Automated Plan Generation for Alphasat Payload Operations

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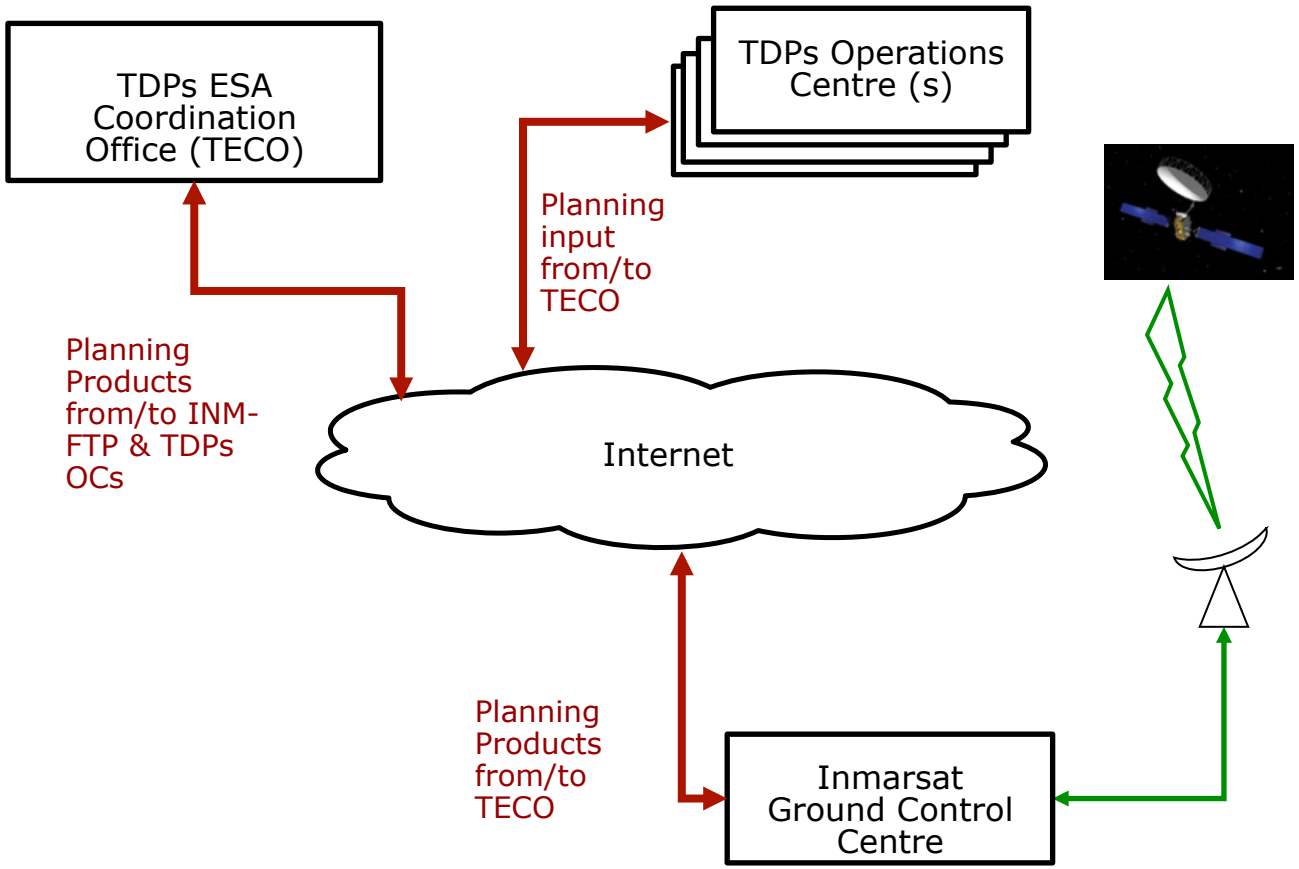
Mission Description

