Link Strategy for the Mobile Satellite System Iridium

Harald Keller, Horst Salzwedel

Faculty of Computer Science and Automation,
Technical University of Ilmenau, Ilmenau

E-Mail: {keller, horst}@theoinf.tu-ilmenau.de

Abstract

This paper developes crosslink routing strategies for the Mobile Satellite System Iridium [1,3,6,8]. Motorola's Iridium satellite constellation, based on the orbit design of Adams and Rider [2] is to provide mobile satellite service for hand-held personal telephones. The Iridium system will have 66 satellites in 6 orbital planes at an altitude of h = 780 km and a minimum elevation angle of θ = 8.2 degrees for an optimal satellite distribution around the globe. It will be a system with direct connections between satellites (Intersatellite Links ISLs). These connections can be established with Intra-Orbit ISLs and with Inter-Orbit ISLs. The problem of routing messages through the satellite network is complicated by the time-varying satellite system geometry. The relative motion between the synchronized orbital planes is relatively small. However, orbital planes 1 and 6 are counterrotating and have large relative motion. Different Inter-Orbit ISL routing strategies are needed for these two cases. The time-varying behaviour of relative azimuth and elevation angles between satellites is analysed using the software systems SatLab [10] and BONeS DESIGNER [11]. Time-varying routing and antenna pointing angles are developed for both synchronized and counterrotating orbital planes.

I. INTRODUCTION

A number of mobile satellite systems (MSS) for low earth orbits (LEO) and for medium earth orbits (MEO) have been proposed, such as Iridium [1,3,6,8], Globalstar [4,6,8] and Odyssey [5,6,8]. These systems will be integrated with terrestrial systems in order to provide mobile communication from any place on the earth to any person at another place on the earth only by using a single handset. These systems can be regarded as extensions of the terrestrial mobile communication systems (GSM, PCS, etc.), which provide mobile communication only in limited regions. The Iridium system will provide voice, data, positioning and paging services through the digitally switched constellation to any place on earth. In order to do this, Iridium will have 66 satellites in 6 orbital planes with a circular polar constellation at an inclination of i = 86 degrees, an altitude of h = 780 km and a minimum elevation angle of θ = 8.2 degrees. The orbital period is T = 101 min. Commercial operation of the Iridium service is currently planned to commence in 1998 [6]. Using the Adams/Rider [2] circular polar constellation the orbital planes have their points of intersection near the poles and their greatest distance above the equator. For this constellation the satellites will fly in northerly direction at one side of earth and move in southerly direction on the other side of earth. This behaviour is shown in Fig. 1. The traces in Fig. 1 are short orbital traces of the 66 low orbiting satellites. We see two region, where the satellites move in different directions. For the Iridium MSS plane 1 and plane 6 are counterrotating orbits and the other planes are corotating relative to each other. Non-geostationary LEO and MEO satellite systems may be interconnected by intersatellite links or by bent-pipe systems through ground based networks. In this paper, intersatellite link strategies are developed for the Iridium MSS. Relative azimuth and elevation angles are analysed between satellites in the same orbital plane and between corotating and counterrotating planes. From these results antenna angles for minimum pointing variations are developed for various intersatellite link strategies.

For the Iridium system we consider a satellite distribution that maximizes the utility of satellite communication systems [7]. The simulation of the Iridium system has been done with the satellite simulation program SatLab[10] and the network simulation program BONeS DESIGNER[11].

II. INTERSATELLITE LINKS (ISLs)

Intersatellite links (ISLs) are RF connections between satellites. Fig. 2 [9] shows the topology of satellites and ISLs of Iridium. We have to distinguish between Intra-Orbit ISLs and Inter-Orbit ISLs. For each satellite there should be 2 or 4 ISLs, 2 Intra-Orbit-ISLs over the whole time and 2 additional ISLs (Inter-Orbit ISLs), if possible.

