OPTICAL SATELLITE NETWORKING

Indicative References

JOURNAL OF LIGHTWAVE TECHNOLOGY, VOL. 18, NO. 12, DECEMBER 2000

Optical Satellite Networks

Nikos Karafolas, *Member; IEEE,* and Stefano Baroni, *Associate Member; IEEE*

JOURNAL OF LIGHTWAVE TECHNOLOGY, VOL. 21, NO. 11, NOVEMBER 2003

Optical Satellite Networks

Vincent W. S. Chan, *Fellow, IEEE, Fellow, OSA*

LASER LIGHT COMMUNICATIONS
Executive Summary

Pacific Telecommunications Conference

PTC - 14

Honolulu, Hawaii

January 21, 2014

esa

What is a network?

It takes 2 “nodes” to have a “link”
It takes minimum 3 “nodes” to have a “network”

If the nodes are satellites and the links are optical we have an

“Optical Satellite Network”

to form an Optical Satellite Network

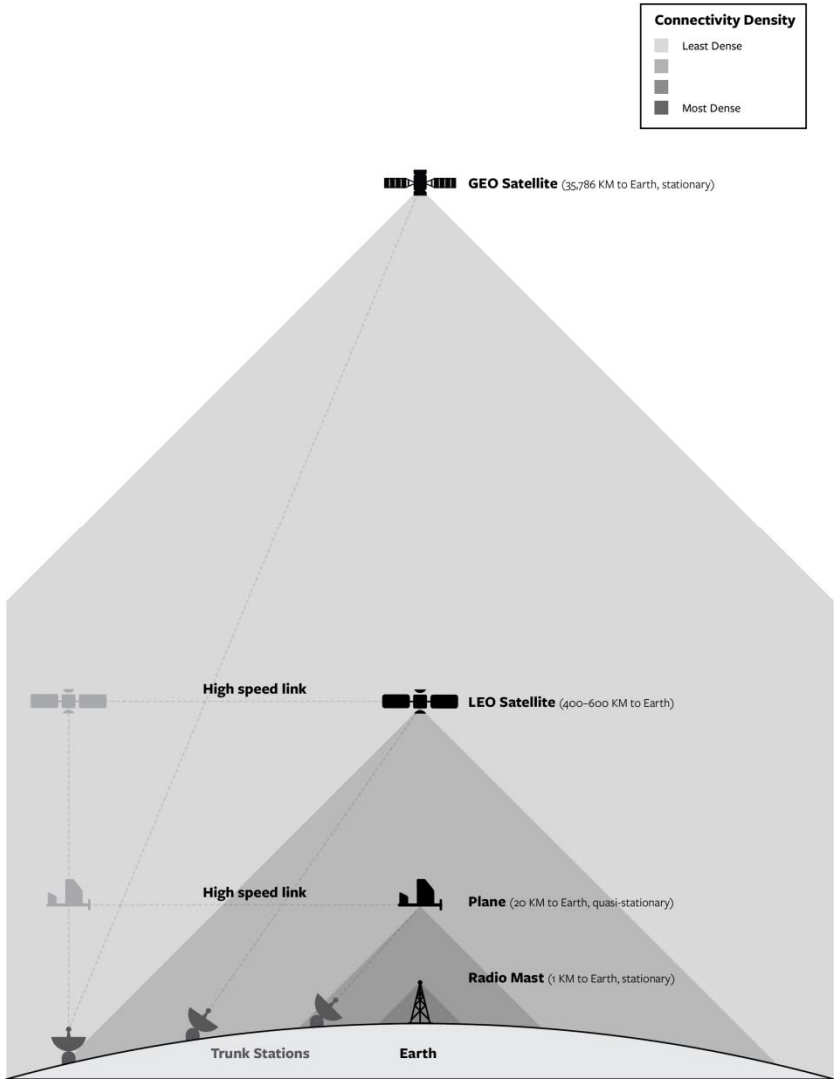
We need:

- A constellation of satellites (or “nodes”)
- Optical Inter-satellite Links
- Satellite to Ground to Satellite Links can be either
  - *RF links (access to end-users and TELCO operator’s Ground Stations) or*
  - *Optical Links (only for TELCO operator’s Ground Stations)*

Satellite Constellations can be formed in different orbits: LEO-MEO-GEO

Platforms at different altitudes

Higher altitudes generally means beams are more spread out on Earth, but giving more trunking opportunities far away from the sites of interest.



Latency is of great concern especially when compared to terrestrial fiber based latency for the most delay-sensitive application like voice/video-conference.

- GEO is longer than fiber delay
- MEO is similar to fiber delay
- LEO is smaller to fiber delay

Remember light travels

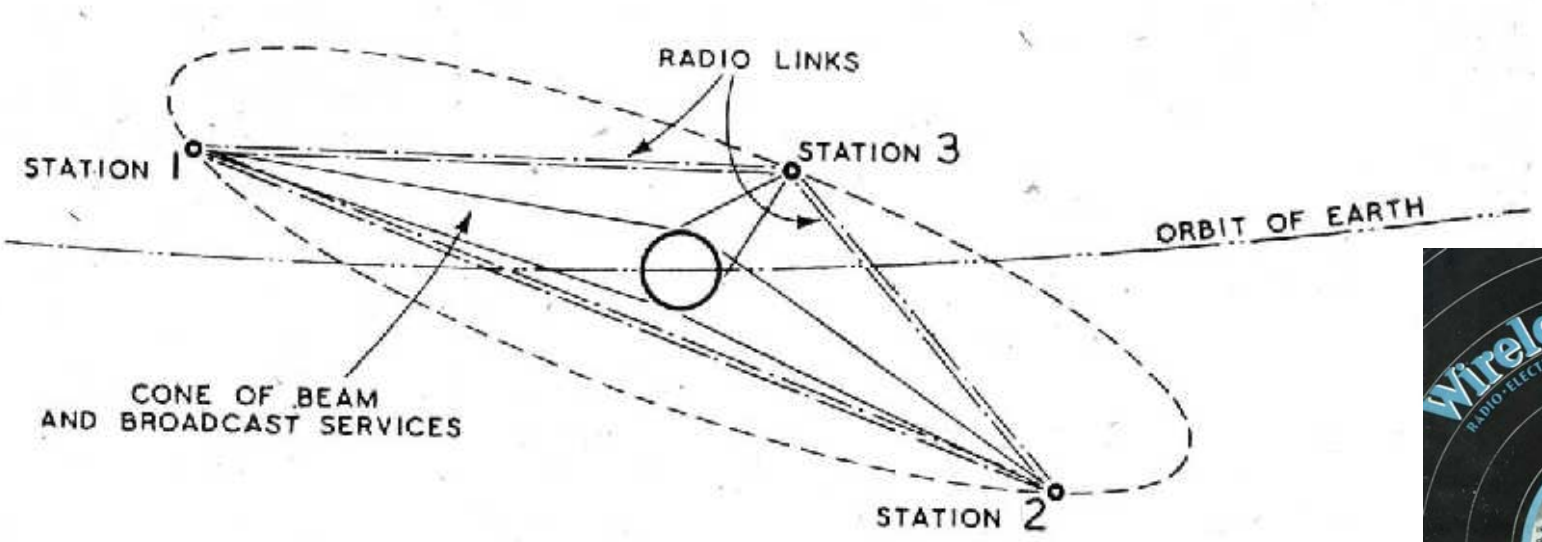
- at 300.000 km/sec in free space
- at 200.000 km/sec in an optical fiber

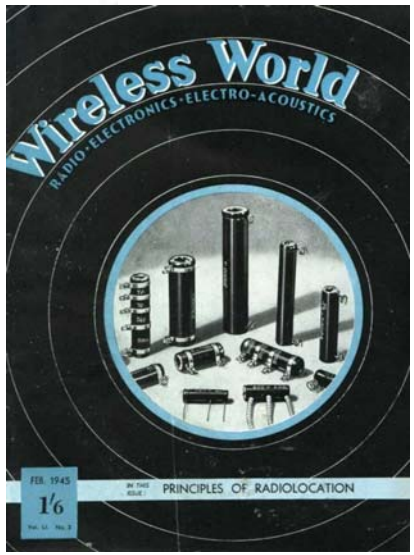
GEO
the first Optical Satellite Network proposal
"a global 3-nodes GEO ring topology-Clarke Network"

proposed by Arthur Clarke in October's 1945 issue of "Wireless World"

…The stations in the chain would be linked by radio or optical beams,

and thus any conceivable beam or broadcast service could be provided…"





