

Satellite Constellation Design Studies for Missile Early Warning



Devi Prasad Panda, Kalpana Bandi, PSR Srinivasa Sastry and K. Rambabu

Abstract Missile early warning system enables the defence services to detect the missile launches. IR imaging sensors on satellite platform can detect vehicle plumes from the launcher, and it can send the data to the ground station. Orbit design and constellation study analysis of missile early warning system is carried out to get the global coverage. The constellation consists of three or four GEO stationary satellites, four highly elliptical orbit (HEO) satellite orbits in two planes to cover higher latitudes on earth and low earth orbit satellites to cover the specific area of interest to track the launcher in middle stage. Number of satellites in the constellation estimated and optimized to cover area of interest. GEO satellite, HEO satellite coverage analysis and LEO satellite orbit parameters analysed. The complete scenario of missile defence scheme is presented.

Keywords Missile early warning · Satellite early warning system · Space-based missile defence

1 Introduction

Missile defence plays a vital role in national security. Missile defence systems are a type of missile defence intended to shield a country against incoming missiles, such as ICBMs or other ballistic missiles. The USA, Russia, France, India and Israel have the missile defence systems. India has ground-based RADAR capability of missile defence which has certain constraints like limited field of view and less time of reaction due to earth curvature. This limits warning time against an ICBM attack to about 10 min the warning may be even less against ship or sea-launched ballistic missile (SLBMs). The other type of early warning system is IR sensors on satellites.

A satellite can detect a missile almost immediately after launch by detecting the infrared radiation from its rocket plume. Space-based system could provide the

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maximum warning time of about 30 min against ICBMs and 15–20 min against SLBMs. So, space-based missile defence has an advantage that it can detect the launch in initial phases and track the missile and provide the launch trajectory to the control station. The satellites and ground-based RADARs are intended to complement each other. In this scenario, user has more time to respond and initiate counter-attack by activating appropriate means like ship, ground or air-based missile defence system.

Satellite early warning system is developed initially by Russia and USA, but they are not up to the mark to meet the missile defence purpose. US air force entered into a contract with Lockheed Martin to launch satellite early warning system in GEO and HEO altogether seven satellites. In that, HEO satellites are launched as a part of USA-184 and USA 200 in 2006 and 2008, respectively. Two GEO satellites are also launched under this program. As part of the Russian satellite early warning system under EKS program, six satellites will be launched in HEO orbit. First satellite was launched in Tundra orbit on 17th November 2015 under this program.

2 Space-Based Missile Defence

Missile launch has three phases in the trajectory. They are boost phase, mid-course and terminal phase as shown in Fig. 1. The boost phase can be detected by GEO

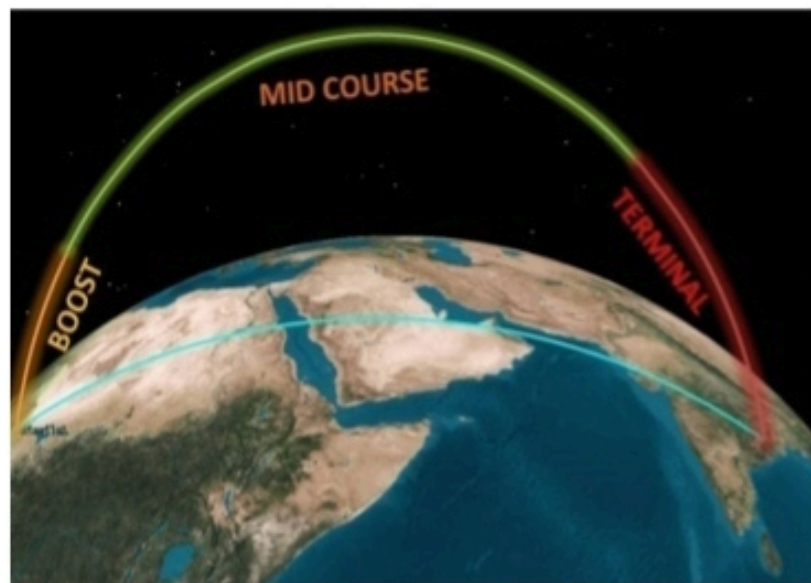


Fig. 1 Missile launch different phases

satellite or HEO satellite as the plumes are at high temperatures. All ground-based missile defence systems always track at terminal phase of the missile leaving very less reaction time. Once the launch is detected by GEO or HEO satellites, the coordinates of launch and trajectory can be computed and transmitted to LEO satellites which can start track the missile in mid-course.

