

Periodic Satellite Constellations for Local Telecommunication and Monitoring Services

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In recent years, the relevant surge in designing satellite constellations in medium and low orbit is related to the growing interest by commercial telecommunication and navigation ventures. Basically, constellation build-up strategies must include, as first step, an accurate coverage analysis aimed at fixing an optimal set of parameters, such as the number of satellites and their spatial distribution, with reference to the required operational purposes.

Higher resolution imaging for Earth observation, reduced transmission power requirements and signal time delays are main advantages of deploying LEO and MEO multi-satellite constellations with respect to geostationary platforms. On the other hand, the motion relative to Earth's surface introduces several complexities: numerical methods for capturing the performance of constellation architecture are needed, since generalized analytical solutions are still elusive.

A large set of parameters is involved in defining constellation configurations, so usually some basic assumptions are taken: this happens, for instance, for Walker constellations, exhibiting a high degree of symmetry and particularly suitable for coverage of large areas (Refs. 1, 2, 3, 4). Yet, for special purposes, like the continuous coverage of restricted areas, geometric hypotheses seem inadequate since too oversimplified.

In a former paper (Ref. 5), the author proposed a correlation-based approach for constellation design: all satellites were assumed to be placed in periodic, equally inclined circular orbits with an identical semiaxis. As a matter of fact, a suitable approach to predict the constellation dynamics and performances for all the operative life can be based on placing all satellites in periodic orbits, so the analysis can be focused only on the period of repetitiveness. For a single satellite, all orbital parameters giving maximum time of visibility of a specific location were found; in that context, symmetry of the periodic ground track with respect to the location meridian was an essential detail.

This paper is focused on constellation configurations aimed at maximizing the time of visibility of a specific target area, with reference to different requirements.

Now, the constellation is assumed to be composed of several satellites placed in equally inclined eccentric orbits with an identical semiaxis. Perturbations, such as atmospheric drag, solar radiation pressure, third body effects, are negligible at the altitudes assumed in the paper; on the contrary, Earth oblateness (J2 perturbation) is relevant and is considered in the model.

Satellite crossings over the preselected target area are translated into a binary time-dependent visibility function, switching between the two basic situations: satellite in view or not. The overlapping of several visibility functions gives a basic idea both about gap intervals (when the target area is in view by no satellite) and about coverage intervals (when the area is visible from at least one of the constellation satellites). A suitable

way for increasing continuous observation time and simultaneously reducing the gap is based on minimizing overlapping between two (or more) visibility functions: such a condition can be faced by introducing a correlation function. The latter depends on time delay between two consecutive satellite crossings over the target and vanishes when no overlapping occurs.

This paper is organized as follows: first, periodic eccentric orbits are defined; all satellites belonging to the constellation must necessarily have identical inclination and semi-axis in order to avoid differential actions by J_2 perturbation on each of them: this circumstance would cause a fast phase-displacement and a substantial alteration of the performances globally attainable by the constellation. Moreover, the critical inclination is assumed so that also J_3 perturbation becomes ineffective. After the selection of a minimum elevation angle, the total time of visibility from a single satellite in the period of repetitiveness can be obtained and depends only on initial RAAN (Right Ascension of the Ascending Node) and argument of perigee.

Two kinds of constellation configurations are proposed, referring to two distinct applicative requirements:

1. a 4 satellite constellation for a local telecommunication service
2. a 8 satellite constellation for local continuous monitoring

Both configurations ensure the continuous coverage of the target area, with a minimum elevation angle greater in the latter case with respect to the former.

In both cases, the 3d graph of the total time of visibility is non smooth with respect to initial RAAN and argument of perigee. As a consequence, this kind of parametric optimization (especially when more than two parameters are involved) requires specific algorithms tailored for non smooth optimization.

Once these two optimal parameters have been found, the so-called visibility function is introduced; then, for each applicative situation, all values for time delays giving continuous coverage are found by minimizing the correlation function. Figures 1 and 2 show two constellation configurations selected to meet the two above mentioned requirements, whereas Figures 3 and 4 show the corresponding visible ground track of a single satellite of each constellation.

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