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SATELLITE SIMULATOR REQUIREMENTS SPECIFICATION BASED ON STANDARD SERVICES

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ABSTRACT

This work aims at presenting the results of modeling a generic satellite simulator functional requirements into the UML use case artifact. The satellite and ground station functions defined in this document aims to be as much general as possible, so they are based on practical publications of related works and in standard space services. The used standards are the CCSDS protocols for telecommand and telemetry exchanging and the ECSS standard for telemetry and telecommand packet utilization. The set of use cases stated in this document is helpful to support who is going to start developing a new satellite simulator. For a new mission definition, the use cases may also used to provide an instantiation basis for the specific uses.

SUMMARY

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DEFINITIONS AND ACRONYMS

AOCS	-	Attitude and Orbit Control System
CCSDS	-	Consultative Committee for Space Data Systems
CLCW	-	Command Link Control Word
CLTU	-	Command Link Transmission Unit
FBMSIM	-	French-Brazilian Micro Satellite Simulator
COP	-	Command Operation Procedure
FTP	-	File Transfer Protocol
FS	-	Flight Software
GST	-	Ground Station
GSRTSIM	-	Ground Station Real Time Simulator
HKTM	-	Housekeeping Telemetry
HKTM-RT	-	Real Time Housekeeping Telemetry or HKTM-P
HKTM-P		Real Time Housekeeping Telemetry or HKTM-RT
HKTM-D	-	Diagnostic Housekeeping Telemetry
HKTM-ST	-	On-board Recorded Housekeeping Telemetry or HKTM-R
HKTM-R		On-board Recorded Housekeeping Telemetry or HKTM-ST
OBDH	-	On-board computer for health monitoring and controlling
PLTM	-	Payload Telemetry
PSS	-	Power Supply Sub-system
RC ACK	-	Remote Command Acknowledge packet
RM	-	Remote Monitoring packet containing ground station equipment status

SCC	-	Satellite Control Center
SCS	-	Satellite Control System
TBC	-	To Be Confirmed
TBD	-	To Be Defined
TC	-	Telecommand
TCD	-	Direct Command
TCI	-	Immediate Command
TCT	-	Time-Tagged Command
TCS	-	Thermal Control Sub-system
TM	-	Telemetry
TMTC	-	Telemetry and Telecommand Sub-system
UML	-	Unified Modeling Language

1

INTRODUCTION

Software simulators are used in space operations to provide validation of Ground and Operations Segments before and after launch of spacecraft. They may simulate the spacecraft, its environment and the ground station providing an accurate and realistic modeling of the interfaces. The simulators must be sufficiently realistic to allow the operators to run flight procedures as if they were interfacing to the real spacecraft (Williams, 2004). Furthermore, an important use of a simulator is encountering unknown scenarios that cannot be tested before launch (Saraf, 2001).

The advantages of developing simulators include the ability to: (i) validate operational procedures, (ii) train operators before launch and (iii) validate the Satellite Control System (SCS) and the TM/TC database (Williams, 2004).

The aim of this report is to show the results of modeling the most common functional requirements of a satellite simulator using the *use case* notation of UML. The report presents a breakdown of the software into modules, describes their main functions and shows the advantages of using use cases to specify this kind of software. The functions related to the on-board data handling computer, were based in the ECSS-E-70-41A (2003), which describes a set of standardized services for an on-board data handling, so they are satellite independent. The protocol supporting the ground and on-board system communication, at the physical to transport levels, are based on CCSDS standards (ESA, 1990).

This report provides a satellite simulator development team with a generic framework from were a specific simulator design can be instantiated. The breakdown and the functions choices allow its reuse for future micro-satellite and small satellite programs in different missions.

This report is organized as follows: section 2 presents the satellite simulator overview, section 3 presents the functional requirements expressed in use cases, section 4 presents the benefits of using use cases.

2

SATELLITE SIMULATOR OVERVIEW

The satellite simulator described in this report, cover functions for simulating the whole satellite behavior, the ground station functions, the environment and the flight dynamics aspects of the satellite in flying.

The simulator, used for the Satellite Control Center's operator team training and also for the Satellite Control System validation, allows the execution of all the operational procedures to be performed by the Satellite Control System, such as control and monitor the satellite during its passage through the visibility area of the ground station. All configuration facilities for the operator's training in different situations such as normal and contingencies satellite operating modes is also taking into account.

Among the main functions of a satellite simulator one may find:

- Ingest and deal with all telecommand[1] types. The typical telecommand types considered in this work are:
    - direct commands (TCD) – which are executed by the on board hardware, as soon as it is recognized on board;
    - immediate commands (TCI) – which are executed by the on board data handling software. This kind of command are executed as soon as they arrive in the satellite;
    - time-tagged commands (TCT) - which are executed by the on board data handling software, only when the time-tag is trigged. This kind of command is associated with a data-time indicating the exact time it should be executed on board.
- Generate platform and payload telemetry. Telemetries are the information from satellite sent to the systems on ground. The types of telemetries that has taken into account here are:

- real time housekeeping telemetry (HKTM-RT). This telemetry is sent directly to ground station, as soon as it is acquired on board and the satellite is into the ground station visibility range. However, it does not exist when the satellite is out of ground station visibility,

- on-board recorded housekeeping telemetry (HKTM-ST). This telemetry is recorded on board when the satellite is out of ground station visibility. It is sent to ground station during the visibility,

- payload telemetry (PLTM). This telemetry refers to the payload acquired data,

- Provide attitude and orbit determination according to the satellite and the space environment;
- Provide mechanisms to allow operators to make the time synchronization;
- Monitor the ground station and keep ground and on-board communication according to the protocol established for the mission.

2.1 Context and users

The satellite simulator will be used in only one operational scenario, in which all functions are available for the simulation conductor at any time during a simulation run. This operational scenario allows the SCC's operators interact with the SCS as the real satellite was in operation. Figure 2.1 illustrates the operational scenario of the satellite simulator.

In this study, the satellite simulator software is supposed to run in a Personal Computer connected to the Satellite Control System in a Personal Computer-server, located in the SCC facilities. It interfaces with two external entities:

- The Satellite Control System (SCS): this system is located in the Satellite Control Center. The satellite operators interact with the SCS for commanding (sending telecommands) and monitoring (through received telemetry from) the satellite,

[1] telecommands are sent to satellite in order to execute an operation.

and also for commanding and monitoring the ground station. Every communication with the satellite is performed via the ground station facilities.

- The Simulation Conductor: the person responsible to operate the satellite simulator from one terminal monitor. It is allowed to configure, start/stop a simulation run. The configuration of the satellite simulator must be prepared according to a training plan elaborated by the SCC's operations manager.

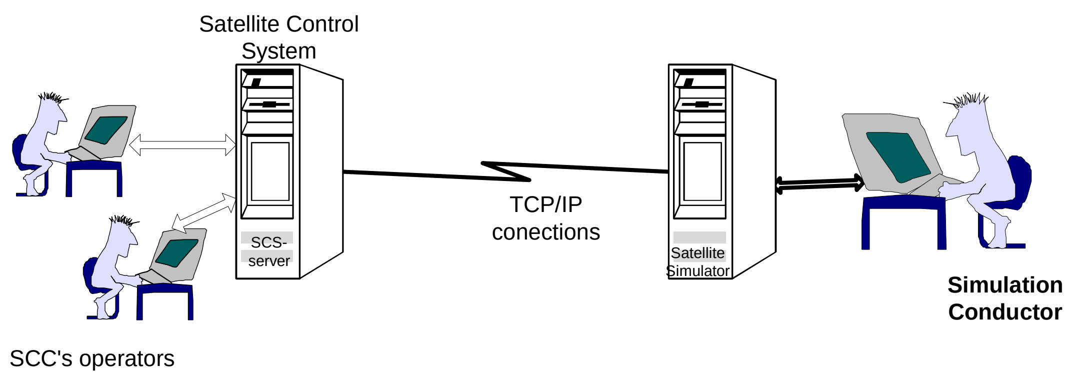

Figure 2.1: Operational Scenario

A satellite simulator is used by different persons in the SCC, which are:

- SCC's operation team: these users indirectly interact with the simulator during the training phases. For them the actual satellite or the simulator should be interchangeable.

- SCC's operation manager: this person plans the simulation configurations in order to provide different situations for the operators training.

- Simulation conductor: who interacts with the operation manager to know exactly how to configure the simulator (according to the Training Plan) and to operate it during a simulation session run.

3

FUNCTIONAL REQUIREMENTS

This section describes the functional requirements of the satellite simulator. These requirements are organize according to a functional breakdown, in which the simulator was divided into 4 modules: ground station, environment and flight dynamic, satellite and simulation management. Figure 3.1 illustrates the functional breakdown.

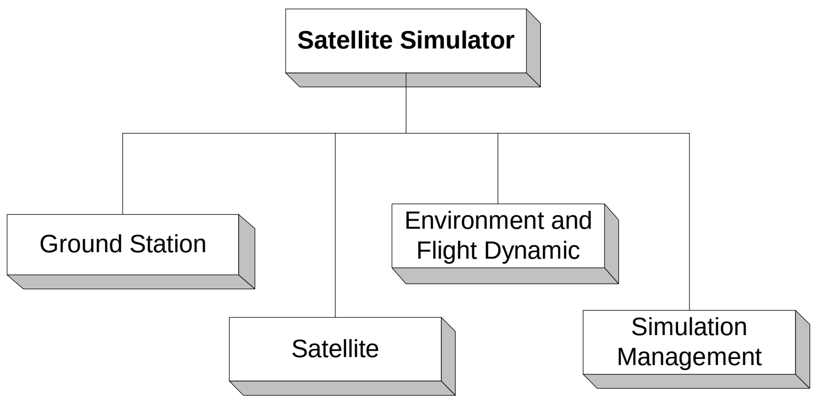

Figure 3.1: Satellite Simulator functional modules

The Ground Station module is responsible for providing the functions related to ground station equipment commanding, sending the telecommands received from SCS to the satellite and sending the telemetries received from satellite to SCS. Further description of this module is presented in sub-section 3.1.

The Satellite module is in charge of treating the telecommands and preparing the telemetries according to the on-board subsystems behavior. This module is described in sub-section 3.2.

The Environment & Flight Dynamic module calculates the satellite orbit, attitude and the visibility range of a ground station related to the satellite orbit. This module is further presented in sub-section 3.3.

The Simulation Management module aims at providing facilities for (i) configuring a simulation run, (ii) controlling its execution and (iii) creating a friendly user interface. The functional requirements of this module are presented in sub-section 3.4.

The modules description follows the scenario-based technique for requirement elicitation named use cases (Jacobson et al, 1992). A use-case identifies actors involved in a system interaction and name this interaction. In a use case description, an actor is an external subsystem or a user that triggers an event or receives a stimulus associated to a use case. Consequently, for defining the use cases, the actor related to the satellite simulator were defined. Table 3.1 presents such actors. As the satellite simulator was divided into four modules, when a module is described, another module is seen as an external entity, so it is considered as an actor.

