FIRST ACQUISITION OF THE SKYBRIDGE CONSTELLATION SATELLITES

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Abstract

This paper presents the results of the first acquisition analysis for the Skybridge constellation satellites.

The study has been performed jointly by CS-CISI, CNES and ALCATEL Space Industries.

The first part of this paper presents the context, and comparison with other well known constellations, the first acquisition strategy for all the satellites of a cluster, and the constraints which must be fulfilled to perform the satellite acquisition. The second part describes two research strategies that have been developed and tested in order to optimize the results. The third part of this paper exposes the results of those previous strategies obtained with a Monte-Carlo analysis based on:

- the injection dispersion values,
- the research strategies patterns,
- the satellite attitude simulation,
- the radio-electric visibilities.

Finally, the results of the study validate the proposed Skybridge constellation first acquisition strategy.

Key words: First acquisition, dispersions, radio-electric visibilities, Monte-Carlo analysis.

Introduction

Skybridge is an ALCATEL Space Industries telecommunication program which will offer continuous interactive multimedia services to millions of users all over the world, by means of a constellation of Low Earth Orbit satellites. The baseline Skybridge constellation is a nominal 80-satellite constellation. For two years, CNES French Space Agency has been working on Skybridge mission analysis. CS-Cisi has joined this study, as subcontractor, to work especially on first acquisition issues.

The challenge lies in the injection in clusters of up to 10 units (on the Ariane 5 launcher). Besides, the use of the Ku-band for TM-TC links leads to narrow antenna beams.

The study consists in validating the first acquisition strategy, taking into account the satellites and the ground stations characteristics. To ensure the satellite acquisition, we have developed two research strategies, corresponding to two different ground antenna searching patterns. A Monte-Carlo analysis has allowed us to validate the first acquisition strategy and to show sensitivity to injection dispersion values, ground station antenna movement, satellite attitude simulation and radio-electric visibilities.

This paper describes the study steps of the Skybridge satellites first acquisition, considering different injection conditions.

General constellations background

Although it has been previously handled for other constellations, the first acquisition phase remains challenging. In fact, each constellation first acquisition depends on choices made for the whole system (launcher, cluster, frequency band, satellite design, ground station network, ...).

A lot of constellations are designed to provide Telecommunications facilities, such as Globalstar, Iridium, Orbcomm and GPS. But none of these systems matches the conditions of the Skybridge constellation.

The Globalstar constellation, which is in deployment phase, has yet realized two successful launches with a cluster of four satellites. The next satellites will probably also be launched in clusters of four units. In fact the use of the C-band does not lead to the same constraints.

The Iridium[1] constellation is now available. Its satellites have been launched using a combination of three different launch vehicles. The US Delta II rocket has been used to launch five satellites at a time, the Russian Proton Rocket has launched seven satellites at a time, and the Chinese Long March 2C/2S had carried two satellites at a time. All the three launchers accommodate a common satellite interface, but use unique deployment systems. The frequency band in this case is the Ka-band. There is no available information in public domain relative to first acquisition failure during deployment.

The Orbcomm[2] constellation satellites have been launched in clusters of 8, using a Pegasus launcher. Lack of precision of this launcher has been offset by the use of the VHF frequency band, enabling large ground antenna beams.

The GPS constellation satellites are injected one by one, so the problem of the first acquisition is much more classical in this case.

For the Skybridge constellation, the difficulties of the study lie in:

- the use of different launchers, with different injection dispersion values,
- different injection altitudes,
- injection in large clusters,
- use of the Ku-band,
- non omni-directional on-board antenna beams,
- no prediction of the satellite's attitude just after injection.

First acquisition strategy

The first acquisition aim is to catch all the satellites of the cluster as soon as possible after the injection. To realize such a task, the chain of events is the following one:

- The first satellite is acquired with at least a given visibility duration after this acquisition. This allows to reduce the injection dispersion values which are the sizing parameters of the first acquisition study. Thus a more accurate orbit is computed for this satellite.
- The enhanced precision of the first satellite orbit facilitates the computation of all the following satellites orbits. These orbits are deduced from the specified nominal sequence of satellites separation, and the fact that the cluster separation dispersions are far inferior to the injection dispersions.
- The ground station antennas pointing data are updated with these orbit parameters.
- The same process is applied to all following satellites.

There is no doubt as to which satellite is under acquisition, each one using a different frequency. Thus, even if several satellites could be tracked simultaneously, owing to slow cluster separation movement, the sole satellite using the appropriate frequency will be effectively tracked.

Such a strategy allows to acquire all the satellites, by successive improvements of orbital parameters estimation. Each acquisition enhances the precision of the estimation of the following one, this process enables to reduce sensitivity to large drifts a long time after injection.

