Non-terrestrial Networks (NTN)

1.Key Ideas

2.NTN Based NG-RAN Architecture

3.NTN Radio Protocol

4.NR Physical Layer Adaptations for NTN

5.NTN Channel Model

6.Outlook

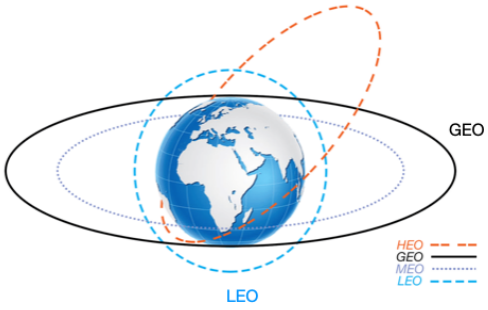
- A global standard based on 5G technology framework for all NTN platforms, whatever orbit, frequency band, or device
- Enable a smooth integration of NTNs into 5G system
- Wide service coverage capabilities and reduced vulnerability of space/airborne vehicles
  - Foster the roll out of 5G service in un-served areas that cannot be covered by terrestrial 5G network and underserved areas
  - Reinforce the 5G service reliability by providing service continuity
  - Enable 5G network scalability

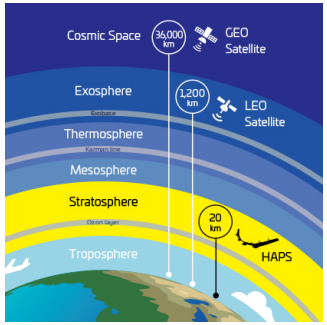
- Open up access to various verticals and a decrease in the cost of network infrastructure and devices due to the economies of scale of 5G ecosystem
- Major impacts
  - Coverage, user bandwidth, system capacity, service reliability or service availability, energy consumption, connection density

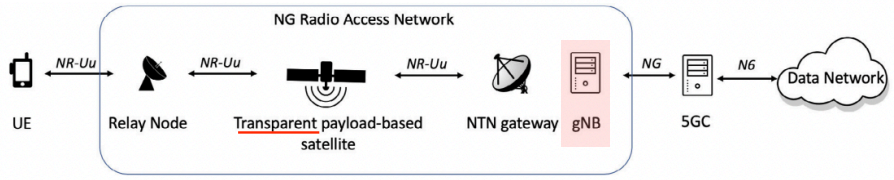
- Use cases
  - eMBB
    - **Multi-connectivity**: users in underserved areas are connected to the 5G network
    - **Fixed cell connectivity**: users in isolated villages or industry premises
    - **Mobile cell connectivity**: passengers on board vessels or aircrafts
    - **Network resilience**: some critical network links requires high availability to prevent complete network connection outage

- mMTC
  - **Wide area IoT service**: global continuity of service for telematic applications based on a group of sensors/actuators scattered over or moving around a wide area
  - **Local area IoT service**: group of sensors that collect local information, connect to each other and report to a central point
- Satellites provide broadband connectivity between the core network and the cells

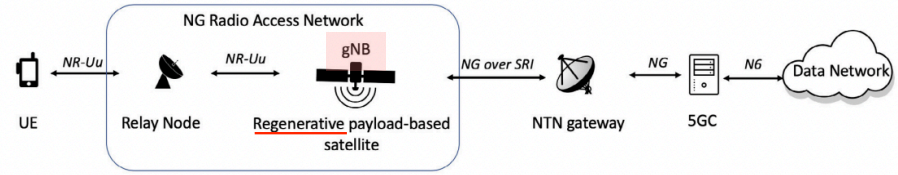
- NR and NG-RAN design aspects need to be reconsidered for NTN
  - Max cell size
    - Especially for LEO and GEO based access
  - Transparent or regenerative payload options
  - Earth fixed or mobile beams
    - Especially for HAPS and LEO based access scenarios



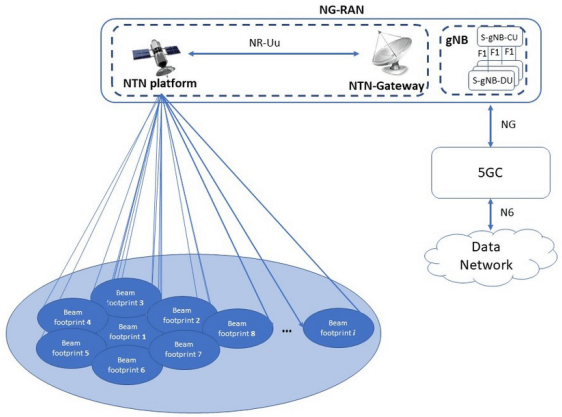




(a) Transparent payload-based satellite

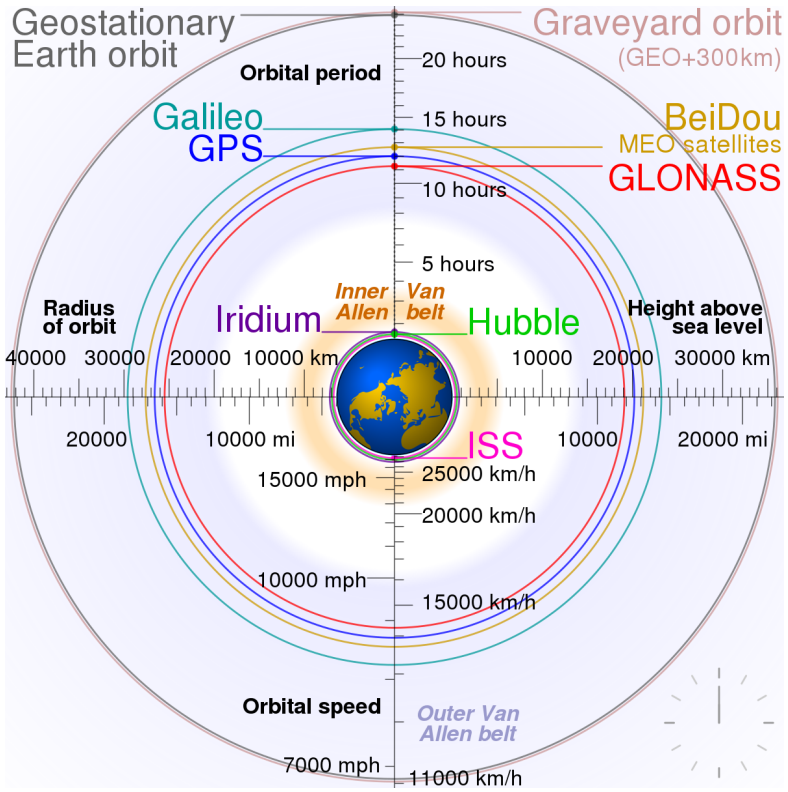


(b) Regenerative payload-based satellite

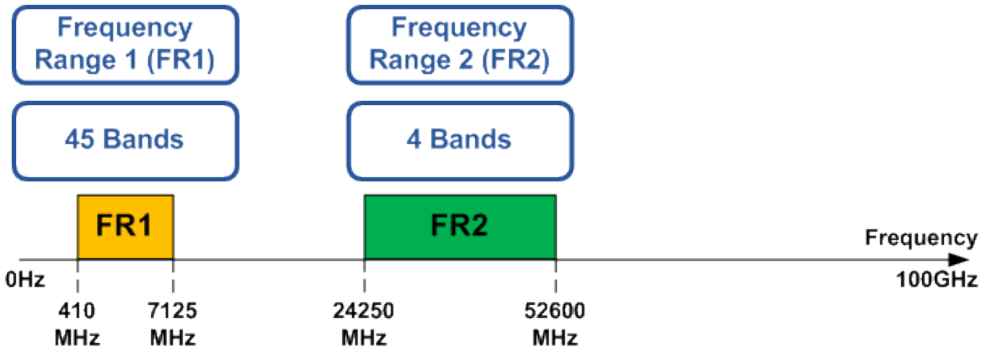


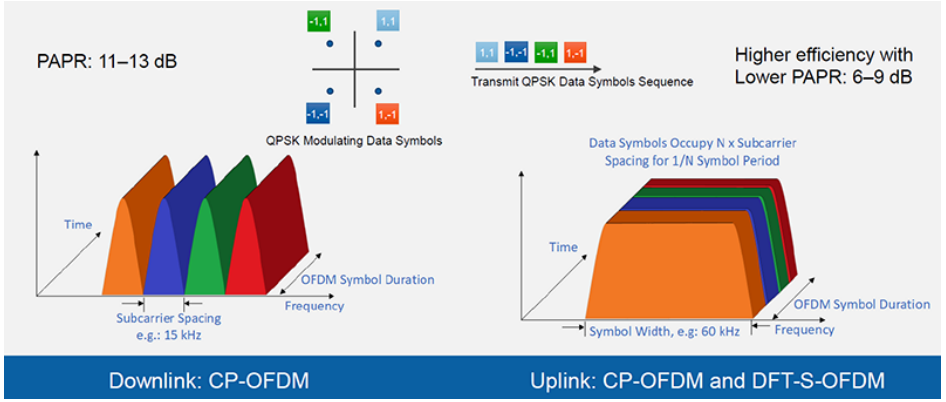
- UE with and without location determination capability, e.g. GNSS
  - Especially for LEO and GEO based access scenarios
- Targeted usage scenarios
- UE types

GNSS：Global Navigation Satellite System
- GPS (US)
- GLONASS (Soviet Union)
- Galileo (Europe)
- BeiDou (China)

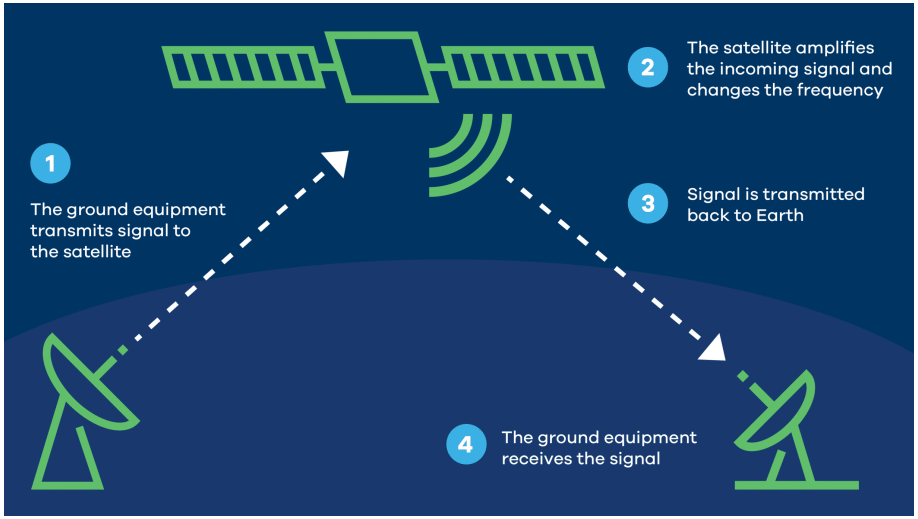


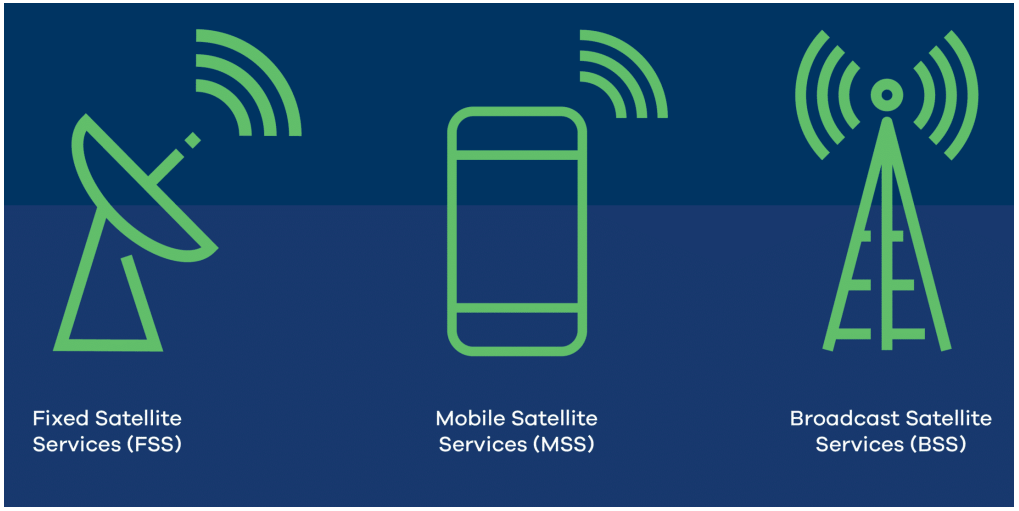
- Direct communications to mass market devices (3GPP defined class 3 UE) should consider
  - Operation of the satellite service link in FR1 frequency range to allow max commonality in RF front end of the devices
  - FDD mode with CP-OFDM on downlink and DFT-S-OFDM access scheme on uplink



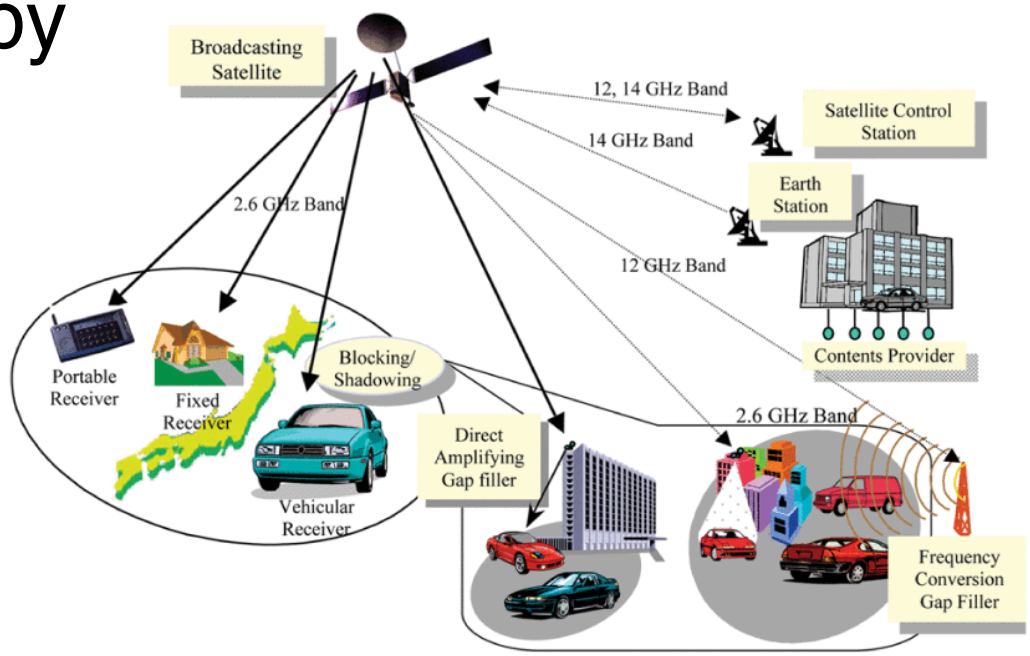


- **Non-terrestrial Network (NTN)** refers to a wide range of systems operating in various frequency bands allocated by ITU
  - Broadcast Satellite Services (BSS)
  - Fixed Satellite Services (FSS)
  - Mobile Satellite Services (MSS)

