IEEE 5G


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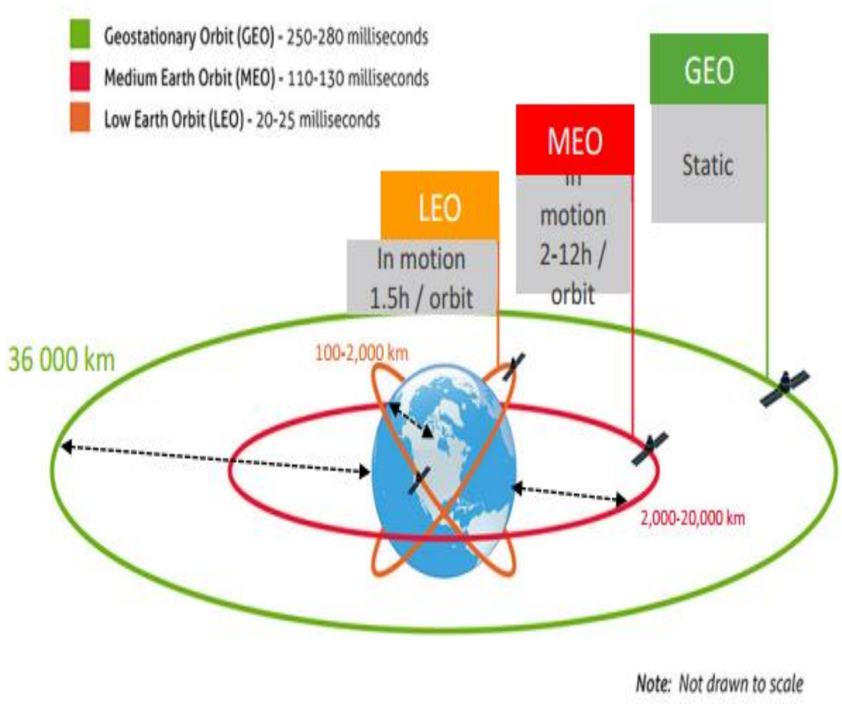
AN IEEE 5G WEBINAR:
5G and Satellite Spectrum and Standards
With Moderation by Peggy Matson
Join us October 19 at 11:00am ET
Geoff Varrall
RTT Programmes

5G and satellite spectrum, standards and scale

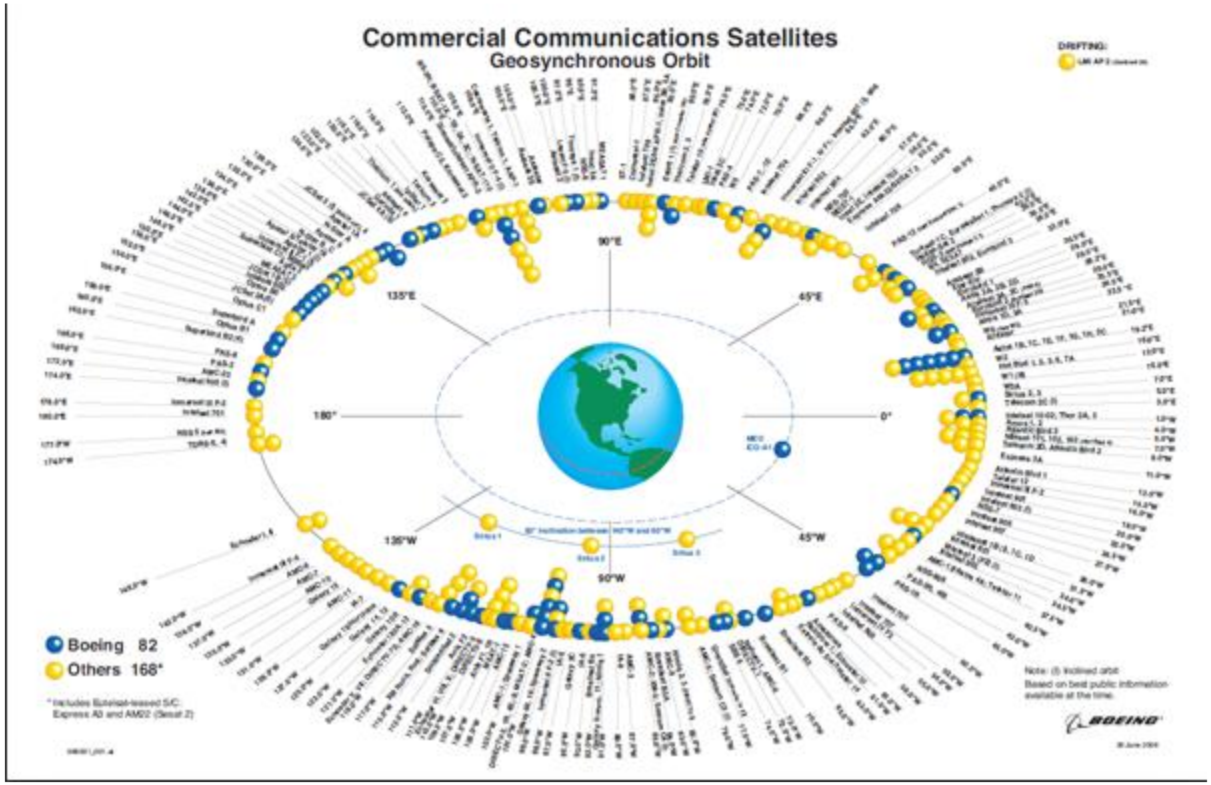
- WRC 2019 race for space spectrum?
- Compatibility/coexistence with GSO, LEO and MEO Ku, K and Ka-band satellite spectrum and 5G terrestrial including 28 GHz
- NEW LEO constellation capabilities including OneWeb and Space X and LEOSAT
- Progressive pitch angular power separation- Spectrum sharing and frequency reuse opportunities and challenges.
- Pass bands and channel bandwidth compatibility and physical layer coexistence
- Present tension points between NEWLEO entities and incumbent LEO and MEO and GSO operators
- Link link budget and long distance latency benefits of nearly always nearly overhead (NANO) or Always Overhead (AO) connectivity when integrated with inter satellite switching
- How this could help meet specific 5G vertical market throughput and latency requirements
- Satellite IOT, present and future technical and commercial trends and standards issues
- Related 5G and satellite regulatory and competition policy challenges and opportunities, longer term V and W band co sharing opportunities