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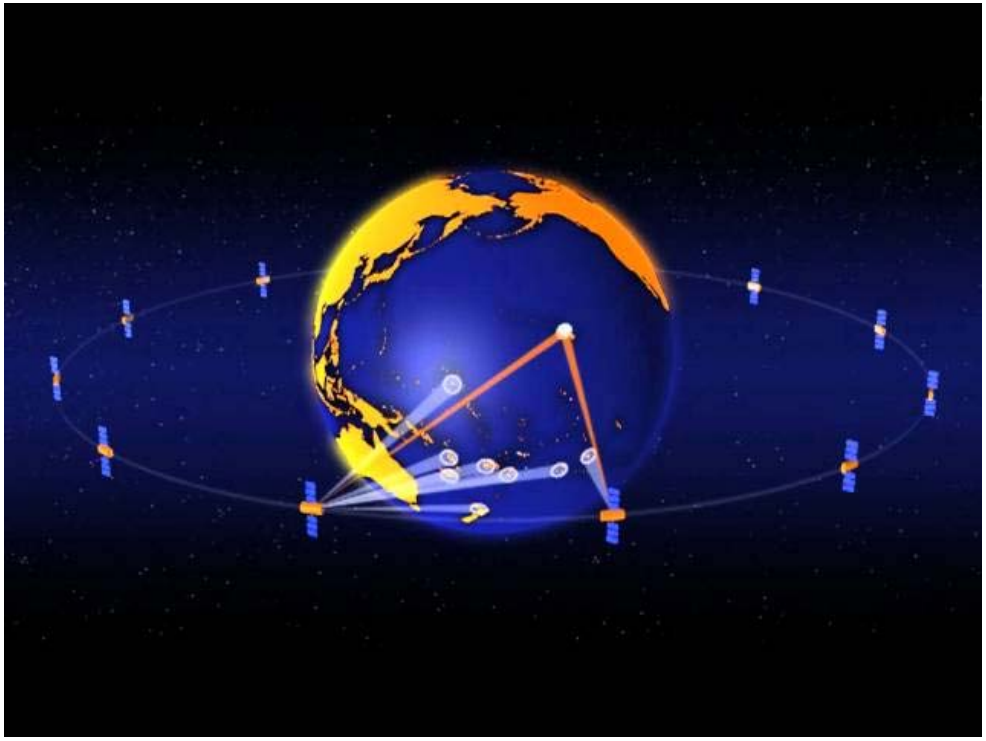
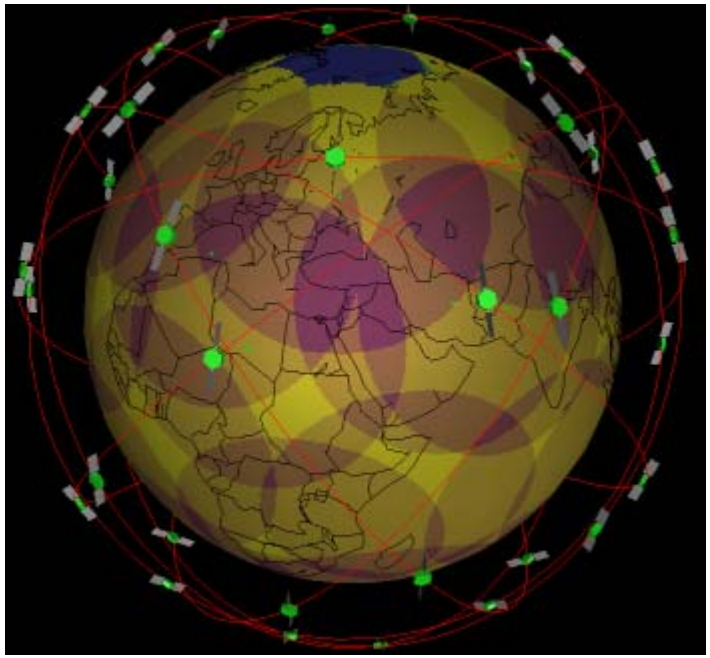
MEO (bent-pipe)



The O3B constellation (video 1.46 min)
https://www.youtube.com/watch?v=ehM7FG1oB9Y

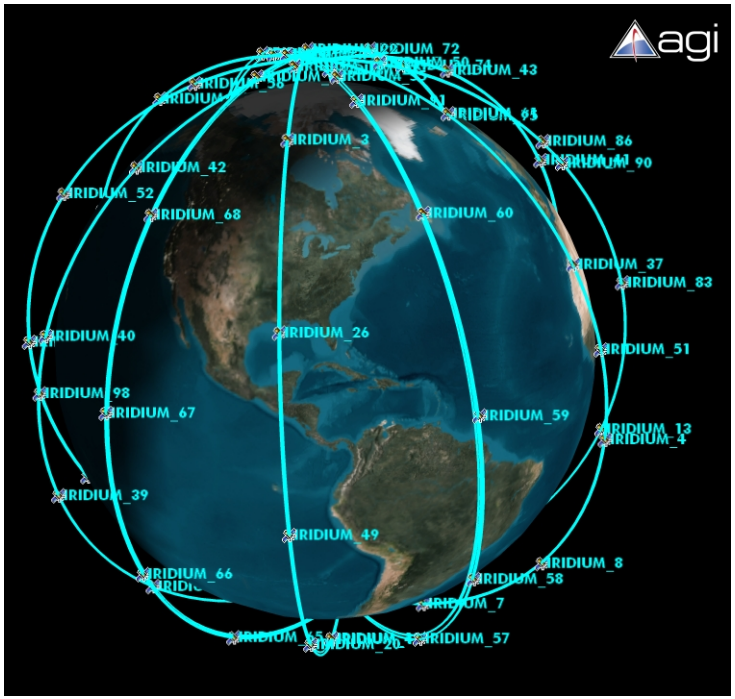
LEO constellations (bent-pipe)



Gloablstar (video network-coverage simulation 0-1.34 min)

https://www.youtube.com/watch?v=G8VPEueequM

LEO (with ISLs i.e a "Satellite Constellation Network")



Constellation run (video Iridium Network run - Seam Visible 2.00 min)
https://www.youtube.com/watch?v=MGJal5uPXRA&list=PLedMFUaKH9DkwVY-q-ulAVBXWeM-Yto9F&index=8

End to end Communications (video maritime Iridium 0.58 min)
https://www.youtube.com/watch?v=AdoxXqMiwGo&list=PLedMFUaKH9DkwVY-q-ulAVBXWeM-Yto9F&index=7

These Satellite Constellation Networks are the ones of interest to apply

- **Optical inter-satellite links**
- **Optical on-board routing**

and hence form an

“Satellite Optical Transport Network”

similar to

“Terrestrial Optical Transport Network”

and

“Submarine Optical Transport Network”

How an "optical satellite constellation network" is formed?

SATELLITE NETWORK **PHYSICAL** TOPOLOGY

- Decide the **orbit** LEO-MEO-GEO (the lower the orbit the more satellites are needed for global coverage – impact on elevation of ground antenna)
- Decide **number of orbital planes** and **inclination**
- Decide **number of satellites/orbital plane**
- Decide on launching policy **π or 2π** and "**phasing**" (i.e. spacing)
- Decide **number of ISLs per satellite**
- Decide which **satellites** will be linked with ISLs

2 main physical topologies

- Ring
- Mesh

Example: *A ring of satellites (O3B type) can form network topology of either:*

- a Ring (2 ISLs/sat)
- a Mesh(4 ISLs/sat)

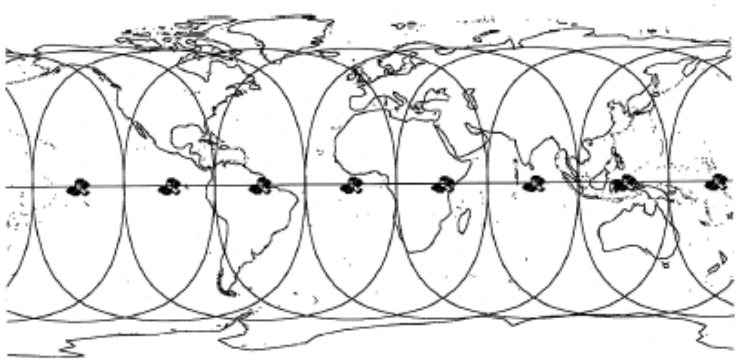


FIGURE 11.3 Equatorial satellite network with two ISLs terminals per S/C in a global ring physical topology.