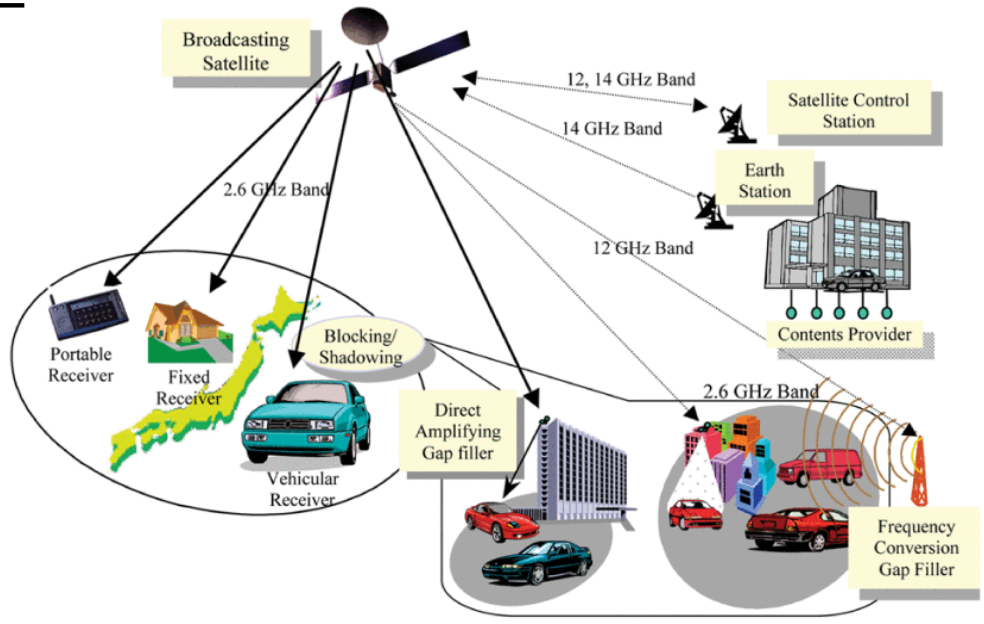




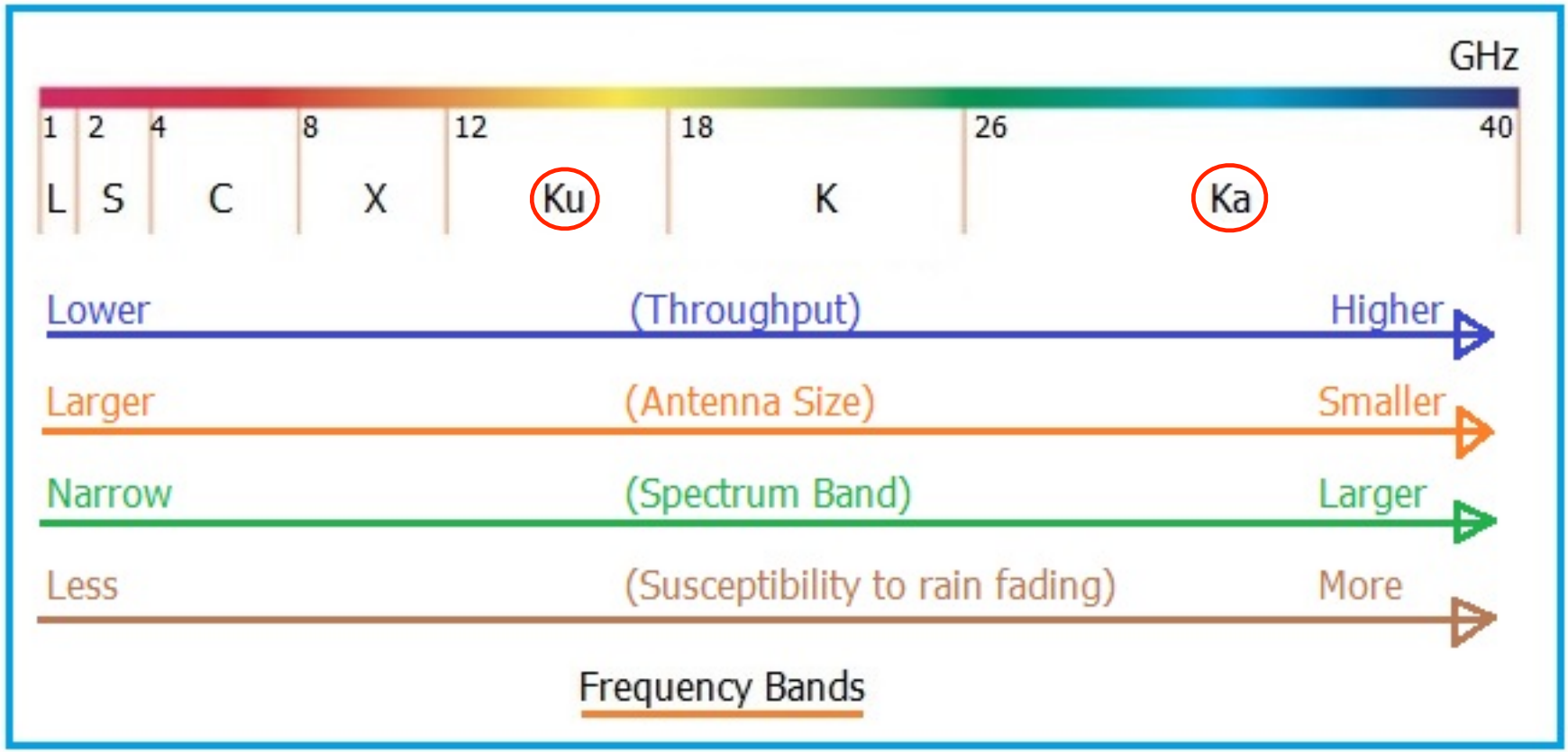
- **Broadcast Satellite Services (BSS)**
  - A radiocommunication service in which signals transmitted or retransmitted by space stations
  - Intended for direct reception by the general public
    - Individual reception
    - Community reception
  - Mainly used for the transmission of television and radio station signals



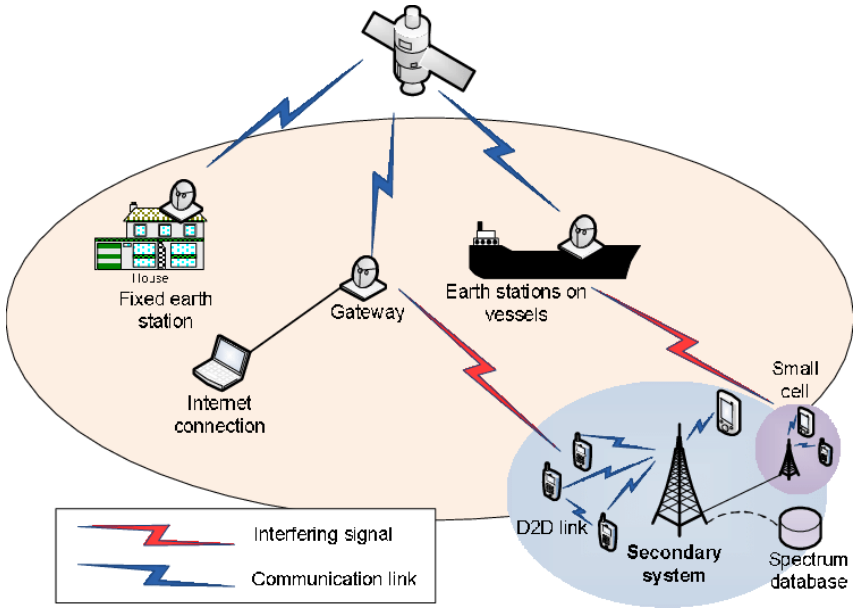
- Use high-power satellites to send signals over a wide range of receivers
- Allows users to receive signals using small, low-cost receiving equipment (such as home satellite dishes)
- Typically operates in high frequency bands, such as the **Ku**-band (12-18 GHz) and **Ka**-band (26.5-40 GHz)

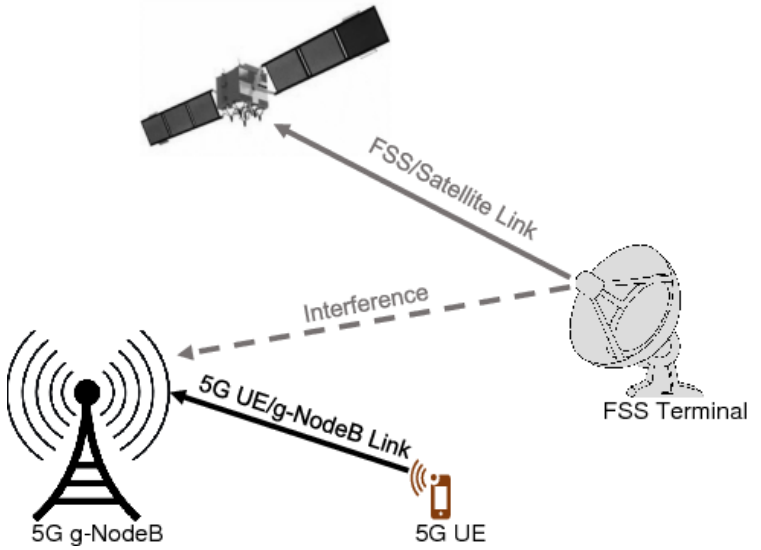


- Exemplary frequency bands
  - **S-band** (downlink & uplink: ~2 GHz)
  - **Ka-band** (downlink: 20 GHz; uplink: 30 GHz)

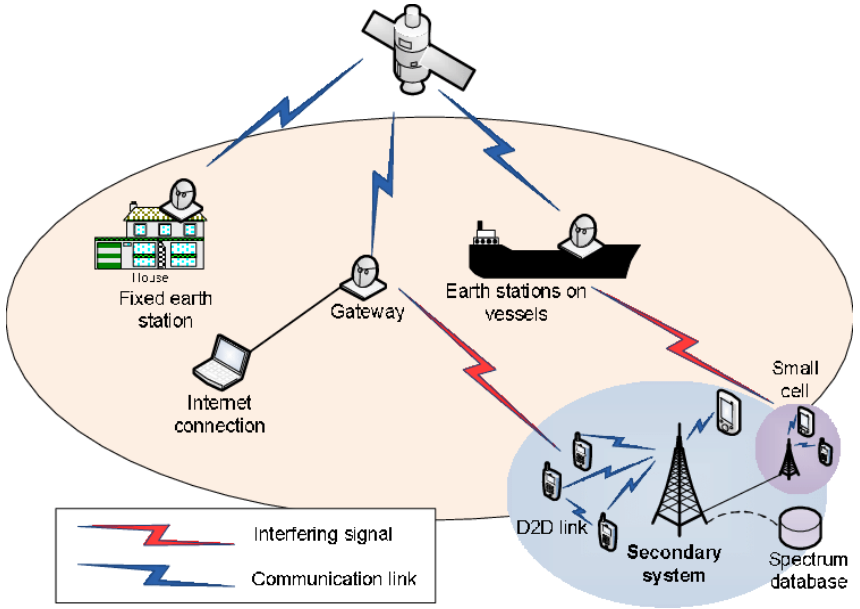


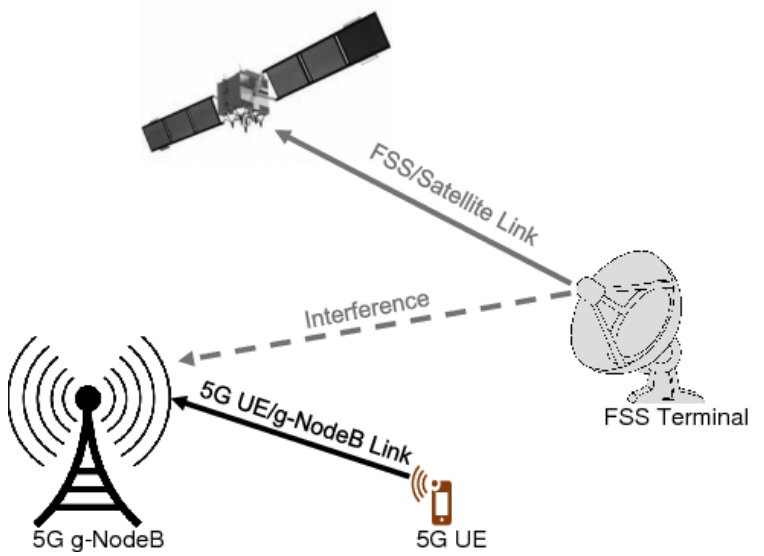
- **Fixed Satellite Services (FSS)**
  - A radiocommunication service between earth stations at given positions, when one or more satellites are used
  - The given position may be a specified fixed point within specified areas
  - In some cases this service includes satellite-to-satellite links, which may also be operated in the inter-satellite service





- The fixed-satellite service may also include feeder links for other space radiocommunication services
- Mainly used for point-to-point communications, such as telephones, data, and network services
- Uses fixed links between ground stations, allowing users to communicate via satellite
- Usually operates in the **C**-band (4-8 GHz) and **Ku**-band and, like BSS, can cover a wide range