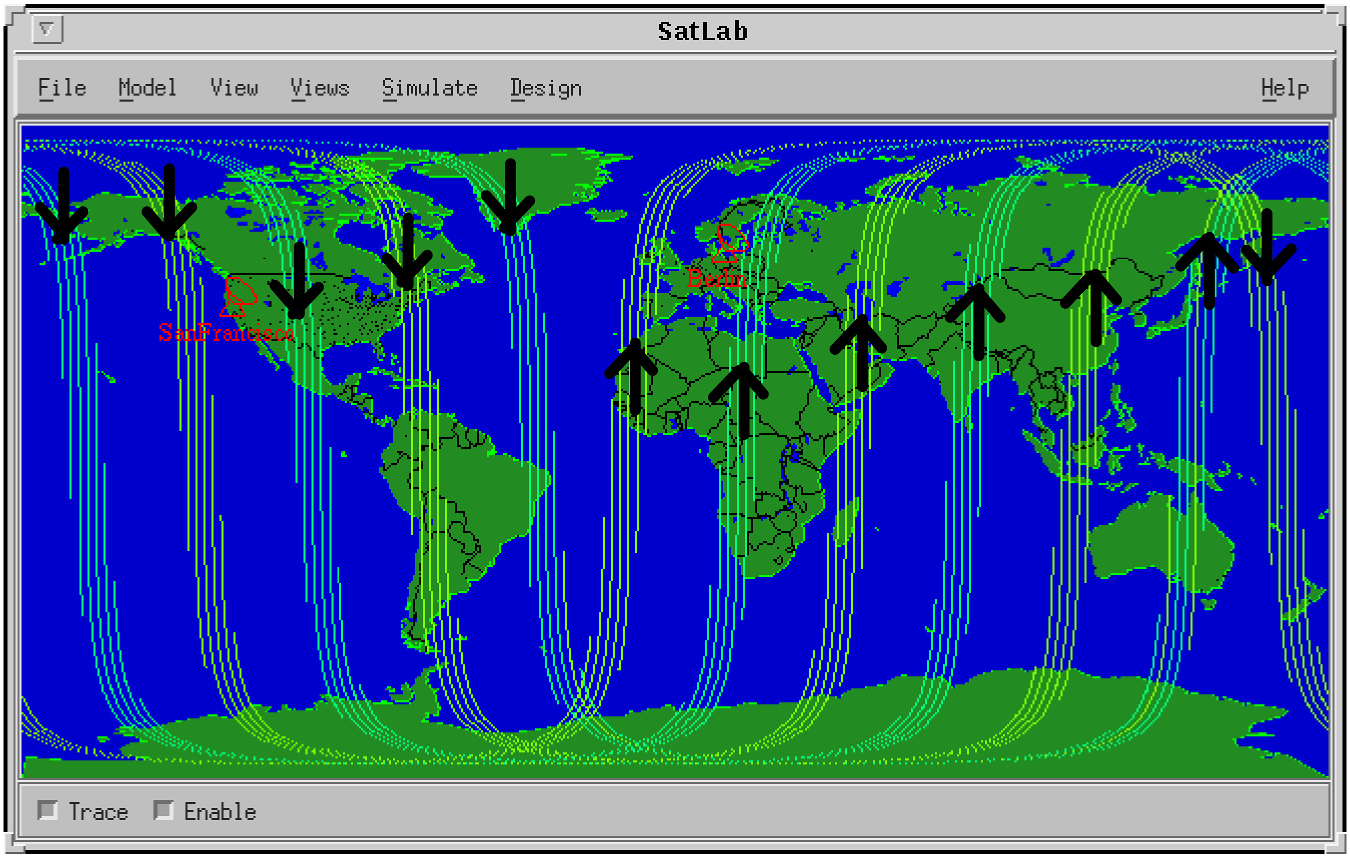

Fig.1: Orbital planes of Iridium over the world map [10]

A. Intra-Orbit ISLs

Intra-Orbit ISLs connect satellites in the same orbit. A satellite has a communication link to the satellite ahead or behind. Since the relative motion of circular orbiting satellites in an orbital plane is zero, the antenna pointing angles for these ISLs are also constant. In Fig. 2 [9] the Intra-Orbit ISLs are shown as solid lines.

