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Tundra Orbit Constellation

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Abstract

The popular geostationary orbit has become overcrowded with satellites. To remedy this problem, Tundra Orbit Constellations have been proposed. A Tundra Orbit is a constellation of three or more satellites orbiting in an inclined eccentric orbit. The purpose of this study is to provide an alternative to the geostationary belt and supply continuous coverage for the Northern Hemisphere, in particular the United States. To ensure the most economical configuration of satellites, an analysis of the benefits of number of satellites in such orbits and the change in coverage they provide must be performed. During analysis, it was discovered that comparisons between current and previous results produced dissimilarities. An evaluation of the software code was performed to determine errors. After an intensive assessment of the software code, errors continue to be sought and the comparisons of results were analyzed.

Introduction

A Tundra Orbit Constellation is a collection of three or more satellites orbiting in an inclined eccentric orbit[1]. A Tundra orbit, as defined by Bruno[2], consists of the following orbital elements displayed in Table A.

Table A: Orbital Elements

Parameter	Value
Semimajor Axis (a)	42164.16 km
Inclination (i)	63.4°
Eccentricity (e)	0.2684
Argument of Perigee (ω)	270°

The above orbital elements were used to perform this study. Particular values for the Right Ascension of the Ascending Node (ω) were defined by Bruno, but adjusted for this analysis using

$$\Omega = -100.0^\circ + (360^\circ/N)t \qquad (1)$$

Where N is the number of satellites in the constellation and t is each satellite in sequence. For example t would be one for the first satellite, two for the second satellite, etc.

Objective

Due to the low elevation of satellites traveling in the geostationary orbit belt, there are many perturbations that affect the satellite signal. Examples might include mountains or tall buildings. Ideally, an elevation of 90 degrees would prevent virtually any obstruction from having an effect on the signal. For example, as one drives around town, there are certain locations in which one cannot receive certain radio stations. As one examines the surroundings, one finds that buildings are common. These buildings block the signal coming from geostationary satellites because they orbit at a low elevation (for users in northern latitudes such as the U.S. and Europe). Therefore, if a satellite is orbiting at an elevation of 90 degrees, it will pass straight above the receiver, removing all possibilities of interference of the signal. If a satellite in a highly inclined eccentric orbit is created with a perigee in the Southern Hemisphere, it will travel quickly throughout that hemisphere and very slowly throughout the Northern Hemisphere, the target region, as it passes through apogee. By transforming that single satellite into a constellation of three or more satellites, they can be staggered so that as one satellite declines in elevation another is rising above the horizon to take its place. To determine the best configuration of satellites, several factors needed to be taken into account. Cost and effectiveness of the satellite coverage were the most important factors. The more satellites in the constellation, the greater the coverage is and a greater population can receive coverage from the satellite. However, more satellites also lead to a greater cost. So, the objective was to optimize cost and effectiveness of the satellite coverage at the same time.

Approach

The previously written software code first needed to be verified. This was done by obtaining the code that plots several different parameters such as time, elevation of the satellites, number of satellites used in the constellation, and latitude and longitude points for the satellites crossing between North America and South America. This code was written using the MATLAB software.

The first plot to verify for accuracy was a time verses elevation plot. This plot proved to be accurate with previous results. Figure 1 shows the elevation verses time for 24 hours for a constellation of just three satellites as seen from Rolla, Missouri. The three satellites are phased evenly and the three peaks represent the maximum points of elevation, which correspond to the apogee of each respective satellite. The lowest points of elevation represent where one satellite sets and the next rises above the horizon. On this graph, the low point is approximately 61 degrees.

