A MULTIMEDIA CONSTELLATION DESIGN METHOD

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Abstract

In order to design a satellite constellation satisfying a given service, the system analysis has first to determine a simplified space segment characterized by the constellation size - the number of satellites - and the satellite size - in term of rough definition of the payload main features. This paper describes a generic design method throughout a multimedia mission. This method has been applied within the framework of the SkyBridge project, even if this paper does not present the real system.

The first section presents a LEO multimedia service by its constraints and need definition. The second part deals with the two-step preliminary analysis led to determine the two characteristics of the simplified space segment. The third part illustrates this method on a fictitious case study by comparing couples (constellation size, satellite size) characterized by their ratio between the global number of links in orbit and the users demand satisfaction. The final section describes an example of complementary simulations.

The great difference between the results highlights the interest of considering such a space segment characterization in a design method.

A LEO multimedia service

A typical multimedia service allows individual terminals, located inside a service cell surrounding a gateway, to connect to this gateway. This connection is realized via a constellation of LEO satellites respecting the GSO systems.

The following paragraphs detail the simplified constraints, need and space segment modeling used in the preliminary simulation process.

Geometrical constraints

A service cell is represented by a reference point and its frontier. A circular coordination zone is then defined around and corresponds to the satellite spot pointed to the reference point.

A satellite is considered to be useful for a terminal inside the service cell when it is seen from this terminal with a sufficient elevation angle and when it respects the GSO frequency sharing constraint for the corresponding cell.

To protect the GSO systems, a satellite is considered to be forbidden for a given cell if a point inside the corresponding coordination zone sees the satellite close to the GSO orbit, as shown in Figure 1.

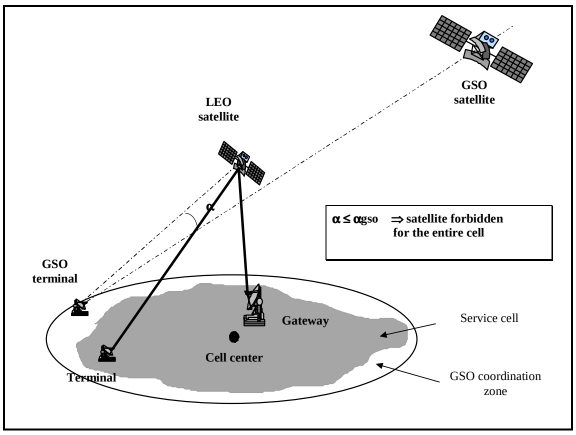

Figure 1 : frequency sharing constraint description

Coverage need

A market survey determines the location of service cells and their terminals density.

This density is translated in terms of global needed throughput. Link budget considerations determine roughly the individual throughput supported by a link between the satellite and the cell. The number of satellites necessary to satisfy the global cell need is finally deduced from this individual throughput per link.

A geometric scenario is then constructed and composed by a set of cells and by their initial need in terms of required coverage level (n_I).

Simplified space segment

A space segment is classically defined by its number of satellites and its payload type.

In order to take into account a notion of payload size in the preliminary design, the satellite is represented in a simplified space segment by a number of available links.

In case of a multiple need over a cell, the possibility for the same satellite to establish more than one link with this cell is forbidden.

A two steps design process

A preliminary simulation cycle is performed with instantaneous temporal considerations thanks to two consecutive simulation types, as shown in figure 2.

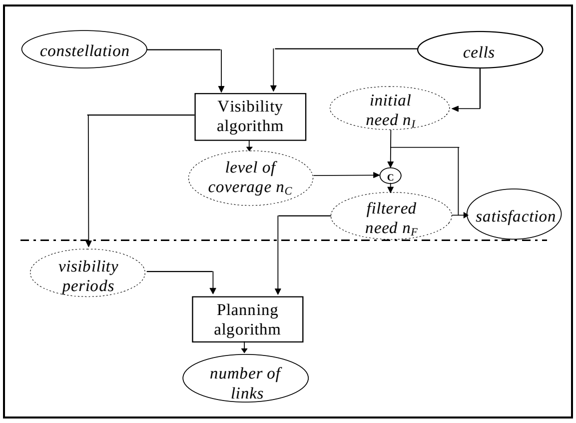

Figure 2 : general architecture of the simulators

The first iterative process finds constellations guaranteeing a sufficient coverage level. The second one comes as an additional characterization in terms of satellite size.

Visibility simulations

A simulator determines for each cell the visibility performance throughout two information types. This simulator uses as entries a constellation geometry and an orbit propagator.

Firstly the level of coverage (n_C) of a cell is calculated. This is defined as the minimum number of satellites seen continuously for all the terminals inside the cell. The number of usable satellites is computed at each time step and for each terminal of the cell. The minimum value is stored for each terminal in the course of the time. After the last time step, the final value attached to the cell is the minimum value found among its terminals.

