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NB-IoT over NTN: technology overview, challenges, and potential solutions

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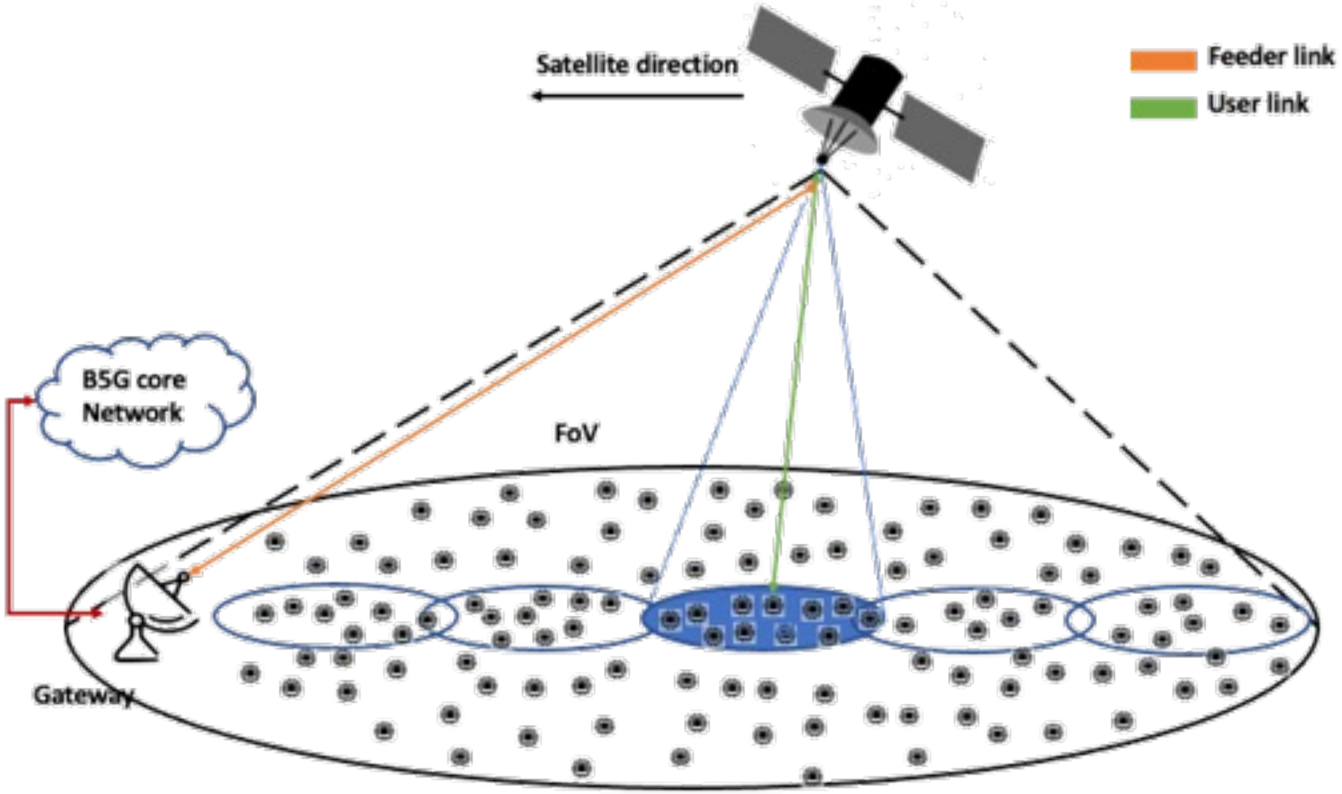
Agenda

- Non terrestrial Network at a glance.
- NB-IoT standard: PHY and MAC layers.
- NB-IoT via NTN.

Objective of the tutorial

- The objective of the tutorial is to illustrate the main elements to allow the **NB-IoT integration over NTN** shedding light on the 3GPP standardization process and on the current State of the Art of techniques related to this topic.



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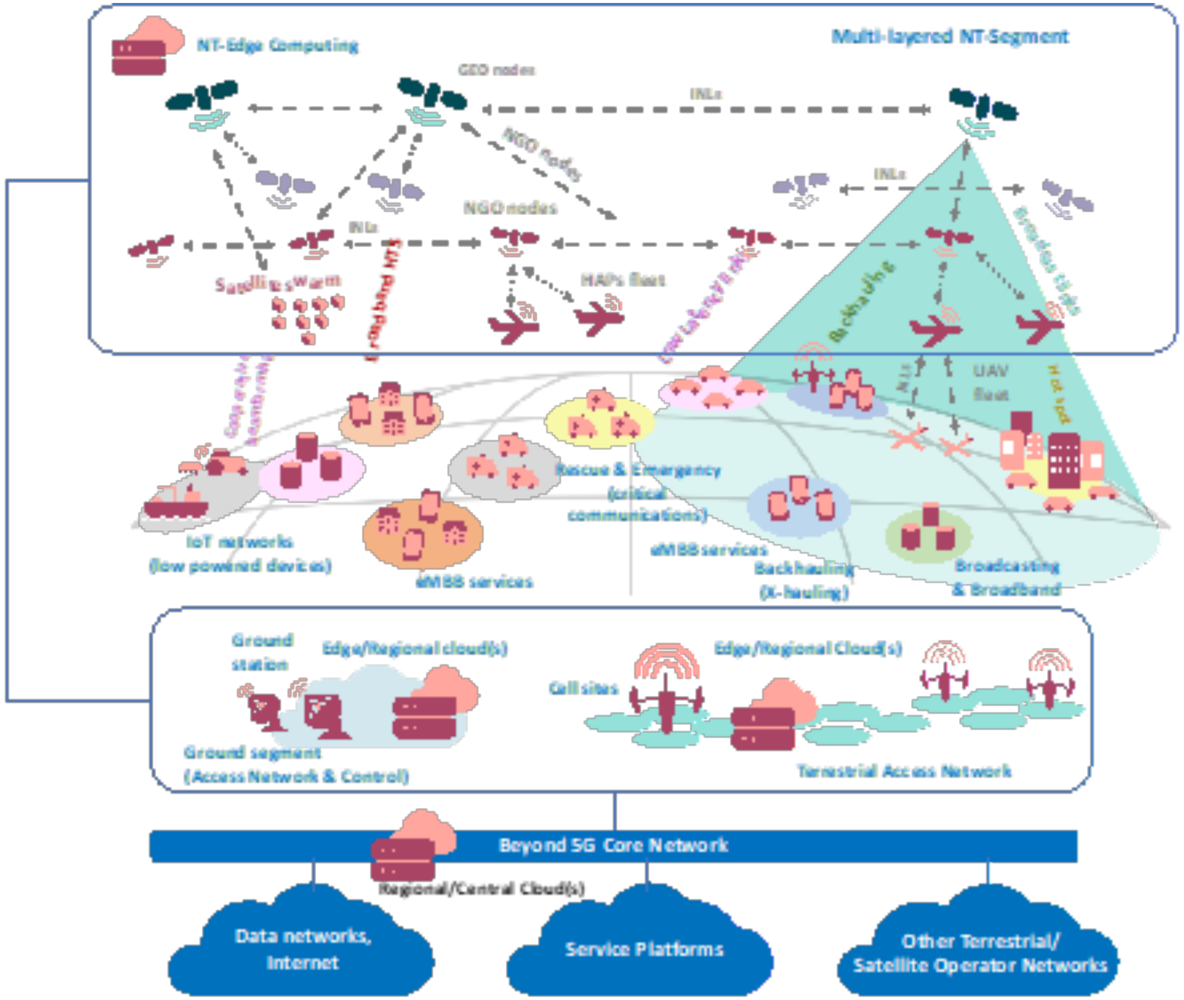
Non terrestrial Network at a glance:

- NTN architecture
- Communication satellites:
  - Orbits
  - Payload
  - Coverage
- NTN and 3GPP
- NTN impairments:
  - Delay
  - Differential delay
  - Doppler shift
  - Differential Doppler shift
  - Doppler spread

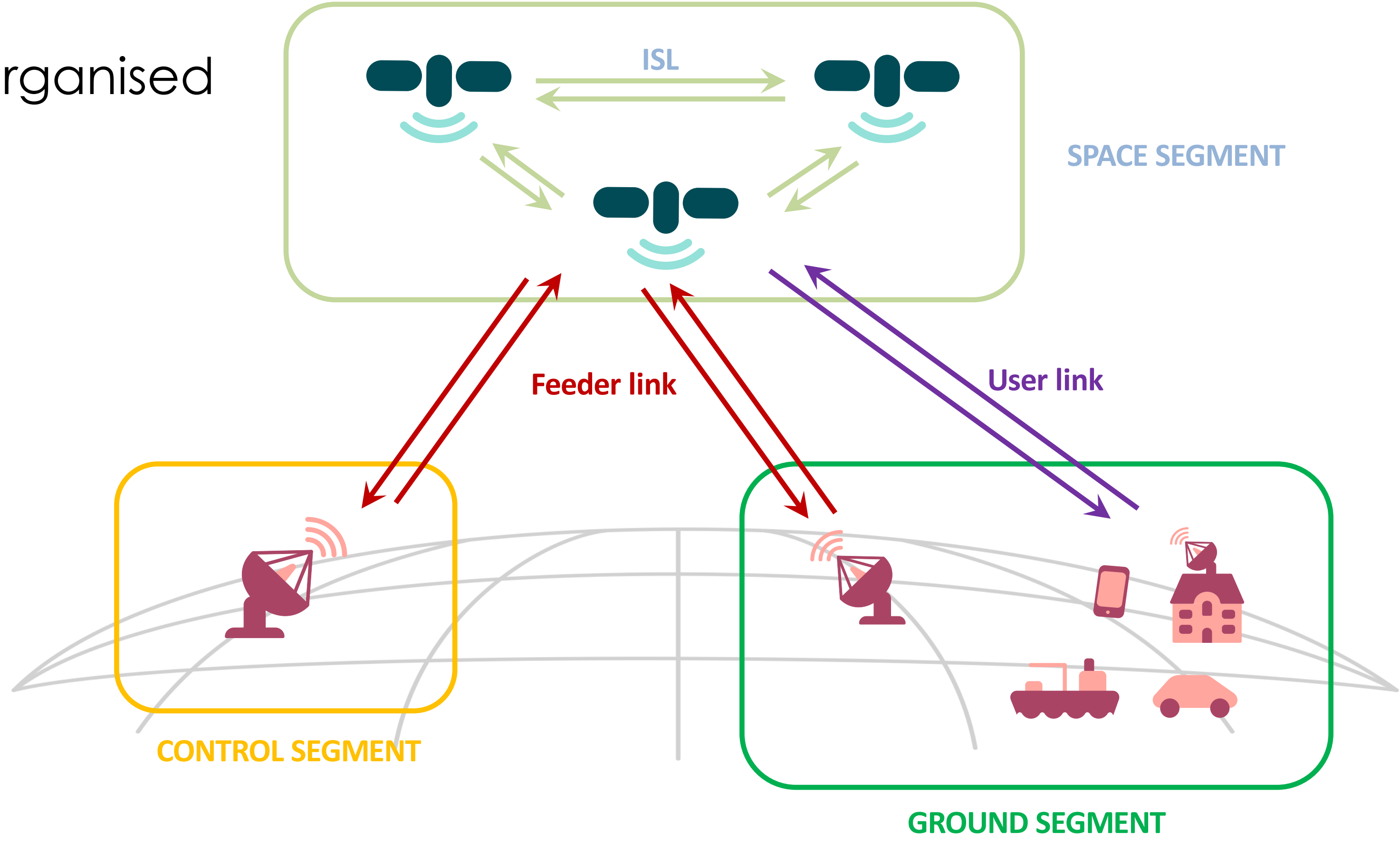
NTN architecture

- Non-terrestrial segment
  - A communication system encompassing flying communication elements
- The flying communication elements can be
  - Air-borne platforms
  - Space-borne platforms



Satellite communications systems

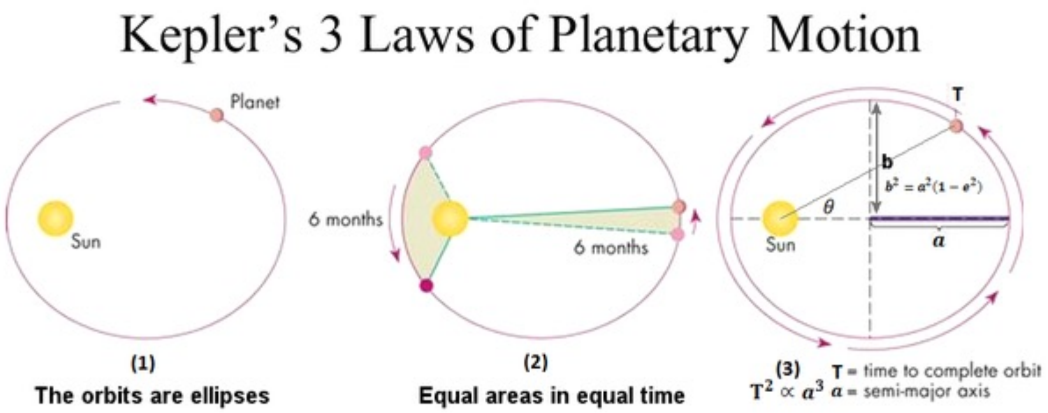
- Space segment
  - 1+ communication satellites organised in a constellation
- Control segment
  - Network Control Center
  - Satellite Control Center
- Ground segment
  - Gateways
  - User Terminals



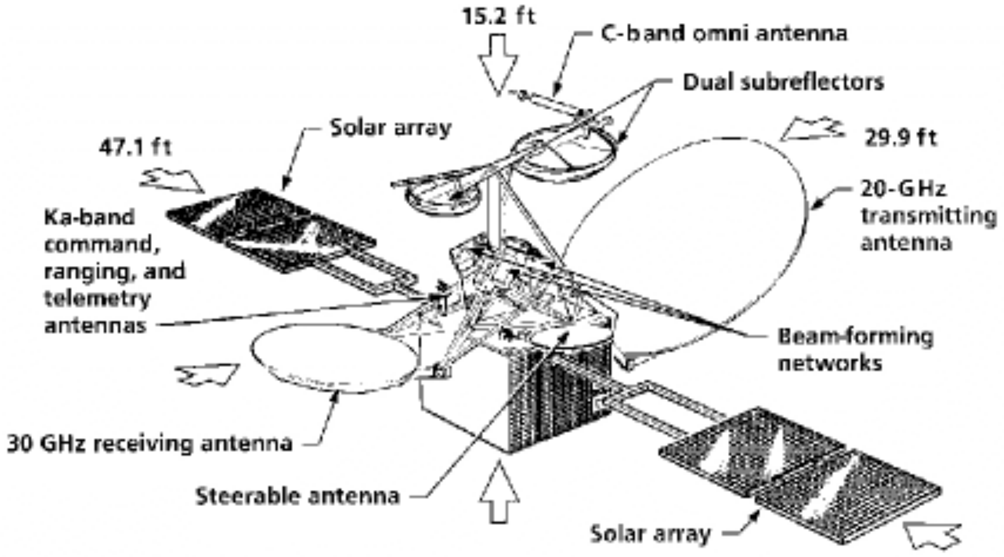
Communication satellites

- Satellite
  - A flying object orbiting the Earth according to the Keplerian Laws.

- Communication satellite:
  - A satellite carrying telecommunications elements.



Source: *https://www.helioseducore.com/keplers-laws-of-planetary-motion/*



Source: *NASA, https://www.nasa.gov/centers/glenn/about/fs13grc.html*

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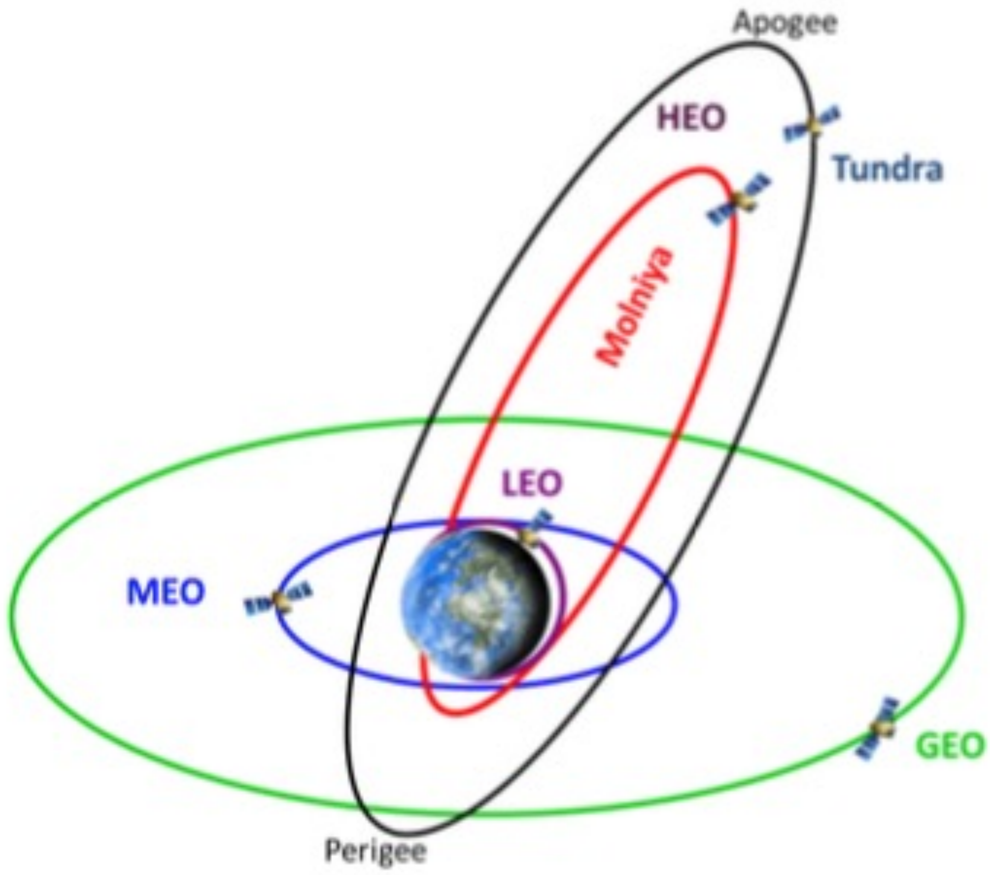
Satellite orbits

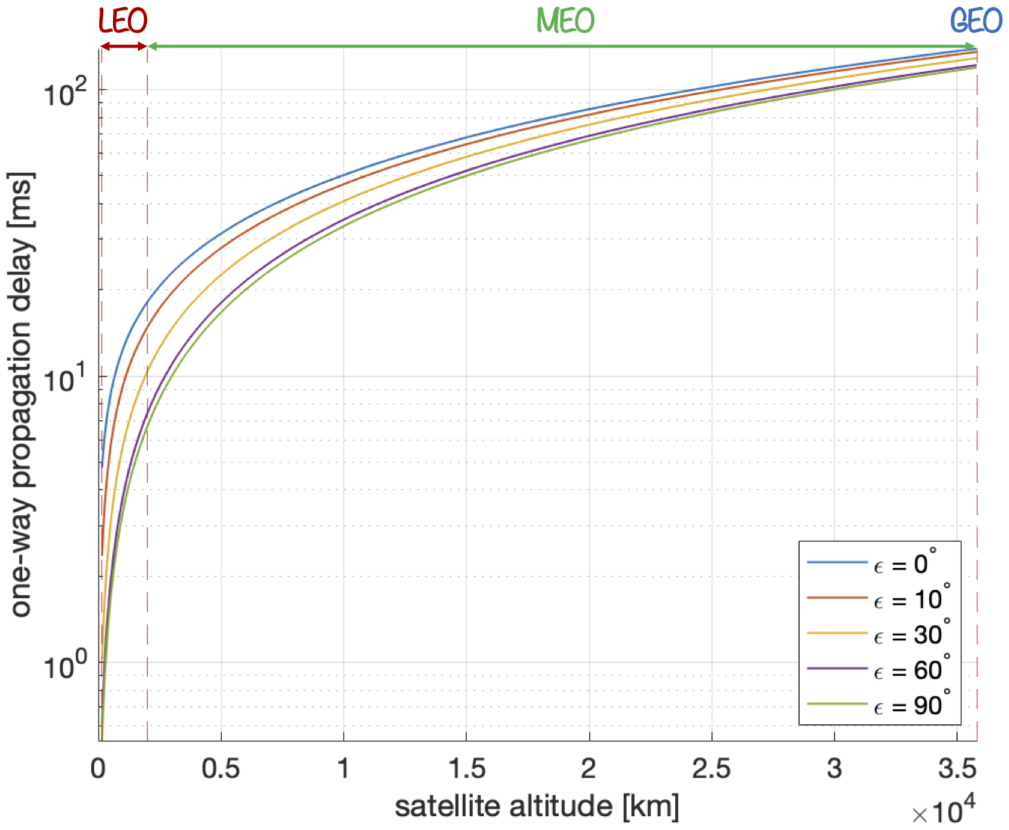
- Geo-Synchronous Orbit (GSO)
  - Period equal to one sidereal day: the satellite appears in the same fixed point at the same time of the day
  - Geostationary Earth Orbit (GEO): GSO on the equatorial plane
    - The satellite appears as a fixed point in the sky
    - altitude ~36000 km
- Non-GSO (NGSO)
  - Medium Earth Orbit (MEO)
    - 2000-36000 km, typically around 20000 km
  - Low Earth Orbit (LEO)
    - 600-1200 km
  - vLEO
    - <500 km



Source: S. Plass et al., "Current Situation and Future Innovations in Arctic Communications," IEEE VTC Fall 2015, Sep. 2015

