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COMMUNICATIONS SATELLITE SYSTEM BY USING MOON ORBIT SATELLITE CONSTELLATION

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ABSTRACT

A communications satellite system placed in three-Lagrange points, L_3, L_4, and L_5, of the restricted three-body problem in Earth-Moon system is proposed in this paper. LEO satellite constellation has been another choice of communications system. The proposed system which is alternatives of limited geostationary orbit resources, has some weak points such as long distance from the Earth, relatively expensive launch cost, long delay time, more required power, and so on. It has good points like less efforts (fuel) for station keeping, less eclipses, etc. This system has limitations for applications to provide commercial services but it is still some attractive points.

Keywords: communications satellite, Lagrange points, Earth-Moon System

1. INTRODUCTION

The moon was the first operational communications satellite and used as a passive reflector by the U.S. Navy in the late 1950s for low data rate communications between Washington, D. C. and Hawaii. Artificial active communications was SCORE, launched in 1958 and it was used for voice communications. Similar to Moon reflection communications, an experimental passive repeater, Echo I which was simply metallic surfaced balloon, was placed in medium-altitude orbit in 1960. Early communication satellites were placed in low-medium orbit and they had advantages of low costs, higher payloads, and relative short RF propagation times and disadvantage of the need to track one satellite to another. The geosynchronous orbit satellite communications system was suggested by Arthur C. Clarke in mid-1940s. The first commercial geosychronous orbit communications satellite, Intelsat (named as "Early Bird") was launched in 1965 (Agrawal 1986). Ironically, the disadvantages of low-medium orbit communications satellite has been overcome by introducing communications system by constellation of low-medium orbit satellites like Iridium. Even though it is just amateur activity, some people have been used the Moon as reflector for communications between persons on the Earth. It is named as E-M-E (Earth-Moon-Earth: Moon bounce) system (EME; http://www.nitehawk.com/rasmit/ws1_1.html). To cover Russian territory, Russia use communications satellites on Molinya orbit that is for communication requirements for satellites in view of high latitude ground stations, as found in Russia, is best accommodated by a highly inclined, eccentric orbit that has the apogee near the communications station latitude.

In this paper, we suggest communications satellite system placed in three Lagrange points, L_3, L_4, and L_5, of the restricted three-body problem of Earth-Moon system.

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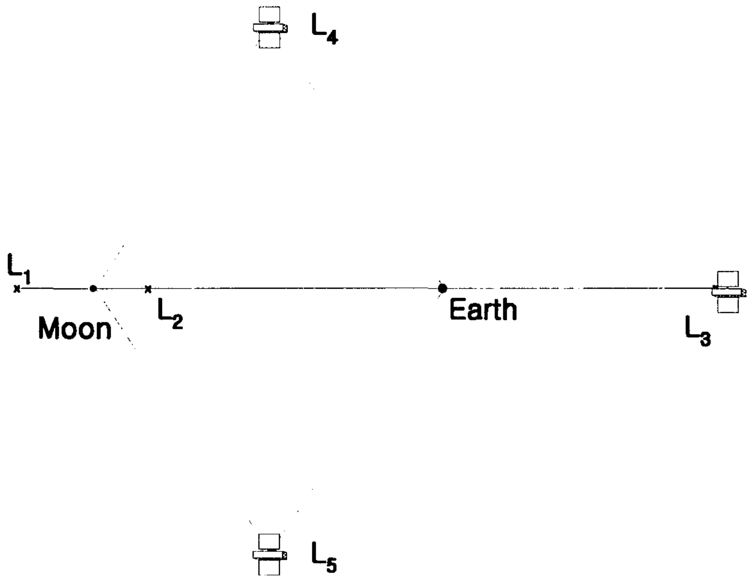

Figure 1. Orbit geometry of the proposed system.

2. MISSION ORBITS

2.1 Orbit Configuration

The restricted three-body problem (Szebehely 1967, Roy 1978) provides both the equilateral triangle and straight line solutions, L_1, L_2, L_3, L_4, and L_5. Generally, the twelve asteroids in L_4 and L_5 of Sun-Jupiter system are called as "Trojans". Similarly, the suggested communications satellite system is composed of three satellites, which are placed in L_3, L_4, and L_5 as shown in Fig. 1. The L_4 and L_5 are stable points and L_3 is marginally stable. Three satellites on the orbits are separated by 120 degrees and they can cover most of the earth surface.

