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Designing a 3GPP NB-IoT NTN service for CubeSats in low density constellations

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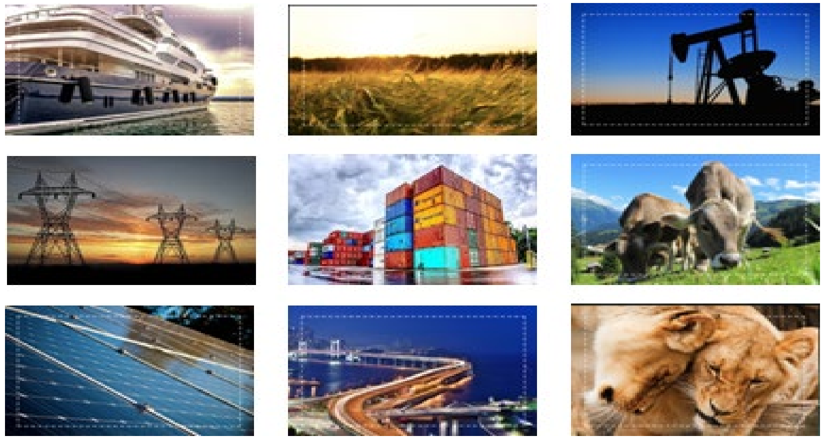
Presenter: Ramon Ferrús

About this talk

- Introduction: Emerging satellite IoT services
- 3GPP work towards NB-IoT NTN
- Sateliot’s NB-IoT NTN solution framework
- Key design aspects:
  - Link budget
  - Beam layout
  - Constellation
  - Discontinuous service and feeder link operation
- Concluding remarks

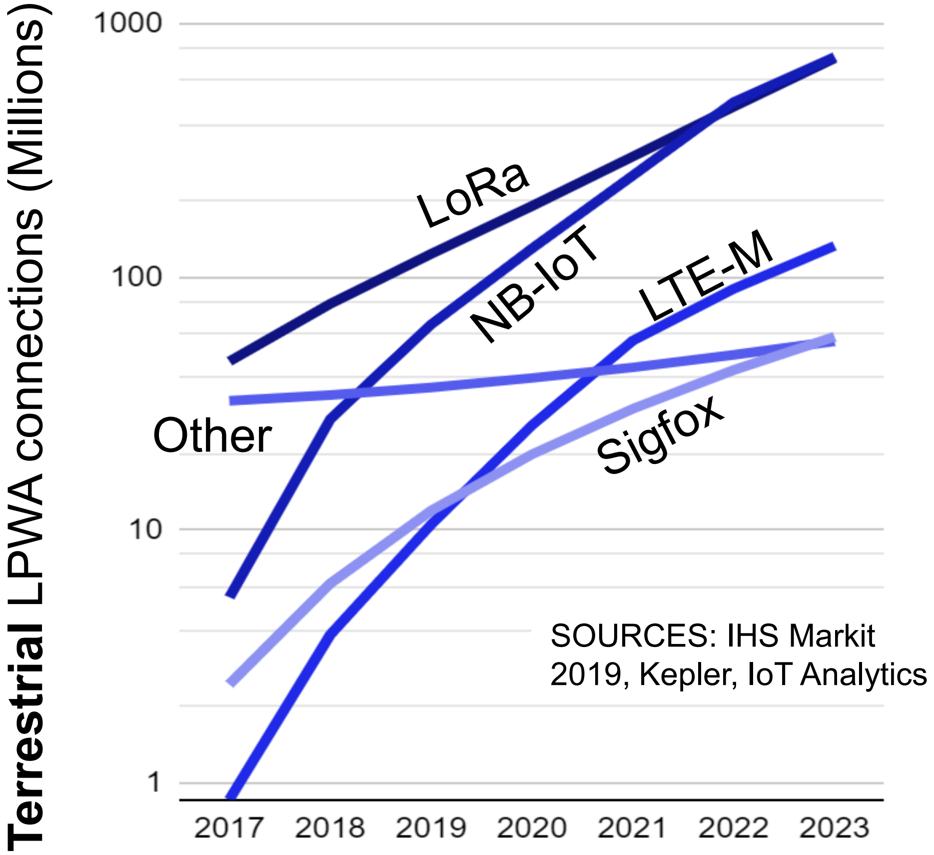
Introduction

- Increasing demand for **IoT services**



- Broad range of applications and technologies:
  - Short-range IoT
  - Wide-area IoT, including 4G/5G cellular for broadband/time-critical IoT and LPWA for massive IoT
- Market potential of **billions** of IoT devices

Low Power Wide Area (LPWA) technologies for massive IoT



In 2020 the LWPA market reached 423 million IoT connections and is expected to grow at a CAGR of 43% to reach 2.5 billion IoT connections by 2025

Introduction

- Lack of **global coverage** and **international roaming** identified as main causes slowing down further mass adoption
  - Use cases representing ~30% of objects can strongly benefit from global coverage
  - There is a vast amount of areas out of reach of terrestrial networks
    - Terrestrial networks only cover 15% of the Earth's surface (50% of the land mass)

- Satellite is well-positioned to fill the coverage gap and provide international roaming.
- A single/integrated implementation (terrestrial+ satellite) alongside a reduced price for satellite connectivity can enable true ubiquitous coverage with the necessary *cost efficiency*

3GPP standardization work towards NB-IoT NTN

- Existing **3GPP Cellular IoT** solutions (NB-IoT, LTE-M) are being extended for Non-Terrestrial Network (NTN)

