Re-routing algorithms in a meshed satellite constellation*


Abstract

In this paper we present a simple model for satellite constellations with polar orbits and inter-satellite links. This model is used to propose and study two algorithms for routing and re-routing communications, which aim at improving the quality of service for long communications. In order to study these algorithms, we have developed a satellite constellation simulator. Some of its results are presented.

Key words: Satellite telecommunication, Network routing, Low earth orbit satellite, Satellite constellation, Intersatellite transmission, Reservation.

I. INTRODUCTION

Geostationary satellites have been widely used because their relative-to-earth stillness makes them easy to work. On the other hand, they present a large communication delay (around 250 ms Earth-to-Earth), a transmitting power loss induced by the earth-satellite distance (36,000 km), and a poor coverage of areas with more than 70° latitude which are densely populated. Moreover there is a lack of viable positions on this orbit. An answer to space, delay, transmitting power loss and poor coverage could be the low (between 400 and 1,500 km) and medium (between 5,000 and 13,000 km) earth orbits (LEO, MEO) [9]. The problem with these orbits, however, is that the satellites are no longer geostationary and it is mandatory to use several satellites to have a wide coverage. This is why the concept of LEO satellite constellations has been introduced [10, 7, 6].

Such constellations may use inter-satellites links (ISL) and form communication networks through which all communications between any two terminals have to be routed. In opposition to terrestrial networks LEO constellations have a time-dependent topology, since the nodes are the moving satellites. Hence, if we consider a terrestrial terminal which communicates through the constellation, we see that it will be successively covered by different satellites, implying handovers [4, 8]. Therefore, the route originally set up for the communication will have to be eventually changed. Thus, in order to maintain a communication, we will have to re-route it at every handover. Notice though, that this dynamical topology is deterministic because the satellites movement is essentially ruled by gravitation laws.

Given that topology changes can be computed beforehand, we can choose to compute at the onset all the future routes, keep them in memory and use them when handovers occur [15, 13, 14, 11, 12]. Unfortunately,
however, the number of routes a communication uses depends on its duration and on the periodicity of the constellation, and may be large. Moreover, the question of where to keep those informations has no trivial answer: the memory storage on board of satellites is limited and if the storage is done on Earth, we will have to keep on sending routing tables to the satellites. Our approach for routing and re-routing is slightly different: we will study algorithms which use the deterministic aspect of the dynamicity of the topology and are to be run in a distributed manner in all satellites of the constellation.

II. MODEL

In the original Iridium constellation [2], the satellites are spread on 6 almost polar orbits, with a seam being induced by contra-rotative orbits 0 and 5. The orbits inclination is 86.5°, which reduces risks of satellite collision over the poles. Their coverage area (or footprint) has a hexagonal form and some inter-orbital links are switched off as they cross the poles, to be immediately relayed by newly re-established ones on the other side. Moreover, the relative speed between two counter-rotating satellites makes it difficult for an ISL antenna to keep track of the signal, therefore satellites are not connected over the seam. In a real constellation, handovers -- and hence rerouting --, may have many causes, like the satellites movement, and, when more than one satellite is visible from the terminal, the fading due to atmospheric conditions and/or bad coverage, the users mobility, and others. In the latter cases, the system simply tries to adapt to unfavorable external conditions, but no guarantee of success is required from it. Since we address in this paper the question of guaranteeing the completion of communications, we shall not consider these phenomena any longer. In order to study algorithmic issues concerning the rerouting of communications, we shall concentrate on the impact of the movement of the satellites only. For this, we will consider in this paper a simplified Iridium-like constellation, as follows.

In our model, there are 66 satellites spread on 6 perfectly polar orbits (i.e., with an inclination of 90°). Each satellite that is not on the seam uses 4 ISLs (one to the following and one to the previous satellites on the same orbit, and one to the satellites with the same latitude on each of the adjacent orbits). The satellites on the seam have only 3 ISLs. Finally, in this model, satellites have a footprint which is a rectangle intersecting with its neighbor’s footprint [3]. The model is drawn on Figure 1, where satellites occupy each line intersection.

Considering that the orbital period of a satellite is 100 minutes and that an orbit is made of 11 satellites, we obtain a coverage time for a satellite (the amount of time a fixed point on Earth is covered by a satellite) of around 10 minutes. This duration is also the maximum time before a handover to the next satellite on the same orbit (called South handover). Since there are six polar orbits, the time between two handovers to the next Eastern orbit (East handover) is 2 hours. Given that we want to study re-routing within the constellation (which occurs simultaneously with a handover), we consider connection-oriented communications, such as long phone calls and, even more interestingly, ATM-like connections. Our analyses use a generic constellation simulator we develop. They concern the dimensioning of ISLs capacity in order to supply quality connection setup and re-routing success rate.

III. TWO RE-ROUTING STRATEGIES

We present two small complexity re-routing algorithms designed for being distributed between all the satellites. Both take advantage of the deterministic aspect of the constellation topology dynamicity and use an x/y routing (cf. Figure 2): a route is made of two parts, an inter-orbital one (called x-part) and an intra-orbital one (y-part).