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Satellite Communications: A Deeper Dive

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CRRBC West

November 5, 2024

Overview

- Introduction to NRC and HTSN Challenge Program
- Satellite communications overview
- Optical satellite communications

National Research Council of Canada (NRC)

NRC at a Glance

R&D SERVICES

$1,471M TOTAL EXPENDITURES

$179M REVENUE

2,293 RESEARCH STAFF

12 RESEARCH CENTRES

182 BUILDINGS AT 24 SITES

15 COLLABORATIVE PROGRAMS

1,005 R&D CLIENTS

1,222 PUBLICATIONS

1,950+ ACTIVE PATENTS
(461 new patent applications)

NRC LONG-TERM ROLES

INDUSTRIAL RESEARCH ASSISTANCE PROGRAM (NRC IRAP)

269 INDUSTRIAL TECHNOLOGY ADVISORS

106 LOCATIONS

$489M GRANTS & CONTRIBUTION FUNDING INVESTED

6,204 UNFUNDED FIRMS RECEIVE ADVISORY SERVICES ONLY

3,486 FIRMS RECEIVE FUNDING

** Figures are from fiscal year 2022-23*

CHALLENGE PROGRAMS

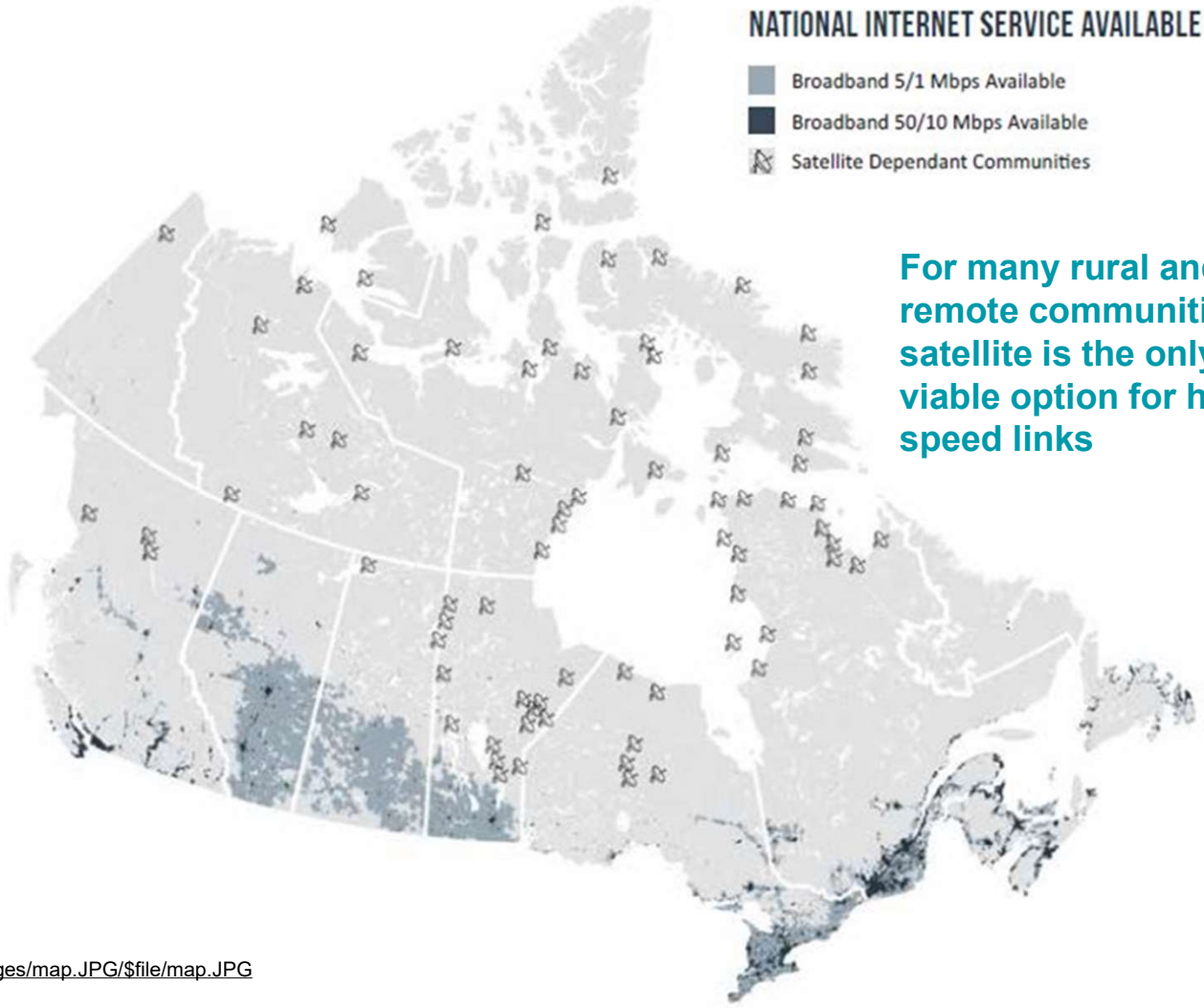
#NRCChallengeAccepted

OBJECTIVE: Leverage NRC facilities, expertise & networks to anchor strategic teams from across academia and industry to address public policy challenges, government priorities and to stimulate business innovation.

CHALLENGE PROGRAMS:

- Materials for Clean Fuels
- Disruptive Technology Solutions for Cell and Gene Therapy
- High-throughput and Secure Networks
- Artificial Intelligence for Design
- Arctic and Northern
- Aging in Place
- Pandemic Response
- Internet of Things: Quantum Sensors
- Applied Quantum Computing
- Critical Battery Materials
- Low Carbon Built Environment
- Construction Digitalization and Productivity

Canada's National Broadband Internet Service Availability Map



For many rural and remote communities, satellite is the only viable option for high speed links

Canadian population: ~40M people

Geographic area: ~10M km^2

Image: https://www.ic.gc.ca/eic/site/139.nsf/vwimages/map.JPG/$file/map.JPG

HTSN CHALLENGE PROGRAM 7-YEARS (2019-2026)

OBJECTIVE
HELP BRIDGE DIGITAL DIVIDE IN CANADA

4 RESEARCH THEMES

$24.9M GRANTS & CONTRIBUTIONS

AVAILABLE TO FUND COLLABORATIONS
LEVERAGING REQUIRED

HTSN is enabling a program vision of “1 Gbps everywhere” by removing key technical bottlenecks and accelerating technology for future networks