Satellite orbits

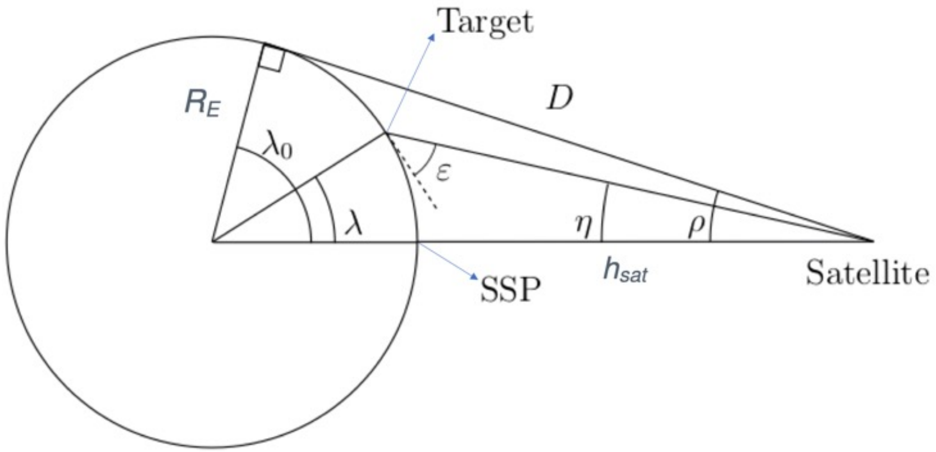
- GSO vs NGSO: latency



Latency

Satellite orbits

- Field of view
- Earth-satellite geometry
  - Max. slant range D
  - Max. Earth central angle λ_0
  - Angular FoV ρ
- At the target location
  - Elevation angle ε
  - Slant range d
  - Nadir angle η
  - Earth central angle λ



$$\rho = \arcsin\left(\frac{R_E}{R_E + h_{sat}}\right)$$

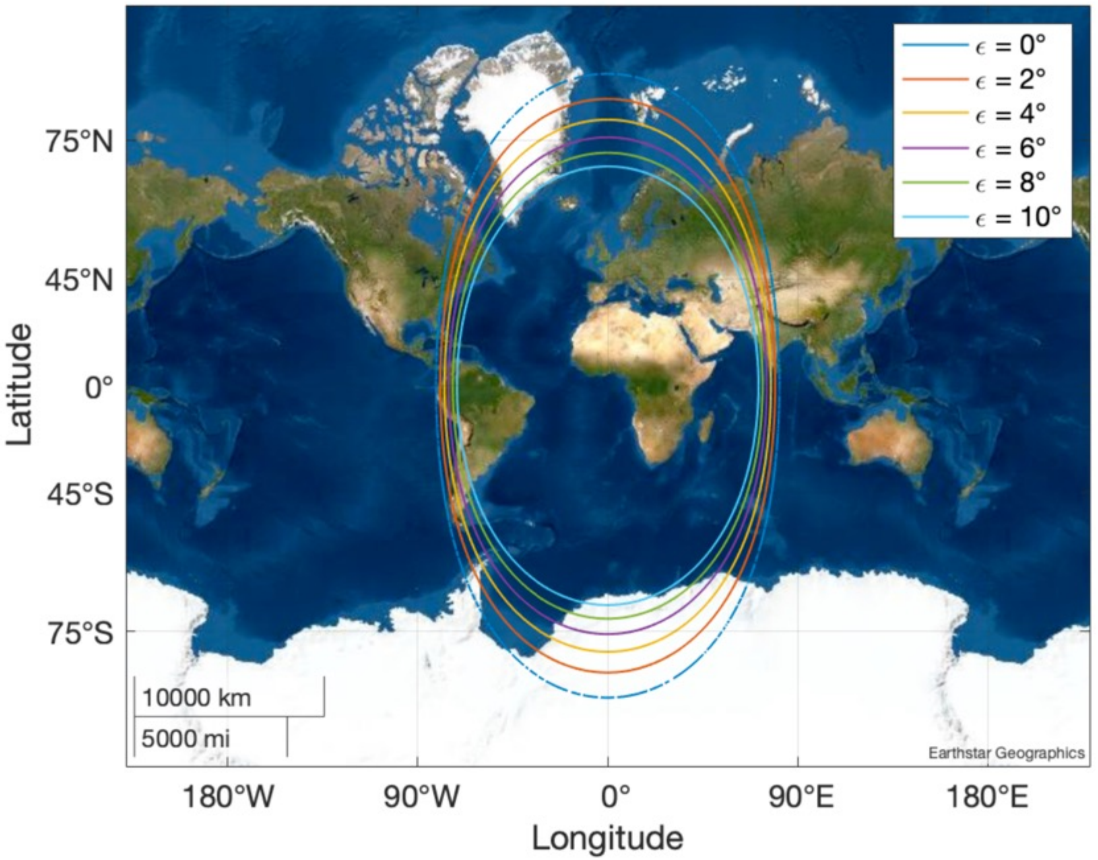
min. elevation angle requirement

$$\rho = \arcsin\left(\frac{R_E}{R_E + h_{sat}} \cos \varepsilon_{min}\right)$$

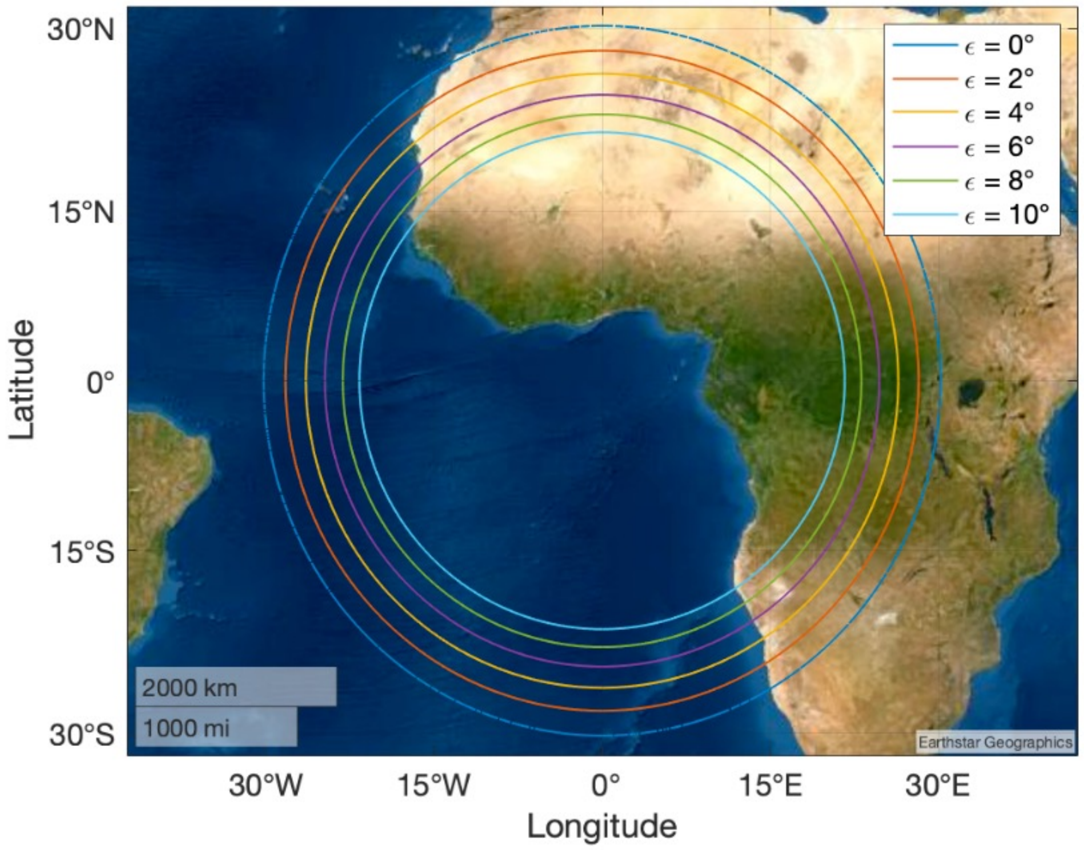
Source: C. Hall, "Spacecraft Dynamics and Control," chapter 2 on "Mission Analysis." Available at: http://www.dept.aoe.vt.edu/~cdhall/courses/aoe4140/missa.pdf

Satellite orbits

- Field of view



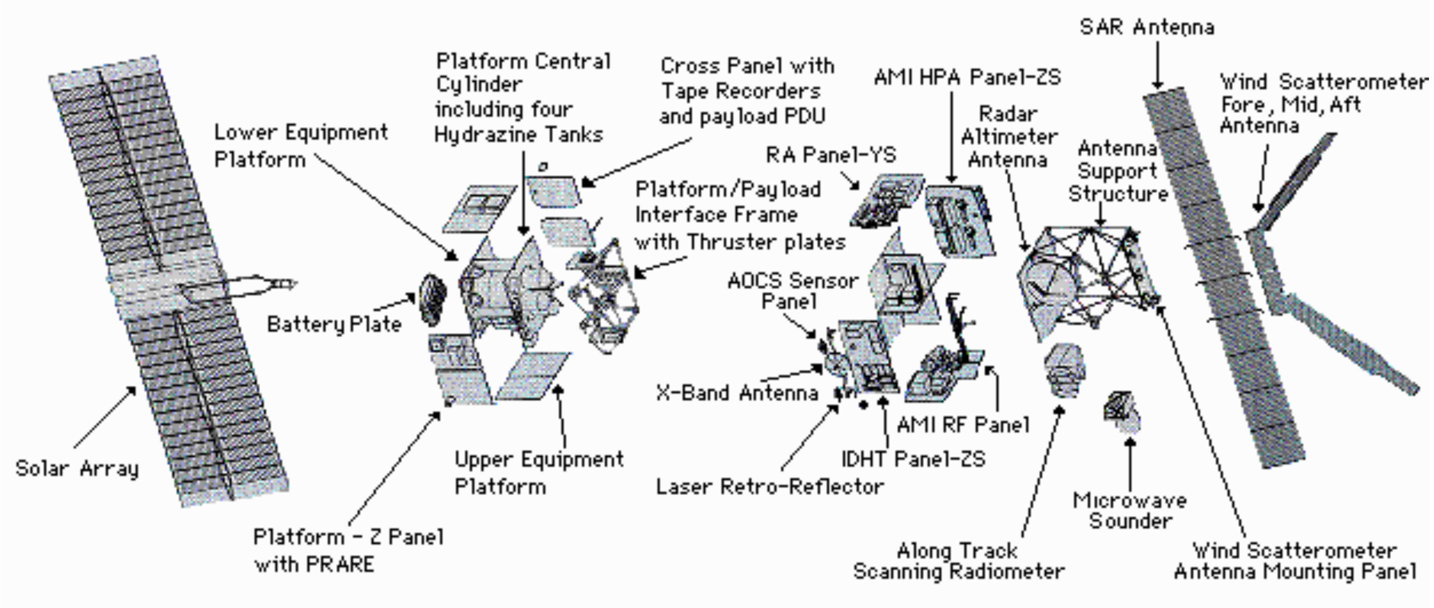
GEO



LEO

Main satellite components

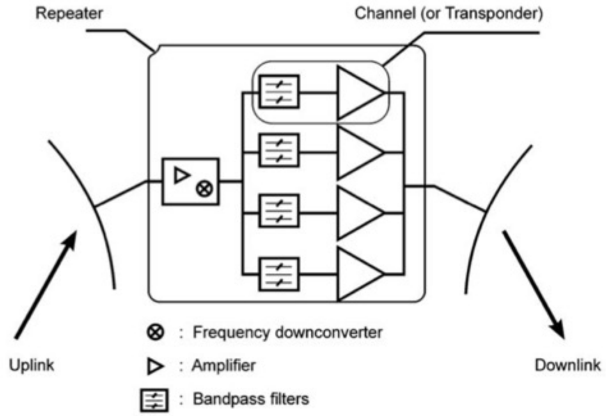
- A communication satellite consists of
  - a platform: the subsystem permitting the satellite to operate
  - a payload: antennas and Tx/Rx equipment



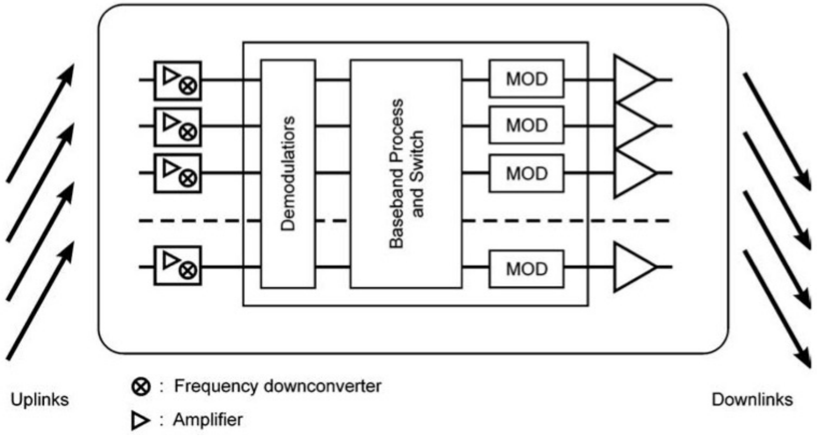
Source: European Space Agency, ERS-1 payload. Available at: https://earth.esa.int/eogateway/missions/ers/description

Payload

- Transparent vs Regenerative
- Transparent Tx/Rx
  - frequency conversion and amplification
- Regenerative Tx/Rx
  - radio frequency filtering,
  - frequency conversion and amplification
  - coding/modulation and demodulation/decoding,
  - switch and/or routing,
- This is equivalent to have all or part of the gNB protocol stack on the NTN platform.



Transparent

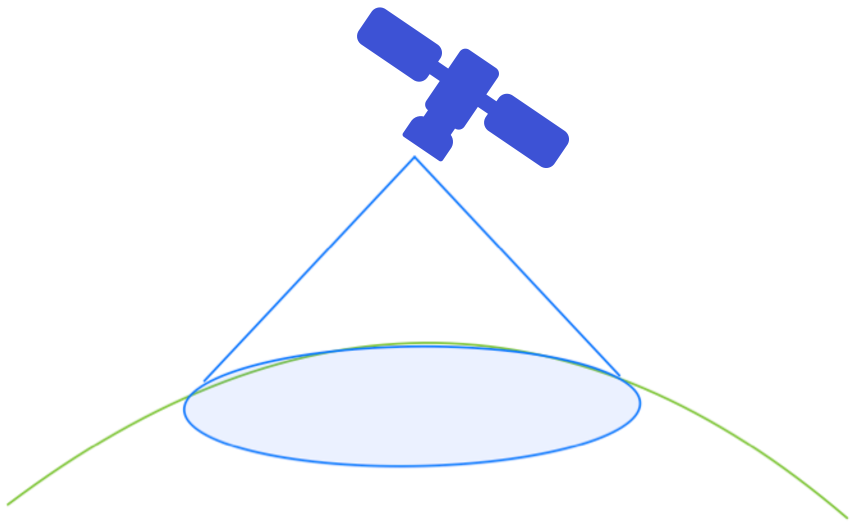


Regenerative

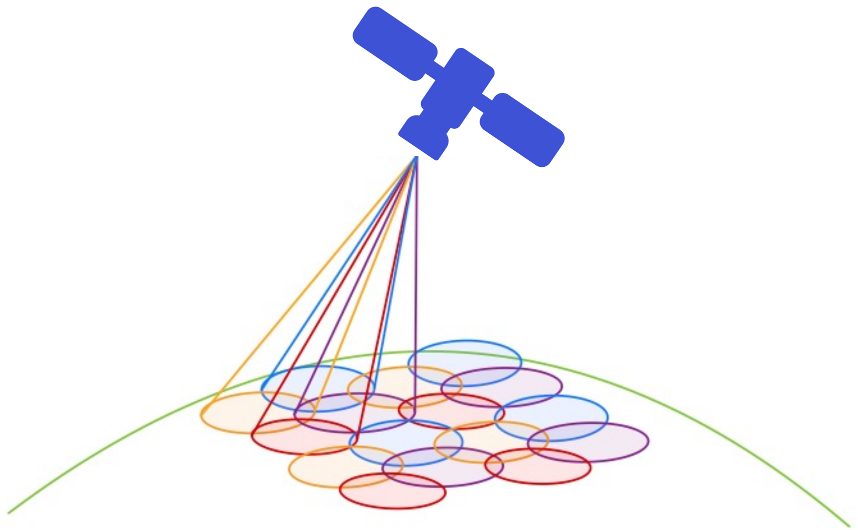
Source: G. Maral, M. Bousquet, "Satellite Communication Systems," 5th ed., Wiley, 2009

Antenna

- Single-beam
  - Tradeoff between coverage extension and overall link quality (lower antenna gains)

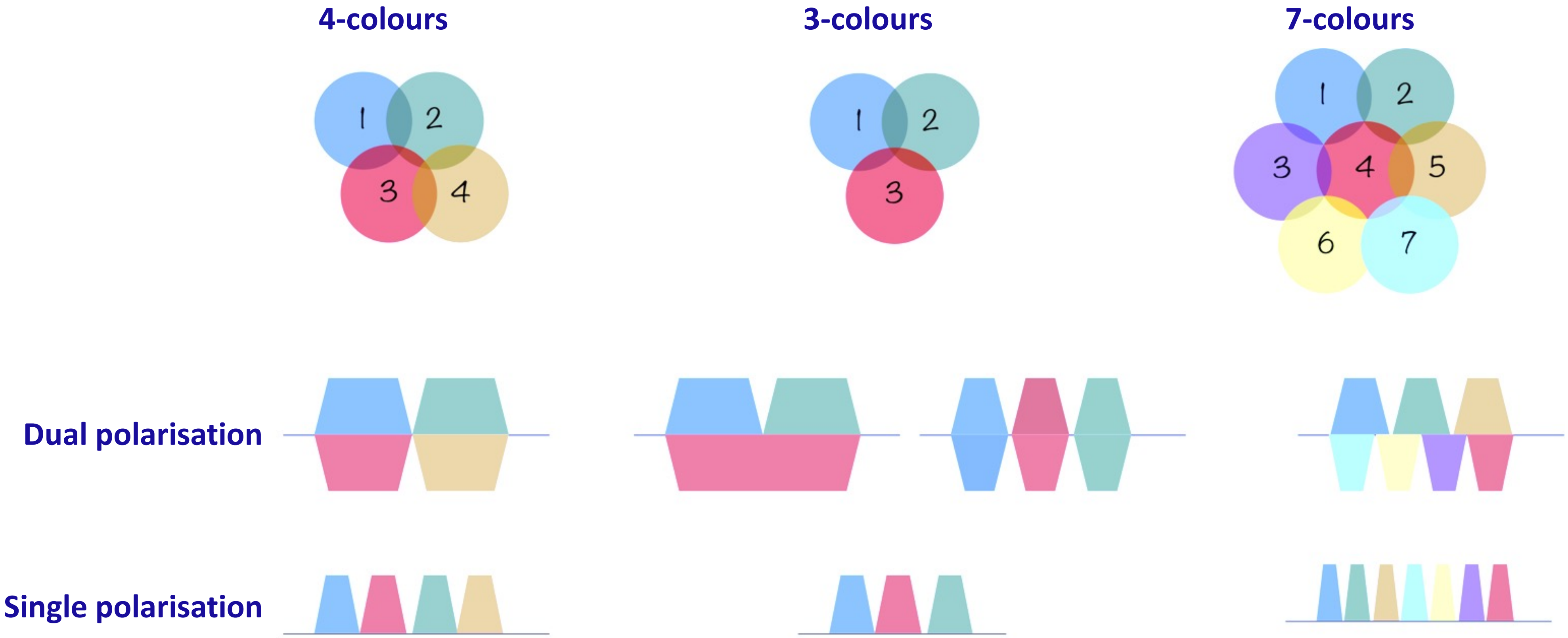


- Multi-beam
  - The link performance improves with the number of beams, also allowing frequency reuse
  - Complexity (mass, on-board connectivity)
  - Interference management



Frequency reuse

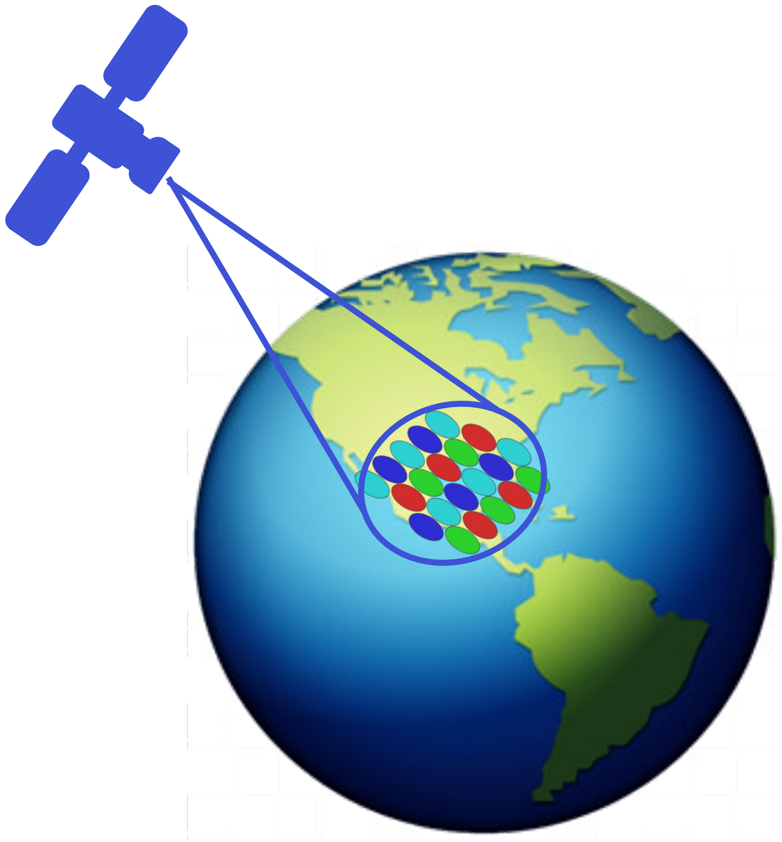
- Frequency reuse scheme: combination of polarisation and frequency band
- Each beam is associated to a "colour"



Coverage

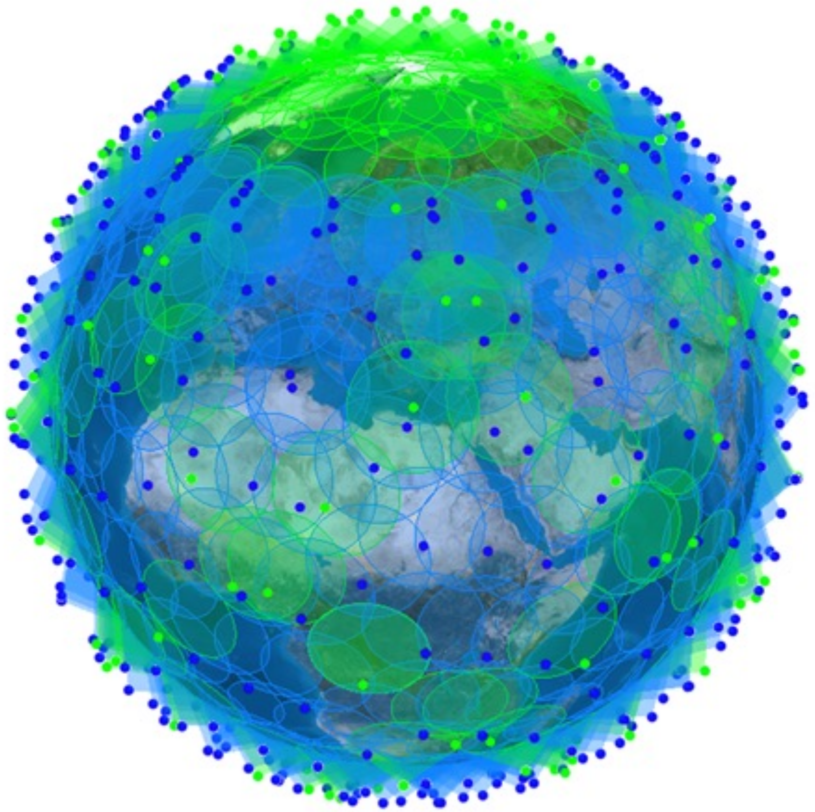
- A single satellite covers a (small) portion of the Earth for a (short) period of time

- To ensure global coverage, or connectivity with a sufficient periodicity, constellations are typically needed



Constellations

- A number of satellites, of a similar type and function, designed to be in complementary orbits for a shared purpose, and under a shared control.



