A Survey on Intersatellite Laser Communication

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Abstract – Laser communications systems are wireless connections through the atmosphere. They work similarly to fibre optic links, except the beam is transmitted through free space under line of sight condition. Laser *is* a generic term used for light amplification by stimulated emission of radiation. A laser is a device that emits light i.e. electromagnetic radiation through a process called *stimulated emission*. Laser communication is the key area in wireless communication. This paper gives an overview of techniques used, features, applications, advantages and disadvantages of laser light.

Index Terms – Intersatellite communication, optical communication, wireless communication, free space communication.

1. INTRODUCTION

Laser light is usually spatially coherent which means that the light is emitted in a narrow, low-divergence beam. The source produces light waves that have the same frequencies and identical phase. Typically, lasers emit light "monochromatic" light with a narrow wavelength spectrum. The word light refers to electromagnetic radiation of any frequency, not just that in the visible spectrum. Hence there are infrared lasers, ultraviolet lasers, X-ray lasers, etc. A laser consists of a gain medium inside a highly reflective optical cavity, as well as a means to supply energy to the gain medium. The gain medium is a material with properties that allow it to amplify light by stimulated emission. In its simplest form, a cavity consists of two mirrors arranged such that light bounces back and forth, each time passing through the gain medium. Typically one of the two mirrors, the output coupler, is partially transparent. The output laser beam is emitted through this mirror. Light of a specific wavelength that passes through the gain medium is amplified (increases in power); the surrounding mirrors ensure that most of the light makes many passes through the gain medium, being amplified repeatedly. Part of the light that is between the mirrors (that is, within the cavity) passes through the partially transparent mirror and escapes as a beam of light.[1]The transmitter and receiver in laser communication must require line-of-sight conditions, they have the benefit of eliminating the need for broadcast rights and buried cables. Laser communications systems can be easily deployed since they are inexpensive, small, low power and do not require any radio interference studies. The carrier used for the transmission signal is typically generated by a laser diode. Two parallel beams are needed, one for transmission and one for reception. Laser communications provide us a solution for how to satisfy ever increasing bandwidth needs are in high demand. Other applications for this technology include temporary connectivity needs (e.g. sporting events, disaster scenes, or conventions), or space based communications.

2. TYPES OF COMMUNICATION

Two types of communications are possible for transferring data from space to earth station:

2.1Communication between satellites:- Here laser communications are preferred over microwave communication due to following reasons:-

i).The received power in both laser and microwave communication is

$$Pr = Pt.Gt.Gr\left(\frac{\gamma}{4\pi r}\right)^2 Lt.Lr.Lp$$

Here Pt is the optical output power generated at the transmitter, GT and GR are the gain values of the transmit and receive antenna, λ is the carrier wavelength, R the distance between the terminals and the factors LT and LR cover the loss within the transmit and receive terminal. However, the last factor, LP, which accounts for loss caused by non-ideal pointing, may correspond to several dB in a free-space laser link.[4].Now, gain of both transmit and receive antenna is given by

$$G = (\frac{\pi.D.r}{\gamma})^2$$

putting this value in above equation, we find that received power is inversely proportional to square of wavelength. As laser communication has more frequency than microwave communication, so received power in laser is more than microwave communication.[4]

ii)Beam width = wavelength/diameter, as in laser wavelength is small ,so beam width is also small which increases radiation intensity for a particular receiver i.e. received power of radiation has more strength.[3]

iii) Limited interference problem.

iv) High gain antenna is achievable.

v) Transmission capacity is more.

vi) Data rate is very high.[3]

2.2 Communication between satellites to earth station: - This communication involves earth atmosphere in between. Various atmospheric conditions like smog , fog, mist ,rain affect laser communication. Laser transmission is limited to shorter distance. So we prefer microwave communication. [3]. This is also be shown by following diagram:-