HIGH THROUGHPUT AND SECURE NETWORKS (HTSN) CHALLENGE PROGRAM

Progress as of 30 Sept 2024

Grants and Contributions (G&Cs)

Projects	Active	Ended	Committed
70	29	41	$23.2M

23 G&C Funding Recipient Organizations

5 NRC Research Centres

HQP and Outputs

273 Highly Qualified Personnel (HQP) supported

403 Peer-reviewed publications

21/6 Patents Filed / Awarded

Project Collaborators

14 University (3 international)

7 Government (2 international)

12 Industry

2 Not-for-profit

Optical Satcom Consortium (OSC)

23 OSC Members

>$7.6M Member In-Kind (>$2.4M NRC)

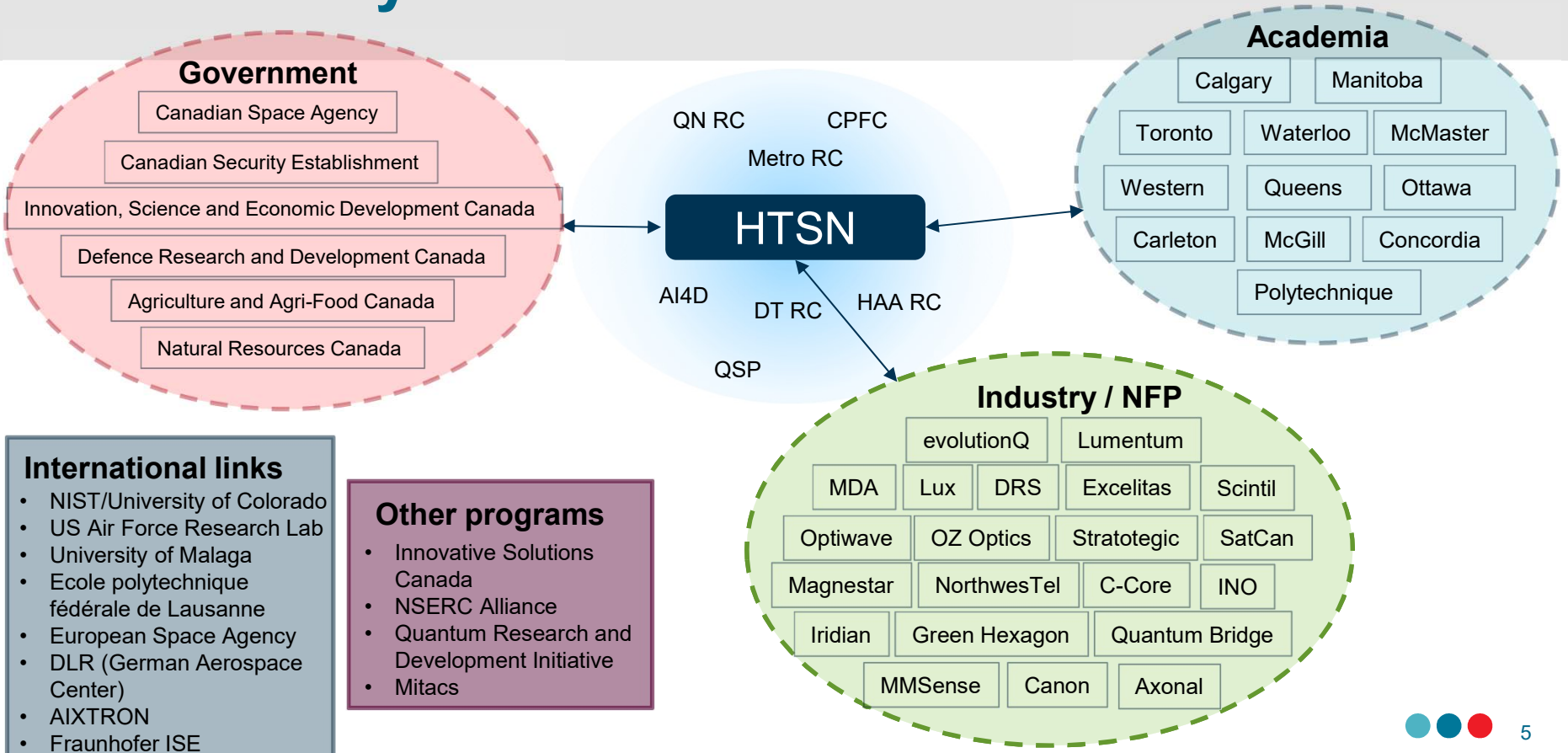
Major Equipment Investments

$1.45M to McMaster University towards an Optical Ground Receiver Extension and **Canada's first optical downlink demonstration**

$2.1M to the Canadian Space Agency for an **Optical Quantum Ground Station** for satellite communications

$1.96M to uOttawa towards equipment for a world-class joint NRC-uOttawa **quantum optics lab**

HTSN Ecosystem



International links

- NIST/University of Colorado
- US Air Force Research Lab
- University of Malaga
- Ecole polytechnique fédérale de Lausanne
- European Space Agency
- DLR (German Aerospace Center)
- AIXTRON
- Fraunhofer ISE

Other programs

- Innovative Solutions Canada
- NSERC Alliance
- Quantum Research and Development Initiative
- Mitacs