2.1 GEO Stationary Orbit and Coverage

GEO stationary orbit is a circular orbit with a radius of 42,164 km and inclination of 0° . A satellite in such orbit has an orbital period equal to earth rotational period which is one sidereal day (1436 min).

The GEO stationary satellites will cover the entire globe except higher latitudes (greater than 81°). Theoretically, one GEO stationary satellite can cover 42% of earth in one stretch as shown in Fig. 2 with elevation circles around.

2.2 Highly Elliptical Orbit (HEO)

Highly elliptical orbit is an elliptical orbit with a low altitude of perigee (<1000 km) and a high altitude of apogee (36,000 km approx.). These extremely elongated orbits have the advantage of long dwell times at a point in the sky during the approach to, and descent from, apogee. HEO orbits offer visibility over earth polar regions, which most GEO stationary satellites lack. The widely usable orbits like Molniya, Tundra and Super Tundra are classified as HEO.

2.2.1 Molniya Orbit and Coverage

Molniya orbit is with a perigee around 500 km and an apogee around 36,000 km and inclination of 63.4° exactly which is called critical inclination, argument of perigee at 90° or 270° with time period of 12 h. The critical inclination of the orbit fixes the perigee position. The orbit is recurrent with a cycle of one day: the ground track passes through the same point every day as shown in Fig. 3. Satellites in this orbit are better suited for the higher latitudes. The subsatellite point remains approximately fixed for ± 3 h around apogee, as shown in Fig. 4. The characteristics of the Molniya orbit are shown in Table 1.

$$\frac{d\omega}{dt} = \frac{3nj_2R_0^2(4 - 5\sin^2 i)}{4a^2(1 - e^2)^2}$$

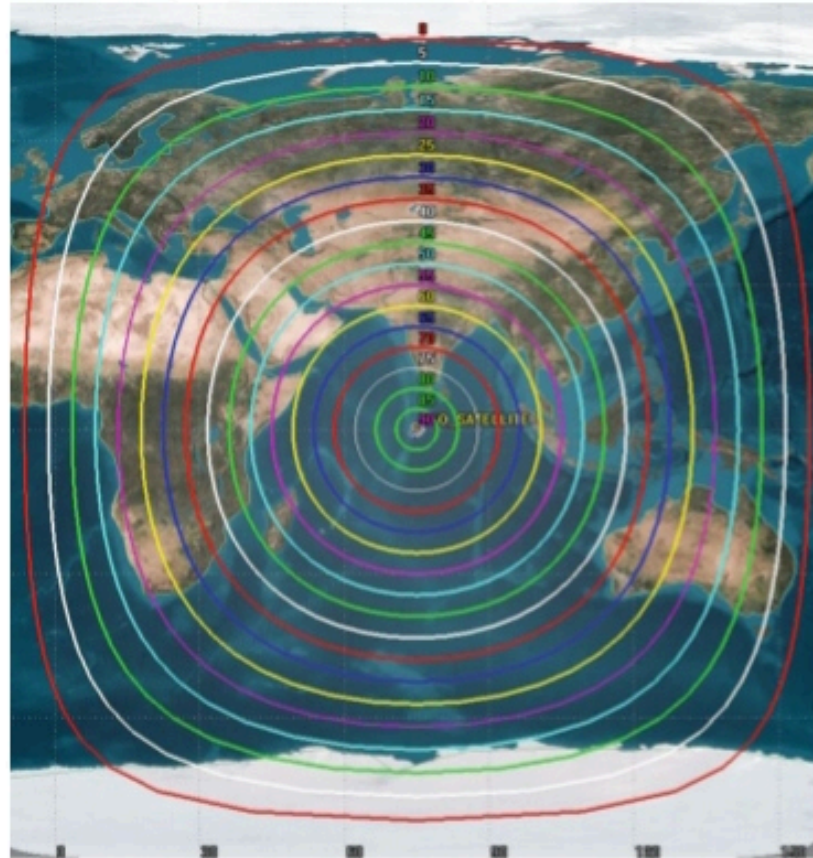


Fig. 2 GEO stationary coverage with elevation circles

where

J_2 2nd order earth oblateness constant ($J_2 = 0.001082$)

a Semi-major axis

e Eccentricity

i Inclination

n Periodicity

R_0 Earth mean radius.