The mission orbits of the proposed system are on the plane of the Moon's obit, which is inclined 5.15 degrees with respect to the ecliptic plane. Also, ecliptic plane is inclined 23.45 degrees with respect to the equatorial plane as shown in Fig. 2. Therefore, lunar orbital plane varies between 18.3 and 28.6 degrees during about 17-year period. And the right ascension of ascending node oscillates between 13 and –13 degrees (Agrawal 1986).

2.2 Launch satellites to L_3, L_4, and L_5

A technique (Belbruno 2002) for transferring an object like spacecraft to the stable Lagrange points, for instance L_4 and L_5, uses a substantially negligible amount of delta-V. Initially, a modified weak stability boundary transfer with parameters sufficient to transfer the spacecraft from the Earth orbit to a vicinity of the Moon is performed. Then, the spacecraft is momentarily captured at a capture point to target the stable Lagrange point using a substantially negligible amount of propellant. In order to launch satellite to L_3 point, Hohmann transfer can be used. It requires delta-V, 3.9311 km/sec compared to geostationary orbit transfer, which requires 3.8841 km/sec as delta-V. Above calculation is carried out with conditions that the initial parking orbit, geostationary orbit and moon's orbit are circular orbit and their radii are 6700 km, 42164 km, and 384000 km, respectively.

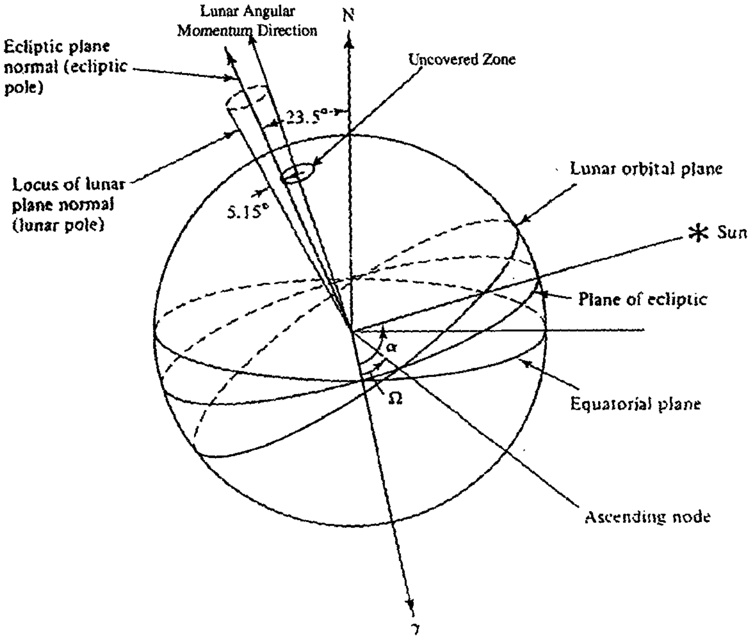

Figure 2. Orbit configuration of the proposed system.

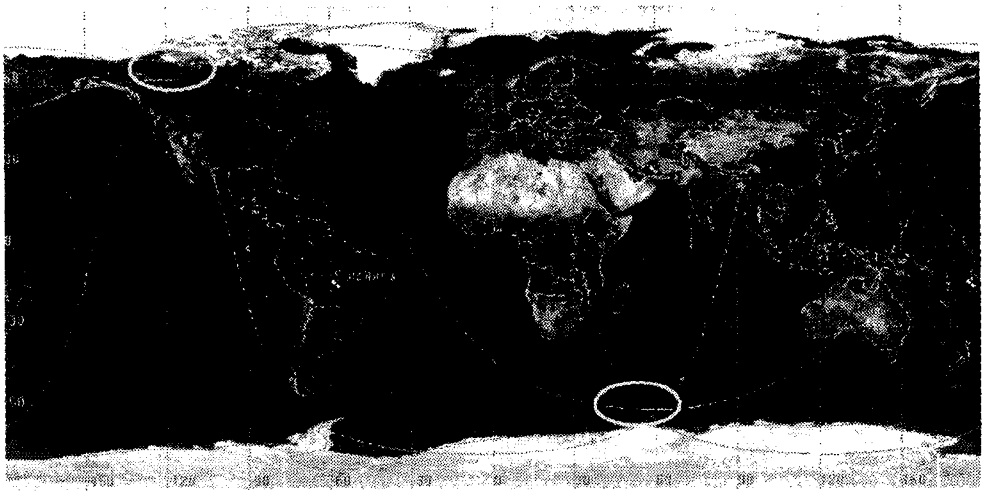

Figure 3. Satellite ground coverage.

