Building resource-dependent conditional plans for an Earth monitoring satellite

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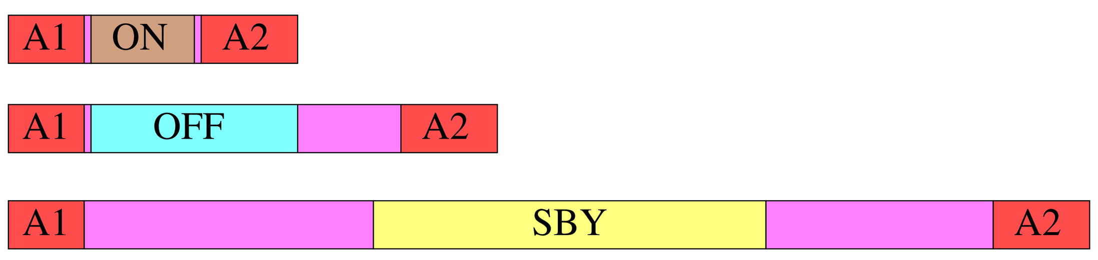
Context

Mission of the French Space Agency (CNES)

- nanosatellite making acquisitions and downloading data to ground stations
- during acquisitions, payload switched on and geocentric pointing

Content of the plans (data downlink ignored here)

- plan = sequence of acquisitions $\pi = [a_1, \ldots, a_n]$
- for each acquisition, fixed start/end times
- between acquisitions, decision rule for choosing a waiting mode and associated setup operations (like payload switch on/off or maneuvers)



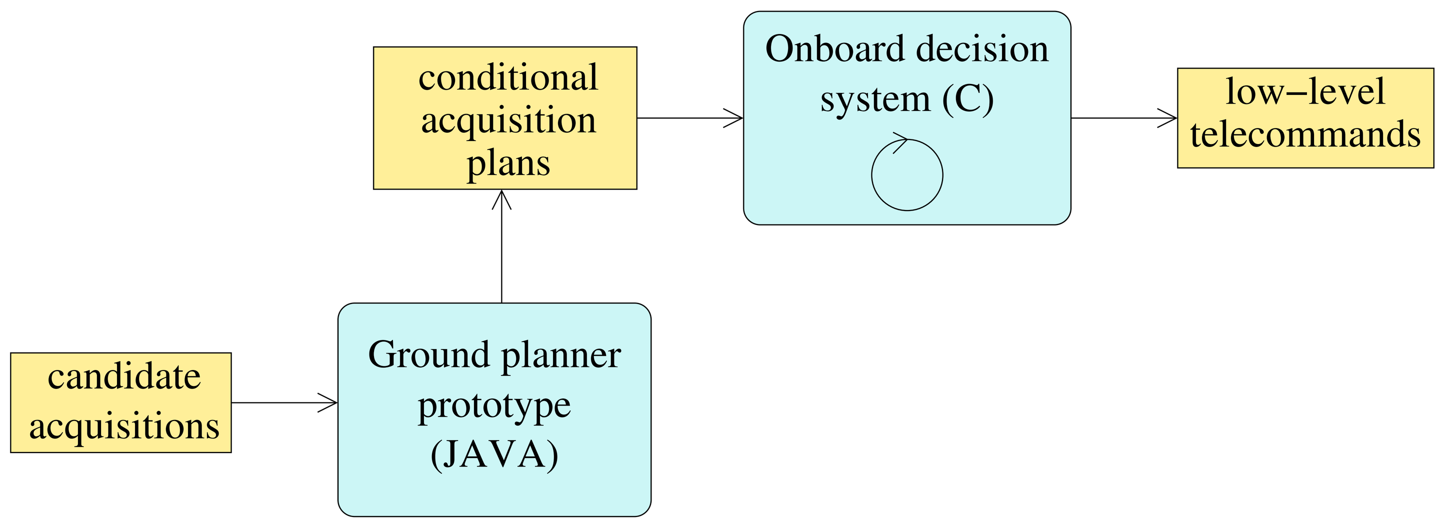
Towards a collaborative ground/onboard system

Existing mission planning tool

- goal: select acquisitions among a set of candidate ones while satisfying memory and energy constraints (complex energy model)
- several margins used on power production and consumption
- significant impact of these margins on system performance (energy = the main bottleneck)

Proposed mission planning system

- definition of a conditional planning and execution approach to better exploit the actual level of energy available [Wörle, Lenzen 2014], [Maillard et al. 2015], [Agrawal et al. 2021]
- system constraints taken into account (existing telecommand format, limited on-board CPU capacity...)

