Radio Division

Communication using Medium Earth Orbit (MEO) Satellites

1. Introduction

Telecommunication market is based on a demand and supply of new more and more attractive services. Telecommunication companies develop and offer new reliable broadband multimedia and interactive services for users situated in urban as well as rural and remote areas with or without robust infrastructure or whether they use a small handheld or desktop end terminal. In order to fulfill the ever growing demand of connectivity, satellite systems are also incorporated in global communications systems. The opportunities in the satellite space are mushrooming at an incredible pace in military and defense applications, broadband IP services, and ground- and space-segment products and services. Satellite systems based on their orbital location can be classified as GEO (Geostationary Earth Orbit), MEO (Medium Earth Orbit) or LEO (Low Earth Orbit). Each of these systems has its own application area.

In India, the communication satellites are generally in the GEO orbit, and there are still studies and deliberations on usage of MEO and LEO communication satellites in this field. The Medium Earth Orbit (MEO) offers a greater width of satellite view and a greater proximity to the earth's surface than the geostationary earth orbit. Global positioning systems and ionospheric sounding satellites have already operated in this orbit and the MEO will appeal to satellite missions undertaking Earth observations, communications, positioning, and scientific explorations. This paper explores general characteristics of medium earth orbit satellites (MEO) communication systems, their global deployment examples and their potential low latency applications in various segments.

2.Current satellite communication systems

Three types of satellite-based communications systems are currently being deployed. The fundamental difference between them lies in the altitude at which the satellites orbit the earth.

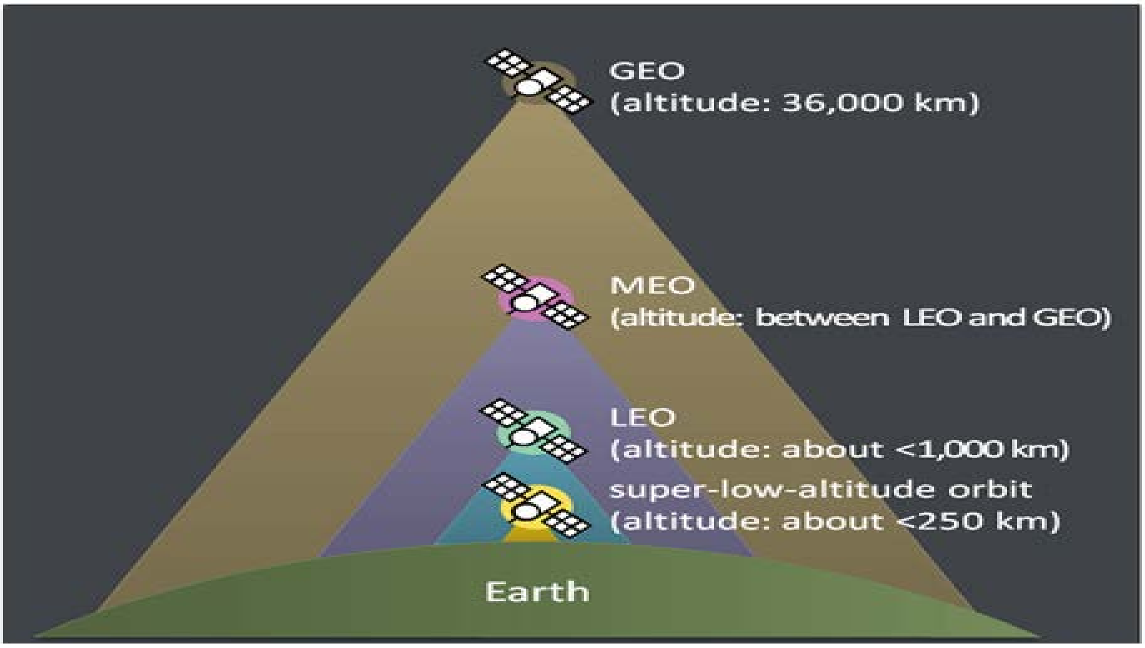
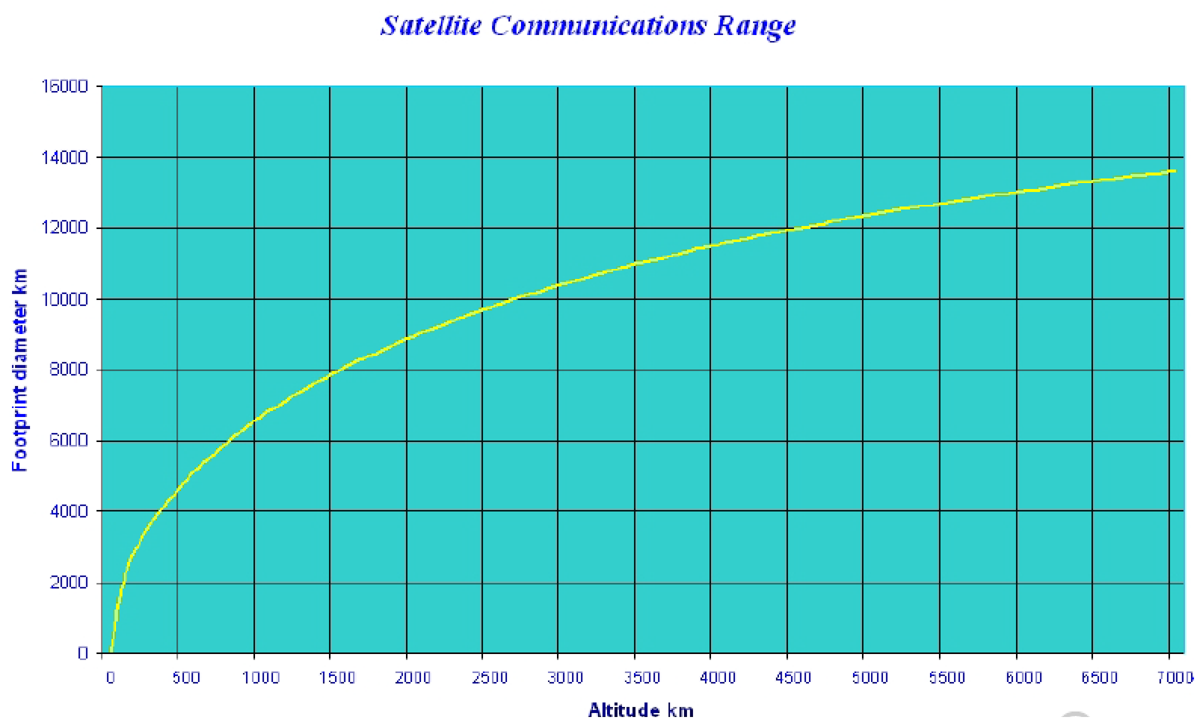