The inclinations of 63.4° and 116.6° solve the above equation, and generally, the former is selected which resulted in frozen perigee.

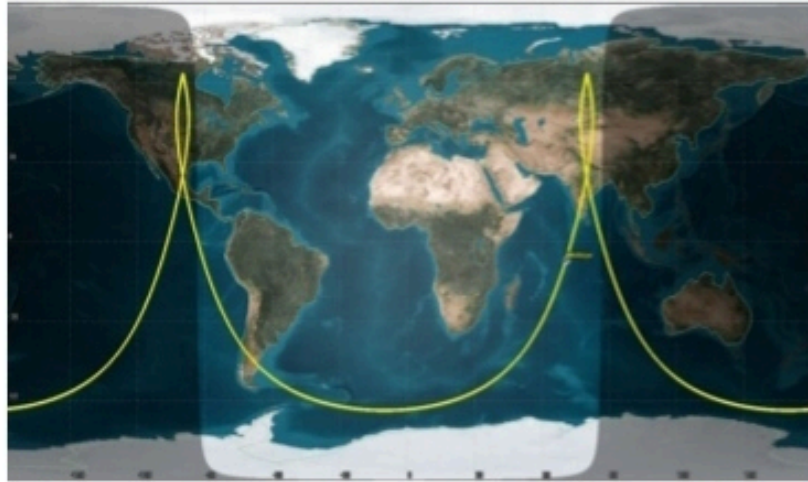


Fig. 3 Recurrent ground track of Molniya orbit



Fig. 4 Satellite subpoint at apogee ± 3 h

Table 1 Molniya orbit parameters

Orbital parameter	Value
Apogee altitude	39,850 km
Perigee altitude	500 km
Inclination	63.4°
Argument of perigee	270°

3 Constellation Design

3.1 GEO Stationary Satellite Constellation

The global coverage is achieved with three satellites in GEO stationary orbit coverage overlap of 0° – 30° elevations can be ensured as shown in Fig. 5. For optimal coverage of Indian subcontinent and neighbouring regions is obtained by appropriate selection of location of two satellites. The third satellite is placed to cover the remaining part of the earth to complete the global coverage at any time. The optimal satellite positions in the constellation are East 15° , East 135° and West 105° with respect to GMT. Specifications of the GEO stationary constellation are summarized in Table 2.

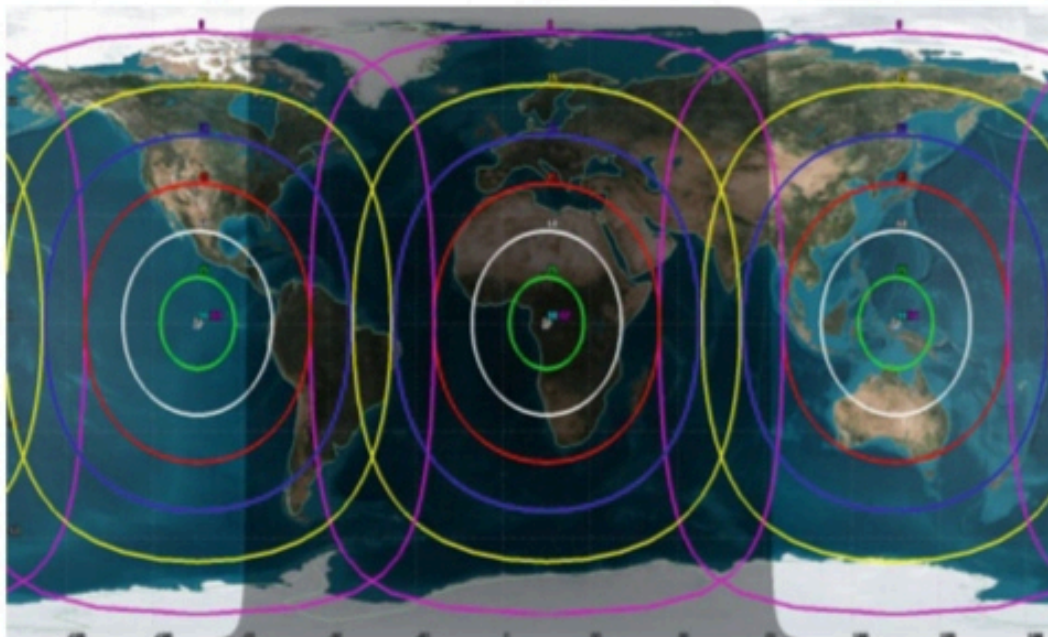


Fig. 5 GEO constellation coverage

Table 2 GEO constellation satellites details

Satellite name	Longitude of ascending node
GEO1	135° (east 135°)
GEO2	15° (east 15°)
GEO3	255° (west 105°)