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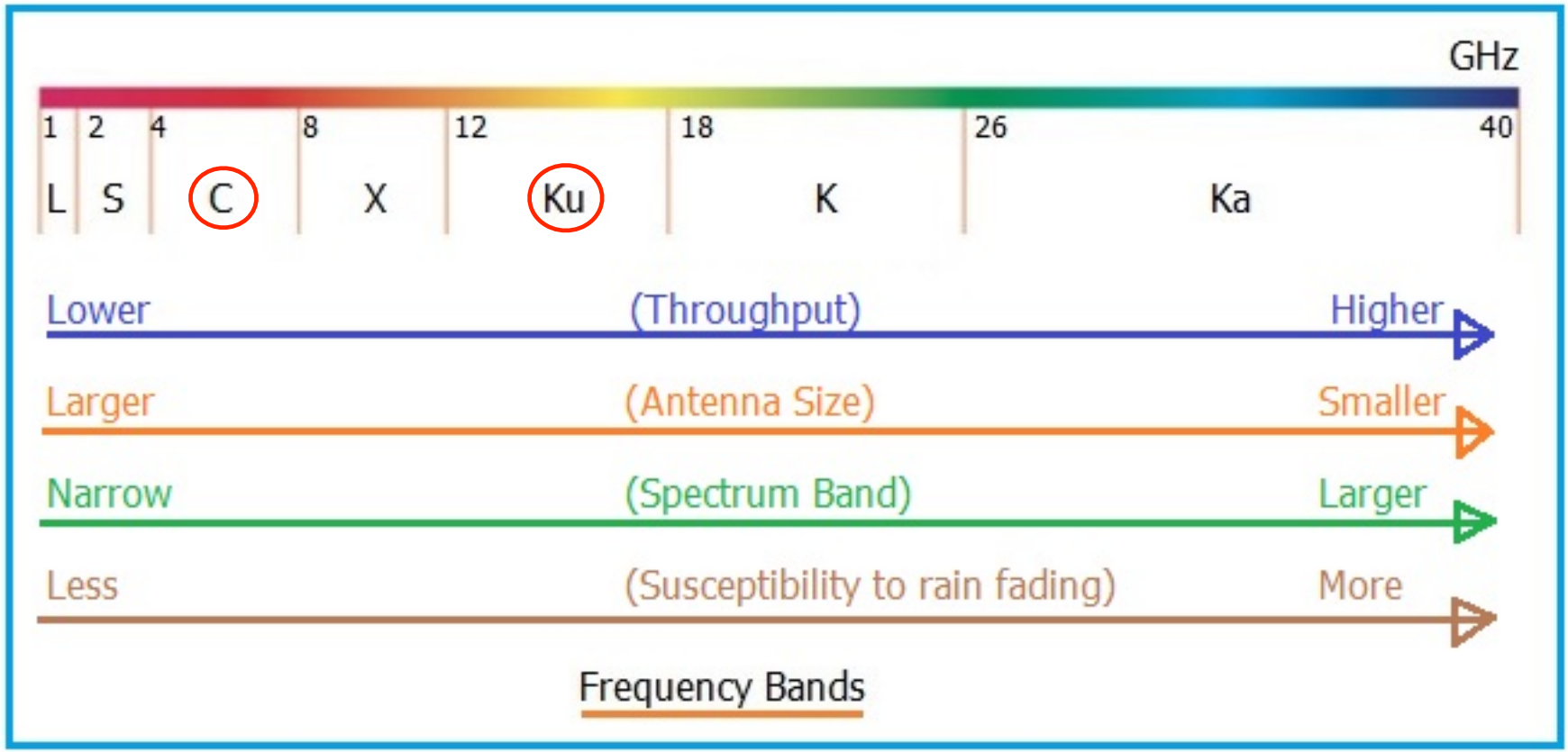
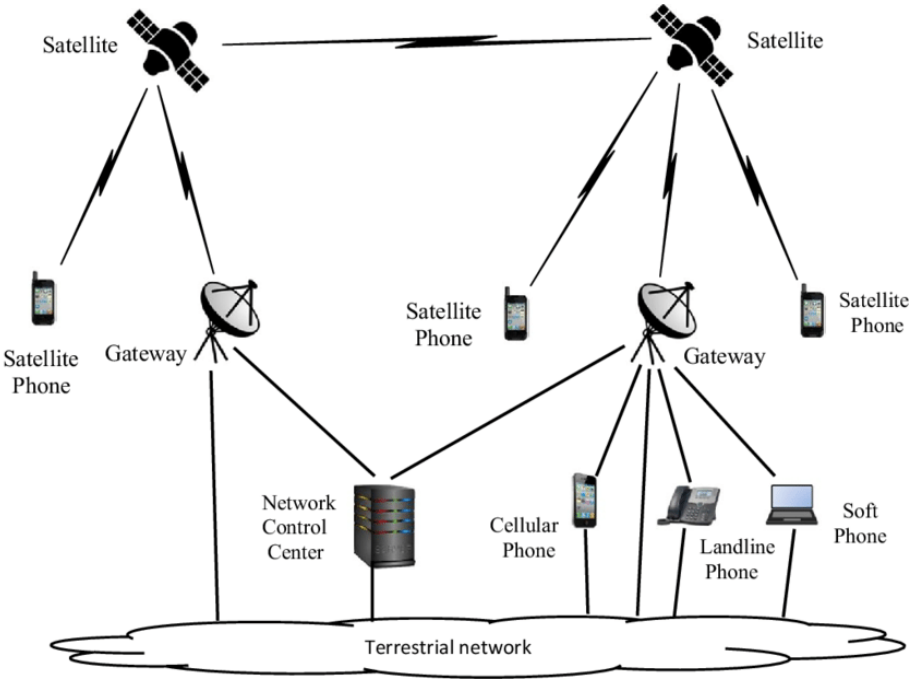
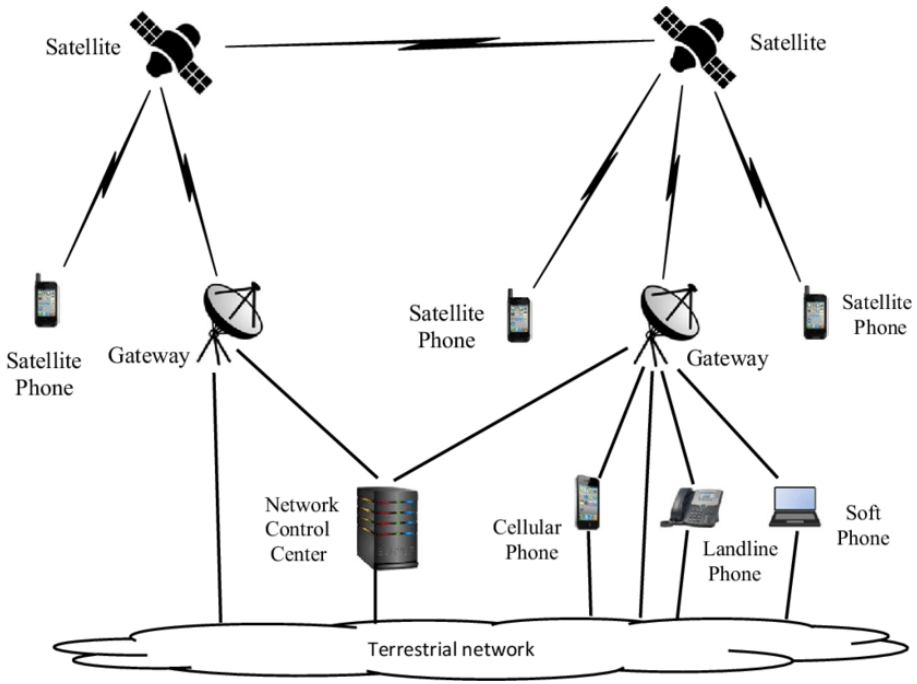


- **Mobile Satellite Services (MSS)**
  - A radiocommunication service
    - Between mobile earth stations and one or more space stations
    - Between space stations used by this service
    - Between mobile earth stations by means of one or more space stations
  - This service may also include feeder links necessary for its operation



- Mainly used to provide communication services for mobile users, such as ships, aircraft, and automobiles
- Allows users to maintain communication connections while on the move
- Typically operates in the **L**-band (1-2 GHz) and **S**-band (2-4 GHz) to ensure that user equipment in motion can maintain a connection with the satellite



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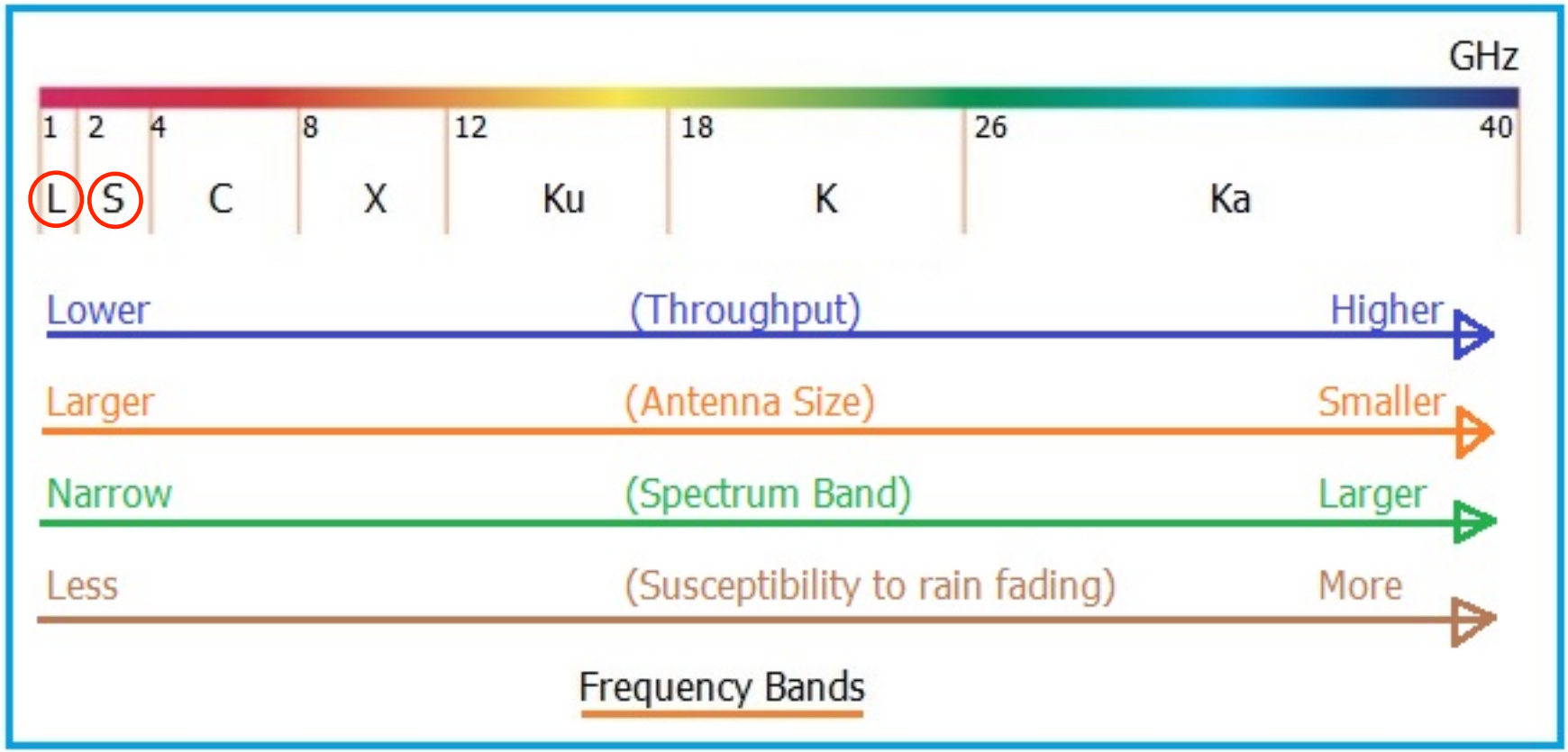
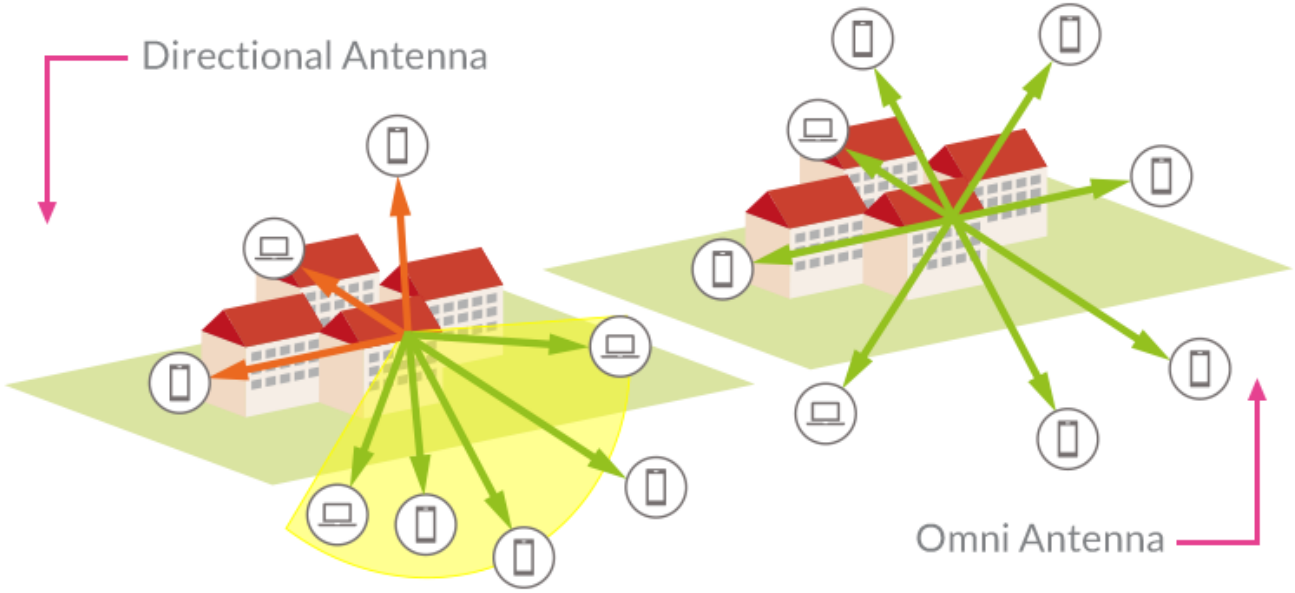
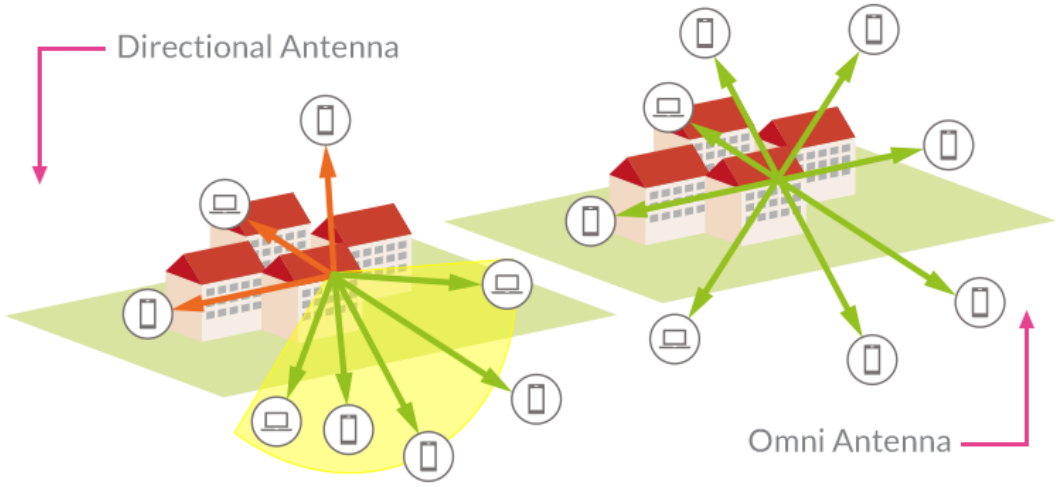


