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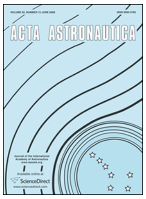

A satellite swarm for radio astronomy

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ABSTRACT

At present the celestial sky has been mapped in considerable detail for every major wavelength band, except for the ultra-long radiowave band. A space-based interferometer consisting of a swarm of satellites would make it possible to map the celestial sources of 0.1–10 MHz radiation. Such a mission concept called the Orbiting Low Frequency Array (OLFAR) is currently undergoing a feasibility study. This paper presents an analysis of possible operational orbits for the OLFAR satellites.

The strategy for OLFAR is to let the satellites drift freely after release into initial orbits. The design of the swarm′s reference orbit is primarily motivated by the need for a low radio-noise environment. This results in lunar orbits being main candidates. The design of the initial swarm configuration is primarily motivated by the need for *uvw*-space coverage. This quantity expresses the variation of lengths and orientations of the satellite relative position vectors over time.

Numerical simulations give strong indications that the required *uvw*-coverage can be met within 1 year of operations with a number of satellites ranging between 25 and 100. A key conclusion is that the orbital behavior of a swarm (characterized by the absence of continuous formation control) is well suited for ultra-long wavelength radio astronomy.

1. Introduction

A satellite swarm is a breed of distributed space system that has been gathering increasing interest over the past few years. It consists of a large number of satellites that cooperate with each other to achieve a common goal. A key characteristic of a swarm is that the satellites do not continuously fly in a tightly controlled geometrical pattern [1]. This feature sets satellite swarms apart from satellite formations. Swarms give rise to their own unique system philosophy and their own unique area of applications. Due to their large number of satellites, swarms are for example highly suited for applications which require observations with high spatial and temporal coverage. Furthermore swarms are well suited for applications which require observations with a synthetic aperture. This paper deals with a niche application from this last category: radio astronomy.

At present the entire celestial sky has been observed in considerable detail in almost every band of the electromagnetic spectrum. However, there is still one major exception: the Ultra Long Wavelength (ULW) radio band. The ULW band is defined by wavelengths longer than 10 m (which corresponds to frequencies lower than 30 MHz) [2]. Each time a new band of the electromagnetic spectrum was explored it led to the discovery of many new celestial objects and phenomena. Some of these discoveries were truly groundbreaking and radically changed our understanding of the universe (examples being the discovery of pulsars and the cosmic microwave background). Exploration of the ULW band holds the promise of uncovering new celestial objects and phenomena. It is needless to say that an ULW telescope has been, and still is, a dream of many astronomers.

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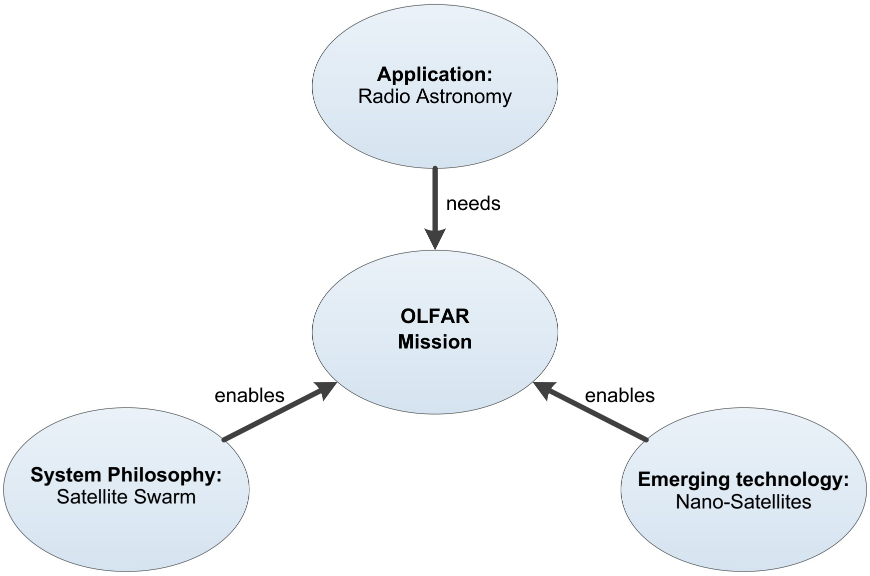

Fig. 1. Factors leading up to the OLFAR mission concept.

There are two formidable technical obstacles that complicate the construction of an ULW telescope. The first one is that the telescope will have to operate from space. The reason is simple: Earth′s ionosphere is opaque to ultra-long radiowaves. The majority of the ultra-long radiowaves from celestial sources are bounced back into space. The ones that do reach Earth′s surface are so thoroughly scrambled that they contain almost no information anymore. The second obstacle is that the telescope will need an enormous aperture size: in the order of kilometers. This is a direct consequence of the large observation wavelength.

Unfortunately the construction of a monolithic spaceborne antenna with a size of kilometres is not feasible with present-day technologies. However a feasible alternative would be an interferometric array: multiple small antennas from which the signals are combined to create a synthetic aperture. Here a collection of small antennas spread over an area with a certain diameter can achieve the same resolution as a single large antenna with that particular diameter. The synthetic aperture technique has already been used in ground-based radio telescopes for decades with great success. These telescopes are limited to observations outside the ULW band due to the aforementioned ionosphere opaqueness.

A spaceborne interferometric array greatly benefits from a large number of satellites. Thus a satellite swarm is a suitable solution. A possible antenna configuration for the individual satellites would be a set of six monopole antennas of 5 m length each [3]. Such an antenna configuration could be feasibly mounted on a satellite of nano-class size (typically defined as having a mass of 10 kg or less). Nano-satellites have a long heritage of strong reliance on Commercial Off-The-Shelf components. This makes them cost-effective, and makes it feasible to build the large numbers of them which are required for a swarm. The current generation of nano-satellites generally still lacks the capability to actively cooperate with one another (e.g. exchanging data and performing distributed data processing). However extrapolation of the current rate of technological advancement suggests that this could be feasible within the coming decade [4]. At that point a mission could be launched in which a group of nano-satellites links up to form a ULW telescope. A consortium of universities and companies is currently investigating the feasibility of this concept. The future telescope itself has been termed *OLFAR* (*Orbiting Low Frequency Array*). Fig. 1 summarizes the factors which have led up to OLFAR.

This paper deals with the design and analysis of possible operational orbits of OLFAR. The operational orbits are the location from which the astronomical observations are to be performed. The imaging performance of OLFAR will be intimately tied to the orbital motion of the satellites. Therefore an orbital analysis is crucial for the determination of the feasibility of the entire mission. The optimal location for OLFAR would be one that is free of the powerful radio noise emitted by Earth. The space behind the far side of the Moon offers excellent shielding against this radio noise [2], and is therefore a candidate location for OLFAR. The analysis in this paper focuses exclusively on Moon-centered orbits.

2. Orbit requirements

2.1. Overview

The goal of creating an all-sky map of extra-galactic ULW objects is the key source of requirements for the orbits. Examples of such objects are giant radio galaxies and quasars. In addition crucial orbit requirements result from an engineering constraint: the limited capability of the satellites to downlink observation data. Fig. 2 shows the flowdown from top-level requirements to orbit requirements. Although a target observation frequency range of 0.1 to 30 MHz is under consideration for OLFAR [1], the analysis