COVERAGE PATTERNS FOR THE MOLNIYA ORBIT AND IRIDIUM CONSTELLATIONS IN REAL TIME WITH THE STK

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Abstract:

In this paper, we are going to introduce a brief discussion about communication or coverage patterns in different kinds of orbits. In most cases, the type of orbit chosen for the satellite is very important for the mission objectives. In addition, the design of the satellite communication link depends on certain subsystems such as antennas, transponders, receivers, etc. The determination of a good satellite communication architecture depends on various perturbations, and scattering and loss of information in the transmission. In order to analyze and visualize the movement of the satellites around the Earth in real time, we used the Satellite Tool Kit (STK) software from Analytical Graphics Inc. (AGI). In this analysis, we used the low-earth orbit (LEO) and the Molniya orbit to introduce the efficiency of the software. In summary, we are going to demonstrate the different architecture of communication for the satellites and the coverage patterns for the satellites in real time.

Introduction:

The objective in this paper is to introduce the theory of communication architecture for satellites and constellations. The paper will be divided into two parts. First, the design of the communication architecture in the satellite-Earth link will be explained. The information that the satellite is collecting must be downloaded to the ground station. But, at the same time, we need to have some tracking of the satellite to know at what time it is passing through a specific point. Simultaneously, the uplink and the downlink of the system must be determined. These are the basic steps for designing the satellite communication system, but this must be coordinated with the orbit of the satellite to optimize communication and the real data rate.

Second, we utilize the Satellite Tool Kit software (STK) to determine many of the coverage patterns for the satellites and use the software to have a real visualization of

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how the satellite orbits around the Earth. The STK helps us to do these simulations in real time; in this way, we can predict or know when the satellite is passing over some strategic place on the Earth such as the ground stations, and bases and facilities that process all the information collected from the satellites.

I-Communication Architecture

Three basic steps are needed to design the architecture of communication for the satellite or constellation of satellites: 1) Mission objectives, 2) Data rates, and 3) Design of the uplink and the downlink between the satellite and the ground station.

To design the communication system in an efficient way, it is noted that the satellite design depends on specific subsystems. The subsystems used for the satellite to communicate to the ground station are the following: 1) Sensor, 2) Transponder, 3) Transmitter, 4) Ground Station, 5) Amplifier and receiver, 6) Demodulation, and 7) Display

Different types of communications exist for the satellite to transfer data to the ground station. These types of communications have advantages and disadvantages on their own; but here we use the low-Earth orbit and Molniya Orbit to perform this analysis and explain briefly the different types of communications.

A) Store and Forward:

The satellite receives the data from a group of ground stations and stores the data in the onboard computer. Then the satellite will download the information to a designated ground station. The low-Earth orbit is at low altitude and moves so fast that the ground station has only a small amount of time to download all the information. For this type of communication only one satellite is needed to communicate with the ground station.

B) Molniya Orbit:

The satellite has a period of 12 hours and for 8 hours it stays in the Northern Hemisphere. The apogee of this satellite is at an altitude of 40,000 km, and located approximately over the North Pole of the Earth; the perigee is at an altitude of 500 km and the inclination angle is 63.14˚. The Russians designed this orbit for the following reasons:

- To cover the polar areas for long periods.
- To have a lower cost of launch per satellite.

But this satellite has its disadvantages:

- Requires continuous changing of antenna pointing angles because when a satellite is out of range, another satellite is coming to continue the transmission in the same area.
- These satellites require station keeping.

C) Low Altitude:

The altitude of this orbit is about 1,000 km. The satellite moves faster around this orbit and most of these satellites have to be connected via crosslinks because the ground station does not have sufficient time to communicate with the satellite. Most of the data is sent through packets of bits between satellites. The advantages of this type of communication are:

- Greater lifetime than for other satellites.
- Reduces jamming susceptibility because of the limited Earth view area around the Earth.

- Has a low launch cost.
- Many have polar coverage depending on the inclination angle.

We summarize all the criteria associated with the design of the communication architecture for satellites or constellations. These criteria for the satellite communication architecture are: 1) Orbit, 2) RF spectrum, 3) Data rate, 4) Duty factor, 5) Link availability, 6) Link access time, 7) Threat or perturbations on the signal.

