

Recent developments in satellite laser communications: Canadian context

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Abstract—This paper presents an overview of recent developments to assess feasibility and relevance of satellite laser communication within Canadian context. The following application scenario will be discussed: LEO – GEO – Ground relay links for high data rate communications. Focus will be made on feasibility and architecture of optical relay including ground receiver.

Index Terms—Laser Communication, Inter-Satellite Links, Optical Downlinks, FSO.

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I. INTRODUCTION

Compared to radio technology, laser communications has the promise of much higher data rates. In addition, the ability to tightly collimate the transmitted laser emission limits the interference between satellites (especially in a LEO constellation) and is hard to intercept or jam. However, the improved pointing, acquisition and tracking performance is required to maintain the link. A key advantage of laser communications is that the shorter wavelength, as compared to RF, permits smaller aperture dimensions and thus reduced size and mass. An interesting future security application currently under research is quantum key distribution for which laser communications is ideally suited.

The increase of demand for communication capacity projected for future Canadian satellite missions, such as: Polar Communication and Weather satellites, new generation of radar Earth observation satellites, and telecommunication satellites (e.g. Anik series), can be partially addressed by using high data-rate communication links. For example high data-rate inter-satellite links can be used to relay high volumes of Earth observation data from a Low Earth Orbit (LEO) satellite to a Geostationary Earth Orbit (GEO) satellite, when the LEO satellite is not visible from a receiving ground station, and then the GEO satellite can download the data to the ground station.

High data rate, of Gigabit per second or greater, communication capacity is considered achievable by using optical communications. So far laser communications between satellites have been demonstrated onboard of just a few missions undertaken by Europe, Japan, and USA.

This study aims at developing specific mission scenarios for high data rate optical inter-satellite link (OISL) systems using, assessment of their feasibility, and defining system architecture based on technology option trade-offs. Particularly, the following two scenarios of communication were studied:

scenario (1): between LEO and GEO satellites, and

scenario (2): between a GEO satellite and a ground station.

Under this scenario 1, the LEO satellite is an Earth Observation satellite with either synthetic aperture radar or multi-spectral optical imaging sensor. The projected data rate requirements for such satellites are defined based on trend analysis from the data-rate growth in Earth Observation satellite data transfer projected for Canada over the next 10 years, with a target commissioning in next 5 to 10 years.

The satellite bus parameters for the LEO satellite are baselined upon the Canadian multi-mission bus technology. The LEO satellite uploads the data to the GEO satellite that serves as a relay to downlink the data to the ground station. In both scenarios (1) and (2), the GEO satellite is a telecommunication satellite.

The OISL system is a piggyback payload for both LEO and GEO satellites. Mass, power, volume allocations for the OISL payload, as well as the environmental conditions (temperature, vibration, radiation, spacecraft pointing stability, etc.) are considered according to each satellite platform.

II. STATE OF THE ART

A. Space-to-Space Optical Links: Scenario 1

OISLs permit networking or interconnection of spacecraft at Mbps to Gbps rates. These links offer higher data rates than RF counterparts and do not suffer from interference effects. However, a key issue in the design of such links the pointing acquisition and tracking (PAT) problem that requires micro-radian accuracy. Work in this area started in the mid-1980's and increased in adoption with the development of reliable semiconductor laser emitters. Indeed, early satellite phone LEO constellations were proposed with laser cross-links for routing calls (Iridium, Teledesic and Celestri). However, few of these links were implemented.

Early ISL links employed intensity modulation with direct detection and achieved data rates of 10's of Mbps reliably. With improved technology, present-day experiments have demonstrated 5.6 Gbps links using coherent optical technologies with in smaller and lighter payloads. Below is a summary of ISL demonstrations in the near past (Table I).

