Implementation of Orbit Constellations for Satellite Distress and Safety Systems (SDSS) of Cospas-Sarsat Network

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Abstract: In this paper is described implementation of different orbit constellation, such as Polar Earth Orbits (PEO), Medium Earth Orbit (MEO) and Geostationary Earth Orbit (GEO) in function of the Satellite Distress and Safety Systems (SDSS) of Cospas-Sarsat networks for all mobile applications. The panel of International Maritime Organization (IMO) together with Inmarsat mobile satellite operator provided technical and economical studies regarding the extension of the GEO satellite system and to cover Polar Regions. This initiative was performed by international Cospas-Sarsat in designing LEO-polar constellation for full Earth coverage. Some important features of a constellation are introduced such as type of polar and other satellites orbits needed for continues coverage in function of combined distress and safety communication solutions for all Mobile Earth Stations (MES) at sea, on the ground and in the air.

Key Words: PEO, MEO, GEO, SDSS, LEOSAR, MEOSAR, GEOSAR, Cospas-Sarsat, MES, LES

1. Introduction

The Cospas-Sarsat Secretariat was established in 1987 at the headquarters of the International Maritime Satellite Organization (Inmarsat) in London. The formal intergovernmental agreement was signed in 1988, thus assuring the long-term continuity of the System, in which three United Nations (UN) agencies were also involved: International Maritime Organization (IMO) for worldwide shipping; International Civil Aviation Organization (ICAO) for worldwide aviation; and International Telecommunication Union (ITU) for radio frequency allocations.

Participation by various other government bodies and industries was also initiated in order to get adequate space segment, equipment standards and new distress beacons approved, manufactured and distributed to the mobile users and more receiving ground stations installed around the world.

The Cospas-Sarsat was established as a joint international satellite-aided SDSS and developed under a Memorandum of Understanding (MoU) among Agencies of the Russia (former-USSR), USA, Canada and France, signed early in 1979. Following the successful evaluation phase started in September 1982, a second MoU was signed on 5 October 1984 by the Canadian Department of National Defense (DND), the Centre National d'Etudes Spatiales (CNES) of France, the Russian (former-USSR) Ministry of the Merchant Marine (MORFLOT) the US National Oceanic and Atmospheric Administration (NOAA), so system was declared operational in 1985.

On 1 July 1988, the four states providing the PEO space segment signed the International Cospas-Sarsat Program Agreement known as LEOSAR, which ensures the continuity of the System and its availability to all states on a non-discriminatory basis. Otherwise, a number of other states, non-parties to the agreement, have also associated them with the program and participate in the operation and the management of the system, see the first Cospas-Sarsat emblem in the **Figure 1.**

In 1985 Cospas-Sarsat also started evaluating the use of GEO satellites as an enhancement to the PEO satellite constellation and to provide almost immediate alerts, with identification, for 406 MHz GEOSAR beacons. The USA, Russia European Commission (EC) and European Space Agency (EC/ESA) in 2000 have announced their plans to include 406 MHz MEOSAR repeater instruments on their respective constellations of Medium Earth Orbit (MEO) **[1, 2, 3]**.

Figure 1. Cospas-Sarsat Emblem – Courtesy of Book: by SNES **[2]**

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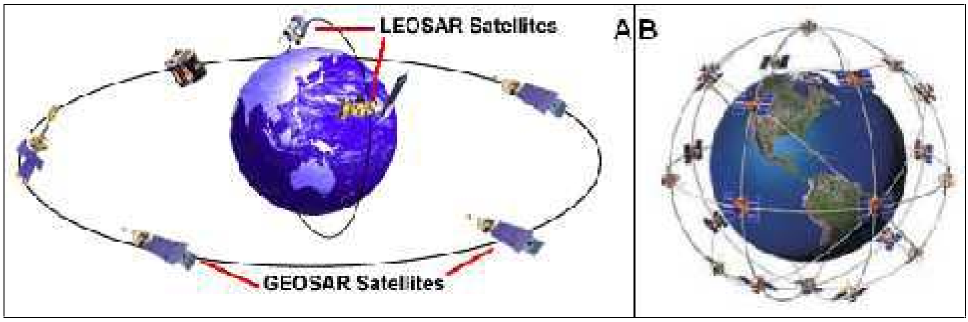