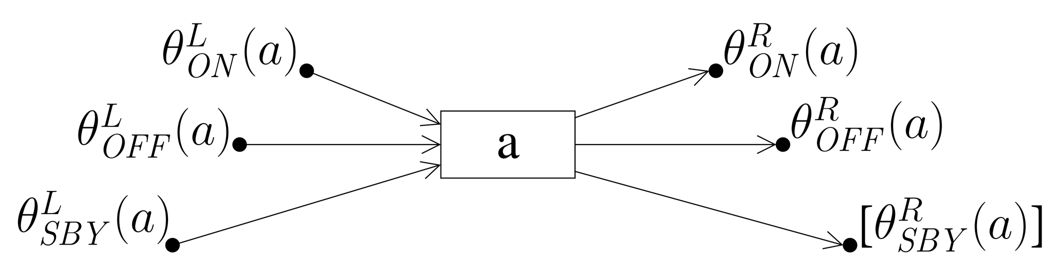


Ground part: synthesis of conditional plans

New algorithm: iterative planning

- pessimistic energy model $M_0 \to$ plan $\pi_0 = [A, B, C]$ (existing baseline planner, acquisitions of π_0 = mandatory acquisitions for the users)
- average energy model $M_1 \to$ plan $\pi_1 = [A, D, B, E, F, G, C]$
- optimistic energy model $M_2 \to$ plan $\pi_2 = [H, A, D, B, E, I, F, G, J, C]$

Activation thresholds for the acquisitions

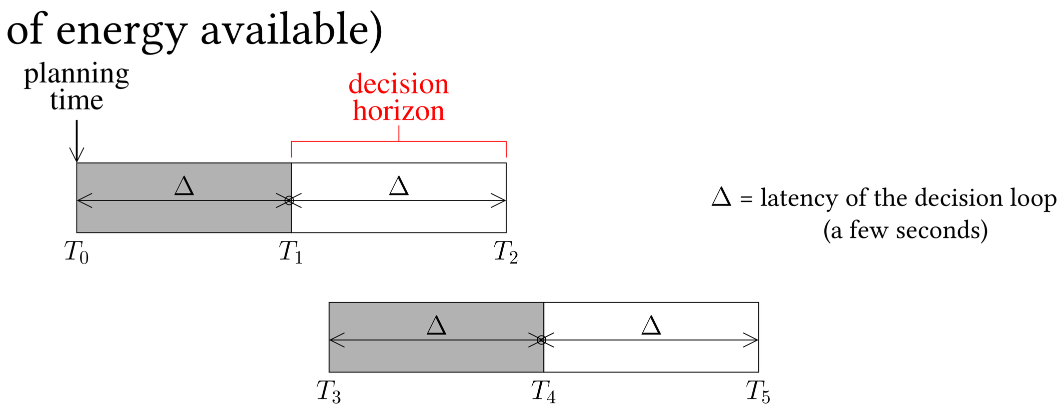


- left and right thresholds usable to plug each acquisition in the waiting modes of the satellite (least-commitment strategy)
- ex1: $\theta^L_{OFF}(a)$ = min level of energy required to trigger a from the OFF mode (at the latest time allowing the setup operations to be performed)
- ex2: $\theta^R_{OFF}(a)$ = min level of energy required at the end of a to use mode OFF
- formal definitions ensuring that the acquisitions of π_0 are always executed

Onboard part: execution of conditional plans

Decision over a rolling horizon

- reception of the conditional acquisition plan
- execution over a rolling horizon to postpone the decisions (to better estimate the actual level of energy available)