Fig 1. Various orbits under satellite communication systems

GEO: Geostationary satellite systems have few satellites covering earth. Satellites sit at an orbit altitude of about 36,000km and as few as three may be enough to provide global coverage. For many years, communication satellites have been maintained in GEO so that the ground antennas could point to a fixed location. Only three or four satellites are then needed to cover entire world for communications services. To make up for the loss of power over sparsely populated regions due to a fixed footprint, earth stations are rather complex and expensive. Also due to distance the propagation delays are long and may cause echo degrading quality of the signal.

MEO: Medium-earth orbit systems are a compromise between LEO and GEO systems. The altitude of the orbit is about 10,000km for these systems and requires fewer and less complex satellites than the LEO systems. Signal propagation delays are more acceptable than a GEO system and number of satellite networks required are less compared to LEO satellite to cover the area.

LEO: Low earth orbit systems, as their name implies, have the closest proximity orbit to earth. Typically satellites orbit the earth at about 900km. Since they do not have high view angle, to offer adequate global coverage these systems require a large number of satellites (24 to 66). These satellites then must be served by a large number of earth stations, perhaps 200 or more. Another option for these are using satellite cross links which requires many complex onboard processing. Low altitude may also increase the risk of "shadowing" of the signal by vegetation, terrain and buildings, this may cause interruptions in transmission.



The following table compares some of the basic aspects of different types of satellite systems:

Parameter	LEO	MEO	GEO
Satellites Needed	Large (Typically more than 30 for global coverage)	Medium (Typically 10 to 15 for global coverage)	Low (Typically 3 to 4 for global coverage)
Satellite Life	3 to 7 years	10 to 15 years	More than 15 years
Hand-held Terminal	Less complex and possible	Medium complexity	Highly complex
Transmission Delay	<20 ms per hop	100 to 150 ms per hop	>200 ms per hop
Propagation Loss	Low	Medium	High
Network Complexity	Complex	Medium	Simple
Signal Hand-off	Frequent	Minimum	None
Visibility of a Satellite	Short	Medium	Almost always
Broadcast Capability	Poor	Poor	Good

