New Aspects of Hybrid Satellite Orbits (HSO) Constellations for Global Coverage of Mobile Satellite Communications (MSC)

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Abstract: In this paper are presented specific designs and configurations of different Hybrid Satellite Orbits (HSO) as platform for development of more reliable and cost effective satellite constellations for global coverage. The HSO constellation can be configured by several types of combinations between existing orbital solutions, such as an integration of GEO (Geostationary Earth Orbit) with HEO (Highly Elliptical Orbit), PEO (Polar Earth Orbit) or LEO (Low Earth Orbit) constellations, and integration of MEO (Medium Earth Orbit) with HEO or LEO. Namely, any of these combinations can provide better global coverage for Northern and Southern Hemispheres, including both Polar Regions. In this context will be introduced five hybrid constellation systems, which are currently using or developing for MSS (Mobile Satellite Systems) communication, distress alerting, safety and security and navigation systems. These HSO constellations can serve for Fixed Satellite Service (FSS) as well.

Keywords: GEO/HEO, GEO/PEO-LEO, MEO/LEO

I. INTRODUCTION

Communication satellites are artificial platforms placed in space for the purpose of communication, navigation, determination, tracking and other MSS and FSS solutions. Modern communications satellites use a variety of orbits including Geostationary Earth Orbit (GEO), Medium Earth Orbit (MEO), Leo Earth Orbit (LEO), Polar Earth Orbit (PEO), Geosynchronous Inclined Orbits (GIO), Highly Elliptical Orbit (HEO) and their integration.

For fixed point-to-point services, communications satellites provide a microwave radio technology complementary to that of communication cables. They are also used for mobile applications such as communications to ships, land vehicles (road and rail), aircraft and hand-held terminals. In addition satellites are providing TV broadcast, broadband, multimedia and Internet for both mobile and fixed applications. Thus, all these satellite services need reliable transmission systems and efficient global coverage. Sometimes one satellite orbit is not able to provide global coverage, so in such a way will be necessary to realize their integrations.

The hybrid satellite constellation today can be configured by several types of combinations between existing orbital solutions such as an integration of GEO with HEO, PEO or LEO satellite constellations. The next hybrid satellite constellation can be integration of MEO with HEO or LEO satellite constellations. Namely, any of these combinations can provide better global coverage for Northern and Southern Hemispheres, including both Polar Regions.
In this context will be introduced shortly five hybrid constellation systems, which are currently using or developing for Mobile Satellite Communications (MSC), distress alerting, emergency, safety and security and navigation systems.

II. COMBINATION OF GEO AND HEO CONSTELLATIONS

A GEO has a circular orbit in the equatorial plane with an orbital period equal to the rotation of the Earth of 1 sidereal day, which is achieved with an orbital radius of 66,107 (Equatorial) Earth Radii, or an orbital height of 35,786 km. Otherwise, a satellite in a GEO, such as Inmarsat, will appear fixed above the surface of the Earth, and remain in a stationary position relative to the Earth itself. Theoretically, this orbit is with zero inclination and track as a point but in practice, the orbit has small non-zero values for inclination and eccentricity, causing the satellite to trace out a small figure eight in the sky.

The footprint or service area of a GEO satellite covers almost 1/3 of the Earth’s surface or 120° in longitude direction and up to 75°–78° latitude North and South of the Equator but cannot cover both Polar Regions. In such a way, near-global coverage can be achieved with a minimum of three satellites in orbit moved apart by 120°, although the best solution is to employ four GEO satellites for better overlapping. This type of orbit is essentially used for commercial communication services for both FSS and MSS with the following advantages: The huge problem of GEO coverage is that cannot provide coverage of both polar areas and in such a way needs integration with other satellite orbits able to provide such coverage.

The HEO configuration in contrary to the GEO configuration is projected to cover landmasses of Northern Hemisphere and also the Polar Regions for both MSS and FSS. The HEO configuration was chosen by the Soviet Space Authorities for the Molniya and Tundra system in order to facilitate launching from their territory and ensure coverage throughout the entire former USSR (Russia) territory [1, 2, 3].