3.2 Molniya Satellite Constellation

Four Molniya satellites can cover the entire higher latitudes in the northern hemisphere and our area of interest near India and neighbouring countries. One Molniya orbit is selected in such a way that it crosses the apogee over India. In this plane, two satellites are needed with 6 h gap as to have the continuous coverage over India. Other two satellites with RAAN shifted by 180° . As on 21 March 2016, the RAAN values are 79° and 259° . Then, four satellites can cover the entire northern hemisphere any time, as shown in Fig. 6a, b.

3.3 LEO Satellite Constellation Design

The mid-course tracking has to be carried out by the satellite in LEO. Once the launch is detected by GEO or HEO satellite, the coordinates will be sent to both ground station and to the LEO satellites which are able to track the launch. The area of coverage decides the number of satellite required in the constellation. LEO satellites will have very limited coverage area due to its altitude constraint. Our area of interest is about $+55^\circ$ northern latitudes and -45° max southern latitudes.

Constellation design analysis is done based on

- (a) The maximum latitude coverage requirement
- (b) Optimized satellite availability for tracking
- (c) Availability of LEO satellite to the GEO or HEO to send the data to the ground control station.

Orbital parameters and constellation details of LEO satellites are shown in Tables 3 and 4.

4 Missile Early Warning System Concept

Space-based missile early warning system is a two-tier system. Tier 1 consists of space system to track the launch in boost phase and mid-course. Tier 2 consists of ground-based RADARs to track during the terminal phase. Tier 1 further divided into two parts, one is GEO and HEO satellites which will detect the boost phase of launch, and the other is the LEO satellites which track the mid-course of launch as shown in Fig. 7. Complete scenario is shown in the flow chart in Fig. 8.