Table 3.1: Actors

Actor	Description (or role)
Satellite Control System (SCS)	• Establish communication with the Ground Station • Control and monitor the GST • Control and monitor the satellite
Simulation Conductor	• Configure, according to the Training Plan, the satellite, the GST, the environment and flight dynamics and the simulation management, in order to characterize different situations for training the operators of the SCC • Interact in real time with the simulator during a simulation session run: read and modify parameter values
Timer	• Any timer that triggers an event depending on temporization
Ground Station	• Send telecommands to Satellite • Receives telemetry from Satellite • Receives visibility status from the Environment & Flight Dynamic • Receives parameter values from Simulation Management
Satellite	• Send telemetry to Ground Station • Receives telecommands from GST • Receives GST visibility status from the Environment & Flight Dynamic • Receives parameter values from Simulation Management
Environment and Flight Dynamic	• Send visibility status to the Ground Station • Send Ground Station visibility status to Satellite • Send satellite position in the orbit to Satellite • Receives parameter values from Simulation Management
Simulation Management	• Send configuration parameters to Ground Station, to Satellite and to Environment & Flight Dynamics • Send parameter value changes to Ground Station, to Satellite and to Environment & Flight Dynamics

The use cases presented in the next sections are summarized in a Use Case Diagram and described in Use Case Tables. A use-case table is organized as follows: each line corresponds to one use case, the first column gives the requirement identification, the second brings the use case description, and the third associates the actor that triggers or uses that use case. The use case description includes an overview of the interaction its represents, entry and exit conditions. Besides that, the use case includes normal, alternative and exception flows characterizing the scenarios related to the use case. These flows describing the scenarios are itemized according to the rules given in Scent methodology. (Ryser, 2000)

3.1 Ground Station

The Ground Station module provides the interface between the Satellite Control System (SCS) and the Ground Station (GST). These interfaces should comply with those provided by a real ground station. In this study, the SCS is supposed to be connected with only one ground station at each time. The information flows exchanged between the SCS and a GST should be classified in real-time and post-passage.

The first includes commands for the ground station equipment, for telecommand, for telemetry. As the ground-board protocol considered here, is the CCSDS protocol, a flow for the CLCW words are also included. For the same reason, the TC is named CLTU.

The second represents the telemetry stored in the ground station during a passage and requested by the operator after the satellite passage by the station. Figure 3.2 shows the GST interfaces with the SCS.

Files comprising Doppler measures and log book may also be generated and made available by the ground station. Additionally, interfaces comprising antenna data pointing and a pass planning generated in SCC and transmitted to GST before a passage may also be included.

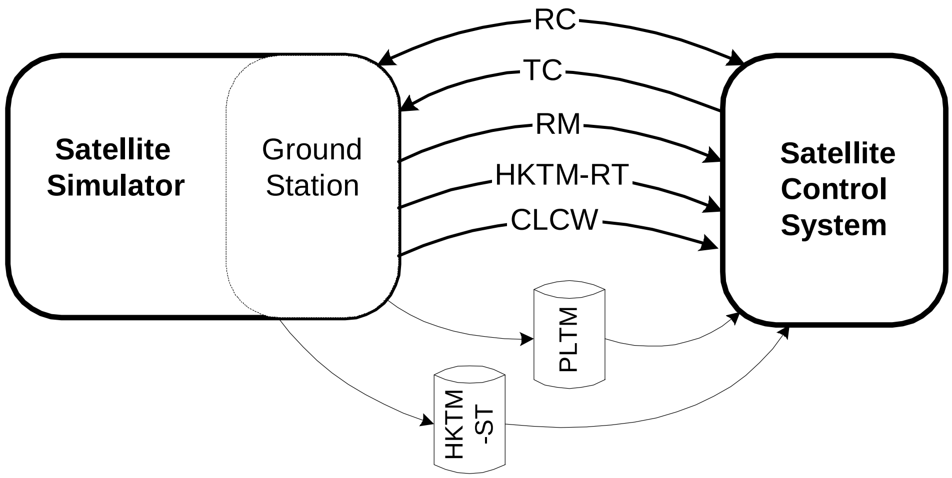

Figure 3.2: Ground station interface with the SCS.

In Figure 3.2 one may observe the two classes of flows:

- Those represented in bolded arrows are allowed via a TCP/IP connection.
- Those including the files containing respectively HKTM-ST, PLTM are received and stored in the files in Ground Station. They are transferred to SCC, via a FTP connection, only under an operator request.

The Use Case Diagram for the Ground Station module is illustrated in Figure 3.3, whereas the use cases description is presented in Table 3.2.

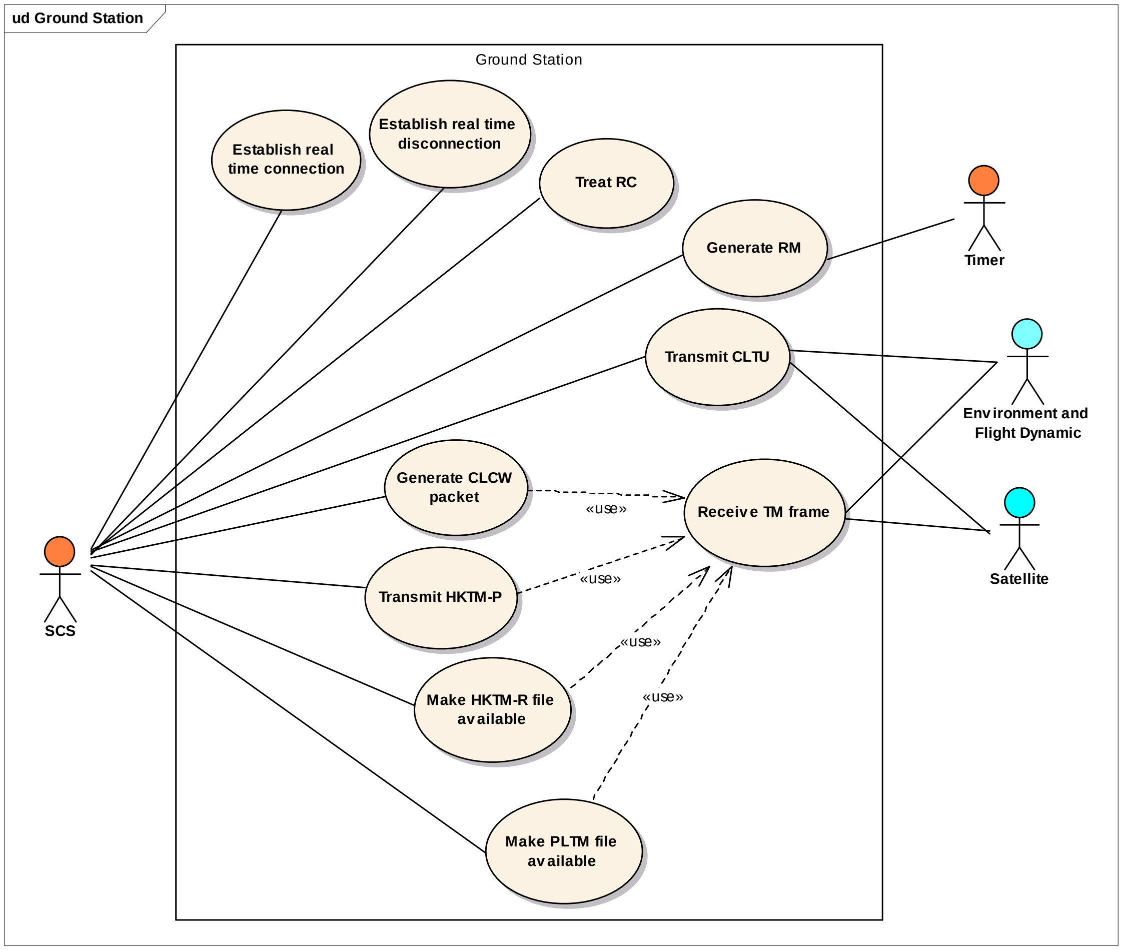

Figure 3.3: Ground Station use cases diagram

Table 3.2: Description of Ground Station use cases

Req Id	Description	Actor
GST.1	**Establish real time connection** *Description:* The SCS (the client) requires a connection to the ground station (the server). Only one ground station can be connected for a satellite passage. *Entry Condition:* *Exit Condition:* • The connections requested by SCS are established *Normal flow:* 1. The SCS sends a connection command to GST for the real time flows (HKTM-RT, CLCW, RM, RC, TC) 2. TCP/IP connections are established. *Exceptional flow*: 2.a A TCP/IP connection is not established.	SCS
GST.2	**Establish real time disconnection** *Description:* The ground station receives a disconnection request, interrupting the	SCS

<table>
<tr><td></td><td>data exchanging between the SCS and the GST, generally after the satellite passage.
Entry Condition:
Exit Condition:
• All the TCP/IP connections are closed.
Normal flow:
1. The SCS send a disconnection command to the GST.
2. The GST stops sending data.
3. The GST closes the TCP/IP connection for the flows.
Exceptional flow:
1.a The connection is not closed for some mistake in the command.</td><td></td></tr>
<tr><td>GST.3</td><td>Receive TM frame
Description: The GST receives TM frames from the Satellite.
Entry condition:
• The satellite is in Lock (the on-board-transmitter is ON AND satellite is in ground station visibility AND the ground-receiver is ON)
Exit condition:
• The TM packets and CLCW information are available
Normal flow:
1. The GST receives the TM frames sent by the satellite
2. The GST extracts the TM packets from the received frame
3. The GST extracts the CLCW information from the received frame</td><td>Satellite,

Environment and Flight Dynamic</td></tr>
<tr><td>GST.4</td><td>Transmit HKTM-RT
Description: The HKTM-RT packet, in CCSDS standard format, is received by the ground station from the Satellite and sent, in real time, to SCS.
Entry condition:
• TCP/IP connection is established for the HKTM-RT data flow.
Exit condition:
• A HKTM-RT packet is sent to SCS.
Normal flow:
1. The GST receives the TM packets from satellite (see GST.3)
2. The GST sends the HKTM-RT packet into a TCP/IP message to SCS.
Exception flow:
2.a. The HKTM-RT connection between the GST and the SCS is not correctly established.</td><td>SCS</td></tr>
<tr><td>GST.5</td><td>Generate CLCW packet
Description: A TM packet, in CCSDS standard format, containing the CLCW information is created and sent in real time from GST to SCS.
Entry condition:
• TCP/IP connection is established for the CLCW data flow.
Exit condition:
• A CLCW packet is sent to SCS.
Normal flow:
1. The GST receives the CLCW word from satellite (see GST.3)</td><td>SCS</td></tr>
</table>

	2. The GST formats the CLCW packet 3. The GST sends the CLCW packet into a TCP/IP message to SCS. *Exception flow:* 3.a The CLCW connection between the GST and the SCS is not correctly established.	
GST.6	**Generate RM** *Description:* RM packets comprising GST equipments parameters status are periodically generated and sent to SCS. These information allows SCC's operators remote monitoring the ground station. These packets are in CCSDS standard format. *Entry condition*: • TCP/IP connection is established for the RM flow. • The T_{RM} timer was trigged, starting RM generation *Exit conditions*: • A RM packet is sent to SCS. *Normal flow:* 1. The GST generates a RM packet, 2. The GST sends the RM packet to SCS 3. The GST configures the T_{RM} *Exception flow:* 2.a The RM connection is not correctly established.	SCS, Timer
GST.7	**Treat RC** *Description:* The ground station receives RC packets sent by SCS, comprising commands as configure an equipment, to be executed in the ground station. *Entry condition*: • TCP/IP connection was successful established for the RC flow. *Exit conditions*: • A confirmation is sent to the SCS *Normal flow:* 1. The SCS sends a RC packet to the GST 2. The GST accepts the command 3. The GST confirms the reception to the SCS. 4. The GST executes the command (if it is to turn on the ground-receiver then the ground-receiver is turned on).	SCS
GST.8	**Transmit CLTU** *Description:* The SCS sends a CLTU in CCSDS standard format to ground station, which are directly send to the Satellite. *Entry condition*: • TCP/IP connection is established for the CLTU data flow. *Exit condition*: • A CLTU is transmitted from GST to the Satellite. *Normal flow:* 1. The SCS sends a CLTU to the GST. 2. If the satellite is in Lock, then he GST sends the CLTU to the satellite.	SCS, Satellite, Environment and Flight Dynamic

	Exception flow: 2.a The satellite is out of the GST visibility range, then the CLTU is not sent to Satellite.	
GST.9	**Make HKTM-ST file available** *Description:* Create a file and store the HKTM-ST packets, in CCSDS format, received from the satellite during a passage. This file is made available for SCS. *Entry condition*: *Exit condition*: • The HKTM-ST file is available for SCS retrieval *Normal flow*: 1. The GST receives the HKTM-ST packets from satellite (see GST.3) 2. The GST creates a file 3. The GST stores the HKTM-ST packets into the file 4. The GST make the file available for SCS retrieval *Exception flow*: 1.a.1. The file will not be created	SCS
GST.10	**Make PLTM file available** *Description:* Create a file and store the PLTM packets (scientific data) formatted in CCSDS packets received from the satellite during a passage. This file is made available for SCS. *Entry condition*: *Exit condition*: • The PLTM file is available for SCS retrieval *Normal flow*: 1. The GST receives the PLTM packets from satellite (see GST.3) 2. The GST creates a file 3. The GST stores the PLTM packets in the file 4. The GST make the file available for SCS retrieval *Exception flow*: 1.a.1. The file will not be created	SCS

3.2 Satellite

The simulation of the satellite behavior as a whole requires not only each satellite sub-system, but also, the satellite modes and the payload operational profiles be simulated.