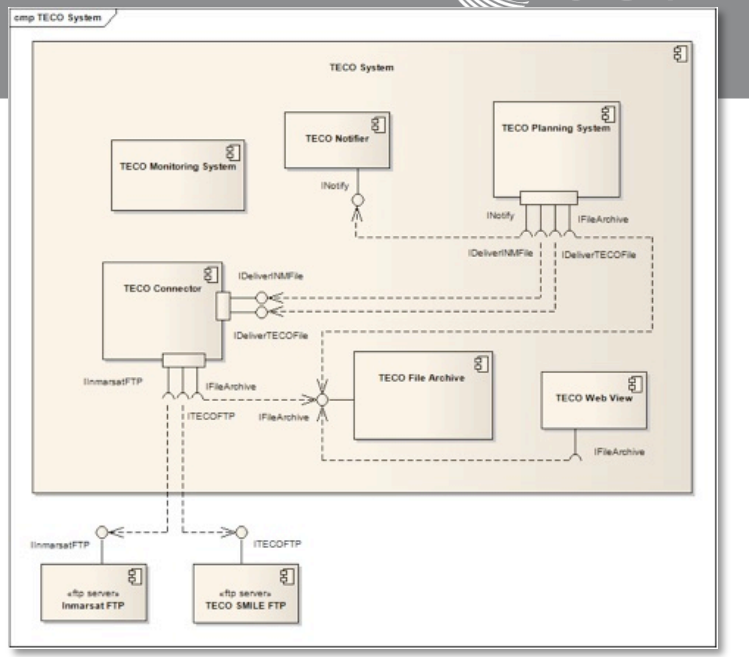
1. Alphasat, based on the new Alphabus platform, will be delivered to orbit to be operated by Inmarsat in 2013.
    a. It will carry an Inmarsat commercial communication payload
    b. 4 Technology Demonstration Payloads (operated as secondary payloads)

2. TDPs:
    a. An advanced Laser Communication Terminal;
    b. A Q-V Band communications experiment;
    c. An advanced Star Tracker with active pixel detector;
    d. An environment effects facility to monitor the GEO radiation environment and its effects on electronic components and sensors.

Workflow and planning interfaces



TECO System



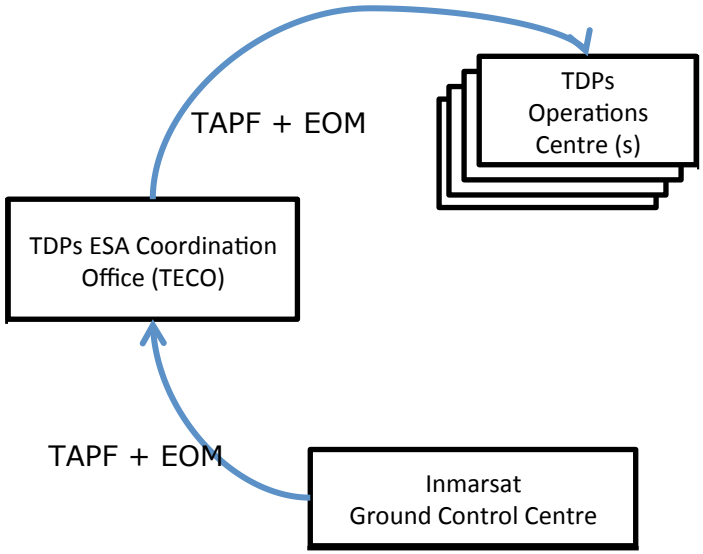
Main goals:

1. TDPs activity coordination + planning support
    a. Collection of activity/task requests
    b. Conflict identification and resolution
    c. Generation of the final activity plan

2. TDPs telemetry reception and archiving
    a. Reception archiving of real time telemetry stream
    b. Collection and archiving of the different planning files
    c. Providing historical data to TDP-OCs

The planning process is completely automated. Only in the case of anomaly is the TECO operator notified and required to intervene.

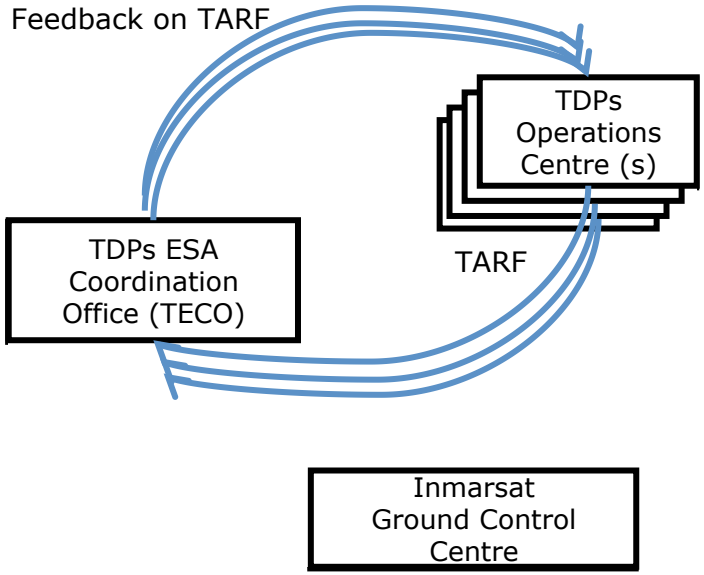
Mission planning cycle (1/3)



