Chinese Lunar missions Chang'E-1 and Chang'E-2 and the ESOC support: an example of systems interoperability

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Both ESOC and BACC have operated satellites successfully for many years using their own systems. ESOC were contracted to investigate possible ground station tracking support for China's first lunar probe, Chang'E-1. BACC, China's lunar exploration project mission control center, and ESOC were therefore faced with the problem of connecting two systems: the BACC missions control system and the ESOC groundstation network ESTRACK; this had to happen within the relative short period of one year. Fortunately ESOC had already provided cross support to other agencies such as NASA and JAXA and the proposal from ESOC was to provide the Chang'E-1 support based on CCSDS standards and therefore to provide systems interoperability without modifying the BACC system and the ESOC system. All interfaces would be based on CCSDS standards and each partner would then be responsible to bridge the CCSDS defined interfaces into their own system.

This paper describes how this in practice was achieved, which CCSDS standards were utilized and how each party handled their interfaces. Test, validation and training is in this context very important. This is also explained and finally the actual support is described. The paper will also provide the lessons learned from this cross support and finally the paper will give the outlook of future cooperation between BACC and ESOC and the utilisation of the CCSDS standards for these supports.

Introduction

Chang'E-1 represents the first step in China's plans to land robotic explorers on the Moon before 2020. The spacecraft is large, weighing in at 2350 kg, and it operated from a low, circular lunar orbit, just 200 km above the surface of the Moon. From here, it performed its science mission for a full year. Named after the Chinese goddess of the Moon, Chang'e-1 is the first phase in the China Lunar Exploration Program (CLEP).

The Chinese lunar mission Chang'E-1 was launched on 24 October 2007 at 10:05 UTC (12:05 CEST) from Launch Pad 3 at the Xichang Satellite Launch Centre in south-west China's Sichuan Province. The Chang'E-1 mission was supported from the ESA ground stations in Maspalomas and Kourou. During the track on the 1st of November 2007 for the first time, ESA tracking stations have transmitted telecommands to a Chinese satellite.

This was the culmination of a long preparation performed by BACC and ESOC that started nearly two years before the launch, where a Chinese delegation visited ESOC in 2005 to explore the possibilities for ESOC to provide tracking support to Chang'E-1. Following detailed discussions on the support ESOC and BACC agreed in February 2006 on a contract to provide the required support.

Concept

Following the agreement on the cooperation ESOC and BACC were therefore faced with the problem of connecting two systems: the BACC missions control system and the ESOC ground station network ESTRACK; this had to happen within the relative short period of one year. The ESOC proposal to BACC was based on ESOC's model for providing cross support to other agencies such as NASA and JAXA and the proposal from ESOC was to provide the Chang'E-1 support based on CCSDS standards and therefore to provide systems interoperability without modifying the BACC system and the ESOC system. This model hide the implementation on both sides and only defines the interfaces needed to be support on both sides. To measure the success of this we used the connect of verification and validation.

- Verification: The process of evaluating software to determine whether the products of a given development phase satisfy the conditions imposed at the start of that phase. [IEEE-STD-610].
- Validation: The process of evaluating software during or at the end of the development process to determine whether it satisfies specified requirements. [IEEE-STD-610]

In other words, validation ensures that the product actually meets the user's needs, and that the specifications were correct in the first place, while verification is ensuring that the product has been built according to the requirements and design specifications.:

- Verification ensures that **"we built it right"**
- Validation ensures that the product, as provided, will fulfill its intended use **"we built the right thing"**

With this defined concept we fully relied on the CCSDS recommendations and that this could be implemented in a relative short time scale with two partners working together the first time on such a support.

How to get there

The key to success for this support is the use of SLE on both sides and therefore ESOC and BACC defined a roadmap to ensure the SLE user function, to be implemented at BACC. The BACC implementation is based on the ESOC SLE API. The objective of the SLE API Recommendation is to enable development of reusable software packages, which provide a high level, communication technology independent interface to SLE application programs for exchange of SLE operation invocations and returns between a SLE service user and a SLE service provider. The ESOC developed SLE API package provides encapsulation of data communication interfaces and therefore eases implementation by programmers not specialised in data communications and protects the application against changes in communication technologies and allows use of different communication technologies. The SLE API provides a high level interface, eases the task application programmers and provides a package of already tested components and therefore decreases development effort, development time, and risk .

ESOC provided the SLE API to BACC and gave an extensive training of the underlying CCSDS recommendations and the use of the SLE API. This training also included some prototyping of applications using the SLE API. Following this training BACC undertook the task to implement the SLE user function and 4 month after the training BACC was ready to start testing the SLE user with the ESOC provider

Application of CCSDS standards

The Chang'E-1 spacecraft was not fully CCSDS compliant and therefore some customization of the ESOC ground segments was necessary.

The problem is that the Chang'E-1 Telemetry Frame is not compatible with the CCSDS recommendations. The ESOC system can however provide support and be configured for any Frame synchronization code. On this basis it can deliver the Telemetry Frames using the SLE Return All Frames but cannot determine the Frame Quality and therefore will deliver the frames with an indication 'undetermined' – meaning that the results of the decoding process for this frame are not specified.