The sub-systems of a scientific micro-satellite generally are: Thermal Control Subsystem (TCS), Power Supply Subsystem (PSS), Attitude and Orbit Control Subsystem (AOCS), Telemetry and Telecommand subsystem (TMTC) and On-Board Data Handling – hardware/ software (OBDH) and Payloads.

In order to organize the presentation of the functional requirements of the Satellite, this module was broken into six sub-modules according to the satellite subsystems as shown in Figure 3.4. The functional requirements provided by TMTC, OBDH, Payload, TCS, PSS, AOCS sub-modules are described in subsections 3.2.1 to 3.2.6 as use cases.

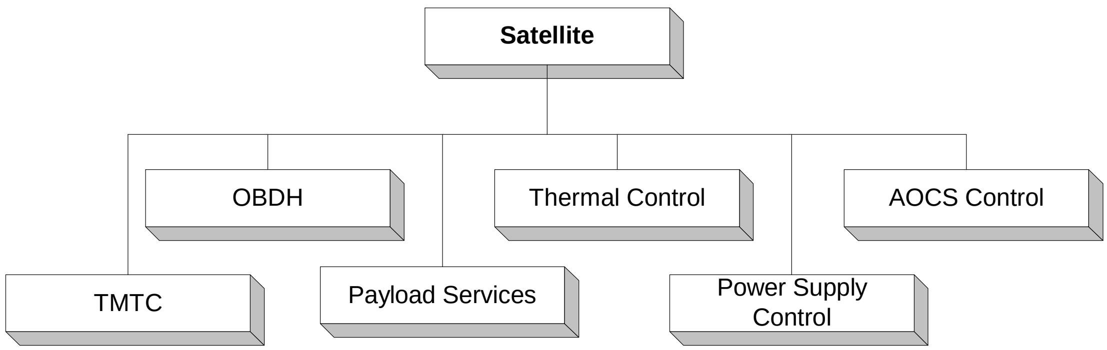

Figure 3.4: Satellite sub-modules

The Satellite use cases description includes new actors. These actors represent the sub-systems comprising the satellite. Table 3.3 presents these actors and their respective roles.

Table 3.3: Actors and roles of the Satellite module

Actor	Role description
TMTC	• Receive CLTUs from the GST • Send telemetry frames the GST • Receive TM packets from the OBDH • Send TC packets to the OBDH
OBDH	• Receive TC packets from the TMTC • Send TM packets to the TMTC
Payload services	• Receive TCU from the OBDH • Send PL report to the OBDH
Thermal control	• Send parameter values to OBDH
Power Supply Control	• Receive parameter values/command from the OBDH • Send parameter values to OBDH
AOCS Control	• Receive parameter values from the OBDH • Send parameter values to OBDH

3.2.1 TMTC sub-module

The TMTC Subsystem includes besides the equipment: transmitters, receivers and antennas; a logical performance of the CCSDS (on-board) protocol, from physical to transport layers, including the Command Operation Protocol (COP1) (ESA, 1990).

Figure 3.5 shows the use case diagram of the TMTC sub-module and Table 3.4 describes the use cases.

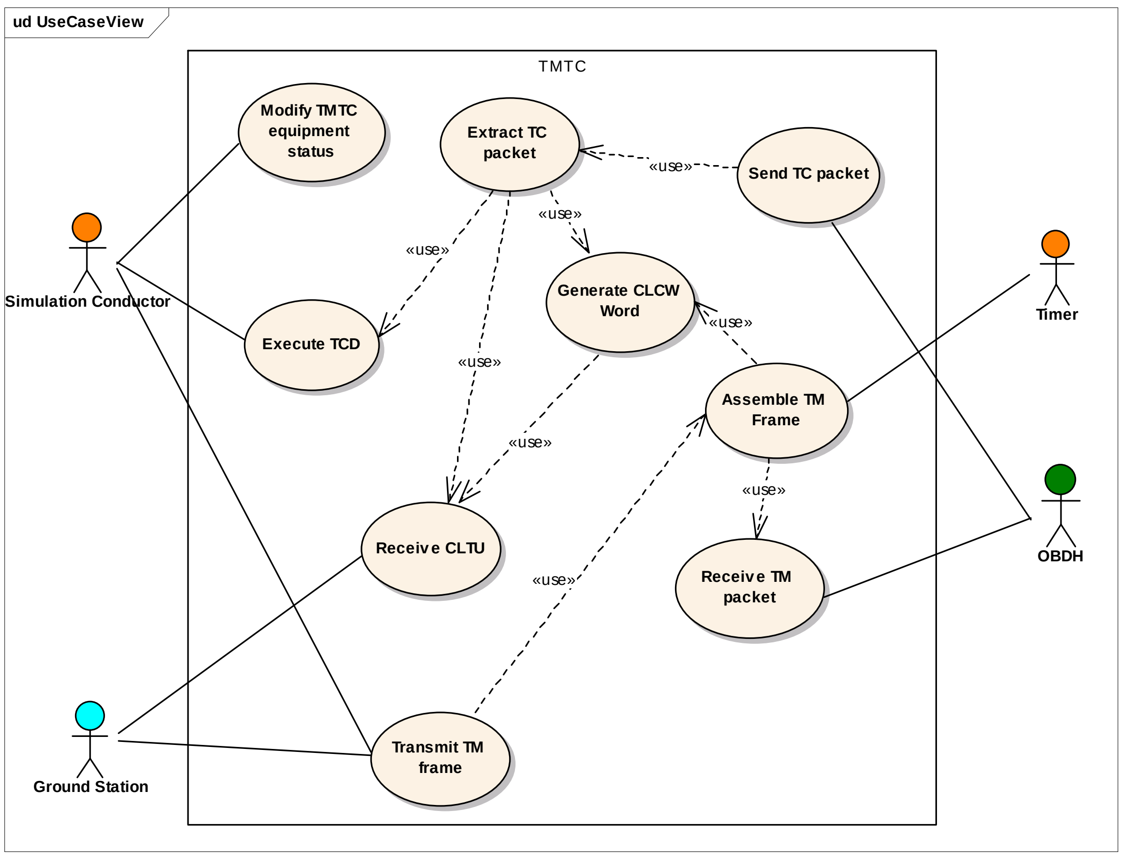

Figure 3.5: TMTC sub-module use cases

Table 3.4: Description of TMTC use cases

Req Id	**Description**	**Actor**
ST-TMTC.1	**Receive CLTU** *Description:* The TMTC receives the CLTU from ground station, validates it and decodes the TC codeblock. A CLTU carries one or more TC frames. *Entry condition*: • The satellite is in Lock (the on-board-transmitter is ON AND satellite is in ground station visibility AND the ground-receiver is ON) *Exit condition*: • The TC codeblock is decoded and available *Normal flow*: 1. The TMTC receives the CLTU from the ground station. 2. The TMTC verifies if the start sequence of the coding layer is ok 3. The TMTC decodes the TC codeblock 4. The TMTC verifies if the tail sequence of the coding layer is ok *Exception flow*: 2a. The start sequence of the coding layer is not ok 2a.1 The codeblock is not make available 4a. The tail sequence of the coding layer is not ok 4a.1 The codeblock is not make available	Ground Station

ST-TMTC.2	**Extract TC packet** *Description:* The TMTC extracts the TC frame from the TC codeblock, after it extracts the TC segment from the TC frame, and then extracts the TC packet from the TC frame. Each TC frame belongs to only one CLTU. (ESA, 1992) *Entry condition*: *Exit condition*: • The TC packet is available • The type of TC packet is available *Normal flow*: 1. The TMTC receives the TC codeblock (see ST-TMTC.1) 2. The TMTC extracts the TC frame from the TC codeblock 3. The TMTC verifies if the SAT-ID is ok 4. The TMTC verifies if the bypass flag is ok 5. The TMTC verifies if the command flags are ok 6. The TMTC verifies if the size of the frame header except for the error control is ok 7. The TMTC extracts the TC segment from the TC frame 8. The TMTC verifies if the MAP number (TC physical destination) is ok 9. The TMTC extracts the TC packet from the TC segment 10. The TMTC verifies if the APID of the packet header is ok *Alternative flow:* 9a. The TC is a TCD 9a.1 Execute TCD (see St-TMTC.8) *Exception flow*:	No external actor
ST-TMTC.3	**Send TC packet** *Description:* The TMTC sends the TC packet and its type to the OBDH. *Entry condition*: *Exit condition*: • The TC packet is sent to OBDH *Normal flow*: 1. The TMTC extracts a TC packet (see ST-TMTC.2) 2. The TMTC sends the TC packet and its corresponding type to OBDH	OBDH

ST-TMTC.4	**Generate CLCW word** *Description*: The TMTC analyses the TC codeblock of the received CLTU, the segment and the frame headers (see ST-TMTC.2) and generates the information to CLCW. The CLCW is sent to ground in a TM frame. *Entry condition*: • A CLTU has arrived *Exit condition*: • CLCW is generated *Normal flow:* 1. The TMTC receives the CLTU (see ST-TMTC.1) 2. The TMTC gets the result analyses of the segment and the frame headers (see ST- TMTC.2) 3. The TMTC gets the protocol service mode 4. The TMTC gets the physical and logical conditions of communication link 5. The TMTC sets the values in the CLCW	No external actor
ST-TMTC.5	**Receive TM packet** *Description*: The TMTC receives the TM packet from OBDH. *Entry condition*: • *Exit condition*: • The TM packet is received *Normal flow:* 1. The TMTC receives the TM packet from OBDH	OBDH
ST-TMTC.6	**Assemble TM frame** *Description*: The TMTC assembles the frames according to the CCSDS standard format (ESA, 1990). The rules to assemble a frame with a list of the TM packets should be obtained from a Data Base. *Entry condition*: • The T_{Frame} timer was trigged, starting TM frame assemble *Exit condition*: • A TM frame is assembled *Normal flow:* 1. The TMTC receives the TM packet from OBDH (see ST- TMTC.5) 2. If there is a CLCW includes it in the TM frame (see ST- TMTC.4) 3. The TMTC assembles the TM frames 4. The TMTC configures the T_{Frame}	Timer