Satellite orbits



LEO, MEO and GSO orbits- with thanks to Inmarsat

GSO Orbital slots



With thanks to the Boeing Corporation

LEO ORBITS and satellites sizes

Orbcomm	775 km
Iridium	780 km
OneWeb	1200 km
Globalstar	1410 km

Pico Satellites (Cube sats?)	Nano Satellites	Micro Satellites	Macro Satellites
<1 kg	< 10 kg	< 500 kg	≥ 500 kg

Inmarsat I-5 Ka band satellites for example are (big) macro satellites with a launch mass of 6100 kg, the body height of a double decker bus, a solar array wing span of 33.8 metres generating 15 kilowatts of power and a xenon ion propulsion system for in orbit manoeuvring.

L Band	**S Band**	**C Band**	**X Band**	**Ku-Band**	**K-Band**	**Ka-Band**	**V Band***	**W Band***
1-2 GHz	2-4 GHz	4-8 GHz	8-12 GHz	12-18 GHz	18-27 GHz	27-40 GHz	40-75 GHz	75-110 GHz
GPS	MSS	TV	Military	Commercial	Military	Commercial	Military and Commercial and Automotive Radar	
Licensed	Licensed	Licensed	Licensed	Licensed	Licensed	Licensed	Unlicensed	

* The asterisk against V and W Band is to remind us that the description E band is also sometimes used to describe a large sub band between 60 and 90 GHz. You may also come across Q band as a designation which like E band comes from the WR22 waveguide naming system. Q band covers from 33 GHz to 50 GHz (9.1 millimetres to 6 millimetre wavelength).

Bands Agreed For Study at WRC 2019

ITU WARC 2019 Bands agreed for study for 5G														
	K-Band		Ka-Band				V Band						W-Band	Total
GHz	24.25 27.5		31.8 33.4	37 40.5		40.5 42.5	42.5 43.5	45.5 47	47 47.2	47.2 50.2	50.4 52.6	66 76	81 86	
GHz	3.25		1.6	3.5		2	1	1.5	200 MHz	3	2.2	10	5	**33.8 GHz**
FCC Upper Microwave Flexible Use														
GHz			27.5 28.35	37 38.6	38.6 40									
GHz			850 MHz	1.6	1.4							64 71		
			Licensed	Licensed *								7 GHz Unlicensed		
GHz				**FCC ITU**										**10.85 GHz**
Summary	**33.8GHz of ITU spectrum for study at WRC2019, 10.85 GHz of FCC UMFU spectrum for study of which 3 GHz is common (37-40 GHz) FCC proposed lower band at 28 GHz not included as an ITU WRC 2019 study band though adjacent to ITU study band * 600 MHz of FCC spectrum from 37 to 37.6 GHz proposed as shared use commercial/federal**													
FCC Future notice of proposed rule making														
GHz	24.25 24.45	25.5 25.25	31.8 33.4				42 42.5			47.2 50.2	50.4 52.6	71 76	81 86	
GHz	200 MHz	200 MHz	1600 MHz				500 MHz			3 GHz	2.2 GHz	5 GHz	5 GHz	**17.7 GHz**
	FCC/ ITU						**FCC/ITU**			**FCC/ITU**	**FCC/ITU**			
GHz														
Summary	**17.7 GHZ of FCC spectrum for study of which 17.7 GHz is common to ITU and FCC (24 GHz, 25 GHz, 32 GHz, 42, 47-50, 50-52 GHz, 71-76 81-86 GHz)**													
IEEE 521-1984 radar bands - X Band 12-18 GHz, Ku Band 12-18 GHz, K-Band 18-27 GHz, Ka- band 27-40 GHz, V band 40-75 GHz, W-Band 75-110 GHz														

