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Constellation Design of Three to Five Satellites in LEO Orbit to Established the Communication from Ground

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Abstract

The design of a constellation is an important aspect from the coverage point of view to efficient use of a CubeSat. For the global coverage, there are many CubeSats required for low earth orbit (LEO) constellation design. However, in this work only 3-5 number of CubeSats has been used to design the LEO constellation to cover the limited area of interest. The study has been focuses on the different elevation angles and it has observed that the elevation angle of 5 degree and altitude of 600 km, one can have the 5 orbital planes to placed their CubeSats and each CubeSats can be placed in each orbital planes. The Maximum coverage area of constellation has been achieved with the 5 number of CubeSats and its value is 6.23x10^7 Km^2at the corresponding earth's central angle of 18 degree and the corresponding coverage percentage of 2.44 % has been found.

1. Introduction

In the modern technological age, the data traffic is huge and its continuously increasing, which demands higher bandwidth with reliable global connectivity. However, there is lack of infrastructure in some region and it affects the global coverage with the conventional wireless connectivity. To solve the above-mentioned issue, one can design the low Earth orbit (LEO) satellite constellation networks and the number of satellites in the constellation depends on properties of satellites and the required coverage area on the earth. The LEO satellite constellation can be defined as a group of satellites which revolves in LEO orbit and control by a point on the ground and perform a same task [1]. During the design of satellite constellation, it is necessary to keep in mind that the coverage area should be focused on the area of interest on the ground and have the efficient level of backhaul capacity of the interest area. There are some methods has been proposed to design the constellation such as polar orbit constellation [2], Walker Delta constellation [3], and Flower constellation [4-5], which aims to the global coverage. There are many different algorithms have been proposed, which focuses on the satellite constellation optimization such as the genetic algorithm (GA), differential evolution (DE), immune algorithm and particle swarm optimization (PSO) [6]. Mostly, the previous study has focused on the global coverage area of constellation, however in this work our main focus is to design a satellite constellation which consists of limited number of satellites, particularly from three to five and achieve the maximum coverage area on the ground. Since, there is limited number of satellites have in the constellation and hence it is difficult to get the global coverage area and hence our aim is to maximize the coverage area. The whole study will be for the LEO satellite constellation with the altitude range of 400 km to 600 km. The authors in [7] and [8] both have discussed the genetic algorithm for regional satellite constellation design to maximize the coverage of target areas.

2. Methodology

2.1 Design of constellation

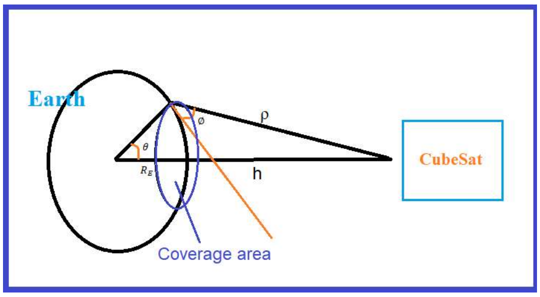

Fig.1. Coverage area of a CubeSat

The coverage area on the ground of the satellite (CubeSat) depends on the its orbital altitude and cone angle of antenna used in CubeSat. The antenna of CubeSat should have low loss, small size, spherical coverage for better performances. After the deployment of CubeSat, it needs to control from the ground, which requires high-gain and compact-size antennas at ground to receive the data communicated from the CubeSat. Generally, CubeSat used the S- and X bands to establish the communication from ground station. Apart from the orbital altitude and antenna of CubeSat, the design of satellite constellation also affects the coverage the constellation mission [9]. There is various technique to design the constellation and one of the simplest techniques is Walker constellation design [10]. The number of satellites in Walker constellations can be defined as

$$n = \frac{N_S}{N_p} \quad (1)$$

Where, n is total number of satellites in a orbital plane, N_s is the total number of satellite in constellation, N_p is the total number of orbital planes used to design the constellation. To achieve the global coverage by a CubeSat constellation, the minimum number of CubeSats n per orbital plane, and the minimum number of planes N_p required for a circular orbit can be determined as [10],

$$n = \frac{360}{2\theta} \quad (2)$$

$$N_p = \frac{360}{4\theta} \quad (3)$$

where θ is the Earth central angle of coverage. the Earth central angle is obtained as follows,

$$\theta = \arcsin\left(\frac{\rho \sin(90+\emptyset)}{h+R_E}\right) \quad (4)$$

where RE is the Earth's radius, h is the orbital altitude of the CubeSat, ∅ is the elevation angle, and ρ is the slant range. The slant range ρ can be determined by the law of cosines as,

$$\rho^2 - 2R_E\,\rho\cos(90+\emptyset) = (h+R_E)^2 - R_E^2 \quad (5)$$

From these above equations, one can sate that the required number of CubeSat in orbital plane and the number of orbital planes increase with increasing the elevation angle and reducing the altitude. This is due to the direct relation between the Earth central angle ρ, the elevation angle ∅, and the orbital altitude h.