3. Characteristics of non-GSO satellite orbits.

- Low latency or transmission delay
- Higher look angle (especially in high-latitude regions)
- Less path loss or beam spreading
- Easier to achieve high levels of frequency re-use
- Easier to operate to low-power/low-gain ground antennas
- Larger number of satellites to build and operate
- Coverage of areas of minimal traffic (oceans, deserts, jungles, and polar caps)
- Higher launch costs and expensive than GEO systems
- More complicated to deploy and operate – also more expensive TTC&M (Tele-tracking Control and Management)
- Much shorter in-orbit lifetime due to orbital degradation
- Improved look angle to ground receivers
- Improved opportunity for frequency re-use as compared to GEO
- Increased exposure to Van Allen Belt radiation

4. ITU Frequency Ranges, Allocations and Services

- **L-Band**-(1-2 GHz)-Includes allocation for MobileSatellite Services (MSS)
- **S-Band**-(2-4 GHz)-Includes allocation for MSS, Digital Audio Radio Services
- **C-Band** –(4-8 GHz)-Included allocation for Fixed Satellite Service(FSS)
- **Ku-Band**-(12-18 GHz)-Includes allocations for FSS, Broadcast Satellite Service(BSS)

- **Ka-Band-(**17.7-21.2 GHz and 27.5-31 GHz)-Includes allocation for FSS Broadband and inter satellite links

  MSS: Voice and data, remote data telemetry, maritime and aeronautical Communications
  FSS: Video distribution, private networks/vast networks, data broadcasting.

The satellites operating in the lower frequency bands L, S, C bands have low power (EIRP) while those in Ku, Ka, X and V bands have high power and hence provide higher throughputs and enhanced broadband service delivery. Medium Earth orbit satellites (MEO) satellites generally use high frequency range for effective communications.

5. Global MEO deployments

NAVSTAR

In the case of MEO satellites, the constellation of from 8 to about 24 satellites is configured in orbits that are typically 10,000 to 20,000 km above Earth's surface. Because the satellites are higher, fewer satellites are need to cover Earth, but the path loss due to the spreading of the antenna beams means the flux density of the beams is less when they reach the ground. The number of satellites in the constellation depends on not only the altitude but also the particular mission the satellites are designed to perform. Space navigation satellites such as the NAVSTAR Global Positioning Systems (GPS) for instance, requires that a user access four or more satellites to get an accurate fix on location. Thus this constellation, although in are latively high orbit, still has some 24 to 27 operational satellites in order that multiple satellites can be seen at the same time. (See Fig. 2.)

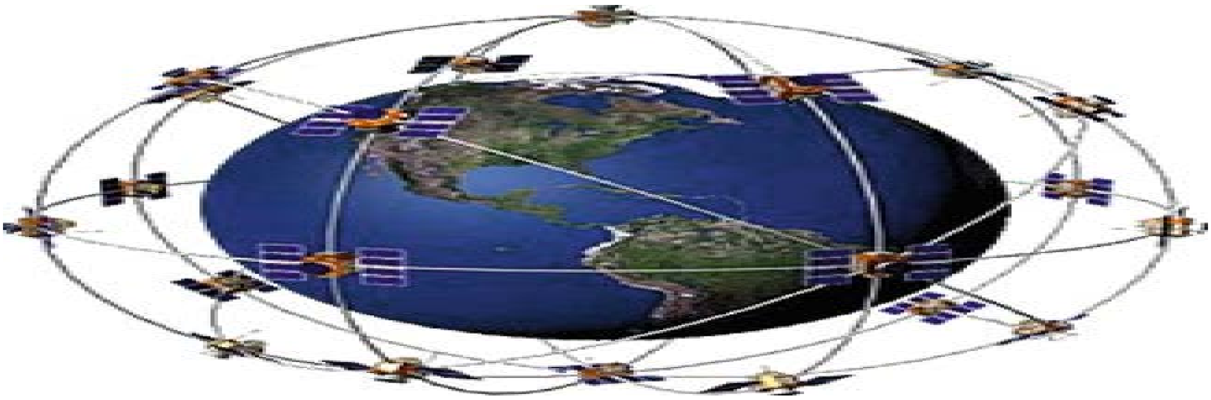


Fig 2: The NAVSTAR GPS satellite constellation (MEO) for space navigation

O3b constellation deployment at 8000 Km

At an 8000 km orbital altitude, round trip latency is typically below 130 msec. and is guaranteed to always be less than 150 msec. within the coverage region being served. This is comparable to long haul fiber routes and about four times less than GEO satellite round trip latency. Operation in the higher frequency satellite Ka Band and the use of small steerable parabolic antennas on the satellites allowed the system to deliver high data rate services into concentrated areas (700 km diameter spot beams).
Bringing the satellites closer to Earth meant that signals between satellites and ground stations incur 13 dB less path loss. MEO satellites can deliver the same flux density at