Figure 2. Cospas-Sarsat LEOSAR and GEOSAR Constellation – Courtesy of Manual: by ALRS **[4]**

2. LEOSAR Orbits

The LEOSAR constellation is first generation of Cospas-Sarsat network that includes six PEO in LEO orbit satellites in three orbital planes, which COSPAS and SARSAT PEO orbits are shown in **Figure 2A.** Their altitude is around 850 km with an inclination of 99^o from the equator. The LEO satellite complete an orbit in about 100 minutes, with each providing global coverage for 406 MHz distress signals about twice a day at equator, but every 100 minutes at the poles. Each LEOSAR spacecraft, usually a weather satellite, carries an onboard receiver that detects signals from activated beacons as the satellite passes overhead. The PEO satellites are affected by Doppler Effect.
The US, Canadian and French SARSAT payload contains:
1. Search and Rescue Repeater (SARR) is able to transpose and repeat to the ground in real time the signal transmitted by distress beacons, while the processing is then done on the ground;
2. Search and Rescue Processor (SARP) is able to detect, demodulate and measure Frequency pf Arrival (FOA) of the received signals. All the data are stored in the internal memory until the visibility of a ground station where the data can be downloaded. The SARP is able to process three distress signals in parallel. The main advantage of the SARP is that it does not require acontinuous ground visibility, as it may transmit its stored data to any Local User Terminal (LUT) on the ground;
3. SARR Transponder is fully redundant and self-contained with its own power supply and TT&C;
4. The SARP Receiver Processor processes the message signals transmitted by the 406.025 MHz distress satellite beacons; and
5. SARSAT Antenna System is providing four antenna, which includes two outer quadrifilar used for the 121.5 and 243 MHz Rx.
The Russian COSPAS satellite repeater contains the components with the same functions such as: UHF 406.025 MHz Band Receiver-Processor; Format Encoder; UHF 1544.5 MHz Band Transmitter and CPSPAS Antenna System.
Russia deployed two new LEO COSPAS satellites placed in near-polar orbits at 1,000 km altitude equipped with SAR instrumentation at 406 MHz. The USA deployed two NOAA meteorological satellites of the SARSAT system placed in sun-synchronous, near-polar orbits at about 850 km altitude and equipped with SAR instrumentation at 406 MHz, supplied by Canada and France. Each PEO satellite makes a complete orbit of the Earth around the poles in about 100 min, traveling at a velocity of 7 km/s **[1, 4, 5]**.

3. GEOSAR and MEOSAR Orbits

As stated earlier, Cospas-Sarsat system is providing two additional satellite orbits.
The GEOSAR satellite orbit is second generation of Cospas-Sarsat that contains three operational plus three spare GEO satellites, namely Indian Insat-2A and the US Geostationary Operational Environmental Satellite (GOES), which also are caring the meteorological payloads, illustrated in **Figure 2A.** The basic features of the GEOSAR system is that carry 406 MHz repeaters onboard GEO satellites and interface the associated ground facilities called GEOLUT. The GEOLUT stations have the capability to detect the transmissions from Cospas-Sarsat type approved 406 MHz beacons relayed by the GEO. A single GEO satellite provides GEOSAR uplink coverage of about one-third of the globe, except for the Polar Regions. Three GEOSAR satellites equally spaced in longitude plane can provide continuous coverage of all areas of the globe between approximately 70^o N and 70^o S. As a GEOSAR satellite remains fixed relative to the Earth, there is no Doppler effect on the Rx RF and this positioning technique cannot be used to locate the distress beacon. To provide rescuers with beacon position information, such information must be either acquired by the beacon through an internal or an external navigation receiver and encoded in the beacon message, or derived, with possible delays, from the LEOSAR system.
The third generation of Cospas-Sarsat network is MEOSAR satellite orbit is MEOSAR will consist of SAR transponders aboard 24 Europe's Galileo constellation, 24 Russian GLONASS spacecraft and 24 US GPS satellite networks, which orbit constellation is shown in **Figure 2B.**