Bands Agreed For Study at WRC 2019

<table>
<tr><td colspan="14">5G PPP E band channelization and coexistence</td></tr>
<tr><td colspan="14">CEPT</td></tr>
<tr><td colspan="4">71-76 GHz</td><td>76-77 GHz</td><td>77-81 GHz</td><td colspan="4">81-86 GHz
Mob RX</td><td>86 -92 GHz</td><td colspan="3">92-95 GHz</td></tr>
<tr><td colspan="4">5G MOB TX?</td><td></td><td></td><td colspan="4">5G MOB RX?</td><td></td><td colspan="3">5G TDD</td></tr>
<tr><td>Guard band</td><td colspan="2">Channels</td><td>Guard band</td><td>Narrow Band Long Range Radar</td><td>Wide Band Short Range Radar</td><td>Guard Band</td><td colspan="2">Channels</td><td>Guard band</td><td>Radio Astronomy Band</td><td>Guard Band</td><td></td><td>Guard band</td></tr>
<tr><td>125 MHz</td><td colspan="2">19 X 250 MHz</td><td>125 MHz</td><td></td><td></td><td>125 MHz</td><td colspan="2">19 X 250 MHz</td><td>125 MHz</td><td></td><td>125 MHz</td><td>11 X 250 MHz</td><td>125 MHz</td></tr>
<tr><td colspan="4">US FCC</td><td></td><td></td><td colspan="4">US FCC</td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="4">4X 1.25 GHz channels</td><td></td><td></td><td colspan="4">4 X 1.25 GHz channels</td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="14">Legacy use</td></tr>
<tr><td colspan="2">71-74 GHz</td><td colspan="2">74-76</td><td></td><td></td><td colspan="2">81-84 GHz</td><td colspan="2">84-86 GHz</td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="2">Fixed
Fixed satellite
(space to earth)
Mobile
Mobile satellite
(Space to earth)</td><td colspan="2">As 71-74 plus
Broadcasting
Broadcasting
Satellite
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Research
(Space to
earth)</td><td></td><td></td><td colspan="4">Fixed
Fixed satellite
(earth to space)
Mobile
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Space research
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Radio astronomy</td><td></td><td></td><td></td><td></td></tr>
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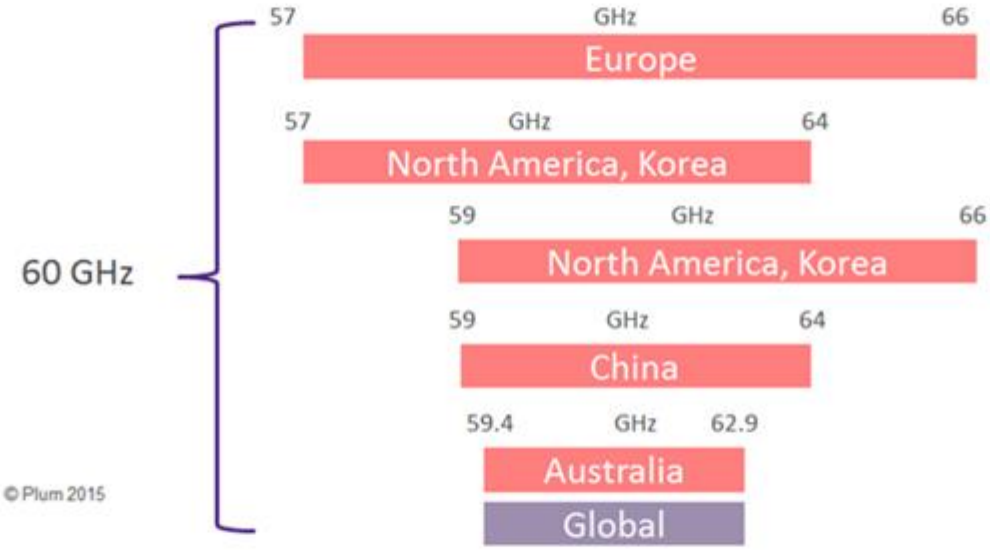
Proximity to 60 GHz Wi-Fi