3GPP NTN scenario

- Preliminary macro-scenarios identified in TR 38.821

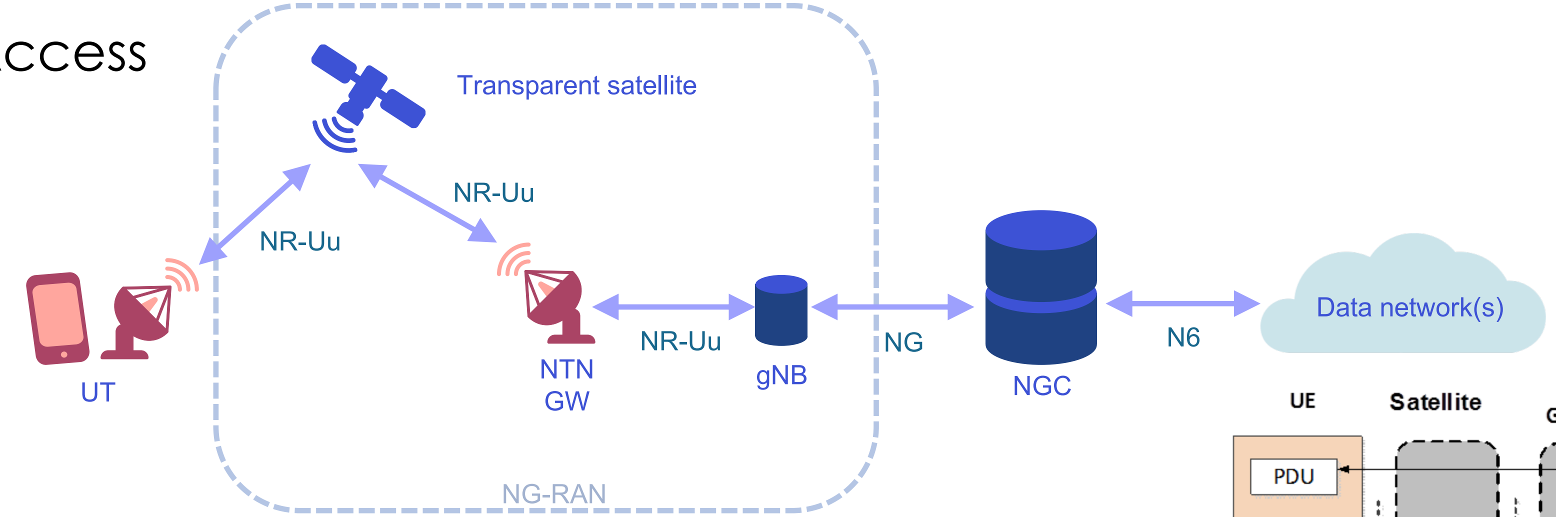
	Transparent satellite	Regenerative satellite
GEO based non-terrestrial access network	Scenario A	Scenario B
LEO based non-terrestrial access network: steerable beams	Scenario C1	Scenario D1
LEO based non-terrestrial access network: the beams move with the satellite	Scenario C2	Scenario D2

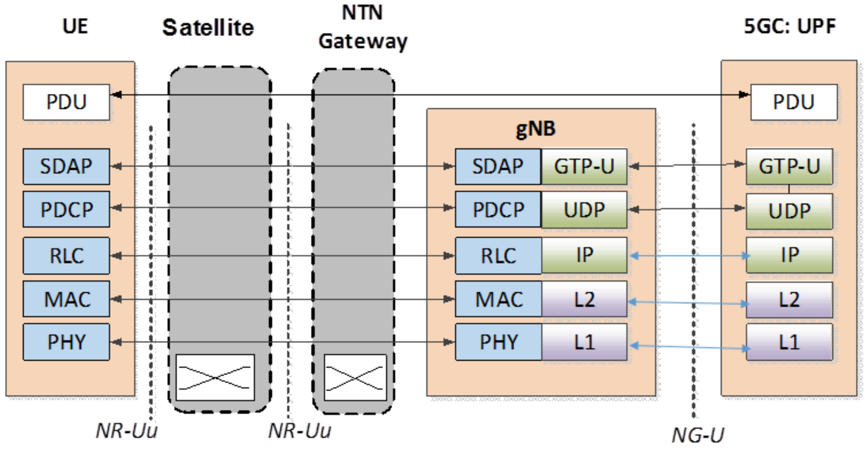
w/o ISL w/ ISL

- The targeted macro-scenarios are
  - GEO with transparent payload (A)
  - LEO with transparent payload and fixed/moving beams (C1/C2)
  - LEO with regenerative payload and fixed/moving beams (D1/D2)
- All of the above scenarios can be implemented by means of
  - Direct access (with/without functional split for regenerative payloads)
  - Relay Nodes (RNs) or Integrated Access Backhaul (IAB) Nodes

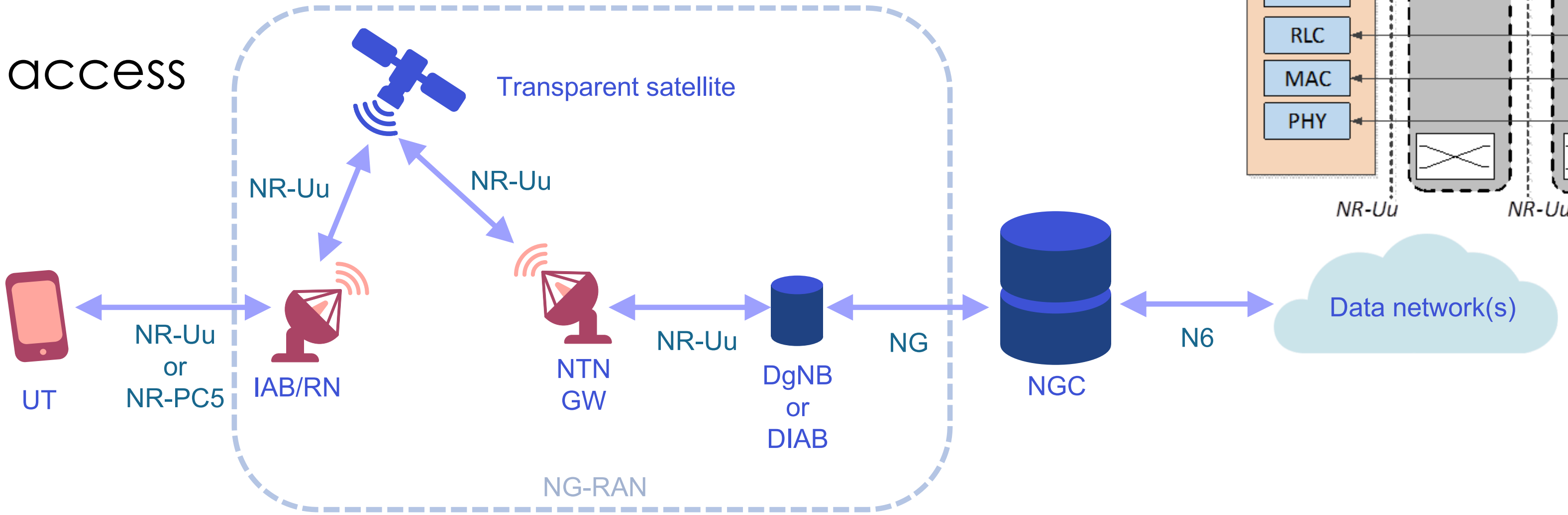
Transparent payload: reference architecture

- Direct Access



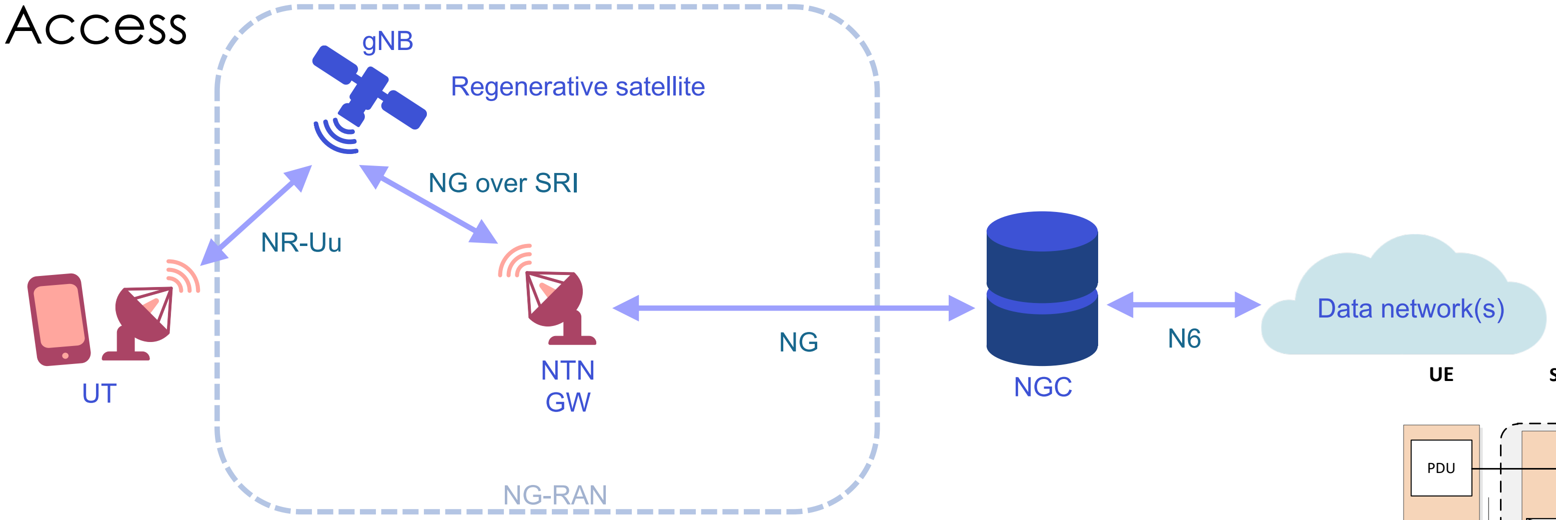


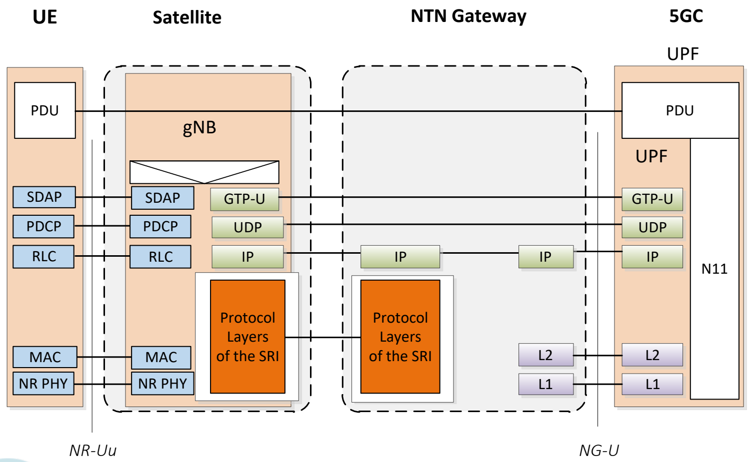
- RN/IAB access



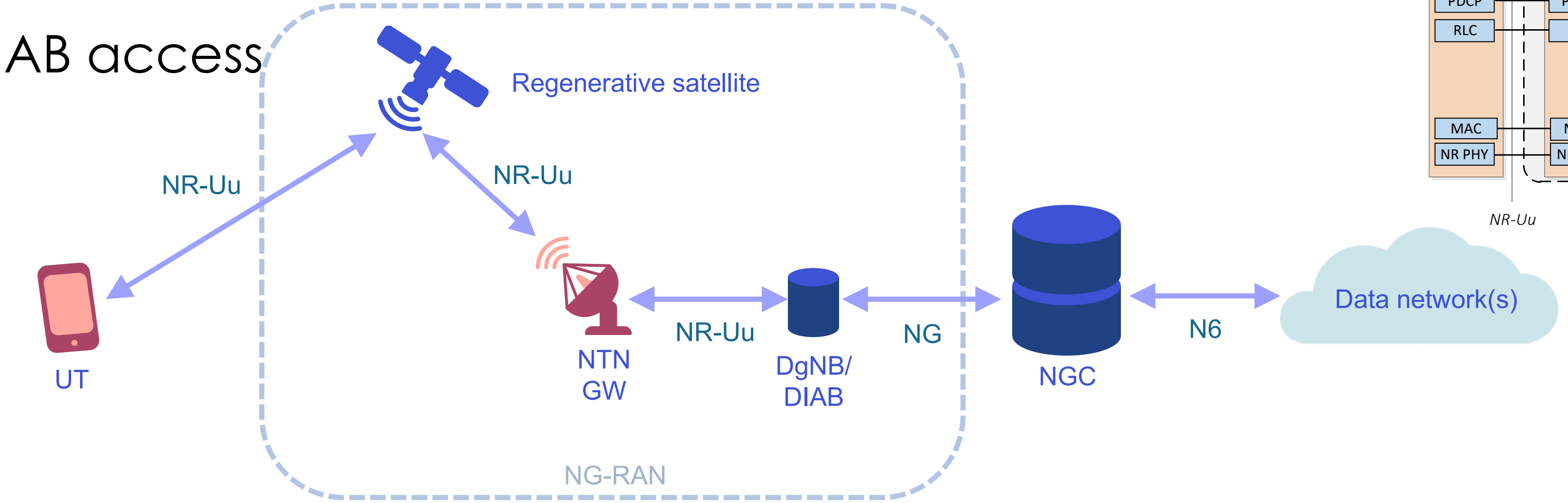
Regenerative payload: reference architecture w/o functional split

- Direct Access





- RN/IAB access



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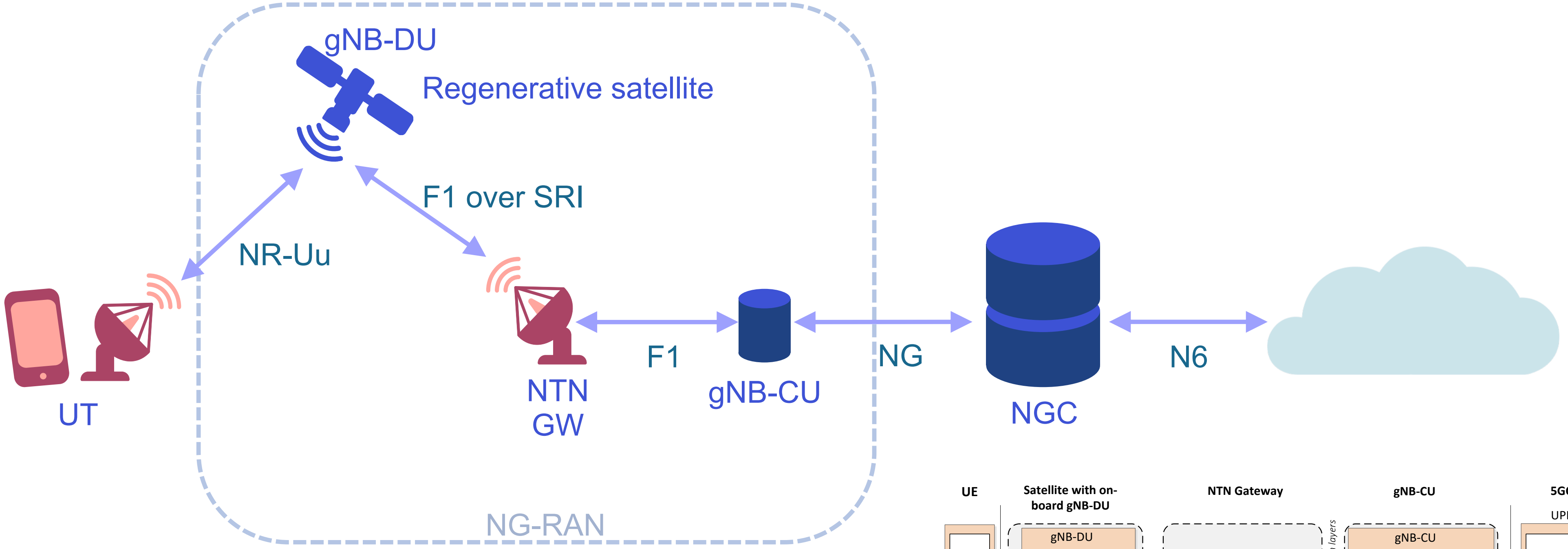
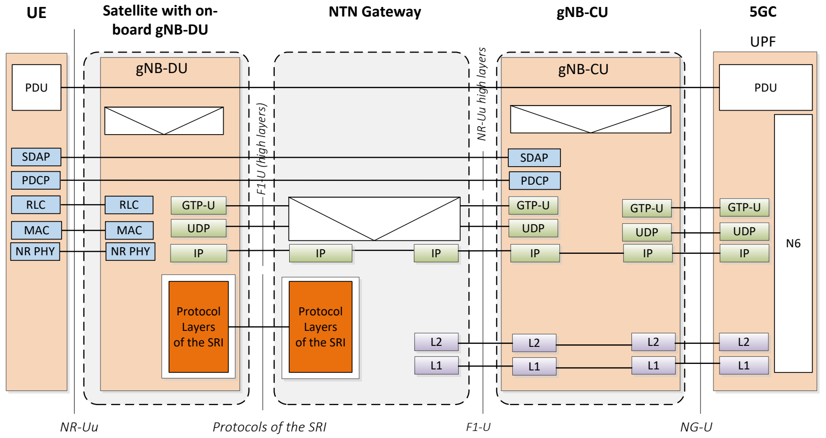
Regenerative payload: reference architecture w/ functional split

- Direct Access





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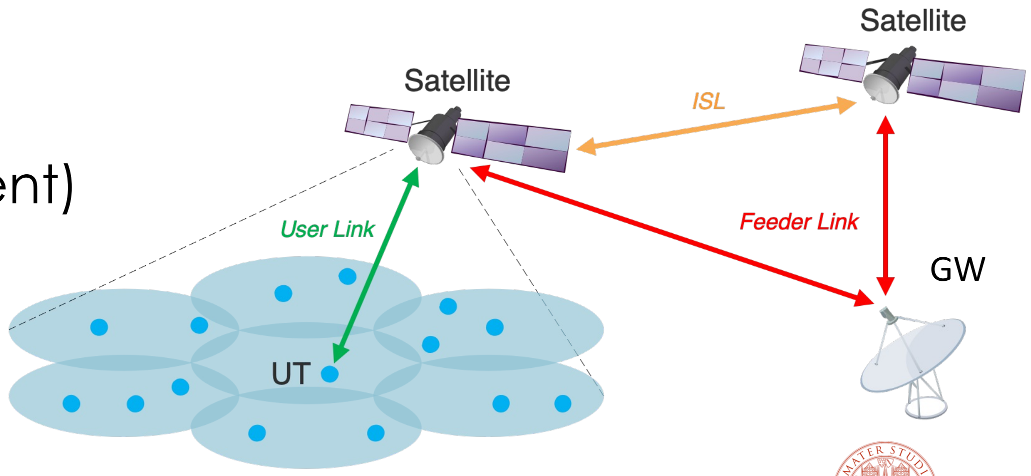
NTN impairments:

- Delay
- Differential delay
- Doppler shift
- Differential Doppler shift
- Doppler spread