Examples of HEO systems are Molniya, Tundra, Loopus, Archimedes and Borealis of the Ellipso system. The Borealis system is a part of Ellipso hybrid constellation, which has to be presented as an HSO constellation. The HEO constellation turned for 180° will be able to cover territories of Southern Hemisphere. The development of MSS solutions is very important for establishment more cost effective, reliable and sustainable networks with MES (Mobile Earth Stations), such as vessels, road vehicles, trains and aircraft, including for rural areas and remote terminals. The project of integrated MSS communication system, called Marathon includes five GEO Arcos-type satellites and four Mayak-type satellites in a HEO, as well as a ground segment that is composed of base stations and terminals installed at fixed or mobile users premises.
Thus, the combination of GEO (Inmarsat) and HEO (Molniya) satellite constellations makes it possible to render MSS services, including those at high latitudes and in the both polar areas, this is especially important for Russia, with its vast northern Eurasian territories and to provide the most reliable MSS between the territories of the Western and Eastern Hemispheres. Otherwise, the hybrid constellation with apogees of HEO satellites permanently situated above the Northern hemisphere can be useful as well as for the Alaska, Greenland and Northern territory of Canada, see Figure 1. The similar hybrid constellation with two HEO satellites can be configured for complete coverage of Southern Hemisphere with apogees on opposite side as shown in the same figure [2, 3, 4].

III. COMBINATION OF GEO AND PEO CONSTELLATIONS

This current combination of orbits has been developed by the efforts of the Cospas-Sarsat, with the assistance of IMO, ITU, Inmarsat and other international and regional contributors. The Cospas-Sarsat space segment is a combination of three GEO operational satellites of the subsystem called GEOSAR (GEO Search and Rescue) and four PEO operational satellites of the subsystem called LEOSAR (LEO Search and Rescue).

The GEOSAR employs one satellite type of Indian INSAT-2A and two US GOES type GOES-E and GOES-W, while the LEOSAR configuration has two satellites supplied by the Russian Cospas (Nadezhda) and two by the US Sarsat (NOAA). Otherwise, the GEOSAR project in the future has to include the European MSC (Meteosat Second Generation) and two Russian Luch-M spacecraft. This system is responsible for providing distress alert of satellite beacons: Emergency Position Indicating Radio Beacons (EPIRB) for Maritime, Personal Locator Beacons (PLB) for Land, and Emergency Locator Transmitter (ELT) for Aeronautical applications, which helps SAR forces on-scene determinations, see Figure 2. In addition can be included Chinese satellite FY-2 and Japanese GI satellite.

The PEO constellation is a synonym for providing coverage of both Polar Regions for different types of meteorological observation, mobile satellite communication and determination. Namely, a satellite in this orbit travels its course over the geographical North and South Poles and will effectively follow a line of any longitude. The PEO constellation is a synonym for providing coverage of both Polar Regions for different types of meteorological observation, mobile satellite communication and determination. Namely, a satellite in this orbit travels its course over the geographical North and South Poles and will effectively follow a line of any longitude [3, 4, 5].
Certainly, this orbit may be virtually circular or elliptical depending upon requirements of the program and is inclined at about 90° to the equatorial plane, covering both poles. The PEO satellites moves in space over a number of orbits determined by its specific orbit line and has to pass over any given point on the Earth’s surface.

Therefore, a single satellite in a PEO provides in principle coverage to the entire globe, although there are long periods during which the satellite is out of view of a particular ground station. Accessibility can of course be improved by deploying more than one satellite in different orbital planes. If, for instance, two such satellite orbits are spaced at 90° to each other, the time between satellites passes over any given point will be halved. The PEO satellite constellation is suitable to provide LEOSAR service for Cospas-Sarsat applications, but has a problem to provide reliable MSC, because the satellite is in view of a specific point on the Earth’s surface for only a short period of time.

Any complex steerable ground antenna systems would also need to follow the satellite as it passes overhead. At any rate, this satellite orbit may well be acceptable for a processing store-and-forward type of communications system and for satellite determination and navigation systems, but not for high-speed transmissions. To solve this technical problem of PEO with GEO constellation the next proposed GEO and LEO integration would be more suitable for MSS and FSS communications applications [2, 5, 6, 7].

IV. COMBINATION OF GEO AND LEO CONSTELLATIONS

Celestri is the Motorola company trademark name for a proposed GEO and LEO satellite hybrid network, shown in Figure 3. The network will combine 9 GEO and 63 LEO satellites in 7 planes with Earth-based control equipment and will provide interfaces to existing telecommunication infrastructures, Internet and corporate and personal networks. This system will offer a 64 Kb/s voice circuit from anywhere in the world. This satellite network architecture is not limited to fixed sized transmission channels but permits dynamic bandwidth assignment based on mobile application demand. Business users will benefit by Celestri’s ability to offer remote access to LAN infrastructures [2, 5].