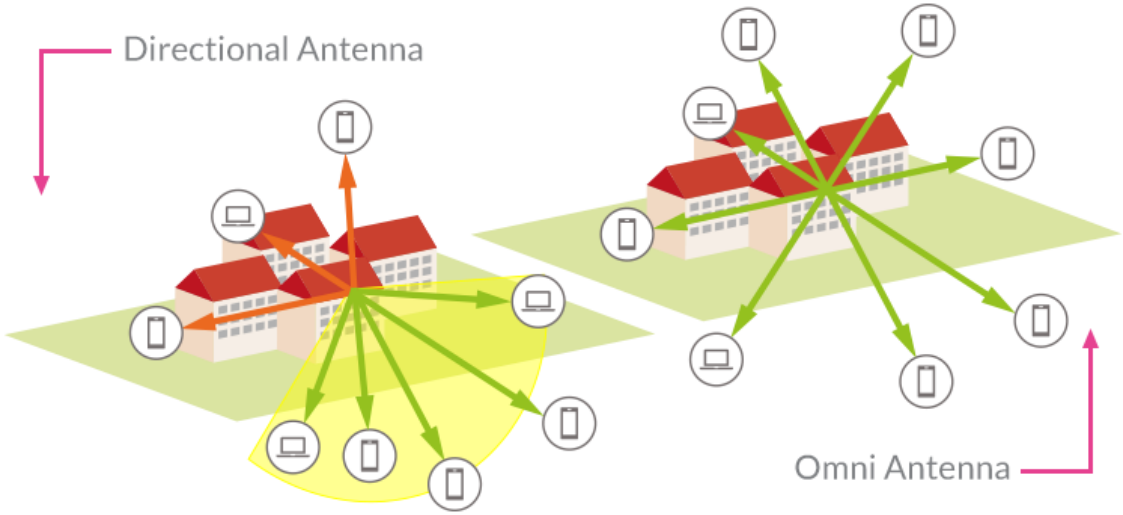
- Two types of NTNs according to the type of terminals targeted
  - Terminals with directional antennas
  - Terminals with omni-directional antennas



- **Terminals with directional antennas**
  - Targeted terminals
    - Mounted on a fixed building
    - Mounted on a moving platform (e.g. bus, train, ship, aircraft, etc.)
  - Service links
    - Typically operate in frequency bands above 6 GHz
    - Typically provide direct-to-home / office or backhaul services



- **Terminals with omni-directional antennas**
  - Targeted terminals
    - Handheld
    - IoT devices
  - Service links
    - Typically operate in frequency bands below 6 GHz
    - Provide narrow to wide band services directly to end-user devices



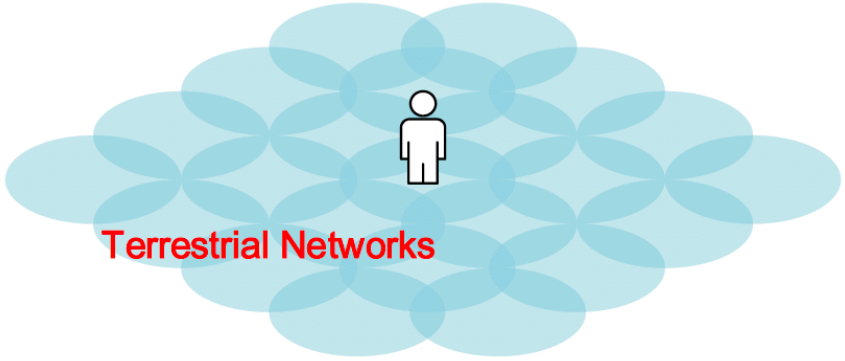
Terrestrial and Non-Terrestrial Networks

Non-Terrestrial Networks (NTN)

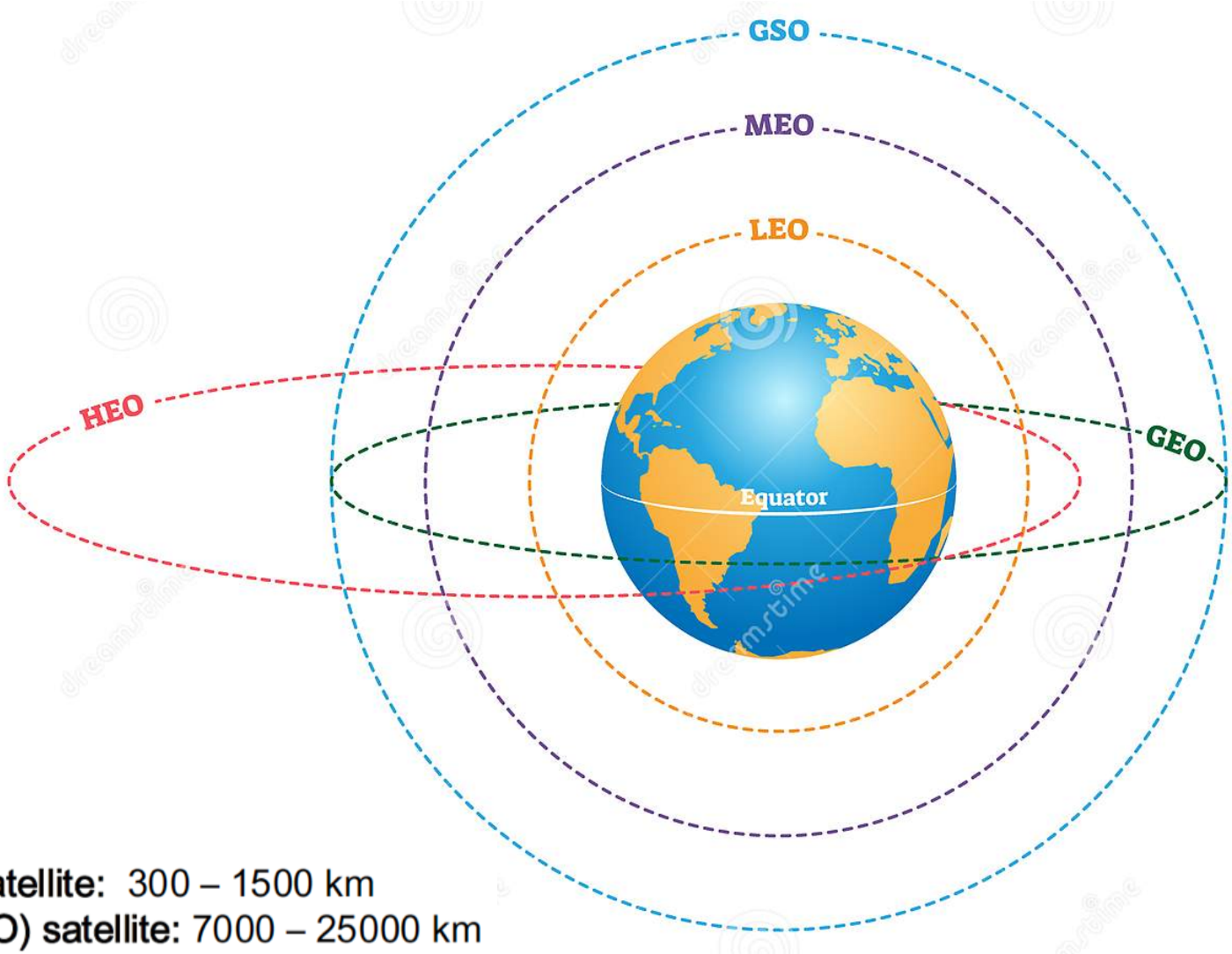
Low-Earth Orbit (LEO) satellite: 300 – 1500 km
Medium-Earth Orbit (MEO) satellite: 7000 – 25000 km
Geostationary Earth Orbit (GEO) satellite: 35786 km
High Elliptical Orbit (HEO) satellite: 400 – 50000 km

UAS platform (including HAPS): 8 – 50 km (20 km for HAPS)

*Unmanned Aircraft Systems (UAS)

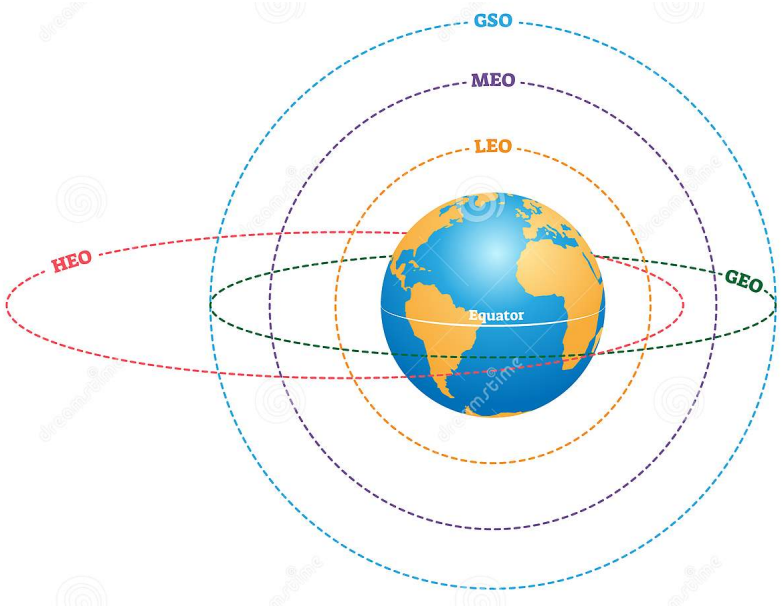


HAPS：High-Altitude Pseudo-Satellite



Low-Earth Orbit (LEO) satellite: 300 – 1500 km
Medium-Earth Orbit (MEO) satellite: 7000 – 25000 km
Geostationary Earth Orbit (GEO) satellite: 35786 km
High Elliptical Orbit (HEO) satellite: 400 – 50000 km

- Both GEO and LEO based NTN access is considered in 3GPP
  - **GEO satellites**
    - Located at an altitude of about 35,786km at a fixed position above the equator
  - **LEO satellites**
    - Circling the earth at altitudes between 300 and 1500km at velocities of about 7 km/s



- **Unmanned Aircraft Systems (UAS)**, including **High Altitude Platforms (HAPS)** based access
  - A special case of non-terrestrial access with
    - Lower delay, Doppler value and variation rate
  - HAPS
    - Airborne vehicles, e.g., planes or balloons, deployed in the stratosphere
    - Operate like satellites, although being closer to earth typically at 20km altitude, they float above conventional aircraft

- Typical throughputs provided by NTNs for the usage scenarios considered in Release-16

Usage scenarios	Experience data rate		Max UE speed	Environment	UE categories
	Downlink	Uplink			
Pedestrian[a)]	2 Mbps	60 kbps	3 km/h	Extreme coverage	Handheld
Vehicular connectivity	50 Mbps	25 Mbps	250 km/h	Along roads in low population density areas	Vehicular mounted
Stationary	50 Mbps	25 Mbps	0 km/h	Extreme coverage	Building mounted

Usage scenarios	Experience data rate		Max UE speed	Environment	UE categories
	Downlink	Uplink			
Airplane connectivity	360 Mbps	180 Mbps	1000 km/h	Open area	Airplane mounted
Internet of Things (IoT) connectivity[b)]	2 kbps	10 kbps	0 km/h	Extreme coverage	IoT

a) Better performances may be achieved.
b) Considering low-power wide area service capability.