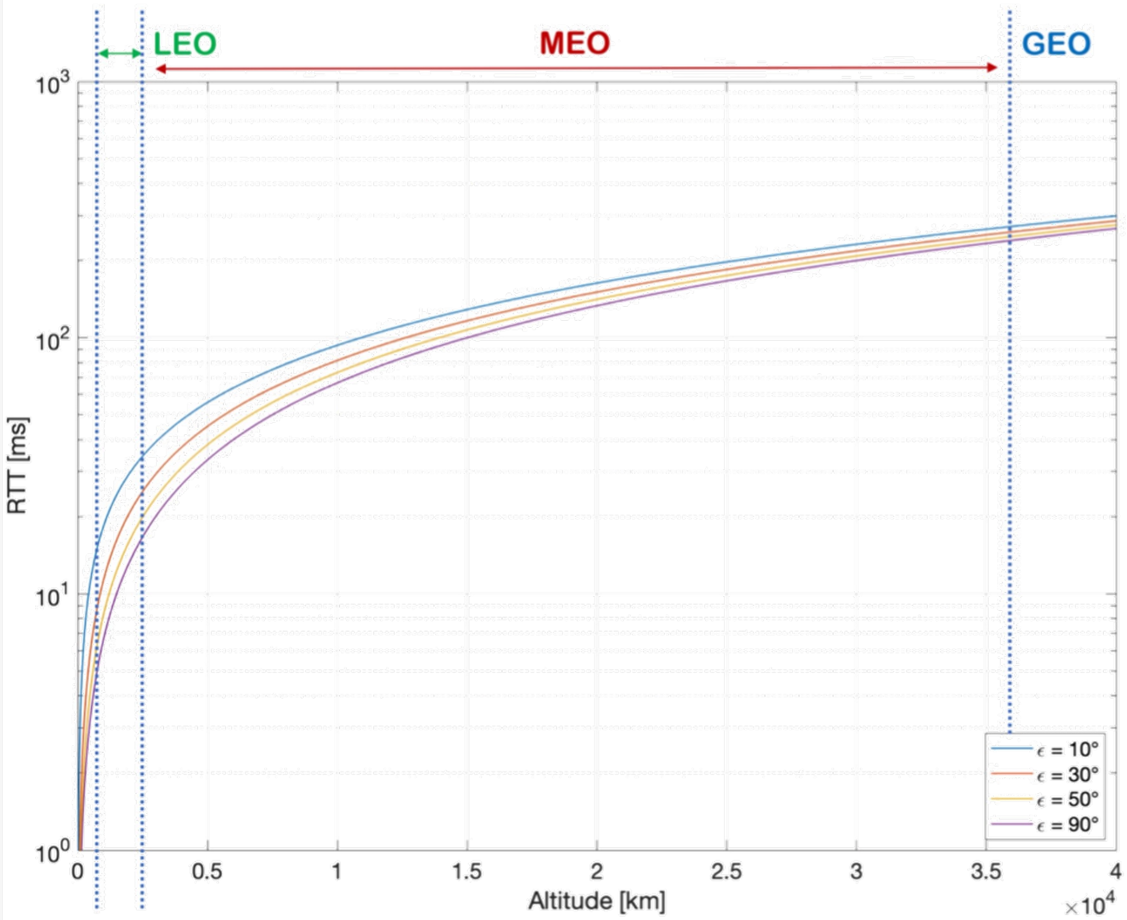
Delay

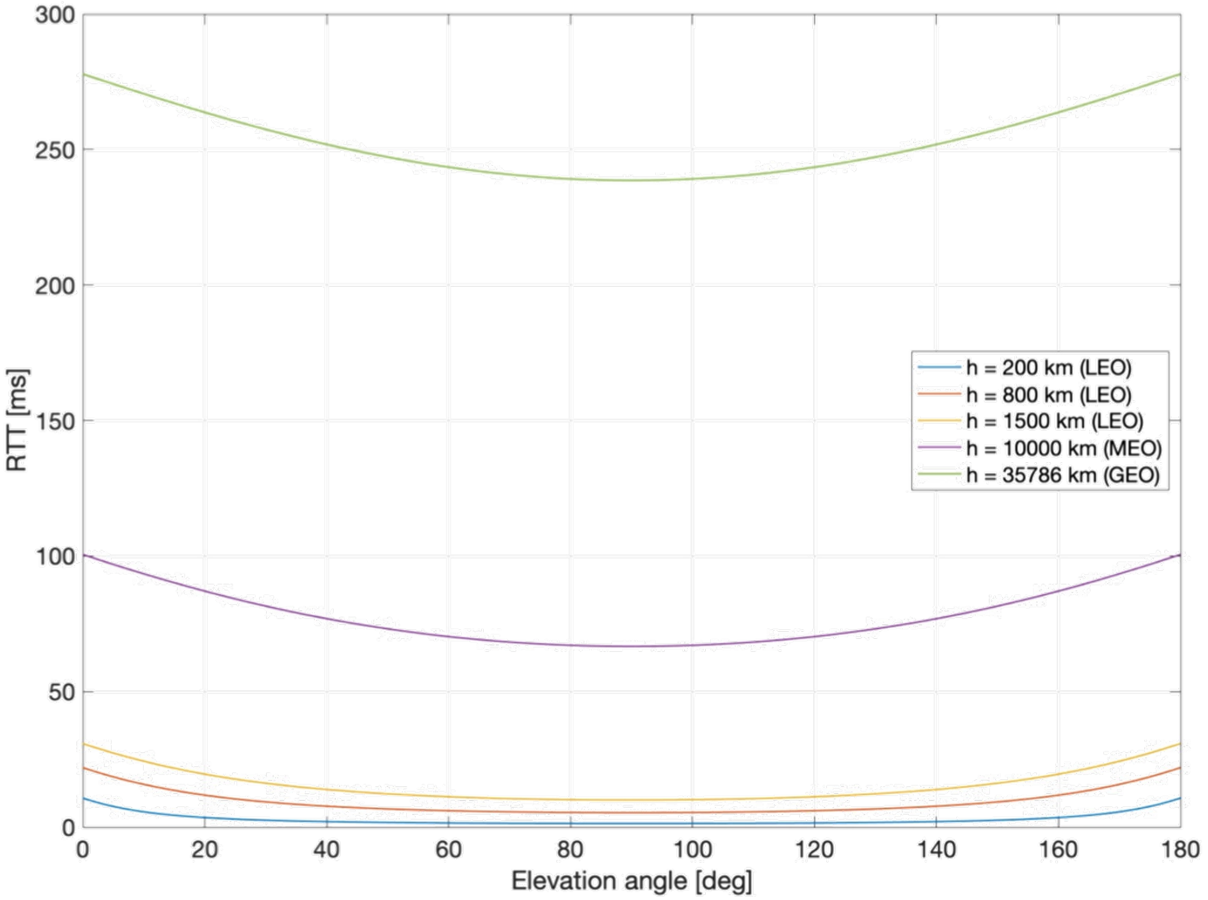
- Different types of delay are involved in SatCom. The propagation delay, directly related to the slant range, is the predominant one and its value is much larger than those of terrestrial networks.
- **Larger the footprint | Higher the orbit | Smaller the elevation angle ⇒ Larger the RTT**
- This could result in bottlenecks with harmful impacts on the protocols and procedures of the system, subject to the kind of air interface implemented:
  - the propagation delay along the user link
  - the propagation delay along the feeder link
  - the propagation delay along the ISL (if present)

$$RTT \approx 2\,T_{OW} = 2\,\frac{d_{UT-Sat}(\varepsilon_{UT}) + d_{Sat-Sat} + d_{Sat-GS}(\varepsilon_{GW})}{c}$$



Delay





- Round Trip Time vs. Altitude
- Round Trip Time vs. Elevation

Differential Delay

- **Differential delay** is the difference among the propagation delay experienced by two different UTs in the access area of the same satellite, *i.e.*, in the same beam in the case of multi- beam scenario.

- In general, for two or more UTs in the same beam, it is possible to split their one-way propagation delay, into two distinct components:

$$T_{OW} = \Delta\tau + T_{com} = \Delta\tau + (T_{user} + T_{isl} + T_{feed})$$

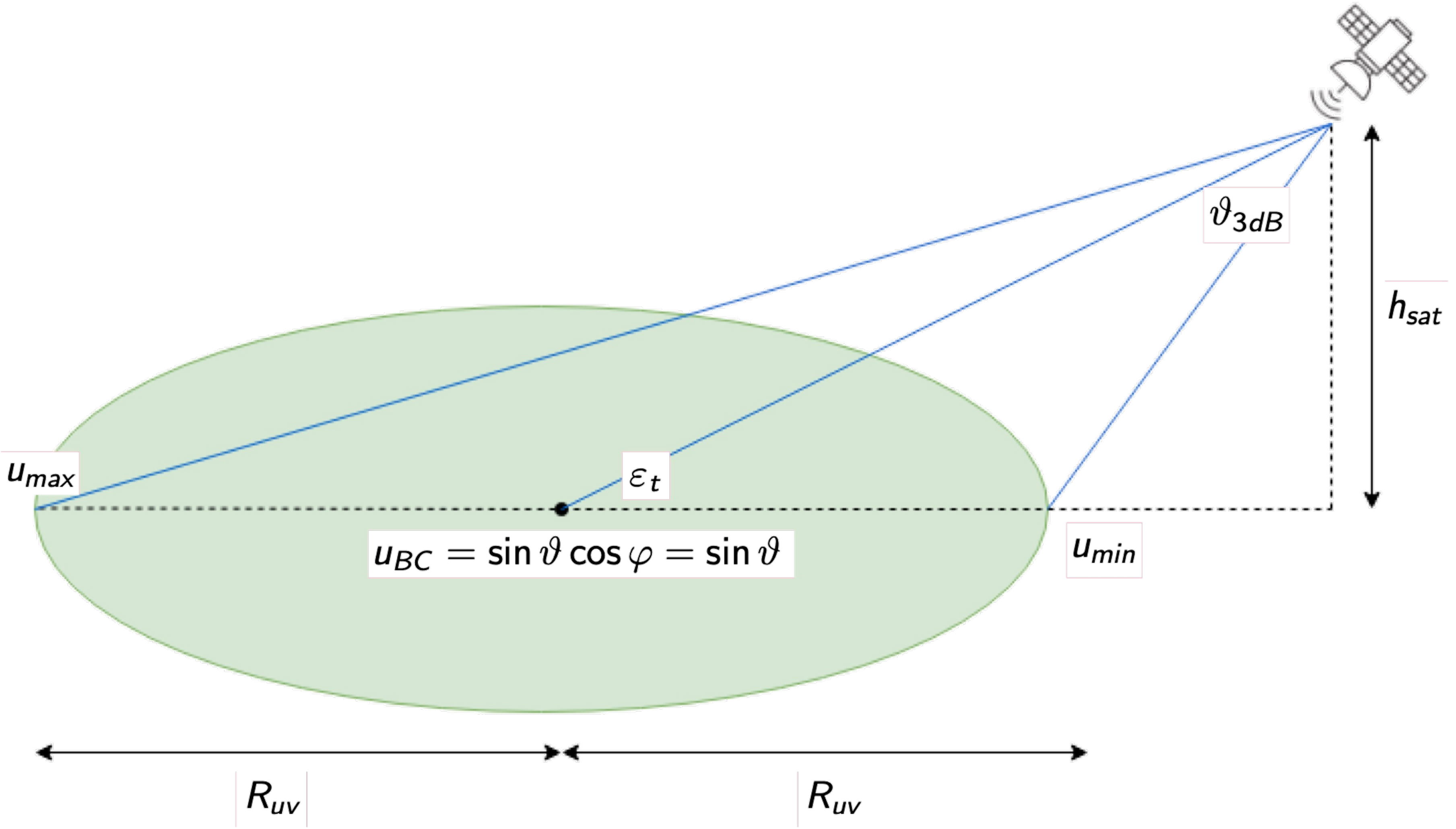
Differential Delay

- $\Delta\tau$ represents the difference in propagation delay of a UT with respect to a reference one in same coverage, *i.e.*, the UT experiencing the minimum delay.
- Referring to the generic UTs positions inside the beam coverage, the differential delay is:

$$\Delta\tau = \tau_B - \tau_A$$

- With: $\tau_i = \frac{d_i}{c} = R_E \frac{\sqrt{(\frac{R_E + h_{sat}}{R_E})^2 - cos^2(\varepsilon_i)} - \sin(\varepsilon_i)}{c}$

Differential Delay



Differential Delay

- For a given NTN configuration (h_{sat}, band), R_{uv} is defined by the θ_{3dB} angle:

$$R_{uv} = \sin(\theta_{3dB})$$

- A target elevation angle ε_t is defined for the beam center location

Differential Delay

- Assuming the beam center located on the u−axis, its coordinates are obtained as:

$$\begin{cases} v_{BC} = sin\theta \; sin\varphi = 0 \\ u_{BC} = sin\theta \; cos\varphi = sin\theta \end{cases}$$

- Where θ is the Nadir angle and $\varphi = 0$ since $v_{BC} = 0$. From the former observations, we obtain:

$$u_{BC} = sin\vartheta = \cos(\varepsilon_t) \frac{R_E}{R_E + h_{sat}}$$

- The beam center ensuring an elevation angle ε_t hs the following coordinates: $(\cos(\varepsilon_t) \; \frac{R_E}{R_E+h_{sat}}, 0)$

Differential Delay

- By means of a geometrical observation, the locations at maximum and minimum slant range are on the beam edge at:

$$\begin{cases} u_{min} = u_{BC} - R_{uv} = \cos(\varepsilon_t)\dfrac{R_E}{R_E + h_{sat}} - R_{uv} \\ u_{max} = u_{BC} + R_{uv} = \cos(\varepsilon_t)\dfrac{R_E}{R_E + h_{sat}} + R_{uv} \end{cases}$$

- With $v_{min} = v_{max} = 0$.

Differential Delay

- When the Sub−Satellite Point (SSP) is inside the beam coverage, the SSP is the minimum slant range location. Thus:

$$u_{min} = \begin{cases} u_{BC} - R_{uv},\ u_{BC} > R_{uv} \\ 0,\ u_{BC} \leq R_{uv} \end{cases}$$

- there might be scenarios in which the maximum slant range point is over the field of view:

$$u_{max} = \begin{cases} u_{BC} + R_{uv},\ (u_{BC} + R_{uv}) \leq \dfrac{R_E}{R_E + h_{sat}} \\ \dfrac{R_E}{R_E + h_{sat}},\ (u_{BC} + R_{uv}) > \dfrac{R_E}{R_E + h_{sat}} \end{cases}$$

Differential Delay

- The following information can be obtained for the minimum and maximum slant range locations:
  - Nadir angle:

$$\vartheta_i = \arcsin u_i$$

  - Elevation angle:

$$\varepsilon_i = \arccos(sin\theta_i \frac{R_E}{R_E + h_{sat}})$$

  - Earth central angle:

$$\lambda_i = \frac{\pi}{2} - \varepsilon_i - \theta_i$$

- With $i = min, max$

Differential Delay

- From the previous equations, the minimum and maximum slant ranges are given by:

$$\begin{cases} D_{min} = R_E \frac{\sin \lambda_{min}}{\sin \vartheta_{min}} \\ D_{max} = R_E \frac{\sin \lambda_{max}}{\sin \vartheta_{max}} \end{cases}$$

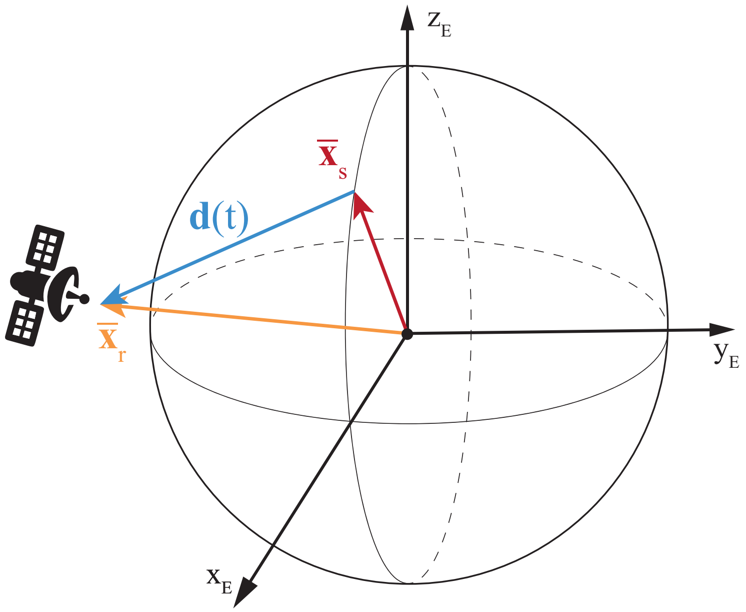
$$\Delta D = R_E \left(\frac{\sin \lambda_{max}}{\sin \vartheta_{max}} - \frac{\sin \lambda_{min}}{\sin \vartheta_{min}} \right)$$

- Thus, the maximum differential delay is given by:

$$\Delta T = \frac{\Delta D}{c} = \frac{R_E}{c} \left(\frac{\sin \lambda_{max}}{\sin \vartheta_{max}} - \frac{\sin \lambda_{min}}{\sin \vartheta_{min}} \right)$$

Doppler shift

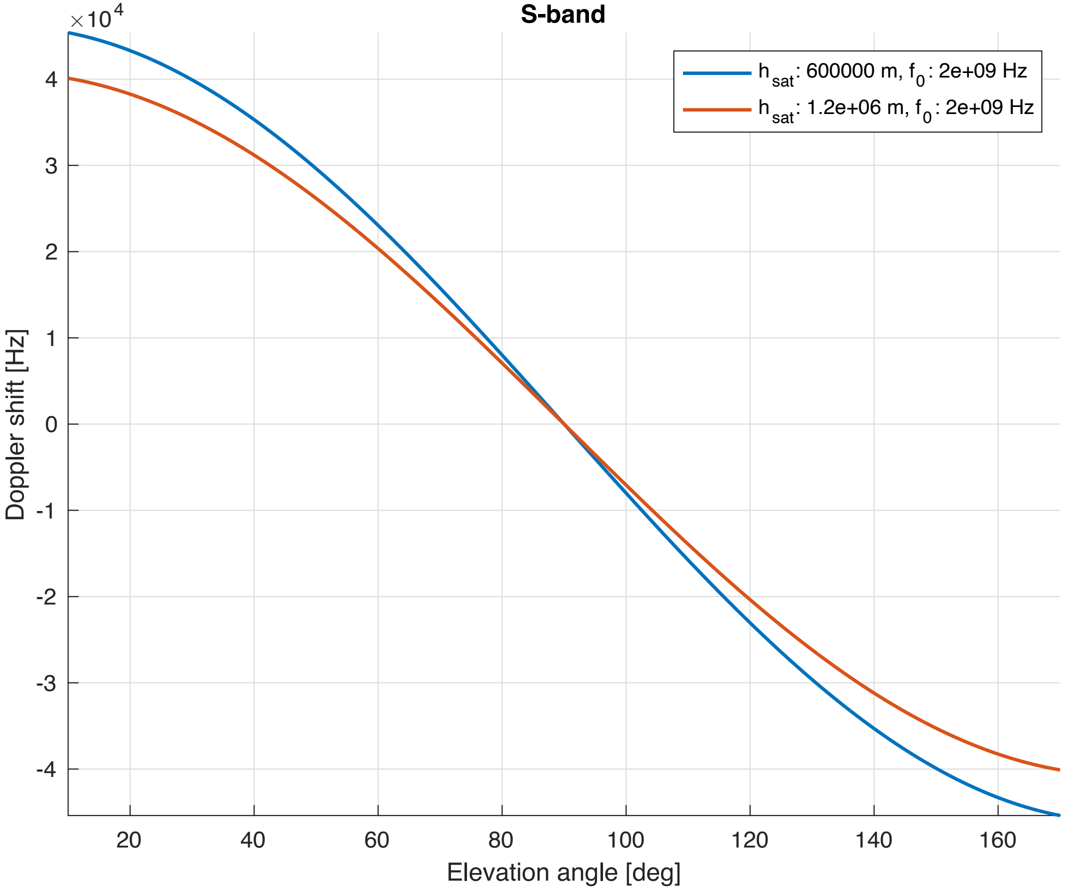
- The **Doppler shift** consists in the change in the carrier frequency due to the relative motion between the satellite and the user terminal.
- When UTs mobility and LEO and VLEO satellite systems are considered, the Doppler shift can introduce significant frequency shifts with respect to those expected in terrestrial systems.