<table>
<tr><td>ST-TMTC.7</td><td>Transmit TM frame
Description: The satellite transmits the HKTM-RT, HKTM-ST, and PLTM frames to GST whenever the satellite is in the GST visibility range.
The telemetry transmission to GST is interrupted as soon as the satellite exits the visibility limits of a GST. Telemetry transmission to SCS is resumed as soon as the satellite enters the visibility limits of another GST.
The satellite transmitter is turned ON whenever the satellite enters into the GST visibility range (detected by the Environment and Flight Dynamic module). The Simulator conductor may turned on and off this transmitter.
Entry condition:
• The satellite is in Lock (the on-board-transmitter is ON AND satellite is in ground station visibility AND the ground-receiver is ON)
Exit condition:
• The TM frame is sent to ground station
Normal flow:
1. If the satellite is in Nominal Mode then
2. The TMTC assembles a TM frame (see ST- TMTC.6)
3. The TMTC sends the TM frames to ground station
Exception flow:</td><td>Ground Station,
Environment and Flight Dynamic,
Simulation conductor</td></tr>
<tr><td>ST-TMTC.8</td><td>Execute TCD
Description: The TMTC has received a direct telecommand (TCD) to be executed by hardware.
Entry condition:
Exit condition:
• The TC is executed
Normal flow:
1. The TMTC received a TCD via a TC packet (see ST- TMTC.2), then execute the TCD
Alternative flow:
1.a. The TMTC received a TCD from the simulation conductor, then execute the TCD</td><td>Simulation conductor</td></tr>
</table>

ST-TMTC.9	**Modify TMTC equipment status** *Description:* The status (ON/OFF/FAILURE) of any TMTC equipment may be modified by configuration, by some internal condition or by the simulation conductor. This use case represents the modification that may be performed by the simulation conductor. *Entry condition*: *Exit condition*: • The status of a TMTC equipment is modified *Normal flow:* 1. The simulator conductor selects a TMTC equipment 2. The simulator conductor modifies the status of the selected TMTC equipment	Simulation conductor

3.2.2 OBDH sub-module

This sub-module is responsible for monitoring and controlling the satellite operation mode, it verifies and executes telecommand, monitors the satellite health and generates periodic, event and statistic telemetries.

The OBDH subsystem requirements, presented here, are based on the most common functions described in the Telemetry and Telecommand Packet Utilization Service (PUS) standard (ECSS, 2003). Except for the requests and reports formats, which are not taken into account here. In the use case description, in the following, the reference PUS (number) means the type of the service described in the referred document.

The satellite has several operational modes, such as: (i) AIT, when the satellite is in ground, before the launch; (ii) launching, period between the separation from the launcher and the next mode; (iii) first acquisition; (iv) **operational nominal** (rough or fine pointing); (v) operational in orbit control – manouver; (vi) **Safe**, only the essential equipment are turned on. However, only the operational nominal and the safe mode are taken into account for simulation in the context of this study.

The functions of the OBDH sub-module are shown in Figure 3.6 as use cases. Table 3.5 describes the use cases.

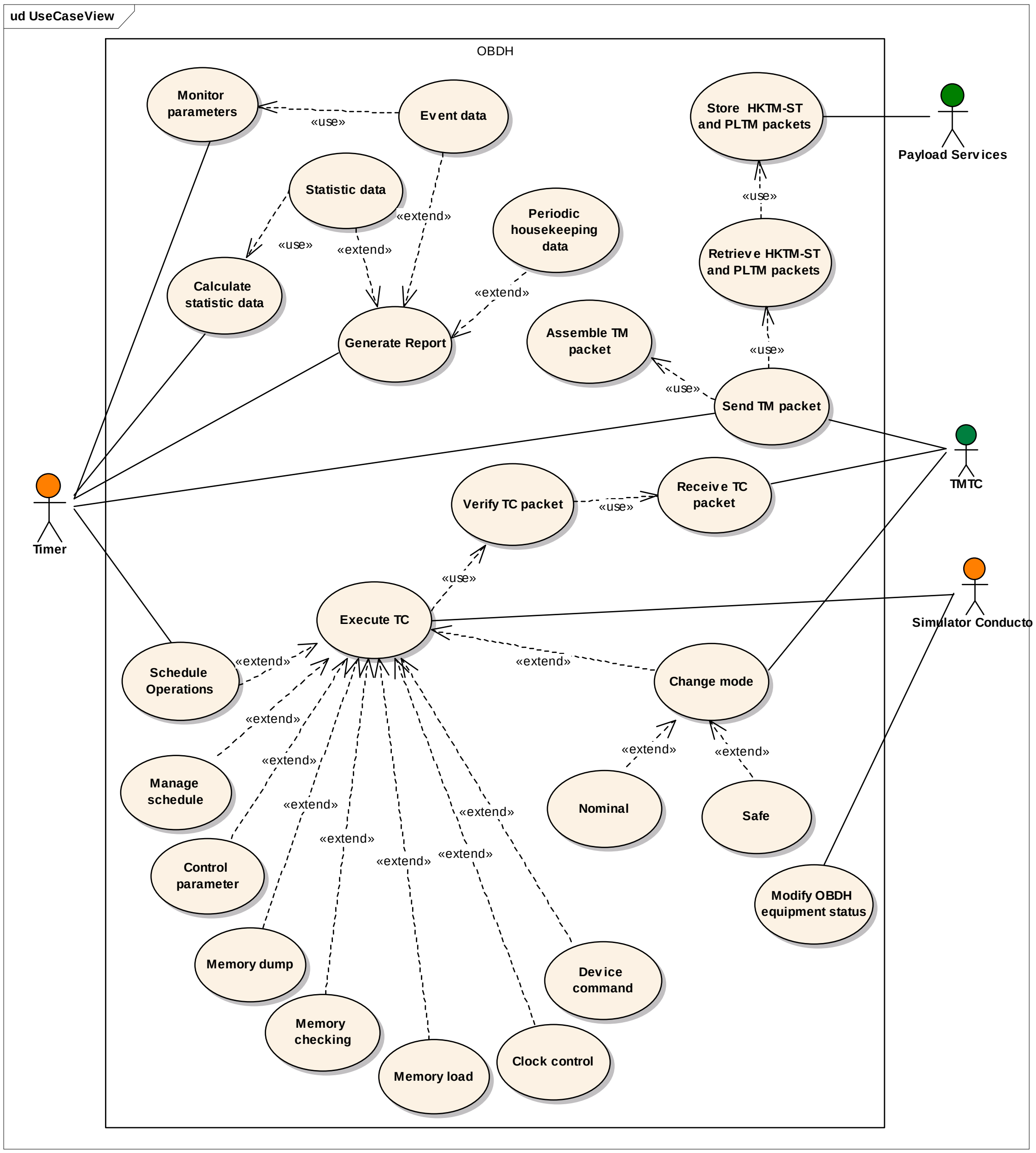

Figure 3.6: OBDH sub-module use cases

Table 3.5: Description of OBDH sub-module use cases

Req Id	Description	Actor

<table>
<tr><td>ST-OBDH.1</td><td>Receive TC packet
Description: The OBDH receives a TC packet from TMTC.
Entry condition:
Exit condition:
• The TC packet is received
Normal flow:
1. The OBDH receives the TC packet from the TMTC</td><td>TMTC</td></tr>
<tr><td>ST-OBDH.2</td><td>Verify TC packet
Description: An immediate or time-tagged telecommand (TCI, TCT) is received in a TC packet. The satellite verifies the TCI, TCT packet correctness and executability.
Entry condition:
Exit condition:
• The TC was verified.
Normal flow:
1. The OBDH receives the TC packet from TMTC (see ST-OBDH.1)
2. The OBDH verifies the type of TC packet: if time tagged (TCT) or immediate (TCI)
3. The OBDH verifies if the TC-ID of the TC packet data field is legal
4. The OBDH verifies if there is some mismatch TC-ID for the current satellite mode/state in TC packet
5. The OBDH verifies if the TC packet due UTC date is greater equal than the current time
6. The OBDH verifies if there is some syntax error in TC packet
7. If the TC is a TCU, then check the payload operational profile
Alternative flow:
Exception flow:
1. If the TC is not OK, then indicates to Monitor parameters use case for event report (see ST-OBDH.14)</td><td>No external actor</td></tr>
</table>

ST-OBDH.3	**Execute TC** *Description*: The OBDH has received a telecommand by the TMTC board or by the simulation conductor. The received TC is executed. *Entry condition*: • The TTimeTaggedTC timer was trigged OR • TC packet was received (see ST-OBDH.1) *Exit condition*: • The TC is executed *Normal flow:* 1. The OBDH verifies the TC packet (see ST-OBDH.2) 2. The OBDH identify the TC-APID 3. The OBDH execute one of the TC types (see ST-OBDH.4 , ST-OBDH.5, ST-OBDH.6 , ST-OBDH.7, ST-OBDH.8 , ST-OBDH.9, ST-OBDH.10 , ST-OBDH.11, ST-OBDH.22, ST.PL.1, ST.AOCS.1)	Simulation conductor, Timer

<table>
<tr><td>ST-OBDH.4</td><td>Device command
Description: The OBDH executes a device command, ie., turn an equipment ON or OFF or load a register.
Entry condition:
Exit condition:
• The TC is executed
Normal flow:
1. The OBDH executes the device command.</td><td>No external actor</td></tr>
<tr><td>ST-OBDH.5</td><td>Schedule operations
Description: This use case consists on queuing and scheduling on-board operations. The set of queues allows the implementation of the work schedules (working plans) concept. See PUS (11).
There is one TC queue per functional entity, e.g., AOCS, payload experiment, etc..
The set of queues shall have the capability to store commands for several days. The number of queues depends on the satellite. The APID identifying each queue is also mission dependent.
Entry condition:
Exit condition:
• The TC packet is queued in the corresponding queue.
• The timer is set with the execution time of the TC.
Normal flow:
1. The OBDH verifies if the TC is time tagged, the time is not expired (see ST-OBDH.2)
2. The OBDH verifies if the TC packet is compatible with the working plan, i.e., if the TC-ID is compatible to the APID queue AND the APID queue[2] does exist
3. The OBDH verifies if the execution-time is different from the others execution-times of the TCs stored in the given queue
4. The OBDH verifies if the queue is not full
5. The OBDH inserts the TC packet in the corresponding APID queue
6. The OBDH configures timer of the inserted TC-ID, the $T_{TimeTaggedTC}$</td><td>Timer</td></tr>
</table>

[2] The APID-queue means the command schedule as defined in ECSS-E-70-41 A – packet TC together with their scheduling attributes

ST-OBDH.6	**Manage schedule** *Description:* The OBDH executes the telecommands which handles TC queues. *Entry condition*: *Exit condition*: • The correct queue is updated. *Normal flow:* 1. The OBDH receives a TC requiring reset an APID-queue 2. All packet TCs of the APID-queue are deleted and the scheduling attributes return to their default values *Alternative flow:* 1a The OBDH receives a TC requiring reset to all APID-queues [3] 1a.1 All packet TCs of all queues are deleted; 1b The OBDH received a TC requiring to delete sets of TC over a time period 1b.1 The selected sets of TCs are deleted 1c. The OBDH receives a TC requiring to time-shifting the TC-time over a time period, of all the TCs in the APID-queue 1c.1 All the TCs are shifted 1d. The OBDH receives a TC requiring a report about the subset of TC in the APID-queue 1d.1 The OBDH generates the report (see ST-OBDH.12) 1e. The OBDH receives a TC or a fail indication that requires the execution-inhibition of the indicated TC-ID 1e.1 The TC is deactivated 1f. A TC or a fail indication requires the execution-activation of the indicated TC-ID 1f.1 The TC is activated to execution (see ST-OBDH.3)	No external actor
ST-OBDH.7	**Memory dump** *Description*: The OBDH was requested to dump data or program code from any OBC memory. See PUS 6. *Entry condition*: *Exit condition*: • The memory area is dumped *Normal flow:* 1. The OBDH obtains the data from the specified memory area 2. The OBDH prepares TM packets (HKTM-ST) for dumping the required data area. 3. The OBDH stores the HKTM-ST in the storage area (see ST-OBDH.18)	No external actor