B. Inter-Orbit ISLs

Inter-Orbit ISLs connect satellites in adjacent orbital planes. Because of the relative motion between the satellites, two satellites on adjacent orbital planes see each other under time-varying azimuth and elevation angles. Therefore, antenna steering is needed. Moreover the links cannot be held permanently, since distances and azimuth angles between the satellites exhibit large variations. In this case switched, time-limited ISL connections are used. Possible Inter-Orbit ISLs are shown as dashed lines in Fig. 2 [9].

III. ANTENNA STEERING

For the determination of the antenna steering angles we first develop optimal antenna steering strategies for corotationg satellites and analyse these strategies for counterrotationg satellites.

A. Inter-Orbit ISLs for corotating satellites

(1) Azimuth angle

Fig. 3 shows the azimuth angle of satellite 1H (orbital plane 1) looking to satellite 2H (orbital plane 2) and vice versa. To enable a connection between these satellites, we must search for periods during which the variation in azimuth over a time interval is small. To find these periods of small variations, we compute the derivatives of azimuth angles, Fig. 4, and the sum of the absolute values of both derivatives in Fig. 5. We can identify two regions where the change is minimal (at time periods around the time points of about $t\approx30$min and $t\approx83$min). These are the optimal time periods for establishing and using ISLs. The geographical location of the satellites during these time periods is above the equator.

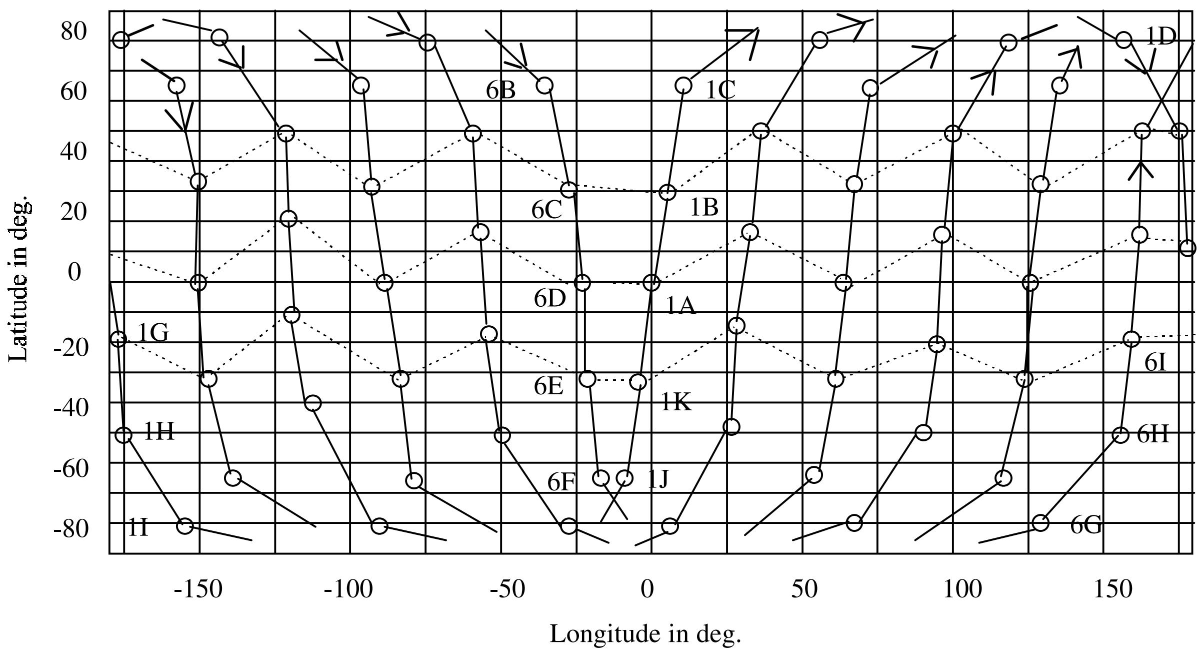

Figure 2: Topology of satellites and ISLs of Iridium [9],

o Subsatellite points, —— Intra-Orbit ISLs, --- Inter-Orbit ISLs

Since the satellite configuration is repeating every orbital period divided by the number of satellites per orbit, the link time period is

$$t_{\mathrm{Lmin}} = t_{\mathrm{period}} \, / \, n_{\mathrm{satellites\_per\_orbit}} \, . \quad (1)$$