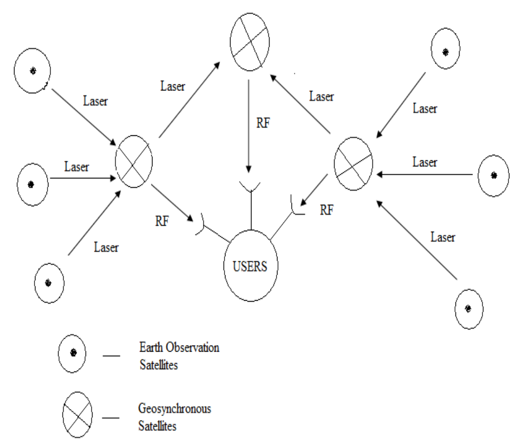

Figure 1: communication from space to earth [3]

3. FEATURES OF SATELLITE COMMUNICATION

a) It involves frequency range of terahertz approx. 10^14 Hz.

b) Band width is very high.

c) Beam width of transmitted optical signal is very narrow.

d) Line of sight communication.

e) Range of coverage is very large

4. ELEMENTS BEHIND LASER SATCOMMUNICATION

4.1System layout

Terminals for optical communication in space are mostly designed for bi-directional links, at least concerning the optical tracking function. They comprise both a transmitter and a receiver that generally share the optical antenna. These requirements lead to a transceiver block diagram as shown in Fig. 2. The light source S is a laser, preferably operating in a single transverse mode in order to achieve the highest possible antenna gain. If the laser operates continuously or in a pulsed mode producing a periodic pulse train, an external modulator (M) is utilized to impress the data signal onto the beam. Alternatively, internal modulation may be employed with some lasers. The modulated beam passes an optical duplexer (DUP) and a fine pointing assembly (FPA) before it enters a telescope acting as[4]

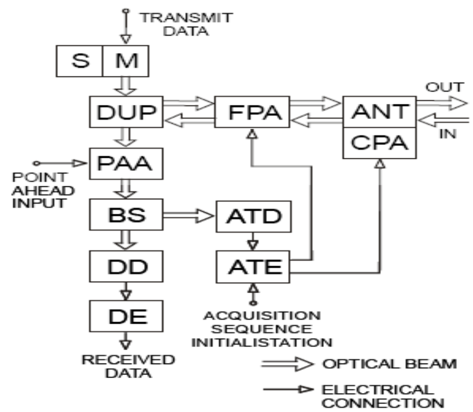

Figure 2: Transciever block diagram[4]

(S laser source, M modulator, DUP optical duplexer, FPA fine pointing assembly, ANT antenna, CPA coarse pointing assembly, PAA point ahead assembly, BS beam splitter, DD data detector, DE data electronics, ATD, acquisition and tracking detector, ATE acquisition and tracking electronics)transmit antenna (ANT). The telescope increases the beam diameter and thus reduces the beam divergence. A coarse pointing assembly (CPA) provides for steering the antenna. The received radiation also passes the antenna and the fine pointing assembly, and is then directed to the receive part of the terminal with the aid of the duplexer. A beam splitter (BS) directs one part of the received beam to the data detector (DD) for demodulation and further signal processing in the data electronics unit (DE). Another part of the received power is used for controlling the fine and corresponding mechanisms in such a way that the acquisition and tracking detector (ATD) is always hit centrally. A point-ahead assembly (PAA) has to be inserted in either the transmit path or the receive path to allow electronic control of the internal angular alignment between transmission and reception[4].

4.2 Data transmitter

Transmitter part of optical satellite link consists of a laser source,modulator and antenna along with some data handling electronics. Some of parts we are going to explain :-

4.3 Laser sources

A variety of laser sources may be used for optical satellite communication systems. These may be gas laser, solid laser and semiconductor laser. Selection of laser sources is dependent upon a number of factors that include range, propagation medium, data rate, and platform limitations. Some of laser sources commonly used in satellite optical communication are listed in table below.