57-64 -71 GHz = 15 GHz

Wi-Fi 802.11ax

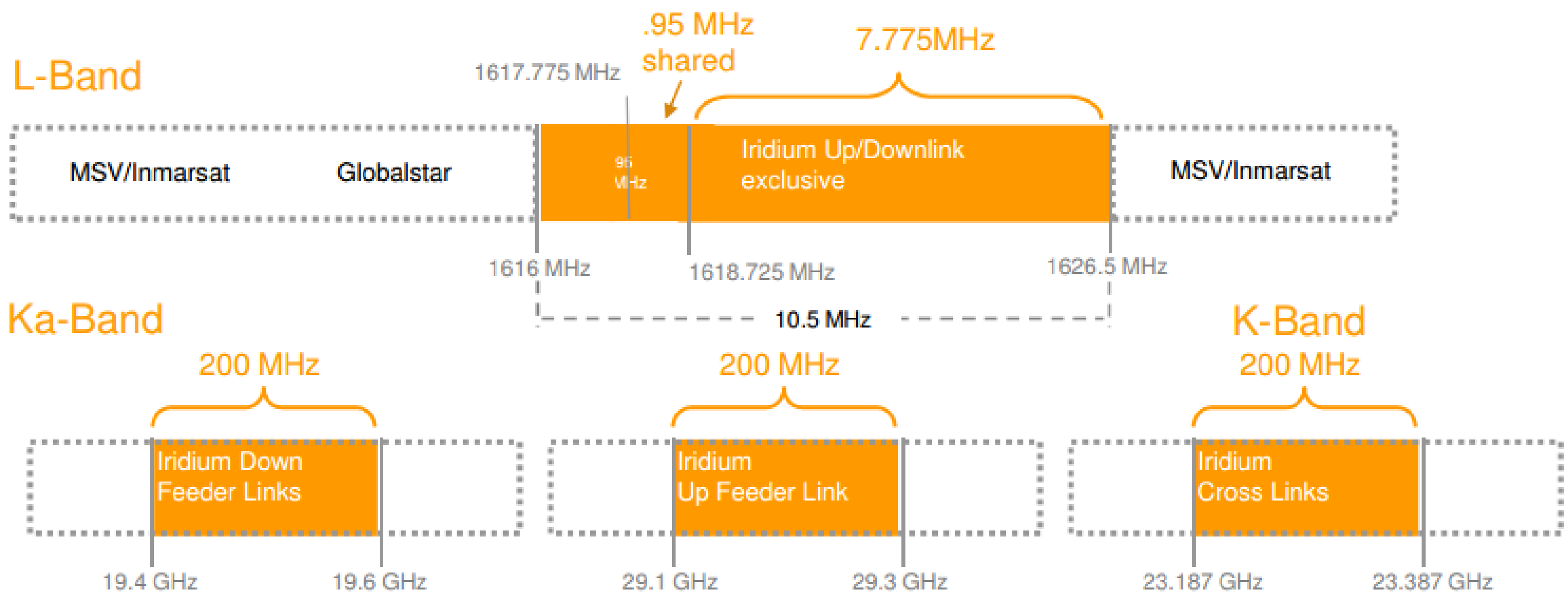
Impact of domestic bandwidth
Amazon Echo and Google Home
50 Wi-Fi access points in a home

#1: What are the key differences between 802.11ac and 802.11ax?

- **Uplink MIMO:** 802.11ac supports multiuser MIMO, but only in downlink mode. In contrast, 802.11ax adds uplink capability, so multiple users can upload video simultaneously.
- **Modulation:** 802.11ax has a higher modulation scheme, moving from 256 QAM to 1024 QAM, which translates to better throughput and 25% higher capacity with 10 bits per symbol.
- **Capacity and efficiency improvements:** 802.11ax uses OFDMA instead of OFDM, which allows FDD versus TDD as well as resource unit allocation within a given bandwidth. Subcarrier spacing is also reduced to 78.125 kHz, which is 25% of 802.11ac spacing, and the symbols are 4 times longer. When combined, all these changes mean that the system is more efficient and can upload or download multiple data packets simultaneously, rather than one at a time.
- **Schedule-based rather than contention-based:** In 802.11ax, the access point dictates when a device will operate, thus handling clients more efficiently. Resource scheduling also significantly reduces the power consumption during sleep time, which improves battery life for clients.

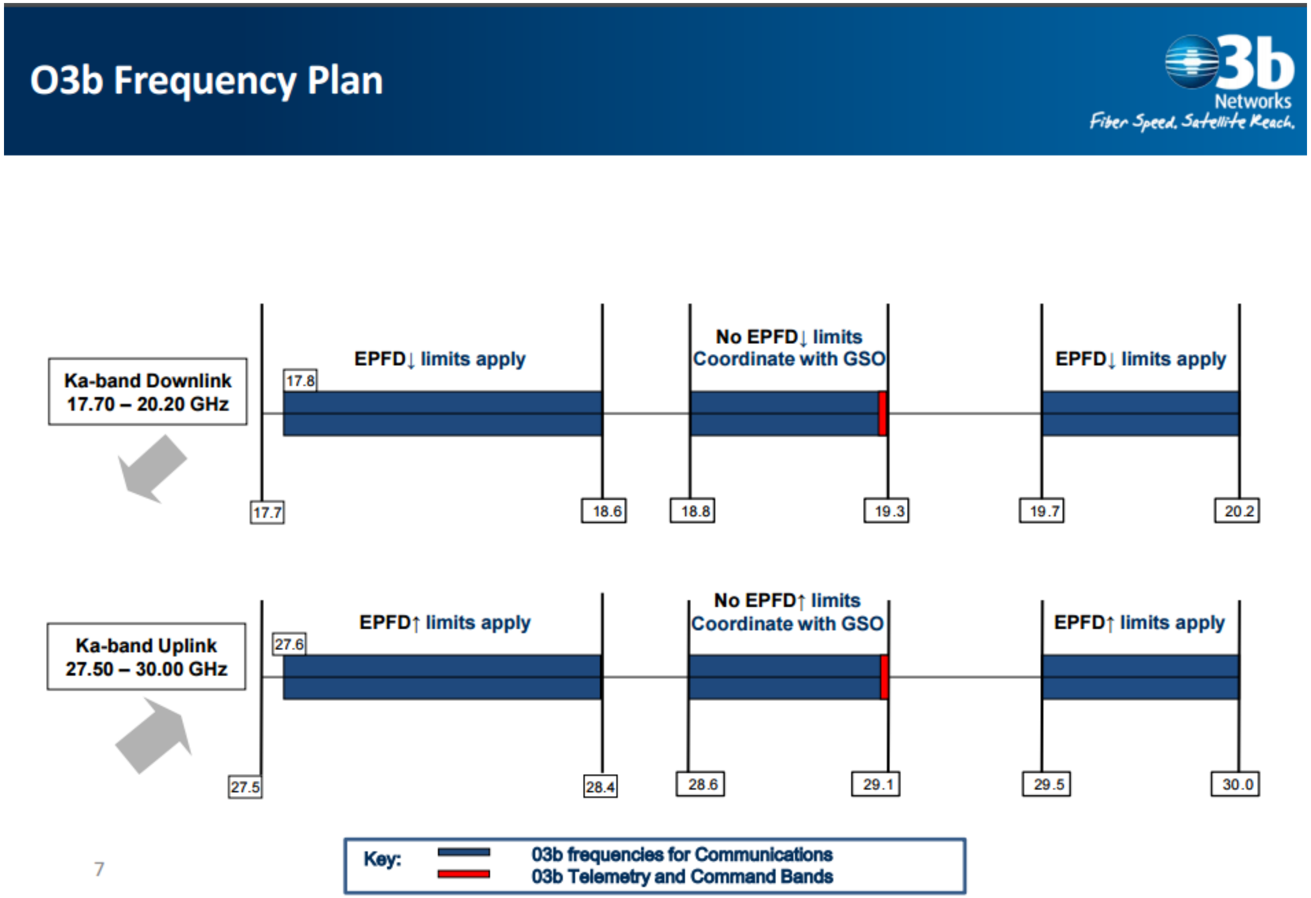
https://vertassets.blob.core.windows.net/download/7d705b86/7d705b86-8245-42b2-a160-863d22a8d720/802_11ax_5_things_to_know.pdf
Qorvo White paper