With t_{period}=101 min and $n_{\mathrm{satellites\_per\_orbit}}$=11 follows the minimal link time t_{Lmin}=9.18 min. With this link time, we can determine the minimal antenna angle for this connection. To do this we have to take $t_{\mathrm{Lmin}}/2$ on the left and on the right side of the changed time value points in Fig. 3. Then we must take the difference between the maximum and the minimum azimuth values at this special points for both azimuth angles. The difference between the maximum and the minimum azimuth value is the minimal antenna angle. For this case the minimal antenna angle is

$$\Theta_{\mathrm{min}} = 9.08 \text{ deg}$$

Fig. 6 shows the antenna angle as a function of link time. Tab. 1 shows the minimum antenna angles for a number of ISLs between two and twenty-two ISLs.

The geographical Region of these links are:

2 ISLs: Over the equator,
4 ISLs: ± 20 deg. Latitude,
6 ISLs: ± 40 deg. Latitude,
8 ISLs: ± 50 deg. Latitude,
10 ISLs: ± 60 deg. Latitude, and so on.

The main communication traffic is in the region of the industrial nations (30-50 deg. Latitude). Therefore 8 ISLs are sufficient to manage the traffic with minimal delay. This results in a minimum antenna angle of θ_{min} = 44.51 deg.

(2) Elevation angle

Fig. 7 shows the elevation angle between the satellite 1H and satellite 2H. The change of the elevation angle is small (about 9 degrees) if using phased-array antenna.