Table1:comparison of laser sources

Laser	Wavelength	Power out	Efficiency	Life time	Characteristics
Nd-YAG	1.06um	0.5-1W	0.5 – 1%	10000Hr	Complex modulation equipments
Crystal GaAs ,AlGaAs	0.8 -0.9 um	Order of tens of milliwatts	5 – 10 %	100000Hr	Small, light , easy mod, Lowpowered , beam combining
CO2	10.6 um	1 -2 W	10 – 12%	20000Hr	Detectors poor, mod difficult
HeNe	0.63um	10MW	1%	50000Hr	Requires ext. modulator

The satellite crosslinks use laser diodes because of their light weight. Since these are low powered devices , so laser diodes are arranged in satellite payloads to form arrays so that so that the laser source output power increases. These are preffered due to their liht weight, small size, high efficiency and reliability. In addition semiconductor lasers are easily modulated by direct current injection. The laser diode has long potential life (~10^5 hr.) The main disadvantage of the laser diode is the limited power per diode son that most of applications require diode arrays, leading to beam combining problems.the intehrated optics technology has developed th ecoherent combining, thus increasing the power in the beam while decreasing the beam divergence [3].

4.5 Modulators

In laser space communication, the modulators are used to modulate the beam of light according to our data. These are the modulators that are used to modulate the laser beam.

a).Direct intensity modulators

Here driving current of laser varied according to type of modulation required. Modulationn rates of 1 Gbps with laser diodes have also been achieved. Direct modulation of light via the source drive the current causes dynamic effectson the emitted spectrum like those of changes in peak wavelength and in laser modes. [3]

External modulators :- other sources of light e.g. gas lasers may not be capable of being modulated at all. This makes external modulators attractive.solid state lasers such as Nd: YAG which are capable of achieving a modulation rates of more than 1Gbps also require external modullators. The external modulators use miniature guinding structures and operate with much less modulating power. Intensity modulation and Binary phase shift keying technique are the type of modulation used to modulate the laser beam.

b). Intensity modulation :- In this technique, the intensity of light is varied according to the data which we want to transffer. But it is more immune to noise.

Binary phase shift keying :- it is the technique in which we vary the phase of our beam according to our data. Binary phase shift keying (BPSK) provides the highest sensitivity for both communication and tracking. It is also the only scheme that provides full immunity against sunlight.

5. PARAMETERS OF OPTICAL SOURCE

Various parameters of optical source are listed below.

a) Wavelength :- A smaller wavelength requires increased surface quality of optical elements which in turn asks for bulkier devices if diffraction limited operation is essential. Thus the mass of the antenna (and hence the load for the coarse pointing assembly) is strongly influenced by the choice of λ. Also, the wavelength dependence of the sensitivity of available optical receivers must be considered. [4]

b).Output power: - The output power will have to be in the range of 100 mw and 1 W, depending on the link distance and data rate.[4]

Transverse mode :- It should be available in a single transverse mode to achieve maximum on-axis antenna gain, and in a single longitudinal mode to obtain optimum spectral efficiency.[4]

c).Polarization :- The usually linear state of polarization emitted by the laser source is to be converted into circular polarization before the beam leaves the terminal. [4]

d).Line width_:- narrow line width between transmitter laser and local oscillator in reciever is required for coherent detection.[4]

6. DATA RECEIVER

Receiver of optical beam has following type of parts[3]:

6.1Receiver antenna**:** These are basically telescopes whose main purpose is to focus the optical signal into photo detectors.

And to reject as much as of background radiations as is practical.

6.2Filters: These are employed to eliminate back ground radiations. That is not of same wavelength as the optical signal. Range of wavelength allowed by optical filter around laser wavelength is optical bandwidth.[3]. Noise in AP, optical preamplifier noise, ransistor and circuit noise, laser phase noise, background radiations are removed by using filters. So it has a very important role in our detection system at receiver.