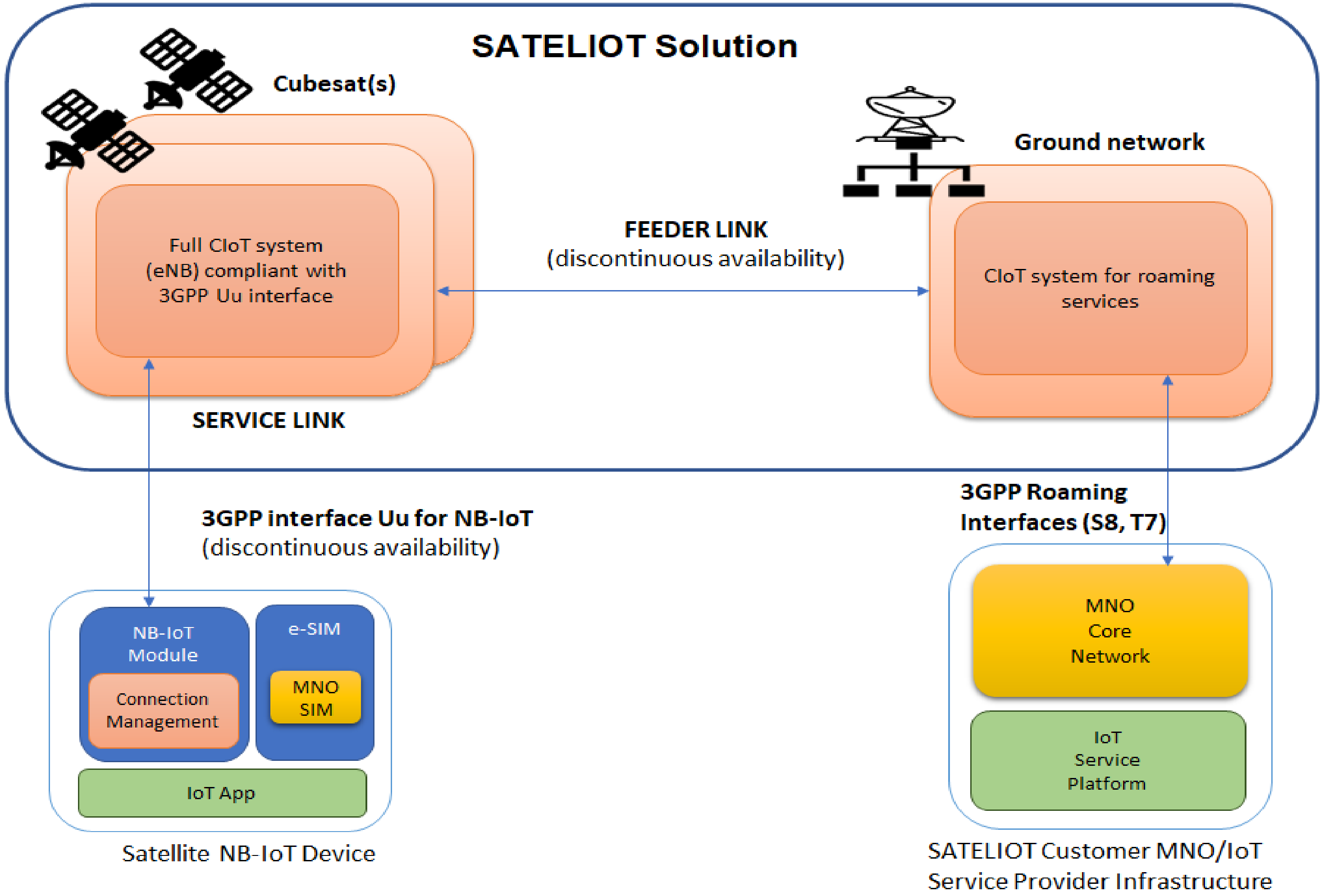
- Extensions addressing both GEO and LEO constellations, latter with earth-moving and earth-fixed beams. Essential adaptations being defined / discussed, such as:

  - Mechanisms for time and frequency synchronization
  - Timing relationships adjustments (random access, contention resolution, scheduling, HARQ timers, etc.)
  - System information enhancements
  - Idle mode and connected mode mobility
  - Tracking areas and paging

- Minimum workable solution expected to form part of **Release 17** (June 2022)