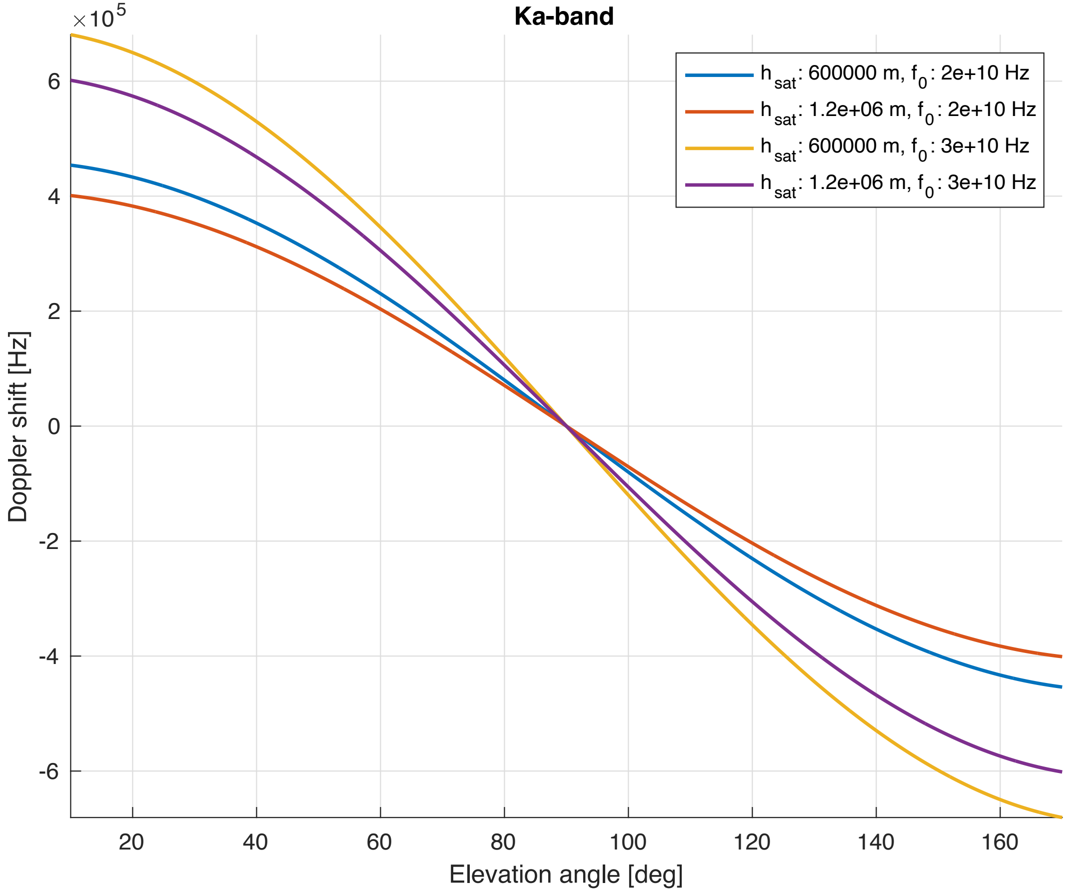


$$f_D(\varepsilon_i) = f_0 \frac{\omega_s R_E \cos(\varepsilon_i)}{c}$$

approximated form as a function of the elevation angle

Doppler shift





NGSO (600-1200 km) @ S-band (2 GHz)

$\varepsilon_{min} = 10°, \varepsilon_{max} = 90°$

NGSO (600-1200 km) @ Ka-band (20-30 GHz)

$\varepsilon_{min} = 10°, \varepsilon_{max} = 90°$

Differential Doppler shift

- The **differential Doppler shift** is the difference among the Doppler shift experienced by two different UTs in the access are of the same satellite, i.e., in the same beam in the case of multi–beam scenario.

- For two or more UTs in the same beam, it is possible to split their Doppler shift, $f_D(t)$, previously defined, into two distinct components:

$$f_D(t) = \Delta f_D(t) + f_D^{com}(t) = \Delta f_D(t) + \left(f_D^{user}(t) \pm f_D^{isl}(t) \pm f_D^{feed}(t) \right)$$

Differential Doppler shift

- By means of orbital and geometric considerations, it is known that the worst case scenario arises when the **beam major semi−axis lies on the satellite ground track.**
- For a terminal not located at the beam center, but located on the beam major semi−axis, the same Doppler curve applies with an horizontal shift given by the time instant at which that UT will see the satellite at $\varepsilon = \pi/2$ elevation.
- The differential Doppler between any two users is obtained **by evaluating the Doppler shift** at the corresponding elevation angles and computing the difference.
- The **maximum variability** is obtained when the UEs are at the **two beam edges** on the beam major semi-axis.

Differential Doppler shift

- In order to define the maximum differential Doppler shift, the elevation angles at the minimum and maximum Doppler shift locations must be computed:

$$\Delta f_{d,max} = f_D\left(\varepsilon_{max}\right) - f_D\left(\varepsilon_{min}\right) = \frac{f_0}{c}(R_E + h_{sat})\omega_s(u_{max} - u_{min})$$
$$= 2 f_0 \frac{R_E + h_{sat}}{c} \omega_s R_{uv}$$

Doppler rate

- The **Doppler rate** is the partial derivative with respect to the time of the Doppler shift.
- The mathematical formulation for the Doppler rate is the following: $\dot{f}_D(t) = \frac{\partial f_D(t)}{\partial t}$
- Steeper Doppler shift curves bring to harsher Doppler rate effects
- Greater elevation angles cause more abrupt changes in Doppler shift → higher Doppler rates.
- Being a variation of the frequency in time as the length of the packet increases, it is necessary to take countermeasures for the Doppler rate.

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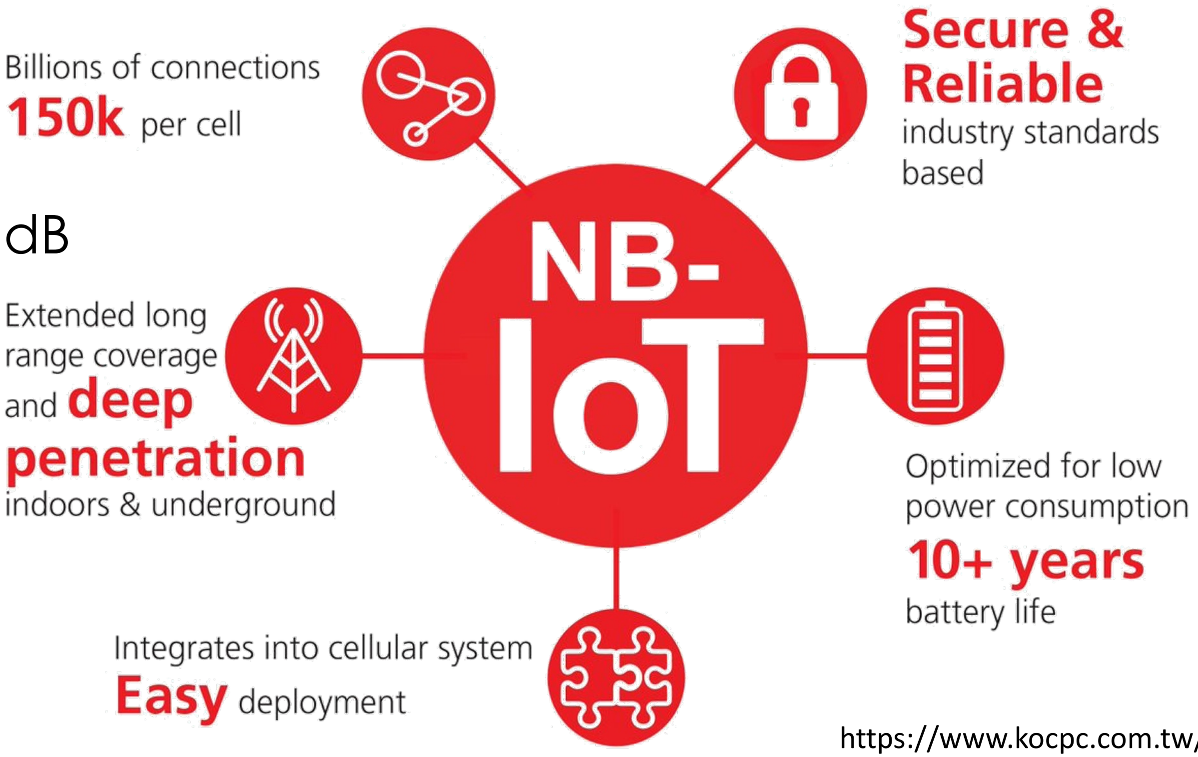
2.2 NB-IoT:

- NB-IoT overview
  - Operation modes
  - Transmission modes
  - Framing system
- PHY layer:
  - Downlink signals
  - Downlink channels
  - Uplink signal
  - Uplink channels
- MAC layer:
  - Random Access procedure
  - NPRACH scheduling
  - NPUSCH scheduling
- Guard time
- Early Data transmission

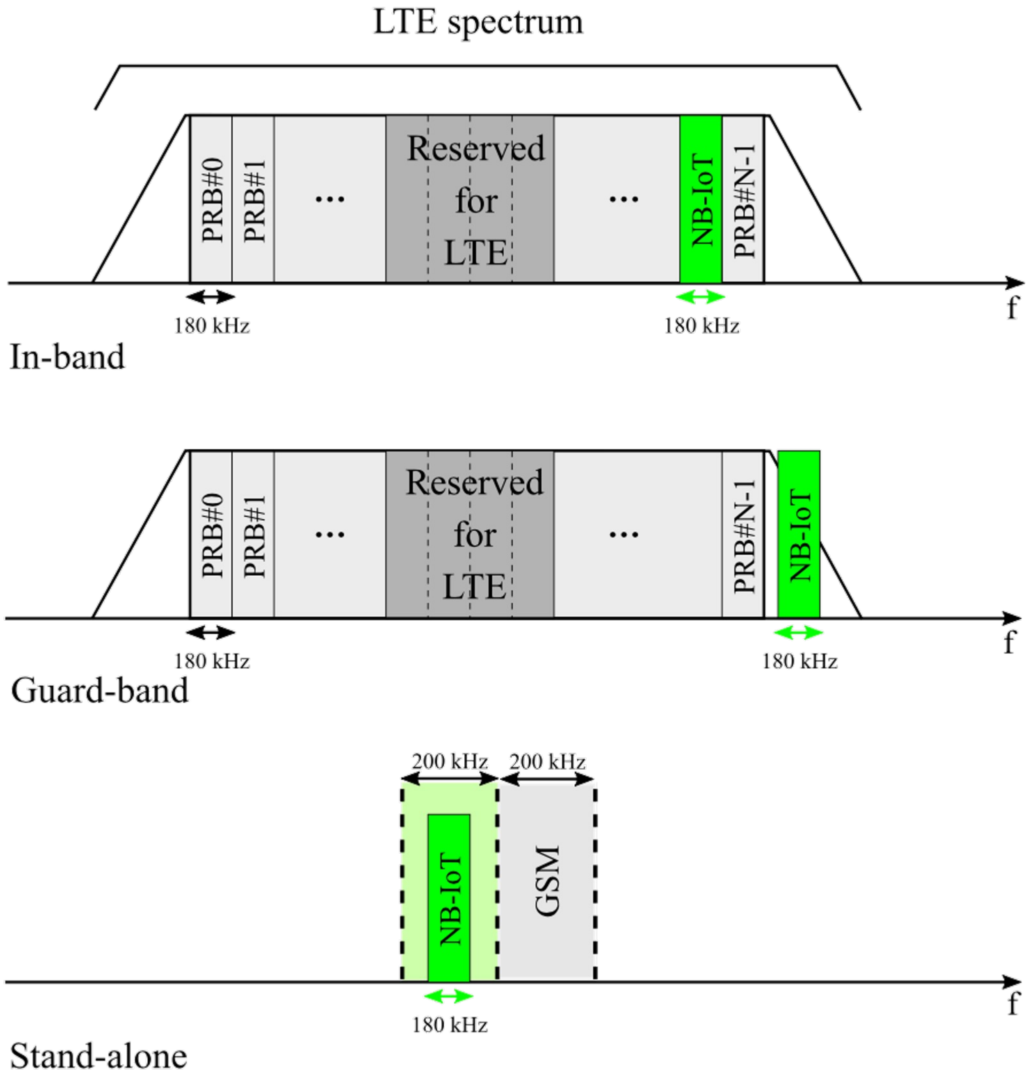
NB-IoT

- NB-IoT targets the low-cost, low complexit, massive mMTC scenario:
  - Low device cost/ low complexity.
  - Extended coverage: 164 dB MCL, 20 dB better than GPRS
  - Long battery life: > 10 years
  - Capacity: ~150k devices per cell.
  - Uplink reports < 10 [s]



https://www.kocpc.com.tw/archives/174069

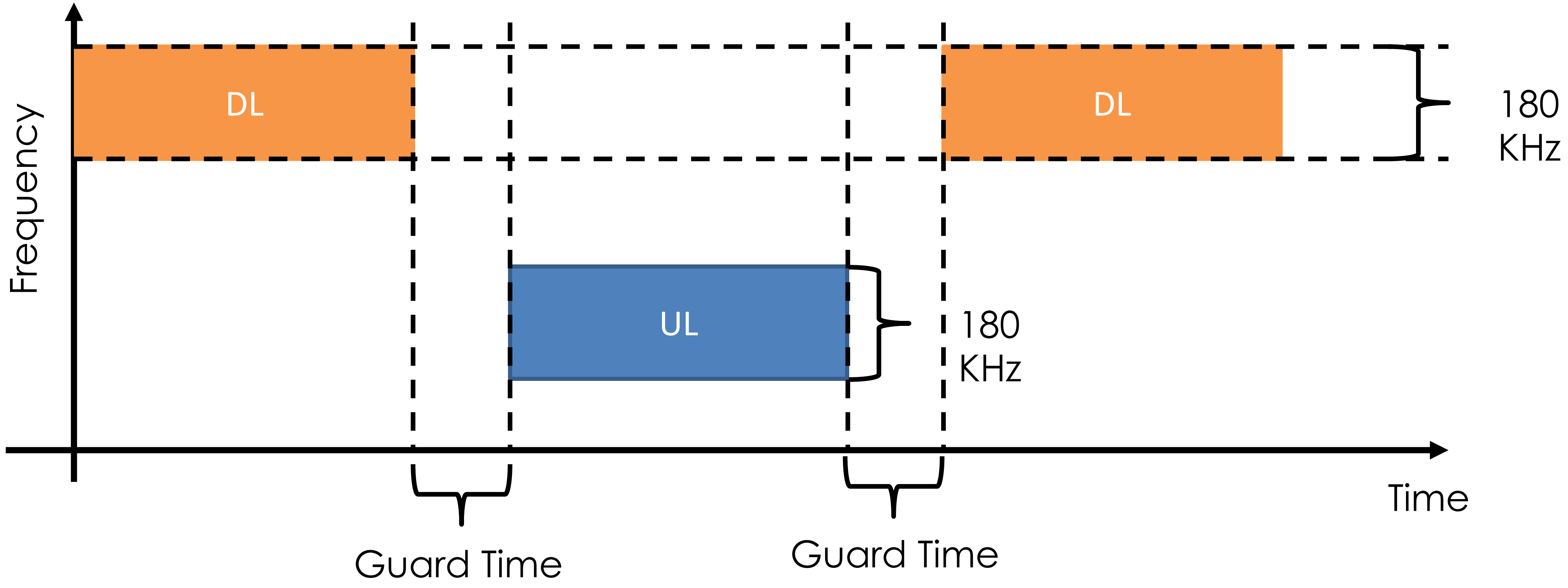
Operation modes



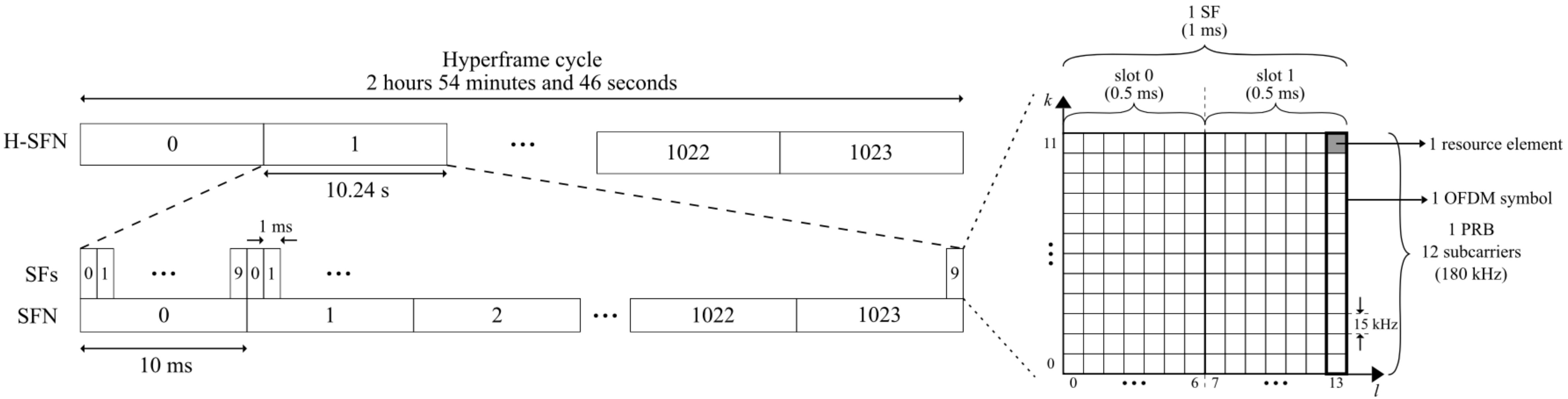
From: A Tutorial on NB-IoT Physical Layer Design

Transmission modes

- Since R.13, NB-IoT supports Half Duplex Frequency Division Duplex (HD-FDD).
- Starting from R.15, Time Division Duplex (TDD) is supported.



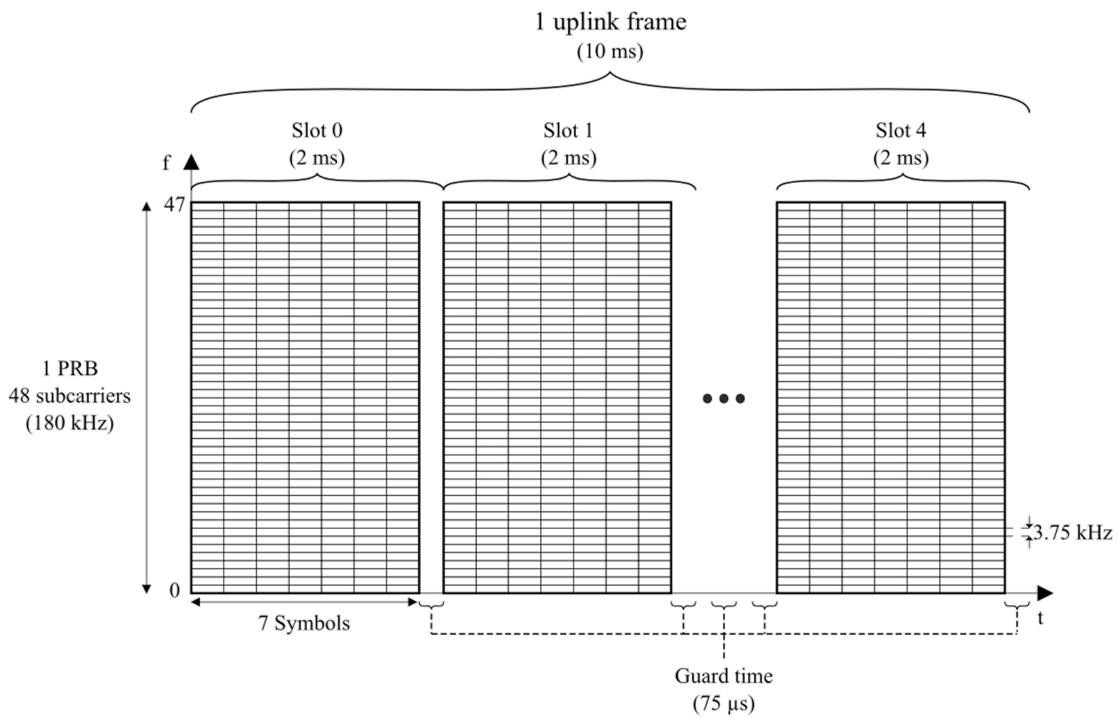
DL framing system



From: A Tutorial on NB-IoT Physical Layer Design

UL framing system

SCS	# sub-carriers	Slot number	Resource elements number	SC-FDMA symbol number	RU duration
3.75 KHz	1	16	112	112	32
15 KHz	1	16	112	123	8
	3	8	168	56	4
	6	4	168	28	2
	12	2	168	14	1



From: A Tutorial on NB-IoT Physical Layer Design

PHY Channels and signals

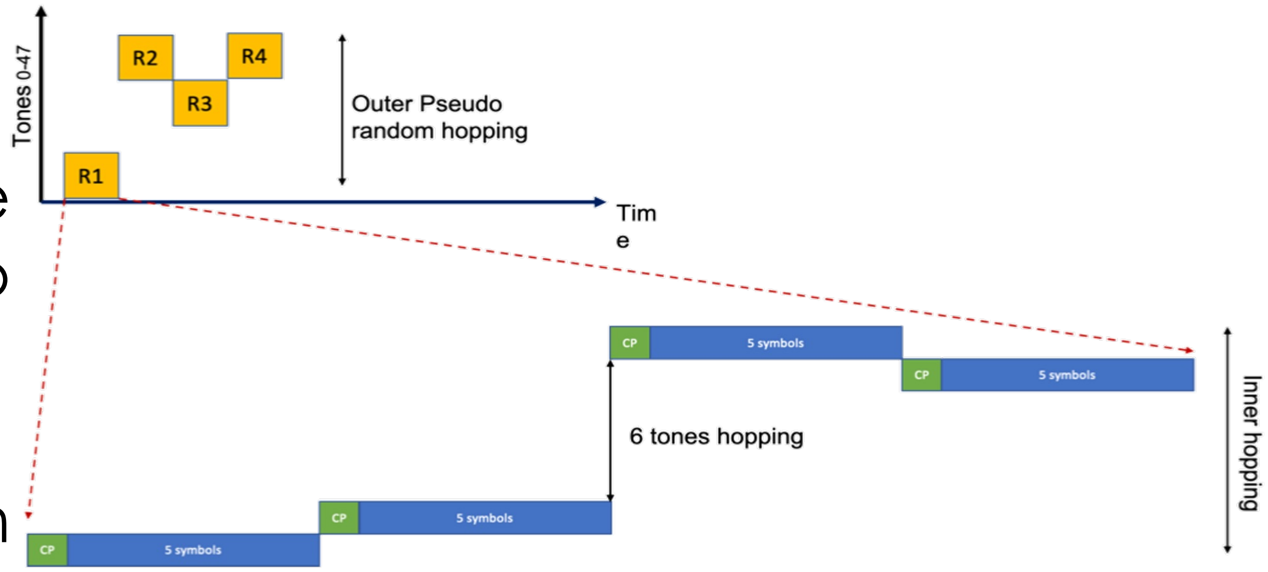
	Type	Name	Role
Downlink	Signals	NPSS	Time and Freq. synch.
		NSSS	Cell ID
		Narrowband Reference Signal (NRS)	Channel estimation
		NPRS	Positioning estimation
		Narrowband Wake Up Signal (NWUS)	Paging signal to inform the device to wake-up to receive the data
	Channels	NPBCH	Transmission of MIB
		NPDCCH	Transmission of control/scheduling
		NPDSCH	Transmission of data
Uplink	Signal	DMRS	Channel estimation
	Channels	NPUSCH	Transmission of data/control
		NPRACH	Transmission of preambles

NPRACH

- The basic unit is the single tone frequency hopping symbol group (SG).

$$SG = CP + N \cdot symbols$$

- Every symbol group is transmitted on different sub-carriers, according to the hopping rule.
- The total number of symbol groups in a preamble repetition unit is denoted by P. The number of time-contiguous symbol groups is given by $G = N_{rep} \cdot P$



Preamble format	CP length	P	N	Sequence length	SCS
0	$66.7\ \mu s$	4	5	$5 \cdot 266.7\ \mu s$	$3.75\ KHz$
1	$266.7\ \mu s$	4	5	$5 \cdot 266.7\ \mu s$	$3.75\ KHz$
2	$800\ \mu s$	6	3	$3 \cdot 800\ \mu s$	$1.25\ KHz$

Generation of NPRACH 1/2

1. Define n_{init}, i.e. the subcarrier selected randomly by the MAC layer from $\{0,1,\ldots,N_{sc}^{NPRACH}-1\}$.
2. Compute $n_{start} = N_{offset}^{NPRACH} + \lfloor n_{init}/N_{sc}^{RA} \rfloor * N_{sc}^{RA}$.
3. Find the frequency location of the i^{th} symbol group as $n_{sc}^{RA}(i) = n_{start} + \widetilde{n_{sc}^{RA}}$. The quantity $\widetilde{n_{sc}^{RA}}$ depends on the preamble format.

