenario where TM/TC is exchanged using several different data formats, each system needs to implement its own TM/TC handling software, and the use of the same TM/TC data by different systems requires format conversion tools which may be complex and error prone.

The use of a standard TM/TC data format would clearly improve the situation, enabling software and database reuse across systems and mission phases. Using XTCE has the additional benefit of enabling interoperability not only within an organization but also across organizations, due to its international nature.

Although the benefits of adopting XTCE are clear, it is not straight forward to do it. XTCE has been defined to support a wide range of heterogeneous spacecraft, which makes it very general and open in some areas. As a result, its adoption by an organization involves the definition of a tailoring guide that describes how to adapt it to the organization needs.

In this context, NASA has produced the "XTCE GovSat Tailoring Guide"[2], a tailoring of XTCE for a particular type of USA Government satellites. It defines rules that either forbid or restrict the use of certain XTCE elements, limiting the scope of the standard and specifying the way it shall be used in a precise way.

Similarly, ESA, supported by GMV, has defined the tailoring of XTCE for ESA missions. This tailoring is especially aimed at enabling the conversion of XTCE databases to the format used by SCOS-2000 (S2K), the ESA Spacecraft Control and Operations System. This would allow the use of XTCE databases by S2K-based Mission Control Systems and EGSE systems, as well as several other ground systems that interact with them.

Although the rules defined by NASA and ESA are different, the two agencies have cooperated in the definition of a common approach for formalizing the tailoring, which could also be adopted by other organizations, thus increasing the XTCE potential for interoperability and software reuse.

II. Rationale for tailoring XTCE

The XTCE standard is presented as an XML Schema with a single root object, which represents the space system; below it the TM and TC definitions are organized hierarchically following the structure of a real space system. A top level view of the schema is shown graphically in Figure 2.

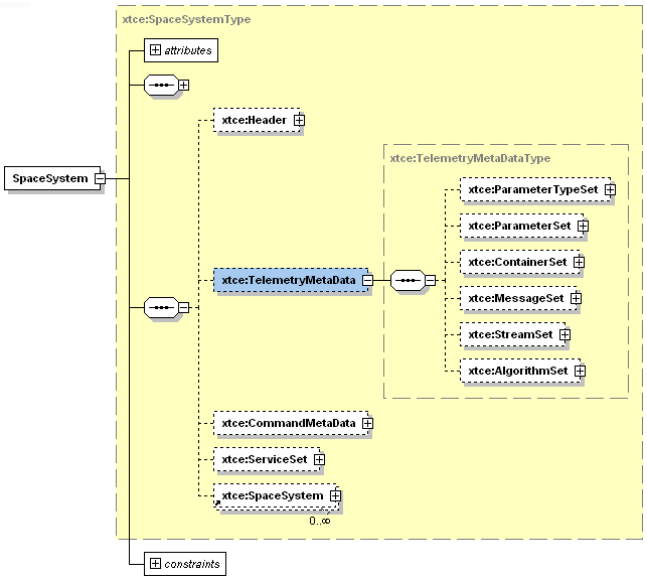

Figure 2. XTCE Schema

The schema has been defined to support a wide range of spacecraft, based on the needs of all the organizations that have collaborated in defining the XTCE standard. As a result it reflects various possible ways of defining TM and TC data, being very general in some areas, and allowing several options for defining the same kind of data in some cases.

As a result, an organization that attempts to adopt XTCE needs to specify (and ideally, standardize) the way the standard shall be used for its specific needs, in order to ensure interoperability. Typically:

1) As only a subset of the schema is really needed in most cases, it is necessary to specify the part that shall be used, and how to deal with mandatory elements that are not needed.
2) As the standard supports different ways of defining the same data, it is necessary to specify the selected way in each case.
3) If the standard does not support all the TM/TC data items that need to be used, XTCE must be extended to be able to incorporate such data.

In summary, the adoption of XTCE by an organization involves the definition of guidelines and rules for using the standard in a particular way. This is the reason why ESOC and NASA, among others, have defined their own XTCE tailoring guides.

