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Comparison of Microwave and Optical Wireless Inter-Satellite Links

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Abstract: microwaves inter-satellite links are considered as the traditional technology of space satellite to satellite communication systems. However, the major next step in the evolution of satellite communication technology is optical links which are considered the next generation of inter-satellite links. The shorter wavelength of optical systems allows modest antenna (telescope) sizes to transmit at a high data rate. However, laser beams in space have many advantages that include high gain, reduced mass, less transmission power, the volume of equipment and no regulatory restrictions. This paper firstly explains the transmission over optical isl system in section ii. Then, the comparison between the rf and optical inter-satellite links is recorded in section iii.
Keywords: free space optics (fso); inters satellite link (isl); rf inter-satellite links; optical inter-satellite links, optical wireless communication (owc).

I. INTRODUCTION

By connecting satellites together, we can cover the globe to establish communication from any place to another on earth. The information is sent by a ground station to the nearest satellite above and then transmitted between the satellites until it reaches the satellite above the destination which then transmits the information down to the destination ground station (see Fig. 1).

That information which is propagated between the satellites falls into several data types or traffic such as Navigation data, Payload data or Spacecraft health &status while each of these types of data has different levels of data rates and bandwidth requirements. ISLs that represent the network links of this satellite networks which can be either optical or radio frequency.

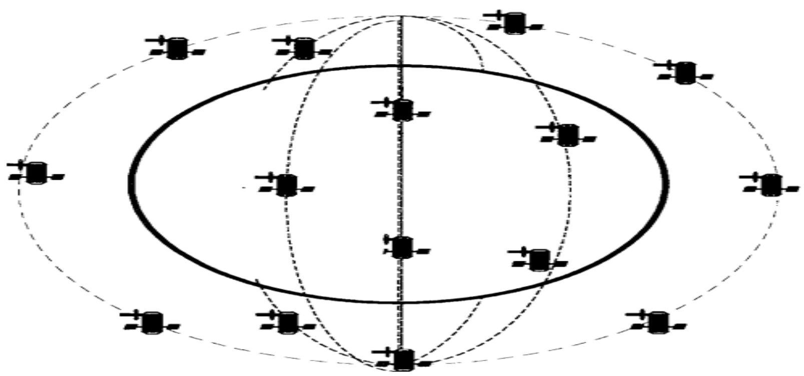

Fig. 1 Satellite communication network

Table 1 shows the frequency bands assigned to inter-satellite links by the Radio Communication Regulations. In the past, the microwave cross links were implemented which have limited data rates capacities, resulting in a limited performance of most satellite networks when the traffic demand at ISL constellations increases. So, if we want inter-satellite links with capacities larger than the microwave cross links with data rate Gbps require antenna and transmitter powers large enough. Optical links offer these high data rates because optical shorter wavelengths allow modest antenna (telescope) sizes that transmit very narrow beams which achieve high received signal levels. Compared to radio frequency links, optical communications in space offer several advantages such as higher data rates, small mass, no interference with other communications systems bands and less consumed power. However, Free Space Optics (FSO) communication is still an emerging technology with some tough technical issues are yet to be resolved such as the complexity of the PAT system because of the beam divergence angle of micro radians using high precision optical systems for space use (optical-mechanical-thermal engineering) and hard understanding for design of systems, Risk

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mitigation, integration and fabrication.

Table 1. Frequency bands for inter-satellite links

Inter-satellite service	Frequency Bands
Radio Frequency	22.55-23.55 GHz
	24.45-24.75 GHz
	32-33 GHz
	54.25-58.2 GHz
Optical	0.8-0.9 µm (AIGaAs laser diode)
	1.06 µm (Nd:YAG laser)
	0.532 µm (Nd:YAG laser)
	10.6 µm (CO2 laser)

II. OPTICAL ISL SYSTEM

As space optical inter-satellite link becomes a reality, the structure and design of Optical Satellite Communication network are now feasible. This optical wireless communication (OWC) is considered as next generation technology of FSO satellite networks due to the ability to connect with data rates up to numerous Gbps. Fig. 2 shows the localization of the optical inter-satellite links which were between FIRE and TerraSAR-X. This links were in February 2008 and considered as the first two optical inter-satellite links between two satellites. The first link was put above Central America and the Pacific Ocean with link distance between 3,700 - and 4,700 km. The second optical link was near to the South Pole with The link distance between 3,700 km and 4,875 km.

Fig. 2. Localization of the first two optical inter-satellite links.

The basic structure of the satellite optical communication system: transmitter, receiver, and PAT system. At first, the transmitter converts electrical signals to optical signals using the laser sources (see table 2).

Table 2. Laser commonly used in satellite communication

LASER TYPE	AVERAGE POWER OUTPUT	EEFFICIENCY	CHARACTERISTICS
Nd- YAG	0.5- 1 W	0.5- 1%	10,000 life hours , diode Or solar pumping , elaborate Modulation equipment .
GaAs	40MW	5- 10%	Nano second pulsing , Life hours 5000 , directly and easily modulated , rugged
CO2(gas laser)	1- 2W	10- 15%	Difficult modulation, Uses a discharge tube, Life hours 20,000 , used in IR range.
HeNe (Helium–Neon)	10MW	1%	power limited and inefficient , external modulation , Life hours 50,000 , has gas tube .

