Phase B

SwissCube Ground Segment

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1 REFERENCES

1.1 Normative references

[N2]	ECSS-E-70-41	ECSS – Ground Systems and operations. Telemetry and Telecommand Packet Utilization.
[N3]	S3-C-ICD-1-3-EGSE_Router_Application_Protocol	
[N4]	GENSO	Global Education Network for Satellite Operations http://genso.org/
[N5]	CubeSat standard	http://cubesat.calpoly.edu/
[N6]	S3_B_SE_1_0_level1and2spec	SwissCube Mission, Science and Project Specifications – EPFL, Marie Dumont
[N7]	S3_B_SE_1_0_level3SSRspec	Space System Specifications – EPFL, Marie Dumont

1.2 Informative references

[R1]	Airglow phenomena	http://en.wikipedia.org/wiki/Airglow
[R2]	ECSS-E-70-31	Ground Systems and Operations. Monitoring and Control Data Definition Standard.

2 List of Acronyms

Ack	Acknowledgement
APID	Application Process ID
CCSDS	Consultative Committee for Space Data Systems
EGSE	Electrical Ground-Support Equipment
EPFL	Ecole Polytechnique Fédéral de Lausanne (Swiss Federal Institute of Technology in Lausanne)
ESA	European Space Agency
ESOC	European Space Operations Centre
ESTEC	European Space Research and Technology Centre
GENSO	Global Educational Network for Satellite Operations [N4]
GS	Ground Station
ICD	Interface Control Document
LMTS	Microsystems for space technologies laboratory
MDR	Mission Data Repository
MCS	Mission Control System
MIB	Mission Information Base
PUS	Packet Utilisation Standard [N2]
S/C	Spacecraft
SCOE	Special Checkout Equipment
TBD	To Be Defined
TC	Telecommand
TM	Telemetry
UL	Uplink
VC	Virtual Channel

3 INTRODUCTION

The SwissCube project is directed by the LMTS in partnership with the Space Center at the Swiss Federal Institute of Technology in Lausanne (EPFL). This project is compliant with the CubeSat space systems standard [N5] (1 litre cube of 1kg) published by Stanford University (UK) and California Polytechnic State University (US) in 1999. The standard offers means to develop space systems at low cost with reduced risks and a common development environment for the universities to collaborate. The objective of the SwissCube project is to focus on the observation of the airglow phenomena [R1].

The scope of this project is to develop the SwissCube ground segment software composed of the Mission Control System (MCS), the TM/TC Front End and easy to use clients to control and monitor the spacecraft. This work is realized with the help of the European Space Agency's European Space Research and Technology Centre (ESA/ESTEC) in the Netherlands where we'll be trainees for 4 months in the TEC-SWG division under M. Per Hemso supervision.

The ground segment is composes of 5 main components:

- A ground station (antenna and other hardware) used to communicate with the spacecraft in radio frequencies; this part is not covered by this project.
- A TM/TC Front End, which realise the link between the MCS and the ground station at EPFL. It shall also provide telemetry archiving and replay functionalities. A similar TM/TC Front End will have to be developed for the integration with the GENSO project [N4].
- The Mission Control System to send telecommands, receive and process/monitor telemetry and store the mission configuration (e.g. the telecommands definitions).
- A scheduler shall be implemented. As the window of visibility of the spacecraft is small (few minutes per pass), all the actions taking place during the passes must be planned in advance.
- User interfaces on top of the MCS to control and monitor the spacecraft as well as to design plans for the scheduler.

This report describes the ground segment architecture, the needs of each actor (user) of the ground segment, the planned functionalities and the requirements of our system.

4 USER REQUIREMENTS

The ground segment shall be able to:

- Monitor and control the spacecraft during: (include 2_PR_23_15)[1]
    - In-flight operation.
    - Spacecraft development at system and subsystems level.
- The project shall apply the ECSS standards for all engineering activities, as long as these standards are applicable given the natural constraints of the project. (2_PR_11_08)[1]
    - Use of CCSDS packets in compliance with the "Ground systems and operations - Telemetry and telecommand packet utilization" ECSS standard [N2].
- Deliver mission product data to the scientific community.
- Interface to the space system:
    - Using the provided ground station.
    - Using the GENSO project [N4].
- The ground to space communication link shall comply with the Amateur Radio Satellites services. (2_PR_11_3)[1]
    - The ground system shall be capable of operating with other external amateur radio satellites than the Project's and possible networks of amateur radio ground stations. (2_PR_15_06)[1]
- Provide graphical user interfaces useable by non-professional ground segment operators.
- Be safely operated remotely.

[1] References from [N6] and [N7].

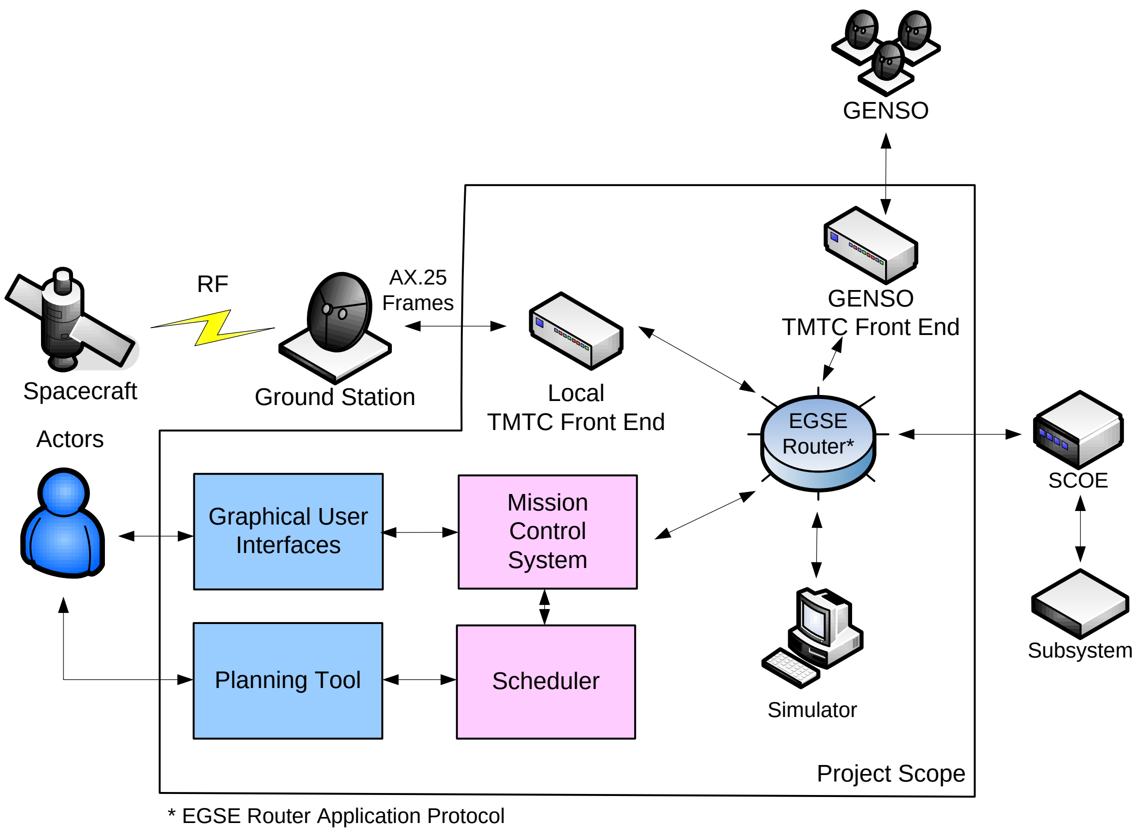
5 DESIGN REQUIREMENTS

The scope of the project is to develop a complete Mission Control System (MCS) and interface it with the Ground Station through a TM/TC Front End (TMTC FE) as well as to the users through graphical interfaces.