TABLE I. OISL PRIOR ART

Mission	Date & Range	Data Rate / Architecture	Power & Mass
SILEX [1,2,3]	1997 LEO to GEO (SPOT IV to Artemis) 45,000 km	50 Mbps (LEO to GEO); 2 Mbps (GEO to LEO); 850 nm, telescope 25cm, pointing accuracy 0.3-0.8 μ rad, BER $<10^{-6}$, 60mW continuous transmit power.	180 W 160 kg
Celestri [4]	1998 Specs only LEO-LEO 1800-1600 km	7.5 Gbps, throughput after overhead is 4.5Gbps; BER $<10^{-10}$.	<100W <25 kg
Teledesic [5] (merged with Celestri in 1998)	2002 Cancelled LEO-LEO < 6000 km	Breadboard results: 24 channels, 290 Mbps, 99.999% uptime, 1064 nm, phase shift keying with homodyne detector	95 W 105 kg
US DoD TSAT [6]	2003-2010 (cancelled) GEO-GEO 80,000 km (claimed)	10 Gbps Tests validated on ground (including closed-loop pointing and tracking). Never launched 1-10W optical amplifiers and reconfigurable routers in satellites	N/A
Artemis – OICETS (LUCE payload) [7]	2005 LEO-GEO First Bi-directional link	50 Mbps (to Artemis) 850nm, 200mW laser diode, NRZ, 26 cm telescope; 2 Mbps (from Artemis); 819 nm, 2PPM.	220 W 140 kg (LUCE)
NFIRE - TerraSAR-X [8]	2008 LEO-LEO 3800-4900 km	5.626 Gbps Coherent BPSK, 1.064 μ m, 700 mW transmit power, FOV=10mrad, BER $<10^{-9}$, 12.4 cm aperture (diameter)	120 W 32 kg
AlphaSat – Sentinel 2A and TanDEM-X [9,10]	2012 (TBD) LEO-GEO 45,000 km	1.8 – 2.8 Gbps; Homodyne Coherent BPSK, design BER $<10^{-8}$, 13.5cm telescope, 1064 nm, 5W transmit power.	140W 45kg

JAXA future OISL mission [11]	In Development LEO-GEO	2.5Gbps, homodyne DPSK; 1.064 μ m, 4 W transmit power., Aperture diameter 10 cm (LEO) and 20cm (GEO).	150 W 35 kg (LEO); 50kg (GEO)
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B. Space-to-Ground links: Scenario 2

A vast majority of space-to-ground links are RF. However, given the huge amounts of data collected by earth-observation satellites higher speed downlinks are required. A key limiting factor to the application of optical wireless links in this application is the impacts of weather and the atmosphere and propagation. Some methods to overcome these impairments have been proposed including spatial (site) diversity in optical ground stations (OGS), adaptive optics, as well as increased storage and burst transmission in favorable conditions. Downlink from LEO and GEO to ground stations has also been demonstrated. On ground studies have also been undertaken such as the Jet Propulsion Laboratory (JPL) optical communications telescope laboratory. In this experiment 30- μ rad low divergence beams sent to low-earth orbit satellites as part of an active satellite tracking experiment [12]. The Table II summarizes some recent demonstrations of space-to-ground communication links.

TABLE II. SATELLITE OPTICAL DOWNLINK PRIOR ART

Mission	Date & Range	Details
GOLD (ground/orbiter lasercomm demonstration) [12,13]	1996 GeoTransfer – Earth Japanese (ETS-VI) and OGS at the Table Mountain Facility in California, USA	Uplink and Downlink 1 Mbps ETS-VI: 830 nm 13.8mW (tx), 7.5cm telescope, 22.4 kg, 90 W (max power), Manchester encoding. OGS: Tx: 514nm (tx), apertures: 1.2m (rx) 60 cm (tx), Tx divergence 20 μ rad, 14.5W Argon laser.
GeoLite (geosynchronous lightweight technology experiment) [1]	2001 GEO – Earth	Designed by MIT Lincoln Labs for US National Reconnaissance Office (NRO). “Multi-Gbps link”. Few details available.
SILEX (Artemis to Ground Downlink) [14]	2004 GEO – Earth	Downlink: 49 Mbps, Uplink: 2 Mbps Satellite: 819 nm (tx), telescope 25cm, 10 mW laser power, 2-PPM, FOV = 70 μ rad OGS: 847 nm (tx), 1.016m telescope, 300 mW max laser power, NRZ, FOV = 87.3 μ rad Average BER for downlink (approx.) 10^{-6} , uplink measurements 10^{-3} (few measurements).
OICETS -to-NICT OGS [15]; similar experiment with DLR [16]	2006 LEO – Earth	2 Mbps uplink, 50 Mbps downlink BER $10^{-4} - 10^{-7}$, four uplink beams to mitigate scintillation at 815nm each 204 μ rad divergence, ground terminal receiver 20cm
NFIRE & Tesat – Ground station [17,18]	2010 LEO – Earth About 500 km range, bi-directional.	5.626 Gbps Coherent BPSK, 1.064 μ m, 700 mW optical Tx power, 12.4cm tx/rx satellite aperture OGS – Tenerife (Spain, 2200m