[3] This comment indicates the corresponding services specified in ECSS-E-70-41 A – their are the service minimum capabilities

ST-OBDH.8	**Memory load** *Description*: The OBDH was requested to send data or program code to any on-board RAM area. See PUS(6). *Entry condition*: *Exit condition*: • The memory data is loaded • The checksum result is available to create a TM packet *Normal flow:* 1. The OBDH calculates the checksum over the data area 2. The OBDH compares the result of the checksum with the checksum value provided by the GST in the load packet. 3. The OBDH loads data in the memory	No external actor
ST-OBDH.9	**Memory checking** *Description*: The OBDH was requested to execute the command for memory checking. See PUS(6). *Entry condition*: *Exit condition*: • The memory checking is executed. *Normal flow:* 1. The OBDH reads the memory area. 2. The OBDH computes the checksum 3. The OBDH generates the report to be sent to SCS with the memory check result (see ST-OBDH.12)	No external actor
ST-OBDH.10	**Clock control** *Description:* The OBDH was requested to update the time of the on-board clock. *Entry condition*: *Exit condition*: • The on-board clock is updated *Normal flow:* 1. The OBDH updates the on-board clock	No external actor
ST-OBDH.11	**Control Parameter** *Description:* The OBDH was requested to control on-board housekeeping parameters, such as, activate/deactivate program code, change hardware configuration, change parameters. *Entry condition*: *Exit condition*: • The on-board housekeeping parameter is executed *Normal flow:* 1. The OBDH executes the requested command for control housekeeping parameters.	No external actor

ST-OBDH.12	**Generate Report** *Description:* The OBDH generates reports which are carried in TM packets. *Entry condition:* • The T_{Report} timer was trigged, *Exit condition:* • The reports are generated to compose TM packets *Normal Flow:* 1. The OBDH generates the report according to the rules get in Data Base 2. If necessary, the OBDH gets the parameter values of housekeeping data (see ST-OBDH. 13), 3. If necessary, the OBDH gets the parameter values of event data (see ST-OBDH. 15), 4. If necessary, the OBDH gets the parameter values of statistics (see ST-OBDH. 17), 5. If necessary, the OBDH gets the parameter values of manage schedule (see also ST-OBDH. 6) that requires to generate report data 6. If necessary, the OBDH gets the parameter values from the AOCS (see ST-AOCS.1) that requires to generate report 7. The OBDH configures the T_{Report}	Timer, AOCS
ST-OBDH.13	**Periodic housekeeping data** *Description*: The OBDH obtains the periodic telemetry parameter values for generating HKTM-RT and the HKTM-ST packets. See PUS (3). The HKTM-RT telemetry parameter values are produced in real-time by the satellite. They contain the general satellite status, non-repetitive part for command acknowledgements and asynchronous telemetry. The HKTM-ST telemetry are composed of satellite parameters continuously recorded on board. This gives the history of the satellite for long-term analysis and some programmable “zooms” on particular events. It also may inform a failure diagnostic, which shows an accurate telemetry over a short period preceding a platform failure leading to safe mode. A list of the HKTM packets needs to be systematically generated when the satellite is in nominal mode. Each HKTM packet is associated to a data collection interval time required to that set of parameters. Data Base keeps this information. *Entry condition*: • One of the $T_{CiclicTM}$ timer was trigged *Exit condition*: • The housekeeping data information for the TM packet are ready *Normal flow:* 1. The OBDH gets the current values of the housekeeping data 2. The OBDH prepares the TM parameters according to the rules defined in the Data Base. (APID, transfer function, position, time etc) 3. The OBDH configures the $T_{CiclicTM}$	No external actor

ST-OBDH.14	**Monitor parameters** *Description*: The OBDH monitors parameters in order to recognize on-board events. See PUS (5). *Entry condition*: • The $T_{Monitor}$ timer was trigged, starting the parameters monitoring *Exit condition*: • Signal if some event has occurred *Normal flow:* 1. The OBDH checks TM parameters against their permitted limits or for some special condition 2. The OBDH Check TM parameters against a specified value 3. The OBDH checks if there is some change in value of a TM parameter against a pair of thresholds 4. The OBDH identifies if an error occurred in the TC-packet 5. The OBDH identifies that an special event has occurred 6. The OBDH generates an event data report (see ST-OBDH.15) 7. The OBDH configures the $T_{Monitor}$ *Normal flow:* 5.a The OBDH detects the satellite mode must be changed and indicates it (see ST-OBDH.22)	Timer
ST-OBDH.15	**Event data** *Description*: Whenever an event of operational significance is detected on board, the OBDH creates a TM packet with **asynchronous** data required by the mission. The information for generating the event telemetry packets (HKTM-RT and HKTM-ST) are get from the Data Base. See PUS (5). *Entry condition*: • The OBDH detected an event (see ST-OBDH.14) *Exit condition*: • The event data information for the TM packet are ready *Normal flow:* 1. The OBDH gets the current values of the event 2. The OBDH prepares the TM parameters according to the rules taken from the DataBase to assemble the referred report (APID, transfer function, position, sequence/order of packets, anomaly information, time, etc)	No external actor

ST-OBDH.16	**Calculate statistic data** *Description*: The OBDH calculates statistics (mean, min, max…) of a parameter set to be sent to ground. The set of parameters and the kind of statistic to be calculate is get from the Data Base. The statistics results will compose a HKTM-ST. *Entry condition*: • The $T_{Statistic}$ timer was trigged *Exit condition*: • The statistical data information are ready *Normal flow:* 1. The OBDH gets the values of the parameters set 2. The OBDH calculates the statistics 3. The OBDH makes the statistics data available 4. The OBDH configures the $T_{Statistic}$	Timer
ST-OBDH.17	**Statistic data** *Description*: The OBDH calculates statistics (mean, min, max…) on board for a parameter set and generates TM packets that report only the result of this evaluation. *Entry condition*: *Exit condition*: • The statistical data information for the TM packet are ready *Normal flow:* 1. The OBDH gets the current values of the calculated statistics (see ST-OBDH.16) 2. The OBDH prepares the TM parameters according to the rules taken from the Data Base (APID, transfer function, position, sequence/order of packets, time, etc	No external actor
ST-OBDH.18	**Store HKTM-ST and PLTM packets** *Description:* The OBDH controls the storage of HKTM-ST and PLTM packets on-board. *Entry condition*: *Exit condition*: • The packet is stored or an error is indicated *Normal flow:* 1. The OBDH receives a HKTM-ST or a PLTM packet to be stored (see PL.3) 2. The OBDH stores the packet on its storage area *Exception flow:* 2.a. The storage area is full 2.a.1. The OBDH overwrites the oldest packet	Payload services

<table>
<tr><td>ST-OBDH.19</td><td>Retrieve HKTM-ST and PLTM packets
Description: The OBDH retrieves a HKTM-ST or a PLTM packet from the on-board storage area.
Entry condition:
Exit condition:
• The HKTM-ST or PLTM packet is retrieved
Normal flow:
1. The OBDH retrieves the oldest packet from the storage area to be transmitted
Alternative flow:
1a. The retrieval is done from a time window selection of packets in the storage area
1a1. The OBDH selects the time window
1a2. The OBDH retrieves the oldest packets in the time window
1b. The retrieval is done from a range of packets selection
1b1. The OBDH selects the packet range
1a2. The OBDH retrieves the oldest packets of the packet range
Exceptional flow:
1c. No packet is available</td><td>No external actor</td></tr>
<tr><td>ST-OBDH.20</td><td>Assemble TM packet
Description: The OBDH assembles a TM packet (HKTM-ST, HKTM-D, HKTM-RT or PLTM) according to the CCSDS standard format. (ESA, 1990)
Entry condition:
Exit condition:
• A TM packet is assembled
Normal flow:
1. The OBDH indicates CV-ID (frame information)
2. The OBDH generates TM packet header with incremental counter
3. The OBDH generates the secondary header
4. If the TM is a HKTM-ST or PLTM then the OBDH retrieves HKTM-ST and PLTM packets (see ST- OBDH.19)
5. The OBDH inserts the TM report in the TM packet-data-field</td><td>No external actor</td></tr>
</table>

<table>
<tr><td>ST-OBDH.21</td><td>Send TM packet

Description: The OBDH sends the TM packets to the TMTC, controlling the order and frequency of the TM packets transmission during the passage.

Entry condition:
The $T_{SendPacket}$ timer was trigged, starting TM packet transmission
Exit condition:
A TM packet is transmitted to TMTC
Normal flow:
The OBDH gets, from the Data Base, information about the sequence of the TM packets expected by the ground segment, i.e the number and the order to send HKTM-RTs, HKTM-STs, PLTMs,
If HKTM-ST and PLTM to be sent, the OBDH retrieve them the storage area (see ST-OBDH.19)
If HKTM-RT to be sent, the OBDH assemble them (see ST- OBDH.20)
The OBDH sends the TM packet to TMTC
The OBDH configures the $T_{SendPacket}$</td><td>TMTC,

timer</td></tr>
<tr><td>ST-OBDH.22</td><td>Change mode

Description: The OBDH changes the satellite mode by a request received in a TC, by the simulator conductor or when the on-board monitoring has detected this is necessary (see ST-OBDH.14).

Entry condition:
A request to change mode has occurred
Exit condition:
The mode of the satellite is changed
Normal flow:
The OBDH changes the mode of the satellite (see ST-OBDH.23, ST-OBDH.24)</td><td>TMTC</td></tr>
</table>

<table>
<tr><td>ST-OBDH.23</td><td>Safe

Description: The satellite is in nominal mode and an event occurs leading the satellite to the safe mode. The satellite can be in safe mode during the first visibility ranges or in case of any anomaly. When in the safe mode the TMs are transmitted in low rate. When in the safe mode:
● all payload equipment are powered off,
● only emergency equipment are powered on.

Entry condition:
• A critical functioning failure occurred
• A telecommand requires to change the mode to safe

Exit condition:
• The safe mode is set
• All equipment that are NOT responsible for satellite safe are powered off

Normal flow:
1. The OBDH power off all equipment that are NOT responsible for satellite safe
2. The OBDH changes the satellite mode to safe mode
3. The OBDH updates the current temperature values to be compatible to this mode (see ST-TCS.1)</td><td>No external actor</td></tr>
<tr><td>ST-OBDH.24</td><td>Nominal

Description: The satellite is in safe mode and an event occurs leading it back to nominal mode.

Entry condition:
• An immediate telecommand indicates that the satellite should be changed to the nominal mode

Exit condition:
• The nominal mode is set
• All equipment are turned on according to the operational profile

Normal flow:
1. The OBDH sets the corresponding variable to indicate the satellite is in the nominal mode.
2. The OBDH turns on all equipment according to the operational profile
3. The OBDH updates the temperature values to be compatible to this mode (see ST-TCS.1)</td><td>No external actor</td></tr>
</table>

ST-OBDH.25	**Modify OBDH equipment status** *Description:* The simulator conductor requires to modify the status (ON/OFF/FAILURE) of an OBDH equipment. A TC may also requires to turn ON or Off an equipment. *Entry condition*: *Exit condition*: • The OBDH equipment status is modified *Normal flow:* 1. The simulator conductor selects a OBDH equipment 2. The OBDH equipment status is modified	Simulation conductor

3.2.3 Payload Services sub-module

The satellite is supposed to have several Payload equipments, which are controlled via immediate or time-tagged telecommands (TCI or TCT). Here these TCs are named TCU[4]. The use case related to the payload equipment functions are presented in Figure 3.7 and described in Table 3.6.