The communication between the TM/TC Front End and the MCS uses the infrastructure provided by the EGSE Router as ESA/ESTEC for the ground testing. It brings flexibility to the ground segment; multiple TM/TC Front Ends can be available (only one used during a pass) and, during the ground testing phase, subsystems testing equipments (SCOE) can easily be added. It also remove strong dependency between the components as it would if they were just designed to communicate directly with each other without this infrastructure.

The clients of EGSE Router infrastructure defined for the SwissCube Ground segment are:

- A MCS used control and monitor either the real SwissCube spacecraft in operation via a TM/TC Front End, a simulator to the MCS or SCOEs for subsystems testing.
- TM/TC Front End for EPFL and HEFR Ground Stations.
- TM/TC Front End for GENSO project [N4].
- SwissCube spacecraft simulator, to test the MCS, the TM/TC Front End and the graphical user interfaces during the development phase.
- SCOEs for the functional tests of the spacecraft or subsystems on ground.



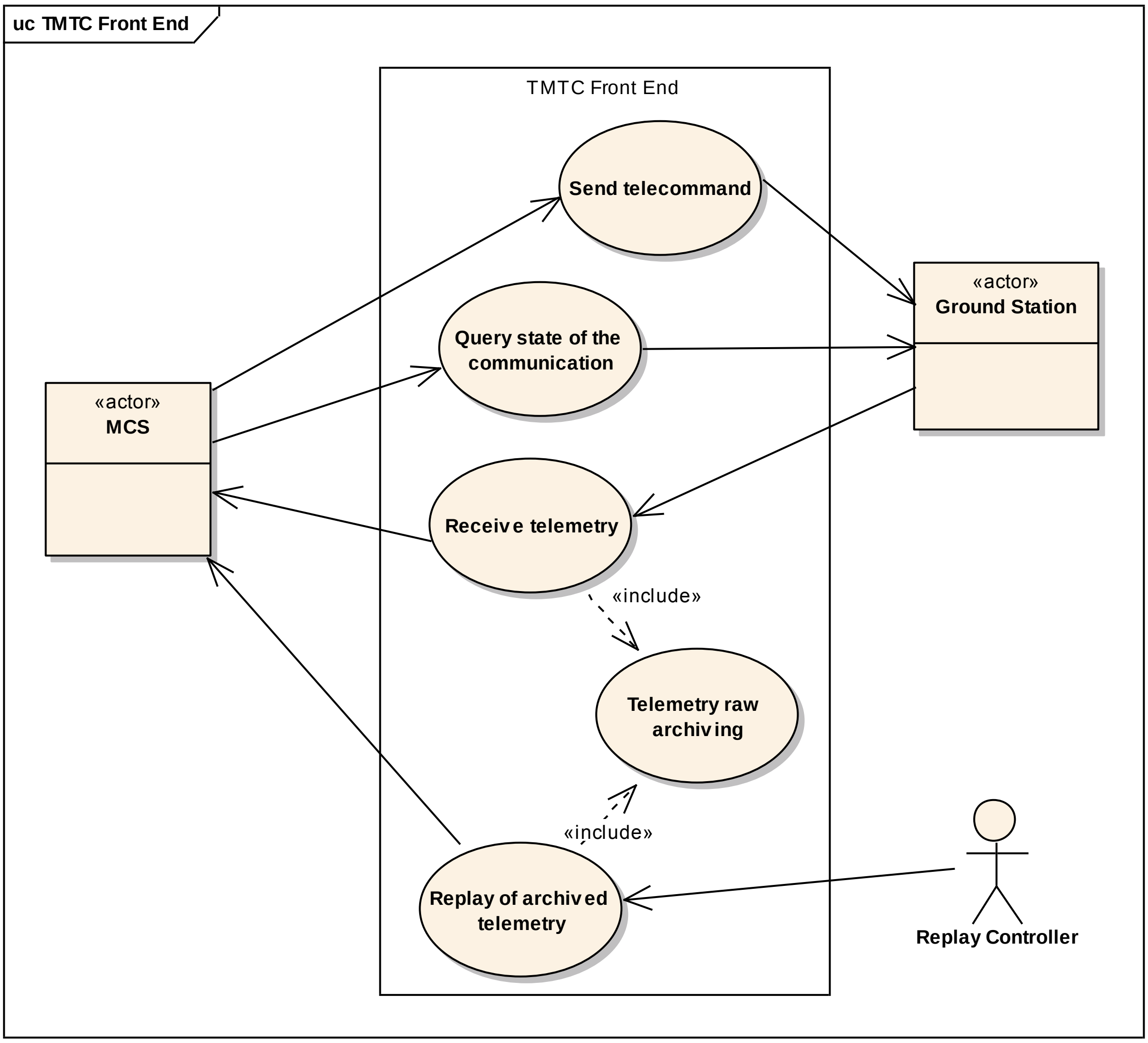
5.1 TM/TC Front End

The role of the TM/TC Front End is to provide the layer between the Mission Control System (MCS) and the ground station (be it the one at EPFL or at HEFR or one of GENSO [N4]), with archiving of raw telemetry and replay functionality of data (e.g. send the payload data on-demand after the end of the pass not to overload he MCS during the pass with data that it doesn't need in real-time). They communicate with each other through the EGSE Router infrastructure.

Requirements:

- Uplink
  - Encapsulation of telecommands (CCSDS packet) into AX.25 frame
  - Flow control (acknowledgments, attempts to send, …)
- Downlink
  - Reassemble of telemetry (CCSDS packet) from multiple AX.25 frame and received from multiple Ground Stations
  - Archiving of raw AX.25 frames
  - Forward of Time Correlation Reports
- Communication State
  - Forward of Communication State Requests/Reports
- Replay
  - Simple way to replay the archived AX.25 frames

TM/TC Front End use case diagram:



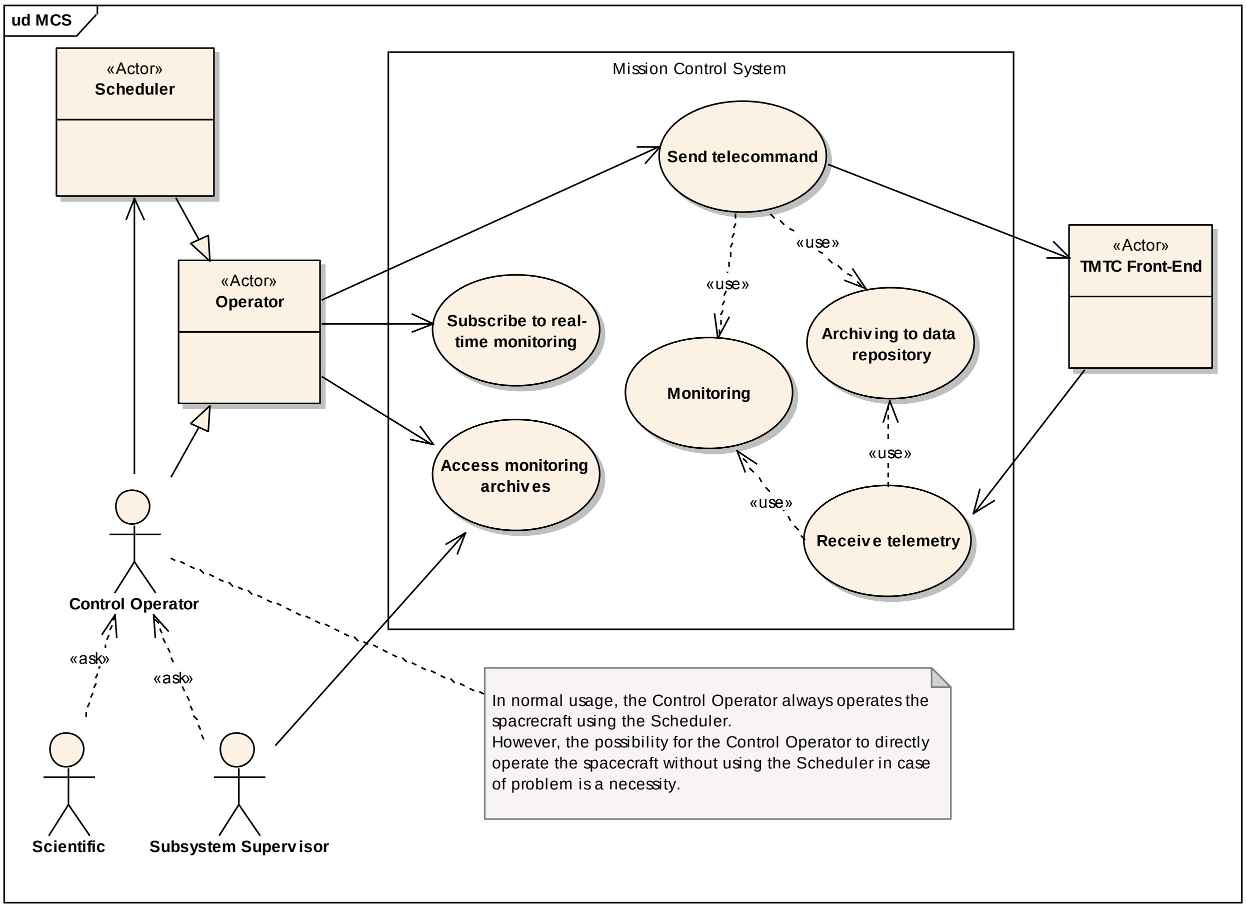
- Send telecommand
  - Send a telecommand to the ground station.
    - Generate the corresponding acknowledgments (GS, UL and ONB).
- Query state of the communication
  - Get the status of the communication link of the spacecraft.
- Receive telemetry
  - Receive the telemetry from the ground station and forward it to the MCS.
- Telemetry raw archiving
  - Archive the telemetry received for replaying it afterwards.
- Replay of archived telemetry
  - Replay an adjustable part of the archived telemetry