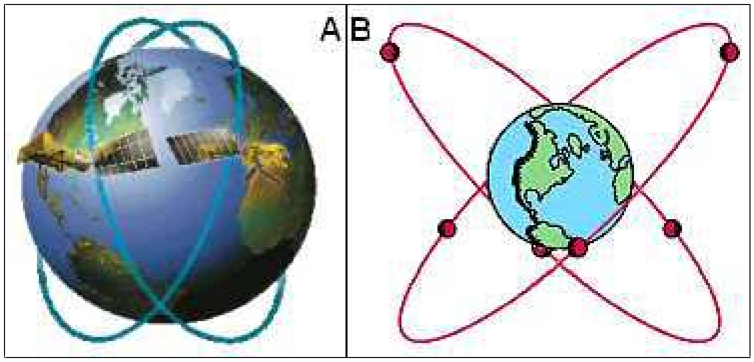

Figure 3. Low and High PEO Satellite Constellations – Courtesy of Book: by Ilcev **[1]**

The MEOSAR assets will report signals from Cospas-Sarsat search and rescue beacons in the 406.0–406.1 MHz band, which will provide via few Land Earth Stations (LES) near-instantaneous detection, identification, and location of 406 MHz beacons. The beacon can transmit coordinates of its position encoded in the alert message (if the position information is available from an on-board GNSS receiver or another source such as a ship's navigation sensors). Or the position can be determined independently by the receiving LUT by analyzing the frequency-difference-of-arrival (related to Doppler-induced variations) and/or the time-difference-of-arrival. It is planned that the MEOSAR system will be able to download information back to the distress radio beacon by encoding "Return Link Service" messages into the Galileo navigation data stream.

The primary missions for the three MEOSAR constellations in total with 72 spacecraft, i.e. the GPS, Galileo and GLONASS, generally referred to as Global Navigation Satellite Systems (GNSS), are positioning, navigation, and timing. As a secondary mission, the SAR payloads have been designed within the constraints imposed by the primary mission payloads. In such a way, the three MEOSAR satellite constellations will use transparent repeater instruments to relay 406 MHz beacon signals, without onboard processing, data storage, or demodulation and remodulation. MEOSAR satellite providers will make their satellite downlinks available internationally for processing by MEOLUT operated by MEOSAR ground segment participants **[1, 6, 7]**.

4. Low and High PEO Constellations

The Low PEO constellation similar to the Low Earth Orbits (LEO) mostly employs both polar and near-polar orbits for communications and navigation utilities. The major problem of this orbit is that with a limited number of low altitude PEO satellites it is impossible to provide reliable and continuous coverage to polar region, because the view of individual PEO spacecraft is relatively small and their transit time is short. As stated above, a particular example of a satellite system that uses this type of orbit is the Cospas-Sarsat SAR network for maritime, land and aeronautical applications. This system uses 8 satellites in 4 near-polar orbits: four US-based Sarsat Low PEO satellite constellations at 860 km orbits, inclined at 99^{o}, which makes them sun-synchronous and four Russian Cospas satellite configurations at 1,000 km orbits, inclined at 82^{o}. However, this orbit was also suitable for the first satellite navigation systems Transit and Cicada, developed by the USA and the former USSR, respectively.

The scenario of Low PEO constellation with two satellites in two orbital planes cannot provide reliable coverage and LEOSAR service, which orbits are illustrated in **Figure 2A.** Because the time for a single satellite orbit is low, less then two hours and a different section of the polar region is covered at each orbit due to Earth rotation, this drawback is somewhat offset. For a given number of satellites, preferably about eight PEO, it is possible to optimize the constellation that maximizes total coverage, then to improve satellite handover or minimize waiting time between transits. However, Low PEO is attractive for mobile determination, tracking and distress communications for two reasons:

Firstly, the transmission path loss is relatively low, allowing reliable communication with a low powered satellite beacon and PEO spacecraft. An altitude of about 1,000 km is the upper limit for good reception of signals at 243/406 MHz sent from emergency distress beacons.