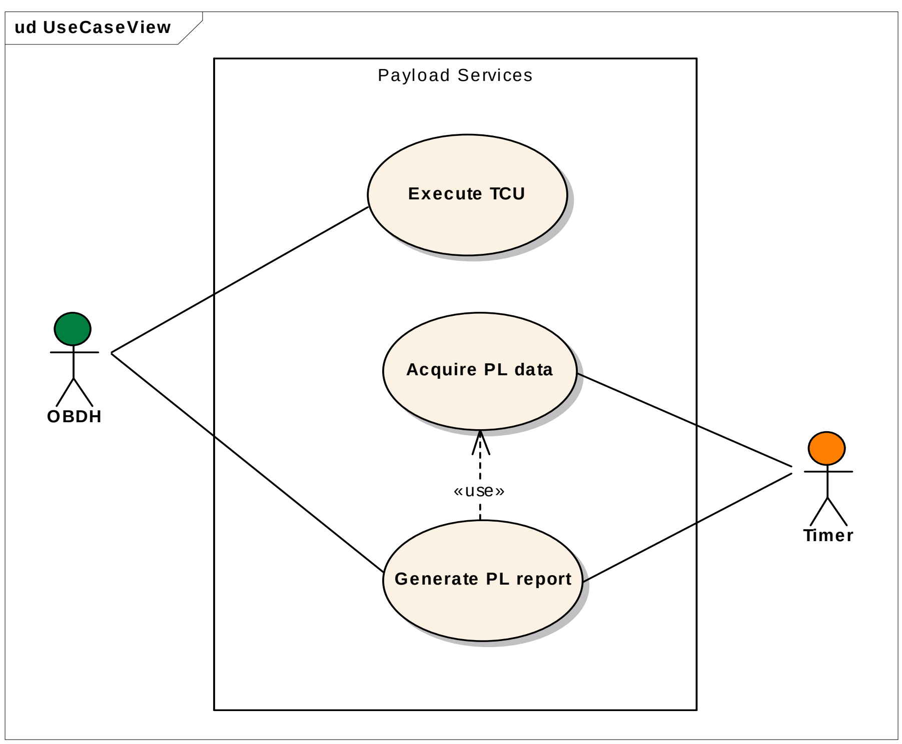

Figure 3.7: Payload services sub-module use cases

[4] Telecomando de Carga Útil

Table 3.6: Description of payload services sub-module use cases

Req Id	Description	Actor
ST-PL.1	**Execute TCU** *Description*: A telecommand designed for payload (TCU) is executed by the corresponding experiment. *Entry condition*: *Exit condition*: • The TCU is executed *Normal flow:* 1. The OBDH indicates the execution of a TC for payload (TCU) (see ST-OBDH.3) 2. The PL receives and executes the TCU	OBDH
ST-PL.2	**Acquire PL data** *Description*: The payload equipment acquires scientific data. *Entry condition*: • The T_{PLdata} timer was trigged, starting payload data acquisition • The PL-equipment is ON • The satellite profile indicates this PL equipment may be turned ON *Exit condition*: • Scientific data were acquired *Normal flow:* 1. The PL reads fixed values data from a pre-defined file (for simulation purposes) 2. The PL configures the T_{PLdata}	Timer
ST-PL.3	**Generate PL report** *Description:* The payload equipment generates PLTM packets. *Entry condition:* • The scientific data for the report are ready • The $T_{PLReport}$ timer was trigged, starting the PLTM generation *Exit condition:* • The reports are generated and make available for OBDH *Normal Flow:* 1. The payload acquires the scientific data (see ST-PL.2) 2. The payload generates a PLTM packet with the scientific data 3. The payload stores the PLTM packets (see ST.OBDH.18) 4. The payload services configure the $T_{PLReport}$	OBDH, Timer

3.2.4 Thermal control sub-module

In simple satellite, the thermal control subsystem is non-active, i.e., it does not comprise equipment like heaters and radiators to modify the satellite temperatures. In this work it is supposed a non-active thermal control, so, the use case for the thermal control sub-module are only related to the thermal variation as illustrated in Figure 3.8 and described in Table 3.7.

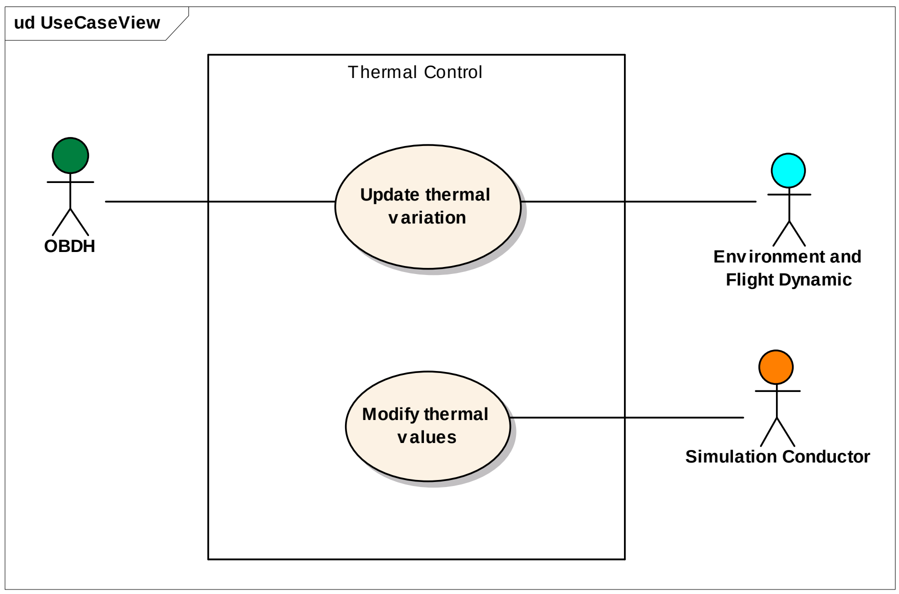

Figure 3.8: Thermal control sub-module use cases

Table 3.7: Description of thermal control sub-module use cases

Req Id	Description	Actor
ST-TCS.1	**Update thermal variation** *Description:* The thermal variation is calculated for each observed point (thermistors) taking into account the current set of thermistors associated to satellite mode (nominal or safe mode). The temperature is modified to each simulation step. *Entry condition*: *Exit condition*: • The new temperature value is updated for each thermistor *Normal flow:* 1. The TCS gets the current temperature in each thermistor 2. If the satellite is in sun, then the TCS increases the temperature value of each thermistors in a linear curve 3. The TCS makes the temperature values available for the OBDH monitoring (see ST-OBDH.14, ST-OBDH.13, ST-OBDH.16) *Alternative flow:* 2a. The satellite is in eclipse then the TCS decreases the temperature value of each thermistors in a linear curve *Exception flow:* 1a. The temperature is out-of-limit the OBDH monitoring will detect (see ST-OBDH.14)	OBDH, Environment and Flight Dynamic
ST-TCS.2	**Modify thermal values** *Description:* The simulator conductor may modify thermal parameters values to simulate failures or to change the temperatures for training purposes. *Entry condition*: *Exit condition*: • The thermal parameters values are modified *Normal flow:* 1. The simulator conductor modifies a parameter value of a thermistor.	Simulation conductor

3.2.5 Power Supply control sub-module

The Power Supply control subsystem comprises the equipment:

- Solar Array Generator (SAG) and solar panels, which control the amount of power supply obtained,
- The battery, which keep the power stored for some period of time,

- Power Conditioning Unit (PCU) and the Power Distribution Unit (PDU), which regulate the power to be distributed to the equipment.

Although each of equipment has their own behavior, the following characteristics are not taken into account in this study: (i) the energy consumption of each equipment, (ii) the Solar Array Generator (SAG), the solar panels, the Power Conditioning Unit (PCU) and the Power Distribution Unit (PDU). Instead, this sub-module simulates the behavior of the battery for which is necessary to keep an updated calculation of the Depth of Discharge (DOD) Charge and the necessary related parameters. The algorithm describing the PSS behavior should be provided by the PSS expert team. In general, the functions to be simulated are illustrated in Figure 3.9 and described in Table 3.8

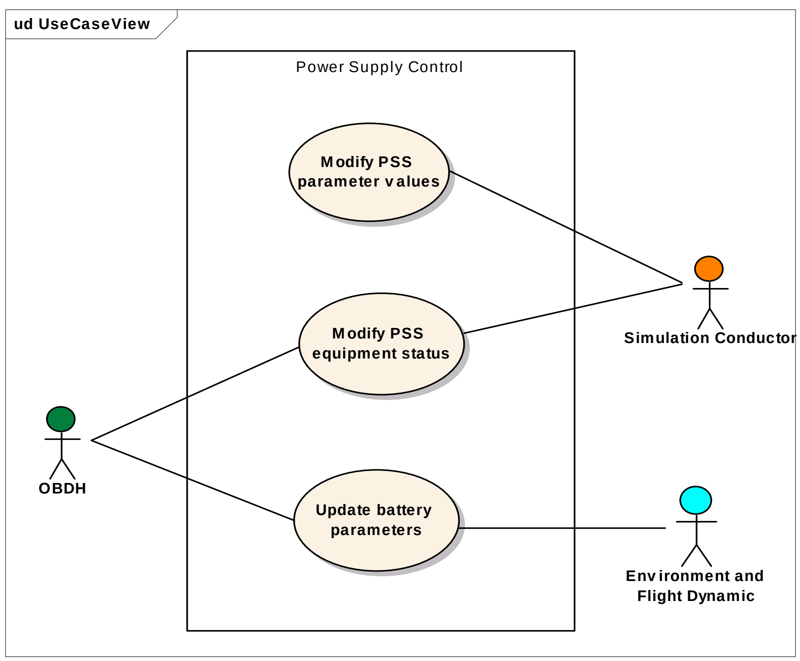

Figure 3.9: Power supply control sub-module use cases

Table 3.8: Description of Power supply control sub-module use cases

<table>
<tr><th>Req Id</th><th>Description</th><th>Actor</th></tr>
<tr><td>ST-PSS.1</td><td>

Update battery parameters

Description: The battery is supposed to controls the power supply to feed equipment. The parameters of the battery model are presented in the following list. In the parenthesis one may find the parameter values).

N_p = Number of branches in parallel (4 branches)
N_s = Number of accumulators in serie (9 accumulators)
C = capability of the accumulators (2.2 Ah each)
P_{cons} = consume profile of an equipment (100 Watts)
I_{GST} = current of the Generator as function of Solar temp (5.0)
$Disp_v$ = dispersion of the voltage of the opened circuit
$Disp_{rs}$ = dispersion on internal resistance
R_{disp} = resistance value

Entry condition:

Exit condition:

- The current battery values of voltage, current and the Depth Of Discharge (DOD) are updated

Normal flow:

1. The PSS gets the current battery parameter values
2. If the satellite is in sun, then the PSS calculates the voltage,
   - the PSS calculates the current,
   - the PSS calculates the Depth Of Discharge (DOD) of the battery
3. The PSS updates the battery parameters according to a given algorithm
4. The PSS makes the battery parameters available for the OBDH monitoring (see ST-OBDH.14, ST-OBDH.13, ST-OBDH.16)

Alternative flow:

2a. If the satellite is in eclipse, then the PSS calculates the values of voltage, current and the Depth Of Discharge (DOD) of the battery for a satellite in eclipse, according to a given algorithm

</td><td>OBDH,

Environment and Flight Dynamic</td></tr>
<tr><td>ST-PSS.2</td><td>

Modify PSS parameter values

Description: The PSS modifies power supply parameters values to simulate failures during the simulation run.