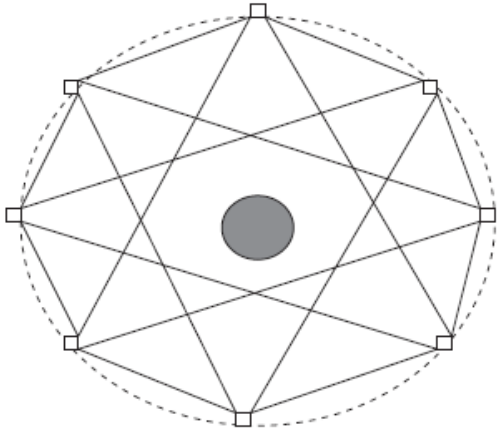


FIGURE 11.4 GEO satellite network with four ISL terminals per S/C in a mesh topology.

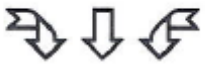
for LEO and truly global coverage

a grid of tens/hundreds satellites is required

Satellite network physical topology properties

- satellite nodes placement in orbital rings formations resulting in a ***grid*** configuration
- continuous propagation of the satellites nodes (in excess of 25000 km/hr in LEO)
- predictable and periodic character of their motion (100 min. orbit period in LEO)
- laser ISLs provide the network with multigigabit connectivity (intra-obit, inter-orbit)
- laser ISLs are maintained throughout the network orbital movement, i.e ***fixed ISL topology….***
- periodic and predictable change of the inter-orbit ISL range

resulting in



a fixed network topology of bidirectional Manhattan Street Network

- cylindrical mesh (ring-chord topologies known as "π constellations")
- toroidal mesh (ring-spiral topologies known as "2π constellations")

Satellite network design properties

- Number of satellites (LEO: 40-140, MEO: 10-30, GEO:3-10)
- Orbital altitude (LEO:700-1500 km, MEO:10000 km, GEO: 36000km)
- Orbital planes (LEO: 6-12, MEO: 1-6, GEO:1)
- Number of satellites per plane (equally-spaced) (LEO:8-24, MEO:5-10, GEO: 3-15)
- Inclination (near polar, inclined or equatorial)
- Phasing between adjacent planes
- Intersatellite links (ususally 4: left-right-fore-aft, 6, or 8)
- Minimum elevation (20^0 to 40^0 for fixed antennas, 10^0 for mobile)
- Number of spot beams (up to about 200 per satellite)
- Coverage area of each spot beam (LEO: 00's kms, MEO: 000s kms),
- Satellite caapcity (currently up to about 10 Gbps)

π Mesh Constellations

6 orbital planes (space by 30 deg)

11 satellites per orbital plane

4 ISLs/per satellite with 3 at the “network seam”

Altitude 781 km

Orbital Period 6013 sec

Inclination 86.4

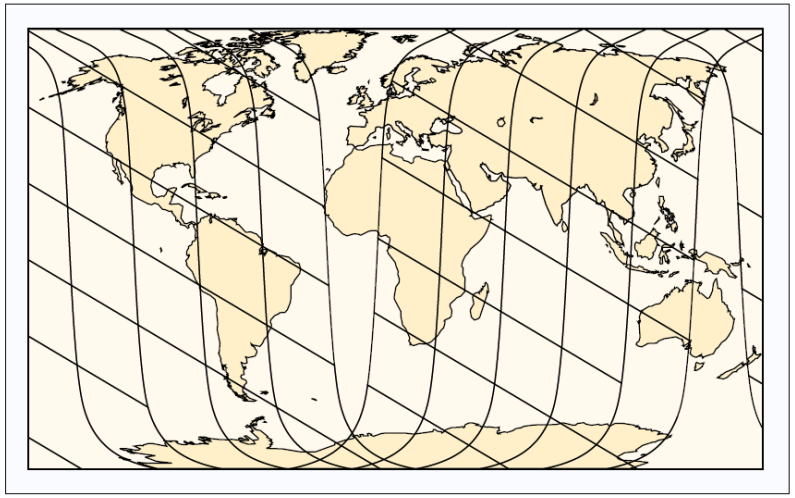
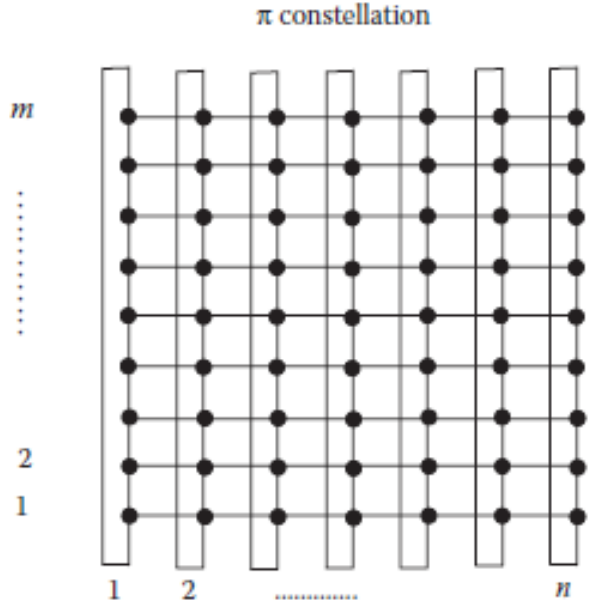


Figure 3. *Depiction of IRIDIUM inter-satellite links.*

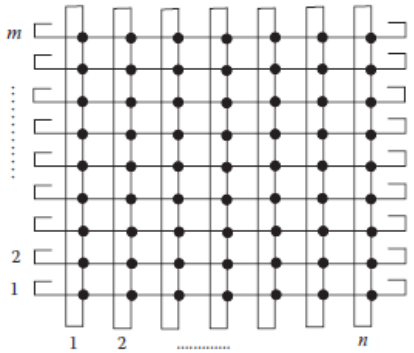
IEEE Communications Surveys • http://www.comsoc.org/pubs/surveys • Second Quarter 1999



2π Mesh Constellations

2π constellation

From: ms = [md - n*p/s] mod(m) To: md = [ms + n*p/s] mod(m)



n: the number of orbits
m: the number of interorbit rows
ms: the row number of the source satellite
md: the row number of the destination satellite
p: the inter-orbit phasing factor
s: the intra-orbit spacing

Satellites:	*63*
Planes:	*7*
Altitude (km):	*1400*
Inclination:	*48^0*
Plane phasing:	*+ 28.57*
Orbit period (sec):	*6825*
ISLs per s/c:	*6*
Azimuth range:	*$\pm 75^0$*
Azimuth change rate (deg/sec):	*< 0.2*
Elevation range:	*-7^0 to -23^0*
Elevation rate (deg/sec):	*0.01*
ISL range (km):	*<5860*
ISL range change rate (km/sec):	*<3*
Physical connectivity (189/1953) :	*0.096*
network diameter (in ISL hops):	*6*
mean intersatellite distance:	*3.25*
nodal input/output degree:	*6*