the Earth's surface as GEO satellites with 13 dB less Equivalent Isotropic Radiated Power (EIRP) from the satellites and can achieve similar receive sensitivity as GEO satellites with much smaller aperture antennas. Operation in the commercial Ka band with shorter wavelengths vs. C or Ku band systems also helps reduce the satellite and ground station antenna aperture size while delivering similar receive sensitivity and radiated power levels. By operating with 13 dB less radiated power, it was possible to reduce the power required by the satellite and reducing the size of the satellite's solar panel area and number of batteries.

Lower power requirements allowed the satellites to be smaller and to weigh less than 700 kg reducing satellite cost. Less weight, smaller size, and lower orbit allows further savings in launch costs as four satellites can be placed into MEO orbit by a single medium lift launch vehicle. Two launches will be required to deploy 8 satellites into the 8062 km MEO orbit. The system is highly scalable and additional satellites can be added to the constellation over time to add additional capacity. In the constellation being deployed, the eight satellites are at an orbit of 8062 km and have an orbital period of 288 minutes. Each satellite revolves around the Earth five times per day in the same direction that the Earth is turning once per day. Therefore, each satellite passes over the same location on the surface of the Earth four times per day. For the initial eight satellite constellation, the Earth can be divided up into eight regions and a satellite will be overhead in each region for 45 minutes. At the end of 45 minute pass, the satellite that has been overhead moves on to the next region to the East and a next satellite in the constellation rises in the West to take its place in that region. This requires a handover from the setting satellite to the next rising satellite in each region. The handover from one satellite to the next in each region cannot take place instantaneously and the handover in the next region cannot take place until the handover in the previous region has completed and the satellite antennas have moved to point at the Gateway and customer locations in the new region.

Implications at ground terminal for deployment at 8000Km

To achieve high throughput on the links, highly directional gimbaled tracking antennas are used in the satellites to create spot beams that are kept pointed at a fixed location on the earth while the satellite is moving. Tracking antennas are also used in the ground terminal equipment to follow the satellites across the sky. Ground terminals can be deployed with a single tracking antenna or with dual tracking antennas to provide two different modes of operation. Single antenna terminals implement a Break-Before-Make Satellite-to-Satellite Handover. At the end of the 45 minute satellite pass, the ground terminal antenna swings back to acquire the next rising satellite. This results in a scheduled break in the data stream while the tracking antenna is moving back, locking on and tracking the next satellite, allowing its modem to achieve carrier sync and produce good frames/packets, and then allowing any router and encryption devices to re-sync if required. For larger slower moving antennas, this can take up to a few minutes. If continuous data transfer is required, dual antennas can be deployed to implement seamless Make-Before-Break satellite to-satellite handover. One antenna is following the satellite across the 45 minute pass. The second antenna is standing by to acquire the next rising satellite when it appears in the region. Once the second antenna is locked on and tracking the rising satellite, the modulators at each end of the link transmit the same signal over both antennas and over the rising and setting satellites for a brief instant. The signals over the second antenna and rising satellite path are received by a separate second demodulator/decoder in the modems at each end of the link. Once the second demodulator/decoder at each of the link has locked onto the incoming carrier and is producing good frames/packets, the modulators stop transmitting over the first antenna (the setting satellite) and the first demodulators/decoders. The second antenna tracking the rising satellite has now become the primary antenna for the next 45 minute pass. During the pass, the first antenna swings back to wait for the next rising satellite and the handover process repeats.

6. Considerations for MEO based satellite network deployment

There are a number of factors to be considered for orbital choice for deploying a satellite system, such as launch costs, path loss, number of satellites and spares to be manufactured, operational and control complexities and most importantly the type of ground system to be utilized. One of the major constraints is orbital crowding. There are already over 300 communications satellites in operation, with most of these in the crowded GEO or Clarke orbit. The challenge lies in finding a satellite location or constellation design for multiple satellites that can meet projected needs.