Entry condition:

Exit condition:

- The PSS parameter value is modified

Normal flow:

2. The simulator conductor requires to modify the value of a parameter
3. The PSS modifies the parameter

</td><td>Simulation conductor</td></tr>
</table>

ST-PSS.3	**Modify PSS equipment status** *Description:* The PSS modifies the power supply equipment status (ON/OFF/FAILURE). A commutation from a principal to redundant equipment may also take place if required. *Entry condition*: *Exit condition*: • The power supply equipments state are modified *Normal flow:* 1. The conductor or a received TC or a detected failure indicates a change in a pss equipment (or point of observation and controlling) 2. The PSS modifies the pss equipment status	Simulation conductor, OBDH

3.2.6 AOCS sub-module

The Attitude and Orbit Control Subsystem (AOCS) is supposed to comprise the equipment like, Reaction Wheels and Torque rods as actuators, Star and Coarse Sun sensors, and a Three Axis Magnetometer. Each equipment will not be simulated in isolation. The AOCS sub-module is supposed to accept and provide the interfaces between the OBDH and the AOCS subsystems. These functions are illustrated in Figure 3.10 and described in Table 3.9.

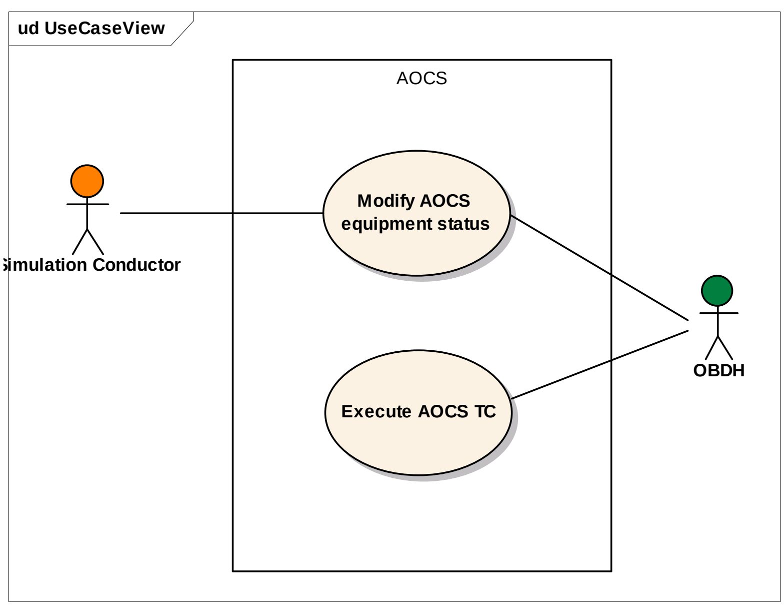

Figure 3.10: AOCS sub-module use cases

Table 3.9: Description of AOCS sub-module use cases

Req Id	Description	Actor
ST-AOCS.1	**Execute AOCS TC** *Description*: A telecommand forwarded to AOCS is received and executed. It is not considered the processing for satellite on-board attitude controlling simulation, however the Data Base and the configuration files should contain the initial values for the AOCS guidance laws. *Entry condition*: *Exit condition*: *Normal flow:* 1. The OBDH indicates the execution of an AOCS TC (see ST-OBDH.3) 2. If the TC is an ephemeris or pointing coefficients TC, then the AOCS keeps the parameter of satellite attitude position according to the nominal attitude required along the orbit evolution, thus, simulating normal operation. *Alternative flow:* 2.a. If the TC requires control attitude parameters (pointing coefficients) to be sent to SCS, then the AOCS generates the report (see ST-OBDH.12)	OBDH
ST-AOCS.2	**Modify AOCS equipment status** *Description:* The AOCS modifies the equipment status (ON/OFF/FAILURE). *Entry condition*: *Exit condition*: *Normal flow:* 1. The conductor or a received TC or a detected failure indicates a change in a AOCS equipment status 2. The AOCS modifies the equipment status	Simulation conductor, OBDH

3.3 Environment & Flight Dynamics

The Environment and Flight Dynamic module of the satellite simulator shall provide the functions related to the satellite flight dynamics, i.e., the orbit and attitude calculus. It also indicates to the other modules the external conditions that may change the satellite behavior, like the sun illumination or eclipse. The functions of the Environment and Flight Dynamic module are illustrated in Figure 3.11 and described in Table 3.10 as use cases.

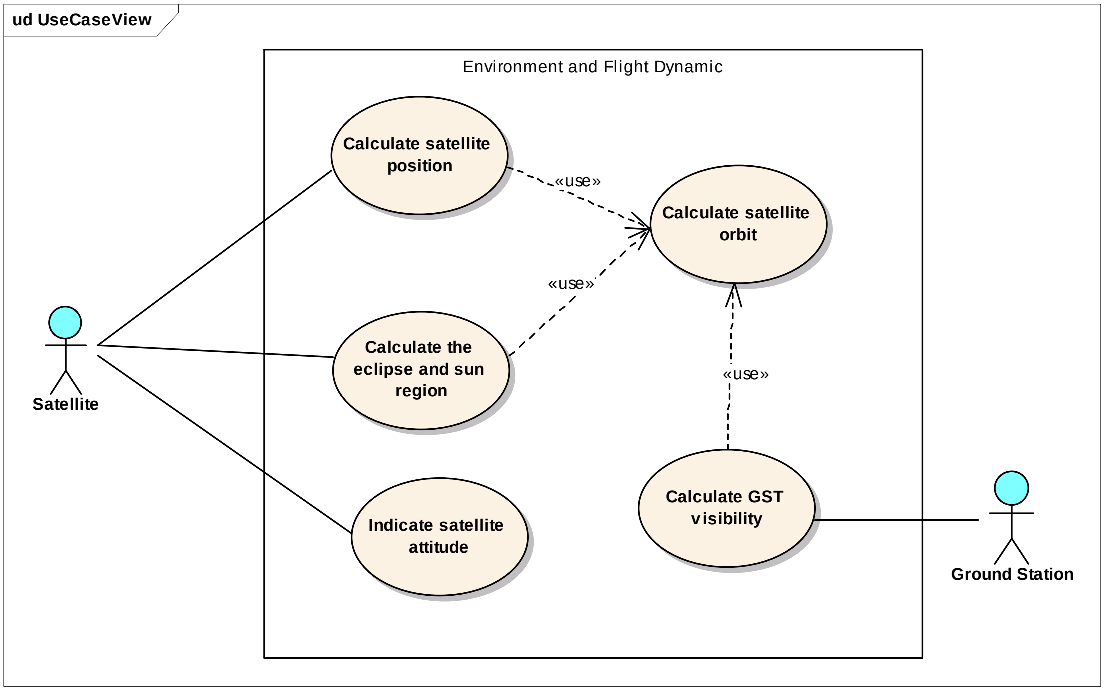

Figure 3.11: Environment and Flight Dynamic module use cases

Table 3.10: Description of Environment and Flight Dynamics module use cases

Req Id	Description	Actor
EFD.1	**Calculate GST visibility** *Description:* The Env&FlightDyn calculates the range of the ground station visibility in the satellite orbit and indicates if the satellite (position) is into the GST visibility or not. The visibility range shall to consider the minimum GST elevation in the horizon *Entry condition*: *Exit condition*: • The GST visibility is available *Normal flow:* 1. The Env&FlightDyn obtains the ground station position to be considered 2. The Env&FlightDyn calculates the satellite orbit (see EFD.4) 3. The Env&FlightDyn calculates the satellite position in the orbit (see EFD.2) 4. The Env&FlightDyn calculates the GST visibility region for that orbit 5. The Env&FlightDyn indicates the ground station visibility to Ground station and satellite modules	Ground station

EFD.2	**Calculate satellite position** *Description:* The Env&FlightDyn calculates the satellite position in the orbit of the satellite. *Entry condition*: *Exit condition*: • The orbit position is available *Normal flow*: 1. The Env&FlightDyn calculates the satellite orbit (see EFD.4) 2. The Env&FlightDyn calculates the satellite position in the orbit	Satellite
EFD.3	**Calculate the eclipse and sun region** *Description:* The Env&FlightDyn calculates the eclipse and the sun region of the satellite orbit. *Entry condition*: *Exit condition*: • The eclipse and sun region is calculated *Normal flow*: 1. The Env&FlightDyn obtains the necessary parameters, like sun position 2. The Env&FlightDyn calculates satellite orbit (see EFD.4) 3. The Env&FlightDyn calculates the satellite position in orbit (see EFD.2) 4. The Env&FlightDyn indicts it the satellite is in eclipse or in sun	Satellite
EFD.4	**Calculate satellite orbit** *Description:* The Env&FlightDyn calculates the satellite orbit. *Entry condition*: *Exit condition*: • The orbit is calculated *Normal flow*: 1. The Env&FlightDyn gets the initial orbit parameters 2. The Env&FlightDyn executes the Keplerian orbit algorithm, without considering the environment perturbations.	No external actor

EFD5	**Indicate satellite attitude** *Description:* The Env&FlightDyn indicates the satellite nominal attitude. The nominal attitude pointing values are pre-defined, keeping the pointing accuracy defined for this satellite. No calculus is necessary for simulation purposes. *Entry condition*: *Exit condition*: • The nominal attitude pointing values are made available *Normal flow*: 1. The Env&FlightDyn keeps the attitude pointing values according to the nominal attitude 2. The Env&FlightDyn makes the attitude pointing values available for report requests	Satellite

3.4 Simulation Management

The Simulation Management module comprises the functions related to parameters configuration and the simulation execution. This module provides a user interface, whose requirements are described in section 8. Due the independence of its main functions, this module was divided into two sub-modules: the Configuration and the Execution as illustrated in Figure 3.12.

The Configuration sub-module includes the functions for attributing initial values to every parameter to be used during a simulation run. These functions are performed before the simulation run starts.

The Execution sub-module comprises functions to support the real time execution including concurrency among the modules, temporization control, parameter visualization, screens customization, among others.

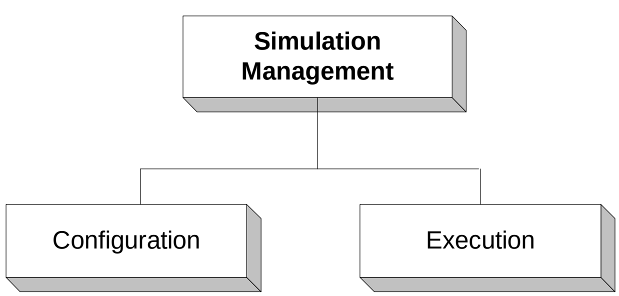

Figure 3.12: Simulation Management Sub-modules

3.4.1 Configuration sub-module

The configuration sub-module provides facilities to the simulation conductor to initialise the parameters with data retrieved from one file, which is referred as configuration file. The configuration file contains the initial values needed to configure the simulator before a simulation run, such as the ground station position, telemetry initial values, orbit parameters, etc. Every configuration file has the same format, the difference among them are the parameter values, which allows one to differ different satellite conditions.

The simulation conductor may choose a configuration file. If the choice is not made, a pre-defined configuration file with default values is automatically loaded. Different configuration files may be prepared and named by the simulation conductor and by the SCC's operation manager (it is proposed the file extension be .cfg). Figure 3.13 illustrates the configuration files.

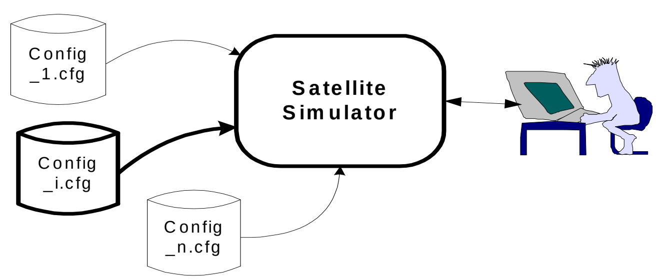

Figure 3.13: Configuration Files

The functions related to the Configuration sub-module are shown in Figure 3.14 and described in Table 3.11 as use cases.