Sateliot's NB-IoT NTN solution framework

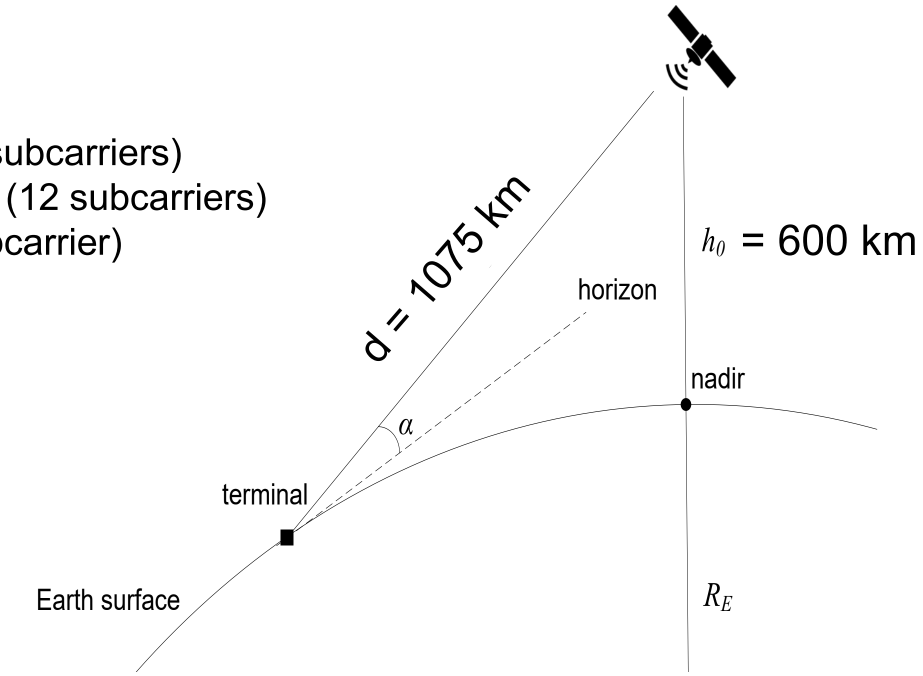
- CubeSat platform
- Regenerative payload
- Low density LEO constellation
- Service link based on NB-IoT NTN
- 3GPP/GSMA roaming architecture
- Store & Forward capabilities for discontinuous feeder connectivity



Key design aspects: Link budget

NB-IoT channel:

- **DL:** 180 kHz (12 subcarriers)
- **UL:** from 180 kHz (12 subcarriers) to 3.75 kHz (1 subcarrier)



Satellite

Satellite type	Small sat / CubeSat
Altitude	600 km, circular orbit
Transmit power (per beam)	**33 dBm**
Satellite Antenna Gain	**{7, 11, 15} dB**
Antenna polarization	Circular
Antenna temperature	290 K
Satellite Noise Figure (NF)	{3 dB, 5 dB} dB

Geometry & Channel

Elevation angle (α) (i.e. elevation at which the UE "sees" the satellite)		{30, 90} degrees
Distance between UE and Satellite (slant range)		**1075.1** km for α=30 degrees **600** km for α=90 degrees
Free space propagation loss		159.1 dB for α=30 degrees 154.0 dB for α=90 degrees
Additional losses	Polarization	3 dB
	Scintillation	2.2 dB
	Atmospheric absorption	0.1 dB
	Antenna pointing mismatch (L_{apm})	{0, 3} dB
	Shadowing	3 dB