V. COMBINATION OF MEO AND HEO CONSTELLATIONS

The new proposed MSS Ellipso is developing in combination with an initial complement of seven Concordia satellites deployed in a circular equatorial MEO at an altitude of 8,050 km and ten Borealis satellites in two HEO planes inclined at 116.6°, shown in Figure 4. The Ellipso constellation has apogees of 7,605 km permanently situated above the Northern Hemisphere and perigees of 633 km and a three-hour orbital period.
This combination of two constellations would provide coverage of the entire Northern Hemisphere including North Pole areas and part of the Southern Hemisphere up to 50° latitude South. In such a way, it will be provided coverage for aircraft flying over North Pole.

Thus, the HEO satellites can spend a greater proportion of their orbital periods over the northern latitudes and, together with the MEO constellation; the Ellipso hybrid system will provide voice, data and Fax communication and navigation determination services to areas with large landmasses, enormous populations with a large density of users and potentially widespread markets. This system is also planned to cooperate with the terrestrial PSTN and other services. The similar constellation with apogees of HEO satellites permanently situated above the Southern Hemisphere can be configured for complete coverage of Southern Hemisphere.

The MEO satellite constellations, known also as Intermediate Circular Orbits (ICO), are circular orbits located at an altitude of around 10,000 to 20,000 km between the Van Allen Belts.

The MEO satellites are operated in a similar way to Big LEO systems providing global coverage. However, compared to a LEO system a MEO constellation can only be in circular orbit, Doppler effect and handover is less frequent, propagation delay is about 70 ms and free space loss is greater.

The MEO satellites are affected by radiation damages from the Inner Van Allen Belt during the launching period; fewer eclipse cycles means that battery lifetime will be more than 7 years; cosmic radiation is lower, higher average elevation angle from users to satellite minimizes probability of LOS blockage and higher RF output power required for both indoor and handheld terminals.

There is in exploitation a special model of MEO constellation known in practice as Highly Inclined Orbit. This particular orbit is of interest because it has been chosen for existing and proposed GNSS systems such as the US Navstar GPS, Russian GLONASS and the newly developed Galileo.

In such a way, complete implementation of GNSS (GPS and GLONASS) orbit configurations would have 24 satellites in 3 orbital planes equidistant from each other, at an altitude of 20,000 km and at an inclination of 55°.

In comparison with existing GNSS the new Galileo system will have 30 satellites in high MEO of about 28,000 km and at a similar inclination of 56°. At this point, its interest to polar MSC would be the eventual prospect of satellite sharing with navigation services, in a similar fashion to a high PEO with minimum of 3 satellites in the same orbital plane [2, 8, 9, 10].

VI. COMBINATION OF MEO AND LEO CONSTELLATIONS

The Kompomash consortium for space systems in Russia is preparing the pilot project of Gostelest satellite system for MSS, using 24 satellites in MEO and 91 in LEO constellation. The launches of these
two constellations was planned to commence in 2001 to 2004, however this project still has the serious financial problems. Otherwise, this MSS project is provided for future global mobile communications with possibility to cover both pole regions, see Figure 5 [2, 11].

![Figure 5. Combination of MEO and LEO Constellations – Courtesy of Book: by Ilcev [5](image)](image)

VII. CONCLUSION

The HSO constellations are very important for MSS distress, determination and communication solutions for Maritime, Land (Road and Railway) and especially Aeronautical Applications. In fact, the current problem is establishment of reliable Aeronautical satellite communications over both poles and particularly on positions of extremely high latitudes exceeding 75°. The present VHF/HF Aeronautical communication system is not anymore suitable for new recommendations of Safety and Security of Flight and requirements for new CNS (Communications, Navigation and Surveillance) satellite system.

Although various satellite orbits can be used singly or in combination for aeronautical communications, the two constellations are used at present: the Inmarsat GEO and Big LEO of Iridium and Globalstar MSS systems. The coverage of almost one third of the Earth’s surface is provided by a single Inmarsat GEO. A constellation of four such satellites is sufficient to provide direct pilot-to-controller communications over the entire Earth up to about 75-80° North and South. Thus, polar coverage is not available with GEO or MEO satellites, but combination with PEO, LEO and HEO have been proposed to remedy this.

REFERENCES