2.3 Ground Coverage Analysis

If we assume that effective elevation angle communication link is grater than 5°, the proposed system can cover whole over the Earth surface except for the area that is defined by the instantaneous orbit angular momentum direction points on the Earth surface and 6° away from that points in angular distance as shown in Fig. 2. Therefore, 12-degree zone where communication link with the

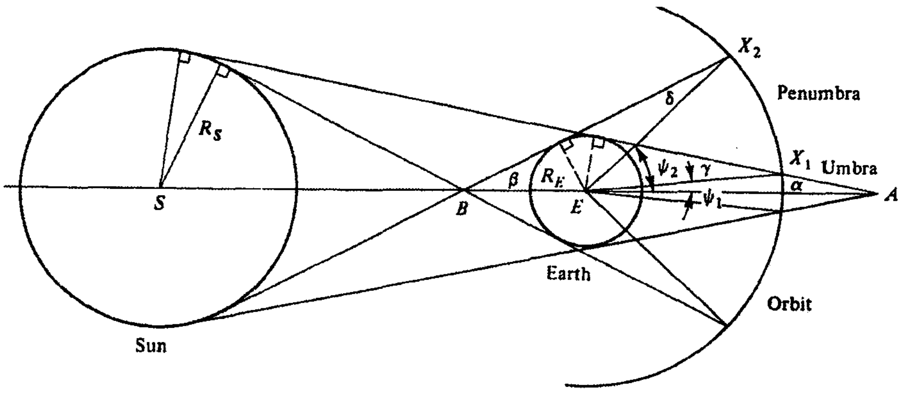

Figure 4. Eclipse geometry: umbra and penumbra.

proposed system is not possible varies between 61.4° and 71.7° for both hemispheres. Geostationary orbit satellites can cover ±76° in latitude with the above assumption. The proposed system can cover most of area where geostationary communications satellites cannot cover. Figure 3 shows three satellites of the proposed communications system and their ground coverage. The ellipses are areas, which cannot cover the proposed system and they are moving along the moon orbit poles as the centers of the ellipses.

2.4 Eclipse Analysis

For eclipse analysis, we assume that satellites on the proposed orbit experience the same eclipses due to the Earth as the Moon does. Different from geostationary satellite, the proposed satellites may have less frequent eclipses. Full eclipse may happen around 17 year-period and partial eclipses are occurred a few times in a year. From definitions in Fig. 4 and following simple calculation, eclipse duration times for partial and full eclipses due to the Earth and Moon.

$$\Psi_1 = \sin^{-1}\{R_E/(R_E+h)\} - \sin^{-1}\{(R_S - R_E)/\rho\} \qquad (1)$$

$$\Psi_2 = \sin^{-1}\{R_E/(R_E+h)\} + \sin^{-1}\{(R_S + R_E)/\rho\} \qquad (2)$$

where h is height of satellite, R_E is the radius of the Earth, R_S is the radius of the Sun, ρ is equal to one AU (Astronomical Unit) or 1.49598×10^8 km. From equations (1) and (2), half angles of umbra and penumura are 0.671° and 1.206°. The maximum eclipse duration time is 4.40 hours and umbra passage time is 2.44 hours. Also, eclipses due to the Moon may be occurred for 1.9 hours by penumbra only. Eclipses for the system are not occurred frequently but if it is occurred, duration time is longer than geostationary orbit satellites which maximum eclipse duration time is 1.2 hours (Pritchard et al. 1993).

3. SATELLITE CONTROL

3.1 Station Keeping Control

The major perturbation is due to Sun attraction force. The perturbation affects are more on in-plane motion than on out-of-plane motion. If we assume station keeping control box as 0.05° × 0.05° , then, the real dimension of control box is 350 km by 350 km. To keep satellite inside the control box, orbit determination using ranging will be required and the corresponding orbit correction maneuver are required. For these maneuvers, ion propulsion system will be effective means due to its high specific impulse and less force compared to chemical thrusters. For the satellite in L_3, more tight station keeping may be required due to instability of the L_3 point. Instability of satellite is increased when it is away from the L_3 point.