This level of coverage has to be compared to the initial need in order to define a satisfied or filtered need. This filtered need is equal to the minimum between the initial need and the level of coverage ($n_F = \min[n_I, n_C]$). Finally a satisfaction ratio is defined as the filtered need divided by the initial need. This satisfaction allows us to evaluate the constellations in terms of coverage performance and to filter interesting designs.

Secondly, and only for interesting designs, visibility files are produced. These files regroup for each satellite its visibility periods in the course of time. A satellite is considered as visible when its elevation angle from the cell center is greater than a given minimum value and when it is not forbidden due to the GSO constraint. This minimum value defines the visibility domain for a satellite to transit traffic.

Planning simulations

The payload size is determined only for interesting designs thanks to a planning algorithm.

This algorithm uses as entries the pre-processed visibility periods and the filtered need (n_F).

At each time step, the number of links on each satellite is determined in order to guarantee the required number of links (n_F) between each cell and n_F satellites. The size of the most loaded satellite is stored. The figure 3 shows an example of the planning problem. The value noticed in the cell represents the filtered need and the satellites are usable by the four cells. The satellite size solution is equal here to 3 links.

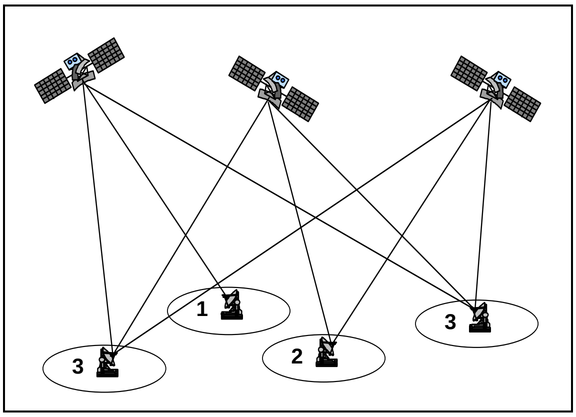

Figure 3: an example of planning situation solving

The final satellite size corresponds to the worst case observed in the course of the time.

The various simplified space segments defined by their number of satellites (as entry of the first simulator) and their number of links per satellite (as output of the second simulator), are finally evaluated by a profitability criterion. This criterion is defined as the number of satisfied users supported by each link in orbit. It is equal to the satisfaction proportion divided by the global number of links in orbit.

A fictitious case study

We will now illustrate this method by a fictitious case study.

The objective of the paper is actually to explain a generic process applied during the SkyBridge design, even if real and confidential data are not used here.

Fictitious hypotheses

The studied system corresponds to fictitious parameters not corresponding to the values characterizing the SkyBridge system.

The geometrical constraints are defined by a minimum elevation angle for the terminal equal to 7° and a GSO frequency sharing inside a 350 km radius cell with 5° of angular separation.

The ground need is composed by a set of 114 cells with a radius of 350 km and distributed as shown in figure 4.

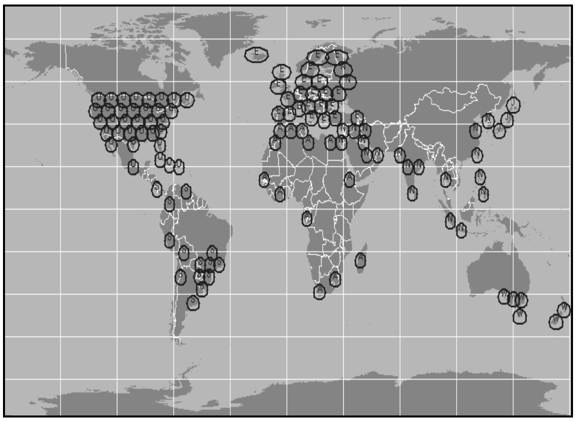

Figure 4: a fictitious cells distribution

The fictitious initial need profile applied to these cells is given in figure 5. The space segment has to establish in this case continuously 171 links between its satellites and the 114 cells.

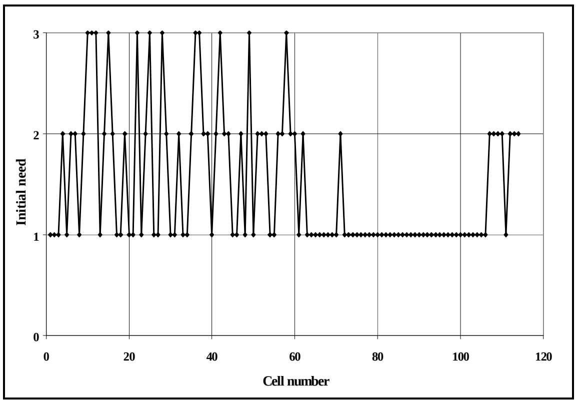

Figure 5: a fictitious initial need profile

Results

Figure 6 summarizes the simulations done for four Walker constellations constituted by 48, 60, 72 and 84 satellites.