In this study, we have concentrated on the acquisition of the first satellite of a cluster, which determines the success for the whole cluster, as a consequence of what has been exposed above.

First acquisition constraints

To perform the satellite acquisition, the following conditions must be fulfilled:

- The satellite shall remain in the ground station antenna half power beam width during a period of time greater or equal to the receiver acquisition time. The difficulty remains in the use of the Ku-band, which involved narrow antenna beams. For the study presented in this paper, the assumed values are:

  - antenna half power beam: 0,32 deg,
  - receiver acquisition time: 1 s.

- The satellite shall be in a radio-electric visibility taking into account the satellite antenna beam. In fact, the baseline Skybridge satellite has two antennas on +Z and -Z faces. So the satellite attitude simulation has a great importance in this study.

- The Doppler error shall be lower than the receiver maximum error.

- Due to the used frequency band (Ku) and the risk of interference with the signal broadcast by geostationary satellites, a frequency sharing constraint[3] has been introduced. The geometric modeling of this frequency sharing constraint has been defined as follow:

Any ground point (user terminal) in visibility with a Skybridge satellite with an elevation angle above 10 degrees, cannot establish a link with the satellite if the angle between the line of sight of the user terminal to the satellite and the line of sight of the user terminal to any point of the geostationary ring is less than 10 degrees.

This constraint splits the visibility intervals and consequently reduces opportunities for acquisition, by reduction of total visibility duration and margins for acquisition.

Research strategies

To optimize the results, we have designed and tested two research strategies:

- The waiting point phase: the ground station antenna waits for the satellite to rise at a minimum allowed elevation. Its azimuth during this phase is computed taking into account the injection orbit semi-major axis dispersion and the Earth rotation. The azimuth is calculated to have the antenna initially pointing the satellite earliest rising point and scanning until the latest rising point. The duration of this phase is a function of the time elapsed since injection.

The figure 1 shows typical elevation vs azimuth during this phase.

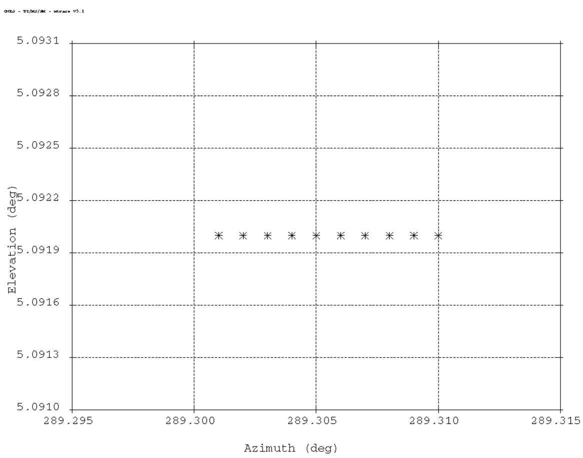

figure 1: Waiting point phase

- The searching phase follows at the end of the previous phase if no acquisition has been performed before. It mixes elevation and azimuth sweep added to the nominal antenna movement in a zigzag pattern.

The figure 2 shows typical elevation vs azimuth during this phase.

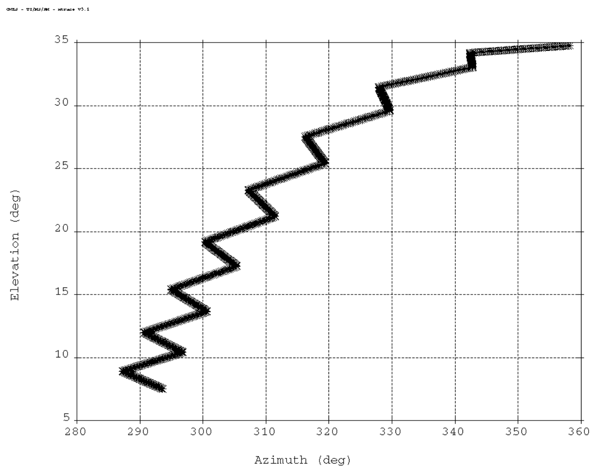

figure 2: Searching pattern phase

The definition of the elevation vs azimuth of ground station antenna searching pattern is of great importance to ensure the acquisition by tuning of this pattern parameters.

This searching pattern has then to be optimized for each visibility, taking into account:

- azimuth and elevation errors at the beginning of the visibility pass,
- visibility duration,
- allowed maximum antenna speed.

Simulation assumptions and data

Initial attitude is mainly driven by the effect of the angular rates integrated before rate damping switch-on. Initial attitude is thus not predictable.

