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C-DOT

Discussion on NTN Integration

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International Workshop on 6G Standardization
March 18, 2026, Vigyan Bhavan, New Delhi

Overview

- Objectives for NTN Integration
- Satellite Constellations
- NTN Deployment Variations
- HEO Considerations
- Satellite Configurations
- Network Performance Considerations
- Interesting Opportunities for R&D
- Overall Expectations

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Objectives for NTN Integration

- Pursue the need for Ubiquitous Coverage globally
- Coverage where Terrestrial Networks may struggle to reach
  - Remote hilly regions, oceans, ….
- Connect the Unconnected
- Dynamic 3D coverage in-flight and in space

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NTN Deployments

- Typically considered deployments - GEO, MEO, LEO, HAPS
- Latencies increase from HAPS to LEO to MEO to GEO
  - 1ms for every 300km
  - One way transport latency
    - 0.17 ms for 50km HAPS
    - 2ms for a 600 km LEO
    - 30ms for a 9000 km MEO
    - ~120ms for a 35786 km GEO
  - Additional latencies for task buffering and task processing
- It would be useful to consider HEOs as well for extended coverage for different regions in a country to increase dwell times

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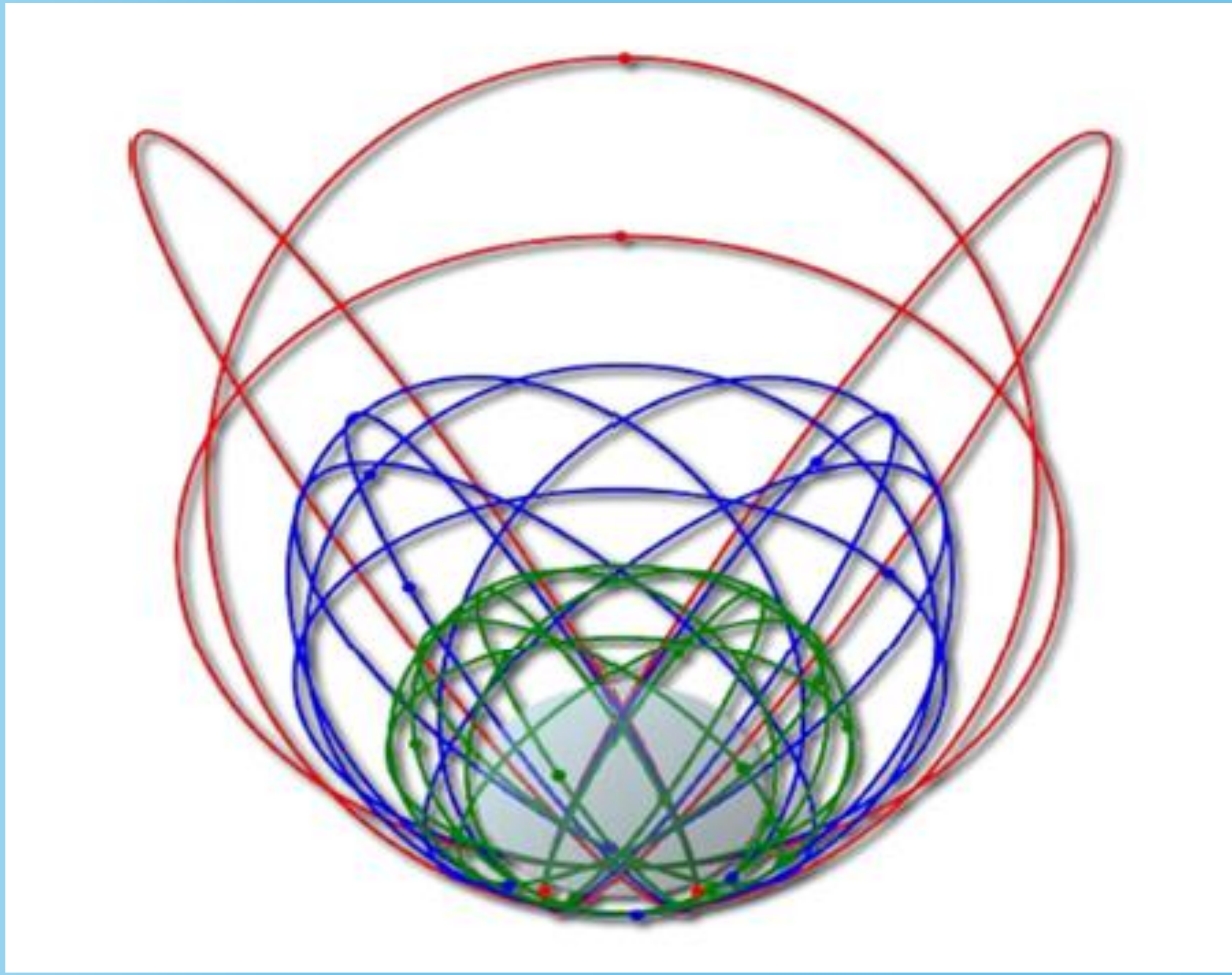
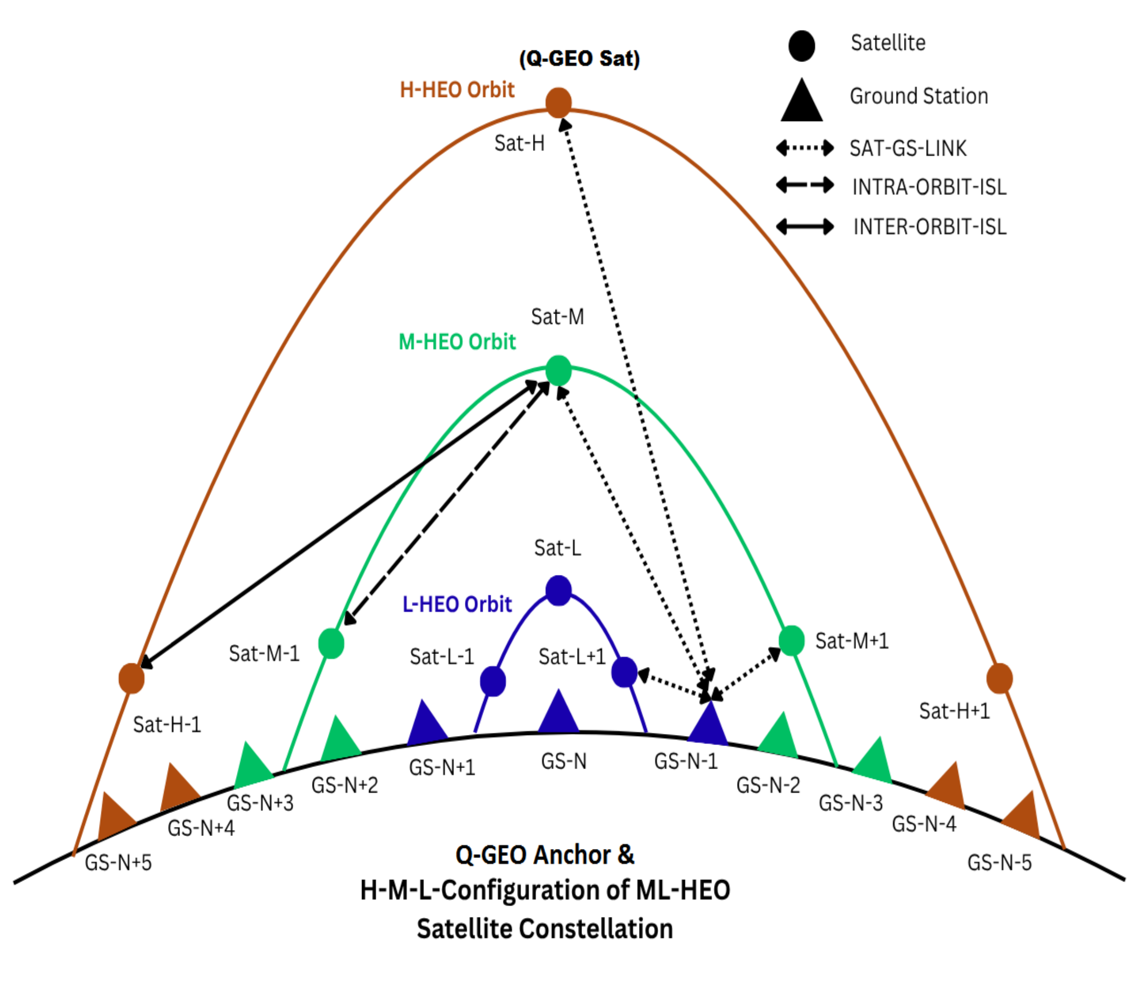
Multi-Level Highly Elliptic Orbits

Network of Interlinked Satellites for High Availability





Sl. No.	Orbit Name	Orbit Duration (Hours)	Ratio
1	High-HEO (H-HEO)	12	2
2	Medium-HEO (M-HEO)	6	4
3	Low-HEO (L-HEO)	3	8

H-HEO

- Maximum Altitude = 39,300 km (approx 40K km)
- Visible over India = 637.6 min (approx 10 hrs)
- Velocity at Apoapsis = 1.56 km/sec
- Velocity at Periapsis = 9.60 km/sec

M-HEO

- Maximum Altitude = 19,800 km (approx 20K km)
- Visible over India = 260 min (approx 4.5 hrs)
- Velocity at Apoapsis = 2.59 km/sec
- Velocity at Periapsis = 9.18 km/sec