II-Computer Simulations

The software package that we have used is a released version 5.0 of the Satellite Tool Kit software package (STK). The company has kindly provided us with an educational license to use many of the STK capabilities. Through that license we can evaluate the orbital motion of the satellite. The STK software is very user friendly and allows simulation in real time. The STK package offers different options for different sets of data input: one for the basic properties, one for the graphic visualization in two dimensions and three dimensions, and other modules for the constraints imposed on the problem. For these simulations, we used the Iridium constellation and Molniya Orbit to demonstrate the communications between the satellite and ground station. We obtain the next results for the simulation of these two orbits that are shown in the following figures:

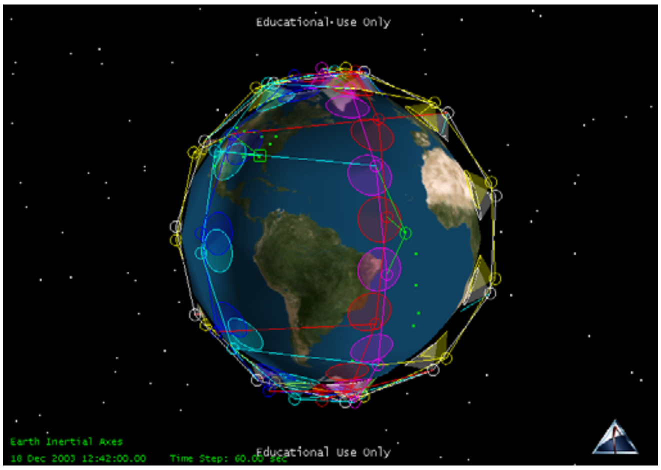

Figure 1. Iridium Constellation

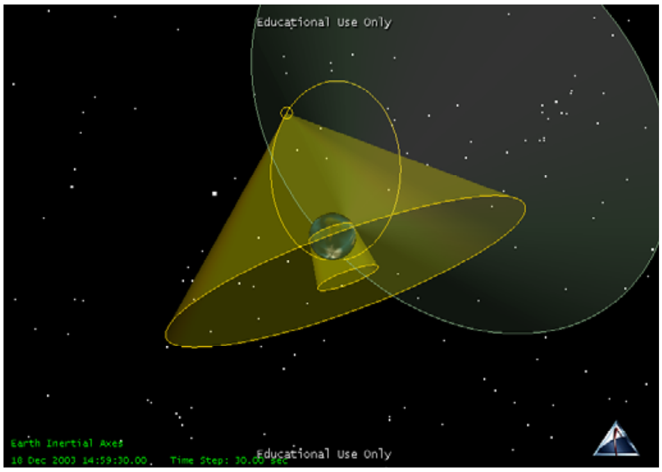

Figure 2. Molniya Orbit

Conclusion:

The computer simulations give us accurate results to determine the positions and times when the satellite is passing over a specific point on the Earth. When we run the STK in real time, we can predict the position, as mentioned earlier, but we can know the time and day when the satellite is within the tracking coverage of any facility around the Earth with very accurate results. These predictions of communication with the satellite will depend on how accurate are the initial conditions for the satellites. The STK helps us to have a visualization in real time of the different coverage patterns for satellites orbiting the Earth.

References:

1. James R. Wertz and Wiley J. Larson, Space Mission Analysis and Design, Third Edition, Microcosm Press and Kluwer Academic Publishers, 1999, Chapter 6 (Pages 131-158), Chapter 13 (Pages 533-586).
2. Marshall H. Kaplan, Modern Spacecraft Dynamics & Control, John Wily & Sons Inc., 1976, Chapter 2 (Pages 24-49).
3. Richard F. Filipiwosky and Eugen I. Muehldorf, Space Communication Systems, Prentice-Hall, 1965.
4. M. Ricahria, Satellite Communication Systems Design Principles, McGraw Hill, New York, 1995, Pages 1-158.
5. Leon W. Couch II, Digital and Analog Communication Systems, McMillan Publishing Company Inc., 1983, Pages 1-99.
6. Richard F. Filipiwosky and Eugen I. Muehldorf, Space Communication Techniques, Prentice-Hall, 1965.