The initial module of the spin vector is randomly chosen and its norm follows a gaussian law with a certain standard deviation.

The cumulated probability of acquisition is computed over the simulation period, taking into account all the available passes.

For each simulation, the initial attitude and orbit dispersions are randomly chosen using gaussian laws. For a set of input data, the acquisition is simulated for each visibility pass in a chronological order.

The first acquisition is successful when:

- the satellite has been in the ground antenna beam longer than the receiver acquisition time, and,
- the ensuing radio-electric visibility has lasted at least the predefined time ensuring acceptable errors on orbit determination.

The ground station network is composed of four sites distributed all over the world, with several antennas per site.

The figure 3 shows the ground track of satellite cluster for the 12 hours following injection by Ariane5.

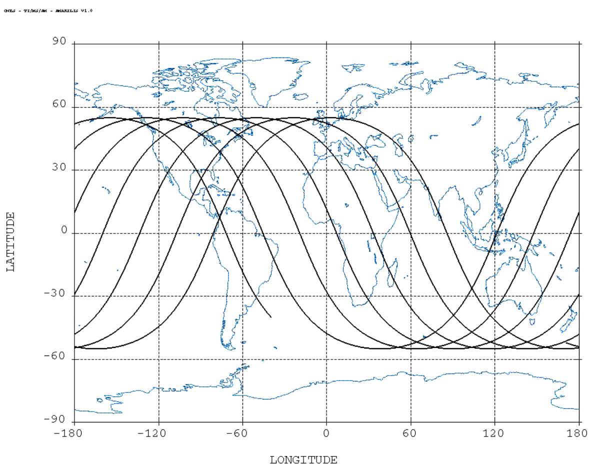

figure 3: Ground track

Simulation contents

Performances evaluation of first acquisition has been realized with a Monte-Carlo analysis, based on:

1. injection dispersion values,
2. the waiting point phase,
3. the searching phase, if necessary,
4. the satellite attitude,
5. the radio-electric visibilities.

For item 1, two main launchers have been studied:

- Ariane5 injection dispersion values are given by the launcher's user manual. We have chosen to take into account correlation coefficients to make more realistic computation,
- a theoretical worst case launcher which is a coherent set of the worst injection dispersions values derived from all considered launchers. We assumed that a success in this case of first acquisition would ensure a success with all launchers.

For items 2 and 3, all details have been given in chapter “ Research strategies ”.

For item 4, satellite attitude has been simulated by the following sequence:

- a rate damping phase,
- a solar pointed attitude phase which starts just after the previous phase.

Item 5 is fully described in chapters “ First acquisition strategy ” and “ Simulation assumptions and data ”.

The acquisition strategy is studied with a Monte-Carlo analysis over 1000 simulations.

If the acquisition is successful on a pass, another set of initial data is chosen to perform a new simulation. Otherwise, the simulation proceeds to the following pass, and repeats the process until the acquisition is successful or the end of simulation is reached (12 hours after the injection).

At the end of the 1000 simulation cases, the probability is given by the ratio between the total number of acquired satellites and the total number of simulations (1000).

Software tool

The software tool specially developed for this study is composed of the following parts:

- random choice on the orbital parameters, the satellite attitude and the ground station antenna depointing,
- attitude evolution simulation,
- real orbit computation, to simulate shifts with ground antennas pointing data, locked on nominal orbit,
- acquisition simulation, with the antenna patterns,
- visibility duration computation.

The tool has been designed with a high modularity constraint to allow the use of different data and algorithms for each item of the simulation. It is also based on the Multi-mission attitude modelization tool Marmottes[4], validated in several operational contexts.

The software tool could easily be adapted for the operational frame. As a matter of fact, during the first acquisition study, the hypothesis have greatly matured: the attitude sequence has changed, different launchers have been studied, and the first results have lead to improve some acquisition techniques, such as the use of overlapping beams, as developed below.

Results in case of ARIANE5 launcher

This study has been performed with only one antenna used for tracking for each ground station.

Different trade-offs have been realised on this case, over the ground station network and the satellite antenna beam. This work has assessed the feasibility of the first acquisition in case of Ariane5 launch, whatever the trade-off values.

In the worst case, the first acquisition is performed 8 hours after the injection, considering 3σ dispersions. With Ariane5 injection orbit, one of the ground site is never useful, whatever the network, in the acquisition scenario. The choice of the ground station network depends on the station-keeping phase and is not optimised for the first acquisition, since injections by different launchers do not allow to select the same sites for each launch.