Existing LEO band plans -Iridium

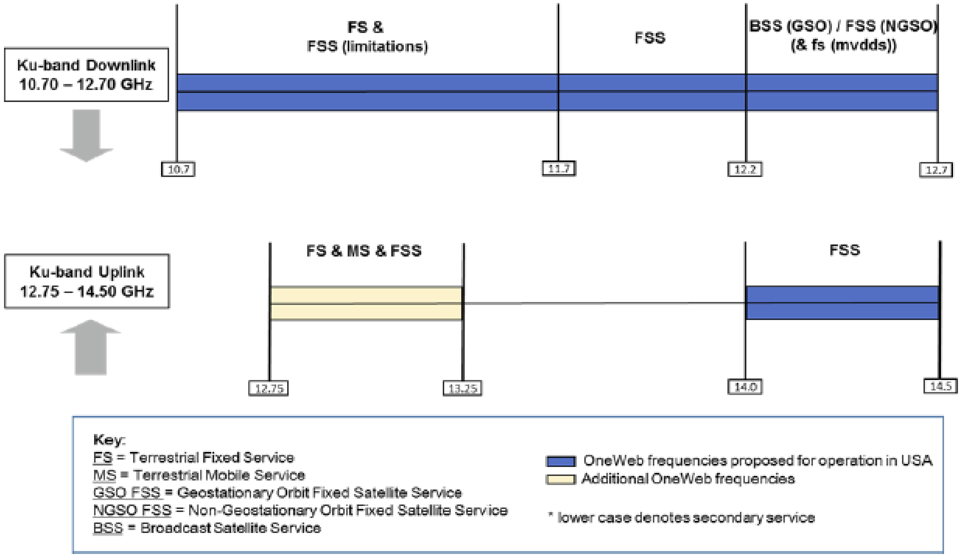


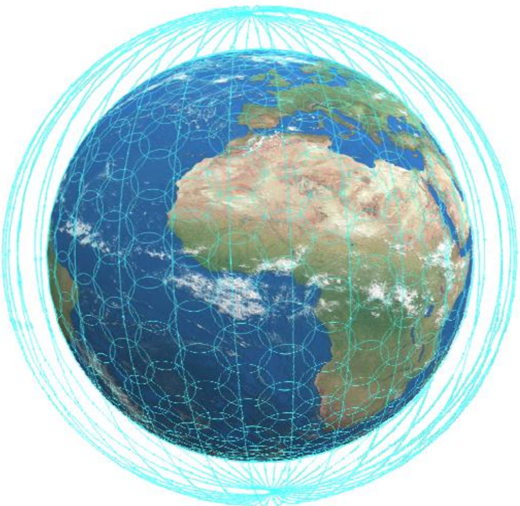
Globalstar 1610-1618 MHz

O3b - formerly the band plan for Teledesic

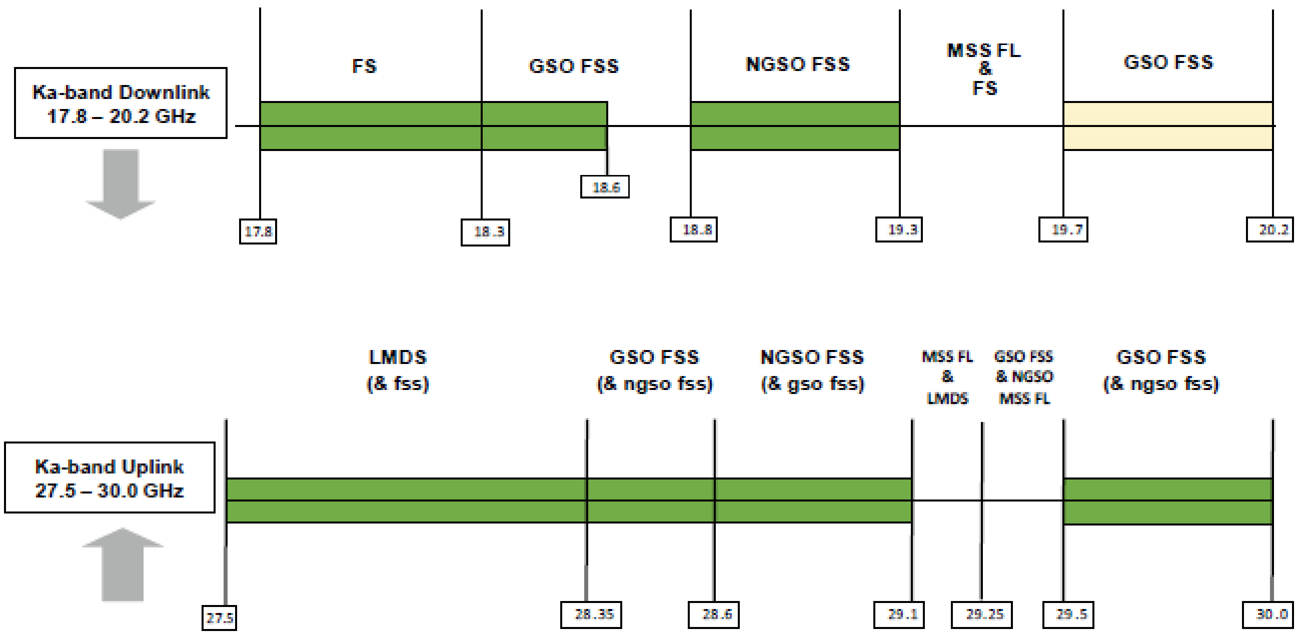


OneWeb Ku-Band - formerly the band plan for Skybridge





OneWeb Ka-Band formerly the band plan for Skybridge