The CCSDS recommendations used was not limited to the SLE but also for the Orbit and Tracking Data CCSDS recommendations were used. For the Tracking Data there was for Chang'E-1 not a CCSDS Blue Book available but for the follow-on mission Chang'E-2.

The final suit of CCSDS standards applied to Chang'E-1 and Chang'E-2 were:

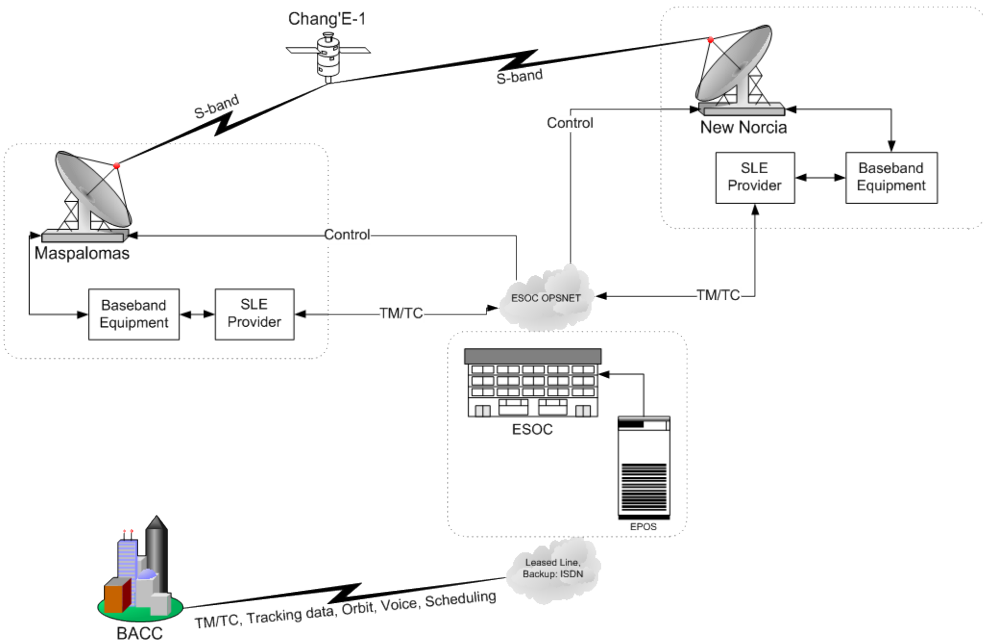
Telemetry:	SLE Return All Frames (RAF)
Telecommanding:	SLE Command Link Transmission Units (CLTU)
Orbit Data:	Orbit Ephemeris Message (OEM)

Tracking Data: Tracking Data Message (TDM)

For the scheduling interface the CCSDS SLE Service Management is not yet approved and therefore a private interface was defined based on exchange of files containing scheduling information in ASCII format.

Overall Architecture

The concept developed into the architecture in figure 1



Technical Verification

This was the first cooperation between ESOC and BACC and therefore major emphasis was put on test and validation. The objectives of this activities is to do the verification of the implementation and to ensures that **"we built it right"** and it includes a number of tests:

The RF Compatibility Tests (RFCT) addresses the compatibility between On-Board Transponder and Ground Facilities. For this verification the satellite system is represented by the RF-Suitcase required to be representative of the Flying model. The RFCT covers the RF interface with the spacecraft by verifying functionalities and performance of up- and down-link and includes verification of TM, TC, Doppler and ranging functions, and combination thereof, as well as spectral analyses and link budget verification. As such it can provide the baseline for the station configuration of the front-end and back-end system.

The End-to-End Data Flow Test addresses the compatibility between the ground station and the control center.. This test included the SLE Return All Frames in timely, complete and offline mode and the SLE CLTU services.

The Offline Data Exchange Tests addresses the compatibility of the offline data exchanges. This test included the exchange of Orbit, Tracking data and scheduling requests.

Following the SLE training course held in China in March 2007, BACC was ready to perform the SLE tests between BACC SLE user function and the ESOC provider function, which already started in July 2012. The tests were successfully and within a week it was possible for BACC and ESOC to validate all the SLE services and this only four month after BACC had the first training on SLE. This is a remarkably achievement and clearly shows that the CCSDS SLE is a mature standard and with the support of the ESOC SLE API and associated training SLE can provide cross support between different agencies ground stations and mission control center on a relative short time.

Operational Validation

The objectives of the operational validation is to ensure that the product, as provided, will fulfil its intended use and yes **“we built the right thing”**. The ground segment operational validation constitutes the ultimate step of the ground segment validation process during which all ground segment subsystems, including operations teams and support data, are exercised through realistic mission operations in order to achieve a final confirmation of the adequacy of the ground segment and operations teams to support the mission. These activities consisted of a number of activities such as:

- Simulations
- Missions Readiness Tests

The simulations campaign will be concluded by the production of a Simulations Campaign report identifying all simulations carried-out, for each simulation their main achievements and the actions placed, and providing the summary list of all actions placed during the course of the simulations campaign. The simulations campaign shall include end-to-end tests involving all relevant operational entities in support of the operations and including, if relevant, non-ESOC entities. For a launch it shall in particular include a dedicated simulation (i.e. Dress Rehearsal) involving the launcher authority during which the combined launch site and spacecraft control ground segment operations during final hours of the count-down and the initial phase following lift-off are exercised.