		above sea level) and Maui (USA, 300m above sea level), 6.2cm tx aperture, no adaptive optics. For 177 sec time duration, transmit 124 GBytes of data, 105 sec needed for initial sync for bi-directional link. Nearly error free downlink, and BER=10 ⁻⁵ for uplink.
Alphasat-to-Ground [18]	2012 (TBD) GEO-to-Earth	1.8 Gbps; receiver to use adaptive optics.
SOTA [19] (Small Optical Transponder for Micro-Satellite) by NICT.	Under dev. LEO -to- Earth 1000km range	10 Mbps (duplex) 1064nm (up) 975nm and 1543nm (down); Mass: 5.3kg, Power: 22.8W for satellite payload.

III. USER NEEDS ASSESSMENT

A. Data Rate Growth Analysis

Using the sensors that generates data in EO satellite applications as the driving factor could help characterise how the technology will evolve. Doing this way only assumes the sensor technology evolution over time.

What is of main interest for the analysis are the high spatial resolution (HR) sensors used on EO satellites mainly for commercial applications. The HR sensors are mainly characterised by the number of pixels they have. The most advertised feature in EO is the resolution or Ground Sampling Distance (GSD) of the panchromatic detector (i.e. multiple wavelengths in the visible spectrum). Nowadays, to be considered HR, the sensor must offer a GSD below three metres. In general, the best HR sensors are below 50 cm spatial resolution at nadir. Most optical HR sensors use linear CCDs with thousands of pixels.

It is also worth noticing that most of the satellites also carry multi-spectral sensor as well as the panchromatic one. However, smaller spatial resolutions are available in the order of 2-4 times larger GSD than in the panchromatic case.

In the frame of the analysis, only optical sensors were considered (i.e. no microwave or remote sensing devices). As well, pure military systems were not treated.

Using the UCS satellite database [20] and information publicly available on the web, four of the most advanced EO satellites were selected. They were considered as the most advanced sensors of their time. Incidentally, they were the ones generating the most data (larger data storage and data transfer rate of their time). Two other satellites were removed from the list, SPOT5 and Pleiades-HR, simply because their GSD was lower (i.e. 2.5 m and 0.7 m respectively) than similar technology launched at the same time (i.e. QuickBird-2 with 0.61 m in 2001 and GeoEye-1 with 0.41 m in 2008).

The data collected on these four satellites included in Table III: number of pixels per array (for panchromatic detector), the number of bits per pixel, the average altitude, the GSD, the instantaneous FOV (iFOV) of the entire array, and the fact whether they carry or not a multi-spectral sensor. Two calculated values were also added to the analysis: the size of a theoretical square image (i.e. the square of the number of pixels

per array) and the number of these images that can fit on the onboard data storage.

The plots were generated based on this table to show the relation and the trend linked to panchromatic detectors used in EO satellite applications (Figures 1 - 4).

TABLE III. EO SATELLITE – DETECTOR DETAILS

Satellite Name	Mass (kg)	Launch Date	Storage (Gb)	Data Rate (Mbps)	Detector PAN # pixels	Altitude (km)	GSD (m)	Array iFOV (deg)	Multi Spectral	Square Image Size (Gb)	# Images on Data Storage
QuickBird-2	1100	18-Oct-01	128	320	27568	450	0.61	2.12	yes	8.36	15
WorldView 1	2500	18-Sep-07	2199	800	39100	496	0.5	2.04	no	16.82	131
GeoEye-1	1955	6-Sep-08	1000	740	35000	681	0.41	1.28	yes	13.48	74
WorldView 2	2800	8-Oct-09	2199	800	35000	770	0.46	1.28	yes	13.48	163

All sensors use X-band link and have 11 bits per pixel.