Secondly, the Doppler shift is high, approximately 30 kHz at 1.6 GHz, allowing accurate location of the distress transmitter. On the other hand, there are several significant disadvantages.

Thus, constellation with two only satellites in PEO cannot provide continuous coverage unless there is simultaneous communication between a distress buoy and a ground terminal because of the small footprint of each individual satellite. Accordingly, message storage and retransmission of distress messages on-board processing would be necessarily adding to the distress alert delay time and also to satellite mass and complexity.

The short visibility period during a transit and the uneconomic need for large numbers of satellites for continuous network coverage makes Low PEO satellites unattractive for mobile communications considerations. If this orbit configured well as an economic solution for distress coverage in polar regions to be used for communications purposes, users would have to operate with the following four restrictions: **(1)** Only burst mode, low speed non-simultaneous data communication would be possible; **(2)** Transmission time and/or bit rate would be limited by satellite message storage capability; **(3)** Replies to the message would require an interrogation or polling system from the MES expecting a reply; **(4)** Depending on the PEO constellation and MES position, a reply could take some hours.

The High PEO constellation, shown in **Figure 2B**, would consist of three satellites separated by 120^{o} in the same circular orbit of 12,000 km altitude, geometrically similar to the GEO and as orbit similar to MEO configuration. Namely, this orbit as a better solution than Low PEO configuration provides continuous coverage to all Polar Regions above 59^{o} latitude. Thus, six satellites in two orbital planes of three satellites each provide continuous and real global coverage, which GEO cannot obtain. By comparison with Low PEO transmission path losses are higher at an altitude of 12,000 km but not to the extent that a distress satellite beacon need be especially high powered to transmit successfully to a High PEO satellite. Reception of the Cospas-Sarsat existing two very low-powered alert and distress frequencies will be quite interfered, but can be quite successful.

The Doppler shift is lower (about 10 kHz at 1.6 GHz), not allowing very accurate area location of the distress transmitters. Single high latitude LES in both Polar Regions allows reception with no delay of all distress messages transmitted from above 59^{o} latitude. Using two polar LES (LUT) terminals located at high latitude with continuous visibility of at least one of the three satellites and linked to the Inmarsat LES, can offer a full range of near continuous links to the Polar Regions.

Many of these PEO communication limitations would be removed if a system of inter-satellite links, possibly in addition to inter-GEO or HEO satellite infrastructure, were used to provide an extended near-continuous, simultaneous two-way communication system.

The complexity and likely cost of such system would almost certainly not be justified by the expected very low level of polar communication traffic. Accordingly, in considering the possible integration of PEO and GEO for communication purposes, it will necessary to determine the additional requirements and constraints arising from polar operation and LES terminals.

For example, a constellation of eight Low PEO would require about six LES worldwide for polar coverage assuming data storing and forwarding techniques, where a High PEO would require a minimum of two LES located in North and South polar latitudes for continuous polar coverage with simultaneous two-way communications. This is not all, it would be necessary to obtain reliable terrestrial links between the LES of each system, as well as inter-satellite links between the PEO and GEO satellites **[1, 6, 8]**.

4. Conclusion

The study that has been performed indicates that there are several top technical and technology solutions to the problem of providing coverage of the Polar Regions for mobile communications, determination, surveillance, distress and safety applications. The need of reliable distress and safety solutions for maritime and aeronautical applications is obvious and the cost of network is insignificant, although the real communication requirements for these critical areas exist, they are difficult to quantify.

The other existing HEO, GIO, MEO, LEO and their orbits combinations can provide much better navigation and communication facilities for Polar Regions, so it is unlikely that the introduction of an PEO communication satellite system alone could ever be justified commercially.

On the other hand, the practical and operational non-commercial Cospas-Sarsat PEO constellation is recently well established for SDSS, with its three LEOSAR, MEOSAR and GEOSAR subsystems. Low cost system providing a limited, reliable polar communication facility, in conjunction with an effective emergency, distress and safety capability and possibly other services may well be feasible if a means is found to finance and operate such PEO satellite systems.

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