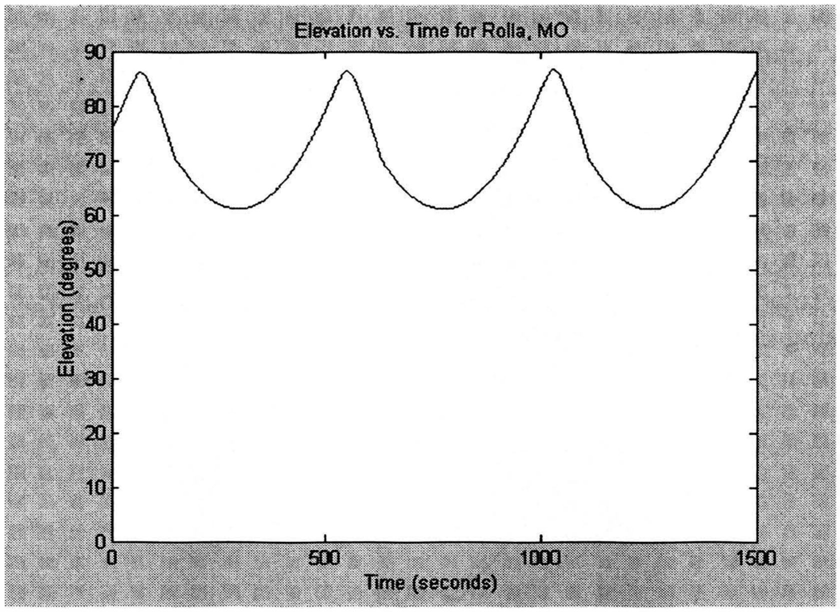

Figure 1: Three Satellites over Rolla, Missouri

A second plot to be verified was also a time verses elevation plot, but with a constellation of nine satellites instead of just three. This plot also proved to be accurate with previous results. The effect of tripling the number of satellites is shown in Figure 2. By increasing the number of satellites to nine the minimum elevation is increased to 73 degrees. However, increasing the number of satellites also increases the cost. Therefore, it would need to be determined if an increase in minimum elevation is worth triple the cost.

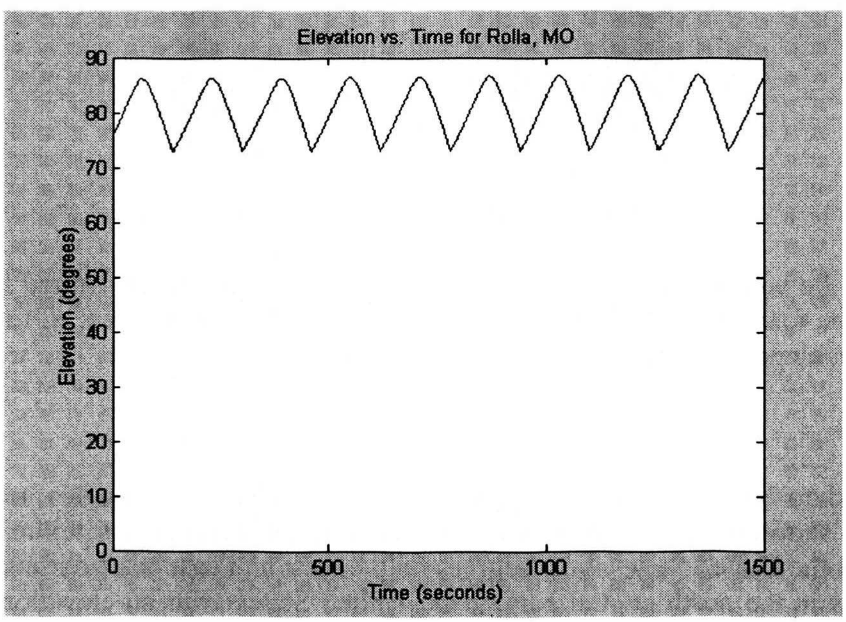

Figure 2: Nine satellites over Rolla, Missouri

Another plot to be verified was a latitude vs. longitude plot (ground track) over North and South America. When compared with previous results, this plot was found to be accurate. Figure 3 shows the pattern of the satellites with respect to latitude and longitude coordinates over North and South America. The graph ranges from 65 degrees south to 65 degrees north latitude, and from 130 degrees west to 45 degrees west. The point at which the satellite crosses over its path is where the elevation increases again. This point is at about 17.3 degrees north. The satellites' pattern is a figure eight due to the slow motion at apogee. The lower portion of the pattern is a clockwise motion because the satellite speeds up to pass through perigee and is traveling faster than the Earth's rotation. The upper portion of the patter is a counterclockwise motion because the Earth is rotating faster than the satellite.

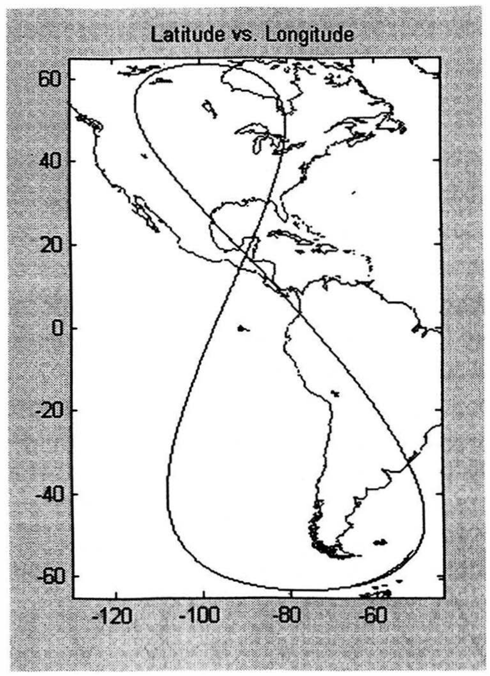

Figure 3: Tundra Ground Track

The last plot to be verified was a minimum elevation angle plot of the United States. This plot was proven to be inaccurate with previous results. Therefore, an analysis of the software code for errors was to be performed.