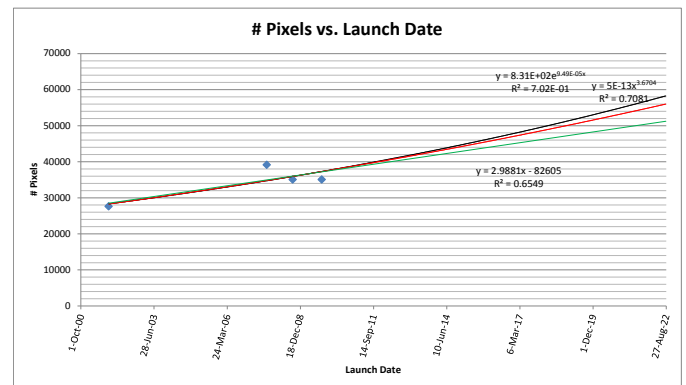


Fig. 1. Number of pixels per array vs. launch date

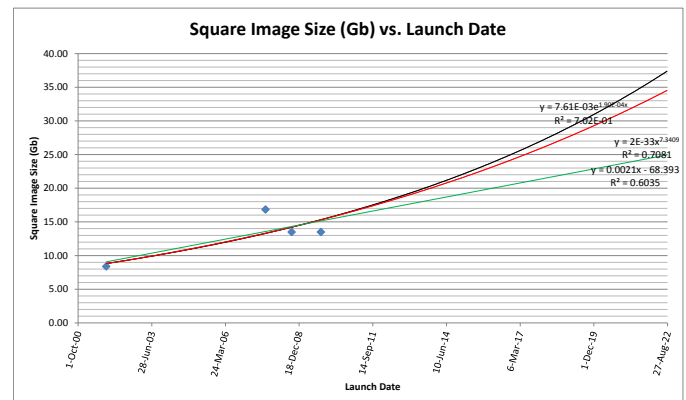


Fig. 2. Square image size (Gb) vs. launch date

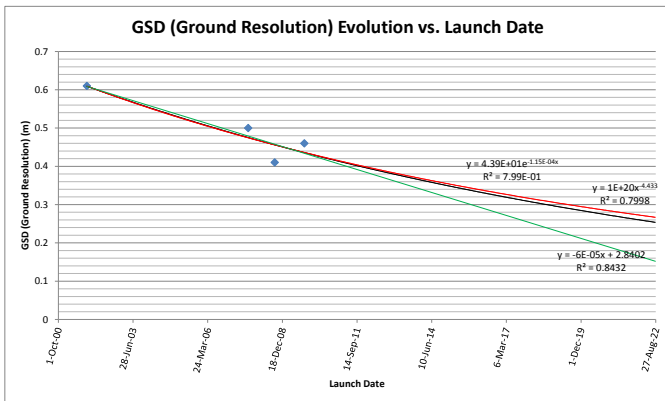


Fig. 3. GSD vs. launch date

All graphs depict strong correlation between the three trend lines. Figures 1&2 show that in the 2022 horizon, one can expect array size of anywhere between 50,000 and 58,000 pixels and 25 - 37 Gbs at the rate the technology is evolving. Multiple factors can play in the detector array size. For instance, the more pixels we have, the larger in dimension an array is which adds volume and mass to the equation since the optics must be larger to accommodate a wider array. It is also possible to make pixels smaller; however, one needs more sensitive detector to counter the fact that less light will hit the pixel and so on. These effects were not considered here neither we took into account a possibility that a disruptive technology may change the market figure overnight.