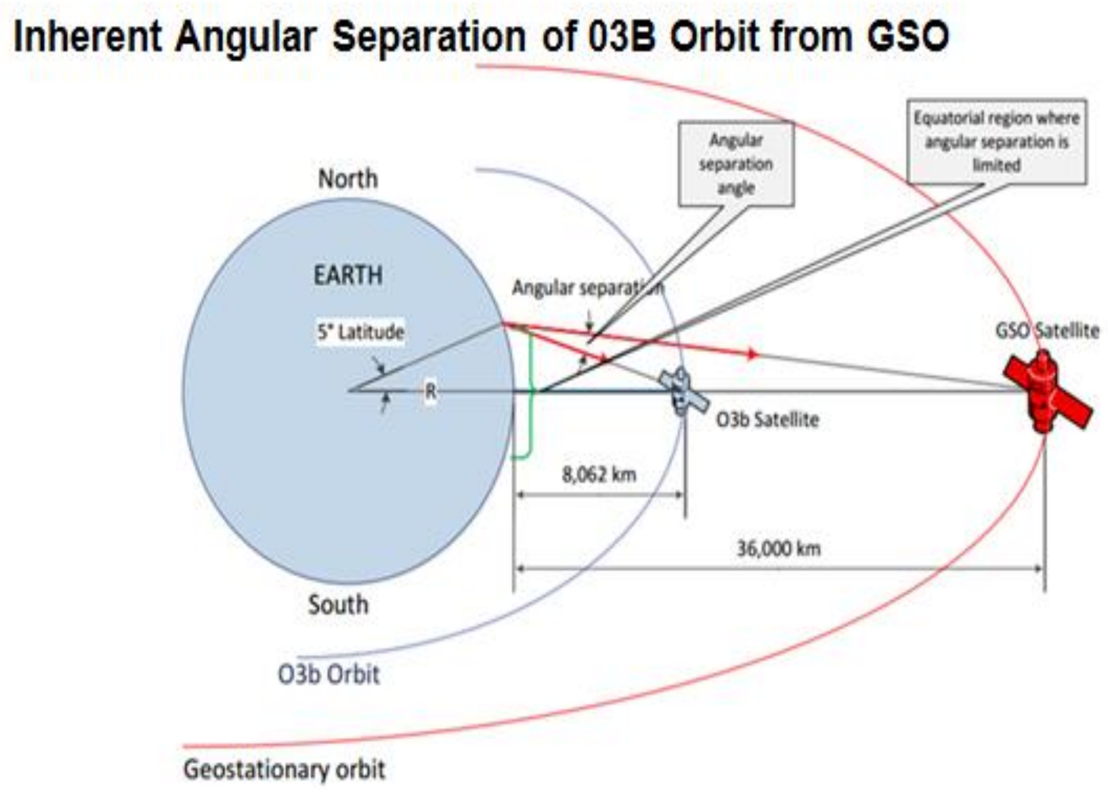


Key:
FS = Terrestrial Fixed Service
LMDS = Local Multipoint Distribution Service
GSO FSS = Geostationary Orbit Fixed Satellite Service
NGSO FSS = Non-Geostationary Orbit Fixed Satellite Service
MSS FL = Mobile Satellite Service Feeder Links
FSS = Fixed Satellite Service