The concepts of a **Satellite Optical Transport Network**

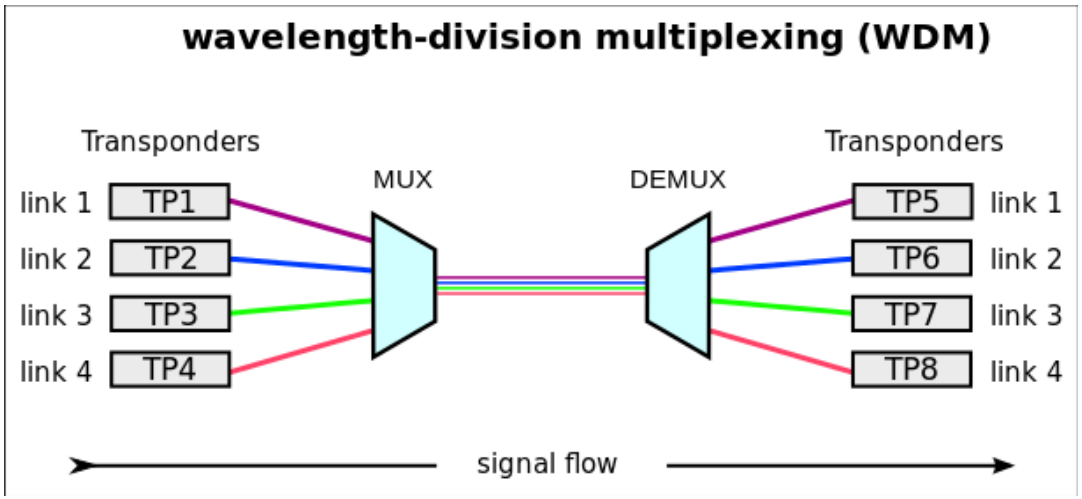
based

Wavelength Division Multiplexed ISLs

and

On board **Wavelength Selecive Routing**

Wavelength Division Multiplexing



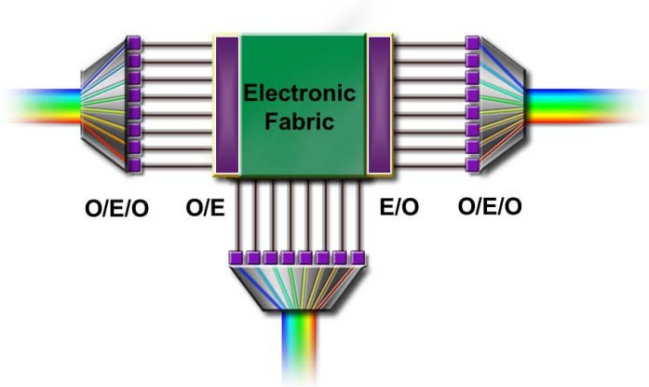
WDM

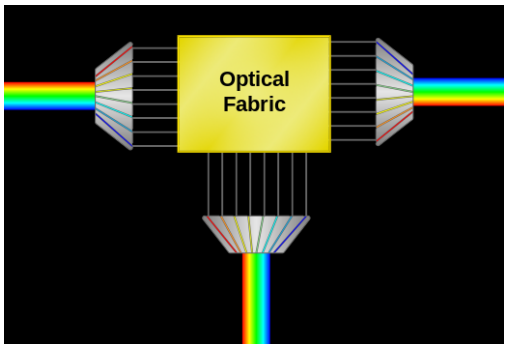
Essentially it is frequency division multiplexing in the optical band. Talking in terms of wavelength was easier because no accurate setting of the laser emitting frequency was possible. With the development of very stable and accurate tuned lasers the term **Optical FDM** emerges indicating close frequency spacing (carriers spaced by some GHz apart) and accurate frequency setting (within a MHz).

Frequency allocation in WDM networks

Frequency allocation plan has been established for the wavelength band of 1550 nm. The ITU has defined the grid of frequencies based on spacing of the optical carriers in multiples and sub-multiples of 100 GHz (usually 200 GHz, 50 GHZ, 25 GHz). 100 GHz correspond to about 0.8 nm spacing at the 1550 band.

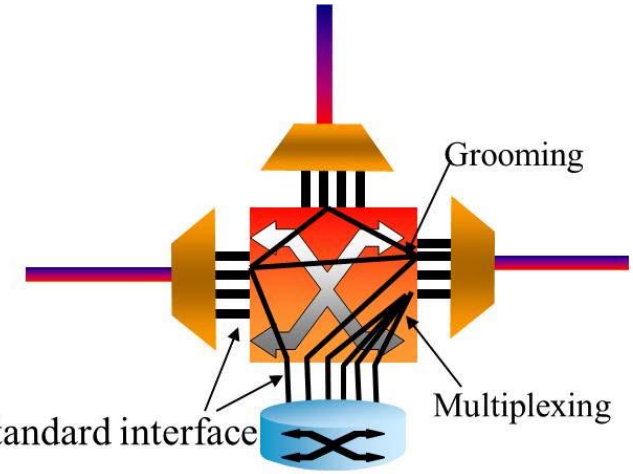
The idea of WDM Links and Wavelength routing via Wavelength Selective Optical Crossconnect





Wavelength routing

It is equivalent to optical circuit switching. In this scheme the optical carriers of a WDM stream input in an optical switch are first demultiplexed, then each wavelength carrier is routed independently in the required output port where it is multiplexed with other wavelength carriers destined to the same output.



en.wikipedia.org/wiki/Optical_mesh_network

The concept of "lightpath"

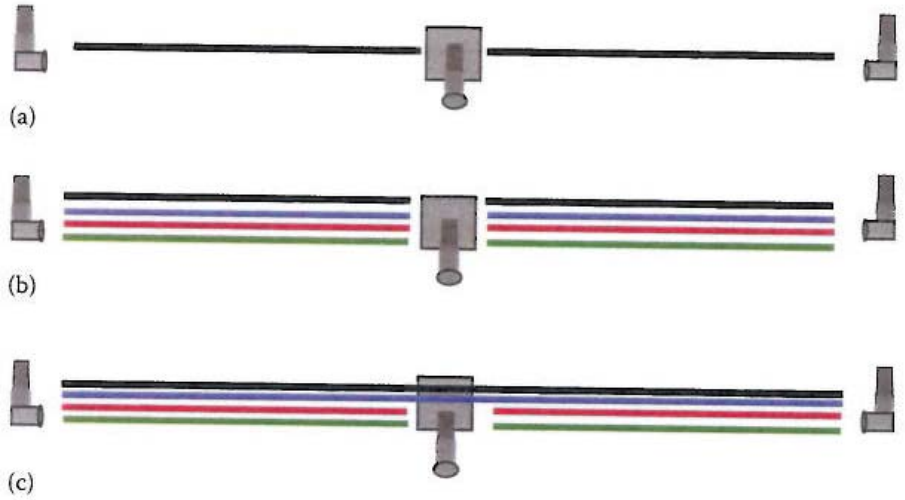
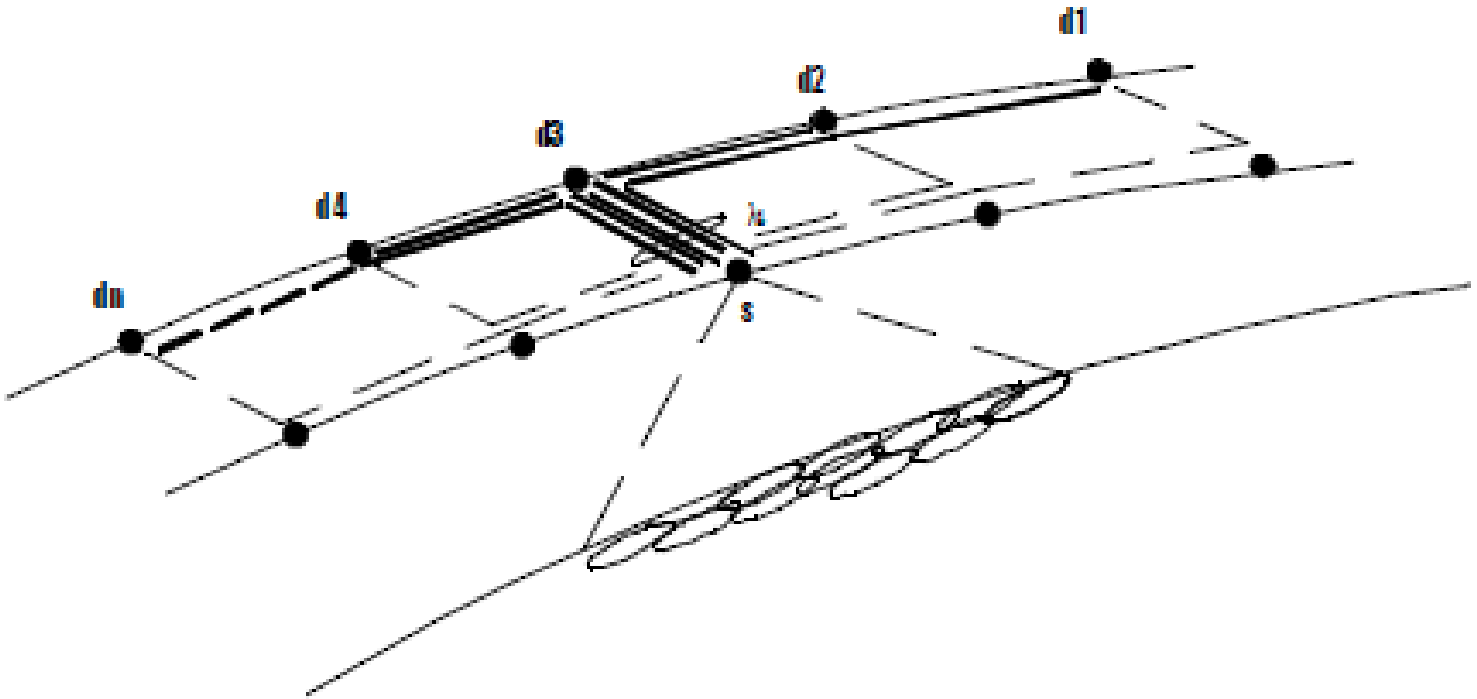


FIGURE 11.5 (a) Single wavelength optical ISL, (b) WDM optical ISL, and (c) WDM ISL with wavelength routing.