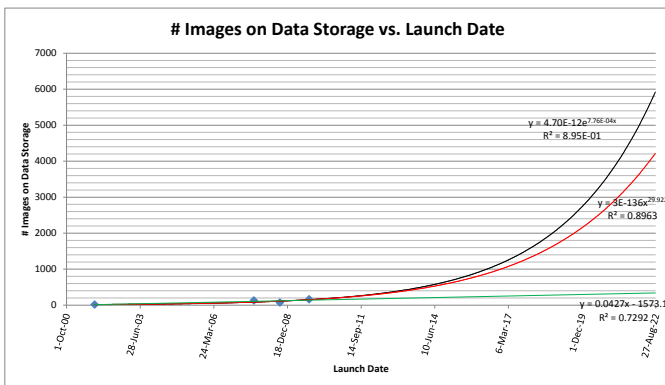


Fig. 4. Number of images on data storage vs. launch date.

The case of Figure 3 shows the trend of the spatial resolution on the ground over time. According to the plot, in the 2022 horizon, the GSD can be anywhere 15 cm and 25 cm. For instance, Satellite Imaging Corporation projects that GeoEye-2 will achieve 25 cm resolution by 2013 [21].

Figure 4 depicts the evolution of data storage by mean of estimating the amount of “square” panchromatic images that can be stored onboard local memory. This aspect is difficult to analyze simply because the onboard memory is sized based on several other parameters such as the number of images acquired per orbit or day, the size of the individual images, the time to the next downlink opportunity, the downlink rate, etc. Based on today’s progress in data storage, it is foreseeable that the size of memory will continue increasing over time as the

size of the images will. The figure suggests it could be anywhere higher than 200 images for 2022. This would translate respectively in 5Tb given a baseline image size of 25Gb (Figure 2) as a minimum estimate.

From the above estimates it is possible to calculate a theoretical minimum data rate considering a 10-minute window as the maximum allowed time for the transfer assuming the full memory is emptied in that one pass. This leads to the data rate projection of 8 to 12 Gbps. The main limitation of this approach is that it does not take into account the fact that other sensors/detectors could contribute to sizing the memory such as the multi-spectral detectors or other EO instruments.

Although these predictions cannot capture the full complexity of the reality, they do demonstrate that there is a real increasing trend and that at the minimum data-rate for high-end EO satellite applications should be in the order of 8 to 12 Gbps in the 2022 horizon. However, the reader is advised that these estimates should be reviewed with care as they only constitute an “order of magnitude” based on projections of existing data. These numbers mainly apply to large and high end EO satellites that generate a sizeable amount of data. It is foreseen that at the rate the technology is currently evolving, it should meet the need of the industry.

B. Canadian Context: Limitation on Mass and Budget

By reviewing the Canadian-built fleet of satellites, it became apparent that total mass of satellites oscillates anywhere between nanosat such as the UTIAS/SFL GNB bus (~7 kg) to Radarsat-2 (~2200 kg). However, this study is constrained to microsat and smallsat such as the Multi-Mission Micro-Satellite (MMMS) (~75 kg) (Table IV) and its extended version (~150kg), and the Multi-Mission Small-Satellite (MMSS) (~480 kg) (Table V) busses respectively.

TABLE IV. MULTI-MISSION MICRO-SATELLITE SPECIFICATIONS

Parameter	Specification
Total Mass / Payload Mass	75 kg / 30 kg
Mission Life	1 year min, 2 year target
Orbit	650 to 800 km altitude, dawn-dusk sun synchronous
Payload Orbit	32W / 60 W
Average / Peak Power	
Bus Rail Voltage	Unregulated 28V (22 to 34V)
Attitude Control Mode	3-axis stabilized Nadir or Inertial pointing
Attitude Pointing Accuracy	Mission dependent. The bus can accommodate star trackers if required.
Propulsion	No
PVT Knowledge	± 50 m (1σ), 1 msec to UTC
On-board Data Storage	512 MB
TT&C Uplink	4 kbps, S-band
TT&C and Data Downlink	2 Mbps, S-band

TABLE V. MULTI-MISSION SMALL-SATELLITE SPECIFICATIONS

Parameter	Specification
Total Mass / Payload Mass	480 Kg / 180 Kg
Mission Life	3 to 5 years