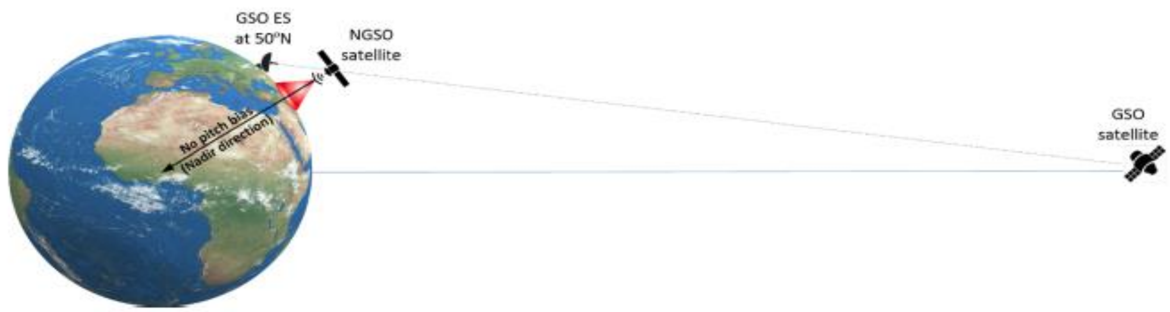
OneWeb frequencies proposed for operation in USA
Additional OneWeb frequencies

* Lower case denotes secondary service

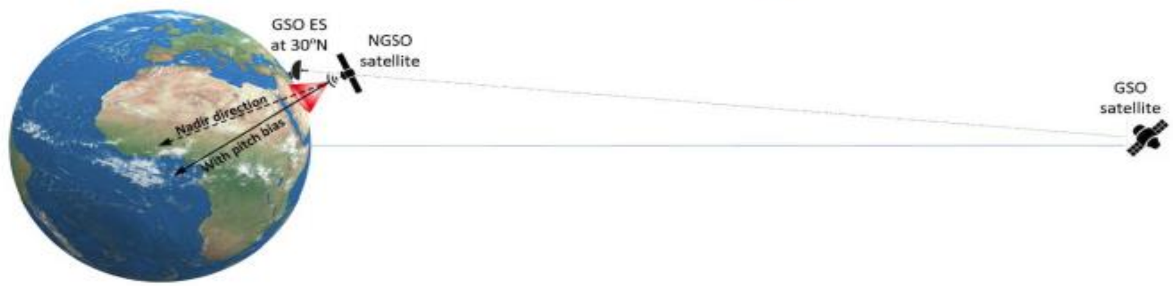
O3b Progressive Pitch MEO to GSO separation



OneWeb Progressive Pitch LEO to GSO separation



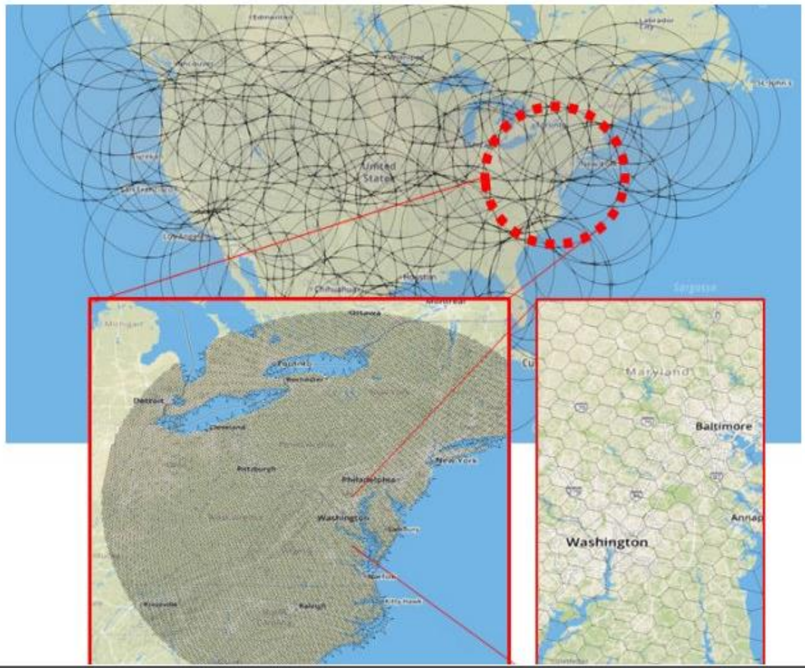
(b) GSO earth station at 30°N (with pitch bias)



So can 28 GHz and other K bands be shared with 5G terrestrial?