Generation of NPRACH 2/2

- For preamble format 0 and 1:

$$\tilde{n}_{\mathrm{sc}}^{\mathrm{RA}}(i)=\begin{cases}\left(\tilde{n}_{\mathrm{sc}}^{\mathrm{RA}}(0)+f(i/4)\right)\bmod N_{\mathrm{sc}}^{\mathrm{RA}} & i \bmod 4=0 \text{ and } i>0\\ \tilde{n}_{\mathrm{sc}}^{\mathrm{RA}}(i-1)+1 & i \bmod 4=1,3 \text{ and } \tilde{n}_{\mathrm{sc}}^{\mathrm{RA}}(i-1) \bmod 2=0\\ \tilde{n}_{\mathrm{sc}}^{\mathrm{RA}}(i-1)-1 & i \bmod 4=1,3 \text{ and } \tilde{n}_{\mathrm{sc}}^{\mathrm{RA}}(i-1) \bmod 2=1\\ \tilde{n}_{\mathrm{sc}}^{\mathrm{RA}}(i-1)+6 & i \bmod 4=2 \text{ and } \tilde{n}_{\mathrm{sc}}^{\mathrm{RA}}(i-1)<6\\ \tilde{n}_{\mathrm{sc}}^{\mathrm{RA}}(i-1)-6 & i \bmod 4=2 \text{ and } \tilde{n}_{\mathrm{sc}}^{\mathrm{RA}}(i-1)\geq 6\end{cases}$$

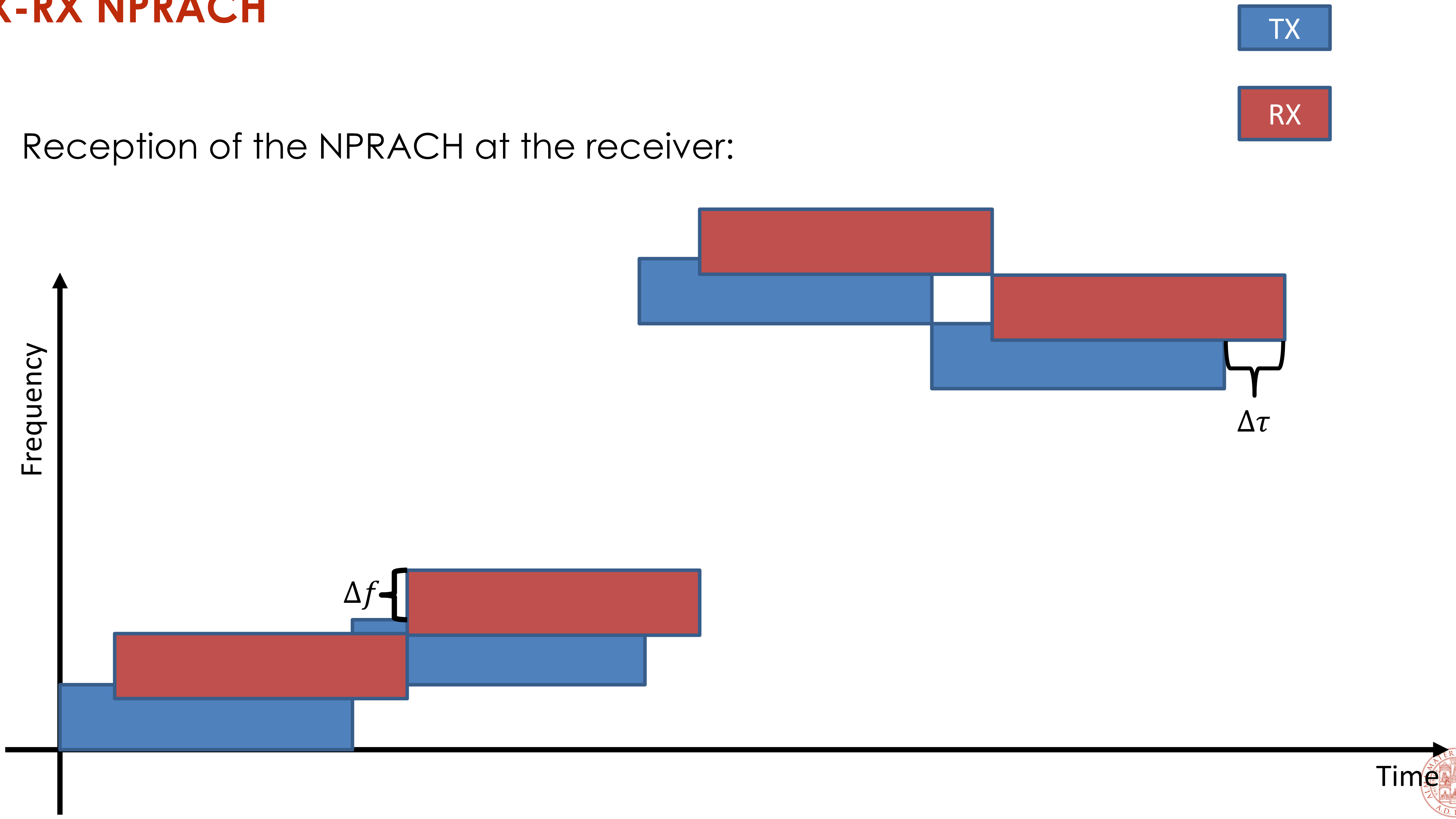
$$f(t)=\left(f(t-1)+\left(\sum_{n=10t+1}^{10t+9}c(n)2^{n-(10t+1)}\right)\bmod\left(N_{\mathrm{sc}}^{\mathrm{RA}}-1\right)+1\right)\bmod N_{\mathrm{sc}}^{\mathrm{RA}}$$

$$f(-1)=0$$

All the subcarriers in the preamble depend on the first one.

TX-RX NPRACH

- Reception of the NPRACH at the receiver:



TX-RX NPRACH

- The detection of the preambles is essential in order to allow the UT to access the network.
- The preamble is a pure complex sine wave → no useful binary information are carried.
- The eNB estimates the frequency offset Δf and the delay $\Delta\tau$.
- This delay is due to the signal propagation time between the eNB and the UT.

$$\Delta\tau = \frac{D}{c}$$

- D = distance between eNB and UT
- c = speed of the light.

Timing Advance

- In order to make the UT temporally synchronized with the eNB, the latter sends to the UT the estimated $\Delta\tau$ also known as Timing Advance (TA) Command.
- The eNB must identify the first sub-carrier where the preamble is sent, which indicates the RAPID (Random Access Preamble Identifier)

NPUSCH 1/3

- The NPUSCH is dedicated to the transmission of data and control information from the UE side.
- Two formats are defined:
  - format 1 for data
  - format 2 for control information (i.e., ACK/NACK).
- In order to adapt the signal robustness to the severity of the propagation environment, different configurations for uplink transmissions are possible.

NPUSCH Format	*Subcarrier Spacing (KHz)*	*Number of Subcarriers*	*Number of Slots*	*Total slots Duration (ms)*	*Number of SC-FDMA symbols per slot*
1	3.75	1	16	32	7
	15	1	16	8	
		3	8	4	
		6	4	2	
		12	2	1	
2	3.75	1	4	8	
	15	1	4	2	

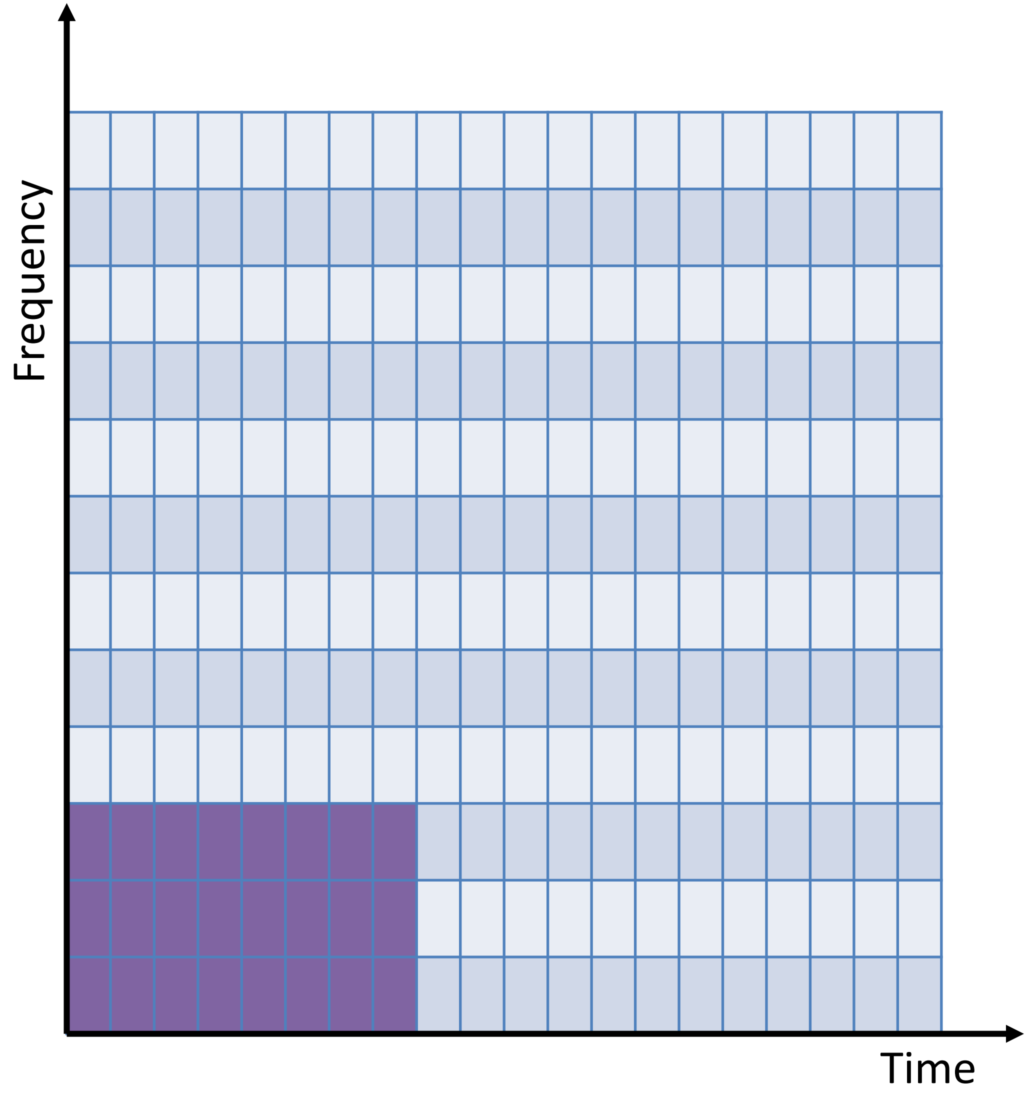
Source: 5G LTE Narrowband Internet of Things (NB-IoT)
Hossam Fattah

NPUSCH 2/3

- The basic unit is the Resource Unit (RU)

NPUSCH Format	Subcarrier Spacing (KHz)	Number of Subcarriers	Number of Slots	Total slots Duration (ms)	Number of SC-FDMA symbols per slot
1	3.75	1	16	32	7
	15	1	16	8	
		3	8	4	
		6	4	2	
		12	2	1	
2	3.75	1	4	8	
	15	1	4	2	

Source: 5G LTE Narrowband Internet of Things (NB-IoT)
Hossam Fattah



NPUSCH 3/3

- The following modulations are supported:

Format	N_{sc}	Modulation
1	1	BPSK, QPSK
1	>1	QPSK, 16-QAM
2	1	BPSK

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MAC layer:

- Random Access procedure
- NPRACH scheduling
- NPUSCH scheduling

Guard time

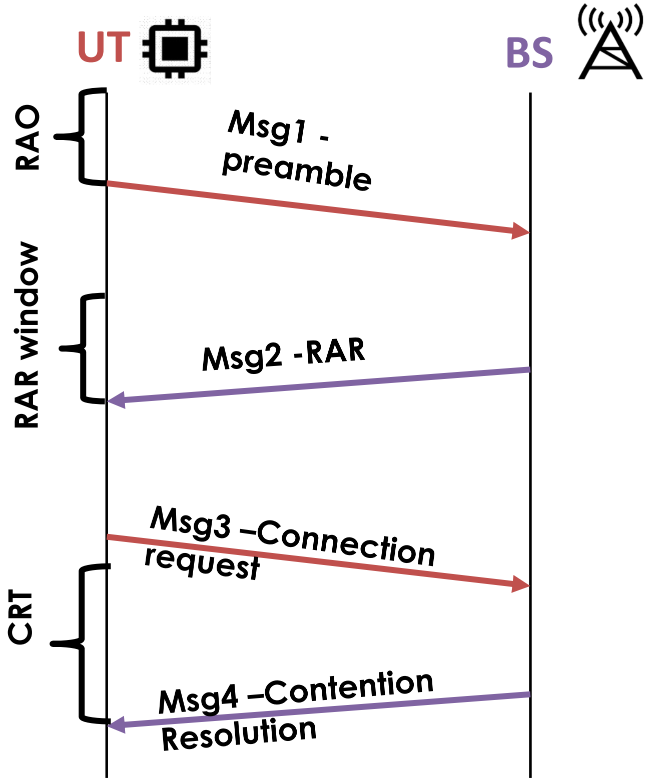
Early Data transmission

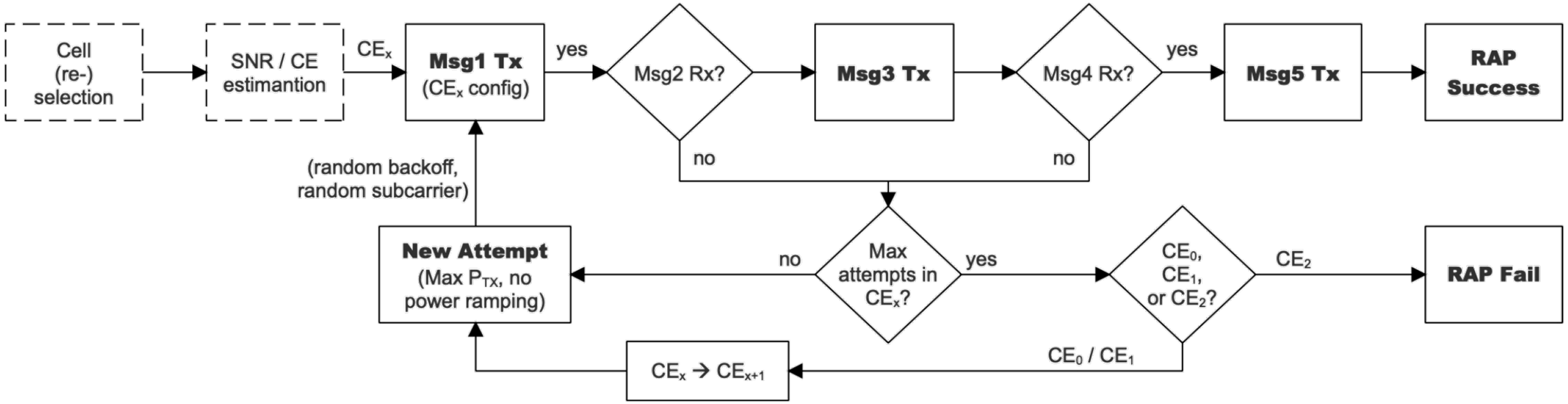
MAC layer

- In NB-IoT, the MAC layer performs several tasks:
  - scheduling of all channels and signals;
  - Random access and contention resolution procedures;
  - handling the time/frequency resource allocation (at the eNB side);
  - multiplexing/demultiplexing data blocks of higher/lower layers;
  - mapping between logical channels and transport channels;
  - managing UTs priority (at the eNB side);

Random Access Procedure

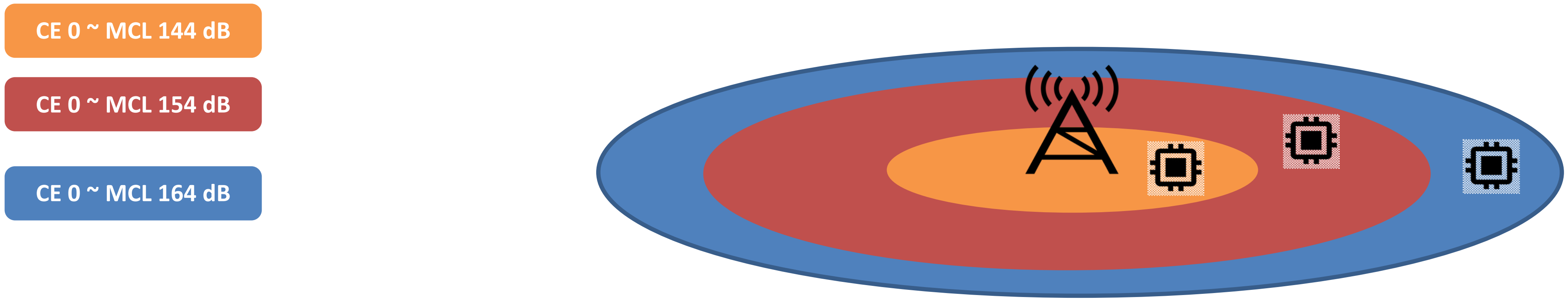
- NB-IoT supports both **Contention based** and Contention Free Random Access





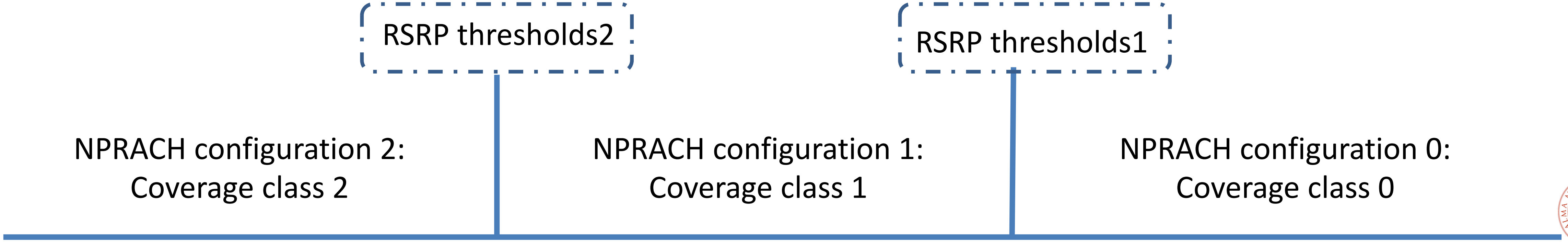
Coverage enhancement zones

- The coverage zone of the eNB is divided into zones called "coverage enhancement levels (CE levels)" → to address the different radio conditions.
- The CE levels are defined by the BS through power thresholds depending on the requirements of the network.
- These thresholds are based on the values of the "reference signal received power (RSRP)".
- The value of the RSRP is computed in the NB-IoT UT devices by averaging the received power over the NRS Resource Elements (Res) within the considered NB-IoT bandwidth.



Coverage enhancement zones

- *CE Level Selection:*
  - two RSRP thresholds can be defined per cell.
  - Every UT in the cell computes its RSRP level and then, depending on the obtained value, selects the corresponding CE level according to the defined RSRP thresholds.
  - Each UT applies a different configuration for NPRACH transmissions depending on its CE level.
  - If the RSRP thresholds are not defined (i.e., not transmitted in SIB2-NB), there will be only one CE level for all UEs and thus one configuration for NPRACH.