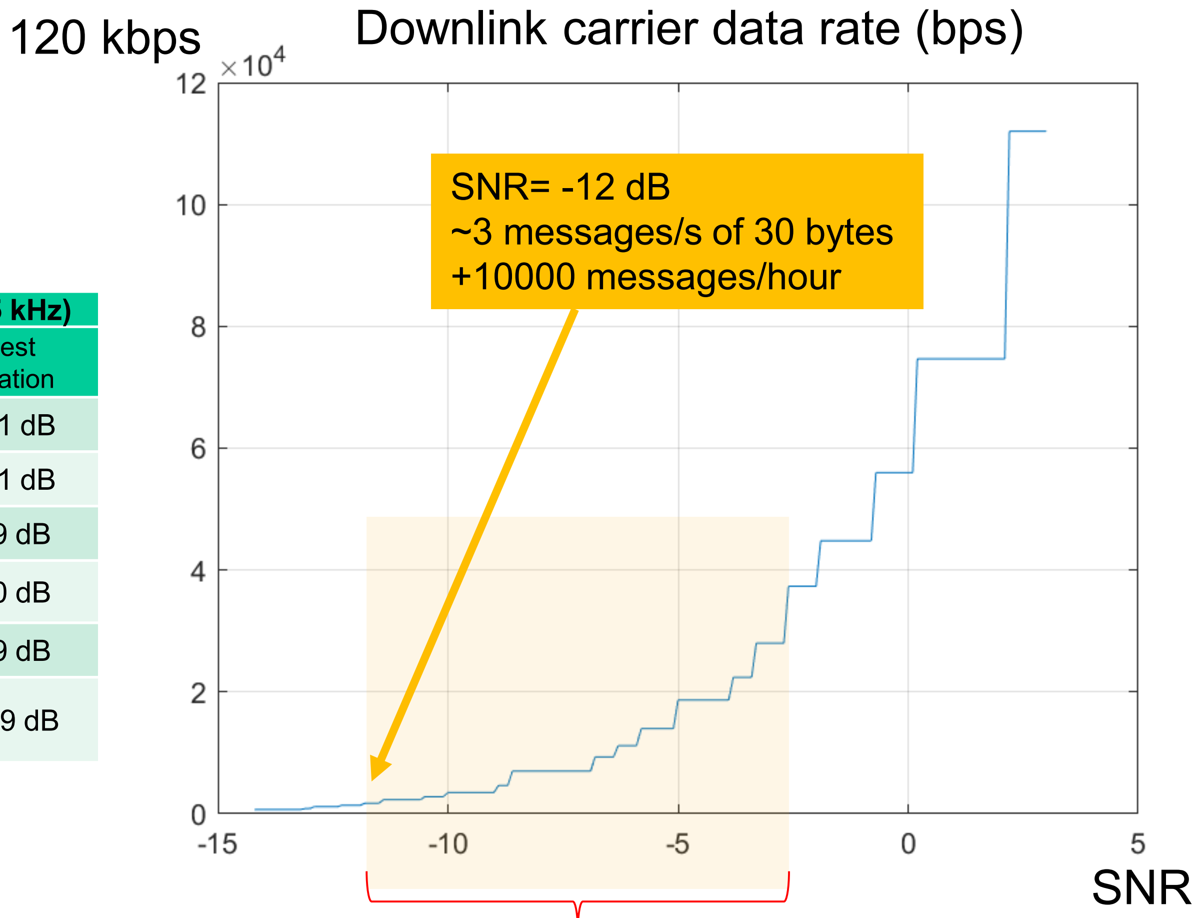
IoT Device

UE type	NB-IoT small form factor device
Frequency band	S band (i.e. 2 GHz)
Transmit power	**23 dBm**
Antenna Tx / Rx gain	0 dBi (Omni-directional)
Polarization	Linear
Antenna temperature	290 K
UE Noise figure (NF)	{4 dB, 7 dB}

Key design aspects: Link budget

Achievable SNR

Satellite Antenna Gain	Sat NF - UE NF	DL SNR		UL SNR (ST 15 kHz)		UL SNR (ST 3.75 kHz)	
		Worst location	Best location	Worst location	Best location	Worst location	Best location
7 dB	5 dB / 7 dB	-16.0 dB	-7.9 dB	-13.2 dB	-8.1 dB	-7.2 dB	-2.1 dB
	3 dB / 4 dB	-13.0 dB	-4.9 dB	-11.2 dB	-6.1 dB	-5.2 dB	-0.1 dB
11 dB	5 dB / 7 dB	-12.0 dB	-3.9 dB	-9.2 dB	-1.1 dB	-3.2 dB	4.9 dB
	3 dB / 4 dB	-9.0 dB	-0.9 dB	-7.2 dB	0.9 dB	-1.2 dB	6.0 dB
15 dB	5 dB / 7 dB	-8.0 dB	0.1 dB	-5.2 dB	2.9 dB	1.2 dB	8.9 dB
	3 dB / 4 dB	-5.0 dB	3.1 dB	-3.2 dB	4.9 dB	2.8 dB	10.9 dB



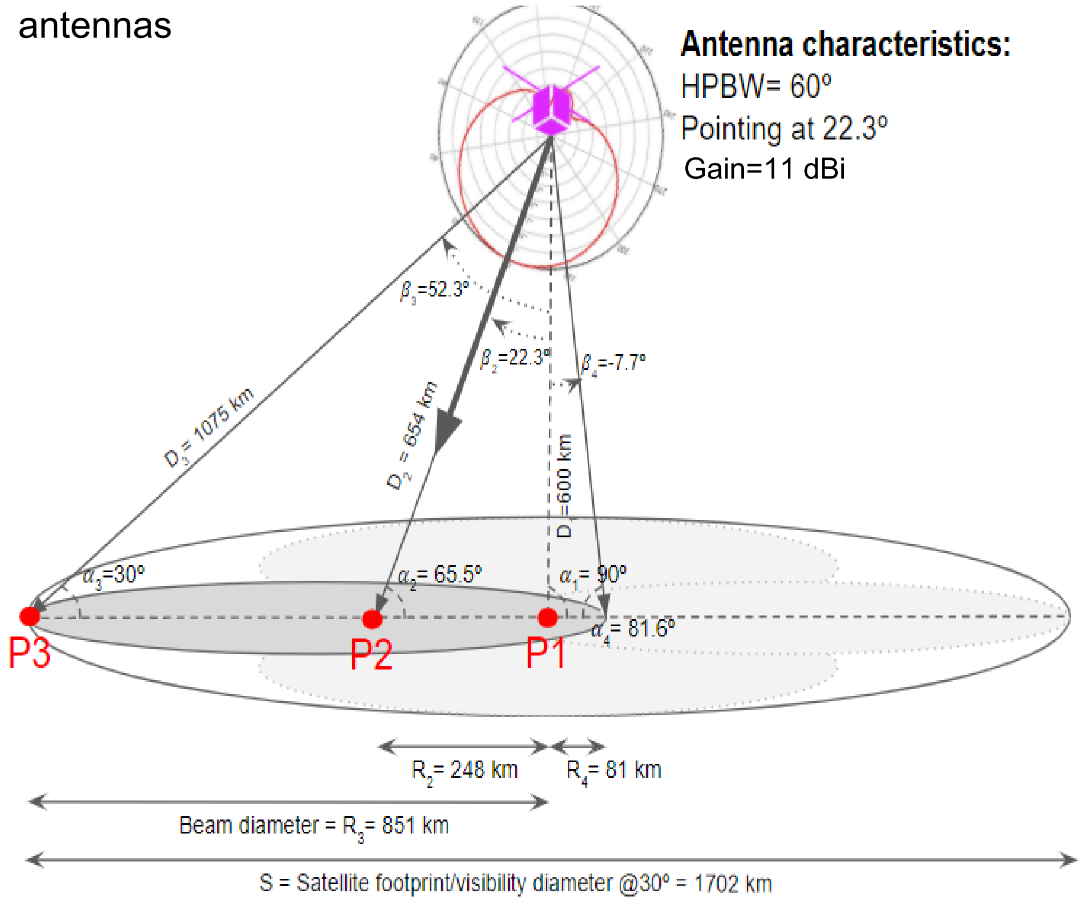
More details in: 3GPP R1-2100521, "Discussion on NB-IoT NTN scenarios with small satellites / CubeSats", Sateliot, Gatehouse, Thales, Kepler, 3GPP TSG RAN WG1 #104-e, January 25th – February 5th, 2021, https://www.3gpp.org/ftp/TSG_RAN/WG1_RL1/TSGR1_104-e/Docs/R1-2100521.zip

Key design aspects: Beam Layout

- Multi-beam configurations can be pursued to achieve a high coverage footprint and increased capacity
- Multi-beam configurations require several RF front-ends and several antennas pointed to different directions or more complex antennas with beamforming capabilities.