5.2 SwissCube Mission Control System

Requirements:

- Sends telecommands
    - Packets compliant with the CCSDS packet format [N2]
        - Telecommands are defined in a Mission Information Base (MIB)
- Receive the telemetry
    - Process the telemetry
        - Extraction of parameter data from the packets as defined in the telemetry definitions of the mission.
            - Including mission product data
        - Housekeeping raw values shall be calibrated
        - The telemetry processing that is mission-specific shall not be hardcoded
        - Monitoring shall be performed
- Archive all the telecommands, acknowledgements, telemetry and housekeeping in a Mission Data Repository (MDR)
- Communicate through EGSE Router infrastructure with other ground segment components (TM/TC Front End, SCOE during testing, etc.)
    - Using the EGSE Router Application Protocol
        - Process the ground segment's acknowledgements
- Distribute the mission data
    - Including:
        - Ground segment and space segments acknowledgements
        - Housekeeping values (with raw values too)
        - Mission definitions (calibration parameters, service type description, etc.)
        - Mission product data
    - Both in a real-time mode or by consulting the archives (by subscription).
        - Support multiple client connected concurrently
    - Can be accessed remotely
        - In a secured and authenticated manner

MCS use case diagram:

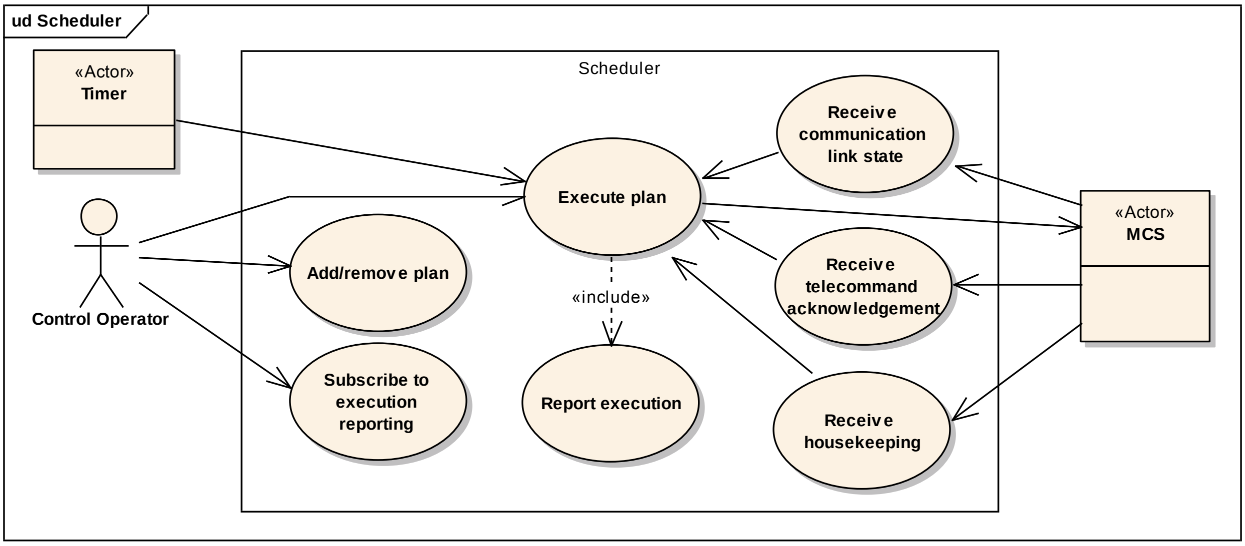


- Archiving to data repository
  - Storage of sent telecommands, received telemetry and processed housekeeping data.
- Send telecommand
  - Send a telecommand to the TM/TC Front End through the EGSE Router infrastructure. Uses the archiving to store it. Notify the monitoring for link-to-command[2] related to the current telecommand.
- Receive telemetry
  - Receive the telemetry and process it. This includes acknowledgments, housekeeping and other defined PUS services. The packet itself and all the data processed are stored using the archiving.
- Subscribe to real-time monitoring
  - Clients subscribe to the MCS to receive data such as new telecommands, telemetry, acknowledgements and housekeeping in real-time.
- Access monitoring archives
  - Clients can access the monitoring archives to get raw and processed data contained in the data repository.

[2] Completion of telecommand defined by an housekeeping value (e.g. Subsystem Switch ON command is considered fully complete only when the housekeeping signals that the subsystem is really switched on).

5.2.1 Scheduler

By connecting to the MCS to its uplink and monitoring interfaces, the scheduler shall add the functionality of planned actions execution defined by the control operator through plans.



- Add/remove plan
  - Add or remove a plan to/from the scheduler.
- Subscribe to execution reporting
  - Clients can subscribe to the scheduler to receive update on the status of the execution of a plan.
- Report execution
  - Report the execution events to the client that subscribed to the execution reporting.
- Execute plan
  - Execute each actions of the plan using the conditions (link state, acknowledgements, housekeeping, etc) defined in it. The start of execution of the plan can be triggered directly by the Control Operator, by a timer to start at a fixed time.
- Receive communication link state
  - Receive information about the link with the spacecraft to be notified of its visibility.
- Receive telecommand acknowledgement
  - Receive an acknowledgement for a telecommand and notify the plan execution of it.
- Receive housekeeping
  - Receive housekeeping and notify the plan execution of it.