Lightpath

It is a wavelength channel connecting two end-nodes through intermediate wavelength routing nodes.

A lightpath can link directly *one satellite with another through intermediate ones*



a Satellite Payload
WDM ISLs and W-S OXC

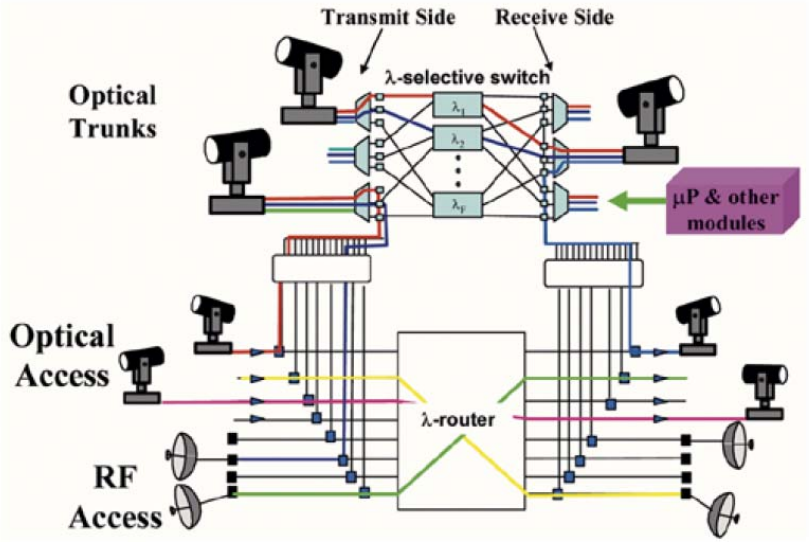


Fig. 19. Optical satellite network WDM switching node.

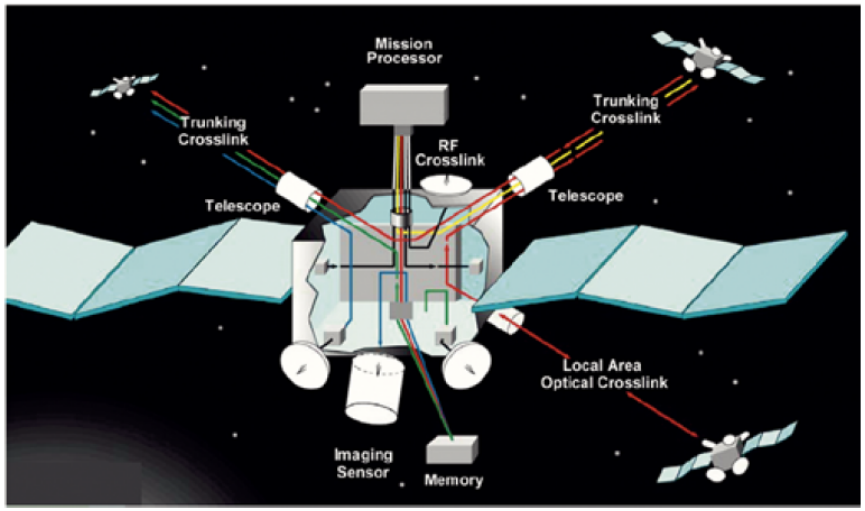


Fig. 16. Optical satellite node connection architecture.

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Optical Satellite Networks

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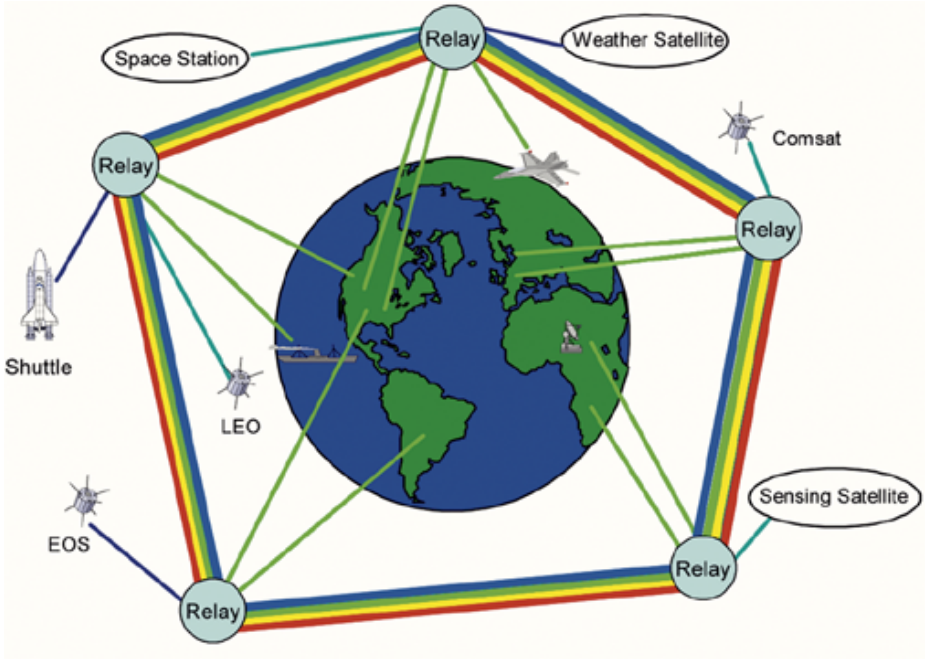
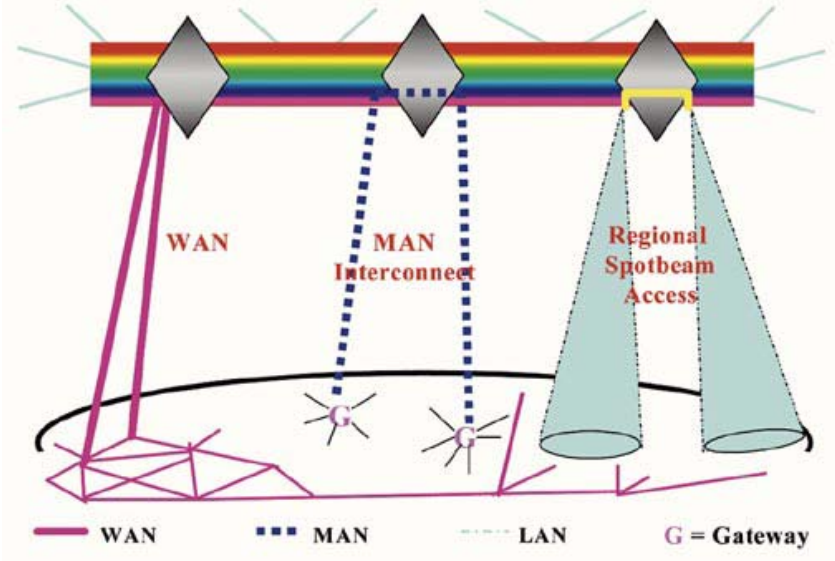
A satellite WDM OTN





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Optical Satellite Networks

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Some key

Networking and **Communication Traffic Management**

considerations

What type of optical networking techniques do we consider ?

A global space **Optical Transport Network** based on:

- WDM ISLs and wavelength routing
- Single-hop, Double-hop, multi-hop

Why optical networking for Satellite Global Area Networks ?

- simplifies drastically routing on the ISL network "hiding" the mobility of the satellites.
- mininises the data transfer delay and delay jitter
- reduces the OBP traffic load (bypassing transit traffic)

In what satellite networks does it apply ?

- use the space segment for networking
- transport intercontinental traffic (i.e. create transit traffic)

Satellite network traffic properties

- Satellite capacity is fixed (not upgradeable)
- Network capacity is fixed (not upgradeable)
- ISL capacity is fixed (for given BER and range but can be adjusted dynamically)
- satellite source traffic varies rapidly with:
  - time (t)
  - longitude (lg) and latitude (lt) of the satellite position
- source to destination connection traffic matrix varies rapidly with:
  - time in source (ts) and in destination (td)
  - longitude and latitude in source
  - longitude and latitude in destination
- Satellite source traffic *time-average* is significantly less than the *expected peak*
- Connection traffic *time-average* significantly less than the *expected peak*

The earth by night tells us some things about tele-traffic

Traffic handling in Matrix OTN

Statistical multiplexing of traffic

- Statistical multiplexing of end-node conections (e.g ATM VPs) on the lightpaths has to be performed to allow efficient utilisation of the lightpath/ISL capacity
- Statistical multiplexing takes place at the source satellite accommodating on each lightpath a number of connections that do not take their peak value simultaneously (exploiting the complementary nature of global timing and geography)

Traffic routing

- 2 shortest paths exist in the double-hop Matrix OTN that allow alternate routing depending on dynamic satellite latitude position

Restoration

- Mesh restoration in ISL failure cases in provided by reserving capacity in operating lightpaths.
- Ring protection approaches are not applicable due to prohibitive distances in the long path connection in the ring.