7.OPTICAL DETECTION SYSTEM

These are of two types mainly

a). Direct detection system

Direct detection system respond to signal intensity and are most widely used in optical communication systems. These are used in signal intensity modulation.[3]

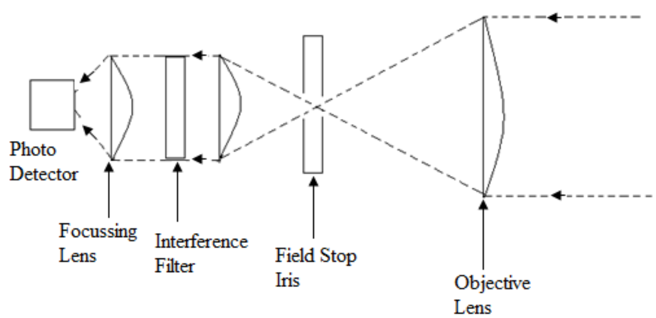

Figure 3 : It shows principle of direct detection system[3]

The signal is recieved by the telescope which is then passed through iris which remove any kind of mode change in recieved optical signal. It is then passed through filters which remove any kind of noise in the recieved signal. Focussing lens are used to focus the signal on photo detector which then detect light and convert it to electric signal. [3]

b). Heterodyne detection stystem

In this system the optical signals is combined with a local oscillator beam and then both signals are foccused onto same detector . These are used in far infrared region and are mostly used in binary phase shift keying. The recieved signal is taken by telescope which act as recieving antenna. It is then passed through beam splitter.The beam is then combined with the beam of local oscillator where difference frequncy components are generated. This component is the passed through focussing lens which is then foccused on photodetector which is then conveted to electric signal .this signal is then passed through I.F.Amplifier and demodulator. Thus demodulation can be done by conventional methods that were used by R.F. signals.

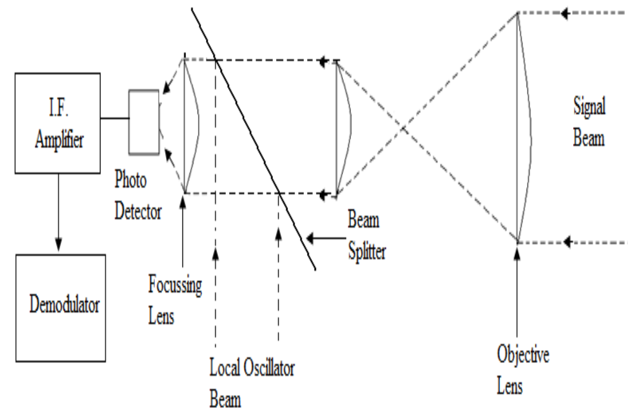

Figure 4. It shows principle heterodyne detection system[3]

For space applications, good receiver sensitivity is an extremely valuable asset, not at least because no inline amplification is possible. It is often characterized by the minimum number of input photons per bit to achieve a bit error probability of 10-6. If other sources of noise than that due to the quantum nature of radiation are negligible, a direct detection receiver needs n = 6.6 photons/bit. As an example for a coherent receiver, a homodyne receiver with PSK modulation would require n = 5.6 photons/bit[4].

7. ANTENNA

As with the RF communication systems, the laser satellite communications systems also utilize antennas to direct the transmitted energy and to recieve the transmitted signal. Here antennas are nothing more than conventional telescopes where size are dictated by wavelength and system requirements.It requires narrow light beamwidths instead of antenna gain pattern of several degrees needed by RF system. It has lensing system for beam transmission and focus.The main specifications of the optical antenna are: diameter of primary mirror (or lens), magnification, aberrations, wavelength dependence of throughput, sensitivity to temperature changes and gradients, and stray light level. Refractive telescopes are envisaged in case of small diameters while reflective systems are preferred for diameters exceeding several centimetres. With increasing antenna aperture it becomes more and more difficult (and expensive) to meet specifications. Large antennas will also increase the mass and size of an optical transceiver considerably, as the telescope and the coarse pointing assembly do contribute appreciably to these characteristics. Presently it is felt that the diameter of diffraction limited antennas should not exceed some 25 cm for free-space laser links. Coarse pointing may be accomplished via gimbals' mounting the antenna or by a separate unit consisting of two orthogonally mounted steering mirrors or one gimballed reflector [4].