- NR impacts to support NTN reference scenarios

Effects		High Altitude Platforms (HAPS)	Low earth orbit (LEO)	Medium earth orbit (MEO)	Geo-stationary orbit (GEO)	High elliptical orbit (HEO)
Motion of the space/aerial vehicles	Moving cell pattern	Yes if beams are moving on earth	Yes if beams are moving on earth (hence high speed)[a]	Yes if beams are moving on earth (hence high speed)	No	Yes if beams are moving on earth (hence high speed)
		No if beams are fixed on earth	No if beams are fixed on earth	No if beams are fixed on earth		No if beams are fixed on earth
	Delay variation	No	High[b]	Medium[b]	No	Low[b]
	Doppler	To be determined	High[b]	Medium[b]	Negligible	Low[b]
Altitude	Latency	Negligible	Low	Medium	High	High

Effects		High Altitude Platforms (HAPS)	Low earth orbit (LEO)	Medium earth orbit (MEO)	Geo-stationary orbit (GEO)	High elliptical orbit (HEO)
Cell size	Differential delay	Small	Typically relatively medium	Typically relatively medium	Possibly relatively high	Possibly relatively high
Propagation channel	Frequency selectiveness impairments	[c]	[c]	[c]	No	No
	Delay spread impairments	[c]	[c]	[c]	No	No
Duplex scheme	Regulatory constraints	Frequency Division Duplexing (FDD) and possibly Time Division Duplexing (TDD)	FDD and Possibly TDD	Only FDD	Only FDD	Only FDD

[a] Assuming a fixed relation between beams and cells.
[b] Doppler and delay variation can be pre-compensated at beam center. In such cases residual Doppler and delay variation can be accommodated by the UE.
[c] Some delay spread and frequency selective effect can be experienced in the case of an omni-directional antenna device especially at a low elevation angle.

NTN Satellites (or UAS Plateform)

One or several sat-gateways that connect the Non-Terrestrial Network to a public data network

Feeder link

A Feeder link or radio link between a sat-gateway and the satellite (or UAS platform)

Gateway

A NTN gateway is a ground station that transmits data to/from the satellite to the local area network.
One or several sat-gateways that connect the Non-Terrestrial Network to a public data network.

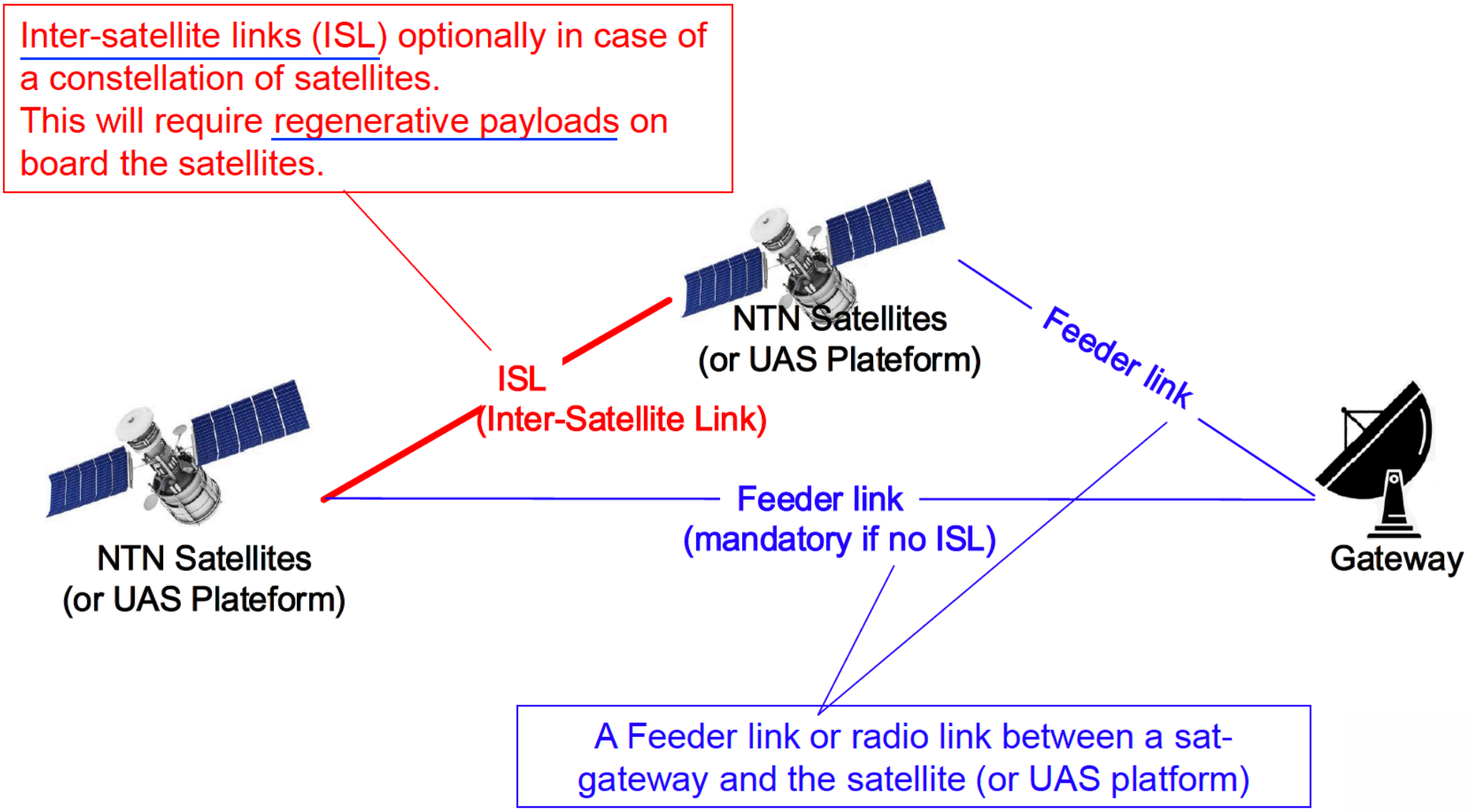
A satellite (or UAS platform) which may implement either a transparent or a regenerative (with on board processing) payload.

NTN Satellites (or UAS Plateform)

A service link or radio link between the user equipment and the satellite (or UAS platform).

Service link

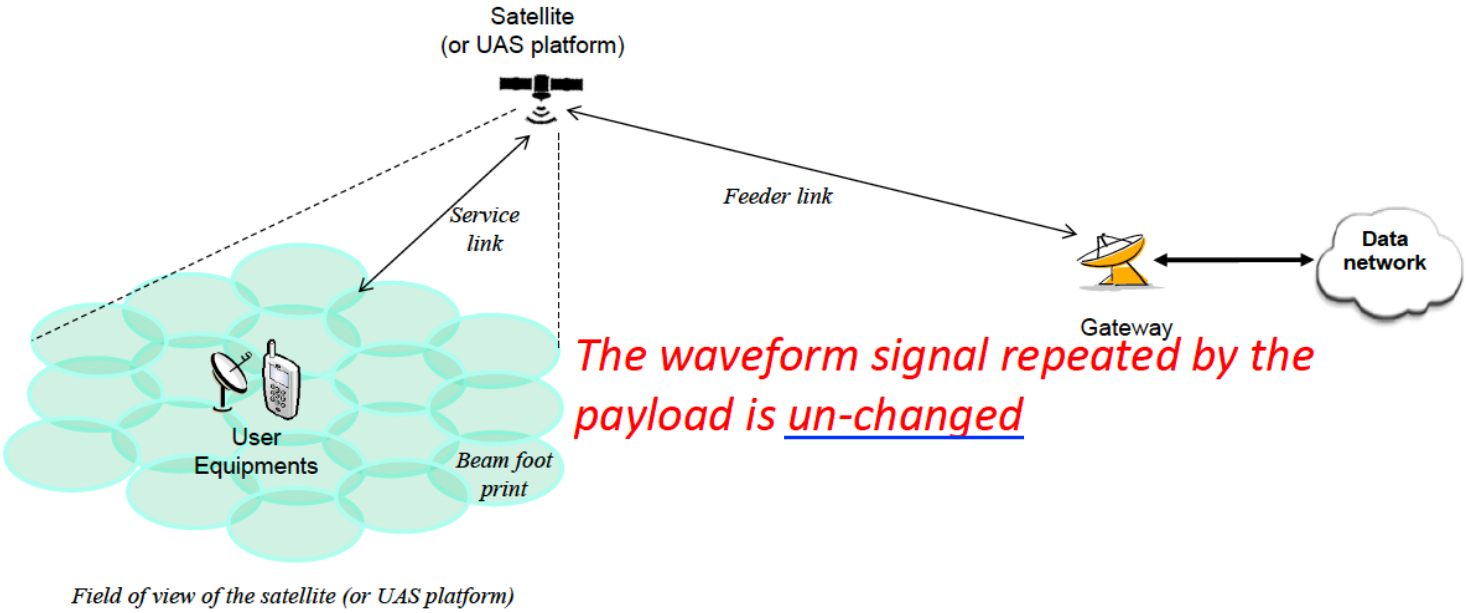
User Equipment are served by the satellite (or UAS platform) within the targeted service area.


Inter-satellite links (ISL) optionally in case of a constellation of satellites.
This will require regenerative payloads on board the satellites.
NTN Satellites
(or UAS Plateform)
Feeder link
ISL
(Inter-Satellite Link)
NTN Satellites
(or UAS Plateform)
Feeder link
(mandatory if no ISL)
Gateway
A Feeder link or radio link between a sat-gateway and the satellite (or UAS platform)

Transparent and Regenerative Satellites

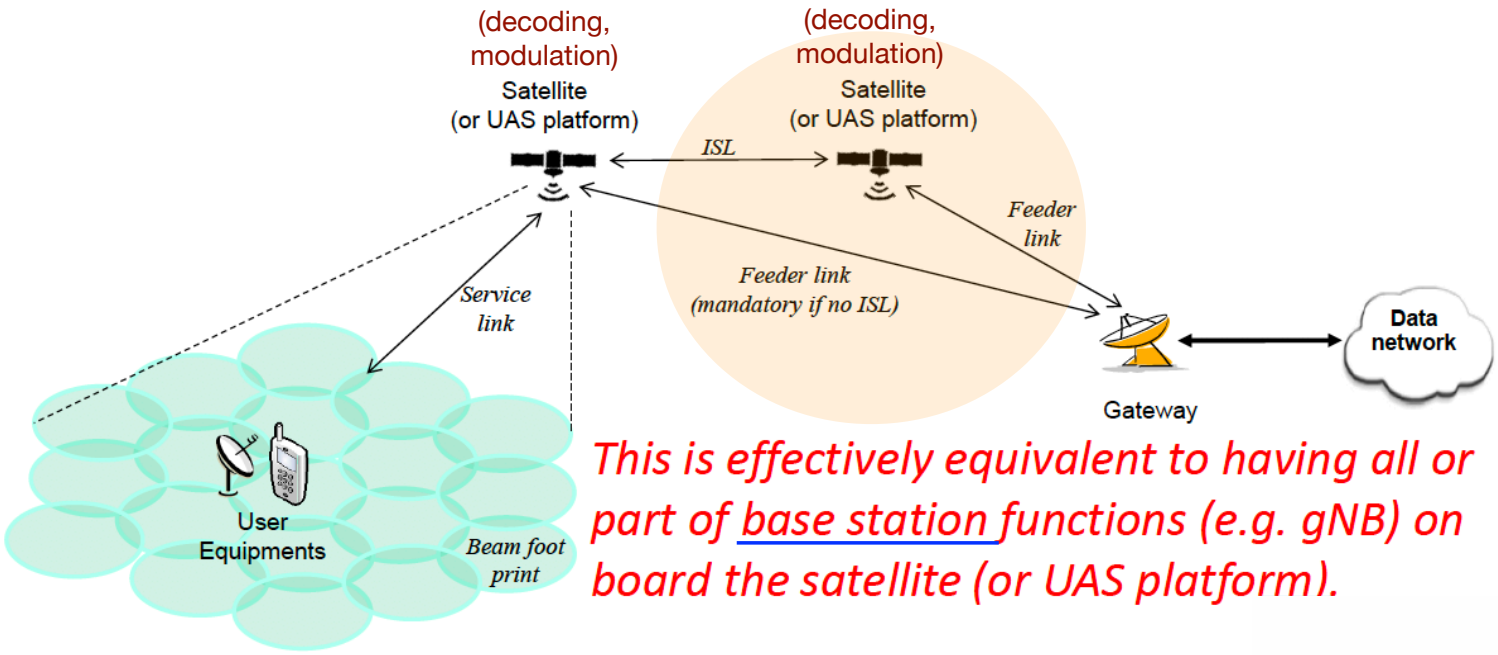
- A satellite (or UAS platform) may implement
  - Transparent payload
  - Regenerative (with on board processing) payload

(A)
NTN typical scenario based on transparent payload



The waveform signal repeated by the payload is un-changed

(B)
NTN typical scenario based on regenerative payload

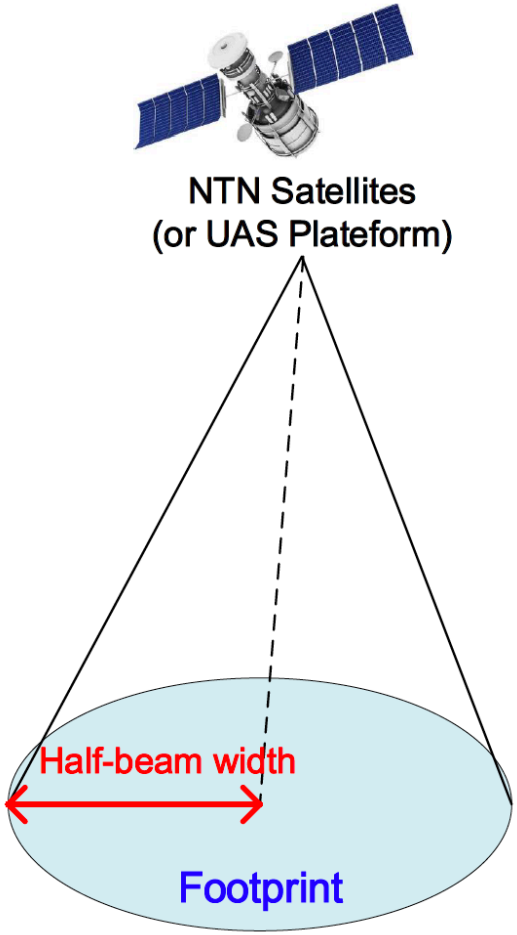


Field of view of the satellite (or UAS platform)

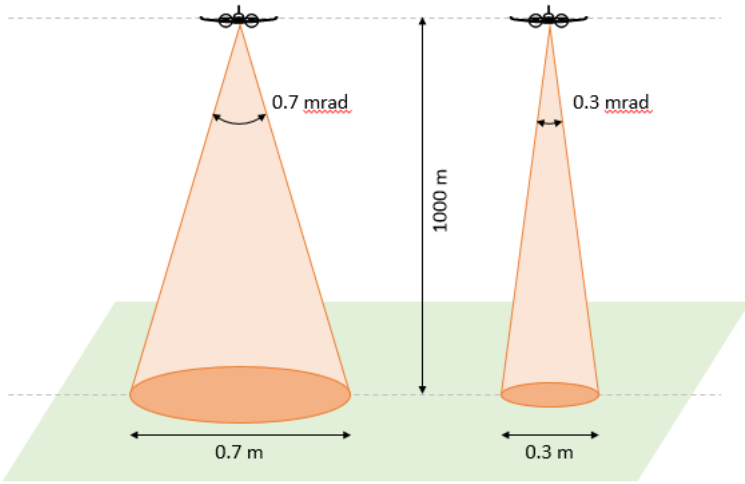
This is effectively equivalent to having all or part of base station functions (e.g. gNB) on board the satellite (or UAS platform).