The task is to.....

...improve the satellite network performance

- Simplicity in routing
- Minimise delays

...while making efficient use of the network resources

(network resources = spacecraft resources)

- Power consumption (Kwatt per Gbps to be transmitted)
- Mass and size of the modules employed on board
- while keeping the technological risk at acceptable levels

... We have to match

Types of constellations

LEO (40-140....or more)

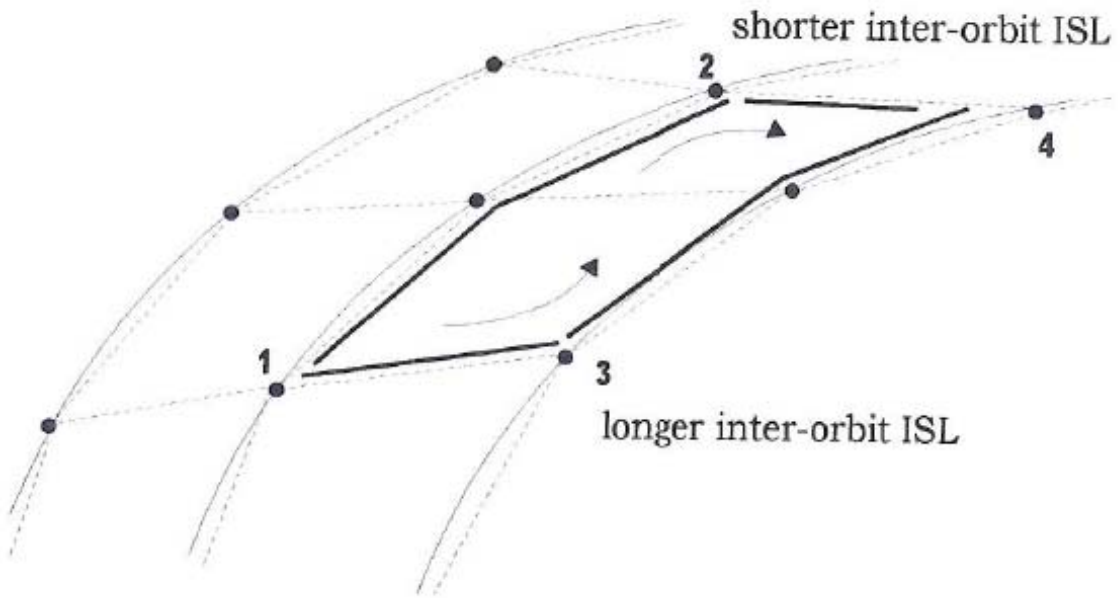
MEO (10-30)

Types of OTN

Single-hop

Double-hop

Multi-hop



Two shortest paths exist

Shortest range path routing
can be based on latitude information
stored on board the satellite

Technological Considerations

On board WDM technologies

➪ ***On board WDM building blocks***

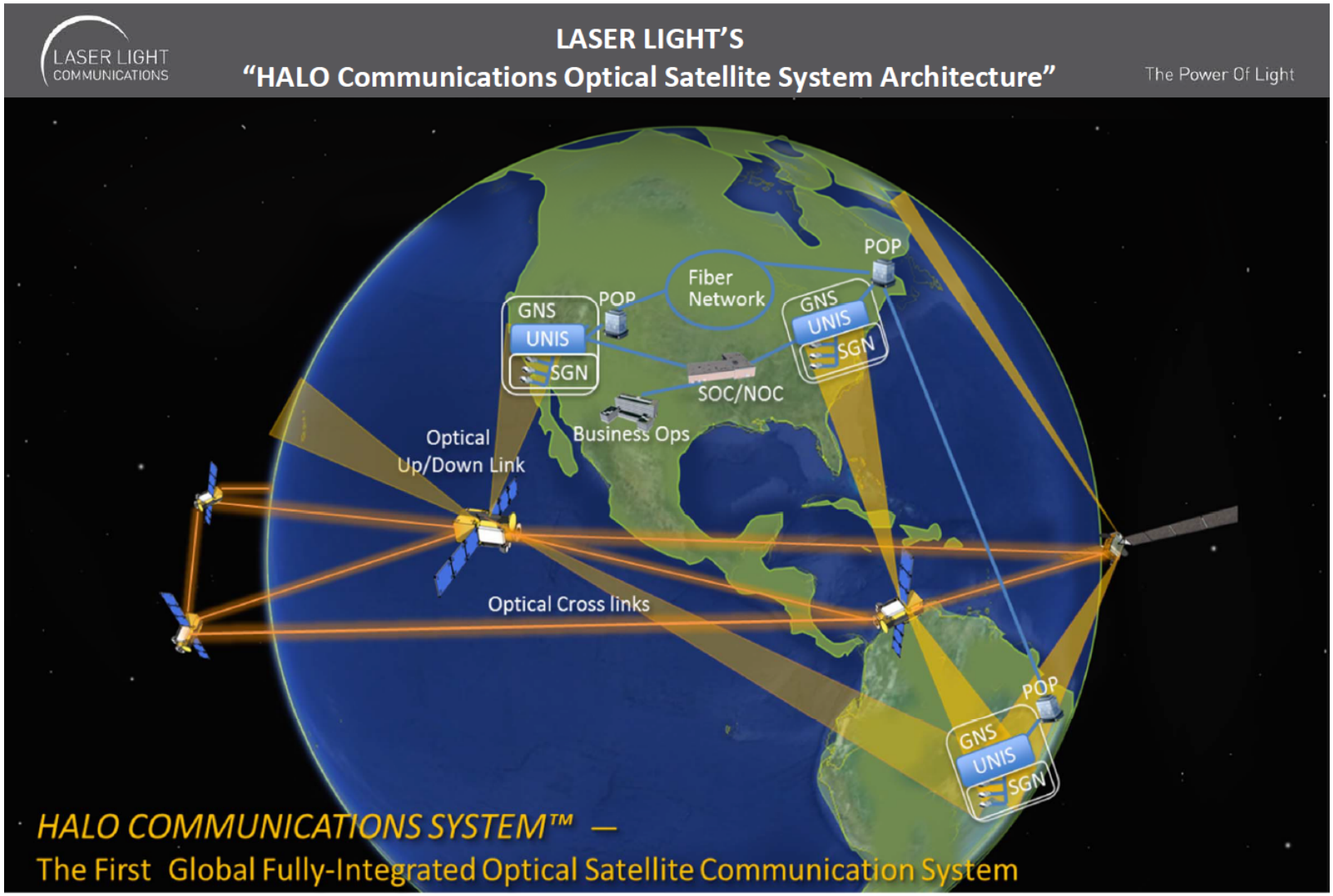
- demultiplexers
- OXC (single hop) or ADM (double or multi-hop)
- multiplexers
- **High power (> 1 Kw) booster amplifiers** (the main power consuming device)

➪ ***The space environment***

- Radiation environment
- Extreme temperature range
- launch vibrations shock
- satellite microvibrations
- microgravity
- vacuum (outgasing)

➪ ***Several technologies employed in fiber networks may disqualify for us in space***