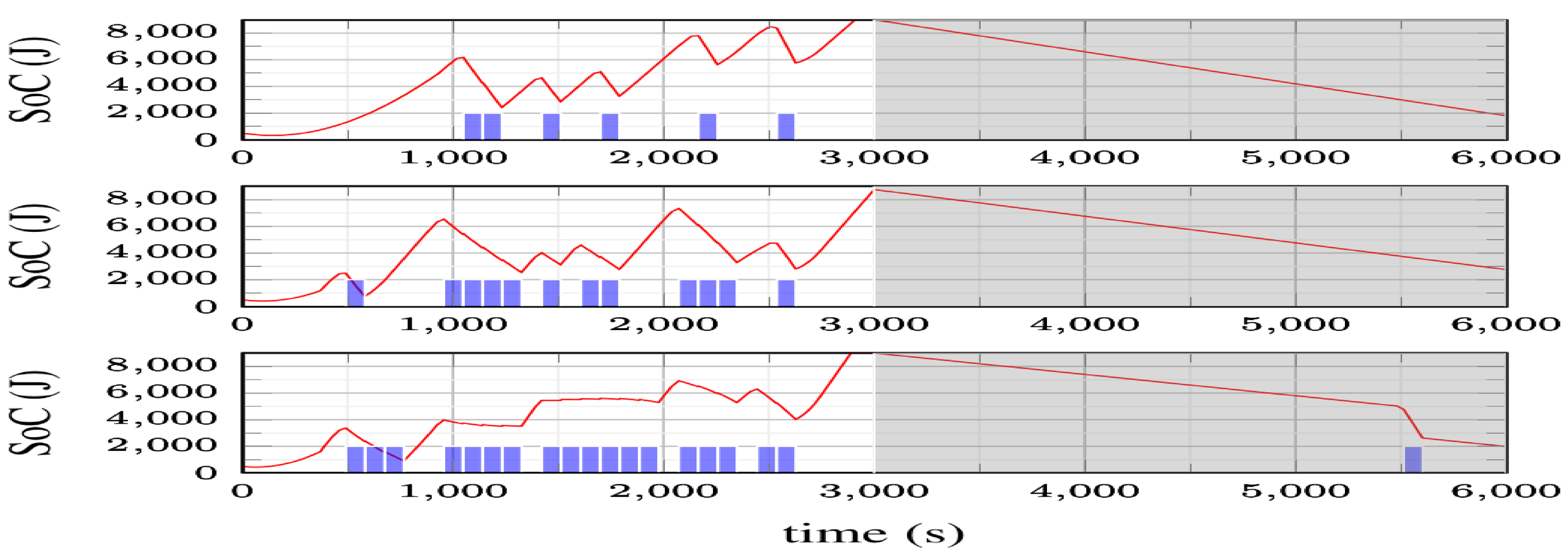
Content of the C code

- if-then-else instructions associated with the different decision branches at the start/end of acquisitions (use of the left/right thresholds computed on the ground)
- instructions generating the low-level telecommands
- instructions updating the current execution state

Experiments and validation

Ground planning (polar orbit, period T=100min)

Acquisition plans obtained with 3 successive energy models M_0 (20% margins), M_1 (nominal power), M_2 (−20% margins)



Onboard execution

- goal: create various execution conditions (no assumption on the real model)
- current energy level randomly chosen in $[Emin, Emax]$ at each decision event
- $\simeq$ 100ms to simulate the whole execution of the orbit (Intel i5 1.2GHz 4GBRAM)
- several telecommand sequences obtained onboard from the same conditional ground plan under different real energy conditions

Validations

- 300 ground plans and 100 random onboard executions per plan $\to$ 30000 runs
- properties satisfied for all runs: (1) all acquisitions in π_0 are always performed, (2) the telecommands produced step-by-step are identical to those that would have been produced on the ground to make the same acquisition plan

Conclusion and perspectives

Contributions

- a collaborative decision making system where the onboard adaptation of waiting modes is expoited when computing the energy thresholds on the ground
- management of several energy models
- change of the pointing of the satellite (impact on power production)
- execution of temporal conditional plans with setup operations

Perspectives

- implementation using the detailed models (maneuver + energy)
- forthcoming in-flight experiment (next year)