Coverage enhancement zones

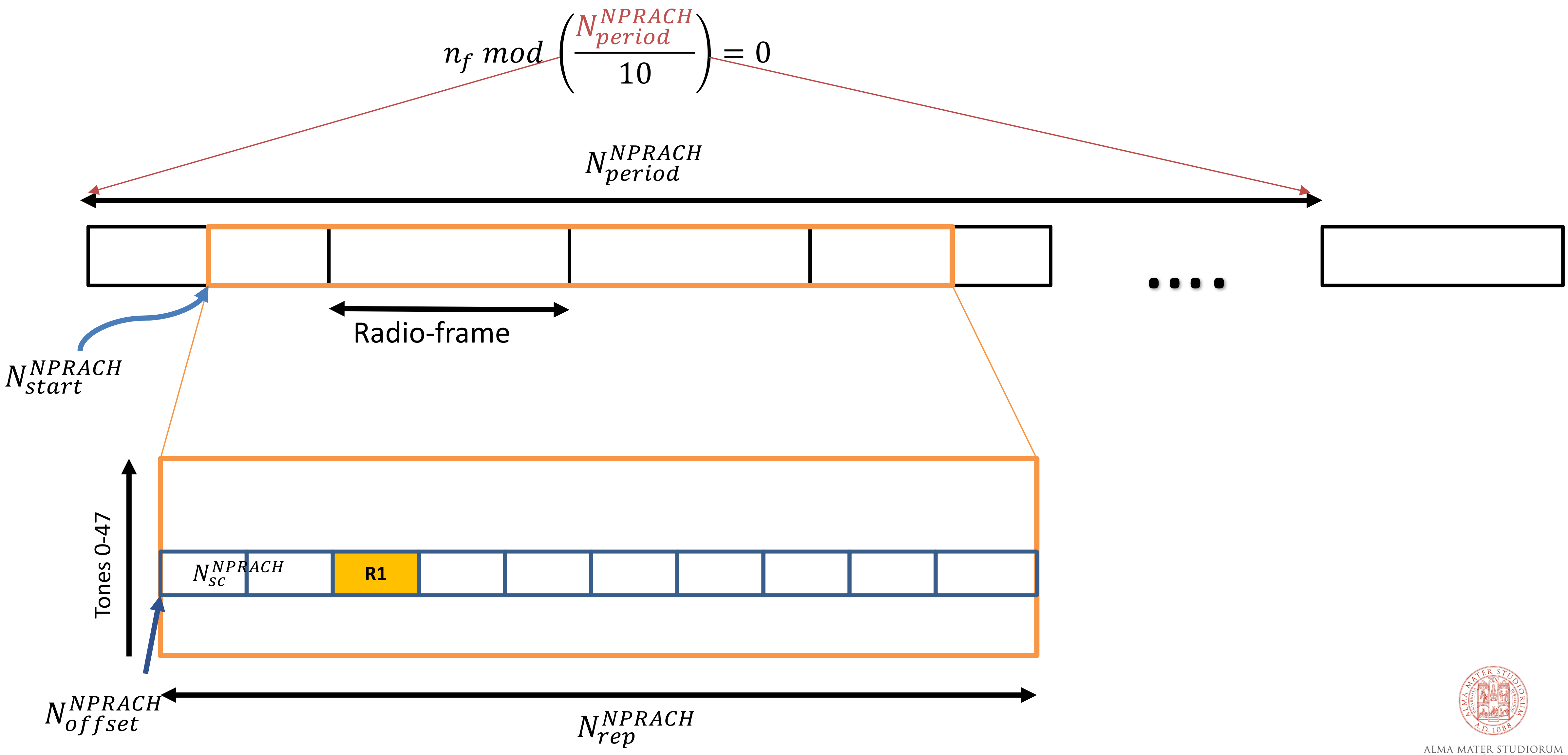
- *Random access parameters:* For each CE level, the following parameters are provided:
  - NPRACH parameter List;
  - RA Response window size;
  - Mac-Contention Resolution Timer;
  - RA – CFRA- Config.

NPRACH scheduling

Parameter	Definition	Value
N_{period}^{NPRACH}	$\{40,80,160,240,320,640,1280,2560\}\ ms$	This corresponds to the NPRACH period over which UEs can do random access.
N_{rep}^{NPRACH}	$\{1,2,4,8,16,32,64,128\}$	This corresponds the NPRACH preamble repetitions.
N_{offset}^{NPRACH}	$\{0,12,24,36,2,18,34\}$	This corresponds to the subcarrier offset within the 180kHz bandwidth.
N_{sc}^{NPRACH}	$\{12,24,36,48\}$	This corresponds to the number of subcarriers being used for random access.
N_{start}^{NPRACH}	$\{8,16,32,64,128,256,512,1024\}\ ms$	This corresponds to the time of the start of the NPRACH transmission
$N_{att\_max}^{NPRACH}$	$\{3,4,5,6,7,8,10\}$	Maximum number of preamble transmission attempt for Coverage enhancement level

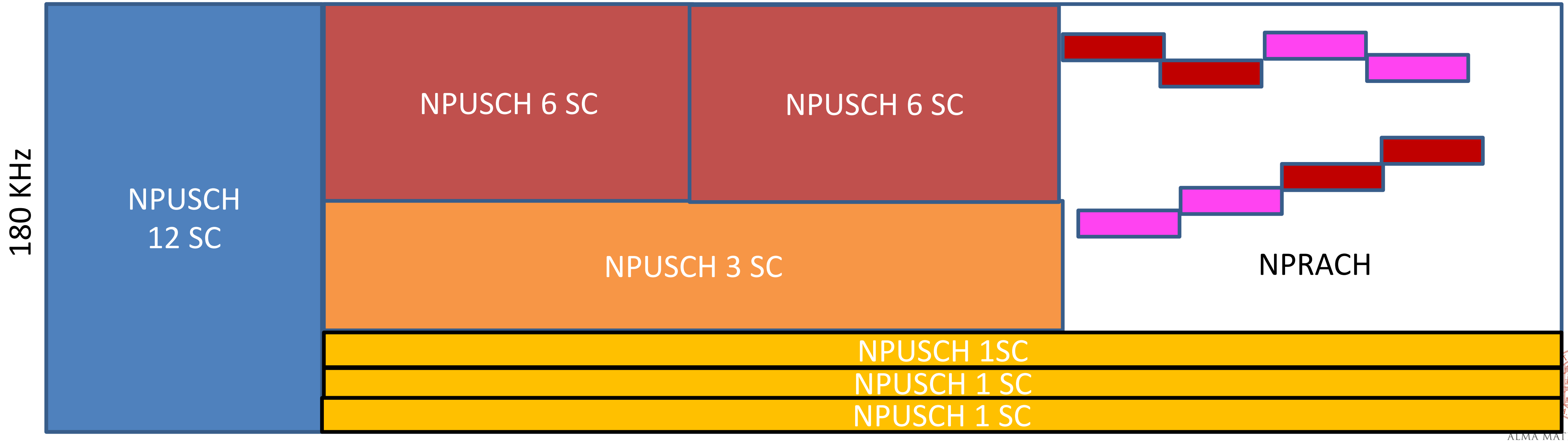
From TS 36.331 Evolved Universal Terrestrial Radio Access; Radio Resource Control; Protocol Specification (Release 16)

NPRACH scheduling



NPUSCH scheduling

- The uplink data or control can be transmitted only in the time/frequency resources not used for NPRACH transmissions.
- The NPUSCH transmissions are scheduled by NPDCCH through DCI format N0 or N1 depending on the type of NPUSCH content to be transmitted (e.g., data or control information).



NPUSCH scheduling

- If the UT has uplink data to transmit → the eNB sends a DCI format N0
- If the UT has control information to transmit → the eNB sends the DCI format N1.
- This happens when the eNB sends a NPDSCH message and wants feedback about the reception of the message by the UT.

NPUSCH scheduling

- NPUSCH scheduling parameters in DCI format N0:
  - scheduling delay (IDelay): identify the k_0 to be applied between the sub-frame of the transmitted DCI N0 and the start subframe of the upcoming NPUSCH transmission.
  - subcarrier indication (Isc) : identify the index of the sub-carrier used in uplink transmission.
  - resource assignment (IRU) : number of resource unit
  - repetition number (IRep) : number of repetitions.
  - modulation and coding scheme (IMCS) : define the modulation order and the size of the transmission block.
  - redundancy version (rvDCI): redundancy version used by the rate matching. It assumes the value 0 or 1.

NPUSCH scheduling

- NPUSCH transmission starts:

$$\mathrm{n} + 1 + \mathrm{k}_0$$

  - $\mathrm{n} =$ the sub-frame in which NPDCCH transmission stops.
  - $\mathrm{k}_0 \geq 8\ [\mathrm{ms}]$

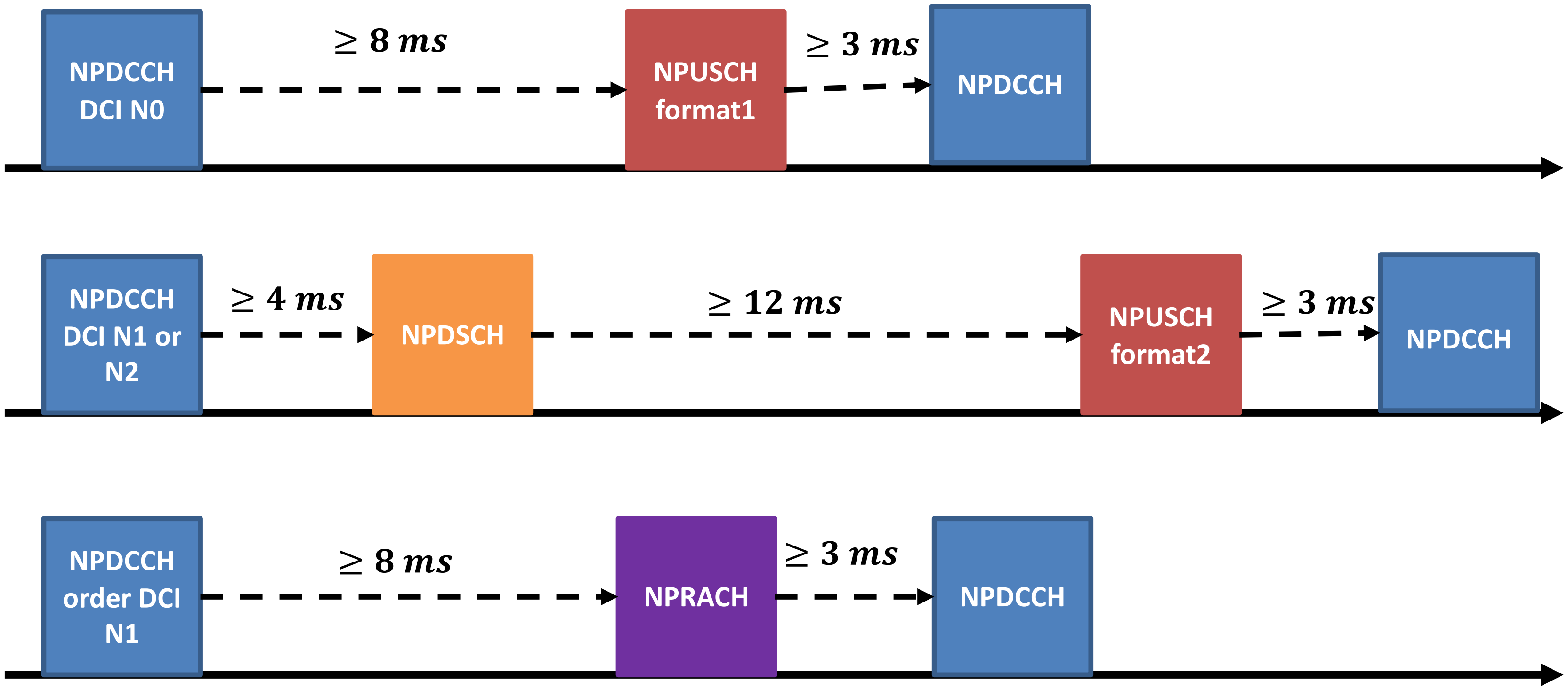
- Total number of slots:

$$\mathrm{N} = \mathrm{N}_{\mathrm{rep}} \cdot \mathrm{N}_{\mathrm{ru}} \cdot \mathrm{N}_{\mathrm{slot}}^{\mathrm{UL}}$$

  - $\mathrm{N}_{\mathrm{slot}}^{\mathrm{UL}}$ = number of slots per RU.

Guard time between UL and DL

- NB-IoT has low processing capabilities and low-cost components → the 3GPP introduced **guard times** between the uplink and downlink transmissions.
- These guard times ensure sufficient time for the UTs to process any sent/received message → to switch from TX to RX or RX/TX



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Early data Transmission

- 3GPP R.15 introduced Early Data Transmission (EDT) for the Control Plane (CP) and User Plane (UP) Optimizations.
- Differently from the four-step random access procedure, a **small data payload (< 1000 bits) is transmitted in Msg3** instead of waiting for Msg5 and Msg6
- The UT indicates that it is doing EDT by transmitting a NPRACH preamble from the configured set of EDT preambles

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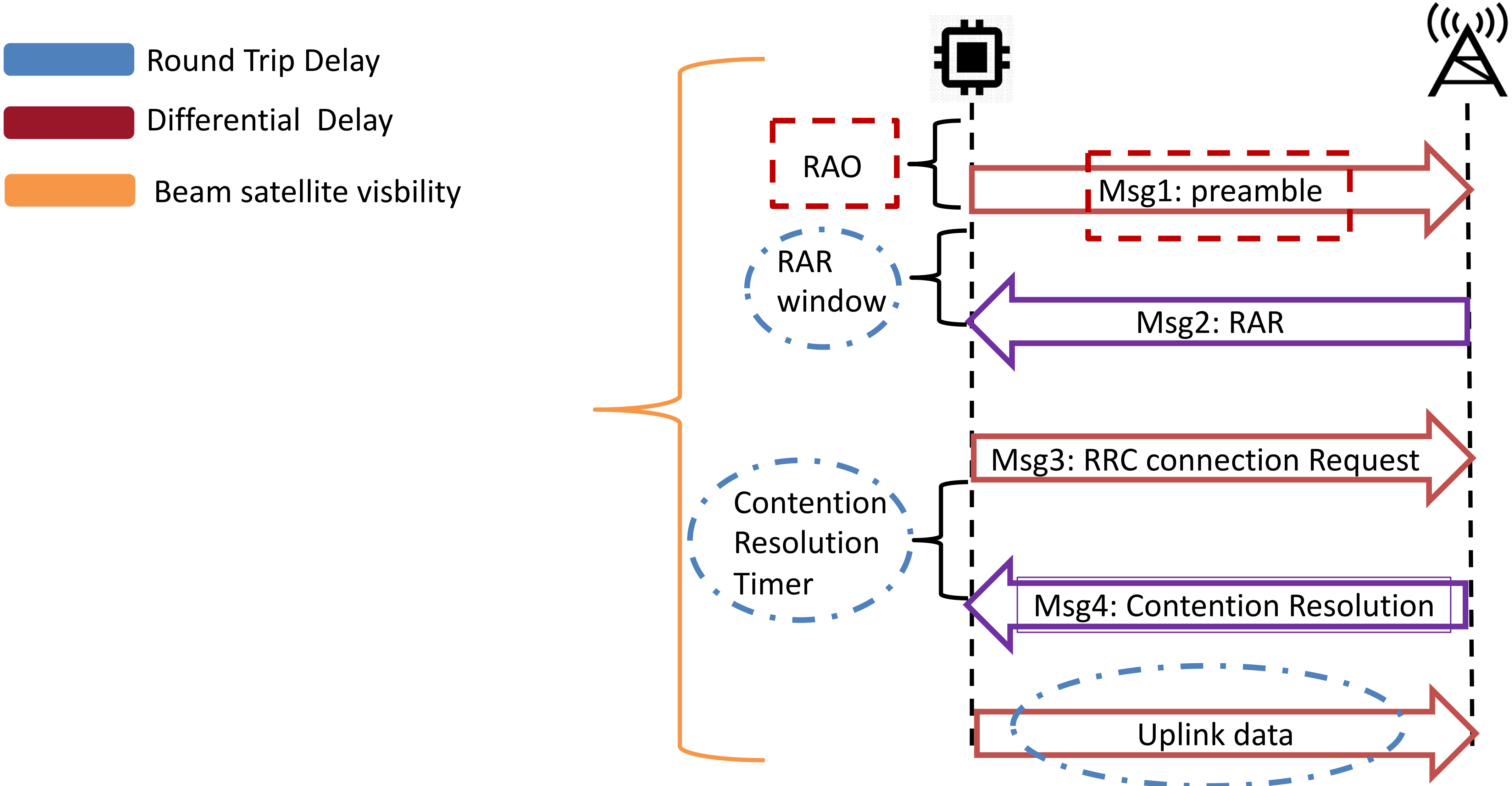
2.3 NB-IOT VIA NTN

- Impact of the NTN channel:
  - Differential delay on preamble
  - Differential delay on RAO
  - Satellite beam visibility window
  - RTD on timers
  - RTD on data transmission
- Future trends

Impact of the NTN channel: delay



Preamble – differential delay

- Before initiating the RA procedure, the UTs are not synchronized in time.
- Preambles are misaligned due to the different distance of the UTs from the eNB.
- This time misalignment should not overcome the cyclic prefix (CP) length.
- The relation between the CP length (T_{cp}) and the NPRACH cell radius is:

$$R_{cell}^{RA} = c \cdot \frac{T_{cp}}{2}$$

Preamble – differential delay

- We need to ensure that the maximum differential delay between any two UTs in the beam does not exceed the delay that can be absorbed by the CP, i.e.:

$$max\Delta\tau(\tau_i, \tau_j) \leq T_{cp}$$

- The differential delay can be computed from the differential slant range between the two UTs, which is given by:

$$\begin{aligned}
\Delta_D &= d_{max}(\varepsilon_{min}) - d_{min}(\varepsilon_{max}) \\
&= R_E \left[\sqrt{\left(\frac{R_E + h_{sat}}{R_E} \right)^2 - \cos^2 \varepsilon_{min}} - \sin \varepsilon_{min} \right] \\
&\quad - R_E \left[\sqrt{\left(\frac{R_E + h_{sat}}{R_E} \right)^2 - \cos^2 \varepsilon_{max}} - \sin \varepsilon_{max} \right]
\end{aligned}$$

Preamble – differential delay

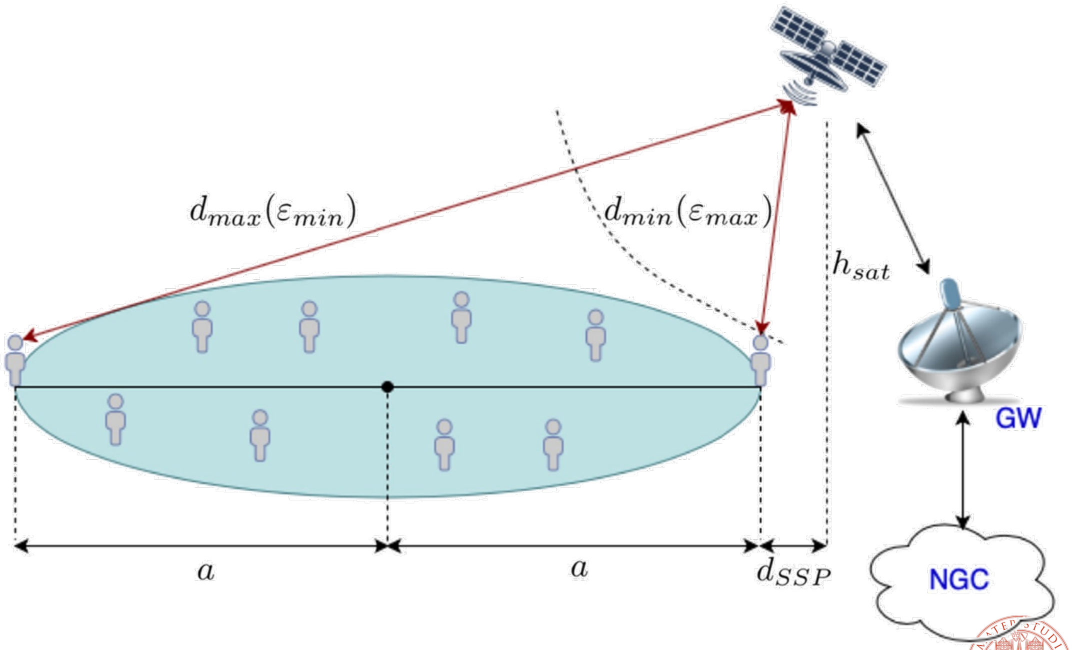
- The differential slant range is upper bounded by R_{cell}^{RA}
- For a certain cell with a minimum elevation angle ε_{min}, the respective slant range d_{max} can be calculated.
- From the previous formula, it is possible to compute the minimum allowed slant range d_{min}, guaranteeing that the differential slant range is within the upper bound:

$$d_{min}(\varepsilon_{max}) \geq d_{max}(\varepsilon_{min}) - R_{min} = d_{min,t}$$