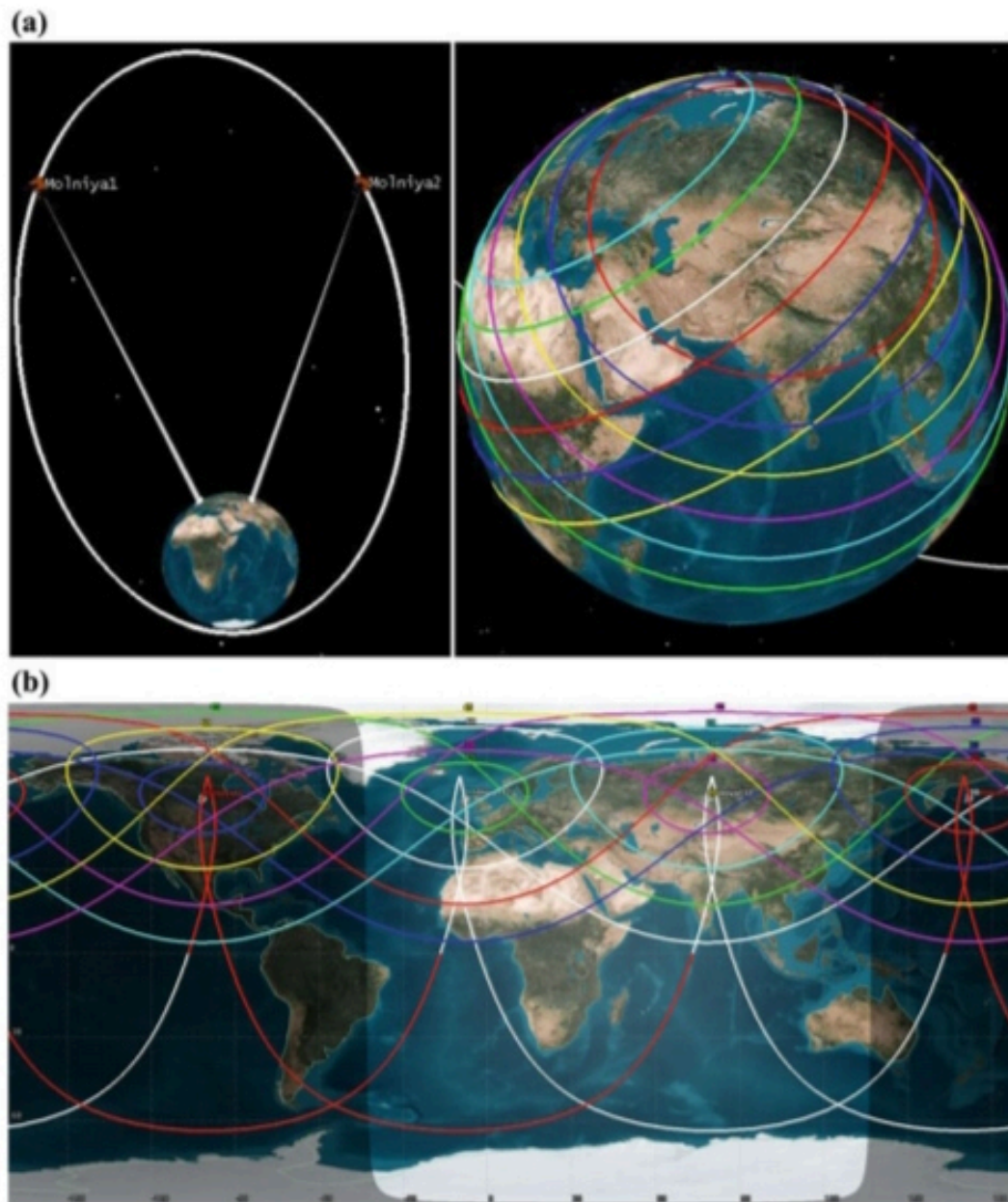


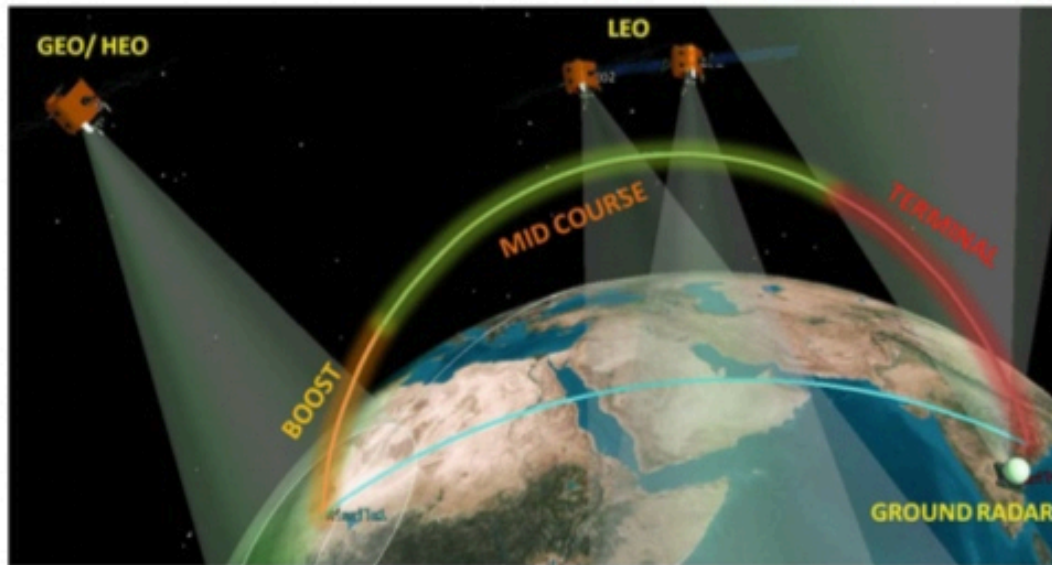
Fig. 6 **a** Two satellites in one Molniya plane and coverage, **b** HEO constellation total coverage on Northern hemisphere of earth

Table 3 Orbit parameters of LEO satellite

Orbit parameter	Value
Altitude	836 km
Repeativity	6 days
Orbit type	Circle
Inclination	55°
Repeativity orbits	85

Table 4 LEO constellation details

Parameter	Value
Number of walker planes	6
Number of satellites per plane	4
RAAN difference per plane	60°
Total satellites	24

**Fig. 7** Missile tracking in different phases with early warning system

4.1 LEO Satellite Visibility to GEO or HEO Studies

LEO satellite visibility studies are done based on geometrical studies only not based on communication link.

Number of LEO satellites availability to different GEO and HEOs are computed at different times and shown in Figs. 9 and 10.