Communications services using medium earth orbit satellites (MEO) offer significant advantages for voice, video and real-time data communications. However, they involve a few system design tradeoffs. The primary advantage of using a Medium earth orbit (MEO) is that round trip latency can be significantly reduced which improves the performance of certain applications. Systems such as Iridium and Globalstar have been deployed into low earth orbit and are designed to deliver primarily voice and very low data rate services. These systems made a number of design decisions based on the markets that they were planning to serve. To provide these services ubiquitously to any location on the Earth's surface requires a large number of satellites in a number of highly inclined orbits. To help further reduce latency and simplify the ground infrastructure these systems employ inter-satellite communications links. This allows traffic to move from one location on the Earth's surface to another without many up and down trips between satellites and ground stations. This feature imposes a requirement on the satellite and ground systems to be able to track and point narrow communications beams accurately at objects that are all moving dynamically (though predictably) relative to each other. Depending on the orbital altitude, the satellite experiences a severe radiation environment and also depending on the orbital altitude and the orbital angle of inclination, the cost of the satellite launch increases. Geosynchronous Earth Orbit satellites are usually placed in fixed orbit locations. In many cases, their satellite antenna radiating patterns have been shaped to only provide coverage over the landmasses below them. This simplifies the ground stations required to communicate with the satellites as they can remain pointed at the same location in the sky all of the time. However, the very high round trip latency of 500 – 600 msec. impacts the performance of many communications applications.

Tradeoffs between coverage area and orbital altitude indicated that an initial MEO constellation in a circular equatorial orbit 8000km above sea level would provide contiguous coverage to territories within the underserved (but highly populated) parts of the developing world.

Figure 3 shows the MEO satellite constellation coverage area from an Equatorial orbit

Operating at this orbit, and placing satellites only around the Equator, reduced the number of satellites required and significantly lowered the cost of the services provided. An initial constellation of eight satellites, at this equatorial MEO altitude, provides continuous service to all parts of the Earth within 45 degrees of the Equator. This constellation can also provide high bandwidth services for emergency responders, disaster relief, and fiber restoral.
Since the MEO satellites are moving in their orbit, they provide the same coverage over the oceans as they do over the landmasses within the +/-45 degree latitudes coverage area. This covers many of the world's ocean areas of interest to navies.

Based on the above-mentioned trade-offs a study for MEO utilization should involve the following:
(a) To obtain a mission value that offsets the above-mentioned financial disadvantages.
(b) To analyze the orbital environment and the practicality and efficiency of a radiation-proof design.
(c) An orbital design that achieves a good balance between (a)and (b) is required. (If an orbit is designed only for the advantages of the orbital environment, the mission values may be affected negatively.)

7. Applications

- **Remote sensing**

.

Agricultural observation	Survey of paddy fields and rice growing conditions.
Forest observation	Detection of wildfires and estimate of global forestry biomass

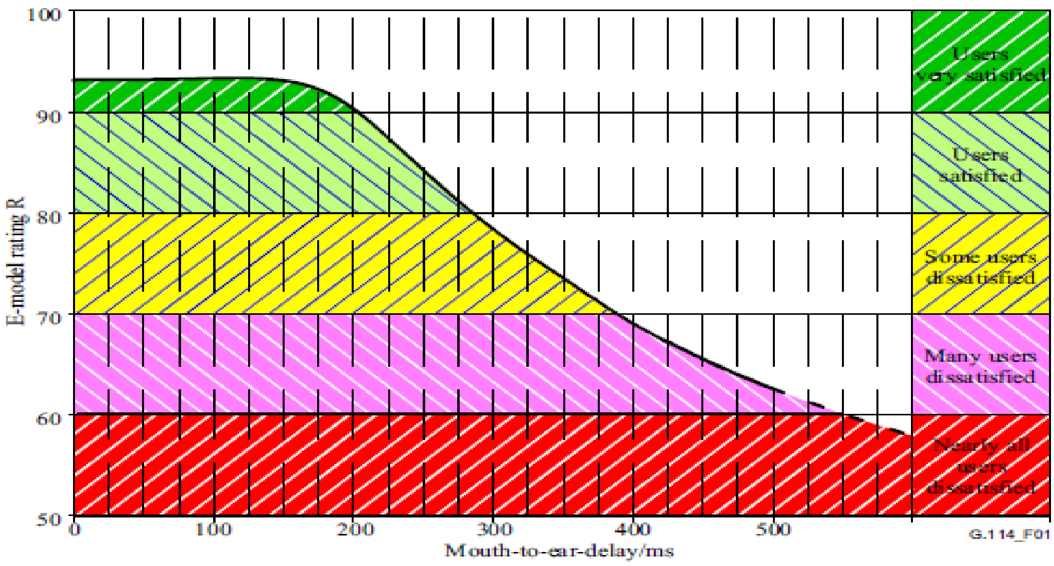
Ocean observation	Forecasting and management of variation in fishery resources. Measurement of velocities and directions of ocean wind.
Air pollution observation	Technical development and demonstration of atmosphere and weather observations.