Optical Satcom Consortium (OSC) Members

SATCAN

Level 1

MDA

Carleton UNIVERSITY

National Research Council Canada | Conseil national de recherches Canada

McMaster University

UNIVERSITY OF WATERLOO

Level 2

INO

Optiwave

National Defence | Défense nationale Canada

UNIVERSITY OF TORONTO

OZ OPTICS LIMITED

LUNA

uOttawa

University of Manitoba

AXONAL NETWORKS

Level 3

LUMENTUM

c-core

Western UNIVERSITY · CANADA

MAGNESTAR

STRATOTEGIC

CSA ASC

Mitacs

Canon

McGill

Satellite Communications

Radio Frequency (RF) Spectrum for Satellite

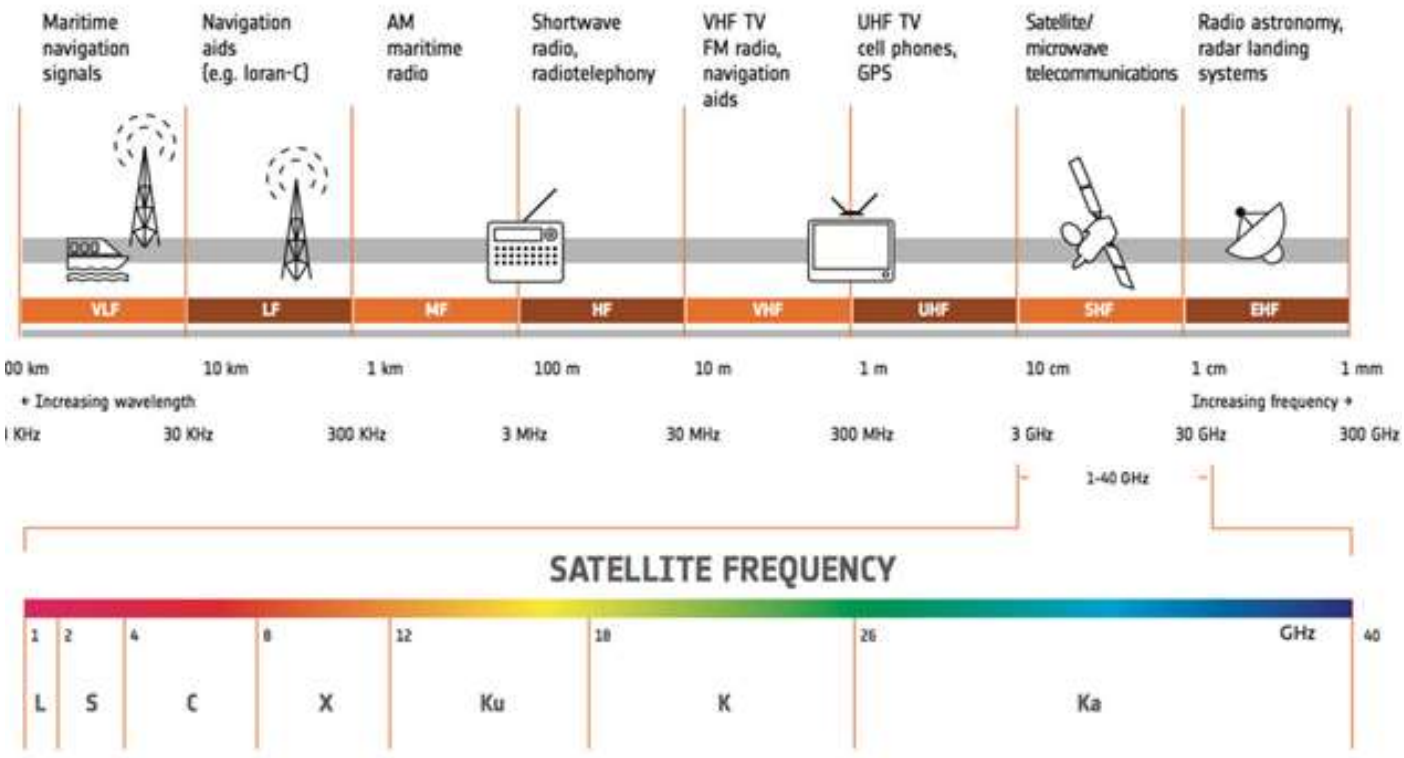
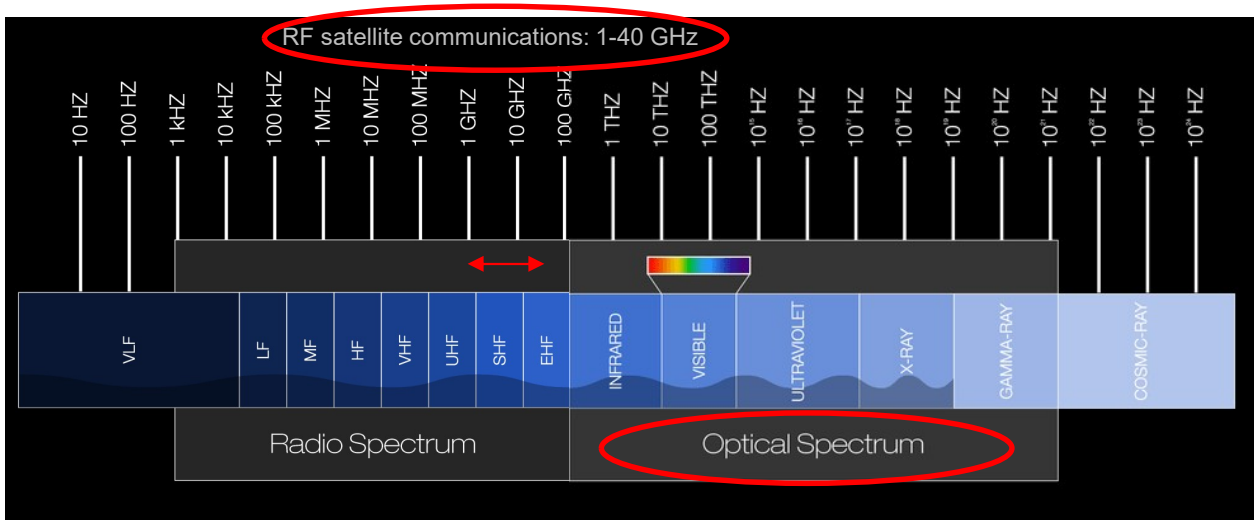


Image: ESA - Satellite frequency bands

Electromagnetic Spectrum

Higher frequencies, faster communications



For higher throughput, need to leverage the optical spectrum

Image: Nasa.gov

Satellite Basics

For existing satellite systems, links are typically RF with some optical inter-satellite links emerging