After the feasibility was assessed, it appeared possible to improve the results of the first acquisition analysis in terms of duration. In order to reduce the 8 hours delay to acquire the first satellite of the cluster, we envisioned to use two antennas per ground station, with correlative motions, in order to make the two beams overlap. The overlap is defined by the duration of the crossing zone (1 second in this study). In addition, overlapping beams offered an opportunity to realise first acquisition in some difficult cases, and to acquire earlier some satellites. Indeed, the correlated movement of two antennas results in an enlarged beam, as shown in figure 4.

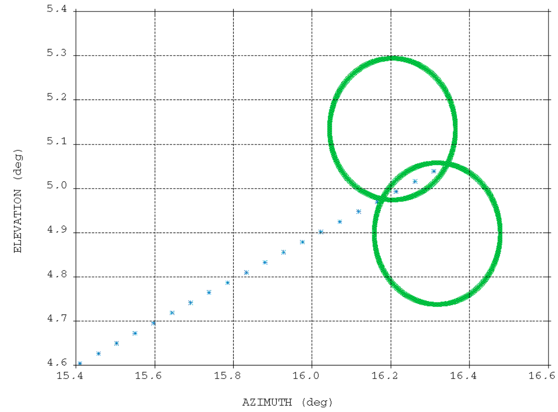

figure 4: Overlapping beams

As a result, the figure 5 shows the statistical improvement of the first acquisition strategy, both in terms of probability and total duration, for a particular case of simulation.

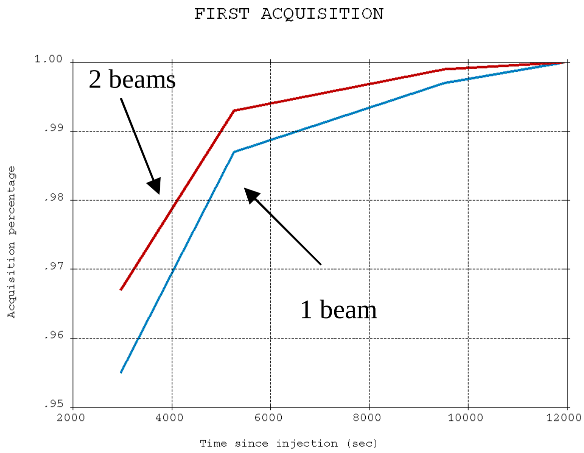

figure 5: Two beams improvement

ARIANE5 launcher conclusion

The study has validated the proposed first acquisition strategy, in case of Ariane 5 launcher, with satisfactory results and robustness to changes of parameters configuration.

Results in case of worst case launcher

The launcher considered in this part does not correspond to any available commercial launcher but consists in a specially constituted set of worst case parameters of all launchers eligible for Skybridge. Some values of injection dispersions have been chosen in order to represent such a case. No correlation coefficients have been introduced to worsen the case.

The computations have been realised with two overlapping ground station antenna beams.

Two types of simulations have been performed:

- A geometric visibilities simulation, considering a theoretical satellite antenna beam of 90 deg on +Z and 90 deg on -Z, in order to analyse the impact of the worst case launcher orbit dispersions. The probability of acquisition reaches 1 at 06h35mn after injection, considering 3σ dispersions. Over 1000 simulation cases, the maximum Doppler compensation error is never reached.

- A radio-electric visibilities simulation, taking into account the attitude evolution of the satellite. The probability of acquisition reaches here 0.997 at 09h39mn after injection, considering 3σ dispersions. Over 1000 simulation cases, the maximum Doppler compensation error is never reached, when the acquisition is performed.

Worst case launcher conclusion

The previous simulations give satisfactory results in case of the worst case launcher. To improve the previous figures, some modifications could be realised, in order to have geometric acquisitions at the earliest:

- parameters of ground antennas searching patterns have to be tuned in order to avoid geometric visibilities problems,
- the use of a third ground station antenna to track an other satellite offering a useful attitude after injection has to be envisaged. This antenna would be tuned on another tracking frequency, defined in chapter “ First acquisition strategy ”. This could provide with an alternate first satellite, while the two first antennas are tracking the main first satellite. The interest of such a combination is to ensure the acquisition of a first satellite for the cluster, even if the attitude of a tracked satellite is not favourable.

Skybridge first acquisition conclusion

In this paper, we have summarized the study carried out by CS-CISI, CNES and ALCATEL Space Industries within the mission analysis task team for Skybridge constellation. The first acquisition strategy and its practical application have been described, with definitions and constraints. The experience acquired has given confidence in the feasibility of the phase, which is a key to the deployment of the constellation.

The adaptability and modularity of the simulation tool specially designed for this part of mission analysis can lead to an operational system in further phases of the Skybridge project.

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