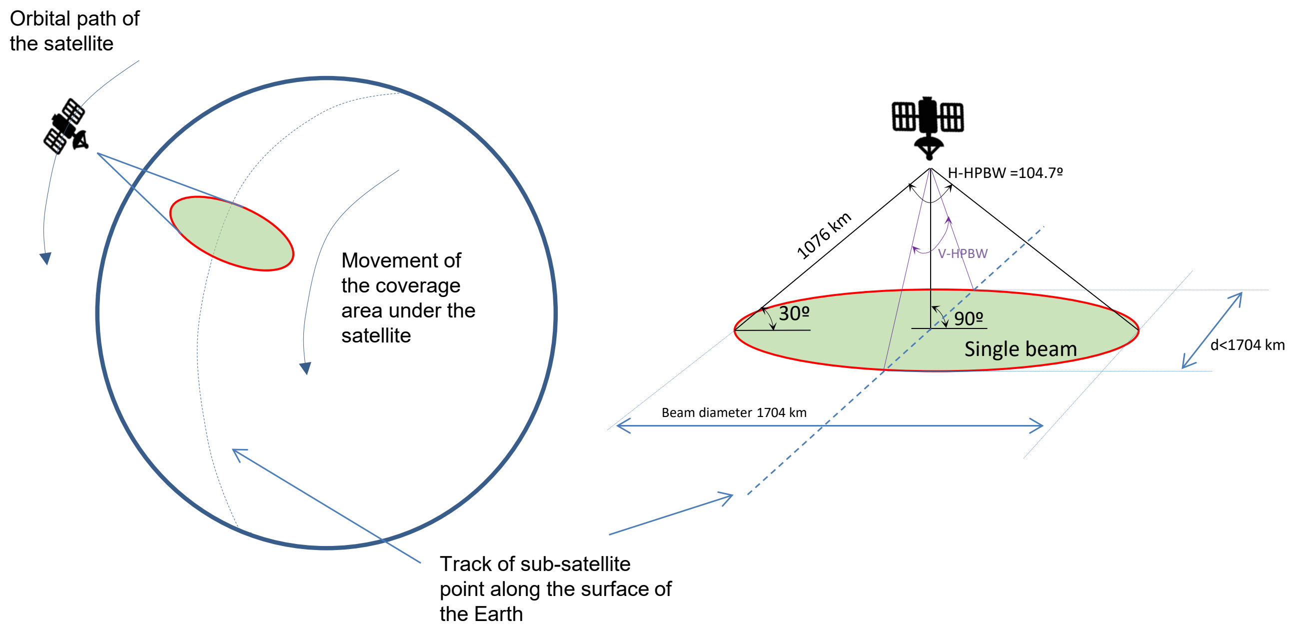
- The feasibility of multi-beam configurations in CubeSats is importantly constrained by:
  - Surface and volume available in the satellite platform to handle multiple antennas
  - Platform power budget
  - Heat dissipation capabilities

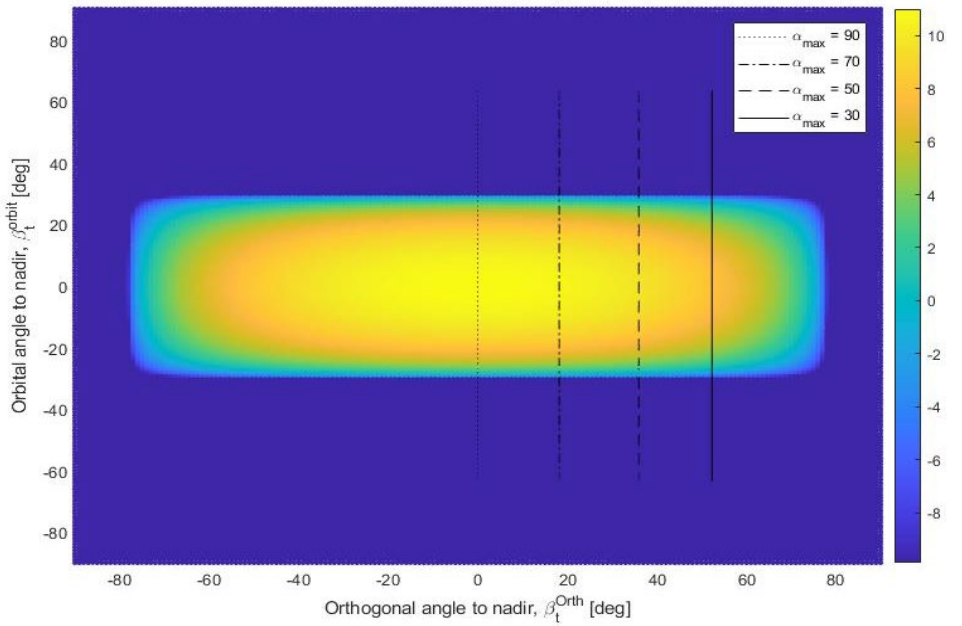
Example of multiple-beam conf. with COTS antennas