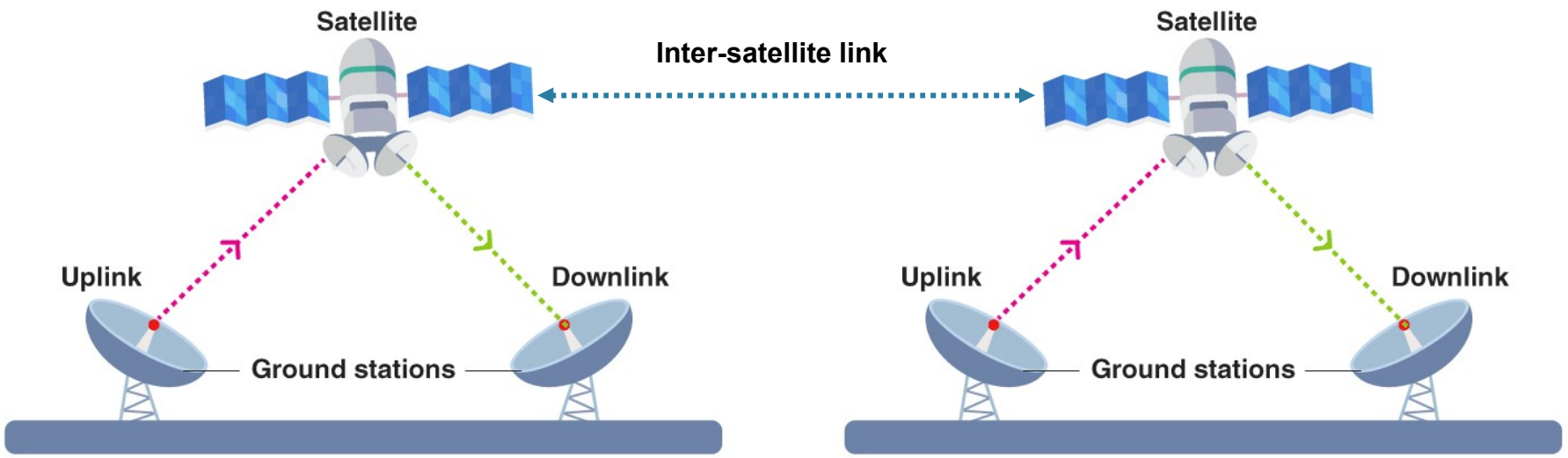


Image: Satellite Communication: Definition, Block Diagram, Advantages, Applications

Satellite Orbits

- Since the 1960s, geostationary earth orbit (GEO) satellites have provided communication services
- Low earth orbit (LEO) satellites have lower latency and often provide higher bandwidth per user than GEO satellites

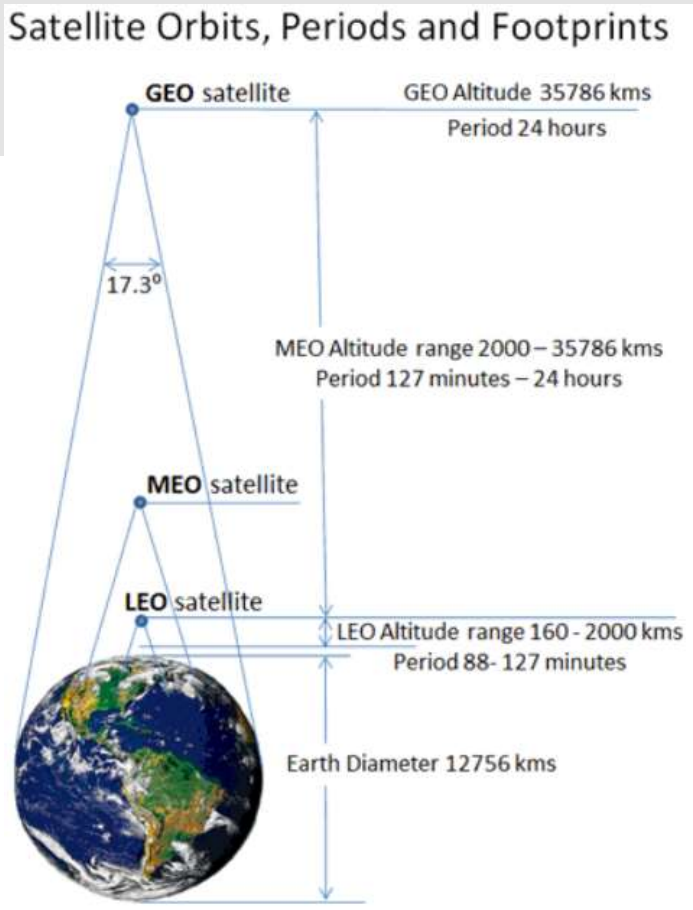
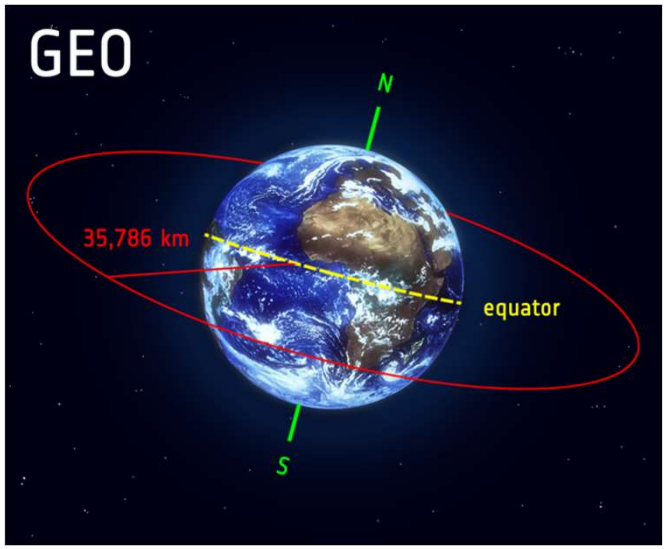


Image: https://www.mpoweruk.com/satellites.htm

GEO Satellites – Large, stand-alone units

Geostationary Earth Orbit (GEO)



Features:

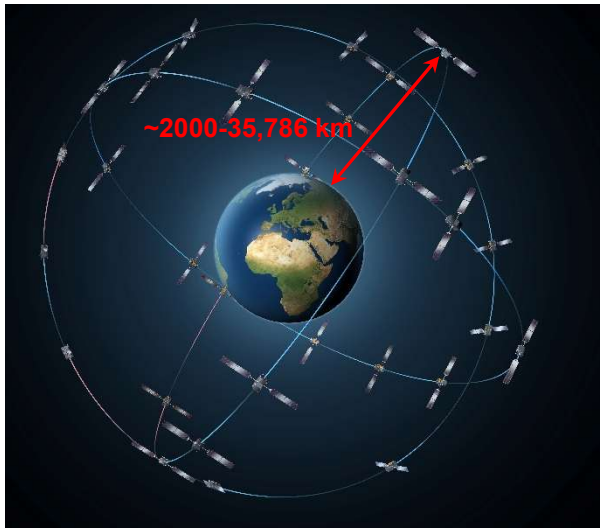
- Large, stand-alone units, each satellite:
  - Can service more than 33% of earth surface
  - Is large and expensive
- Orbit: 35,786 km above equator
  - Moves in sync with earth's rotation, stays above same point on the ground
  - High and low latitudes hard to reach
- Higher orbit = high latency (delay), e.g. 600-800ms
- Use radio frequency bands, no optical signals

Applications: Weather data, broadcast TV, low speed telecommunications

Ref: ESA - Types of orbits

MEO Satellites – Alone or constellations

Medium Earth Orbit (MEO)



Features:

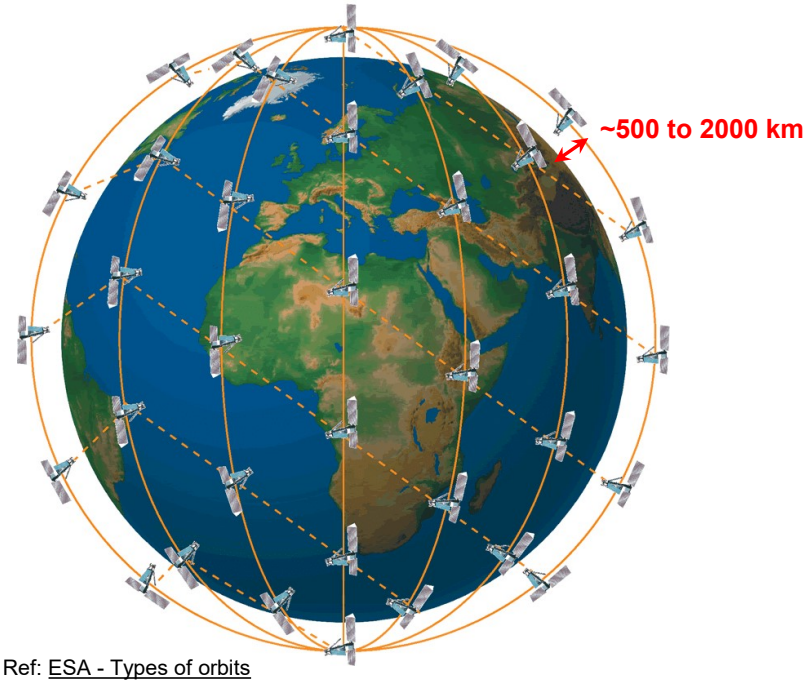
- Work alone or as constellations, each satellite can service a good portion of the earth's surface
- Orbit: ~2000 to 35,786 km above earth
- Satellites not synchronous with earth rotation
  - Period (one full orbit around earth): 127min – 24 hrs
- Medium orbit = Medium latency, e.g. 125-250 ms

Applications: GPS / navigation

Ref: ESA - Types of orbits

LEO Satellites - Constellations

Low Earth Orbit (LEO)



Ref: ESA - Types of orbits

Features:

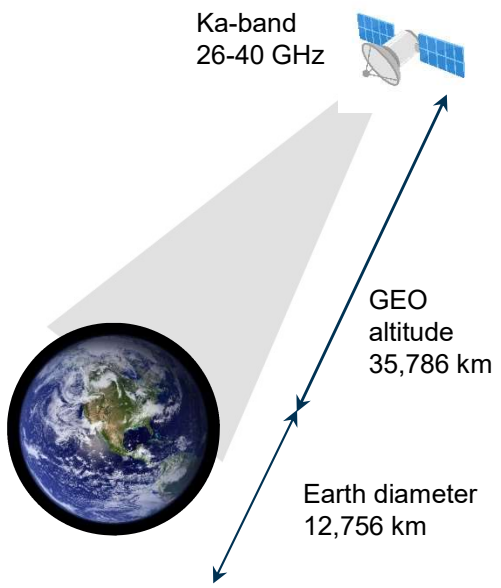
- Work in “constellations” of interconnected satellites, each satellite:
  - Can service only a small portion of the earth’s surface (about 500 km x 500 km)
  - Is relatively small and “cheap”
- Orbit ~500 to 2000 km above earth
- Satellites not synchronous with earth rotation
  - Period (one full orbit around earth): 88-127 min
- Lower orbit = lower latency, e.g. 30-50 ms (Starlink | Technology)
- Optical inter-satellite links are in use and emerging

Applications: Earth observation, broadband internet

Communication Services from GEO Satellites: Viasat

Year	Satellite	Band	Total Capacity	Cost Base of Capacity	Peak data rates (down)
2006	**Wildblue-1**	Ka-band	7 Gbps	>$200/Mbps/mo.	3 Mbps
2011	**Viasat-1**	Ka-band	140 Gbps	$20/Mbps/mo.	12 Mbps
2017	**Viasat-2**	Ka-band	260 Gbps	$13/Mbps/mo.	30 Mbps
2022	**Viasat-3**	Ka-band	1,000 Gbps	$4/Mbps/mo.	100 Mbps
2028	**Viasat-4**	TBD	5 to 7 Tbps	TBD	500 Mbps *(extrapolated)*
Post-2030	**Viasat-5**	TBD	10 to 15 Tbps	TBD	1 Gbps *(extrapolated)*

Ref: OSC Technology Roadmap, SatCan, 2022

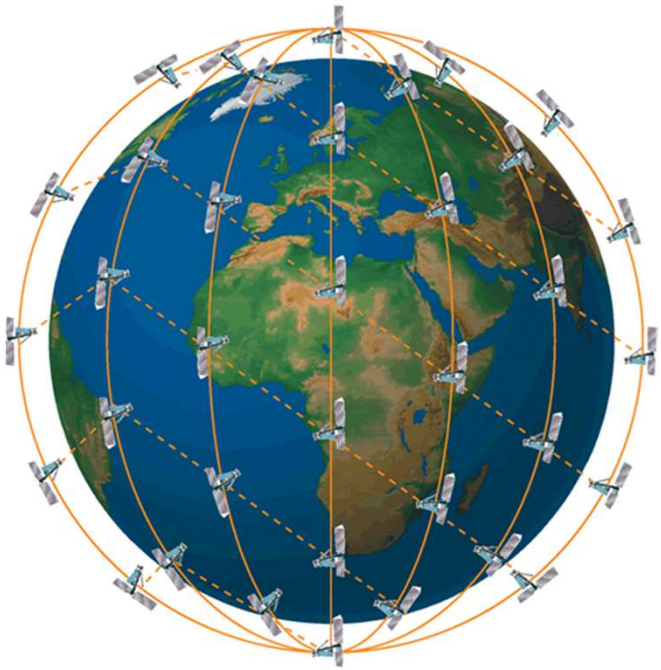


- **Each Viasat-3 satellite (3 satellites) planned for 1 Tbps total capacity**
  - Advertised downlink speed up to 100 Mbps
- **1st satellite launched April 2023**
  - Main antenna failed to deploy correctly, losing >90% of satellite's planned capacity
- **Company filing $420M insurance claim**