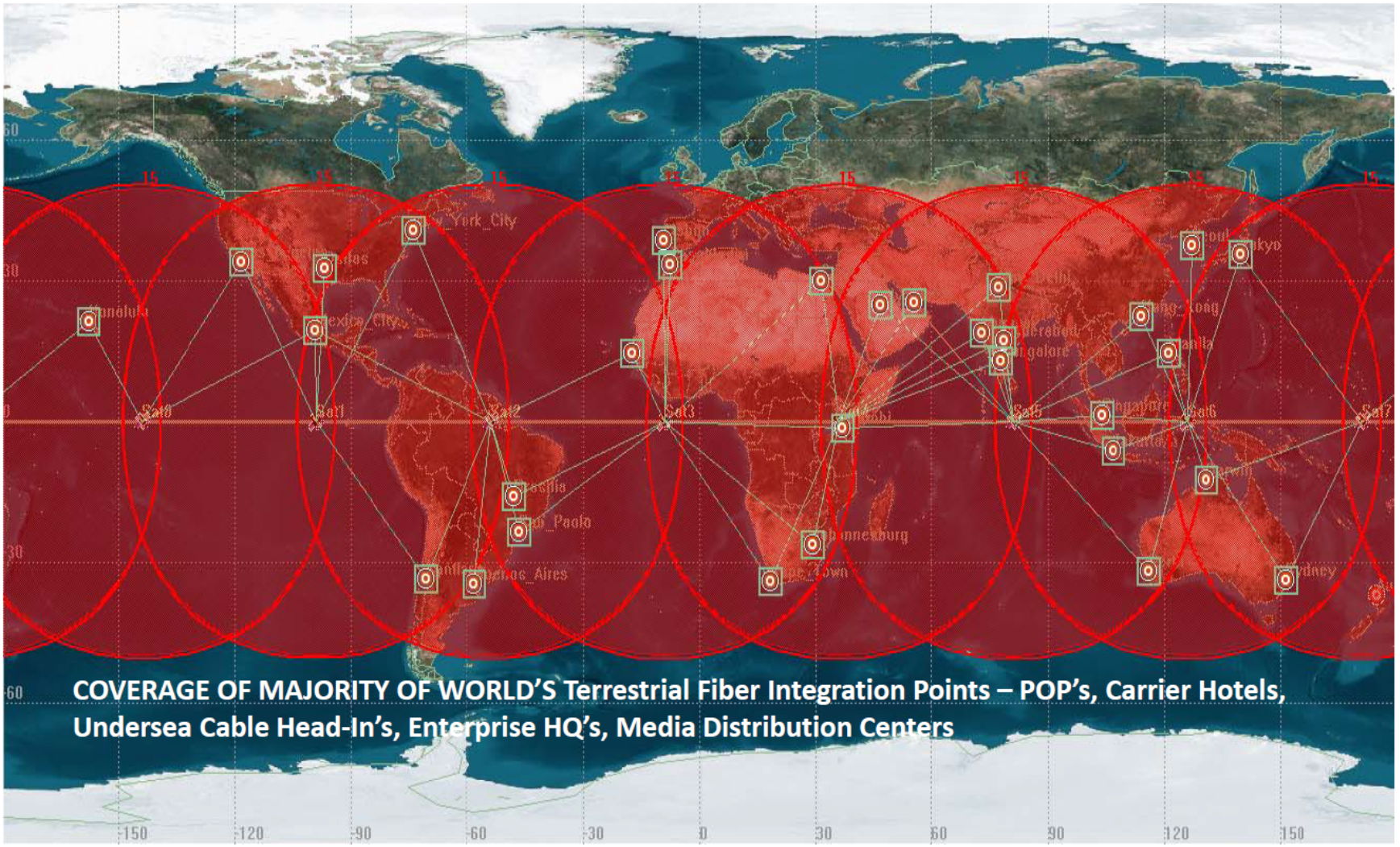
Newly Proposed Systems


LASER LIGHT
COMMUNICATIONS
LASER LIGHT'S
"HALO Communications Optical Satellite System Architecture"
The Power Of Light
POP
Fiber
Network
GNS
UNIS
SGN
POP
GNS
UNIS
SGN
SOC/NOC
Business Ops
Optical
Up/Down Link
Optical Cross links
POP
GNS
UNIS
SGN
HALO COMMUNICATIONS SYSTEM™ —
The First Global Fully-Integrated Optical Satellite Communication System

LASER LIGHT COMMUNICATIONS

LASER LIGHT'S PROJECTED SATELLITE FOOTRINT

The Power Of Light

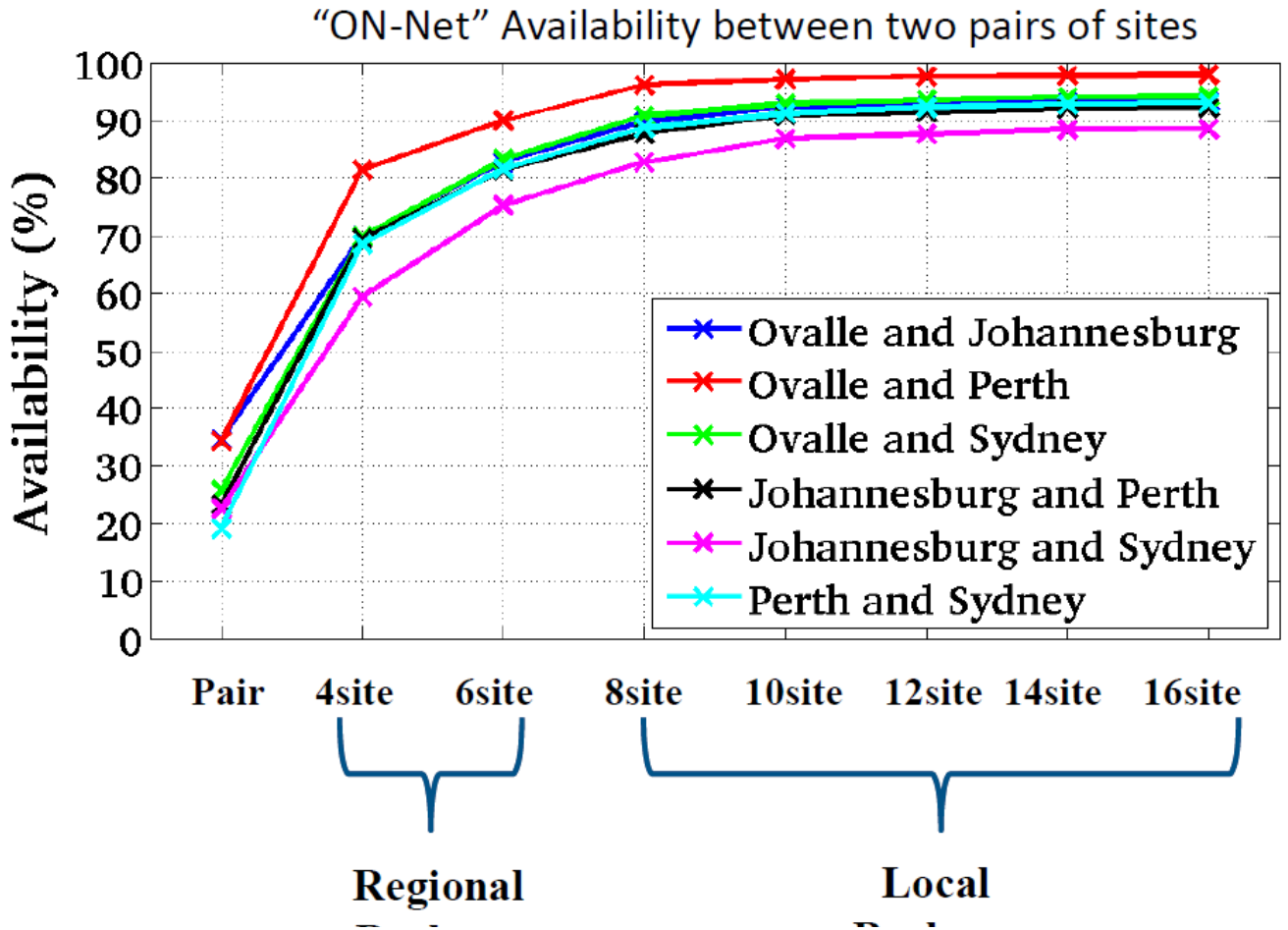


Access OGS in various points with spatial diversity so as to increase the availability to acceptable levels