L-HEO

- Maximum Altitude = 7,400 km (approx 7.5K km)
- Visible over India = 160 min (approx 2 hrs)
- Velocity at Apoapsis = 4.50 km/sec
- Velocity at Periapsis = 8.37 km/sec

Parameter	H-HEO	M-HEO	L-HEO
C-band Satellite Parameters			
Transponder saturated output power	20 W	20 W	20 W
Antenna gain on axis	30 dB	30 dB	30 dB
Transponder bandwidth	36 MHz	150 MHz	1000 MHz
Downlink frequency band	3.7–4.2 GHz	3.7–4.2 GHz	3.7–4.2 GHz
Signal			
Signal bandwidth	30 MHz	120 MHz	850 MHz
Min. permitted overall C/N in receiver	9.5 dB	9.5 dB	9.5 dB
Receiving C-band Earth Station			
Downlink frequency	4 GHz	4 GHz	4 GHz
Antenna gain on axis at 4 GHz	40 dB	40 dB	40 dB
Receiver IF bandwidth	27 MHz	105 MHz	750 MHz
Receiving system noise temperature	75 K	75 K	75 K
Downlink Power Budget			
Transponder output power (Pt)	13 dB	13 dB	13 dB
Transponder output back-off (Bo)	-2 dB	-2 dB	-2 dB
Satellite antenna gain (Gt)	20 dB	20 dB	20 dB
Earth station antenna gain (Gr)	40 dB	40 dB	40 dB
Free space path loss at 4 GHz (LP)	-196.3 dB	-190.4 dB	-181.3 dB
Edge of beam loss (Lant)	-3 dB	-3 dB	-3 dB
Clear air atmospheric loss (La)	-0.2 dB	-0.2 dB	-0.2 dB
Other losses (Lm)	-0.5 dB	-0.5 dB	-0.5 dB
Received power (Pr)	-119 dBW	-113.1 dBW	-104.5 dBW
Downlink Noise Power Budget in Clear Air			
Boltzmann's constant (k)	-228.6 dBW/K/Hz	-228.6 dBW/K/Hz	-228.6 dBW/K/Hz
System noise temperature (Ts)	18.8 dBK	18.8 dBK	18.8 dBK
Noise bandwidth (Bn)	74.3 dBHz	80.2 dBHz	88.8 dBHz
Receiver noise power (N)	-135.5 dBW	-129.6 dBW	-121 dBW
C/N Ratio in Receiver in Clear Air			
C/N = Pr – N	16.5 dB	16.5 dB	16.5 dB
Link margin over 9.5 dB threshold	7 dB	7 dB	7 dB
Capacity using Link Margin (approx)	**70 Mbps**	**270 Mbps**	**1900 Mbps**

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HEO Satellite Performance Perspective

- Extended visibility over mid-latitude regions, unlike GEO and fast-moving LEO.
- Long dwell time at apogee → high elevation angle, fewer blockages, and higher link availability.
- Lower Doppler and slant-range variation during dwell → stable QoS and fewer link adaptations.
- Minimal handovers when deployed as HEO constellations
  - smoother user experience in voice/video calls
- Ideal for India, maritime corridors, and disaster-prone areas with limited terrestrial reach.
  - Improved continuity for aviation, maritime, and emergency communication missions

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Satellite Configuration Variations

- Service Link to Device, Feeder Link to Ground
- Satellite as a pure data pipe (think of it as a WiFi connection through space)
- Satellite as an NTN transparent bent pipe (gNodeB / aNB on the ground)
  - RU, DU, CU all on the ground
- Satellite as an NTN fully regenerative payload (gNodeB / aNB in space)
  - RU, DU, CU all in space
- Satellite as a split gNodeB / aNB X
  - For example RU, DU in space, CU on the ground, or RU in space & DU/CU on the ground
  - Such split systems can have high signalling overheads with high latencies between split nodes, and such configurations may not be viable

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Network Performance Aspects to Consider

- High speeds and low dwell times of LEO satellites
- Doppler and Frequency Compensation
- Mobility management for devices
- Weather-induced attenuation
- Terminal alignment & link ARQ/PHY issues
- Congestion and fair use policies
- Beam switching for mobile users
- Ground gateway backhaul dependencies

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Network KPIs for Consideration

- Service Availability
- Accessibility
- Retainability
- Downlink Throughput
- Uplink Throughput
- Downlink Latency / Jitter
- Uplink Latency / Jitter
- Impact of HARQ enabling on application performance
- Impact of HARQ disabling on application performance
- End-to-end latency tolerance for DTN connectivity flows
- Impact Windows (Rain fade, Solar flares, …)

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Interesting R&D Opportunities to Consider