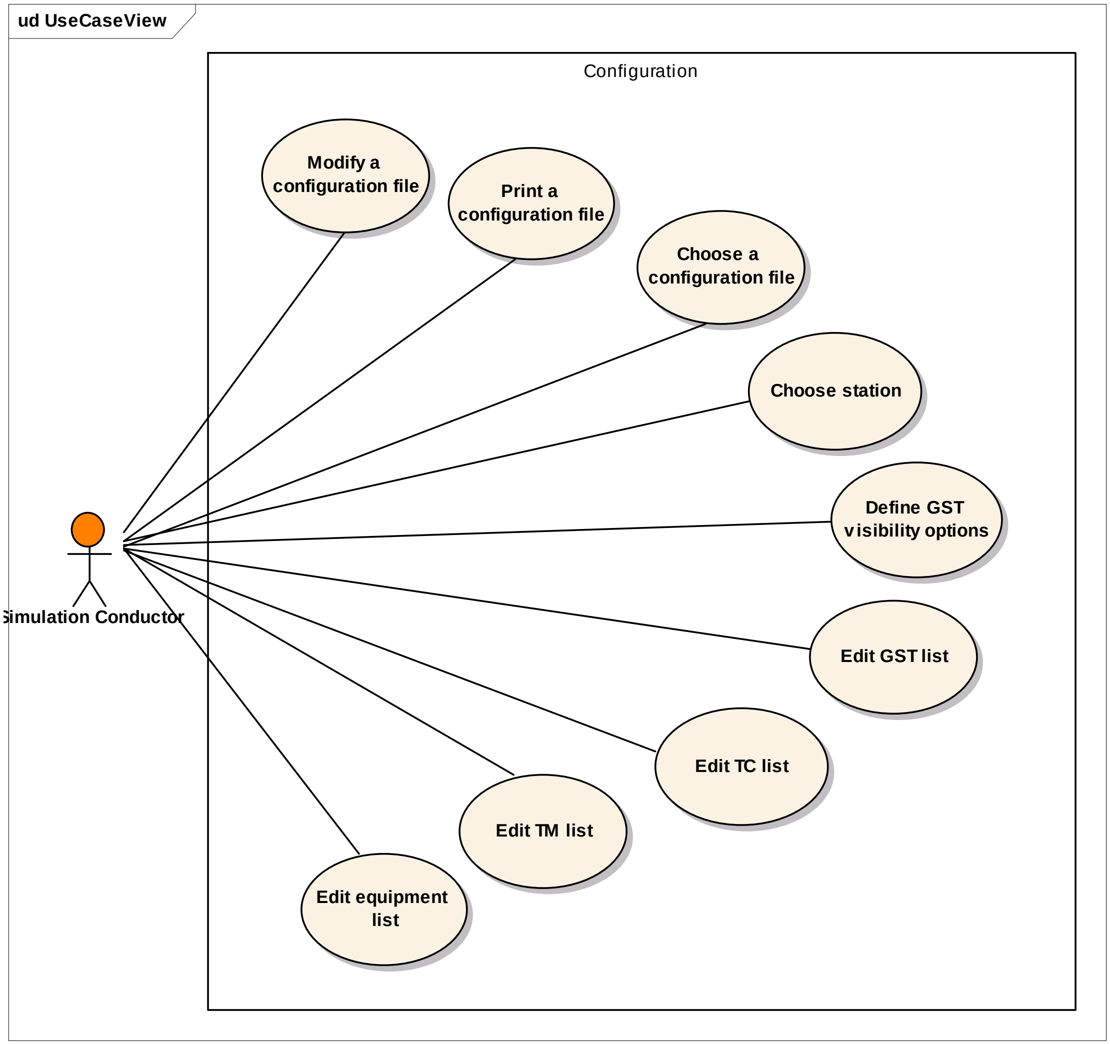

Figure 3.14: Configuration sub-module use cases

Table 3.11: Description of Configuration sub-module use cases

Req Id	Description	Actor
SM-CONF.1	**Choose a configuration file** *Description:* The simulation conductor chooses a *configuration file*. The parameter values given in this file initialize the simulation parameter of every the simulator modules before a simulation run. *Entry condition*: • A default configuration file exists *Exit condition*: • **Only one** Configuration File is chosen **or** the default file is considered *Normal flow*: 1. The Simulation Conductor chooses the default Configuration 2. The parameter values of the Configuration file are displayed	Simulation Conductor

	3. The parameter values of the Configuration file are loaded before the simulation run starting *Alternative flow:* 1.a The Simulation Conductor chooses a Configuration File from a directory 1.a.1 return to step 2	
SM-CONF.2	**Modify a configuration file** *Description:* The simulation conductor chooses to modify the parameter values of a Configuration File. The modifications are saved in the same or in a new file configuration file. *Entry condition*: • A default Configuration File exists *Exit condition*: • The parameter values of the Configuration File are modified *Normal flow*: 1. The Simulation Conductor chooses a configuration file 2. The Simulation Conductor chooses to modify some parameters: • Orbital elements: (i) Epoch time (GMT): year, month, day, hours, minutes, seconds; (ii) Semi-major axis: meter; (iii) Eccentricity; (iv) Inclination: degree; (v) Right ascension of the ascending node: degree; (vi) Argument of perigee: degree; (vii) Mean anomaly: degree; • Attitude parameters • Ground station: names, coordinates and visibility conditions • TCs to be stored on on-board queues • TC list: enable/disable, time-tag, queue identification • TM list: parameter values and ranges • Satellite equipment status: main/redundant, on/off, normal/failure • Satellite current operation mode 3. The Simulation Conductor confirms his modifications 4. The Simulation Conductor chooses to save the modified parameter values into the same opened current configuration file *Alternative flow:* 4.a. The Simulation Conductor chooses to save the modified parameter values into another configuration file 4.a.1 A new configuration file is created with the new values.	Simulation Conductor
SM-CONF.3	**Print a configuration file** *Description:* The simulation conductor wishes to print the parameter values of a Configuration File. *Entry condition*: • A printer is well-configured *Exit condition*: • The parameter values of the Configuration File are printed *Normal flow*:	Simulation Conductor

<table>
<tr><td></td><td>1. The Configuration sub-module prints the file

Alternative flow:
1. The Simulation Conductor chooses a configuration file (default or other)
2. The Configuration sub-module prints the Configuration file</td><td></td></tr>
<tr><td>SM-CONF.4</td><td>Choose station
Description: The simulation conductor chooses one or more ground stations to be part of the configuration file. A pre-defined list of ground stations and its corresponding locations should be provided by the simulator, this list is referred here as GST Parameters Repository.
Entry condition:
• The GST Parameters Repository exists
• A configuration file exists
Exit condition:
• One or more ground stations are chosen or the ground station recorded in the current configuration file is used.
Normal flow:
1. The Simulation Conductor chooses from the GST Parameters Repository one or more GST to be considered in the simulation session
2. The Configuration sub-module stores the chosen ground stations in the current configuration file
Alternative flow:
1.a. The ground station stored in the current configuration file is considered.</td><td>Simulation conductor</td></tr>
<tr><td>SM-CONF.5</td><td>Define GST visibility options
Description: The simulator provides the simulation conductor with two kinds of GST visibility options to be chosen: always visible or limited. The visibility options are recorded into the current Configuration file.
These options means:
• Always visible: In this case, the telemetry transmission to SCS will not be interrupted when the GST visibility limit is achieved during a simulation run. In this option the GST is always visible by the satellite.
• Limited: In this case the telemetry transmission to SCS will be interrupted as soon as the GST visibility range limit is achieved during a simulation run. This is the default option.
Entry condition:
• A Configuration file exists.
Exit condition:
• One visibility option is chosen or the default is considered
Normal flow:
1. The Simulation Conductor chooses an visibility option.
2. The Configuration sub-module stores the visibility option in the current configuration file
Alternative flow:
1.a. If no option is chosen, then the default is considered.</td><td>Simulation conductor</td></tr>
</table>

SM-CONF.6	**Edit GST list** *Description:* The simulator conductor can add a new GST, delete a selected GST or modify a GST parameters from the GST Parameters Repository. *Entry conditions*: • A GST Parameters Repository exists *Exit condition*: • The operation is finished *Normal flow*: 1. The simulator conductor adds a new GST and its parameters *Alternative flow*: 1.a.1 The simulator conductor deletes a selected GST 1.a.2. The simulator conductor modifies GST parameters	Simulation conductor
SM-CONF.7	**Edit TM list** *Description:* The simulator conductor can add a new TM, delete a selected TM or modify TM parameters from the Data Base. *Entry conditions*: • the Data Base exists. *Exit condition*: • The operation is finished *Normal flow*: 1. The simulator conductor adds a new TM *Alternative flow*: 1.a.1 The simulator conductor deletes a selected TM 1.a.2. The simulator conductor modifies TM parameters	Simulation conductor
SM-CONF.8	**Edit TC list** *Description:* The simulator conductor can add a new TC, delete a selected TC or modify TC parameters. *Entry conditions*: • the Data Base exists *Exit condition*: • The operation is finished *Normal flow*: 1. The simulator conductor adds a TC *Alternative flow*: 1.a.1 The simulator conductor deletes a selected TC 1.a.2. The simulator conductor modifies TC parameters	Simulation conductor

SM-CONF.9	**Edit equipment list** *Description*: The simulation conductor can add a new satellite equipment, delete a selected equipment or modify the list of the satellite equipment and its parameters. *Entry condition*: • the Data Base exists *Exit condition*: • The operation is finished *Normal flow:* 1. The simulator conductor adds an equipment *Alternative flow*: 1.a.1 The simulator conductor deletes a selected equipment 1.a.2. The simulator conductor modifies equipment parameters	Simulation conductor

3.4.2 Execution sub-module

The Execution sub-module provides facilities to execute a simulation. Table 3.12 presents the minimum set of functions, required to support a simulation run. The functions here, are not described as use cases.

Table 3.12: Execution sub-module requirements

Req Id	Description
SM-EC.1	**Handle a simulation session** The simulator shall provide facilities to simulation conductor to handle a simulation section in order to: 1. Open the simulation session 2. Close the simulation session 3. Save the simulation session 4. Restore the simulation session 5. Execute a simulation run
SM-EC.2	**Handle a simulation run** The simulator shall provide facilities to simulation conductor to handle a simulation run, in order to: • Start to run the simulation • Stop the simulation run • Pause a simulation run • Continue the simulation run

<table>
<tr><td>SM-EC.3</td><td>Provide user interface facilities
The simulator shall provide facilities to simulation conductor to visualize TM values organized in customizable TM screens. These following facilities may be executed previously or during a simulation execution:
Create a new TM screen
Modify an existing TM screen
Save a TM screen
Delete an existing TM screen</td></tr>
<tr><td>SM-EC.4</td><td>Control the simulation time
The simulator shall provide facilities to control the simulation time, as:
Make available the simulation time to be used as a reference time to TM packet assembled during the simulation run
Allow the user to set the simulation time and/or the simulation time scale (simulation speed)
The simulation time may be advanced or delayed concerning the system time</td></tr>
<tr><td>SM-EC.5</td><td>Control the simulation tasks execution
The simulator shall provide facilities to control the simulation tasks execution. The following facilities should be:
Load a simulation task
Start the execution of a simulation task
Stop the execution of a simulation task
Configure parameters for a simulation task
Associate events to a simulation task
Associate step periodic execution time to a simulation task
Associate a LOG to a simulation task</td></tr>
</table>

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