8). SATELLITE BEAM ACQUSITION, TRACKING AND POINTING

We know that transmitting beam should be quite narrow to have maximum power spectrum. But it creates beam pointing problems. Beam should be correctly pointed towards the receiver otherwise communication can be disturbed. To establish an optical link in space, a sophisticated spatial pointing and acquisition procedure must be initiated. Information on the position of the two space terminals has to be available. Still, because of position uncertainty and incomplete knowledge of the spacecraft's orientation (attitude uncertainty), one terminal's beam width has to be widened deliberately as to illuminate the second terminal despite the uncertainty in position. A spatial search operation by the (narrow beam) receive path of the second, and subsequently, of the first terminal have to follow before acquisition is completed and switching to the tracking mode can occur. For proper pointing optical beacon system is used. In this system, an optical beacon transmitted by the receiving satellite back to transmitted satellite is used. This beam should have broader beam width so that it can accurately detect the transmitter. The transmitter antenna receives the beacon transmitted to it by receiver antenna and then transmitted its own modulated data back to receiver. Thus the receiver satellites position can be determine and pointing error can be minimized [3].The following diagram shows the beacon tracking system.

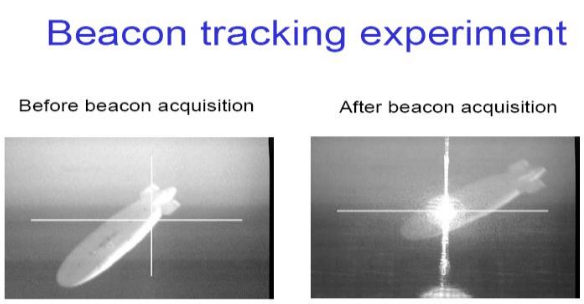

Figure 7: it shows the proper pointing due to beam tracking. [6]

8.1 Point ahead angle

There is a situation in which though the transmitting antenna has received the beacon but before it could transmit the laser modulated beam, the receiver satellite may move out of the transmitters beam width. In such a case it is necessary to know the angle by which the receiving satellite has moved ahead of transmitting satellite. This angle of drifting of receiving satellite is called 'point ahead angle' because of the finite velocity of light (c) and the relative angular velocity of two communication terminals moving in space, the transmit beam must be directed towards the receiver's position it will have at some later time. This point ahead angle is given by:

$$\beta = 2\ vR/c$$

where vR is the relative velocity component of transmitter and receiver, orthogonal to the line-of-sight, as illustrated in Figure. Point ahead is generally required in both dimensions. It amounts up to 40 μrad for a GEO-GEO link and up to 70 μrad for a LEO -GEO satellites link and may thus be appreciably larger than the beam width. The point ahead angle can be introduced in either thereceive or the transmit path of each transceiver and must be adjustable if vR varies with time. It is difficult to design a control loop for automatic adjustment of point ahead. Therefore today's concepts rely on the calculation of point ahead angles from known ephemeris data and on open loop implementation [4]

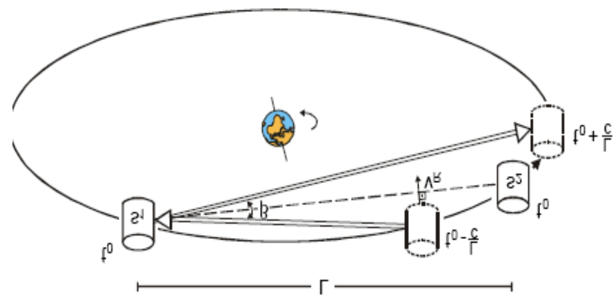

Figure 8 : it shows the beam ahead angle[4]

9. FUTURE SCOPE

The Transformational Satellite System (TSAT): It provides orbit-to-ground laser communications. Throughput for the five-satellite constellation could top out at 10 to 40 gigabytes per second, with a total program cost of $12 billion-to-$18-billion for the entire constellation. The Transformational Satellite Communications (TSAT) System will provide DoD with high data rate Military Satellite Communications (MILSATCOM) and Internet-like services as defined in the Transformational Communications Architecture (TCA). TSAT is key to global net-centric operations. As the space borne element of the Global Information Grid (GIG), it will extend the GIG to users without terrestrial connections providing improved connectivity and data transfer capability, vastly improving satellite communications for the war fighter [7].TSAT system is to provide improved, survivable, jam-resistant, worldwide, secure and general purpose communications as part of an independent but interoperable set of space-based systems that will support NASA, DoD and the IC. TSAT will ultimately replace the DoD's current satellite system.[7]