Distribution of Inmarsat input: windows availability and spacecraft status

on day 7 by 16:00 UTC

Mission planning cycle (2/3)

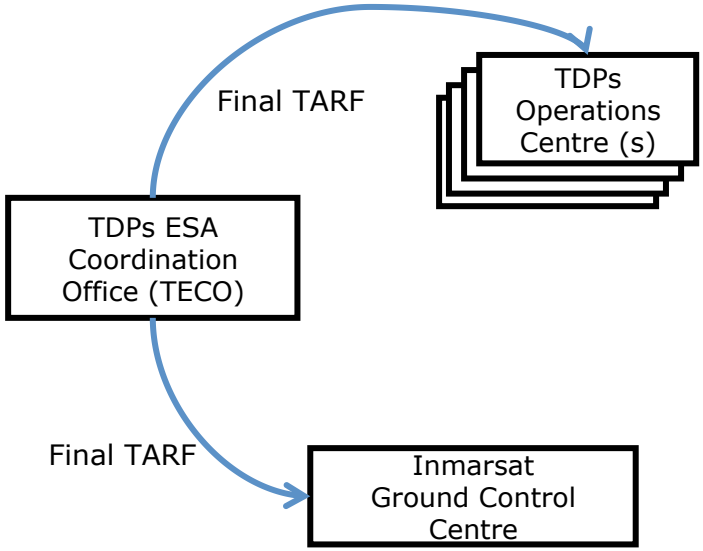


Generation of the TDP operation plan based on input requests provided by TDP-Ocs

iterative construction of conflict free plans:

1. TDP-OCs submit their input requests – TECO produces an initial plan
2. TDP-OCs submit their updated input requests – TECO produces a new plan
3. TDP-OCs submit their final input requests – TECO produce the final plan

Mission planning cycle (3/3)

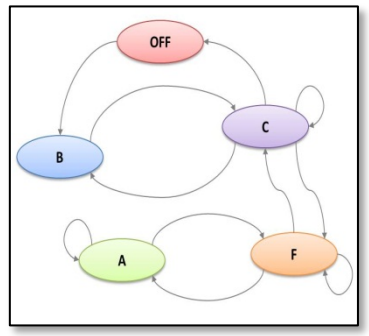


Distribution of the final TDP operation plan

by 12:00, day 1 next cycle

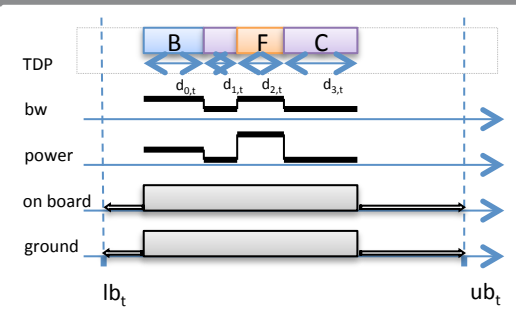
Domain Model (1/2)

- TDP
  - It can be seen as a timeline which represents the status of the payload
  - Finite state machine (to represent valid transitions)



- Spacecraft status and opportunity windows
  - Different time interval types
    - S/C available (for task execution)
    - No ground control (but on-board only task yes)
    - No TDP tasks execution
    - TDPs OFF (this requires a task to switch off the payload)
    - Manoeuvres (task can be executed but can affect the task execution)

Domain Model (2/2)



- Task Requests
  - TDP
  - Feasible Time interval
  - Sequence of subtasks <dur, submode, bandwidth, power>
  - "On-board only"/ "on-board + on-ground"
  - A weight value w