Communication Services from LEO Constellations

Year	Constellation		# of Sats	Capacity per Sat	System Capacity	Optical ISLs	Optical Ground Link
2020-27	SpaceX Starlink	Gen1	4,425	20 Gbps	88 Tbps	Yes	No
2025-32		Gen2	30,000	>60 Gbps	>1,000 Tbps	Yes	Yes
2025-35	Telesat Lightspeed	Gen1	300	50 Gbps	15 Tbps	Yes	No
2032-40		Gen2	1,373	TBD	>70 Tbps	Yes	Yes
2021-26	OneWeb	Gen1	650	8 Gbps	5 Tbps	No	No
2025-30		Gen2	6,372	TBD	>50 Tbps	Yes	Yes
2024-30	Amazon Kuiper	Gen1	3,326	50 Gbps	166 Tbps	Yes	No

Ref: OSC Technology Roadmap, 2022



- **Each satellite covers a small area (~500 km x 500 km)**
- **Smaller capacity per satellite, higher capacity per user**
  - Current service levels: Maximum ~100-200 Mbps downloads
- **Shorter distance = lower latency**
- **Optical inter-satellite links (ISLs) makes routing faster and more secure**
- **Satellite to ground links radio frequency (RF) (Ka-Band)**
  - Second generation plans for optical satellite to ground links

LEO Satellite Constellations – SpaceX StarLink

- **As of September 2024, >6,000 LEO satellites at 550km altitude**
  - Each satellite has 3 optical ISLs operating at up to 200 Gbps
  - Possible extension to as many as ~40,000 satellites
- **>4 million subscribers**
- **Residential plan in Canada**
  - **Cost:** CA$140/month for service (unlimited data, no contract) and CA$299-$499 for hardware
    - Currently in Iqaluit: “StarLink is at capacity in your area”
  - **Speed:** Download 25-220 Mbps; upload 5-20 Mbps (“actual speeds may be lower than expected speeds during times of high usage”)
  - **Latency:** 25-60 ms on land, 100+ ms in certain remote locations (e.g. Northern Canada)

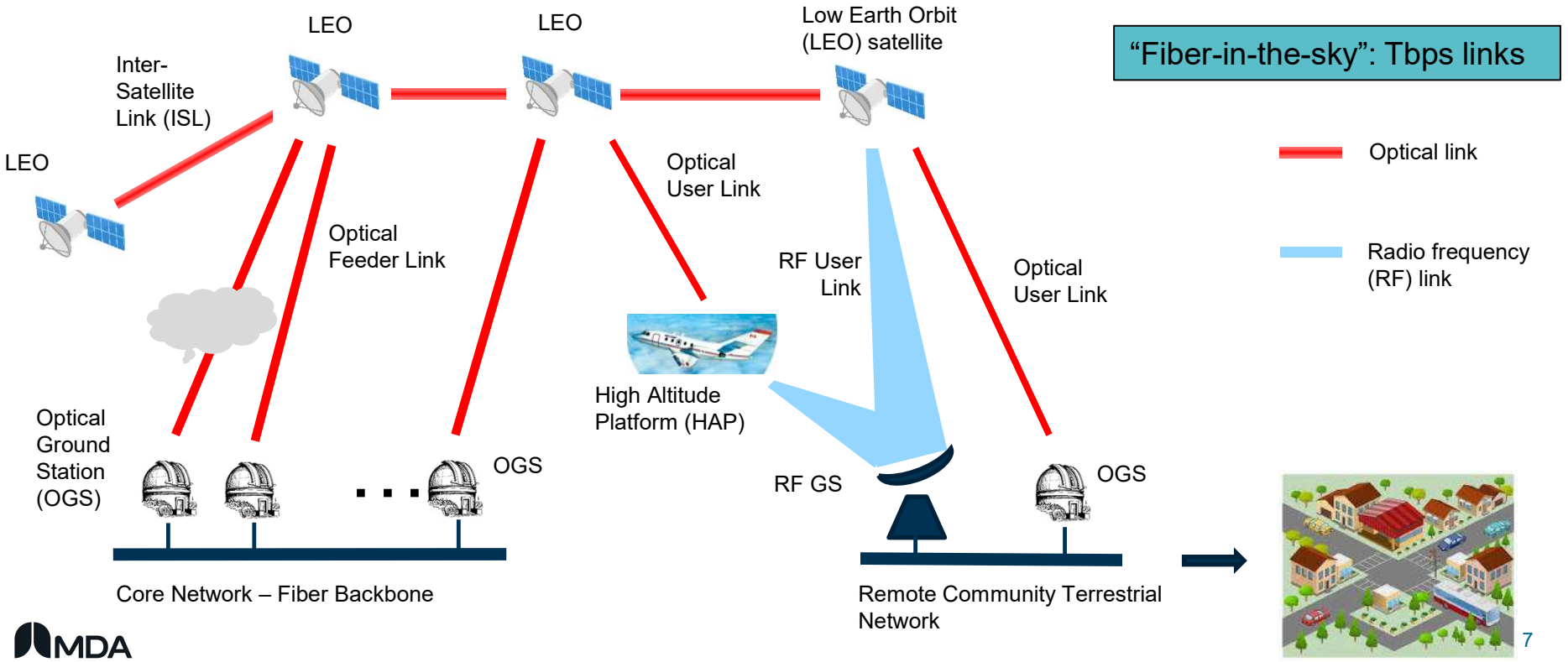
Sources: https://www.starlink.com

LEO Satellite Constellations – Telesat LightSpeed

- **Government loans in support of Telesat Lightspeed as of 2024**
  - Government of Canada: $2.14B
  - Government of Quebec: $400M
- **Scheduled to begin launch in 2026**
- **198 LEO satellites at ~1,300 km altitude**
  - 30-50 ms latency
  - Multiple Tbps of capacity
  - Gbps speeds
  - Ubiquitous coverage
  - 20X faster than GEO