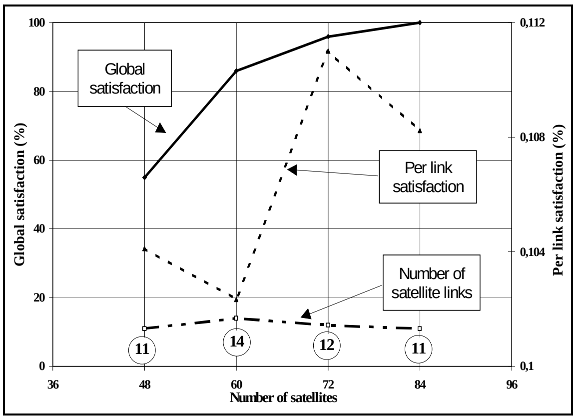

Figure 6: characterizations of the studied constellations

The upper continuous line shows the improvement of the need satisfaction when the number of satellites increases (60% with 48 satellites and 100% with 84 satellites).

The lower dashed line describes the corresponding evolution of the satellite size: the biggest satellite (14 links per satellite) is obtained with the 60 satellite constellation.

The middle dotted line comes as the synthesis of both first curves by representing the need satisfaction per link in orbit or profitability. The most profitable concept is the constellation constituted of 72 satellites with 12 links on each satellite.

Analysis

The choice of a concept among the four presented is difficult and depends on several cost considerations. The income of such a system comes from the need satisfaction. The expenses derive from the satellite cost and the launching cost. The profitability of the system is finally deduced by the balance between the incoming and the outgoing.

The number of satellites influences the launching cost by the deployment strategy and the satellite cost by the recurrence effect. The satellite size influences the launching cost by the number of satellites launched in a single flight and the satellite cost by the payload complexity.

According to the final budget, constraints can be defined upon the number of satellites, the satellite size or the satisfaction level.

If the satellite size is limited, the 84-satellite concept is adopted. But if the number of satellites is limited, the 60-satellite design will be preferred.

An example of complementary simulations

In order to take into account more precise system constraints, for example a continuity constraint, a further simulation level is applied to the most promising concepts.

Visibility simulations

The visibility simulations model then hand-over mechanisms to confirm the preliminary coverage determination taking into account access constraints. Such an algorithm verifies coverage continuity assuming that a level of coverage is delivered over the entire cell by only one satellite, except during hand-over periods when complementary satellites can be used. A terminal switching between two satellites has to see both satellites simultaneously during a recovering period.

Planning simulations

For the planning simulation, the payload is fixed before the simulation and modeled more precisely : for example, a link is characterized by a polarization and is split in several sub-bands. Such an algorithm assigns the available resources in order to optimize the global capacity of the system taking into account link budget considerations and using specified hand-over mechanisms.

The size of the payload is here issued from the preliminary study but is increased by a number of links dedicated to the constraint reinforcement (for example the multiple links necessary during hand-over periods). This additional number of links is determined thanks to an iterative study increasing the number of links.

Figure 7 shows the evolution of the satellite modeling from the visibility simulation to the capacity simulation.

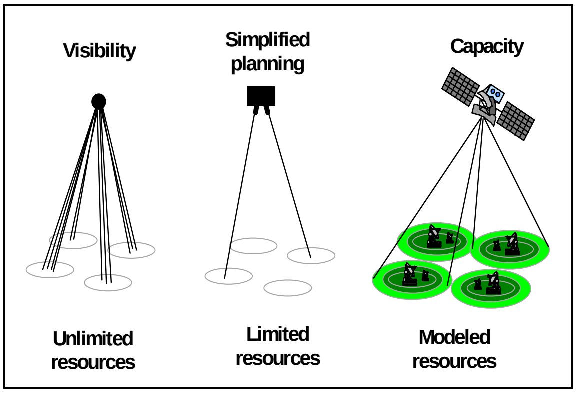

Figure 7 : evolution of the satellite modeling in the capacity simulation chain

Conclusion

The determination of potential satellite constellations answering a specific need has to be done very quickly and early in a project cycle.

This paper shows how various simulators adapted to different modeling levels allow both to filter progressively potential designs and to define space segments more and more precisely.

This generic principle is illustrated here for a multimedia service. The paper focuses on a fast method allowing a preliminary design of a simplified space segment taking into account geometric constraints.

But the promising concepts have to be compared for example in terms of capacity, operational availability, deployment complexity and duration. These performances are then determined by specific simulators using as entry the identified designs. An idea of such complementary studies is mentioned at the end of the paper through a capacity simulator description.