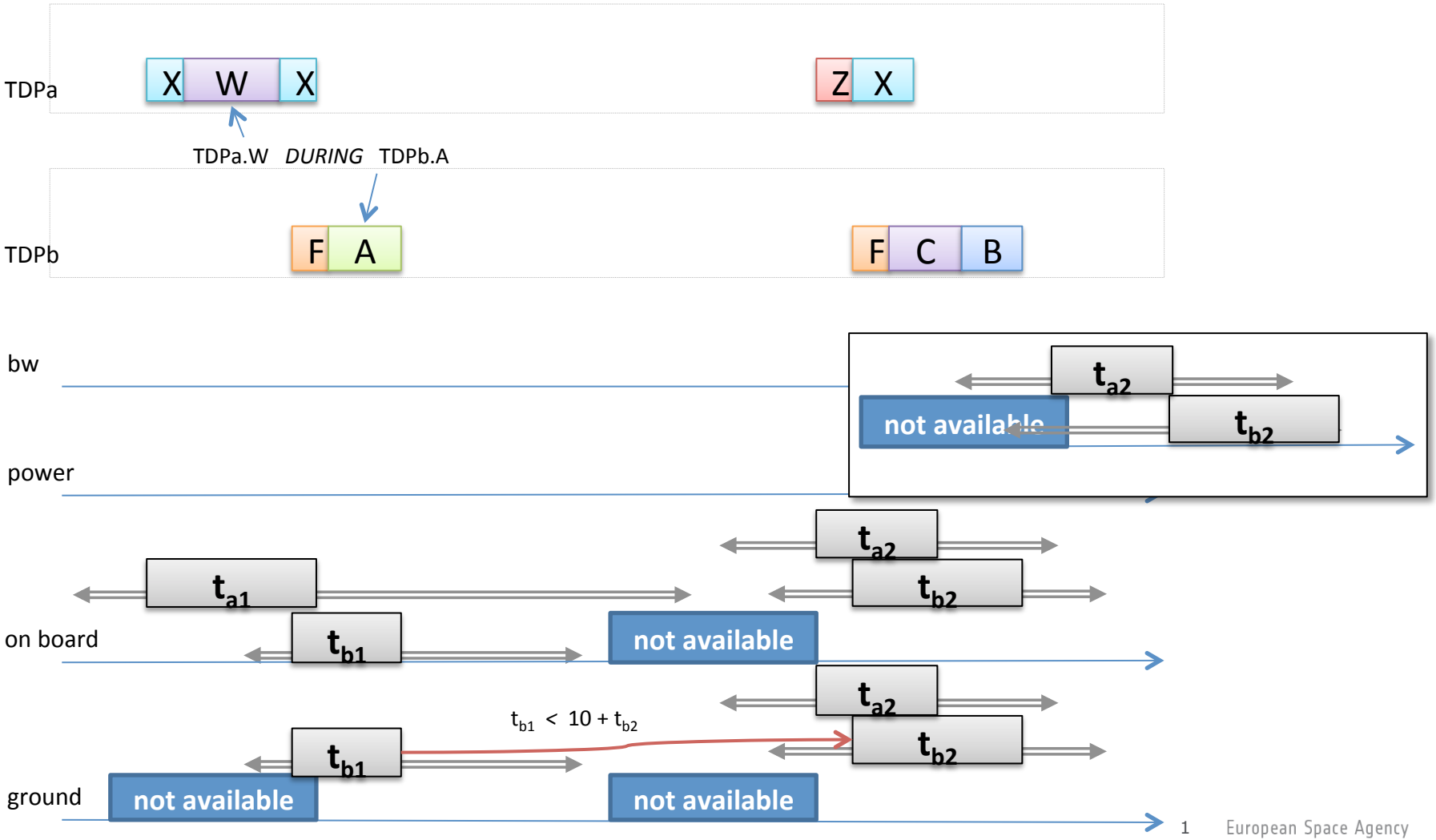
- Constraints
  - Among TDPs – e.g., *TDP1.B during TDP2.Z*
  - TDP vs S/C – e.g., *TDP1.F not-during S/C.manoeuvres*
  - Among tasks – e.g., *tr1<tr2 and allocate(tr1) iff allocate(tr2)*
  - Resource constraints – e.g., bandwidth and power limits