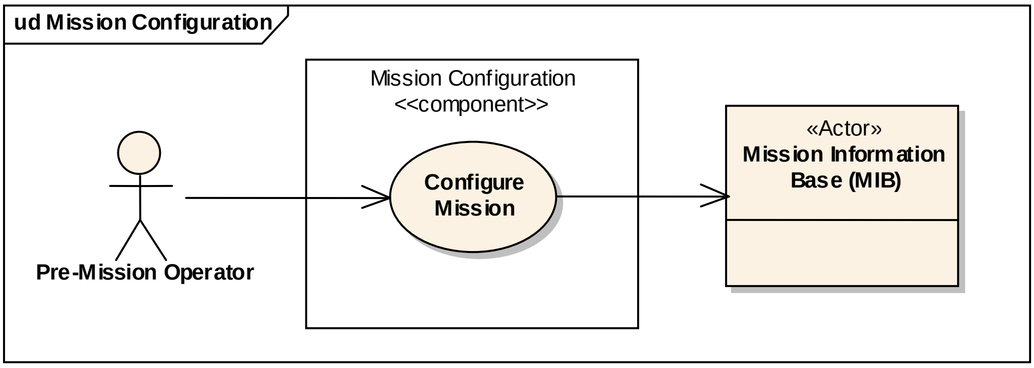
The scheduler shall also have a plan designer to create the plans in a complete graphical manner. This also includes the creation of on-board schedules that will be then uploaded to the spacecraft using the scheduler and a plan. This graphical tool is necessary but first the scheduler ICD must be clearly defined, therefore a very simple text based version of a tool can be developed before the availability of the complete one.

Further details are TBD.

5.3 User Interfaces

- Develop graphical user interfaces to:

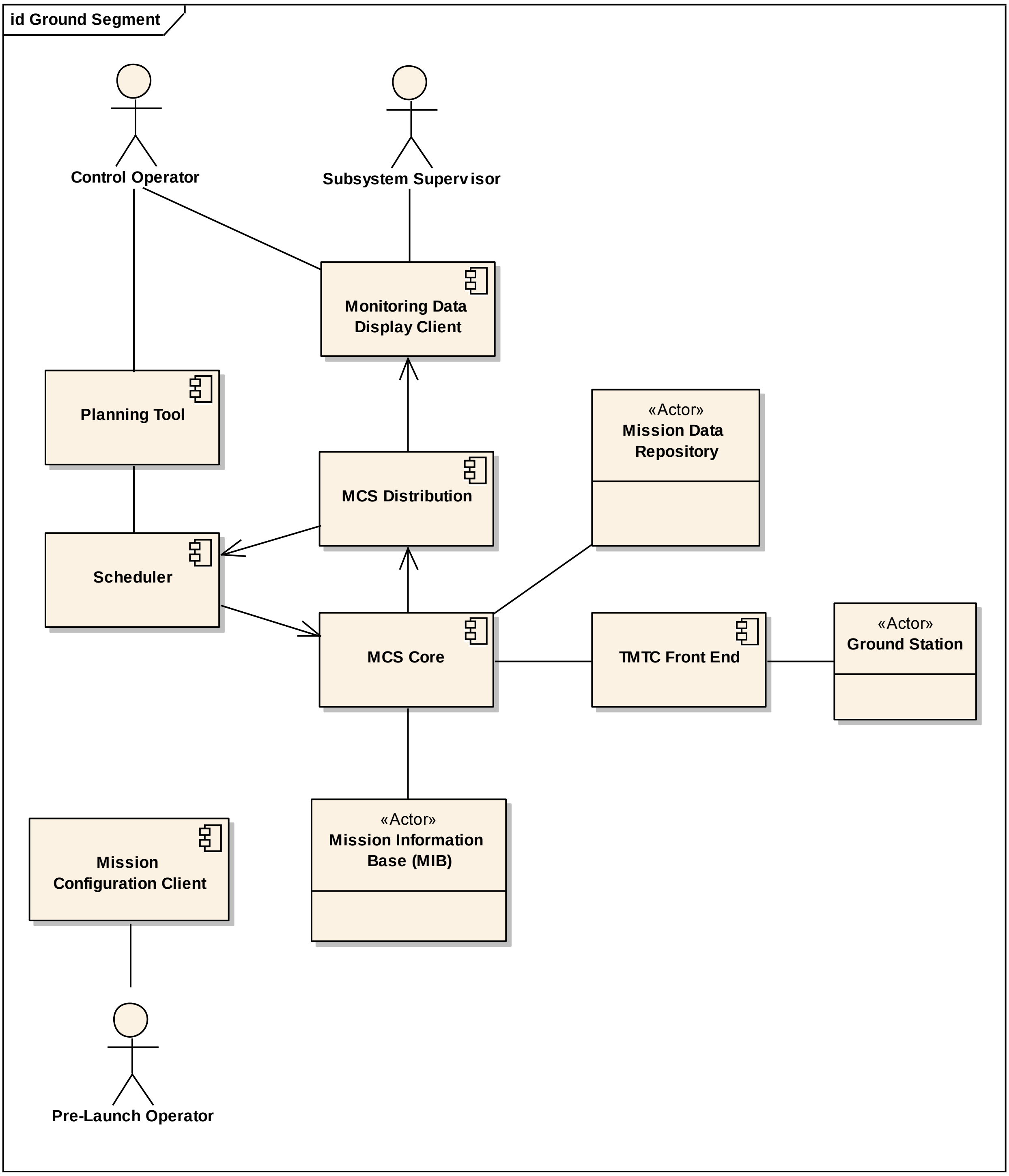
  - Configure the mission (telecommands and housekeeping parameters definitions, …)



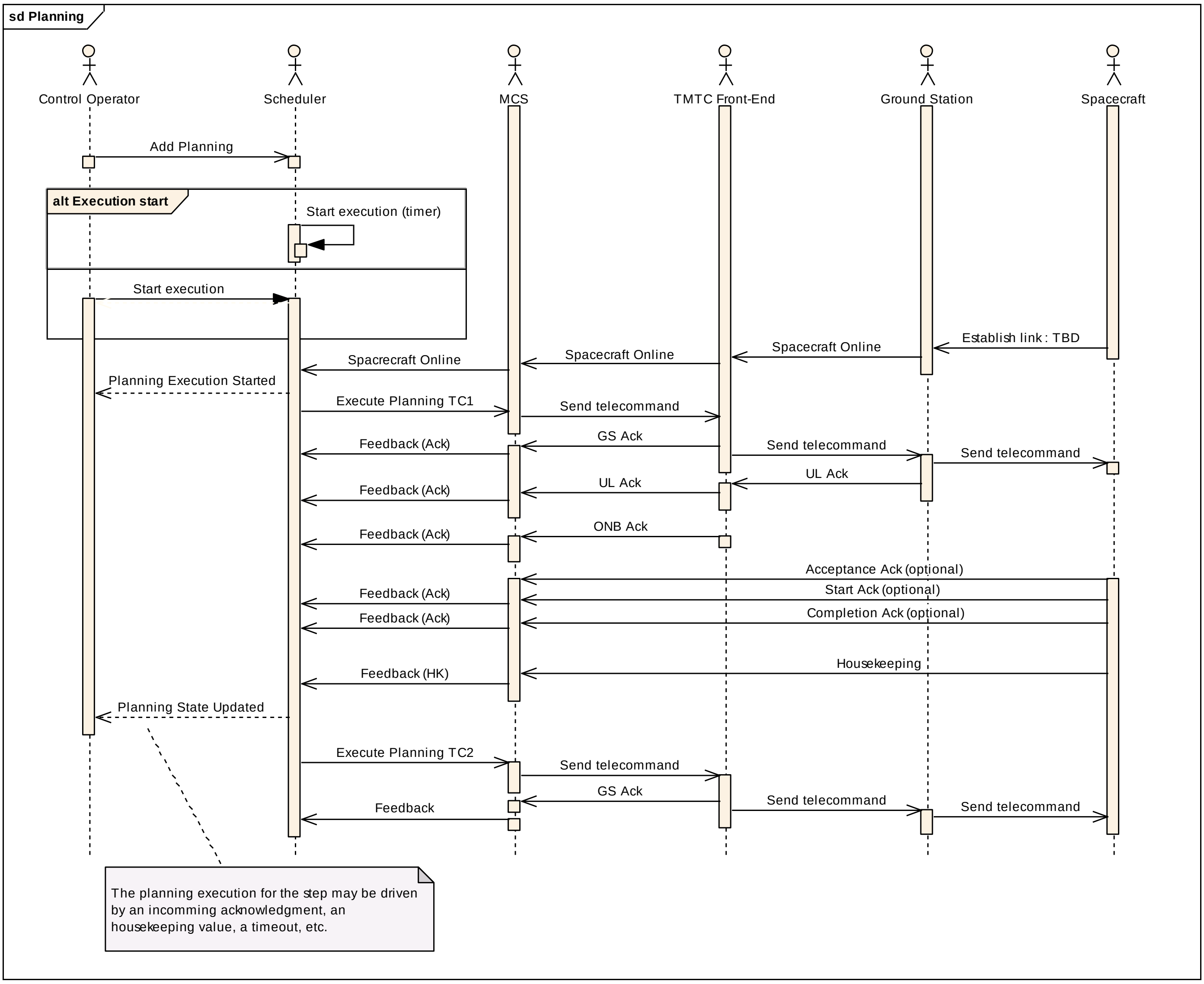
  - Provide basic telecommand sending before the availability of a complete planning tool.
  - Monitor the spacecraft in real-time.
  - Retrieve the scientific payload data.
  - Design the plans in a graphical manner.
  - Replay the archived telemetry from the TM/TC Front End
- The graphical interfaces must be straightforward to employ for non-professional spacecraft operators.
- Exploitable remotely.