3.2 Satellite Pointing Accuracy and Control

Three-axis stabilized attitude control system is recommended for the system. If the main lobe for RF is assumed as 3 degrees, then pointing accuracy to cover the whole over Earth is around 0.5 degrees. The major disturbance for the system may be caused by solar radiation torque. To maintain the required pointing accuracy, reaction wheels can be used and momentum dumping to remove accumulated momentum can be performed by using thrusters or fins to induce torque.

4. COMMUNICATIONS

4.1 Delays

The communication issues for the proposed system give lots of problems to solve. The first is very long time delay, which is about 2.6 seconds. Geostationary communications satellite has just 0.24 seconds, which is detectable to common people during international calls. The special handling of this delay is required to overcome this long delay time. Due to this delay, voice communication service may not be possible. Instead, data communications and direct broadcasting service are proper for the proposed system.

4.2 RF Power Attenuation

The second is long distance which make RF power generated by communications satellite 100 times less than that by geostationary satellite. Arithmetically, we need 100 times powerful transponder than geostationary communications satellite. Otherwise, we may need larger receiving antenna, which is required for the service. To compare power transfer from a transmitting antenna to a receiving antenna, we calculated transfer power for geostationary satellite and the proposed satellite with 10 W transmitted power, 42.5 dB gain for ground antenna, and 30 dB for satellite antenna as follows (Agrawal 1986)

Received Power (geostationary) = 10 + 42.5 + 30 - 196.4 (path loss for 4 GHz) = -113 dBW
Received Power (proposed) = 10 + 42.5 + 30 - 216 (path loss for 4 GHz) = -133 dBW

To compromise path loss with respect to the geostationary, 20 W more power for transmitter is required for the equivalent intensity of RF signal from above simple calculations. In addition, we need to take into account rain attenuation for the worst case such as 5° elevation angle and very heavy rain as 16 mm/h. Then, we need more power as 5 W. If we choose frequency band as 30 GHz, then 200 dBW is required more for the extreme condition set above. By the way, rain attenuation is the same condition with the geostationary communication system.

4.3 RF Interferences

The third is frequency interference. Under the ITU regulation, all of satellite communications should not interfere other communications satellite. If the proposed system uses the same frequency to the geostationary communications satellite, there is some possibility to interfere other communications satellites. To avoid this, the channel switching onboard or usage of high frequency band is needed. Considering power attenuation, we have dilemma for choosing frequency. High frequency communication service has some trouble for tropical rainy area (Pritchard et al. 1993) due to severe rain attenuation. If we choose low frequency, it cannot cover various services such as multimedia that requires wider bandwidth. Therefore, the proposed system should use high frequency and low frequency service at the same time to compromise each other.

5. GROUND STATIONS

To control the proposed communication system, we may need three ground stations, which can track the satellites. The locus of a satellite is almost the same as the Moon with different phases. Therefore, loci of satellites are deterministic if the satellites are maintained their nominal orbits. Tracking satellites is quite simple for the system. Orbit determinations for the satellites are very important to perform station keeping of them. For this, special ranging tone may be required for more accurate orbit determination. Different from geostationary communication system, customer for the proposed service need tracking antenna instead fixed one. But tracking system may be simple and deterministic. Self-contained driving program can handle tracking problem if the location of antenna to be installed is provided one time. EME people already have antennal tracking program for their activities, which has been proven by real operation. Also, we need to take into account switching over from one satellite to another when the one is set. There is service disconnection momentarily without redundant antenna.

6. CONCLUSIONS AND RECOMMENDATIONS

New satellite communications system placed in Lagrange point such as L_3, L_4, and L_5 is proposed and discussed. This system has many limitations to provide commercial services but it is still worth to be considered as new resource to use for our future. Despites all of disadvantages described in the paper, it can cover more area than geostationary satellite system and requires less efforts to maintain their orbit except for the satellite in L_3 point. But, we have many problems to solve for this system such as long time delay, large path loss, RF interferences, ground tracking, and so on. If this system is combined to high frequency band, it can be global infra for multimedia broadcasting services and gateways for mass data exchanges, which are not real-time critical. Also, there is some possibility to provide early detection of asteroid approach and solar magnetic storm if the corresponding detection sensors are equipped. Additionally, this system can be used for relay communications of deep space mission spacecraft.

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