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The transmitter telescope collimates the laser radiation in the receiver satellite direction after that the optics of two satellites must be aligned with the line of sight during the entire time of communication to establish optical communication successfully. To meet this requirement, the satellites should implement a pointing, acquisition, and tracking (PAT) subsystem, this subsystem has three phases:

- Pointing: laser source in the transmitter points its beams towards the direction of the receiver according to the orbit equation using Ephemerides data.
- Acquisition: receiver scans the region of space where it can receive the signal if detects the transmitted beam enters the tracking phase. The duration of this phase is typically 10 seconds. The transmitted beam should be wide to reduce this duration.
- Tracking: in this phase, the transmission between the two satellites becomes continuous by using beacon signal on one satellite and a quadrant detector and tracking system on the other (see figure 3).

Finally, the receiver telescope focuses the received beam onto the optical filter which prevents the background radiation from entering the next stages of a subsystem. After that the optical filter pass the received beam to the optical amplifier, the output beam or radiation of amplifier signal convert into an electrical signal by using photodiode.

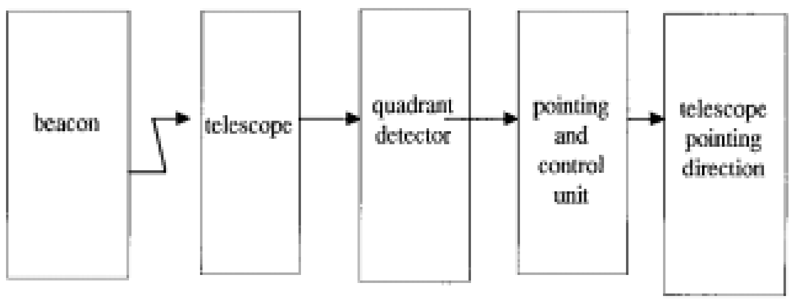

Fig. 3 Tracking System Scheme

III. COMPARISON BETWEEN OPTICAL AND MICROWAVE ISL SYSTEMS

In the recent years, Optical Wireless Communication (OWC) has been the attractive satellite to satellite cross-links instead of the conventional radio-frequency (RF) system which is visible from a summary of the comparison between RF and optical inter-satellite networks. Table.3 explains the most important terms which are used usually as comparable terms between FSO and RF wireless ISLs.

Table 3. Comparison between FSO and RF wireless ISLs

Terms	Microwave link	Optical link
Frequencies	22.55 – 23.55 GHZ 24.45 – 24.75 GHZ 32-33 GHZ 54.25-58.2 GHZ	0.8-0.9 µm (AIGAas laser diode) 1.06 µm(Nd:YAG laser) 0.532 µm(Nd:YAG laser) 10.6 µm (CO2 laser)
Data rate	Peak data rates of 600 Mbps if the system using FDM approach .	Provide up to 10 Gbps
Transmit power	23 GHz : 117 to 1476 W 33 to 416 W 13 to 168 W 32 GHz : 61 to 763 W 17 to 215 W 7 to 87 W 60 GHz : 17 to 217 W 5 to 61 W 2 to 25 W	Laser (FD Nd:YAG) : 4 to 55 mW 0. 3 to 3. 5 mW .02 to .22 mW Laser (GaAs) : 11 to 136 mW .7 to 8.5 mW .04 to .5 mW

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Antenna / optics size (diameter)	3 ft 4 ft 5 ft	6 inch 12 inch 24 inch
Weight or mass (Kg)	23 GHz 76 to 660 35 to 220 28 to 100 32 GHz 48 to 350 27 to 120 24 to 55 60 GHz 25 to 120 20 to 50 22 to 35	Laser (FD Nd:YAG) : 47 to 50 68 180 Laser (GaAs) : 47 to 50 68 180
Modulation and multiplexing	QPSK , QAM FDM	Continuous optical carrier intensity modulation, direct detection, WDM – DWDM
Antenna gain	20dB (Tx Antenna Gain) 20dB(Rx Antenna Gain)	78dB (Tx Antenna Gain) 112dB(Rx Antenna Gain)
Complexity	Low complexity	More complexity and sensitivity of all optics
Cost	High cost with comparable data rate.	Much lower cost with comparable data rate.
Regulations restrictions	RF spectrum which is regulated by national and international agencies up to 300 GHz	The optical spectrum in space is virgin territory and is currently unregulated.
Beam width	Wider beam width (e.g., At 10 GHz ,λ= 3 cm with , D = 1.0m yields 67.2 mrads)	Narrower beam width (e.g., λ = 1.0 micron with D = 10 cm yields 22.4 μrad)
Noise	Noise is mostly thermal and excess noise in the amplifiers	Noise is related to fluctuations of the photon flux being detected that contribute to noise in the detection system.
Interference	Inter-channel and intra-channel interference Due to close proximity of RF carriers in RF spectrum.	Optical frequencies are out of these problems.

IV. DISCUSSION AND CONCLUSION

Optical technology offers a number of potential advantages over microwave as high data rate, small antenna size, narrow beam width which leads to very high antenna gains on both transmit and receive and reduction of interference. This enables low transmitter powers (laser) to be used leading to a low mass, low power terminal but it is also a disadvantage since the beam width is much less than the precision of satellite altitude control (typically 1.75 or 0.1 mad). Another advantage of the optical communications systems is that unlike the RF spectrum which is regulated since there are no regulatory restrictions on the use of frequencies and bandwidths in laser frequencies, only natural ones. The complexity of pointing system is the main drawback of the

optical ISLs which derives from the necessity of pointing process from one satellite to another over long distances (tens of thousands of kilometers) with small beam divergence angle (micro radians) while the satellites move and vibrate.

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