Current Status

The plots found to be inaccurate displayed the minimum elevation angles across the United States. Figure 4 shows the previous results using a constellation of three satellites. The minimum elevation across the United States is 55 degrees on the west and east coast oceans. The maximum elevation occurs in the north central part of the United States with an elevation of 75 degrees. This plot ranges from 125 degrees west to 65 degrees west longitude (x-axis) and 24 degrees north to 50 degrees north latitude (y-axis). This is the same range used in Figures 5, 6 and 7 as well. It is clear that coverage would be more effective at higher latitudes towards the center of the United States according to this plot.

In comparison with the previous results, Figure 5 displays the current results for a constellation of three satellites over the United States as well. According to this plot, minimum elevation angles consistently increase northward. The minimum elevation across the United States is 62 degrees in the southeast part of the United States. The maximum elevation is 70 degrees at the northwest part of the United States. Due to differences in software code, Figures 4 and 5 fail to produce the same results. An in-depth analysis of the code has been performed throughout the course of this research with a final resolution still being sought. A further analysis and examination of the code is in progress to ensure correct and accurate results.

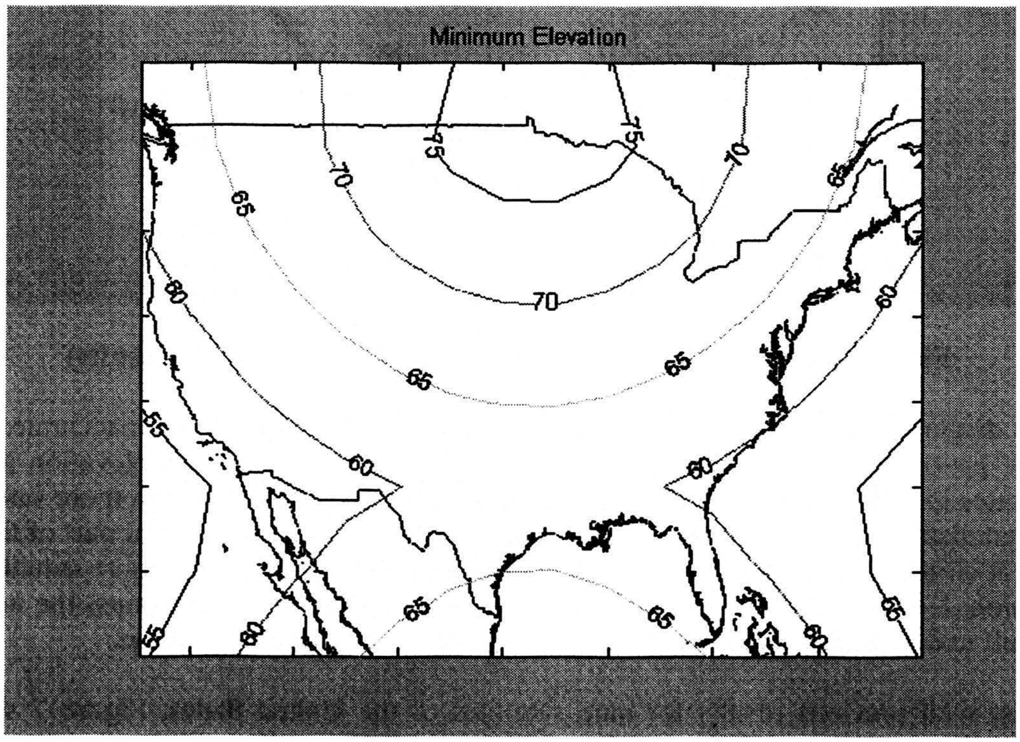

Figure 4: Three Satellites over the United States (previous results)