a). Far-IR semiconductor laser for future THz-carrier free-space communications

New experimental results are presented for the far-infrared p-Ge laser that enhance its prospects for application to secure satellite and short-range terrestrial free-space communications on a THz carrier. An optical means of gain modulation has been discovered that may potentially permit far-IR pulse generation via active mode-locking with low drive power. A compact high-field permanent-magnet assembly is demonstrated for applying the magnetic field required for laser operation without need of liquid helium. Compact light-weight laser-excitation electronics have been designed to run of a low voltage direct current supply.[8]

b).Laser communication between planets

According to NASA, laser communication will be used for interplanetary distant communication and also to measure movement of planets. Thus it will lead to new kind of researches.[1]

c).Laser communication in atmosphere

New Mexico State University researchers have developed a new and effective method for overcoming one of the major obstacles encountered by free-space laser communication systems – the signal interference caused by atmospheric turbulence. Free-space laser communication can be thought of as "wireless" optical communication to transmit the signal through the atmosphere with high data rates and security. But a number of practical problems need to be solved, including the signal loss caused by atmospheric turbulence. With funding from the U.S. Air Force Office of Scientific Research, a group of NMSU researchers is working on several fronts to solve those problems. Giles and Qingsong Wang, a graduate student who just completed his doctoral degree in electrical engineering, have devised a method for altering a laser beam in a way that greatly reduces the interference that occurs when the beam passes through turbulence. Their solution involves reducing the coherence of the laser beam by transmitting the beam through a combination of a single-mode fiber followed by a multimode fiber bundle, Wang said. The method, protected by a patent application, dramatically reduces signal error rates in laboratory tests in which a laser beam is transmitted through artificial turbulence, Giles said. The next stage in the project will be to build a transmitter and receiver for testing the performance when the beam is transmitted a few hundred yards through actual atmospheric conditions. "Normally in a laser with high coherence, parts of the beam will interfere with each other and create a speckle pattern," he said. "If you transmit through an atmospheric path, you are going to accentuate the speckle pattern and you will have areas of darkness and areas of brightness that move around due to the turbulence." But because the beam expands over distance, to a meter or more in diameter, the wandering dark spots in the beam can cause unacceptable signal dropouts[9].

10. APPLICATION AND ADVANTAGES/DISADVANTAGES

10.1 Application

a) Bidirectional systematic link between two GEO's

The orbital distance between the GEO satellites may lie anywhere between a few degrees and some 120°, corresponding to distances between a few thousand kilometres and 75 000 km

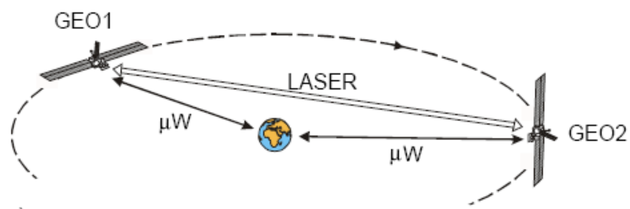

Figure 11: Bidirectional systematic link between two GEO's [4]

To transmit data from one part of earth to other that is very far away, this is best method. Connection to ground is made by microwave.

b) If a LEO satellite want to send a large amount of data at a single point on earth

Large data streams generated on a low-earth orbiting satellite (a LEO, with a distance to ground of less than 1000 km) may advantageously be transmitted to a GEO acting as a relay before being directed to the earth via microwaves (see Fig. 4b). Distances for this asymmetric link may be as large as 45 000 km. The concept allows continual data transfer to a single earth station for at least half a LEO orbit.