6 Technical Description

The ground segment that this project aims to develop is composed of the following components which are described in the subsequent chapters:



Interaction between the components of the complete system:



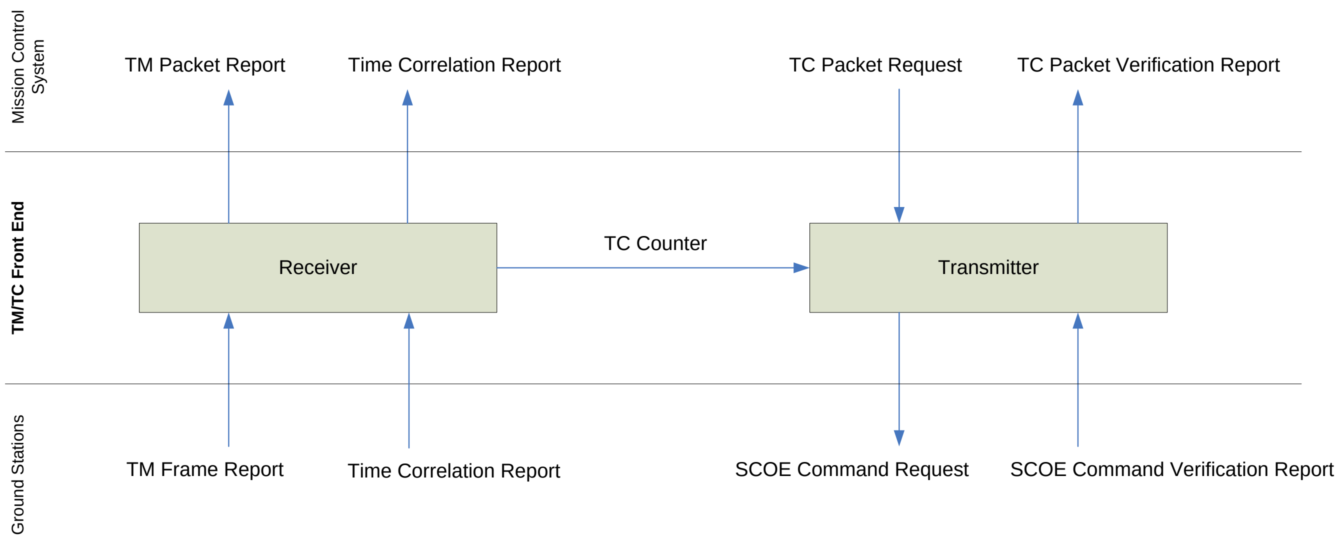
- The Control Operator adds a plan to the scheduler before the pass.
- The plan planned is scheduled to start just before the pass and wait for the contact with the spacecraft (it could also trigger the actual actions needed for the contact, TBD).
- Once the contact established, the execution of the first action is done and the telecommand sent.
- All acknowledgements resulting from the telecommand as well as the housekeeping are processed by the MCS. The scheduler is notified of them.
- When the execution step is considered done, the scheduler processes then to the next one.

6.1 TM/TC Front End

The TM/TC Front End is a layer between the Mission Control System (MCS) and the Ground Stations (GSs). Specifically, it is a layer of level 2 of the OSI model. It provides a logical data link between the ground and the satellite. His counterpart onboard the satellite is a part of the COM.

As a layer of level 2, it will have to provide a flow control and detection of errors.

It has a bidirectional interface with the MCS and another with the GSs. The services provided by these interfaces are represented in the schema below.



The TM/TC Front End contains the following main parts:

1. AX.25 encoding/decoding library
    - Our own implementation of the AX.25 protocol to match with the needs of the SwissCube project
2. TC Transmitter
    - State machine
3. TM Receiver
    - Set of virtual channels
        - Set of reassemble units
4. Replay controller GUI

More technical details can be found in the TM/TC Front End Semester Work Report.

6.2 Scheduler

TBD

6.3 SwissCube Mission Control System

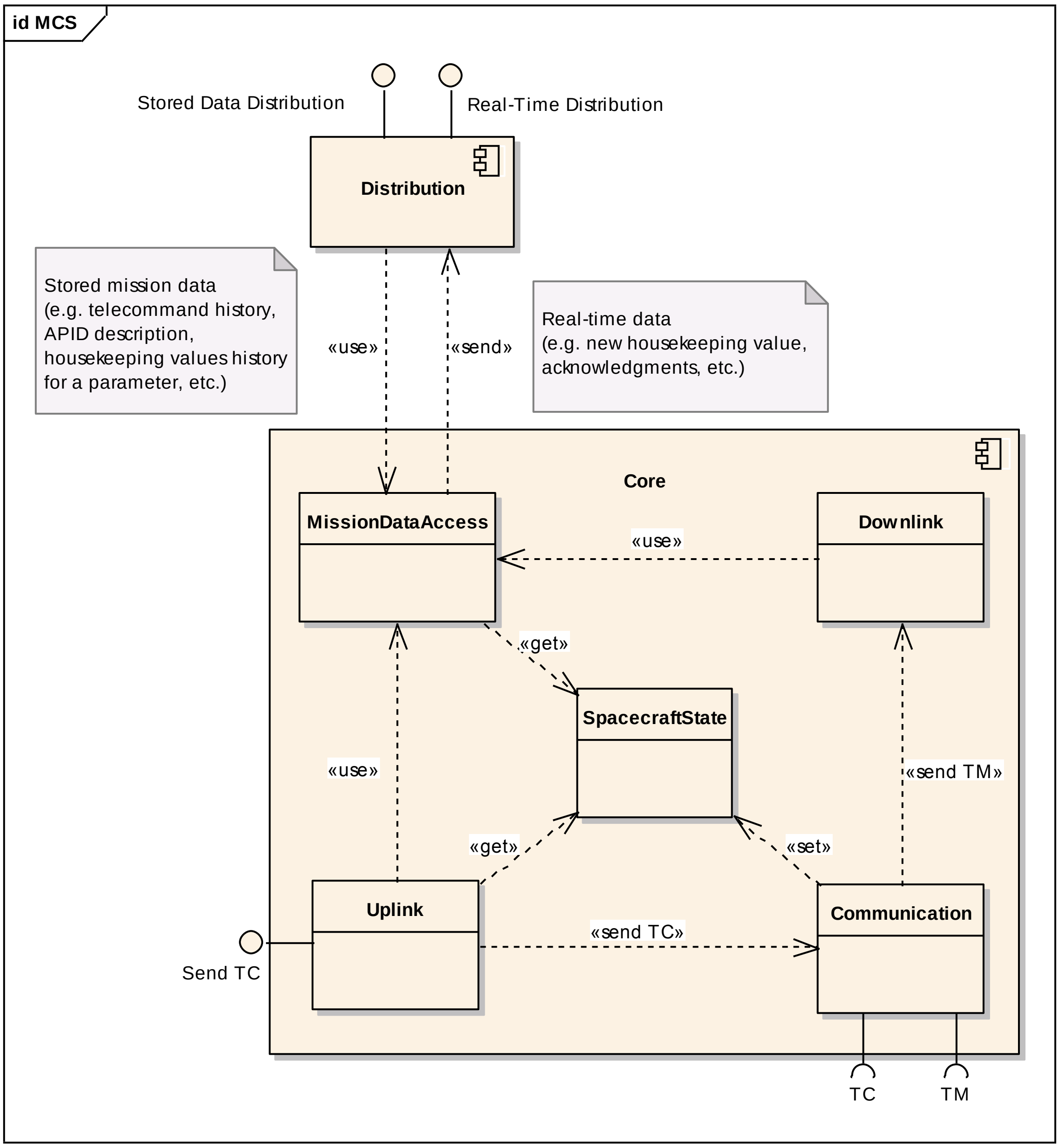
The Mission Control System role is to send telecommands to the spacecraft (by the mean of a TM/TC Front End and a Ground Station), and to process the received telemetry. For this task, we will develop a new Mission Control System for the SwissCube project. ESA uses the system SCOS 2000 developed by ESA/ESOC and industrial partners. SCOS 2000 is a generic system and is functionally complete, but it is complex to configure and not quite adapted for a small spacecraft. Therefore we have decided for the option of designing and implementing our own MCS system, believing that this will result in a more adequate solution for the project.