Communication and broadcasting

A. High throughput IP traffic channelization applications

- **Interactive Conversational Voice and Video Conferencing**

If round trip delay exceeds 250 - 300 msec, voice conversations take on an unnatural quality and lose their interactiveness. Participants cannot interrupt each other and have to wait for one speaker to finish talking. They effectively become half duplex calls. Voice call quality is usually measured by a Mean Opinion Score (MOS) or by the E-model as defined in ITU Recommendation G.114. The Figure below depicts the typical user satisfaction metric with respect to mouth to ear delay as defined in E-model.



A similar phenomenon occurs for videoconferences. In addition to the loss of interactivity for the voice conversation, high latency causes the loss of facial queues of when a speaker on the screen has finished talking. The result of high latency is that conversations are more cumbersome with a lot of false starts. Voice and videoconferences over high latency links generally they take more time resulting in lower user productivity.

- **Enterprise Resource Planning and Distributed C2 Systems**

Enterprise Resource Planning (ERP) systems such as SAP and Oracle support remote access. These applications have a number of handshakes between the remote access client and the server for each transaction. With 500 - 600 msec. of GEO satellite round trip latency for each handshake, multiple round trip delays are involved and the client – server response time becomes very slow and it takes the remote staff longer to do their work reducing productivity. Custom workarounds have been developed for these applications by IT systems developers to allow remote access from users that are connected over GEO satellite links. These typically involve application level modifications to amount of information that is sent across the link or the deployment of remote terminal servers or application servers that implement part of the enterprise application at the remote site.

B. Intelligence, Surveillance and Reconnaissance

Intelligence, Surveillance and Reconnaissance (ISR)missions require high data rates to move high-resolution multispectral imagery back from areas of conflict to intelligence aggregation and processing centers. High capacity beams can retrieve up to 100 Mbps of data from a small ISR platform equipped with the right size tracking antenna. Steerable spot beams can be quickly moved to cover an area of interest and can follow a moving ISR platform. These spot beams can also deliver several 100 Mbps of processed intelligence information to forward battle locations in real-time. Transportable, rapidly deployable terminal equipment can be positioned at key locations around the globe to support emergency responders and disaster relief efforts. Steerable spot beams can be moved to critical locations within a matter of hours. It is also possible to offer rapid restoral services for under sea and terrestrial fiber that has been cut. Because of the very high bandwidth available and low latency, the fiber restoral services provided by the MEO satellites can approach the data rate and performance of the fiber connections.

8. Global regulations related to MEO

WP 4A is studying rules to regulate the a) Bringing into use, and b) deployment of non-GSO satellites systems.

Conclusion

Medium earth orbit (MEO) satellites deliver lower latency to underserved locations on Earth. This paper describes different features of MEO constellation. Lower latency means that bits transit the system quickly, therefore supporting business applications that are latency sensitive. The close proximity to Earth also allows MEO to concentrate more power on its small beams. These beams can be easily repointed to cover new areas, hence offering flexibility to the markets.

This paper is an attempt to give a concise overview about MEO satellite based satellite systems and further studies can be taken up in this direction to understand and explore their future need and use in the Indian telecom scenario.

REFERENCES.

[1] "ITU-T Recommendation G.107 The E-model: A Computational Model for Use in Transmission Planning," Dec. 2011.

[2] "ITU-T Recommendation G.114 One-Way Transmission Time," May 2003.

[3] Oracle Corporation White Paper, "How to Tune Your Oracle Forms Server Applications", March 2000.

[4] C. Partridge and T. Shepard, "TCP/IP Performance over Satellite Links," IEEE Network, Sept./Oct. 1997, pp. 44-49.

[6] Loral Cyberstar, Inc., "TCP/IP Performance over Satellite Links – Summary Report", March 2000.