Problem and solution

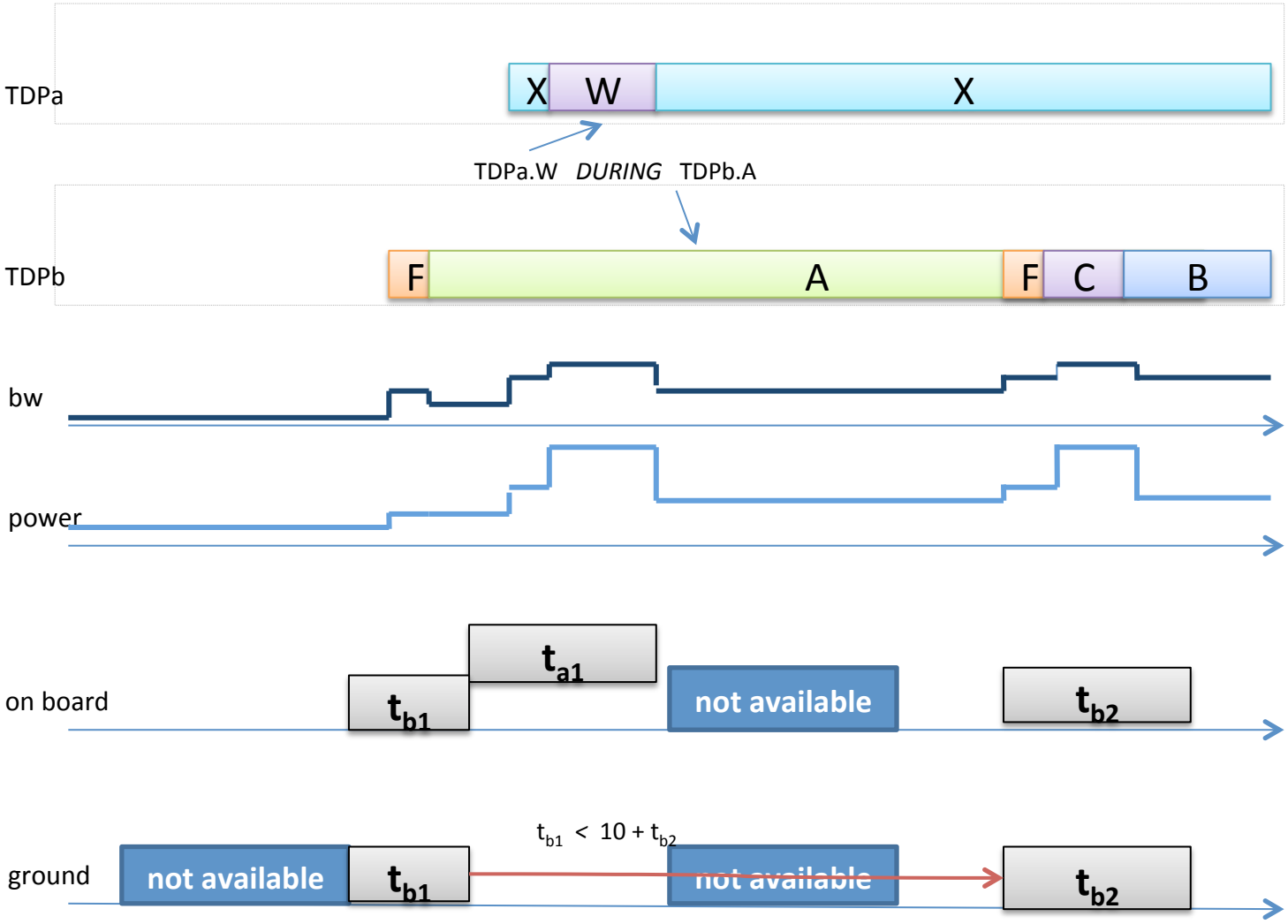
- Problem:
  - A set of task requests
  - A set if initial submode for each TDP
  - A set of constraints
  - S/C status and availability

- Solution
  - A set S of allocated tasks
  - Maximize $Value(s)=\sum tr\in S\uparrow\blacksquare w(tr)$