The central component is the Core (diagram on the next page), which is decomposed in 5 main parts:

- Communication — Provides the connection with the EGSE Router infrastructure. It outputs the telecommands and receives the telemetry.
- Uplink — Entry point of the new telecommands to send.
- Downlink — Process all the telemetry and acknowledgements.
- Mission Data Access — Provides access to all the mission control data (TM, TC, housekeeping etc.) stored in the MDR.
- Spacecraft State — Contains the information about the spacecraft such as its current visibility or on-board time.

The second component is the distribution system. It has the two main functionalities of providing the new arriving mission data in real-time to the connected real-time clients and enabling external access to all the mission data.

These components are organized in the following manner:



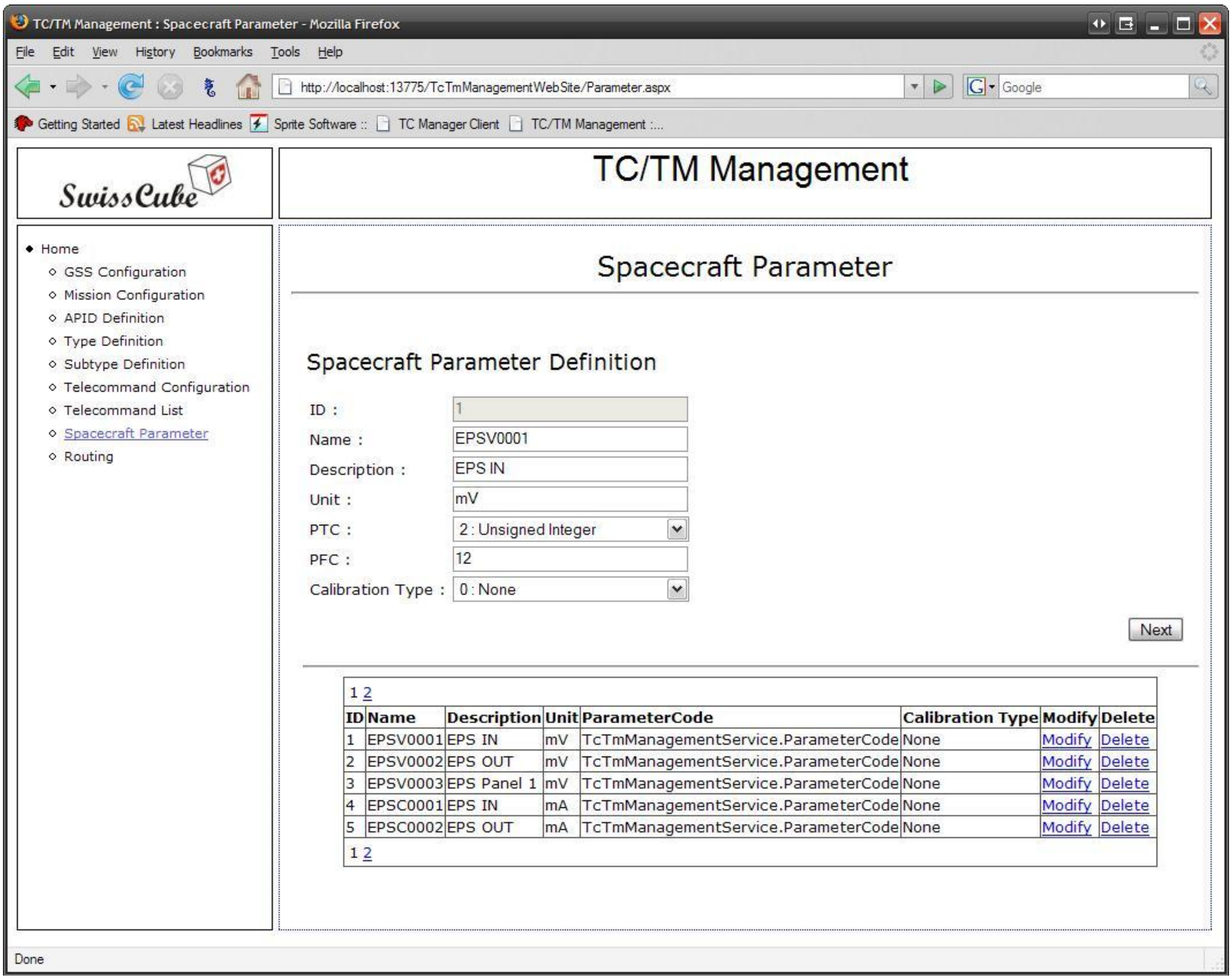
6.4 User Interfaces

6.4.1 Mission Configuration Client

The Mission Configuration Client is a web site used to configure the mission and add all the necessary information in the Mission Information Database (MIB).