Beam Footprint

- Footprint of a communications satellite
  - The ground area that its transponders offer coverage
  - Determines the satellite dish diameter required to receive each transponder's signal

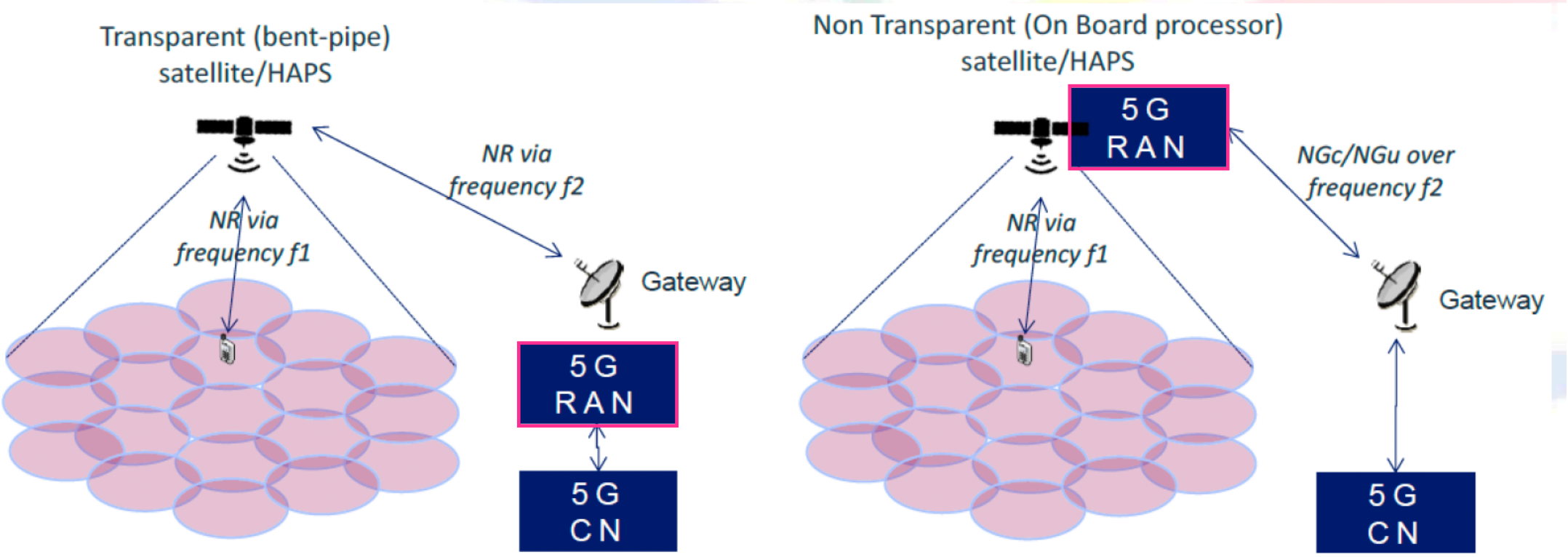


- Earth footprint of a satellite beam
  - Depends on the satellite altitude and the elevation angle
  - May be quite large compared to usual terrestrial cell size
- For **GEO** based NTN access
  - Only fixed beams relative to the ground are considered
- For **LEO** based NTN access
  - Moving beams are possible as well



Attributes	GEO	Non-GEO	Aerial
Beam foot print size in diameter	200 – 1000 km	100 – 500 km	5 - 200 km

NTN Beam Patterns



Types of NTN Platforms

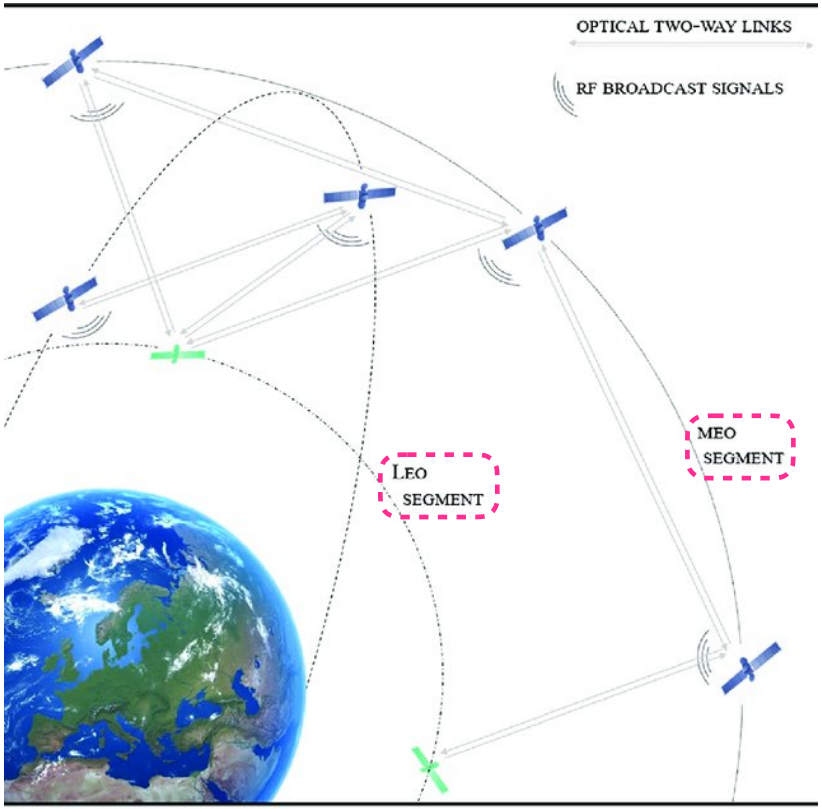
Platforms	Altitude range	Orbit	Typical beam footprint size
Low-Earth Orbit (LEO) satellite	300 – 1500 km	Circular around the earth	100 – 1000 km
Medium-Earth Orbit (MEO) satellite	7000 – 25000 km		100 – 1000 km
Geostationary Earth Orbit (GEO) satellite	35786 km	notional station keeping position fixed in terms of elevation/azimuth with respect to a given earth point	200 – 3500 km
UAS platform (including HAPS)	8 – 50 km (20 km for HAPS)		5 - 200 km
High Elliptical Orbit (HEO) satellite	400 – 50000 km	Elliptical around the earth	200 – 3500 km

- Propagation delay

eMBB scenario: GEO $h_{sat} = 35786$ km			One way
Elevation angle	**Path**	**Distance [km]**	**Delay [ms]**
RN: $\vartheta_{RN} = 10°$	Sat-RN	40586.07	≈ 135.28
GW: $\vartheta_{GW} = 5°$	Sat-GW	41126.72	≈ 137.09
mMTC-NB-IoT scenario: LEO $h_{sat} = 600$ km			
Elevation angle	**Path**	**Distance [km]**	**Delay [ms]**
UE: $\vartheta_{UE} = 10°$	Sat-UE	1932.25	≈ 6.44
GW: $\vartheta_{GW} = 5°$	Sat-GW	2329.03	≈ 7.76
mMTC-NB-IoT scenario: LEO $h_{sat} = 1500$ km			
Elevation angle	**Path**	**Distance [km]**	**Delay [ms]**
UE: $\vartheta_{UE} = 10°$	Sat-UE	3647.55	≈ 12.16
GW: $\vartheta_{GW} = 5°$	Sat-GW	4101.72	≈ 13.67

Reference Scenarios

- **GEO satellite and UAS**
  - Provide continental, regional or local service
- **A constellation of LEO and MEO**
  - Provide services in both Northern and Southern hemispheres
  - Provide global coverage including polar regions, this requires
    - Appropriate orbit inclination
    - Sufficient beams generated, and
    - Inter-satellite links



Kepler constellation: **MEO** and **LEO** satellites carrying optical frequency references, interconnected by two-way laser links

NTN Scenarios

NTN scenarios	A	B	C1	C2	D1	D2
	GEO transparent payload	GEO regenerative payload	LEO transparent payload		LEO regenerative payload	
Satellite altitude	35 786 km		600 km			
Relative speed of Satellite wrt earth	negligible		7.56 km per second			
Min elevation for both feeder and service links	10° for service link and 10° for feeder link					
Typical Min / Max NTN beam foot print diameter (note 1)	100 km / 1000 km		50 km / 500 km			
Maximum Round Trip Delay on the radio interface between the gNB and the UE	541.46 ms (Worst case)	270.73 ms	25.77 ms		12.89 ms	
Minimum Round Trip Delay on the radio interface between the gNB and the UE	477.48 ms	238.74 ms	8 ms		4 ms	
Maximum Delay variation as seen by the UE	Negligible		Up to +/- 40 µs/sec (Worst case)		Up to +/- 20 µs/sec	
Maximum delay difference within a NTN beam as seen by the UE	16 ms (Worst case)		4.44 ms			

	Transparent satellite	Regenerative satellite
GEO based non-terrestrial access network	Scenario A	Scenario B
LEO based non-terrestrial access network: steerable beams	Scenario C1	Scenario D1
LEO based non-terrestrial access network: the beams move with the satellite	Scenario C2	Scenario D2