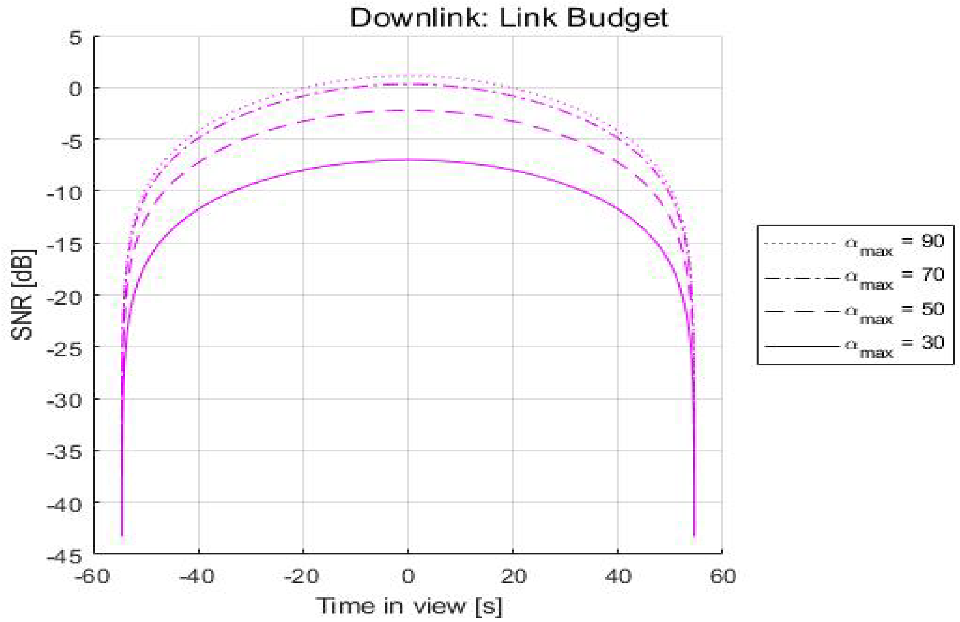


Key design aspects: Beam Layout

- E.g. Large, single-beam with **antenna arrays** delivering beams with large Horizontal HPBW and narrow Vertical HPBW







More details in: 3GPP R1-2103716, "Link budget analysis for Set-4", Sateliot, Gatehouse, Thales, 3GPP TSG RAN WG1 Meeting #104-bis e-meeting, to be held in April 12th - April 20th, 2021, https://www.3gpp.org/ftp/TSG_RAN/WG1_RL1/TSGR1_104b-e/Docs/R1-2103716.zip

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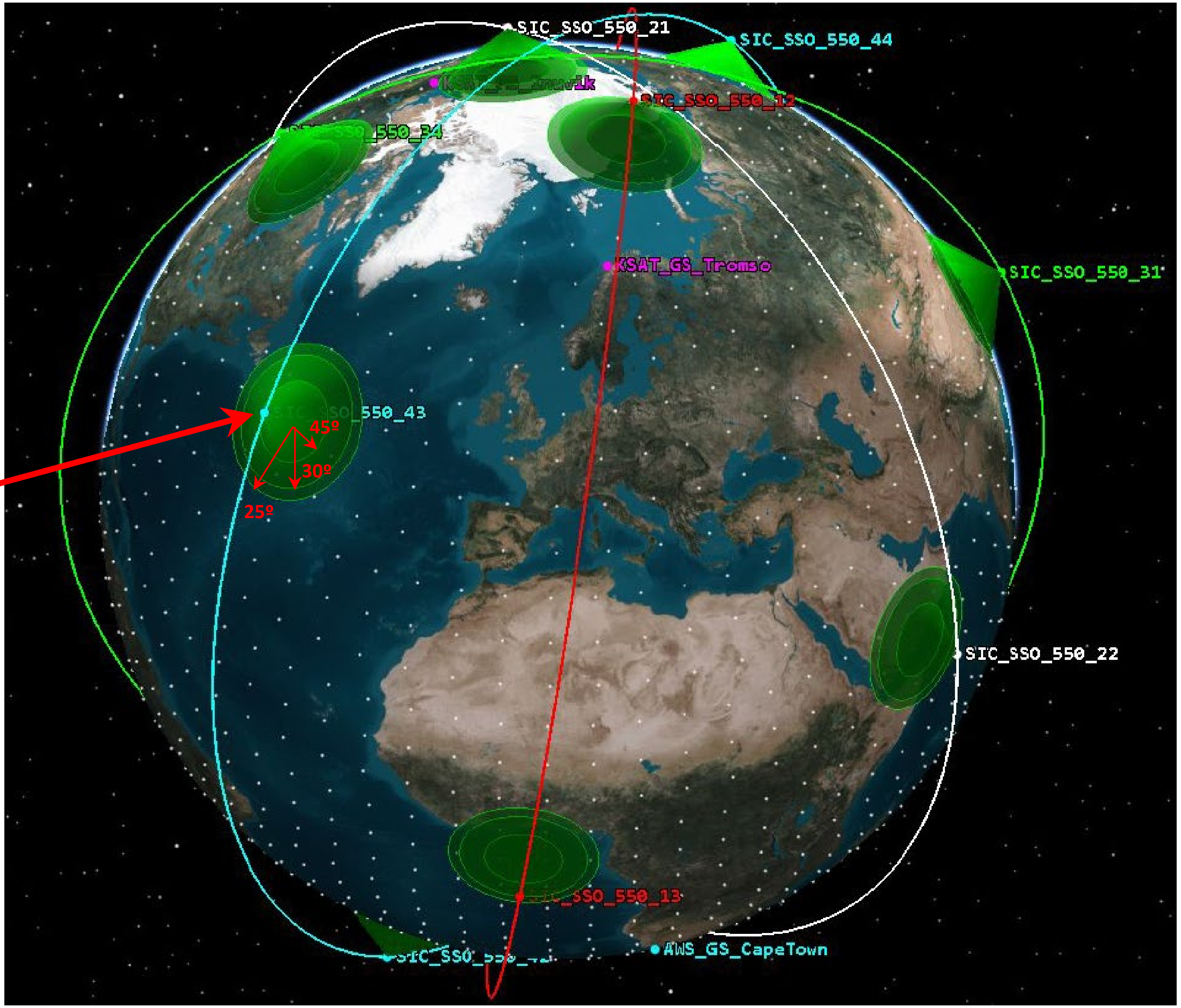
Key design aspects: Constellation