Sources: https://www.telesat.com

Optical Satellite Communications: HTSN Vision



LEO Example: Connecting Remote Villages

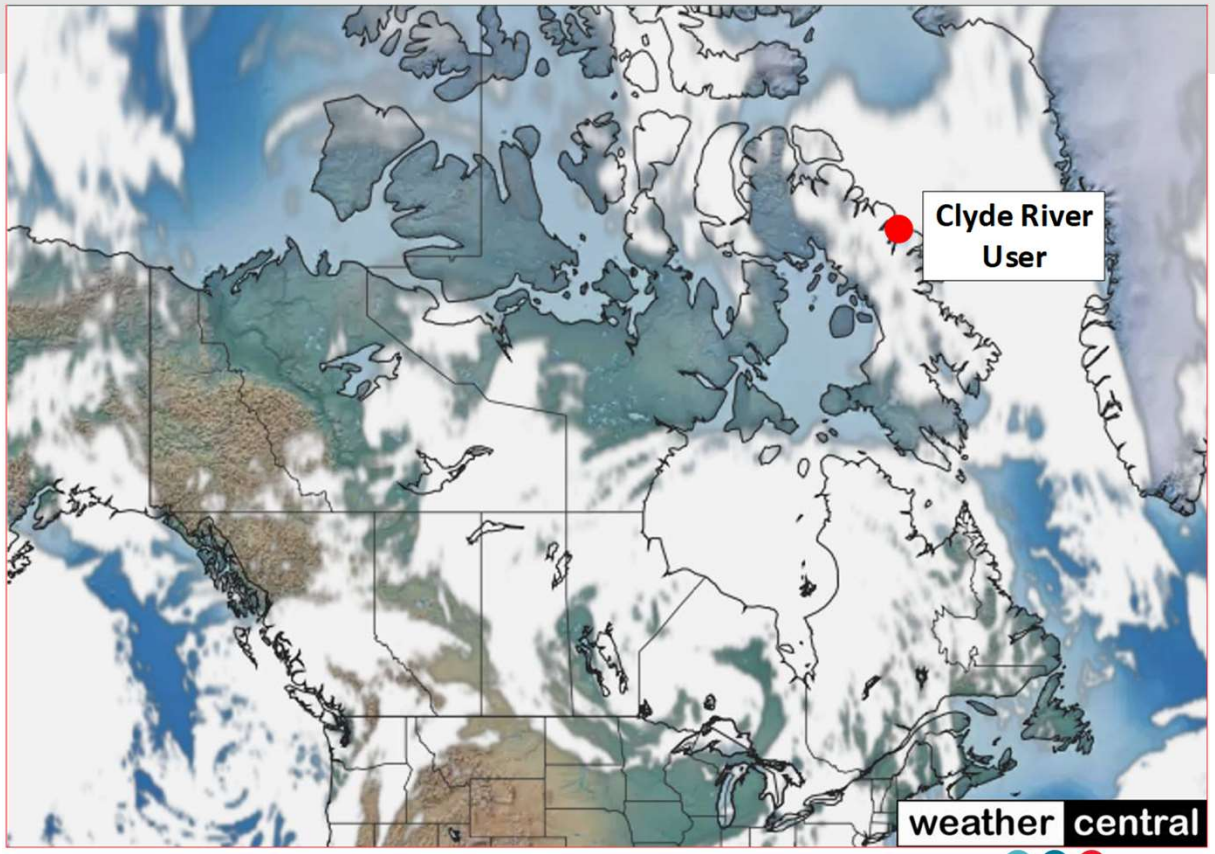
Objective: Provide high speed internet connectivity to Clyde River

Challenges:

- No nearby fiber link
- Low capacity on existing GEO satellites
- For sat-ground laser link: cloud coverage is wide in Clyde River

However, there are areas in Canada without clouds, some of which have points of presence (PoPs) (e.g. Calgary)

Solution: Connect to the Calgary OGS / PoP and establish a route to Clyde River



Ref: OSC System Architecture Presentation, MDA Space, 2022

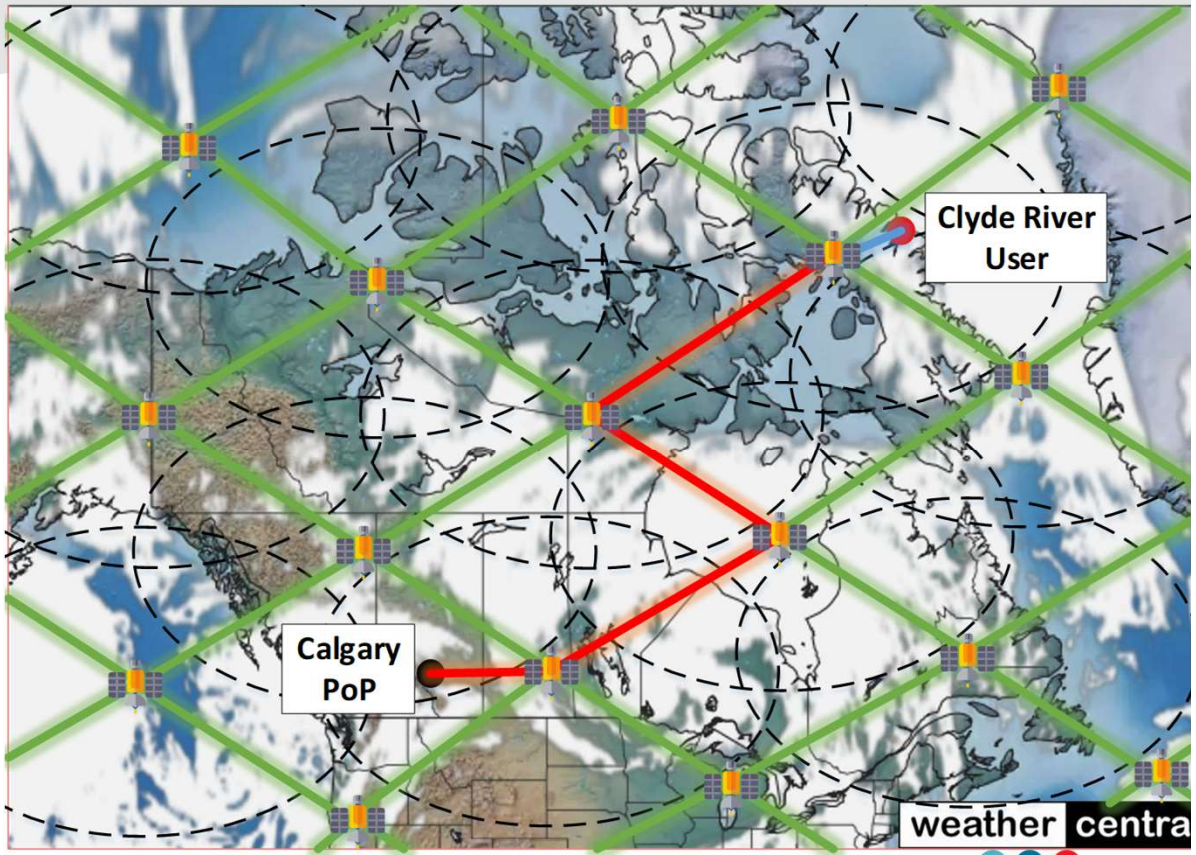
LEO Example: Connecting Remote Villages

The Calgary OGS is selected and the optical link established, along with the space-based route, to Clyde River