III. Tailoring approach

A generic approach has been followed to adapt XTCE to ESA's needs. It was previously used by NASA to create its own tailoring, and it is generic enough to be used by other organizations for the same purpose.

The approach consists of systematically navigating the XTCE schema tree, and specifying rules for each of the elements in the tree, which must be met for a given XTCE database to be claimed compliant to the tailoring. The rules have different purposes:

1) Forbid elements or attributes that have no applicability in the specific context. For optional elements or attributes, the rule will specify that they must not be present, and for mandatory ones it will specify default values which must be enforced. This effectively downsizes the scope of XTCE to the specific needs, removing the difficulties caused by the excessive generality of the standard.
   Figure 3 illustrates the idea with an example.

2) Constrain elements in particular ways, for instance limiting the size of certain values or forcing a fixed number of elements within a list. This makes XTCE compatible with the organization's way of managing TM and TC data.

3) Extend elements in particular ways, through the use of the AncillaryDataSet item, an element of the schema envisaged for adding information to the supported types. The different ways supported by XTCE to hold additional data are described in more detail below in section A.

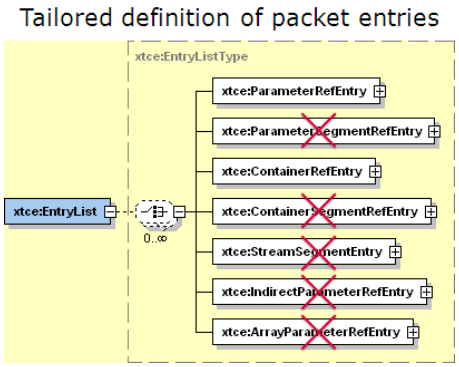

Figure 3. Tailoring Example. *From seven supported ways to define a packet entry in XTCE, only two are allowed.*

Figure 4. AncillaryDataSet Item

The tailoring is then formalized as a list of rules, which need to be enforced in addition to the compliance to the XTCE schema.

An additional element of the tailoring is a normative template file which shall be taken as starting point for the definition of compliant TM/TC databases. It contains fixed definitions that apply to all the databases used in the particular context. For instance, CCSDS packets would be defined in this template, and considered normative, when applying XTCE to CCSDS-compliant missions.

Overall, the tailoring consists of three elements:

1) The **tailoring guide**, describing the tailoring from a high level perspective in order to explain the content of the other two.
2) The **normative template**, providing fixed definitions which are considered mandatory and shall not be changed.
3) The **tailoring rules**, specifying the way the XTCE schema shall be used in a formal way.

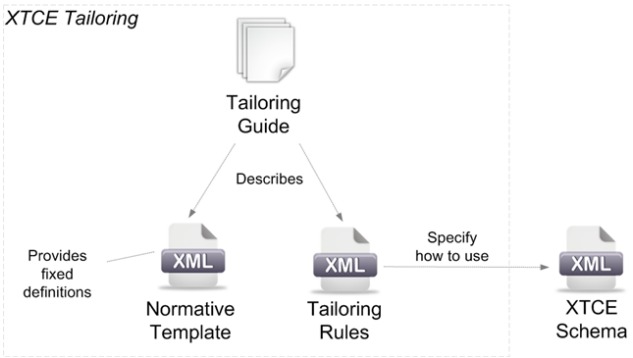

Figure 5. XTCE Tailoring Elements

Another generic aspect of the tailoring approach is the way the rules are formalized. It is done using XPath, an established standard which is supported by a wide range of XML software tools. Each rule is specified as an XPath expression that evaluates to true or false. This provides several advantages:

1) It prevents misunderstandings in the definition and interpretation of the rules.
2) It makes the verification of the rules easier. A single piece of software could be used to verify compliance to any set of rules, and could be shared by different systems and organizations.

Figure 6 illustrates how the normative template and the tailoring rules can be used in practice, in combination with the XTCE schema, to build compliant TM/TC databases, and verify the compliance of a given database to the specific tailoring.