Orbit	Low Earth Orbit
Payload Orbit Average / Peak Power	150 W / 400W
Bus Rail Voltage	Unregulated 28V (22V to 34V)
Attitude Control Mode	3-axis stabilized Nadir or Inertial pointing
Attitude Pointing Control	Mission dependent. The bus can accommodate star trackers if required.
Propulsion	Optional Hydrazine (40 m/s)
PVT Knowledge	± 10 m (3σ), 0.15m/s, ± 1 msec to UTC with GPS option
On-board Data Storage	1.5 GB
TT&C Uplink	4 kbps, S-band
TT&C and Data Downlink	4 Mbps, S-band

To cite few existing Canadian examples, SciSat is a smallsat (~152 kg) and MOST is a microsat (~60 kg) which are both currently in operations. In the near future, NEOSat (~74 kg) and Radarsat Constellation (~1300 kg each spacecraft) will be launched by Canada.

In developing future missions and spacecraft, the budgetary constraint, and thus the mass, should be taken into consideration as it will impact whether a mission can be supported by Canada.

Canadian priorities are driving the kind of missions that, as Canadians, we can undertake. Earth Observation and scientific missions should be considered as potential applications that would benefit Canadians as the CSA mandate implies: "To promote the peaceful use and development of space, to advance the knowledge of space through science and to ensure that space science and technology provide social and economic benefits for Canadians".

A few examples of potential missions were put forward as an attempt to better define end user needs.

1. Northwest Passage Monitoring

With the opening of the Northwest Passage during summer months, it is tempting for other nations to use it as a shortcut. This can be viewed as a loss of sovereignty in the North. EO satellite dedicated to such application may be envisaged. The ISL concept proposed in this study would also benefit this kind of mission as near real-time high definition imagery monitoring could be achieved.

2. Canadian Territory Monitoring

This category is a generic one to perform EO-type tasks over the entire Canadian territory. It can range from catastrophic event such as flooding or forest fire (see below) tracking to generic cartographic mission for urban planning for instance. The need for real-time high data-rate ISL is debatable depending on the needs of the mission. An example for such need is described below..

3. Forest Fire Tracking

A recent study (POETE) concluded that at least two LEO satellites at 700 km on sun-synchronous orbits could be used to track fires anywhere in Canada. Real-time ISL could be beneficial to minimize the latency of the communication with the ground station anywhere above Canada. Such Earth Observation missions may involve also payloads imaging the surface in many spectral bands (e.g. 6 in the POETE concept

study). Therefore, the high data-rate link capability may also be beneficial for that application.

4. Automatic Identification System (AIS)

One possible reference mission that could be considered is for AIS applications used to identify and locate automatically vessels/ships worldwide. The use of ISL could minimize the latency of the system in providing the information to the users. Past studies (from COM DEV) demonstrated that short data latency in such a system would be beneficial. It would include a constellation of a number of LEO satellites on sun-synchronous orbits that could use the ISL with the GEO above Canada to minimize the data latency. In this case, the high bandwidth is not required but the latency minimization is.

The reader is advised that the list of potential missions provided herein is not restrictive and constitutes only a first iteration. In the future, a more thorough assessment should be performed to ensure all priorities are covered and a more complete list of potential applications and missions is devised.

IV. LINK ARCHITECTURE

In this section we present a high-level consideration for link requirements, architecture, and operational constraints.

A. Link and Payloads

As directed by the objective of the study, it is focused on the data dump capability, i.e. one-way communications as a minimum. Figure 5 presents the envisioned relay link.

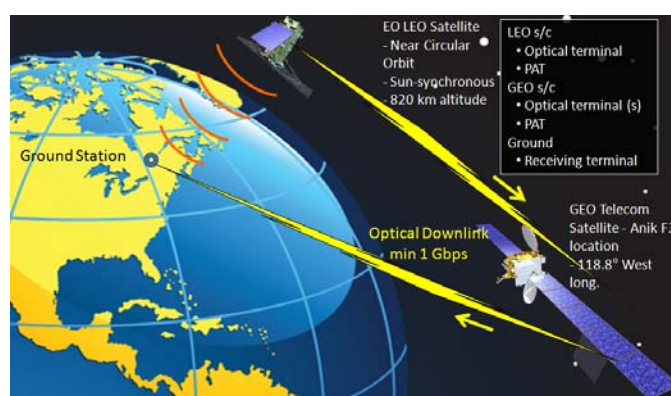


Fig. 5. Link architecture.