1.Key Ideas

2.NTN Based NG-RAN Architecture

3.NTN Radio Protocol

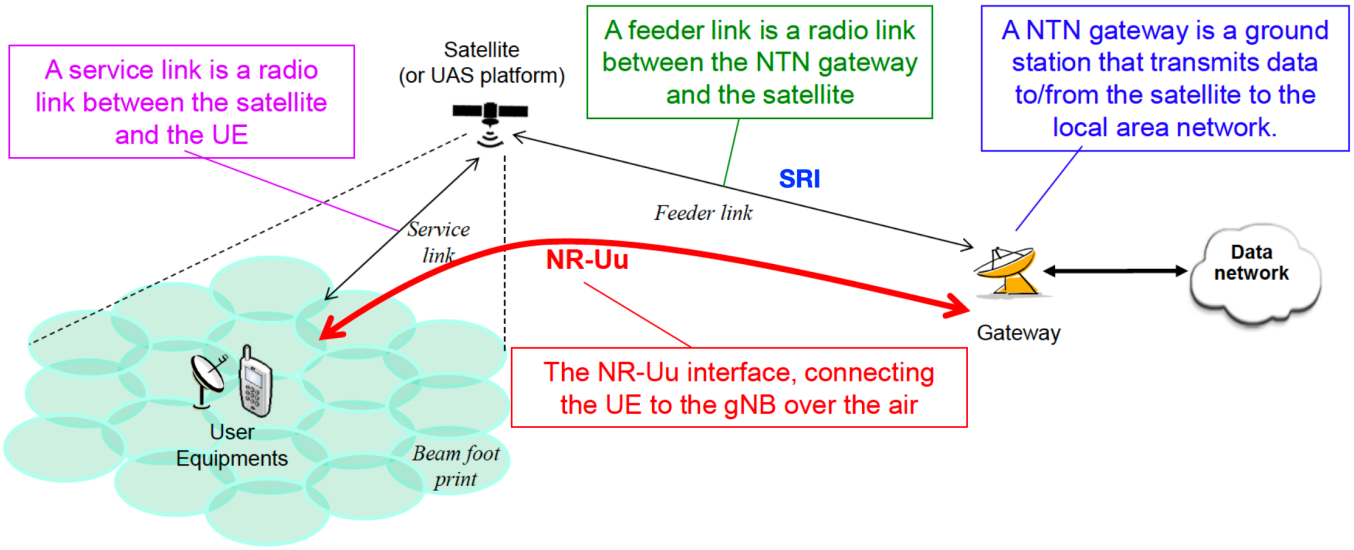
4.NR Physical Layer Adaptations for NTN

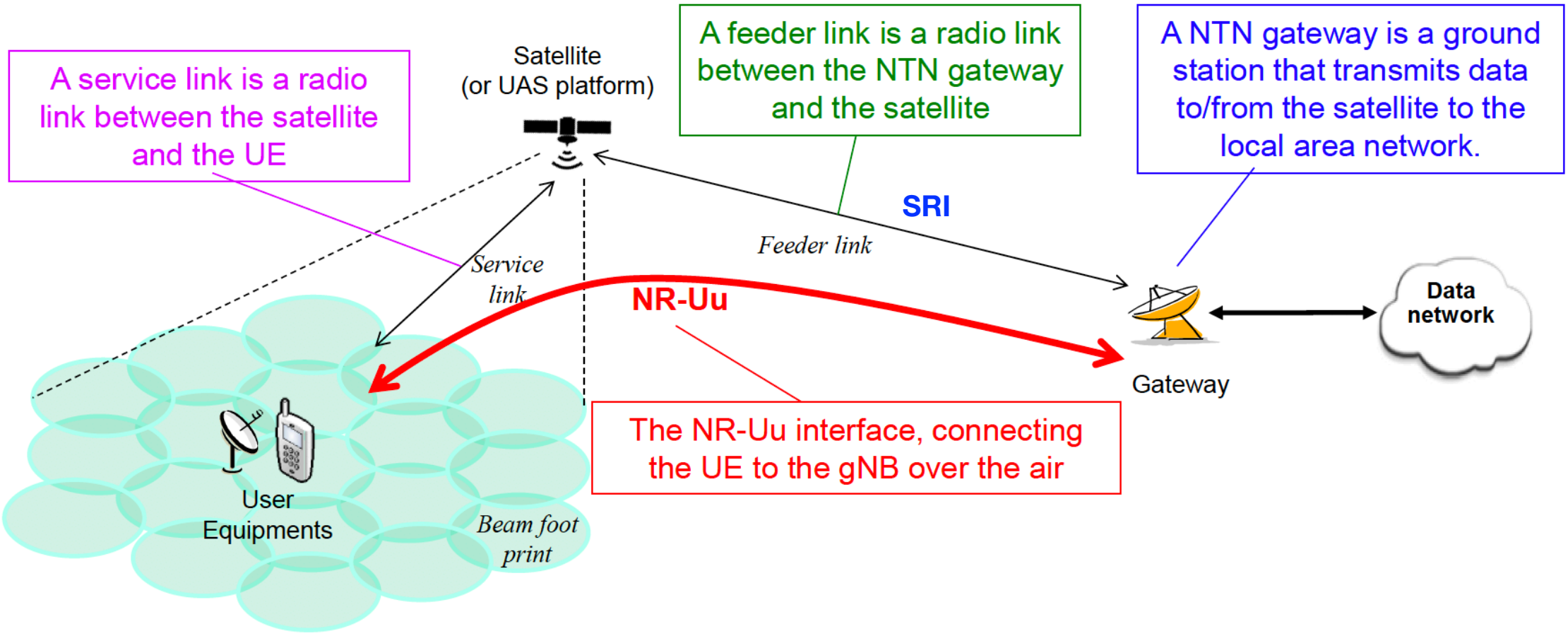
5.NTN Channel Model

6.Outlook

Transparent Satellites

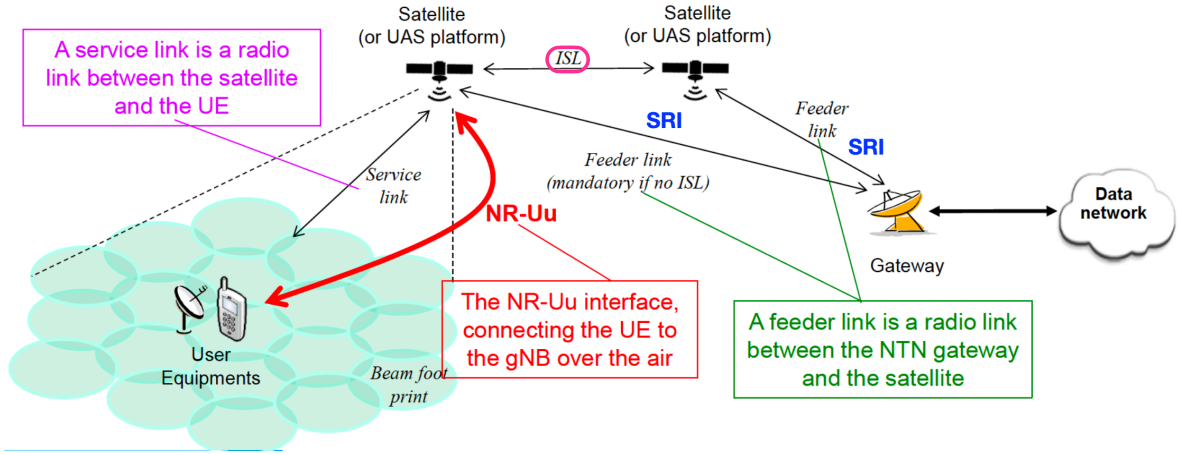
- **Satellite Radio Interface (SRI)**
  - On the feeder link between NTN G/W and satellite
- **NR-Uu radio interface**
  - The satellite repeats NR-Uu radio interface from feeder link (b/w NTN gateway & satellite) to service link (b/w satellite & UE), and vice versa
  - The satellite does not terminate NR-Uu
  - NTN G/W supports all necessary functions to forward the signal of NR-Uu interface

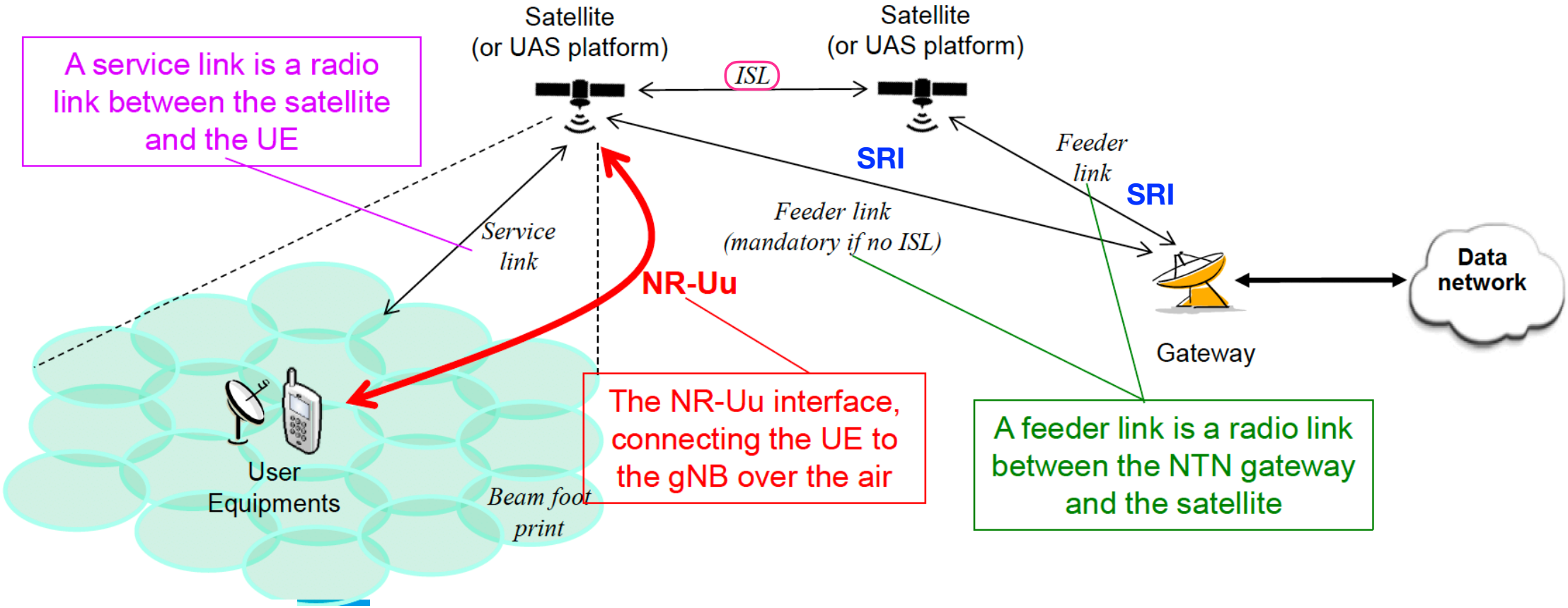



A service link is a radio link between the satellite and the UE
Satellite
(or UAS platform)
A feeder link is a radio link between the NTN gateway and the satellite
A NTN gateway is a ground station that transmits data to/from the satellite to the local area network.
SRI
Feeder link
Service link
NR-Uu
Data network
Gateway
The NR-Uu interface, connecting the UE to the gNB over the air
User Equipments
Beam foot print

Regenerative Satellites

- The satellite payload implements regeneration of the signals received from Earth
- **NR-Uu radio interface**
  - On the service link b/w UE and satellite
  - The satellite terminates NR-Uu
- **Satellite Radio Interface (SRI)**
  - On the feeder link b/w NTN gateway and satellite
- **Inter-Satellite Links (ISL)**
  - Satellite payload also provides Inter-Satellite Links (ISL) b/w satellites
  - ISL is a transport link b/w satellites
  - ISL may be a radio interface or an optical interface that may be 3GPP or non 3GPP defined



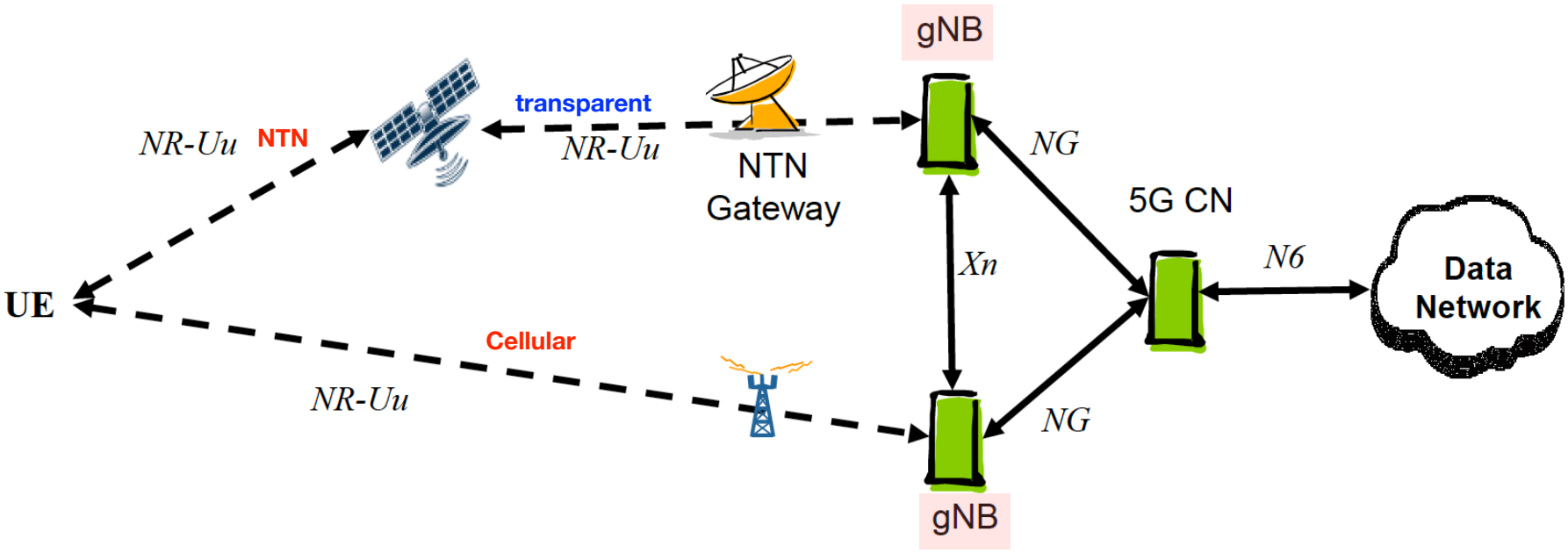

A service link is a radio link between the satellite and the UE
Satellite (or UAS platform)
Satellite (or UAS platform)
ISL
SRI
Feeder link
SRI
Feeder link (mandatory if no ISL)
Service link
NR-Uu
Data network
Gateway
User Equipments
Beam foot print
The NR-Uu interface, connecting the UE to the gNB over the air
A feeder link is a radio link between the NTN gateway and the satellite

Transparent vs. Regenerative Satellites

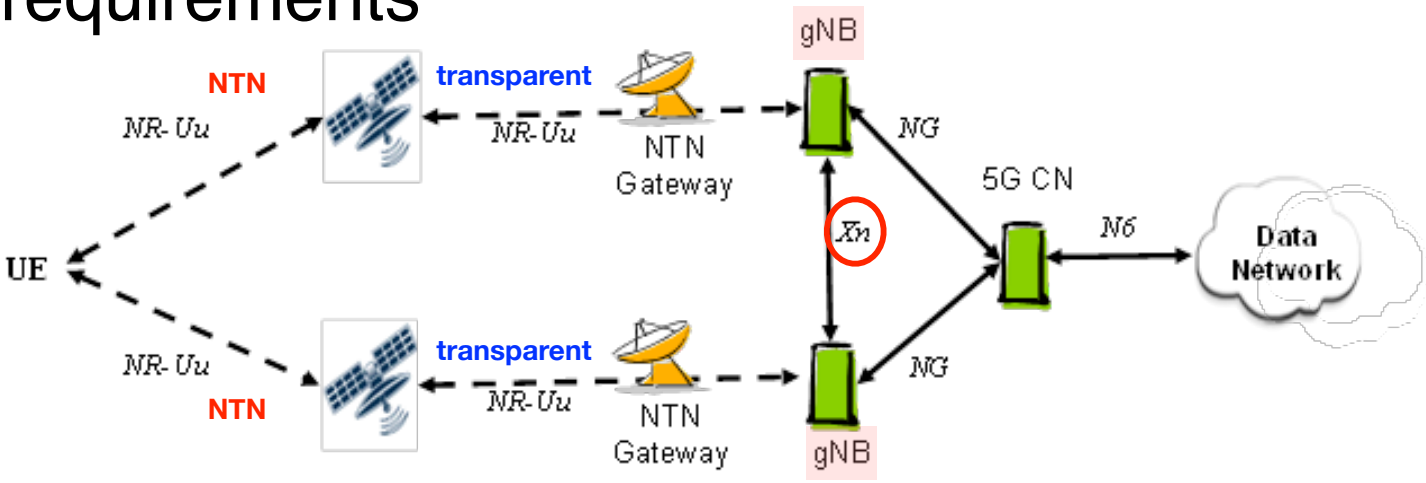
	Transparent satellite	Regenerative satellite
Satellite Beheaviour	The satellite repeats the NR-Uu radio interface from the feeder link (between the NTN gateway and the satellite) to the service link (between the satellite and the UE) and vice versa.	The satellite payload implements regeneration of the signals received from Earth.
NR-Uu Interface	NR-Uu radio interface on the link between the UE and the NTN gateway.	NR-Uu radio interface on the service link between the UE and the satellite.
Inter-Satellite Links (ISL)	No ISL	ISL is a transport link between satellites.
Satellite Radio Interface (SRI)	SRI on the feeder link is the NR-Uu. The satellite does not terminate NR-Uu.	SRI on the feeder link between the NTN gateway and the satellite The satellite terminates NR-Uu.