- Reference constellation to benchmark service KPIs
  - 16-satellite Walker constellation
  - Optimized to reduce maximum revisit time at high latitudes
  - 5 Ground Stations

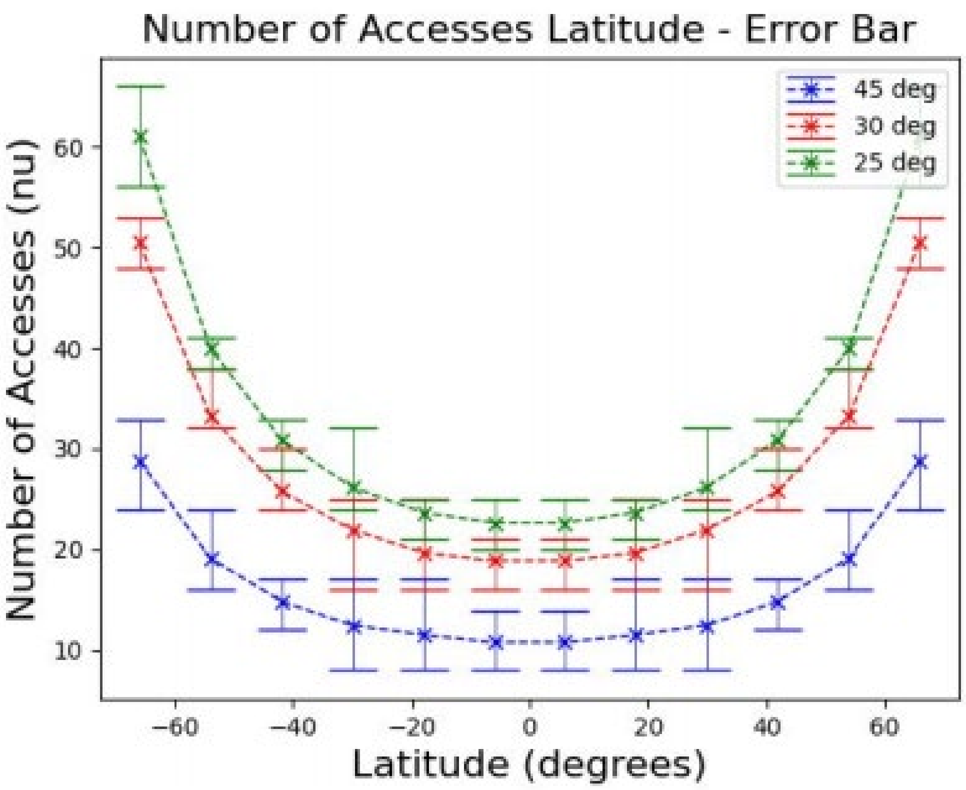
Different sizes of the satellite visibility cone have been considered to establish the satellite coverage footprint. They correspond to the following elevation angles as seen from a IoT device:

-45 degrees
-30 degrees
-25 degrees

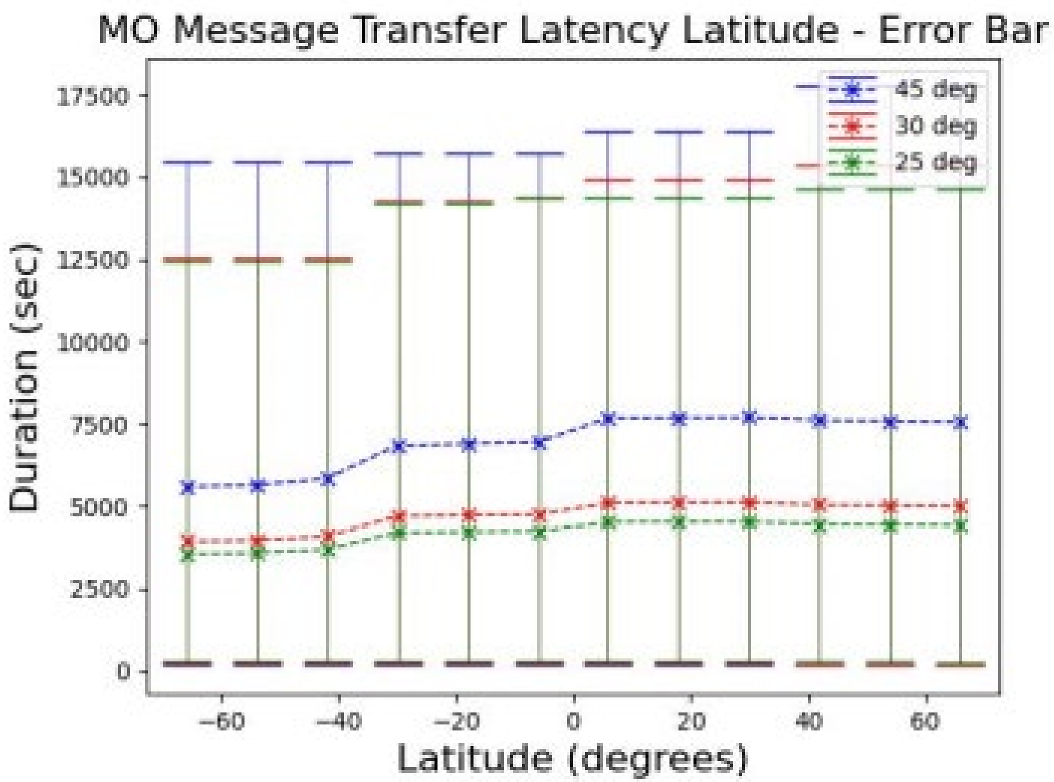


Key design aspects: Constellation

<u>Messages Frequency KPI</u>

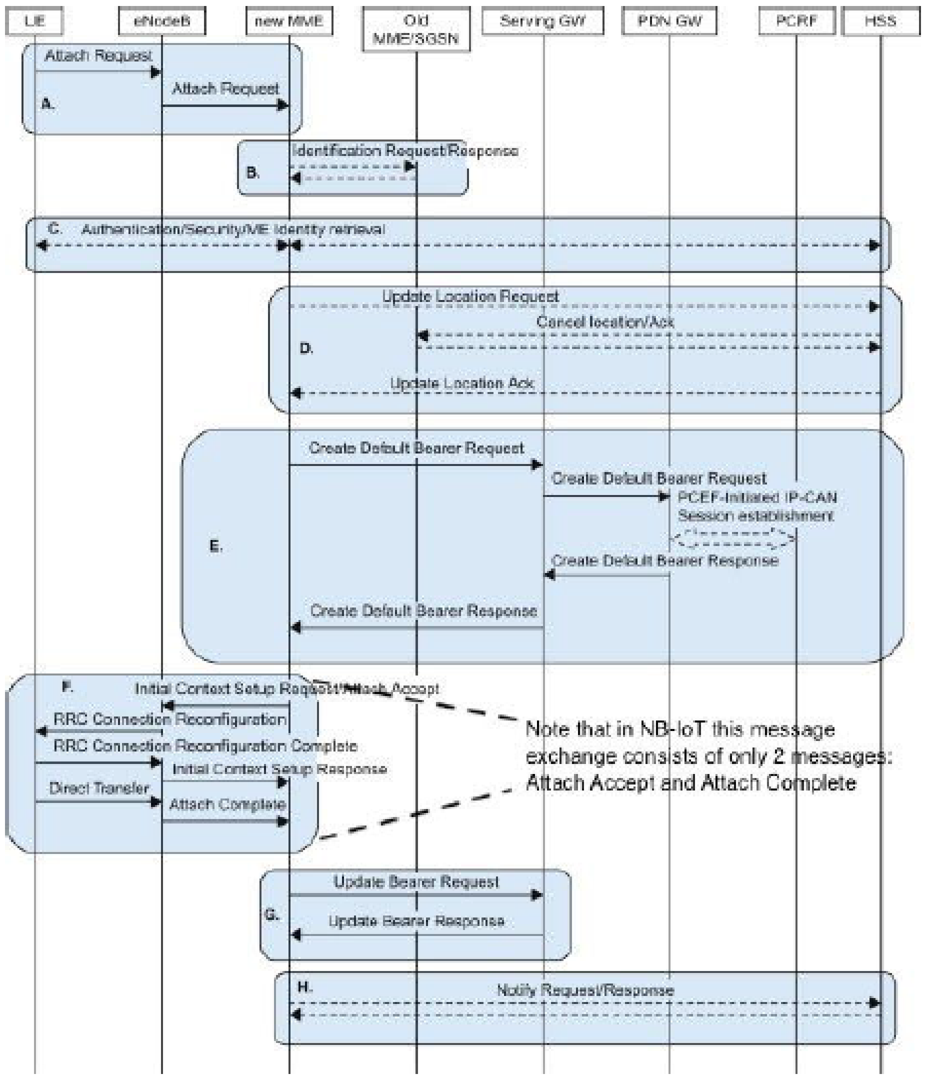


<u>Message Latency KPI*</u>



*Worst case latency assuming the message is generated just after a satellite pass so that the device has to wait until next satellite. Only 5 GS considered.

Key design aspects: Discontinuous operation support



3GPP standard procedure for Network Registration

- It assumes connectivity between device, eNB (radio) and Core Network is always on.

Modifications to this procedure has been developed to support Registration w/o continous connectivity between the satellite eNB and the ground CN.

Concluding Remarks

- Growing market for massive IoT services
- Satellite access well positioned to play a key role in global, interoperable IoT services, filling the coverage gap of terrestrial networks
- 3GPP undergoing 5G standards adaptation to address this market
- Business propositions and economically viable solutions ready to support early NB-IoT NTN service deployment in the 2022/2023 timeframe
- Challenging service design aspects with CubeSats being addressed (e.g. beam layouts, constellation, service discontinuity features, etc.)

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Thank you !

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