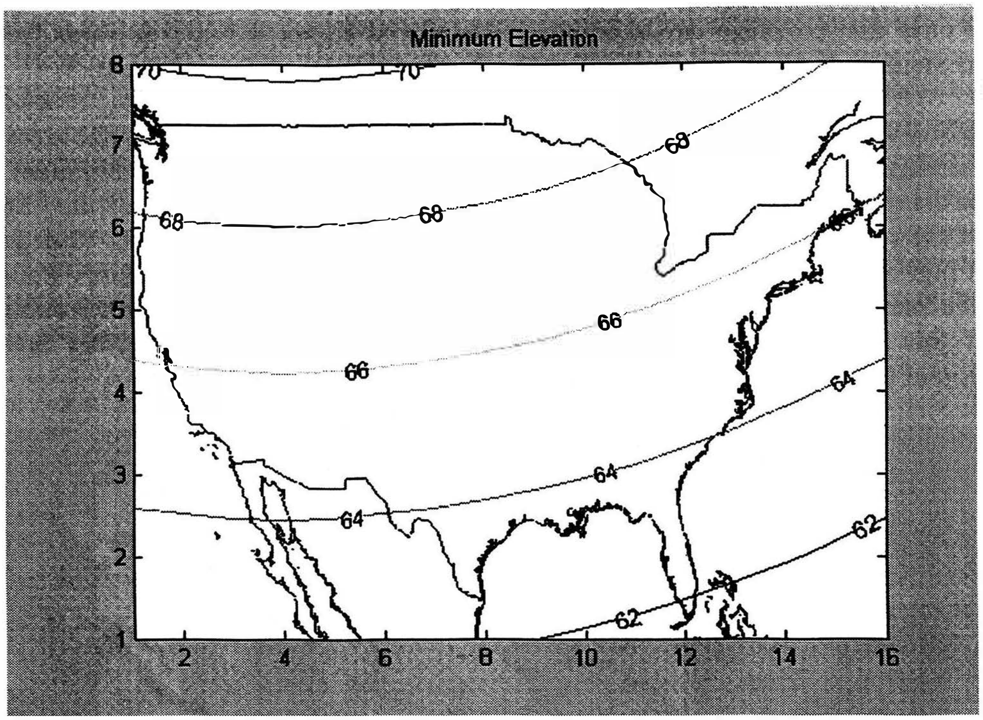

Figure 5: Three Satellites over the United States (current results)

The plots displaying a constellation of nine satellites were also found to be inaccurate. Figure 6 shows the previous results using this number of satellites. The minimum elevation across the United States increases to 65 degrees on the west and east coast oceans when more satellites are in the constellation. The maximum increases to 80 degrees in the north central part of the United States. It is clear that an improvement in reception can be seen when using more satellites in the constellation. However, this improvement in reception must be weighed against the increase in cost as well to determine the number of satellites to be used in the constellation.

In contrast with previous results for nine satellites of the United States, Figure 7 shows the current results for a constellation having this amount of satellites. According to this plot, symmetry is not seen for elevation angles. Figure 6 showed an equal representation of elevation angles on the west side of the United States as well as the east side. However in this plot, the symmetry does not begin in the center of the United States but in the west central part. Also, the minimum and maximum elevations disagree with Figure 6. In Figure 7, a minimum elevation of 74 can be found in the southern part of the United States. A maximum elevation of 78 can be found in the northwestern part. On account of dissimilarities in software code once again, Figures 6 and 7 fail to produce similar results. Another in-depth analysis of the code has been conducted with a final resolution still pending. A further analysis of this code is in progress to ensure correct results for future Tundra orbit constellation designs.