Example – problem



Example – solution



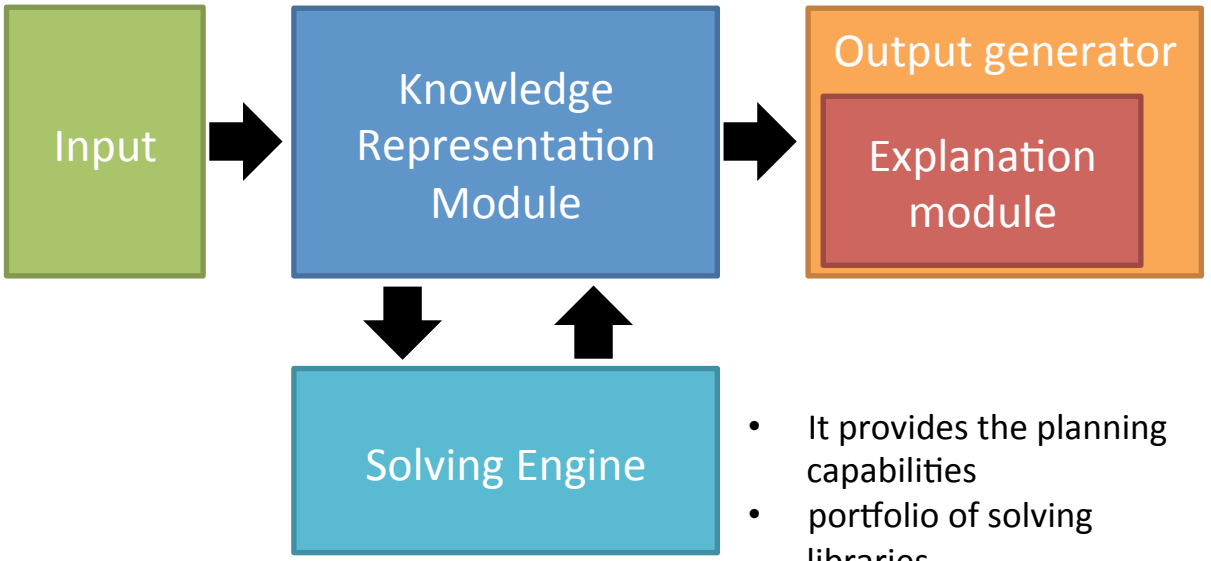
Planning approach

Timeline representation
+
Solving process decision representation
Labels:

- Type of decision
- Generator
- Reason

- It transforms the internal representation of the plan into the requested format.
- need of complementing the final solution with sufficient information to the users (**explanation module**)