LEO to MEO to GSO to 5G separation

Boeing V band progressive pitch+ fractional beam width



Boeing proposes a constellation of between 1,396 and 2,956 V-band satellites in 35-74 orbital planes at 1,200 km in altitude. Each satellite's footprint would be subdivided into thousands of 8-11-km-diameter cells, with each cell using up to 5 GHz of bandwidth. Boeing also wants regulators to clear the way for a mega-constellation in C-band, athough Boeing is not planning its own C-band constellation. Source: Boeing

37.5 to 42.5 GHz downlinking from spacecraft to terminals on Earth
47.2 to 50.2 GHz and 50.4 to 52.4 GHz for uplinking back to the satellites
The industry rumour mill in 2017 suggested Apple was providing finance
See also Google and OneWeb, Jeff Bezos (Amazon) and Blue Origin, Mark Zuckerberg (Facebook) and Eutelsat

Terrestrial latency versus space latency

Time	distance	
One second	300,000 kilometres	186,000 miles
One Millisecond	300 kilometres	186 miles
One Microsecond	300 metres	1000 feet
One Nanosecond	30 centimetres	One Foot

To put this in to a geographic perspective, Singapore is 50 kilometres from east to west and a radio or optical signal will take 166 microseconds to go from one end of this high tech island to the other. Malaysia coast to coast will take one millisecond.

Figure 3.1 Singapore at light speed

Australia from the east coast to west coast is 4000 kilometres so that's a coast to coast travel time of just over 13 milliseconds.

A reminder of last month's excellent webinar

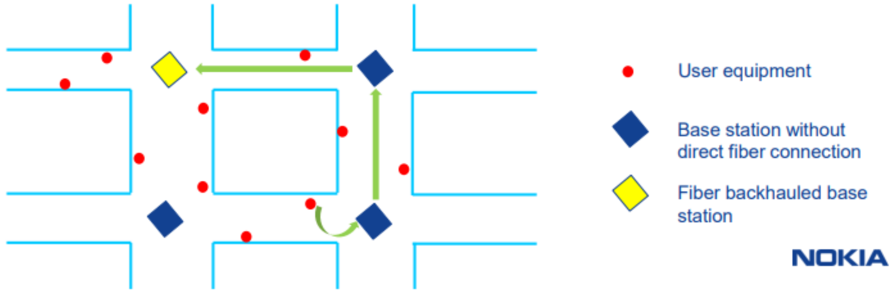
IEEE Webinar

September 20th , 2017

Dr. Amitabha Ghosh

Self-backhauling Needed for Millimeter Wave Cellular

- New radio would likely require **dense deployments right from the initial phases** to get sufficient coverage (esp. for frequency > 20 GHz).
- Economically not feasible to provide fiber connectivity to each site until the new radio deployments become mature.
- Self-backhauling is enabling multi-hop networks with shared access-backhaul resources.



NOKIA

Satellite latency for backhaul and direct connectivity

- **GSO satellites** orbit the earth at 36,000 kilometres above the equator. Radio waves go at the speed of light which is 300,000 km per second. For users on the equator communicating with a satellite directly overhead, the total distance, single hop (up and down) is 72,000 km so the time delay is **480 ms** for a round trip.

- **MEO network** (using O3b as an example) orbit height is 8,062 km. A typical single hop path involves sloping path lengths of 11,000km producing a single hop distance of 22,000 km producing a latency of 73 milliseconds. O3B claim a round trip latency of better than **150ms** based on a double hop distance of 11,250 + 11,250 + 11,250 + 11,250 km.

- **LEGACYLEO networks** the propagation delay is smaller still. Iridium's constellation operates at 780 kilometres, Orbcomm is a little higher at 825 kilometres and Globalstar is at 1,414 kilometres. The propagation delay experienced in a LEO satellite system varies as the satellites change position but will be **4.3 milliseconds per hop for Iridium**, **4.5 milliseconds for Orbcomm** and **7.8 milliseconds for Globalstar for 'bent pipe' applications with the satellite directly overhead.** These figures should be doubled for round trip delay.
- Australia West to East is 4000 kilometres (13 milliseconds), Africa North to South is 8000 kilometres (26 milliseconds)

- **NEWLEO networks** LEOSAT similar constellation to Iridium based on the same Thales space system platform but utilising 7 GHz of paired spectrum (3.5+3.5 GHz) at Ka band for individual user uplinks and downlinks (compared to 10+10 MHz of paired spectrum in L band available to Iridium) and optical inter satellite switching. The FCC filing is based on 120 to 140 satellites in a similar polar orbit to the Iridium Next Constellation. Focussed on delivering performance gain over long distance fibre based on the fact that radio and light waves in free space travel faster than radio and light waves in fibre. Over distances of more than 10,000 kilometres this speed advantage outweighs the additional route length (the earth to space, space to earth hop) providing a latency gain for high value applications such as high frequency trading, the oil and gas industries, corporate networking and government agencies (LEOSAT are working with the European Space Agency on 5G and satellite.

High count LEO always directly overhead=LOS= minimal surface scatter and absorption

New Rocket Age? New Rocket men?

Peter Beck
Rocket lab USA

New Space? New Delivery Economics?

Big Re usable rockets		Small rockets	Small reusable space vehicles
Space X Falcon Heavy	Blue Origin New Glen		
70 metres tall	82 metres tall	17 metres tall	Big enough for 10people
Liquid fuel	Liquid fuel	Liquid fuel	Liquid nitrous oxidiser with thermoplastic polyamide solid fuel propellant
>200,000 kilonewtons	>200,000 kilonewtons	200 kilonewtons	200 kilonewtons
50 tons to LEO orbit	50 tons to LEO orbit	250 kg to 500 km sun synch.	10 people to 110 kilometres
			

Plus satellite innovations – electric satellites, new propulsion and power options