With the current level of technology and components the optical communication payload data-rate of 1 Gbps is considered to be realistic as an absolute minimum. Based on data-rate growth analysis the target data rates for 2022 horizon are 8-12 Gbps.

Using LEO-Ground precursor scenario the maximum transfer time of 10 minutes per orbit is assumed. The minimum bit error rate (BER) should be better than 10^{-9} based on the state of the art.

Optical communication payload should fit either on MMMS or MMSS as piggy back. Therefore, it should be compatible with MVP (i.e. mass, volume, power) envelope allowed on such satellite without impinging too much the total available payload. The satellite in GEO is likely to be a large telecom satellite such as Anik F3. The MVP envelope is not

constrained at this point and should use the one obtained on the LEO platform as guideline.

Optical communication payload should implement a pointing, acquisition and tracking (PAT) subsystem to achieve high performance closed-loop pointing & tracking. The typical baseline value for payload coarse pointing accuracy can be around or better than 1 mrad. At the same time, the communication payload fine pointing accuracy should be better than 10 μ rad.

Communication and possible beacon channels may use different wavelength. More specifically, for communication channel, different wavelength ranges has been exploited so far as shown in Tables I and II. For a ten year perspective a standard 1.55 μ m telecom range represents the most attractive chose. The major advantages of this wavelength range are:

- high power sources & high modulation capability;
- high data rate (up to 40 Gbit/s);
- eye safe wavelength;
- direct detection thanks to low noise optical fiber pre-amplifiers;
- Inter-operability with potential international partner satellites and OGSs.

Preliminary evaluation of LEO payload concept based on available technology and link budget calculation resulted in a payload with major parameters shown in Table VI.

TABLE VI. LEO COMMUNICATION PAYLOAD PARAMETERS

Parameter	Details
Payload Mass	50 Kg
Power, operation/standby	100W/40W
Full FOV	Hemispheric
Communication wavelength	1550 nm
Data rate	1 Gbps
Communication transmit power	2 W
Modulation	PPM or Coherent BPSK*
Telescope diameter	~12.5 cm

* PPM – Pulse Position Modulation; BPSK - Binary Phase-Shift Keying.

In order to implement LEO-GEO tracking the following approach is envisioned. Beaconless tracking is performed by the GEO, that is, tracking is done using the received communications signal. However, beacon tracking is performed by the LEO. It is assumed that the GEO has a secondary beacon emitter at a different wavelength than the communications wavelength.

Preliminary parameters of GEO payload concept are shown in Table VII. A 1 m diameter OGS telescope is assumed in this scenario.

TABLE VII. GEO COMMUNICATION PAYLOAD PARAMETERS

Parameter	Details
Payload Mass	100 Kg
Power, operation/standby	150W/70W
Communication wavelength	1550 nm

Data rate	1 Gbps
Communication transmit power	5 W
Transmit modulation	PPM*
Telescope diameter	25 cm

* PPM – Pulse Position Modulation.

B. Optical Ground Station

The availability of the link to OGS is limited by cloud cover. The only real manner in which the impact of cloud cover can be mitigated to improve link reliability is to use a series of OGS sufficiently separated to provide nearly independent cloud events, so called OGS site diversity. Figure 6 presents considered potential OGS locations across Canada.

The yearly average cloud coverage data was obtained from NASAs International Satellite Cloud Climatology Project (ISCCP) [22]. The Table VIII presents some statistical data on average cloud cover in a number of Canadian sites.

In order to compute the availability using a number of OGS the following formula was used:

$$Availability = 1 - \prod_{i=1}^n Pr_{cloud,i} \tag{1}$$

where Pr_{cloud} is the probability of cloud cover at site i . The implicit assumption with this equation is that cloud coverage is independent from OGS location to location. The approximation is reasonable given the large distance between the sites. In addition, to maximize the availability, the product is computed starting with stations with the smallest probability of cloud coverage.