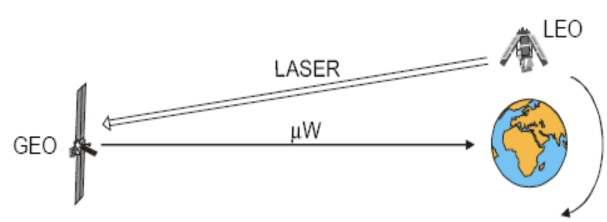

Figure 12 : Bidirectional systematic link between two GEO's [4]

c) Transferring of data from interplanetary deep space probes to earth station

Another use of a laser data link was already included in the upper part of Fig. 1. Characterized by very large distances (e.g. millions of kilometers) and by relatively low data rates (e.g. some 100 kbit/s), such a link would serve to transfer data from interplanetary and deep space probes to relay satellites orbiting the earth. This relay could be equipped with a large receive telescope. Further transport to ground stations would use microwaves. As an alternative, an optical ground station would receive the probe's data after passage through the atmosphere.

d) For satellite networks now being planned or established to serve mobile data transfer, interconnectivity at very high data rates could be achieved by optical links. Frequency allocation problems - as they persist increasingly for radio links - are practically non-existent, with the merit of negligible mutual interference. Another advantage is the expected smaller mass and volume of optical terminals.

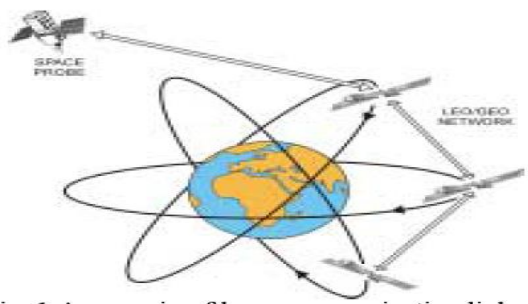

Figure 13 : Transferring of data from interplanetary deep space probes to earth station[4]

10.2 Advantages of space laser communications

There are several advantages of space laser communication systems.

i).Greater bandwidth leads to high transmission capacity.

ii).Narrow beamwidth leads to

iii).Increased intensity at receiver.

iv). Reduced crosstalk.

v). Optical transmitter and receiver size is smaller, so power consumption is less.

vi). Maintaining and installation in satellite is less costly

vii). Satellite relays are inherently wide area broadcast i.e. point to multipoint whereas all terrestrial relays are point to point.

viii).Satellite circuits can be installed rapidly .Once satellite is in position, earth station can be installed and communication can be established in days or even hours. Terrestrial circuits require time consuming installations.

ix).Mobile communications can be easily achieved by satellite communicationsas it has unique degree of flexibility in interconnecting mobile vehicles.

xi). In satellite communications the quality of transmitted signal and location of stations sending and receiving information are independent of distance.

xii).Digital and analog transmissions are possible on same satellite.

xiii). Earth stations can be relocated and reconfigured providing flexibility and utilisation of satellite capacity.

x).Satellite costs are independent of distance whereas terrestrial network costs are proportional to distance.

10.3. Disadvantages of satellite communications

i). As beam width is narrow, so pointing, acquisition and tracking problems occur which has to be solved . It makes system complex.

ii). A major challenge with laser communications in space is keeping transmitter and receiver locked onto each other.

iii).With satellite in position the communication path between terrestrial transmitter and receiver approx. 75000 km long. Since velocity of emwaves is 3* 10^8 km/s, there is a delay of ¼ sec between transmission and reception of signal.

iv).Delay reduces satellite's efficiency for long distance transmission.

v). Bandwidth is gradually becoming used up.

vi). Launching of satellite in orbit becomes costly.

vii).For proper tracking and acquisition makes the system little complex.

11. CONCLUSION

The aim of this paper is to learn about Satellite communication and its application in different field. A satellite is an object which revolves around the earth in a fixed path called orbit. A communications satellite (sometimes abbreviated to SATCOM) is an artificial satellite stationed in space for the purposes of telecommunications. Modern communications satellites use a variety of orbits including geostationary orbits, Molniya orbits, other elliptical orbits and low (polar and non-polar) Earth orbits. In this paper, we have discussed various kinds of satellites which we have used till now, basic component requirements of a satellite, technology behind these. We have also discussed the evaluation of satellites i.e. how these satellites come into play and what are the new advancements are going to come in near future and how it affects our life.

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