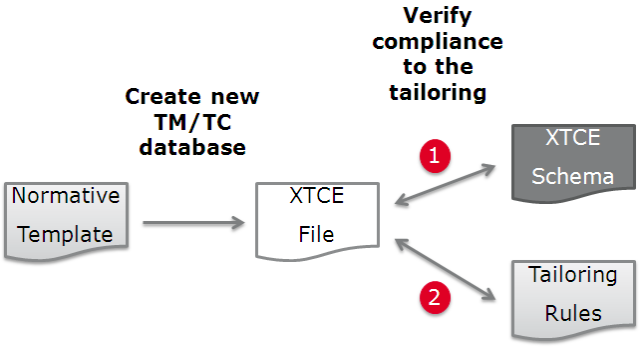

Figure 6. Tailoring Usage Scenario. *A new TM/TC database is created from the normative template, and needs to be checked first against the XTCE schema and then against the tailoring rules.*

A. Selected approach for extending XTCE

The "XTCE CCSDS"[3] best practices report describes several ways of extending XTCE in order to hold data which are not directly supported by the XTCE schema:

1) Use ancillary data: Most XTCE elements include as part of their definition an "ancillary data set" which can hold any kind of data as key-value pairs. The report presents this option as the recommended approach, followed in order by the next two.
2) Create a new schema to define the additional data.
3) Create a new schema that imports the XTCE schema and adds additional types, at the same level as the root SpaceSystem type in order not to modify the existing XTCE definitions.
4) Misuse existing XTCE elements, to include data which do not fit anywhere else. This approach is explicitly discouraged, as it would compromise the compliance to the standard.
5) Create a new schema through modification of the XTCE schema, or by importing it and modifying some types as needed. This is also discouraged because it breaks the compliance to the XTCE standard.

Following this recommendation, the first option is selected to extend XTCE with organization-specific data. The tailoring rules can enforce the presence of certain ancillary data as needed in each case, and they can also be used to specify how these data must be set, simulating the definition of new types.

This is not incompatible with using other schemas to define additional data, but this would be out of the scope of the tailoring, which is only concerned with enforcing a certain usage of the standard XTCE schema.

IV. Overview of ESA's tailoring guide

The definition of an XTCE tailoring for ESA missions had as a primary objective to enable the conversion of the tailored XTCE to the format used by SCOS-2000 (S2K), the ESA Spacecraft Control and Operations System. This system is used in most ESA missions, mainly for spacecraft monitoring and control (through S2K-based Mission Control Systems), but also for electrical integration and testing (through S2K-based EGSE systems). Therefore, making XTCE compatible with the S2K database format would make possible the use of XTCE as a TM/TC exchange format during the Operations and AIV phases of ESA missions.

As a secondary objective, the XTCE tailoring for ESA was also intended as a specification valid for any spacecraft supporting the ECSS Packet Utilization Standard (PUS), which would be applicable to other European organizations such as CNES or DLR. In order to achieve this, the tailoring rules have been categorized as being "PUS generic" or "S2K specific", so that the former can eventually be applied to PUS-compliant missions in

isolation from the rest of S2K-specific rules. However it shall be noted that the need to ensure compatibility with the S2K format imposes a certain way of defining the PUS rules which is not necessarily applicable in cases where S2K is not used.

In the end, the main driver for the tailoring has been to define a mapping between the S2K and XTCE formats which makes it possible to convert from one to the other without data loss, in both directions, as depicted in Figure 7 and Figure 8. Only then would it be possible to use XTCE in the scenarios in which the S2K format is presently used for TM/TC data exchange.

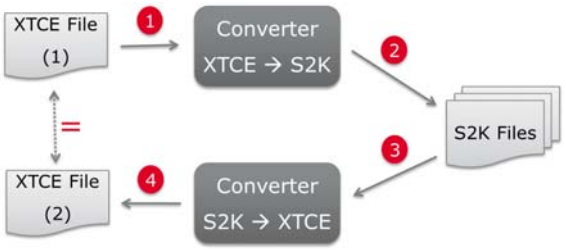

Figure 8. XTCE→S2K Conversion Roundtrip

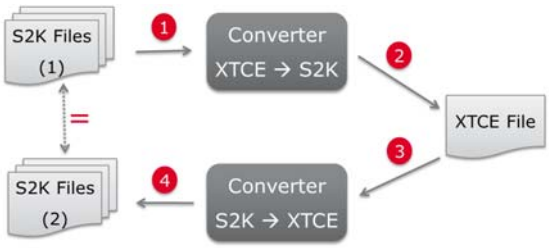

Figure 7. XTCE→S2K Conversion Roundtrip

This is a very demanding requirement, considering the differences between the two standards. The main differences and the implied difficulties are summarized in the following points:

1) **Scope**: As already mentioned, XTCE has a very wide scope, and the S2K format is focused on the TM/TC data required by a monitoring and control system and in particular SCOS-2000.
The tailoring needs to deal with the differences of scope by:
   a. Disallowing XTCE definitions which have no equivalent in S2K (ensures XTCE→S2K roundtrip conversion).
   b. Enforcing the extension of XTCE with S2K definitions that have no equivalent in XTCE (ensures S2K→XTCE roundtrip conversion).

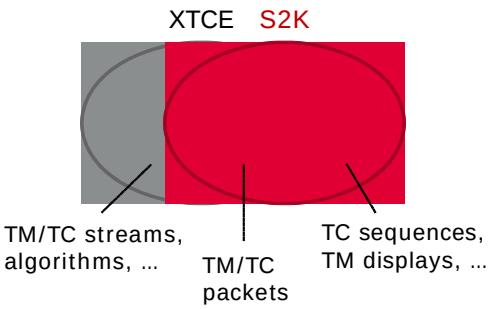

Figure 9. Scope of XTCE and S2K formats

As a simplification, the tailoring does not cover the whole set of S2K data. A subset has been intentionally discarded, which includes:
   a. S2K-specific data which are out of the scope of XTCE (e.g. TC sequences, TM parameter groups, TM displays). There are no elements in the XTCE schema to hold this kind of information, but a separate schema could eventually be defined to hold it, as a future XTCE-compliant solution (see section III.A).
   b. Logarithm calibrations, which are not currently supported by XTCE, but they are expected to be in the future. The ESA tailoring can at that time be adapted to cover also these data.

The scope of the tailoring is thus reduced to the definition of TM and TC packet data, including:
   a. TM packet structures and identification criteria.
   b. TM parameter data: parameter types, calibrations, alarms.
   c. TC packet structures.
   d. TC parameter data: parameter types, calibrations, ranges.

2) **Data model**: XTCE is based on a hierarchical data model, while the S2K format is based on a relational one, defined by a set of interrelated tables. This introduces the difficulty of mapping XTCE hierarchical structures to the S2K format. The tailoring solves this by enforcing a way of using XTCE which minimizes the use of hierarchical definitions. In addition, the use of the normative template for fixed data enables the definition of some fixed hierarchical data, which do not need to be converted to the S2K format.

3) **Data format**: The XTCE format is an XML schema, while the S2K format consists of a set of text files, which are typically generated through the export of a relational database (one file per table). The difficulty in this case is the mapping of schema types to database types; some tailoring rules need to be defined to ensure the conversion roundtrip, because the differences may cause some values to be truncated or reformatted through the conversions.

With these differences in mind, the tailoring rules are defined to enforce that the XTCE schema is used in a very specific way, which ensures compatibility with the S2K format. Following the approach described in section III, each element of the schema is carefully analyzed and compared with its S2K equivalent. One or more rules are specified to achieve the mapping:

1) When there are different ways to define the S2K data in XTCE terms, a single one is selected, and the rules are defined to explicitly forbid any other.
2) When the XTCE elements are not expressive enough to hold all S2K data, the rules specify the need for additional ancillary data.
3) When the XTCE items are too complex, the rules disallow any attribute or sub-element which is not needed.
4) When some XTCE type definition does not fully map its S2K counterpart, the rules are defined to verify the additional constraints imposed by S2K, such as specific field lengths or formats.

In addition, a set of rules are defined to specify the way TM and TC packets need to be defined for compliance with the ECSS Packet Utilization Standard (PUS) and the CCSDS recommendations for packet TM and TC. The standard CCSDS and PUS packet headers are defined in the normative template that complements the rules, specifying fixed data which are considered reserved and mandatory. The tailoring does not prevent the definition of non-standard TM/TC packets, but imposes certain rules on how to define the standard ones.