2.2 Coverage area of a Satellite

The coverage area of a satellite is an important parameter during the design of a constellation. It depends on the line-of-sight (LoS) propagation and the minimum elevation angle as shown in Fig.1. Assuming that the surface of the Earth is an ideal sphere, the coverage area of a satellite can be calculated by using eq. (6) [11],

$$S = 2\pi R_E^2\,(1-\cos\theta) \quad (6)$$

Further, the % Coverage area can be estimated by eq. (7) as mentioned below,

$$\%\ \text{Coverage area} = \frac{(1-\cos\theta)}{2} \text{x } 100 \quad (7)$$

3. Results and Analysis

The study has conducted for different elevation angles and possible different orbital planes. The main objective of this study is to design a constellation of limited number of CubeSats particularly with the 3-5 CubeSats. Since, due to limited number of CubeSats study focused on the maximize the coverage area in order to use the CubeSats in efficient way. The table 1, clearly shows the for the different elevation angle, the requires number of CubeSats and corresponding altitude and earths central angle. For the 6 number of orbital planes, we can have 3 CubeSats, each CubeSat can be placed in all different alternate orbital planes, while for the 5 orbital planes, there may have 5 CubeSats and can be placed in each different orbital planes, which enhances the performances. The study continues with the other elevation angles of 10, 15, 20 and 25. The earths central angle can be estimated by the using of eq. (4), which depends on the altitude, slant range and the elevation angle.

Table-I. Required Number of CubeSat for different elevation angle and corresponding earths central angle

Elevation angle	No of orbital plane	Altitude	No of CubeSats	Angle (θ)
5	6	500	3	15
5	5	600	5	18
5	5	700	5	18
10	7	500	4	12.85714
10	6	600	3	15
10	6	700	3	15
15	8	500	4	11.25
15	7	600	4	12.85714
15	7	700	4	12.85714
20	10	500	5	9
20	9	600	5	10
20	8	700	4	11.25
25	12	500	6	7.5
25	10	600	5	9
25	9	700	5	10

The primary focus of the current study is to enhance the surface coverage area of the constellation and hence by the using eq. (6), the total coverage area has been estimated for the earth's central angles of up to 30 degree and shown in Fig.2. The figure 2, shows the with the increase in the earths central angle the corresponding coverage area will also increases. The Maximum coverage area of constellation has been achieved with the 5 number of CubeSats and its value is 6.23x 10^7 Km^2 at the corresponding earth's central angle of 18 degree. However, the maximum coverage area of constellation will be lower with the 3 or 4 number of CubeSats as depicted in Fig.2. Therefore, to achieve the greater coverage area 5 number of CubeSats is suitable with the 5 orbital planes and each orbital planes contains a CubeSat in their particular orbit.

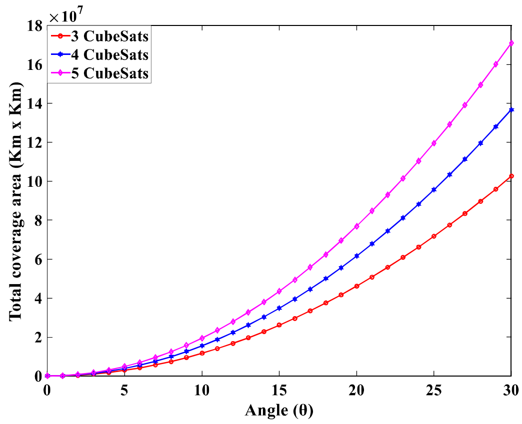

Fig. 2. Total coverage area for different earth's central angle for different CubeSats

The figure 3 shows the percentage of coverage area with the different earths central angle, which has been estimated by using eq. (7). The figure clearly shows that with the increase in the earths central angle the coverage fraction area will also be increases. The coverage percentage of 2.44 % has been found for the 18 degree of earths central angle, which is the corresponding value of 5 CubeSats placed in 5 orbital planes to achieve the maximum coverage area on the ground by the constellation.

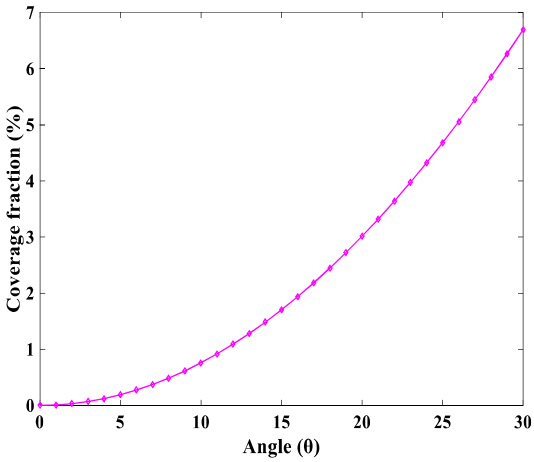

Fig.3 Coverage fraction for different earth's central angle

4. Conclusion

The current study has focused on the design of the constellation with the 3-5 number of CubeSats to achieve its maximum surface coverage area. The study focused on the different elevation angles and it has observed that the elevation angle of 5 degree and altitude of 600 km, one can have the 5 orbital planes to placed their CubeSats and each CubeSats can be placed in different orbital planes with the different true anolomy values to avoid any interferences. The Maximum coverage area of constellation has been achieved with the 5 number of CubeSats and its value is $6.23\text{x}10^7$ Km^2 at the corresponding earth's central angle of 18 degree and the corresponding coverage percentage of 2.44 % has been found. The current study has been fixed altitude, however in future the study can be extended with the different altitude to enhance the coverage performances.

5. Acknowledgements

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6. References

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