Multi Connectivity involving NTN-based NG-RAN

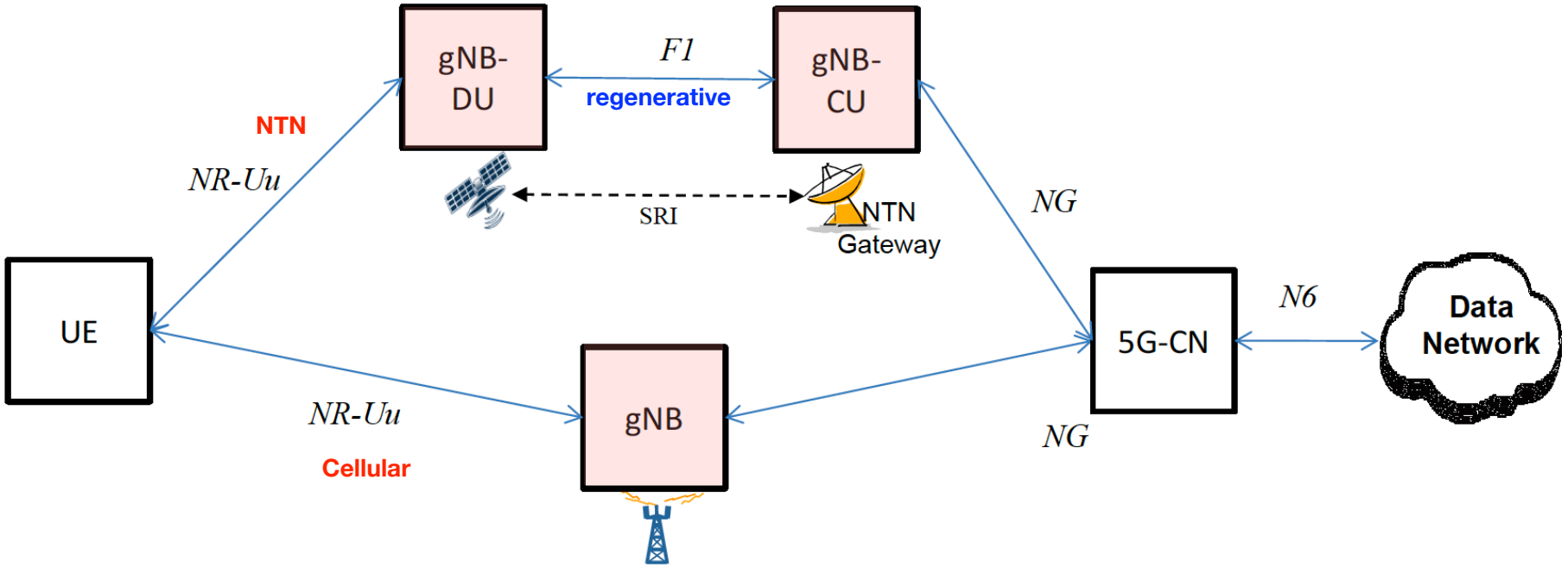
- (1) A UE is connected to a 5GCN via simultaneously a transparent NTN-based NG-RAN and a cellular NG-RAN



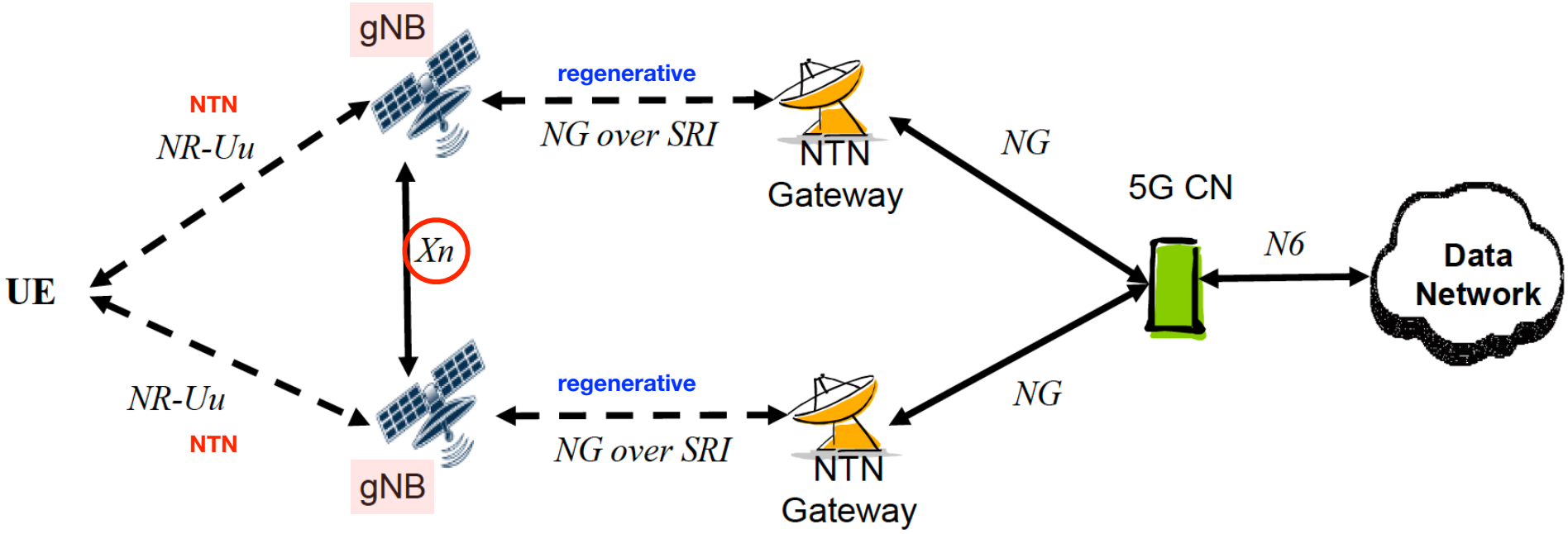
- (2) The combination of two transparent NTN-based NG-RANs either GEO or LEO based or a combination of both
  - Provide service to UEs in unserved areas
  - **LEO NTN-based NG-RAN**
    - Features relatively low latency can be used to support delay sensitive traffic
  - **GEO NTN-based NG-RAN**
    - Provides additional bandwidth to meet the targeted throughput requirements



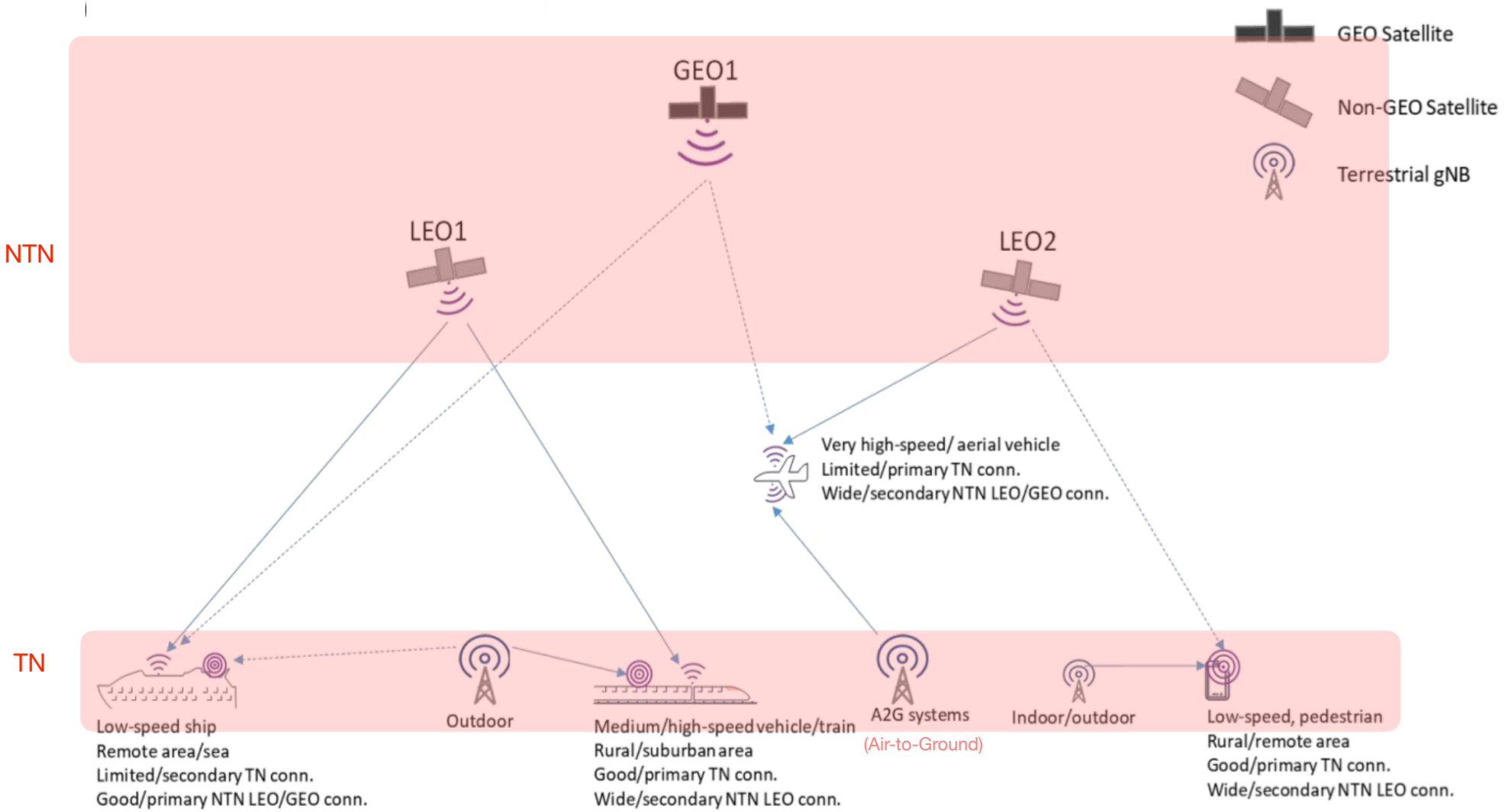
- (3) The combination of a regenerative NTN-based NG-RAN (gNB-DU on board) and a cellular NG-RAN
  - Provide service to UEs in underserved areas



- (4) The combination of <u>two regenerative NTN-based NG-RAN</u> (gNB on board)
  - Either GEO or LEO based or a combination of both with Inter Satellite Links (ISL) in between
  - Provide service to UEs in <u>unserved</u> areas

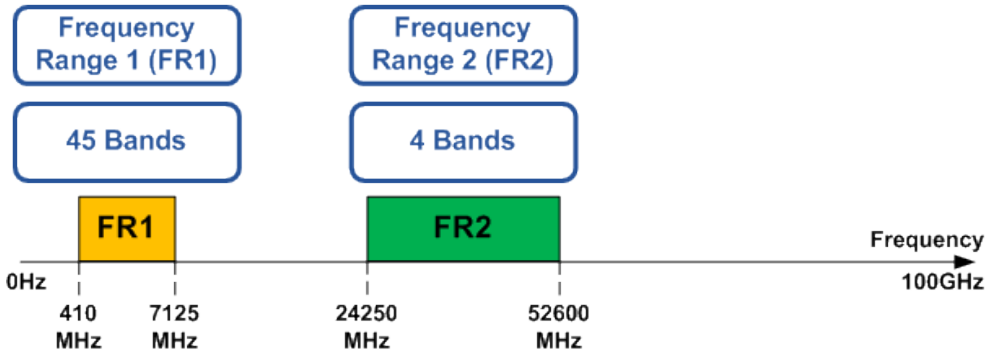


Mobility b/w TN & NTN



Service Continuity b/w NTN & TNs

- 5G system shall support service continuity b/w 5G terrestrial access network and 5G satellite access networks
  - Owned by the same operator, or
  - Owned by two different operators having an agreement
- NTN and TN could operate in
  - Two different frequency bands (e.g. FR1 vs FR2), or
  - Same frequency band (e.g. FR1 or FR2)



Satellite & UE Parameters

- **Satellite** parameter in TR 38.821 for system level simulation and evaluation

Satellite orbit		GEO	LEO-1200	LEO-600
Satellite altitude		35786 km	1200 km	600 km
Satellite antenna pattern		Section 6.4.1 in [2]	Section 6.4.1 in [2]	Section 6.4.1 in [2]
Payload characteristics for DL transmissions				
Equivalent satellite antenna aperture (Note 1)	S-band (i.e. 2 GHz)	22 m	2 m	2 m
Satellite EIRP density		59 dBW/MHz	40 dBW/MHz	34 dBW/MHz
Satellite Tx max Gain		51 dBi	30 dBi	30 dBi
3dB beamwidth		0.4011 deg	4.4127 deg	4.4127 deg
Satellite beam diameter (Note 2)		250 km	90 km	50 km
Equivalent satellite antenna aperture (Note 1)	Ka-band (i.e. 20 GHz for DL)	5 m	0.5 m	0.5 m
Satellite EIRP density		40 dBW/MHz	10 dBW/MHz	4 dBW/MHz
Satellite Tx max Gain		58.5 dBi	38.5 dBi	38.5 dBi
3dB beamwidth		0.1765 deg	1.7647 deg	1.7647 deg
Satellite beam diameter (Note 2)		110 km	40 km	20 km

- **UE** parameter in TR 38.821 for system level simulation and evaluation

Characteristics	VSAT (Note 2) High gain	Handheld Low gain	Other (Note 1) Ship, airplane
Frequency band	Ka band(i.e. 30 GHz UL and 20 GHz DL)	S band (i.e. 2 GHz)	Ka band(i.e. 30 GHz UL and 20 GHz DL)
Antenna type and configuration	Directional Section 6.4.1 of [2] with 60 cm equivalent aperture diameter	(1, 1, 2) with omni-directional antenna element	Directional (M,N,P,Mg,Ng) = (TBD,TBD,2,1,1); (dV,dH) = (TBD, TBD)λ with directional antenna element (HPBW=65 deg)
Polarisation	circular	Linear: +/-45°X-pol	Linear: +/-45°X-pol
Rx Antenna gain	39.7 dBi High	0 dBi per element Low	TBD dBi per element
Antenna temperature	150 K	290 K	TBD K
Noise figure	1.2 dB	7 dB	TBD dB
Tx transmit power	2 W (33 dBm)	200 mW (23 dBm) Power class 3	[TBD W (TBD dBm)]
Tx antenna gain	43.2 dBi High	0 dBi per element Low	TBD dBi per element
NOTE 1: Moving platforms (e.g., aircrafts, vessels), building mounted devices. These values are provided for information. NOTE 2: VSAT terminal characteristics could be implemented with phased array antenna			

VSAT : Very Small Aperture Terminal