Figure 10 summarizes the elements of the ESA tailoring and their purpose.

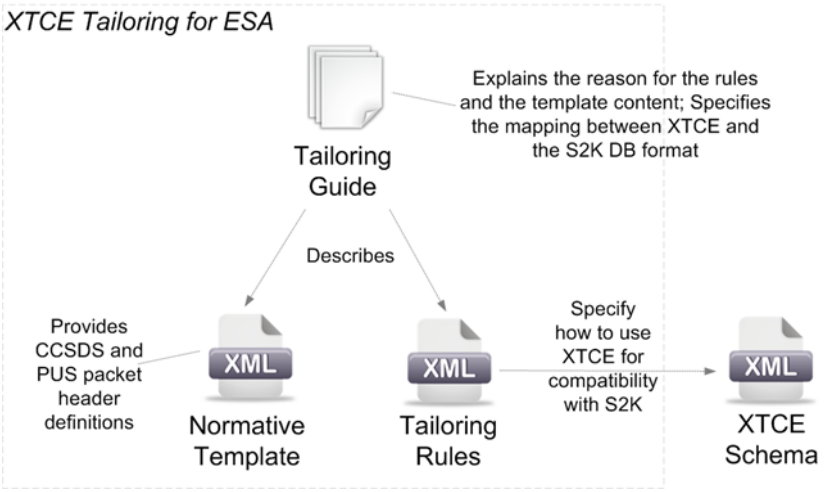

Figure 10. XTCE Tailoring for ESA

V. Conclusion

The XTCE tailoring for ESA is a step towards the adoption of XTCE for use in ESA missions. The approach taken to adapt XTCE to ESA needs has also been followed by NASA and could eventually become a de-facto standard for tailoring XTCE. Although the tailoring rules defined for different organizations will generally differ, it is possible to use a common tailoring method in all cases, and formalize the result in a common way.

The current version of the XTCE tailoring for ESA defines a mapping to the S2K format that allows the use of XTCE in several scenarios where the S2K data format is used nowadays. The conversion between the XTCE and S2K formats will be implemented in DABYS, ESOC's framework for managing mission and application configuration data, and TM/TC data in particular. This will bring XTCE support to the current ground systems infrastructure, favoring the use of XTCE in new TM/TC exchange scenarios.

It is acknowledged that ESA's tailored XTCE format has some limitations, which are caused by the difficulties in mapping the XTCE and S2K formats. The different scope of the two formats causes and overuse of XTCE ancillary data which is not desirable, and the XTCE format needs to be extended with S2K-specific data which are not relevant in many TM/TC exchange scenarios. However, these limitations could be solved in future versions of the tailoring, based on the evolution of the XTCE and the S2K formats.

In summary, the availability of an established tailoring method, together with an initial version of the ESA tailoring and the associated working software, are a good starting point for XTCE adoption; from this point the tailoring could rapidly evolve based on practical experience.

Appendix A
Acronym List

AIV	Assembly, Integration and Validation
CNES	French Space Agency
DABYS	Generic Database Software
DB	Database
DLR	German Aerospace Center
ECSS	European Committee for Space Standardization
EGSE	Electrical Ground System Equipment
ESA	European Space Agency
ESOC	European Space Operations Centre
FDS	Flight Dynamics System
MCS	Mission Control System
MPS	Mission Planning System
NASA	National Aeronautics and Space Administration
ODB	Operational Database
PUS	Packet Utilization Standard
SCOS	Spacecraft Control and Operations System
S2K	SCOS-2000
SDB	Spacecraft Database
TM	Telemetry
TC	Telecommand
XML	eXtensible Markup Language
XTCE	XML Telemetric and Command Exchange

References

[1]XML Telemetric and Command Exchange (XTCE), CCSDS 660.0-B-1, Issue 1, October 2007

[2]XML Telemetric and Command Exchange CCSDS, CCSDS 660.0-M-0.0, Draft 1.4, March 2010

[3]XTCE GovSat Spezialization, Draft Issue 0, March 2011