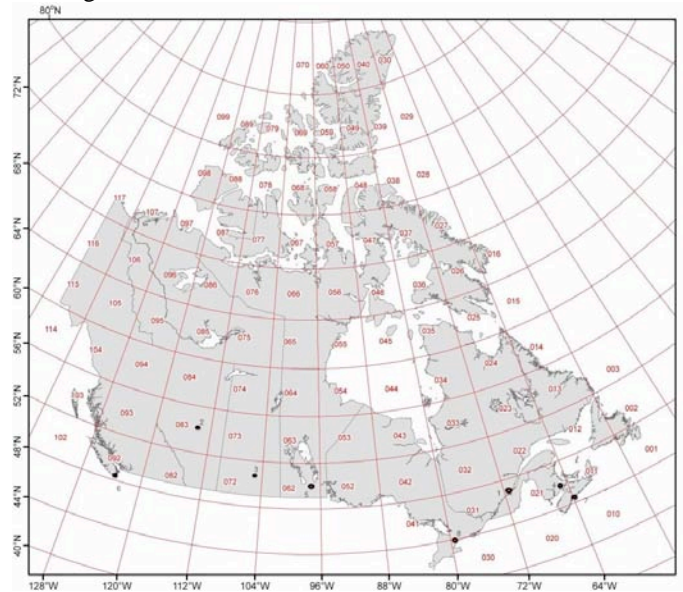


Fig. 6. Location of Eight Candidate Optical Ground Station Sites.

TABLE VIII. POTENTIAL OGS LOCATIONS AND ANNUAL AVERAGE CLOUD COVERAGE PERCENT

Location	Latitude (deg N)	Longitude (deg W)	Average Cloud Cover (%)
1. CSA Headquarters, St. Hubert QC	45.52	73.39	71.1941
2. Edmonton, AB	53.68	113.48	71.9880

3. Moose Jaw, SK	50.34	105.56	69.2517
4. Gagetown, NB	45.84	66.44	72.1012
5. Winnipeg, MB	49.90	97.23	70.3518
6. Esquimalt, BC	48.44	123.43	71.4367
7. Halifax, NS	44.66	63.59	76.2831
8. CFB Borden, ON	44.27	79.92	72.0203

Table IX summarizes the link availability using a differing numbers of OGS starting from 1 and moving to using all 8 locations.

TABLE IX. LINK AVAILABILITY FOR DIFFERENT NUMBER OF OGS.

Number of OGS site used	Availability (%)
1	30.7
2	51.3
3	65.3
4	75.2
5	82.2
6	87.2
7	90.7
8	92.9

What is striking is that that ignoring all other sources of loss other than the clouds, the availability with one OGS is only about 30%. Even using all 8 locations one obtains an overall availability of 92%.

Given the high latitude of Canadian sites and relatively high cloud coverage over Canada, it would be advisable to consider OGS abroad if high availability is important.

One of possible locations of OGS is at St-Hubert QC, where an astronomical observatory can be adapted for a precursor/technology demonstration LEO-OGS mission (Figure 7).



Fig. 7. Astronomical observatory at St-Hubert CSA headquarters.

V. CONCLUSIONS

An entire optical satellite relay system (LEO-GEO and GEO-ground) seems feasible. GEO-ground portion of the link is the weakest point of the optical link architecture because a fairly low availability can be achieved due to recurrent cloud cover over the entire country. Here are some potential avenues around:

- use RF V-band as backup link;
- use optical link GEO-HAP (High Altitude Platform above the cloud);

- use OGS in another country with less cloud coverage (e.g. Australia).

Implementing a full size optical system on a microsat may not be desirable. Microsat may not need as high data transfer capacity as larger satellites do. Procuring such a system can be very expensive and would defeat the purpose of building a very small and inexpensive satellite. It might not be possible to decrease enough the MVP to fit to a microsat without impinging too much on the payload real estate and still achieve the same link distances at the same rates.

As optical terminals are already readily available in Europe, Canada may want to focus in developing (or participate in the development of) OISL payload for smaller satellites such as for microsat, possibly, for LEO-LEO or LEO-Ground applications with smaller distances.

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