Mission Readiness Tests (MRTs) start at L-6 weeks and will last until the Dress rehearsal. The number of MRTs to be conducted is typically 12 per stations (two MRT per weeks and per stations). The MRT objectives are to verify the operational readiness of the ground station functions and network to support the mission and to train the stations personnel and the network controller at ESOC on the operational topics specific to that mission. Based on the results of MRT, the station configuration can require some minor update (typically fine tuning). Every MRT session shall leave the affected ground station in nominal configuration.

Operations

ESA ground tracking support to China's Chang'E-1 successfully started on 1 November 2007 at 03:35 UTC with the first receipt of telemetry signals from the Chinese mission at ESA's 35m deep-space station at New Norcia, Australia. Two hours and 39 minutes later, the first telecommands to Chang'E-1 were transmitted via ESA's 15m station in Maspalomas, Spain, when the satellite was nearly 200 000 km from Maspalomas station. An hour later, the ESA station in Kourou, French Guiana, also successfully received telemetry and transmitted commands to Chang'E-1.

New Norcia, Maspalomas and Kourou stations are part of ESA's ESTRACK ground station network, and are remotely controlled from the European Space Operations Centre (ESOC), in Darmstadt, Germany. The successful communications mark a major milestone as this is the first time a telecommand to a Chinese spacecraft has been transmitted from an ESA station. In addition to receipt of telemetry and transmission of telecommands, the Maspalomas and Kourou stations also performed ranging and Doppler measurements used to determine the spacecraft's location and direction.

Lessons Learned

There were a number of lessons learned from this cooperation:

- The ESOC SLE API together with a training course is a very good way to get SLE implemented in a short period and with a high confidence that it will be successful
- Such training is very useful for newcomers to SLE and should be offered as part of a CCSDS promotion of the SLE to interested parties

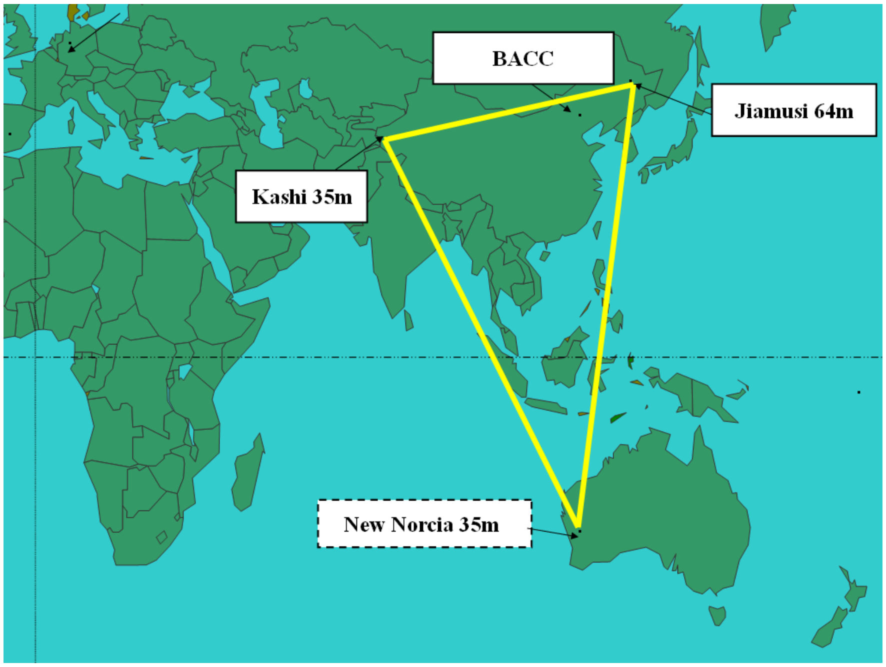
- Usage of SLE was beneficial for both parties; inclusion of additional stations was flexibly possible.
- Application of Standards (used by ESA) went well and eased implementation
- Non-standard items on TM/TC level did not pose a problem due to the lower layer of the requested service
- Very good cooperation from both sides, mutual respect and multicultural understanding
- The presence of the BACC engineers at ESOC during the support proved to be very valuable

Future Cooperation

There are a number of future support planned between ESOC and BACC:

- Chang'E-3 is a Lander and rover Moon mission. The Chinese plan to launch Chang'E-3 in the time scale 2013 to 2014. The support will be X-band for Telemetry, Tracking and Command for transfer orbit support from 1st day to 4th day, 6-8 hours/day.

- Chang'E-4 is also a Lander and rover Moon mission and will follow Chang'E-3. Both missions require support in X-band and also Delta-DOR in order to find the exact landing site. The following Delta-DOR constellation is foreseen:



Conclusion

This paper describes the process followed for the ESOC support to the Chinese lunar missions Chang'E-1 and Chang'E-2. The support was fully relying on the use of CCSDS standard for the interfaces and this proved to be the right decision and the support for both missions were flawless.