From Figs. 9 and 10, LEO satellite availability to track the missile in mid-course can be arrived. Minimum of eight LEO satellites are always available to track the missile with this constellation. This constellation can track more number of launches at the same time as the LEO satellites availability is more.

4.2 Communication Systems

Any satellite in any constellation (i.e. LEO, GEO, HEO) can communicate over a two data link with any other constellation in addition to the ground station. All GEOs and HEOs are able to communicate each other as well as to ground station as shown in

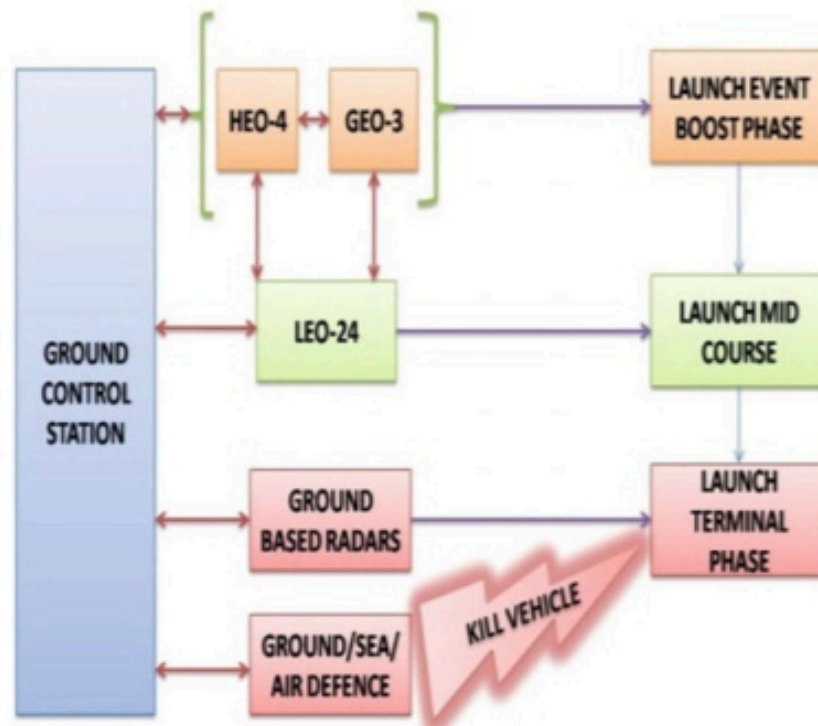


Fig. 8 Flow chart of space-based missile defence

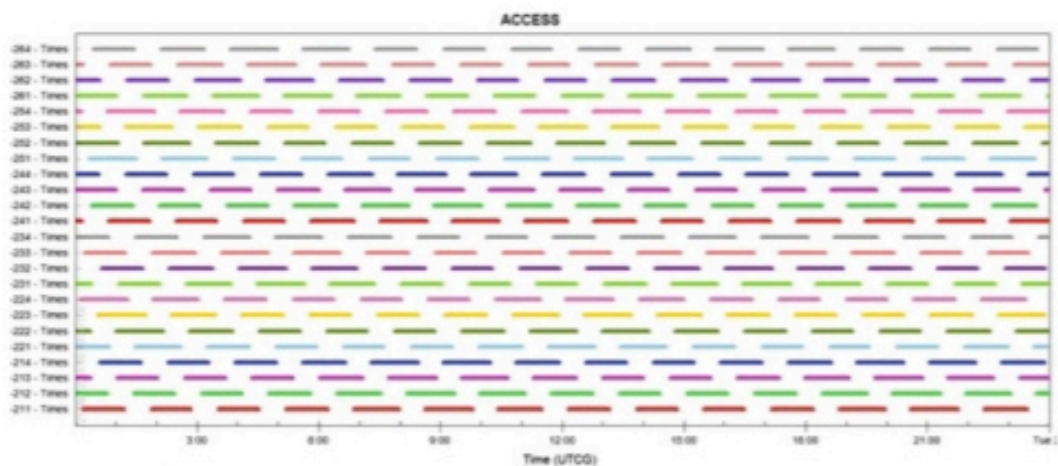


Fig. 9 GEO satellite visibility with LEO satellite

Fig. 11. Then, the ground station will compute the trajectory and alert the appropriate LEO for tracking. The LEO chain will hand over to ground-based tier-2 RADAR systems at appropriate time for activating countermeasures like launch kill vehicle as per the ballistic missile defence plan.