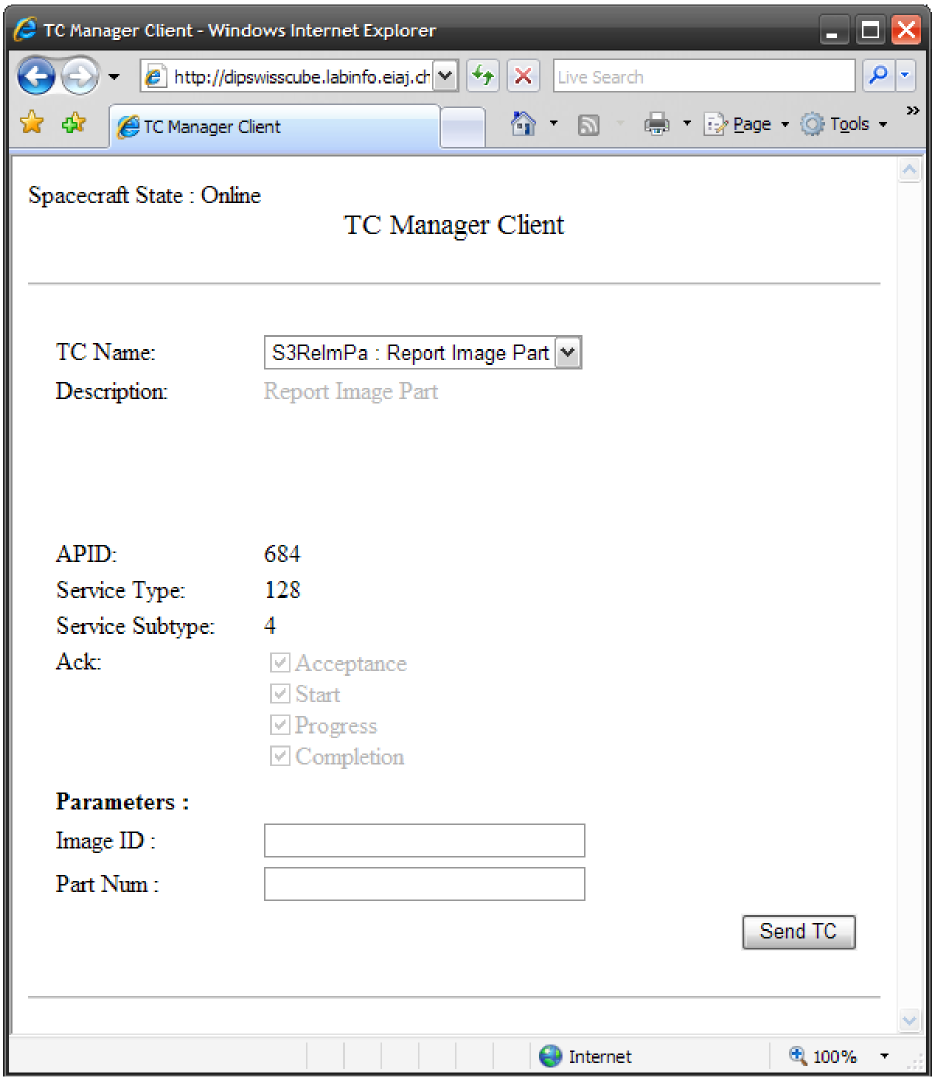
It currently implements the following features:

- Mission Constants definition (see Annex B of [N2])
- Application Process ID (APID) definitions
- Service Types definitions
- Service Subtypes definitions
- Telecommands definitions with their parameters
- Spacecraft parameters definitions (housekeeping)



6.4.2 Telecommand Manager

The telecommand manager is a web application that provides a basic mean to send telecommands. Its use will be reduced once the scheduler and design tool are developed as all actions would be defined by plan. But it would still be useful in case of problem that telecommands can be manually sent directly to the spacecraft.



6.4.3 Simple Monitoring Data Display

This web application provides a simply mean to visualize all the monitoring data remotely. Only viewing the telemetry is publicly available, the other sections require the user to be authenticated.

It implements the following features:

- Telecommands detail (CCSDS packet fields values) and their current acknowledgement status
- Telemetry listing (CCSDS packet fields values)
- Housekeeping values for each defined spacecraft parameters
- SwissCube payload images display

Telecommands

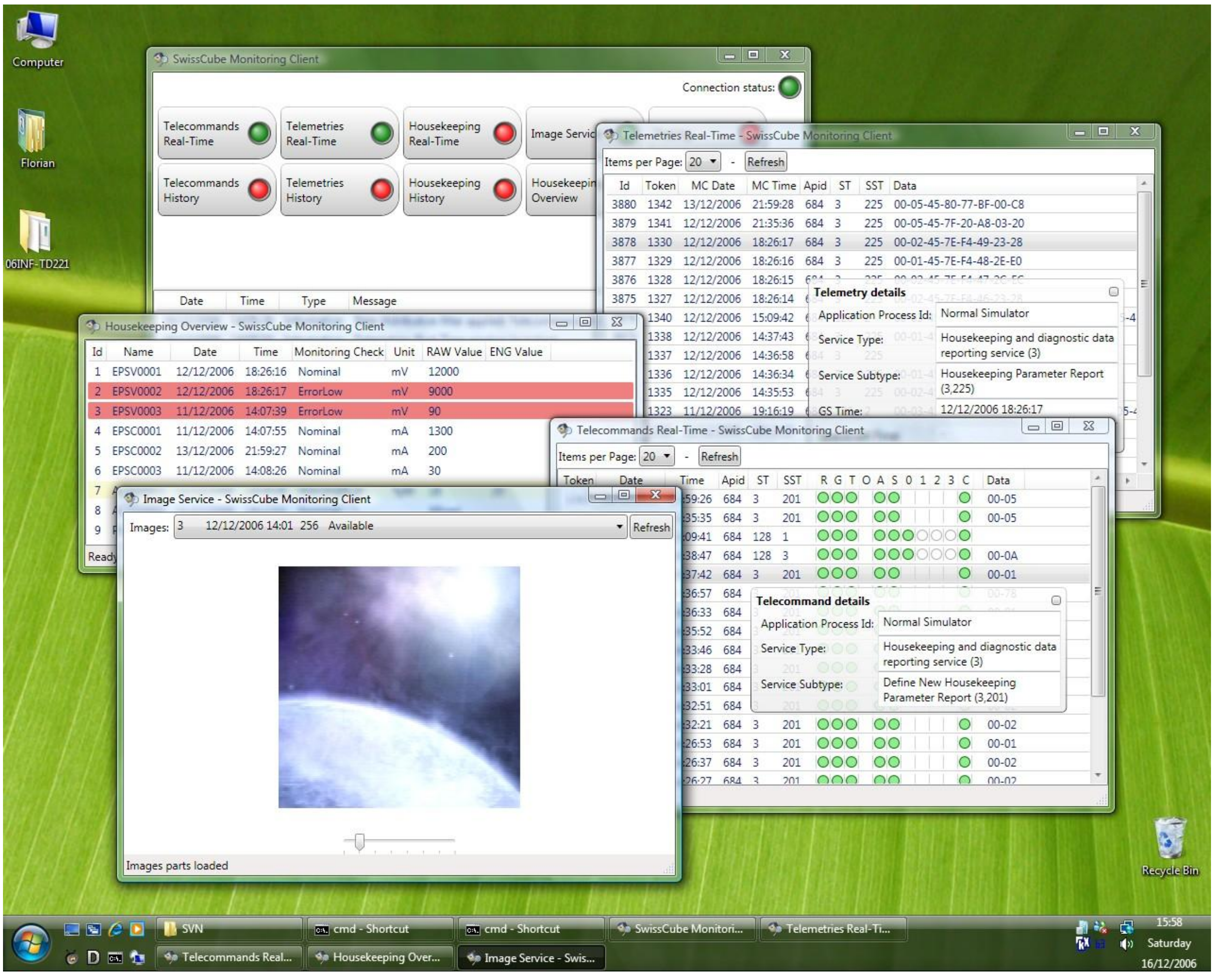
- Home
  - Housekeeping
  - Telecommands
  - Telemetries
  - Image Service

1 2 3 4 5 6 7 8 9 10 ...