LASER LIGHT COMMUNICATIONS

ADDRESSING THE ATMOSPHERIC CHALLENGE

The Power Of Light



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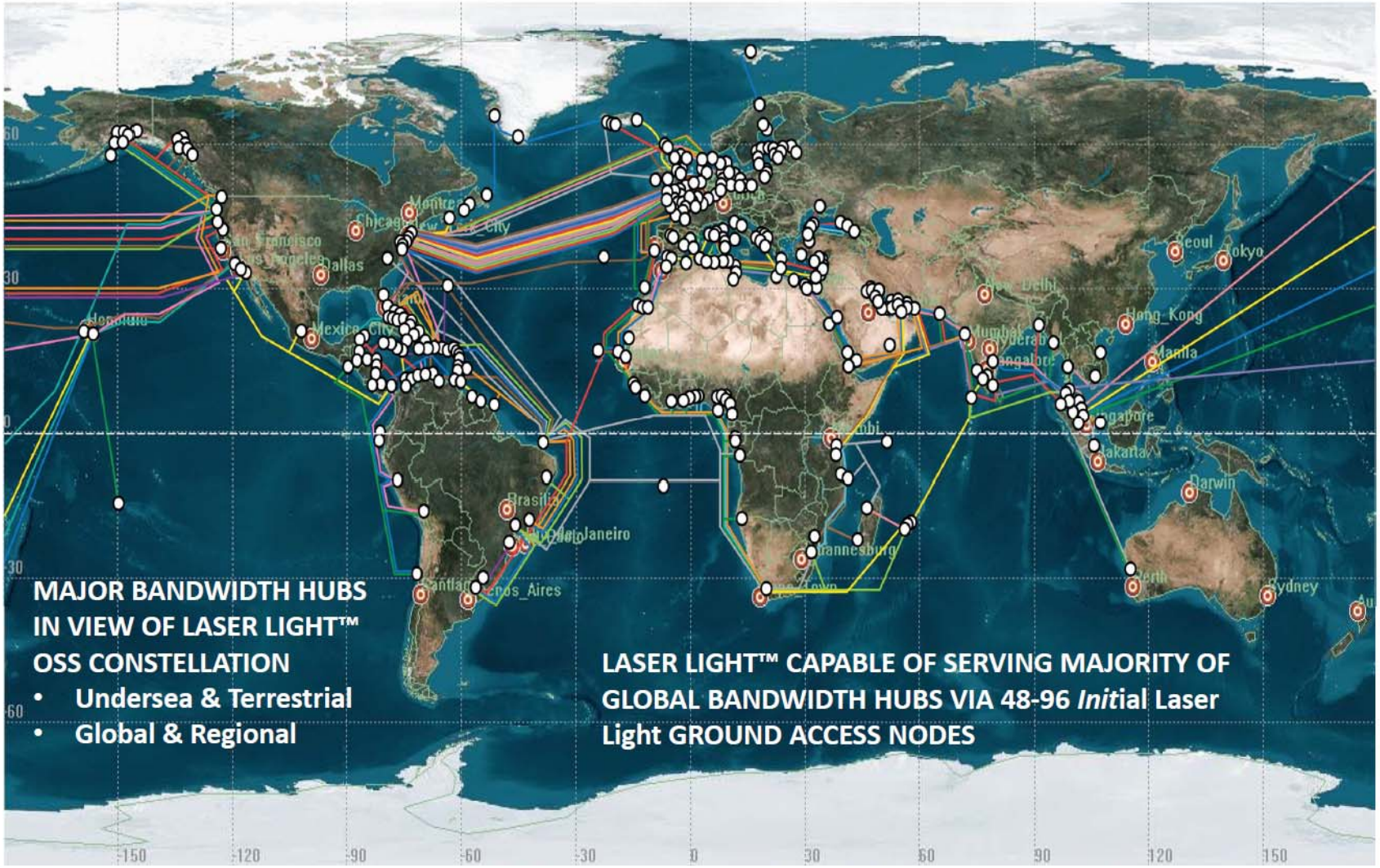
GLOBAL TERRESTRIAL FIBER-CABLE SYSTEM

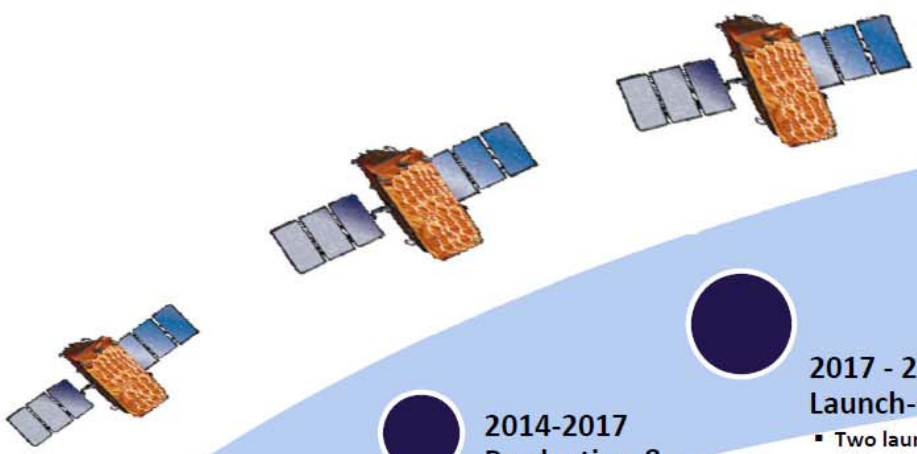
The Power Of Light



LASER LIGHT COMMUNICATIONS

KEY CALENDER MILESTONES

The Power Of Light



2012 Concept/Form

- Conceptual design
- Independent technical and program reviews
- LASER LIGHT™ Communications Announcement

2013-2014 Validate the Technology and The Business Model

- System Design & CONOPS Development
- RFI/RFP of Critical Component suppliers of spacecraft, launcher, network, distribution and integration partner
- Establishment of HALO Center: Commercial Optical Laser Demo & Test Facility
- Capital Raise – Halo & Laser Light

2014-2017 Production & Pre-Subscription

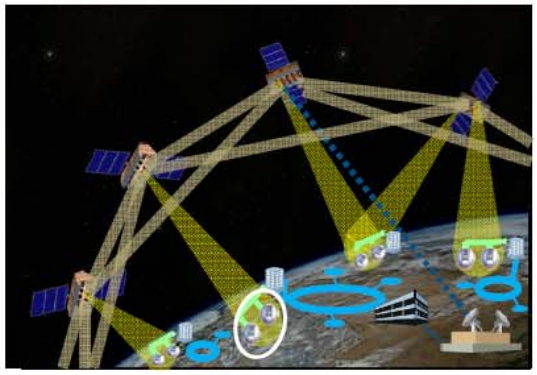
- Close Equity & Project Finance Facilities for Fully-Funded Plan
- Staff-Up
- Open The HALO Center
- Commence Manufacturing of all space and ground hardware
- Identification and negotiation of ground facilities partnerships
- Solicitation of Laser Light™ potential customer requirements; products & services

2017 - 2018 Launch-OOT

- Two launches (with a 3rd as backup)
- On-Orbit Test (OOT)
- Initial Operating Capability
- Ground site deployment and operations

2017-203X Operations

- Full operational capability
- Execute business plan



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Bloomberg Business Week 1 February 2015

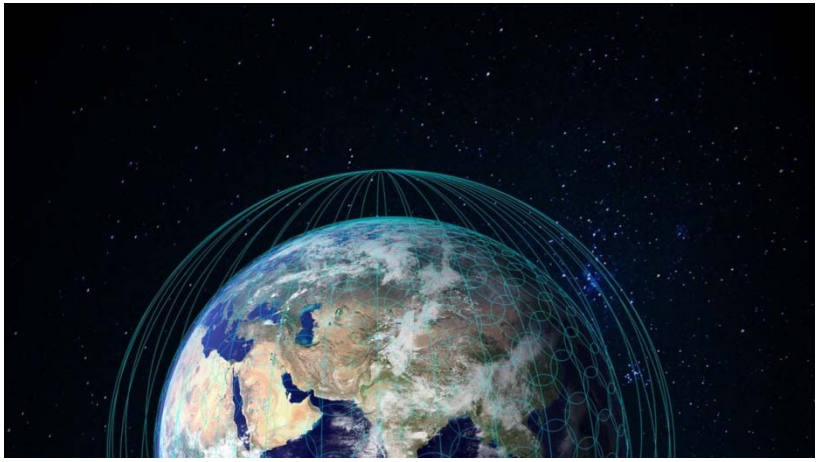
The 2 new proposals

X-Space

- Google and Fidelity Investment 1 B$
- 4000 satellites
- LEO @ 1100 km
- with optical links?
- To be launched by SpaceX launchers
- To operate by 2020

OneWeb

- Virgin Galactic and Qualcomm
- 648 satellites
- LEO@1200 km
- To be launched by Virgin Galactic Launcher One S/C
- To operate by 2018-20



and in Summary

The first **RF Satellite Constellation Network**, IRIDIUM, operates since 1999 in LEO

The first **Optical Trunk Satellite Network,** LaserLight, is currently under construction and to be operational by 2017 in MEO

Two proposed LEO Constellation Networks are to fly by 2020. Optical ISLs are considered which may created an **Optical Internet Access Network in the Sky**

Thank you all for attending !

and for more information

Send me an email at : **Nikos.Karafolas@esa.int**

and study the Proceedings of the
"International Conference on Space Optics – ICSO"

www.icsoproceedings.org

They are accessible by everyone free of charge !