- Hybrid Terrestrial / Non-terrestrial routing
- Inter-Constellation Coordination
- Spectrum sharing between terrestrial and non-terrestrial deployments
- Dynamic Computing in Space
- Dynamic Storage in Space
- Opportunistic AI Inferencing in Space
- Coordinated Sensing, Motion, and Communications (CSMC)

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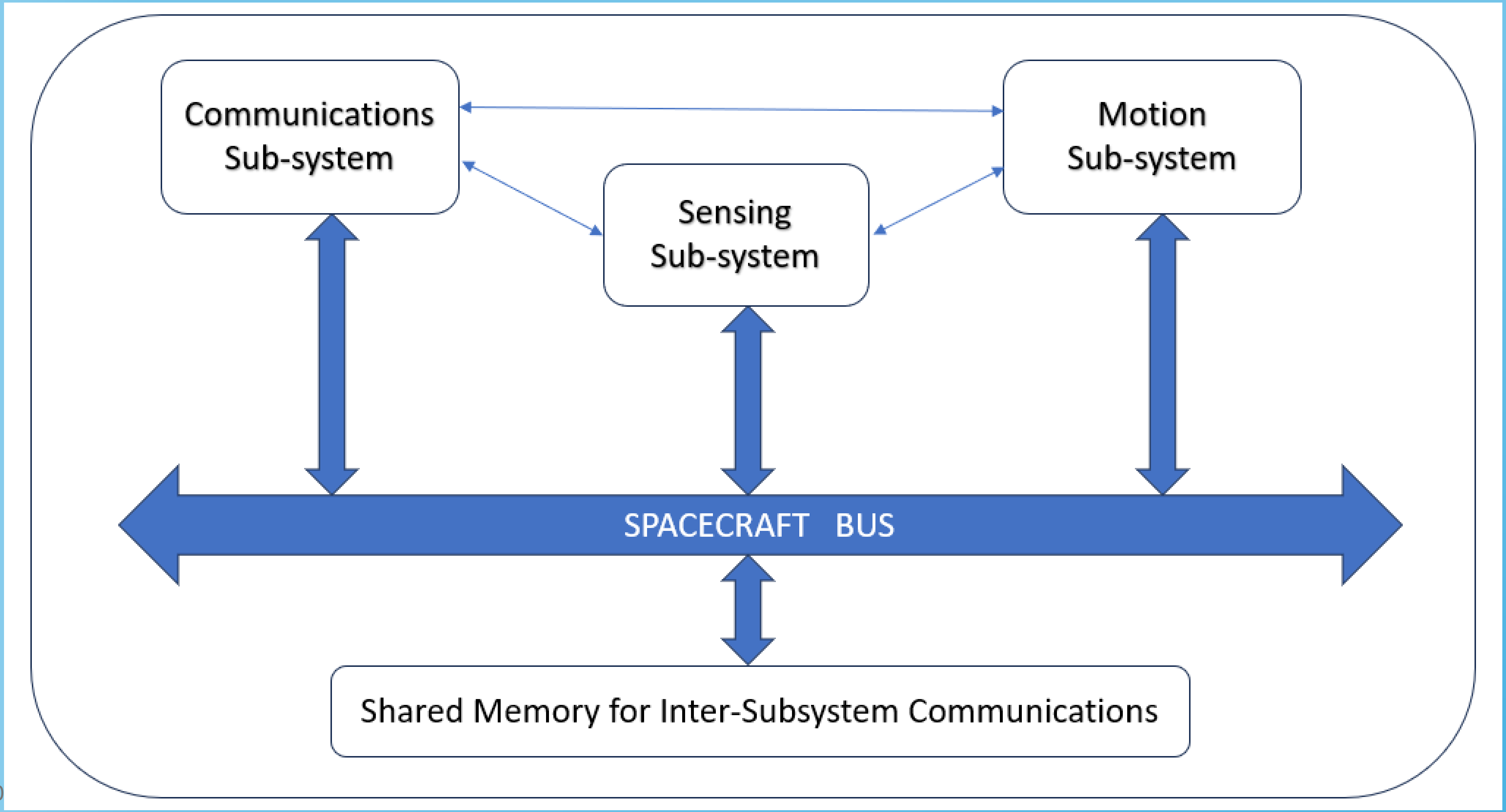
An Opportunity for R&D
-Coordinated Sensing, Motion & Communications



Overall Expectations

- It would be good to think differently when it comes to satellite connectivity

- It is not necessarily about obtaining high speeds or low latencies

- *Satellite systems can be primarily about providing ubiquitous coverage to the planet and to connect the unconnected and to provide service which was otherwise not available*

- Once we reset our expectations on this, we will be happy with pursuing satellite connectivity and NTN integration

- We have to think of it as an opportunistic connectivity mechanism that will be a blessing when it is available and where it is available
  - *Any other benefits such as opportunistic space computing or AI in space or hybrid routing can be a bonus*

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Thank you.

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