Token	Date	Time	Apid	SF	SC	ST	SST	R	G	T	O	A	S	0	1	2	3	C	Data
1342	13/12/2006	21:59:26	684	0	953	3	201	O	O	O		O	O					O	00-05
1341	12/12/2006	21:35:35	684	0	952	3	201	O	O	O		O	O					O	00-05
1340	12/12/2006	15:09:41	684	0	951	128	1	O	O	O		O	O	O				O	-
1339	12/12/2006	14:38:47	684	0	950	128	3	O	O	O		O	O	O				O	00-0A
1338	12/12/2006	14:37:42	684	0	949	3	201	O	O	O		O	O					O	00-01
1337	12/12/2006	14:36:57	684	0	948	3	201	O	O	O		O	O					O	00-78
1336	12/12/2006	14:36:33	684	0	947	3	201	O	O	O		O	O					O	00-01
1335	12/12/2006	14:35:52	684	0	946	3	201	O	O	O		O	O					O	00-02
1334	12/12/2006	14:33:46	684	0	945	3	201	O	O	O		O	O					O	00-05
1333	12/12/2006	14:33:28	684	0	944	3	201	O	O	O		O	O					O	00-02
1332	12/12/2006	14:33:01	684	0	943	3	201	O	O	O		O	O					O	00-0C
1331	12/12/2006	14:32:51	684	0	942	3	201	O	O	O		O	O					O	00-02
1330	12/12/2006	14:32:21	684	0	941	3	201	O	O	O		O	O					O	00-02
1329	12/12/2006	14:26:53	684	0	940	3	201	O	O	O		O	O					O	00-01
1328	12/12/2006	14:26:37	684	0	939	3	201	O	O	O		O	O					O	00-02
1327	12/12/2006	14:26:27	684	0	938	3	201	O	O	O		O	O					O	00-02
1326	12/12/2006	13:42:11	684	0	937	3	201	O	O	O		O	O						-
1325	12/12/2006	13:40:55	684	0	936	3	201	O	O	O		O	O						-
1324	12/12/2006	13:40:03	684	0	935	3	201	O	O	O		O	O						-
1323	11/12/2006	19:16:18	684	0	934	128	1	O	O	O		O	O	O				O	-

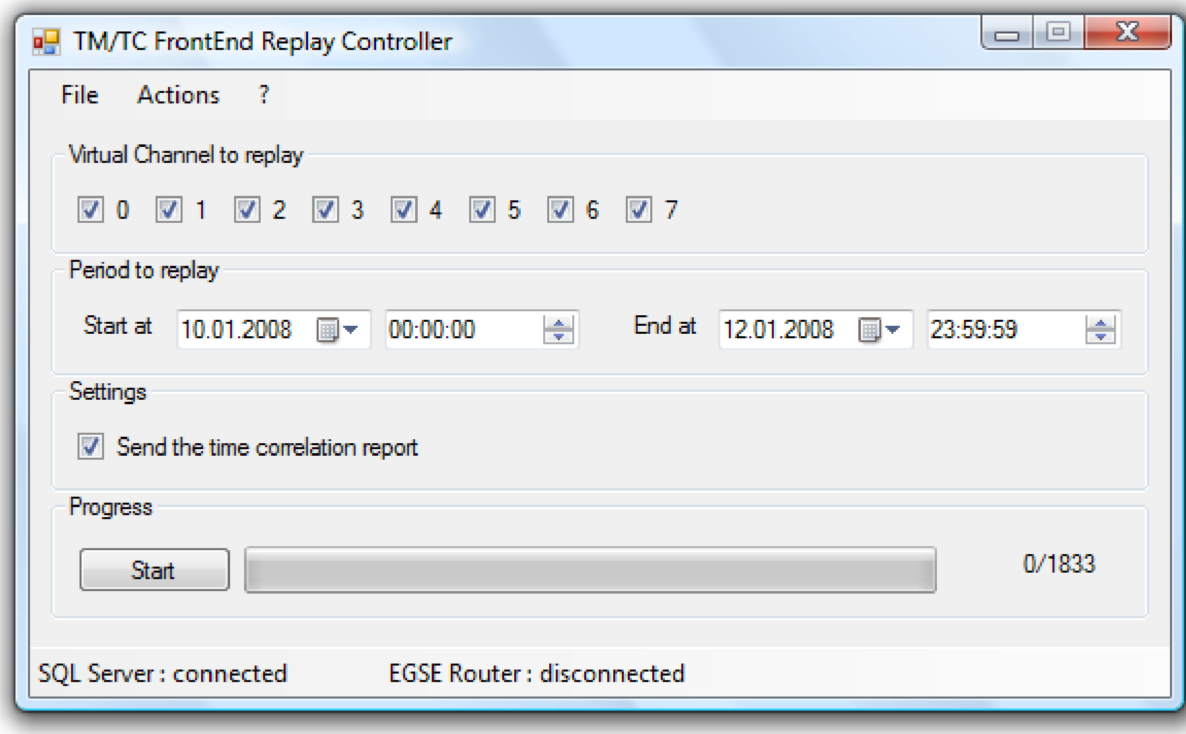
6.4.4 Monitoring Data Display Client

The monitoring client enables monitoring of the spacecraft in real-time. Like the core of the MCS, it uses modules to provide additional mission-specific functionalities. New modules could be developed just for testing or for other missions without modifying the software (plug-in system).



6.4.5 TM/TC Front End Replay Controller

The Replay Controller is a part of the TM/TC Front End. This simple software has been built to simplify the replay of AX.25 frames from the archives. It merely reads rows from the SQL server and generates the corresponding TM Frame Reports. The rows can be filtered by date and VCID. The transmission of the Time Correlation Reports is optional.



6.5 Software Environment

6.5.1 Mission Control System

- Application Type: Server Application
- Operating System: Microsoft Windows Server 2003 SP1, Windows XP SP2 or Windows Vista
- Development Language: C# with .NET Framework 3.0
- Development Environment: Microsoft Visual Studio 2005
- Inter-Process Communication: Windows Communication Foundation
- Database Server: Microsoft SQL Server 2005

6.5.2 TM/TC Front End

- Application Type: Server Application
- Operation System: Microsoft Windows Server 2003 SP1, Windows XP SP2 or Windows Vista
- Development Language: C# with .NET Framework 3.0
- Development Environment: Microsoft Visual Studio 2005
- Database Server: Microsoft SQL Server 2005 (can be Express Edition)

6.5.3 Scheduler and Planning Tool

- TBD

6.5.4 User Interfaces

6.5.4.1 Mission Configuration Client, TC Manager and Simple Monitoring Data Display

- Application Type: Web Application
- Operating System: Microsoft Windows Server 2003 SP1, Windows XP SP2 or Windows Vista
- Development Language: C# with ASP.NET 2.0
- Development Environment: Microsoft Visual Studio 2005

6.5.4.2 Real-Time Monitoring Data Display Client

- Application Type: Locally Installed Application
- Operating System: Microsoft Windows Server 2003 SP1, Windows XP SP2 or Windows Vista
- Development Language: C# with .NET Framework 3.0
- Development Environment: Microsoft Visual Studio 2005
- Graphical Interface Library: Windows Presentation Foundation

7 RECOMMENDATIONS

For the continuation of this project, we need the following information on the spacecraft and ground station:

- Detailed functional definition of all the subsystems to define exactly which telecommand the ground will send and which telemetry will be received from the spacecraft.
- Detailed description of all housekeeping parameters (complete definition, e.g. name, size, calibration...) available on the SwissCube spacecraft.
- Definition of what's needed from us for the testing the subsystems.
- The requirement upon the MCS by payload test equipment.
- Specification of the ground station hardware, existing software and interfacing.
- Detailed information about how the Ground Stations will treat the AX.25 frames.
- Detailed information for the interfacing with the GENSO client.

8 CONCLUSION

8.1 Current state

- SwissCube Mission Control System
    - Using CCSDS packets.
    - Modular architecture with mission-specific monitoring modules.
    - Able to use the EGSE Router infrastructure.
    - Real-time monitoring data distribution.
- TM/TC Front End
    - All features have been implemented
    - Full testing tools with a GUI are available
- User Interfaces
    - Mission Configuration Web application
    - Basic telecommands sending Web application.
    - Simple monitoring web application.
    - Real-time monitoring client application with scientific data retrieval.

8.2 Future tasks

- Finalize ICDs
- TM/TC Front End for GENSO
- SwissCube Mission Control System
    - Implement enhancement taken from ESA collaboration
    - Design and implement a scheduler.
    - Improve and implement new mission-specific modules.
    - Implement time correlation.
- TM/TC Front End
    - Run a set of tests (load, protocol compliance, ...)
    - Make some changes to be consistent with the Ground Station ICD
- User interfaces
    - Add import/export (mission configuration, monitoring data, etc.)
    - Planning tool
- Write the documentation