The Clyde River user is covered by clouds: an RF link is used

Satellites are moving, but it is deterministic (i.e. trajectories are known as a function of time)

Cloud coverage is varying but can be predicted on the short/medium term



https://ca.weathercentral.com/weather/ca/satellite/ca-satellite-cloud-cover

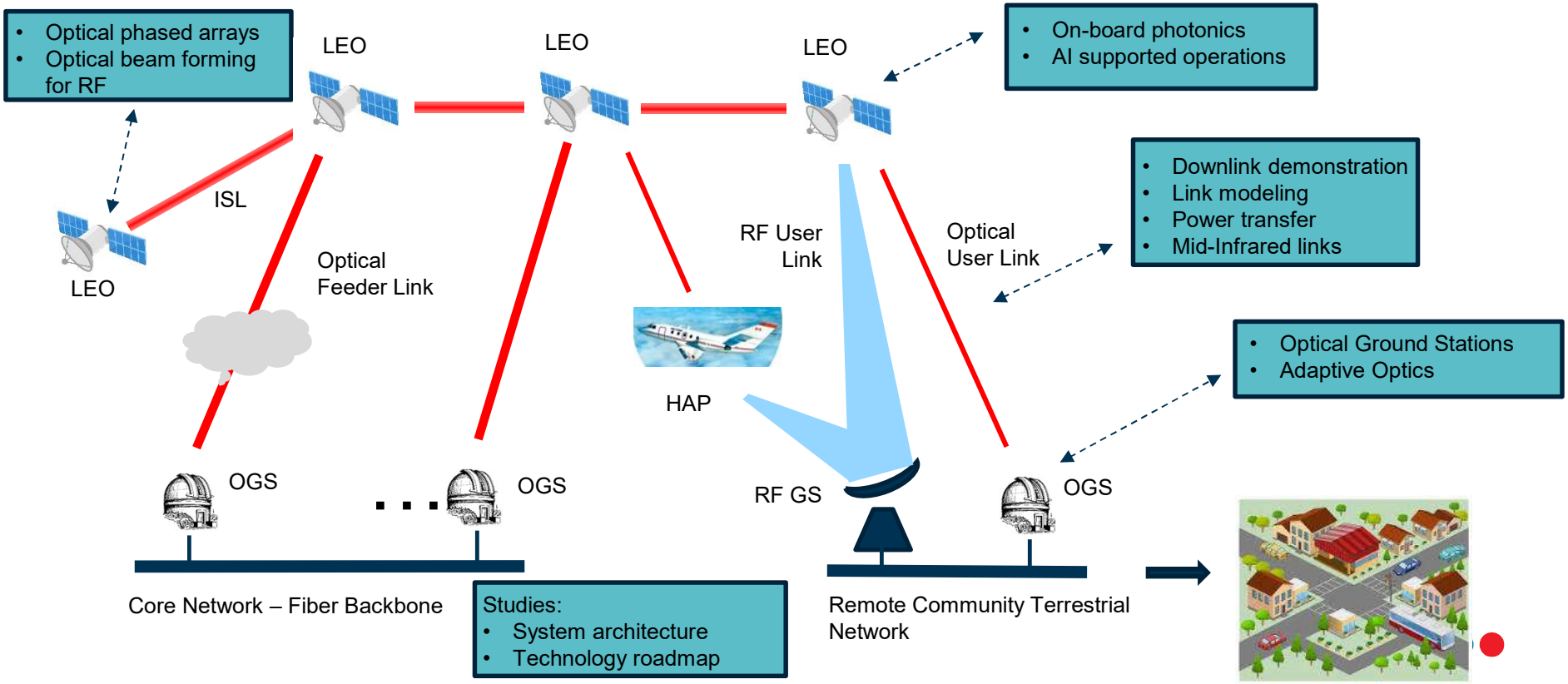
Ref: OSC System Architecture Presentation, MDA Space, 2022

Comparing Optical and RF Ground-to-Satellite Links

Characteristic	Laser Link (free space optical link)	RF Link
Spectrum	near infrared and visible light band	Ka, Ku, and mm-wave band
Spectrum allocation	Unlicensed	Licensed by ITU
Bandwidth	THz (Tb/s)	GHz (Gb/s)
Wavelength	nm	up to mm
Antenna size	smaller antenna (lens) size	much larger antenna size as it is proportional to wavelength
Beam spread	much narrower (1 km radius or so)	typically 1,000 times wider
Directivity	very high	much lower
Power consumption	more received power for a given transmitted power	less received power due to beam spreading
Security	very difficult to intercept due to its directivity	easy to intercept due to the beam spreading and reflections
Interference	minor interference due to reflections	severe interference from neighboring users
Line-of-sight obstructions	severely impact performance	severely impact performance at mm-wave band, but better than FSO otherwise
Pointing error	Degrades link quality dramatically	Much less affected by pointing errors than FSO
Weather conditions	can cause attenuation of 250 dB/km with dense fog	Affected by rain (drops comparable to wavelength), but still much better than FSO under harsh weather conditions

Ref: OSC System Architecture, MDA Space, 2022

HTSN: Key Optical Satcom Investments



HTSN Project, “Canadian Optical Communication Downlink Demonstration with Optical Channel Assessment”

- **Timeframe: August 2024 - March 2026**
- **Collaborators: McMaster University, MDA Space, NRC, NRCan, DLR (German Aerospace Centre)**
- **Key outcomes:**
  - A *mobile research facility* will be developed and deployed at a Canadian location
  - *First demonstration* of an optical data downlink from a (LEO) satellite to a location in Canada
  - *Atmospheric mitigation experiments* will be performed using other HTSN-developed technologies
  - *Database of real atmospheric measurements* will be created

Summary

- **Many communities in Canada are satellite-dependent**
- **LEO satellite communications are being deployed and offer broadband internet; capacity will increase and costs will decrease over time**
- **The future of space communications is optical satcom, enabling orders of magnitude higher capacity**
  - Will allow seamless extension of high-capacity terrestrial systems into space, expanding coverage and reducing latency and connection costs
- **Canada is ideally positioned to become a leader in optical satcom due to our geography and technological strengths**
  - HTSN investments have seeded vital expertise in optical satcom in Canada

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Questions?

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High Throughput and Secure Networks Challenge Program: https://nrc.canada.ca/en/research-development/research-collaboration/programs/high-throughput-secure-networks-challenge-program

Optical SatCom Consortium: https://www.satellitecanada.org/osc