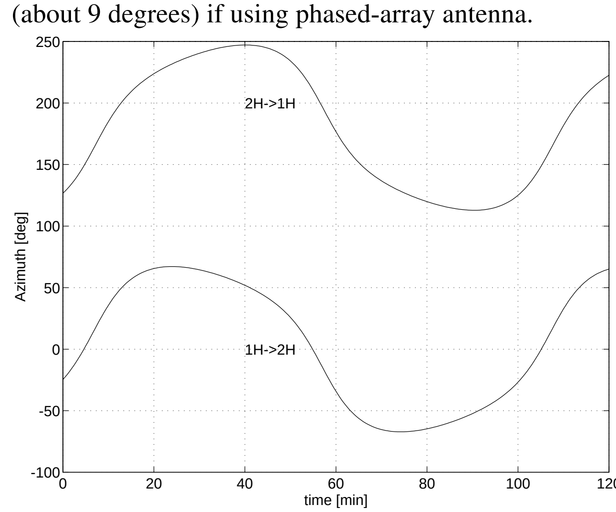

Fig 3.: Azimuth angle between satellites 1H and 2H

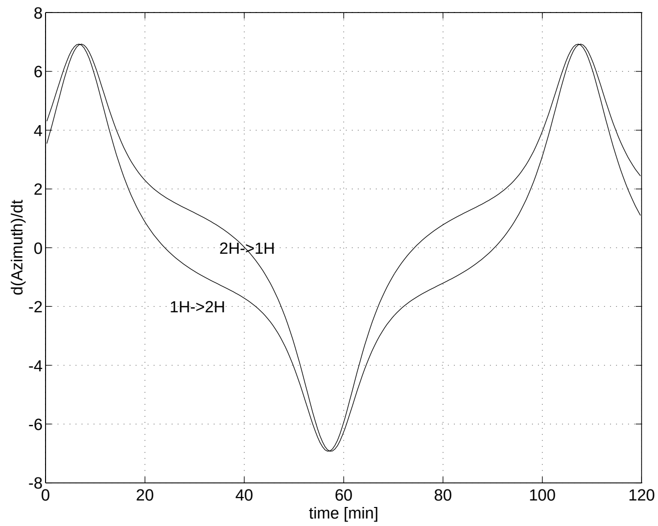

Fig. 4: First derivation of the azimuth angle between satellites 1H and 2H

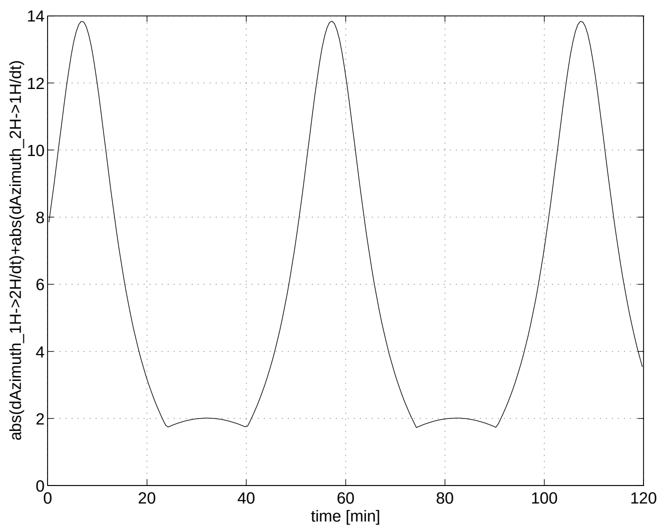

Fig 5.: Sum of absolute values of the derivatives of azimuth angles between satellites 1H and 2H

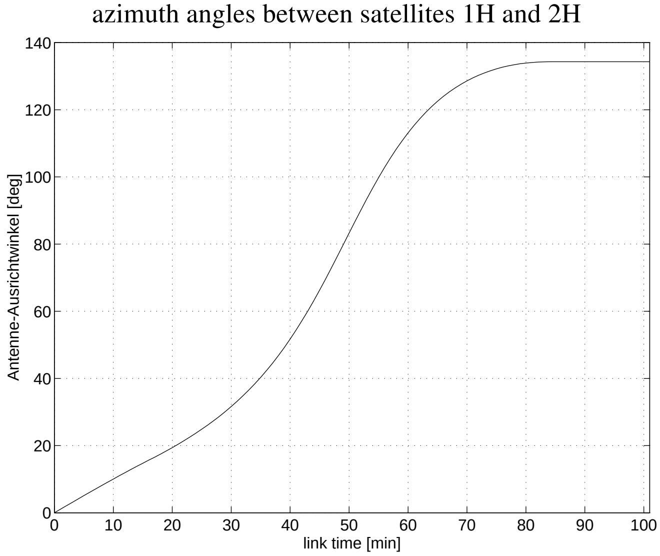

Fig. 6: Antenna angle as a function of link time for corotating orbital planes

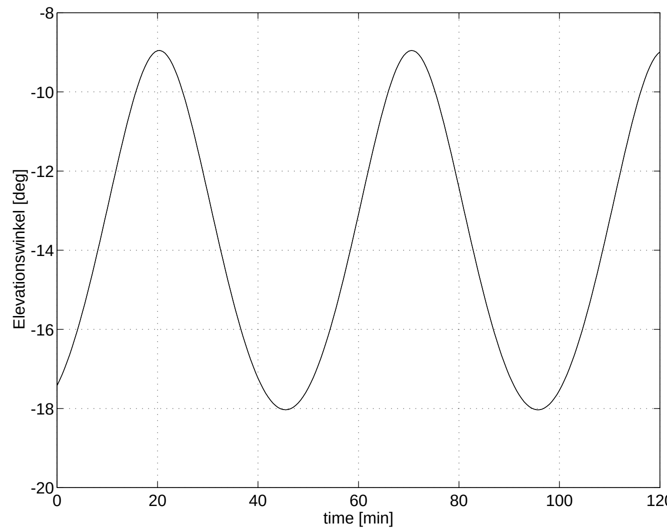

Fig. 7: Elevation angle between satellites 1H and 2H

ISLs	Min. Link Time	Θ_{min}
2	9.18 min	9.08 deg.
4	18.36 min	17.46 deg.
6	27.55 min	28.74 deg.
8	36.73 min	44.51 deg.
10	45.91 min	69.58 deg.
12	55.09 min	99.78 deg.
14	64.27 min	120.94 deg.
16	73.45 min	131.00 deg.
18	82.64 min	134.20 deg.
20	91.82 min	134.29 deg.
22	101 min	134.29 deg.