Domain
+
Problem

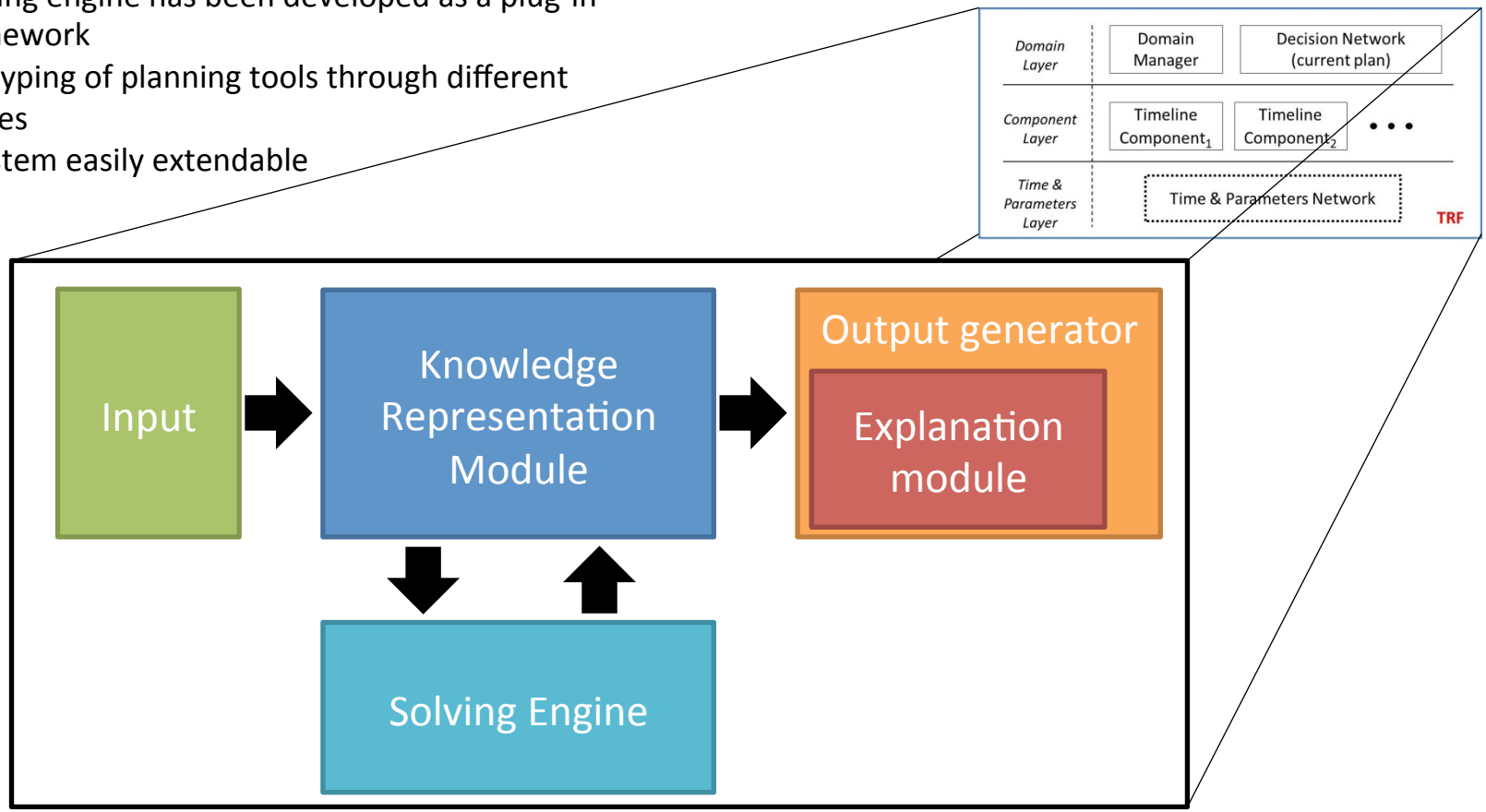


- It provides the planning capabilities
- portfolio of solving libraries.

Planning approach

The TECO planning engine has been developed as a plug-in of the APSI framework

- rapid prototyping of planning tools through different functionalities
- planning system easily extendable



Solving approach

1. Two main types of component:
    a. state variable timelines (used to represent the different TDPs)
    b. re-usable resources (i.e., ground control availability, satellite availability, power, and bandwidth usage)

2. Two solving approaches have been merged into a meta-schema based on a branch-and-bound algorithm:
    a. a planner to allocate the different tasks on the state-variable timelines
    b. A scheduler to generate a feasible solution with respect to both the re-usable resources and the temporal constraints.

Explanation

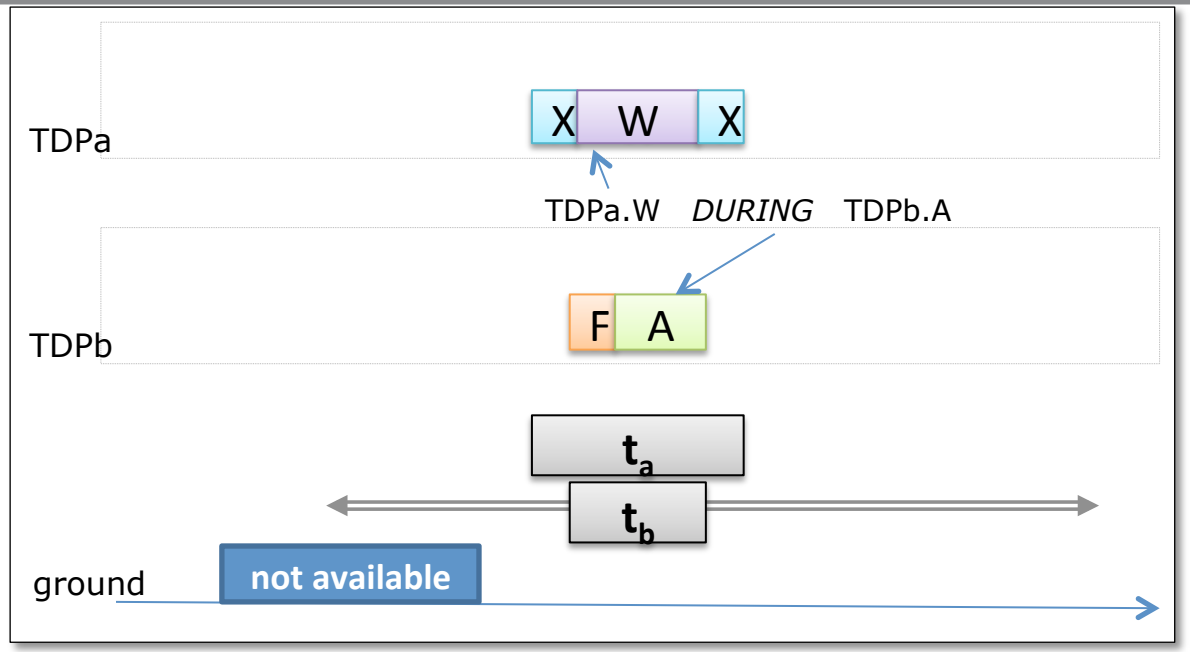
Need of generating explanation

a. TECO as the system has been designed to be completely automated
b. A proper explanation is also needed to have effective iterations between TDPOCs and TECO.
   - Time limit of 20 min

The approach is based on the following points:

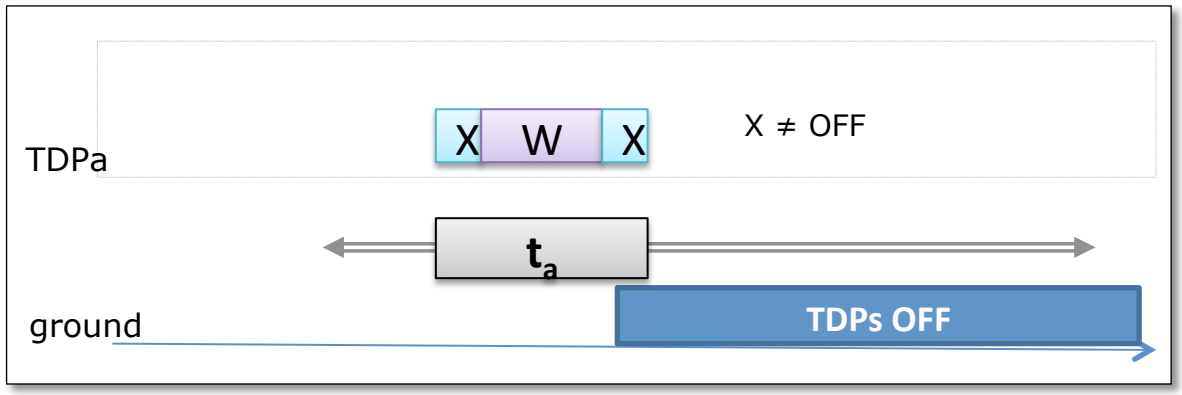
1. A "protocol" to exchange information between TDP-OCs and TECO
2. "Labeled decisions" with information about the solver and the motivation of the decision.
3. An "Explanation Generator" module to generate the information for the system users by applying the given protocol.

Explanation – examples



planner: B *before* A
scheduler: *no solution*

Explanation should consider
1) scheduling conflict
2) planner decision
3) domain theory



scheduler: A *before* TDPs OFF
planner: *no solution*

Explanation should consider
1) planning conflict
2) domain theory

Explanation

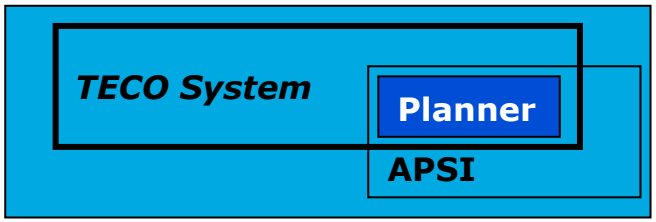
1. The final explanation is not generated directly by the different solvers
    a. the solvers can have only a limited view of the current situation
    b. to allow decoupling the set of used solvers from the final explanation generation process (and the associated protocol)

2. The approach consists in "tracing back" all the decisions
    a. collecting the different annotations added during the solving process.
    b. identifying the specific case based both on the solvers and on the content of the different annotations

3. Modular approach to facilitate future re-usability and evolution
    a. a different type of user accessing the TECO system (e.g., web-client) which can require a different protocol
    b. modifying the set of solvers.

Status of the TECO system

1. Developed as a plug-in of the APSI framework
    a. The framework has general functionality which can be used to model and solve planning problems



2. Modelling the Alphasat TDP process
    a. the model considers the necessary constraints and design features for establishing a planning rule DB.
3. Re-using some of the solving functionality to implement the conflict check and conflict solving phases

1. intensively tested with several artificial problem benchmarks
    a. 10-100 task requests
    b. week time horizon

2. Validation in end-to-end test sessions with realistic task requests provided by the different TDP-OCs.
    a. nominal cases,
    b. resource conflicting requests,
    c. TDP modes inconsistent requests.
3. TECO system can return a solution in the given time bound (20 minutes), is robust towards non-nominal cases, and can provide sufficient explanations to the TDP-OC operators

Lessons learned

1. The efficiency of the solving approach was crucial
    a. To introduce the automated system solution
    b. To modify the workflow with TECO/TDPs iterations

2. A flexible architectural design of the system which allowed us to cope with the several changes experienced in the definition of the problem
    a. re-use of the APSI-TRF
    b. requirements were not fixed

3. Need of a Knowledge Engineering Environment for supporting and facilitating the development of planning systems
    a. Better rapid prototyping approach

Future work

1. Evolution of current solving approach:
    a. Robust/flexible solutions (e.g., chaining approach, Policella et al. 2009)
    b. Force the minimization of differences between the solutions produced at each iteration (El Sakkout et al, 1998)

2. Enrich the feedback to the users
    a. Provide not only explanation but also suggestions on how to fix current problems

3. Exploit explanation as a possible means to better integrate planning and scheduling solvers (in general set of solvers)