In this paper, we used MATLAB to determine the values of orbit period, Sun angle, Ground station accessibility times and coverage time over area of interest, etc. We also used Systems Tool Kit (STK) version 10.1.

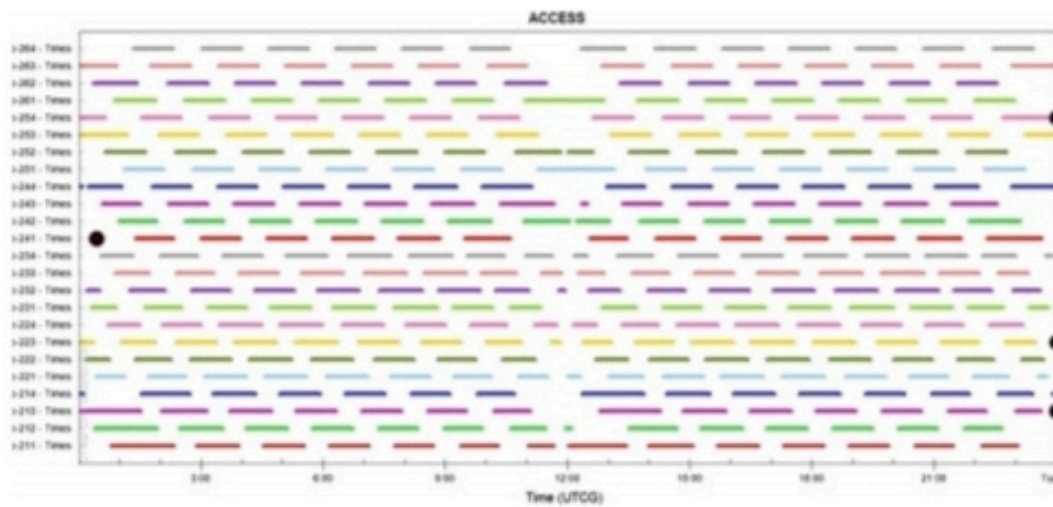


Fig. 10 HEO satellite visibility with LEO satellite

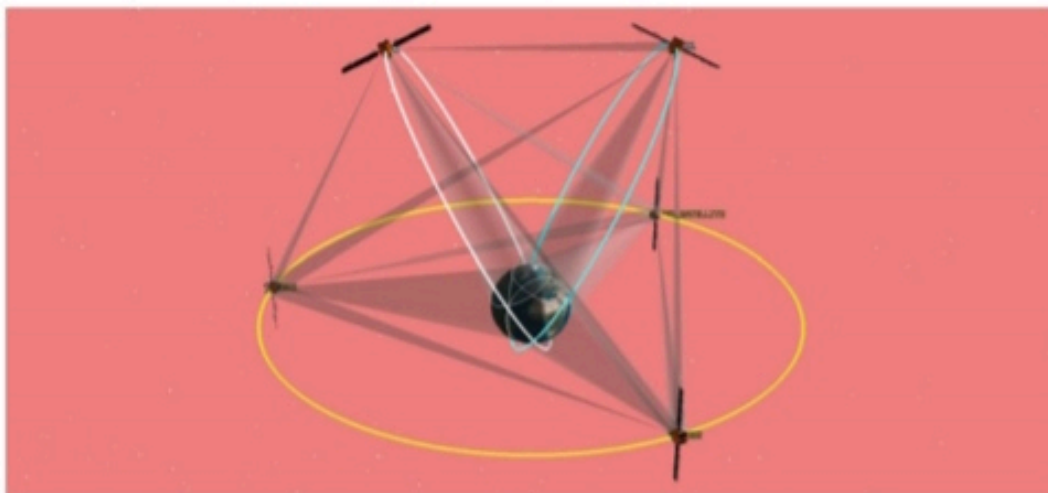


Fig. 11 Communication chain between GEOs and Molniya satellites

5 Conclusions

Missile defence is a growing area of concern across the globe. No nation with proper national security policy can afford to ignore anymore as number of countries entered the game of missiles. The most important issues in missile defence are the global coverage, in-terminable coverage and available reaction time. Three GEO stationary satellites, four Molniya satellites, 24 LEO satellites with IR sensors onboard can provide the capability to detect and track the missile. The studies presented optimal solution to address all above issues, particularly for Indian scenario.