Tab 1.: Antenna values for various link times

B. Inter-Orbit ISLs for counterrotating satellites

(1) Azimuth angle

Orbital planes 1 and 6 of the Iridium system are counterrotating and have large relative motion. The same antennas of satellites in orbit 1 (6) are looking at satellites in orbit 6 (1) on one side of the earth and are looking at orbit 2 (5) on the other side of the earth. Therefore the following question arises:
Do we need special antenna steering for satellites of orbit 1 and orbit 6 or can we simply use the antenna steering angle for the case of corotating Inter-Orbit ISLs ?
In this case the link time can be calculated by

$$t_{\mathrm{Lmin}} = t_{\mathrm{period}} / (2 * n_{\mathrm{satellites\_per\_orbit}}) \qquad (2)$$

With t_{period}=101 min follows t_{Lmin}=4.59 min for 2 ISLs.
Fig. 8 shows the azimuth angle between satellit 1B (orbit plane 1) and orbit plane 6. Fig. 9 shows the azimuth angle between orbit plane 6 and satellite 1B.

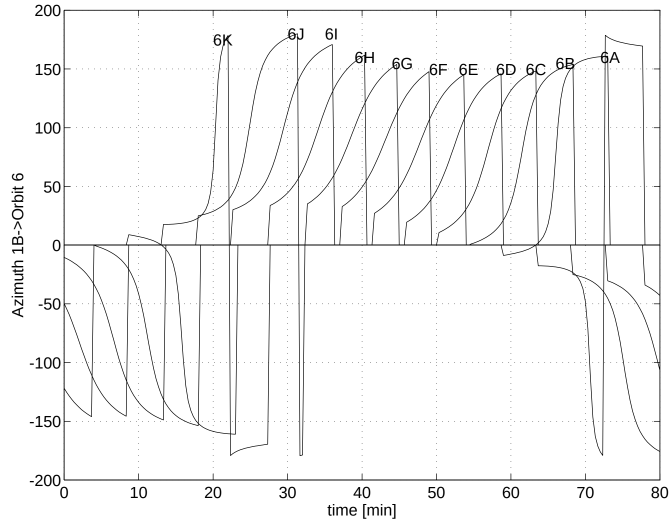

Fig. 8: Azimuth angle between satellit 1B and orbit plane 6

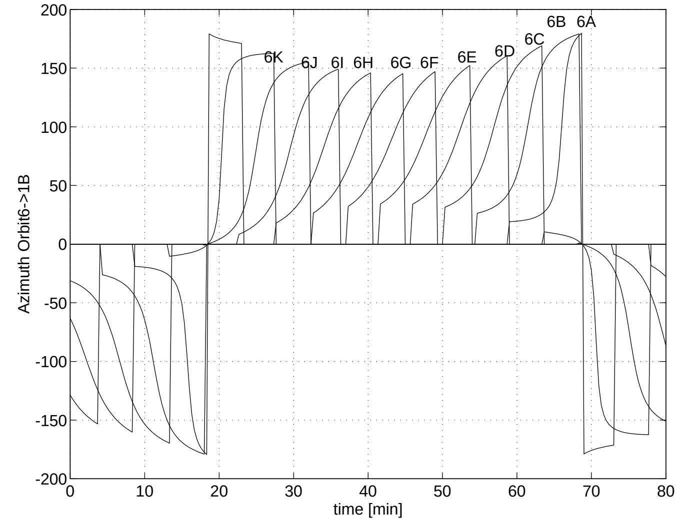

Fig. 9: Azimuth angle between orbit plane 6 and satellit 1B

We have examined the case with 8 ISLs. The figures show, that also for this case .an antenna pointing angle of Θ = 44.51 is optimal to get 8 ISLs. Therefore we can use the values of Tab. 1 also here and need no special antenna steering for the case of counterrotating orbital planes.

(2) Elevation angle

The graph of the elevation angle is analog to the case of satellites with motion of in the same direction.

IV. CONCLUSION

In this paper we developed link strategies for the Iridium mobile satellite system. We determined link times for feasible numbers of Intra-Orbit ISLs for the case of corotating orbital planes. Antenna angles with minimum pointing variations have been computed. If the main communication traffic comes from the industrial nations, eight ISLs (four ISLs on each side of the earth) are sufficient to manage the traffic with minimal delay. We showd, that these antenna pointing angles can also be used for the case of counterrotating orbital planes and that no special antenna steering is necessary for this case.

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