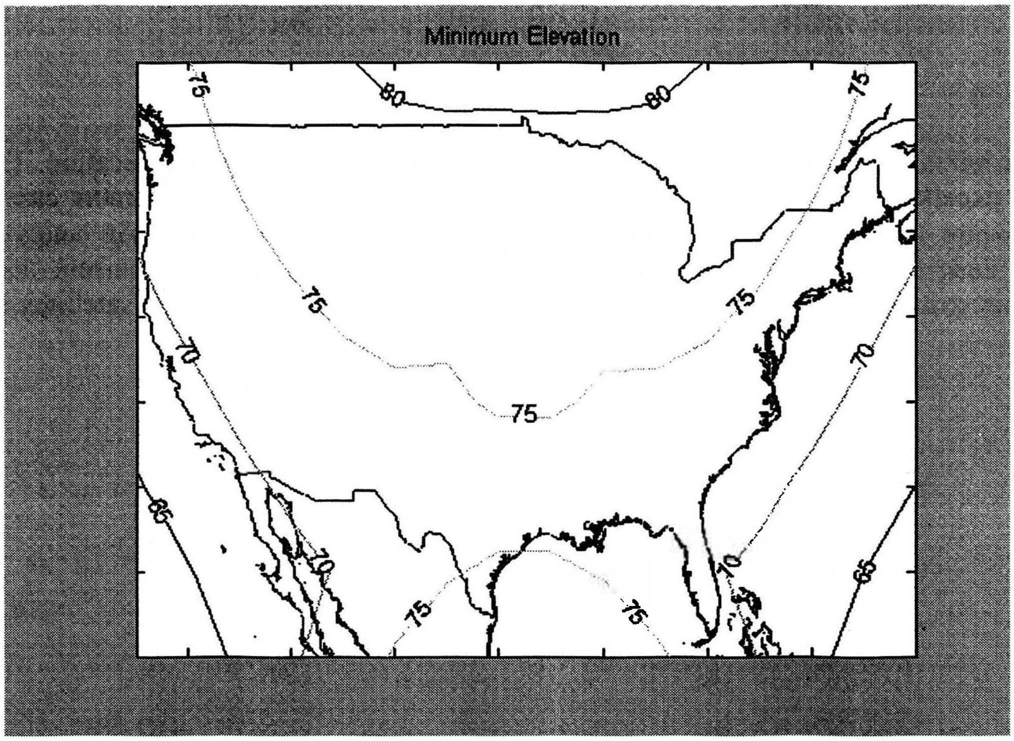

Figure 6: Nine Satellites over the United States (previous results)

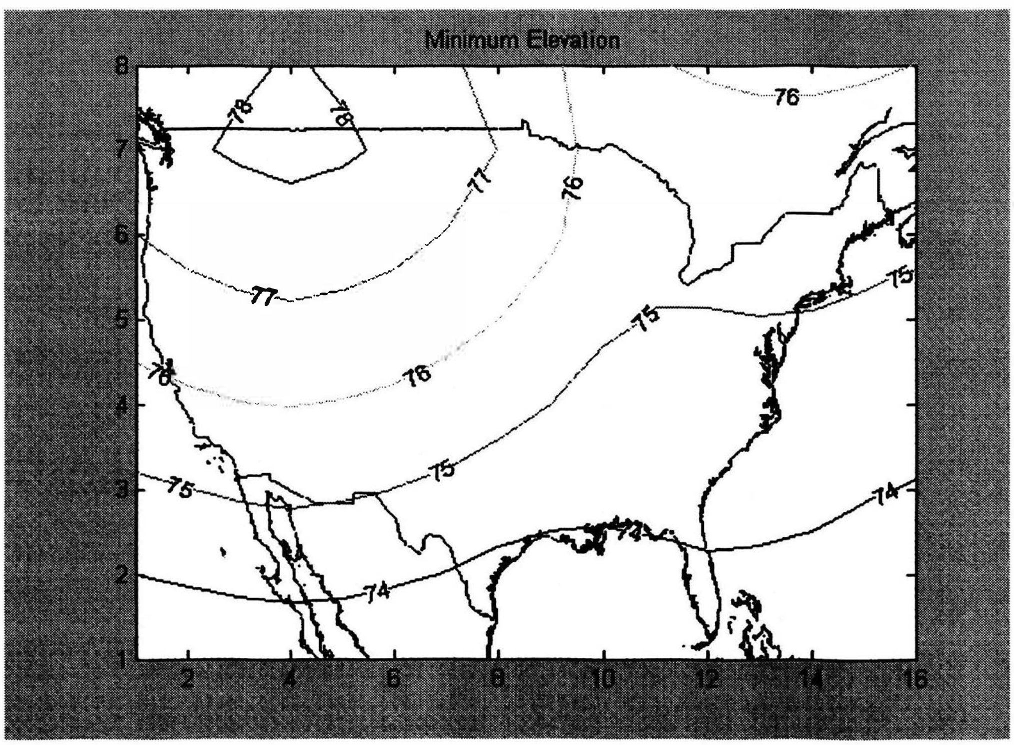

Figure 7: Nine Satellites over the United States (current results)

Conclusion

At higher latitudes, Tundra orbit constellations are ideal for satellite communication. They prove to be an excellent alternative to the overcrowded geostationary belt. Customers can expect to receive better reception from satellites in a Tundra orbit constellation. An analysis of the software code continues to correct dissimilarities between previous and current data. In the future, this software will be utilized to design an effective constellation of satellites in Tundra orbit.

References

1. Rondinelli, G.; Cramarossa, A.; Graziani, F.; “Orbit Control Strategy for a Constellation of Three Satellites in Tundra Orbits,” AAS paper AAS89-411, August 1989.

2. Bruno, M.J. and Pernicka, H.J., “Mission Design Considerations for the Tundra Constellation,” presented at the AIAA/AAS Astrodynamics Specialist Conference, Monterey, California, August 5-8, 2002.