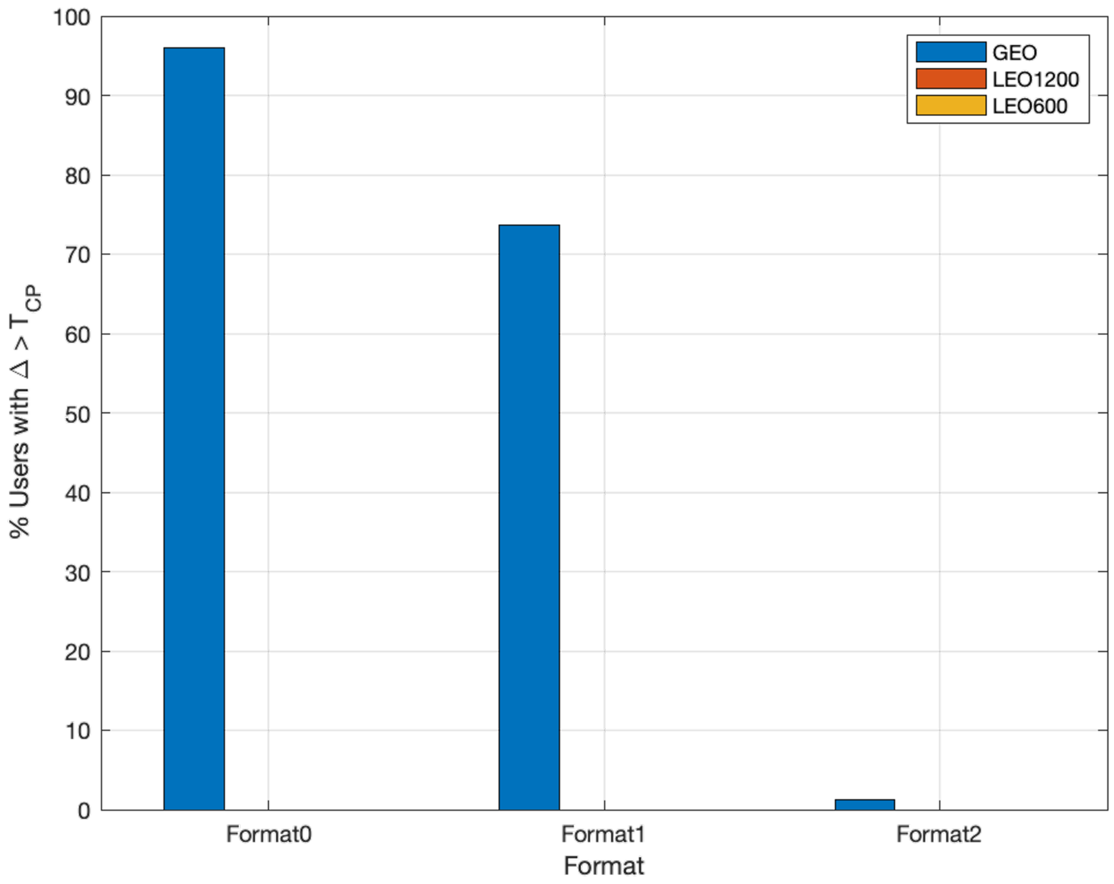
Preamble – differential delay

- Once the target minimum slant range, $d_{min,t}$, has been computed, the maximum beam size in terms of the major semi-axis a can be easily obtained through geometrical considerations from the Fig:

$$
\begin{aligned}
2a &= d_{max}(\varepsilon_{min}) \cos \varepsilon_{min} - d_{SSP} \\
&= d_{max}(\varepsilon_{min}) \cos \varepsilon_{min} - \sqrt{d_{min,t}^2 - h_{sat}^2} \\
\Rightarrow a &= \frac{d_{max}(\varepsilon_{min}) \cos \varepsilon_{min} - \sqrt{d_{min,t}^2 - h_{sat}^2}}{2} h_{sat}
\end{aligned}
$$



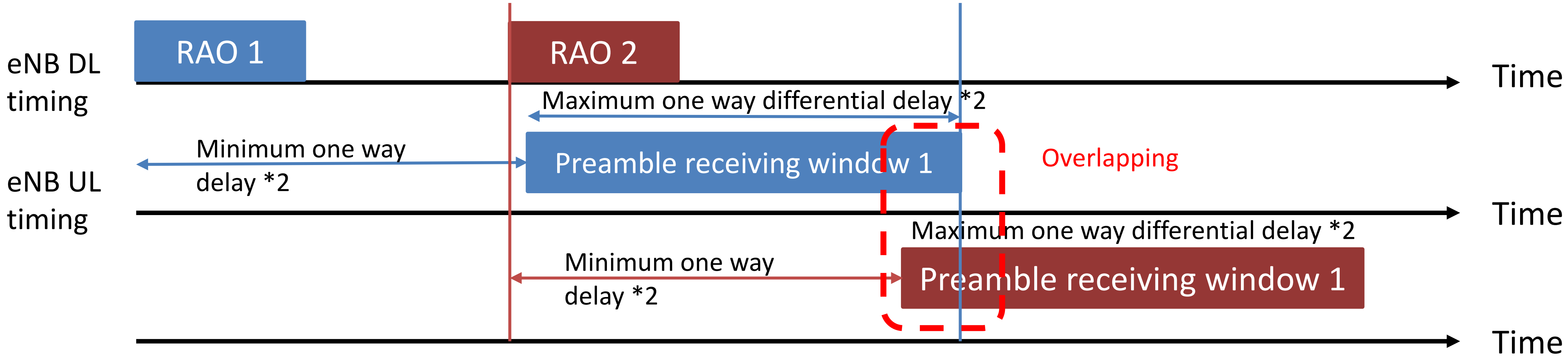
Preamble – differential delay



	GEO	LEO 1200 km	LEO 600 km
ε_t	45°	90°	90°

RAO– differential delay

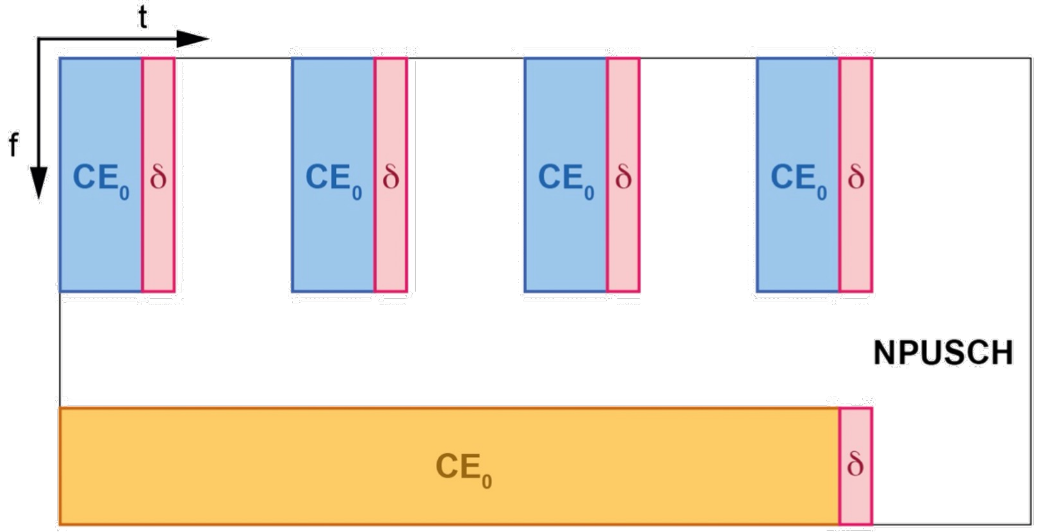
- The large differential delays between the users brings to so called preamble ambiguity problem → preambles from near/far users can overlap when received by the eNB.
- The network needs to know in which RAO the user transmits the preamble in order to estimate the TA.



Necessary changes to support NB-IoT and eMTC over satellite - Ran103e

RAO – differential delay

- The satellite channel characteristic RTT and the bigger beam dimensions, with respect to the terrestrial cell case, brings to larger **differential delays** (**Δτ**) among UTs.
- A proper **Cyclic Prefix** and **Guard Time** durations must be chosen in order to cope with the differential delay.
- As we have seen, the **Timing Advance** (TA) should be large enough to absorb the differential delays among UEs.
- This leads to a loss of Radio Resources with respect to the terrestrial case:



NB-IoT over GEO Satellite: Performance Analysis

$$\delta = \Delta\tau + 4 \cdot T_{cp} \cdot N_{rep}$$

$$\Delta_{loss} = \sum \frac{3.75 \cdot N_{sc}}{180} \cdot \frac{\delta}{T_{RAO}}$$

GNSS aided solution

- GNSS aided solution:
  - It is based on the capability of the UTs to estimate their location and the position of the satellite.
  - With an ideal estimation, a perfect pre-compensation of the differential Doppler shift and propagation delay at the user side would be possible.
  - Regardless of the cell size, the messages from different UTs will be aligned both in time and frequency → it is possible to use large beam.

Round trip delay

- We focus on a **single link between** a UT in the generic b-th beam and the network entity which terminates the RA protocol.

- Depending on the type of satellite payload, the termination can happen either on-board or at the system GW.

- For the transparent payload:

$$RTT = 2\tau_i + 2\tau_{GW}$$

- For the regenerative payload:

$$RTT = 2\tau_i$$

Satellite beam visibility

- Visibility analysis for LEO satellite at 600 and 1200 km of altitude, considering 3 different beam sizes configurations each.
- One beam centered at satellite nadir has been considered.
- It is important to complete all the access and data transmission procedures within the satellite visibility window, due to the fact NB-IoT does not support mobility.

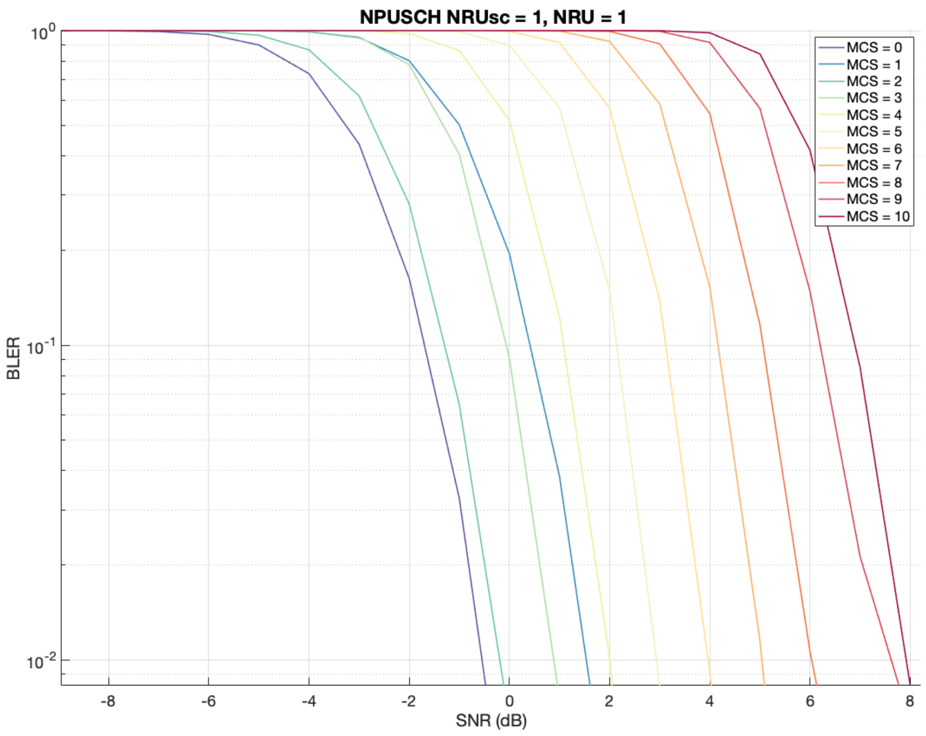
Sat Altitude	Set Name	Beam Diameter	Sat visibility window (10° min elevation)	Beam visibility window (nadir beam)
600 [km]	Set 2 (TR 36.763)	90 [km]	8.49 [min]	13.4 [s]
	Set 3 (TR 36.763)	234[km]		33.86 [s]
	Set 4 (TR 36.763)	1700[km]		246.9 [s]
1200 [km]	Set 2 (TR 36.763)	190 [km]	14.59 [min]	31.12[s]
	Set 3 (TR 36.763)	470[km]		76.98 [s]

NPUSCH transmission – round trip delay

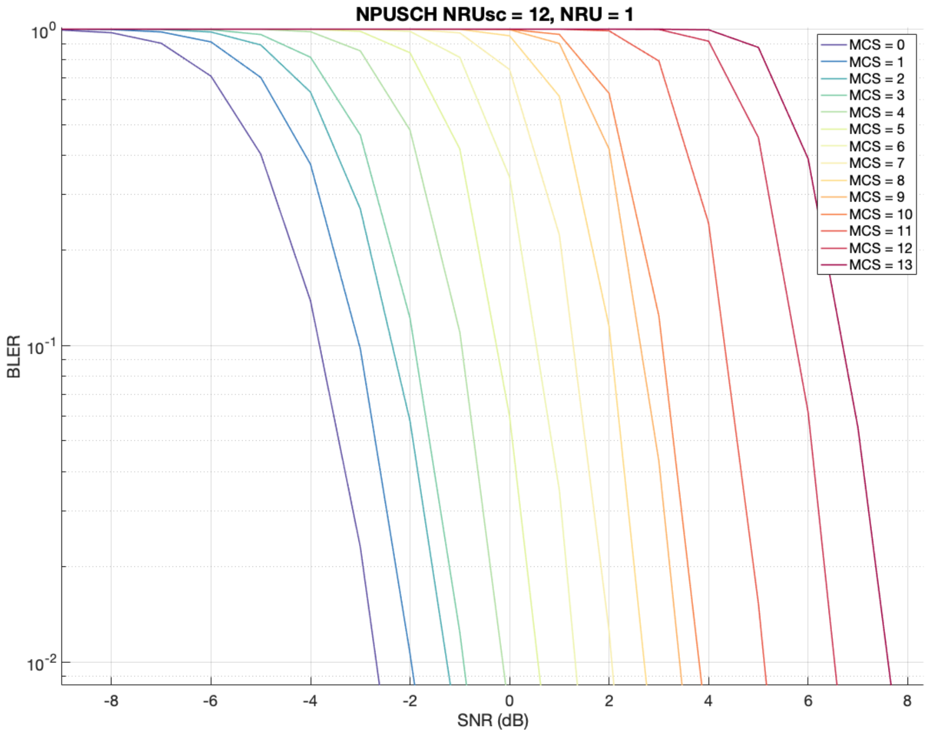
- The total delay of the communication will be extended with the use of the satellite.
- Analysis of procedure duration from the start of the RA Procedure (successful) until the transmission of the last payload bit has been conducted
- Collisions are not considered (best case scenario)

NPUSCH – BLER

Single Tone Transmission



Multi Tone Transmission (12 sc)



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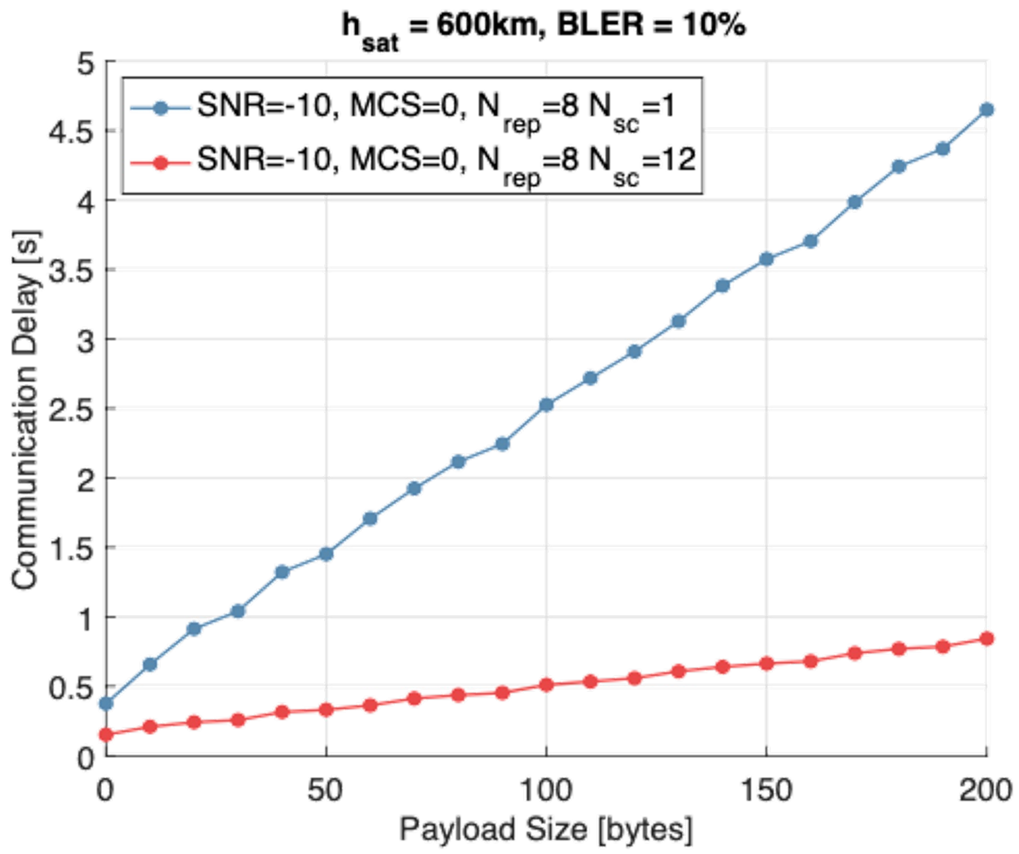
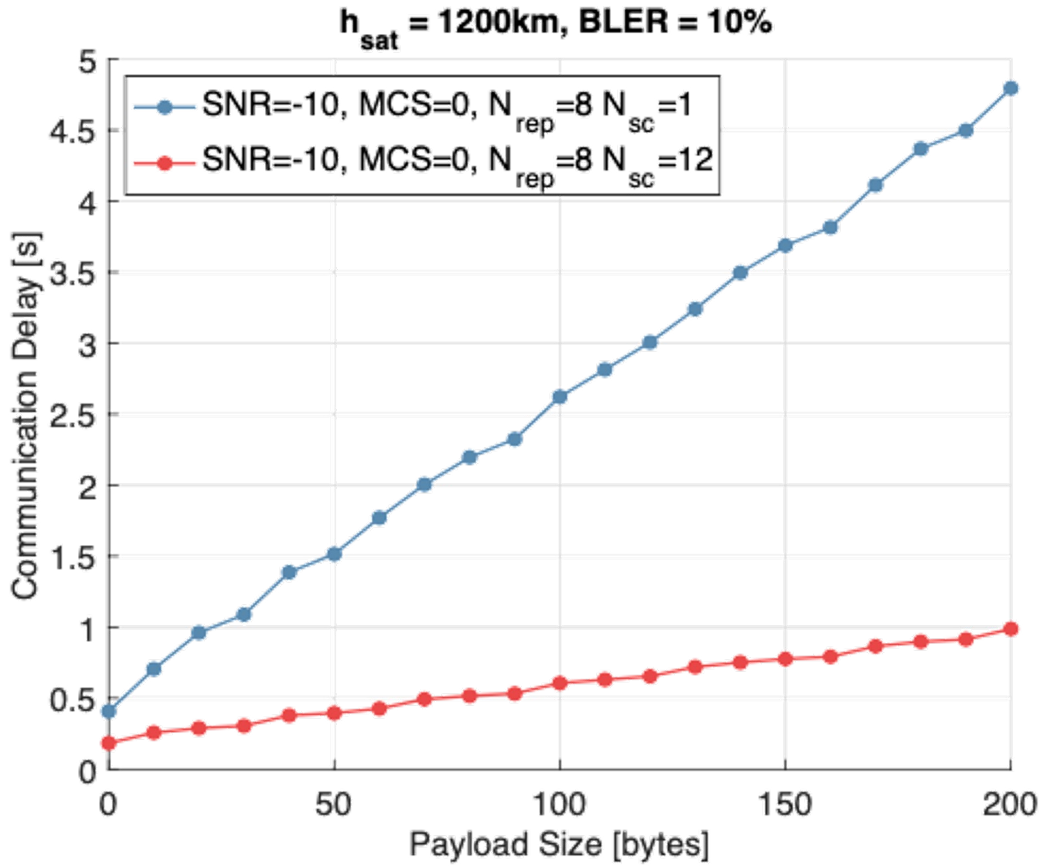
NPUSCH transmission – round trip delay





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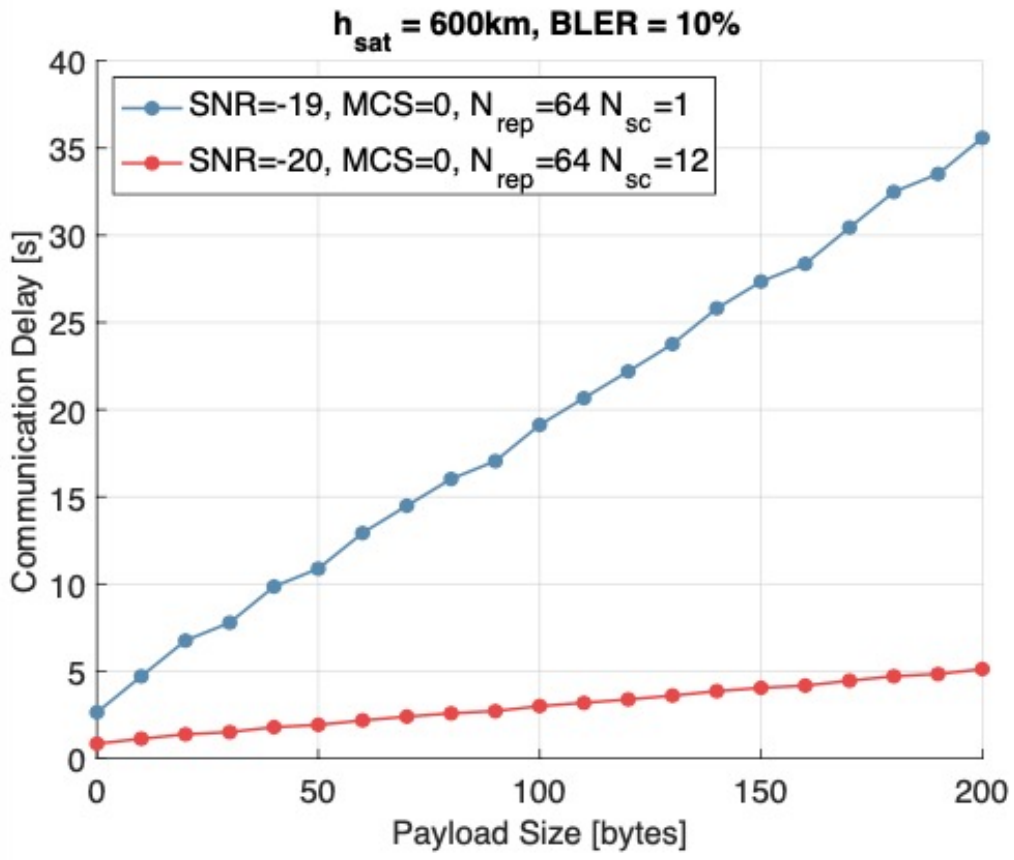
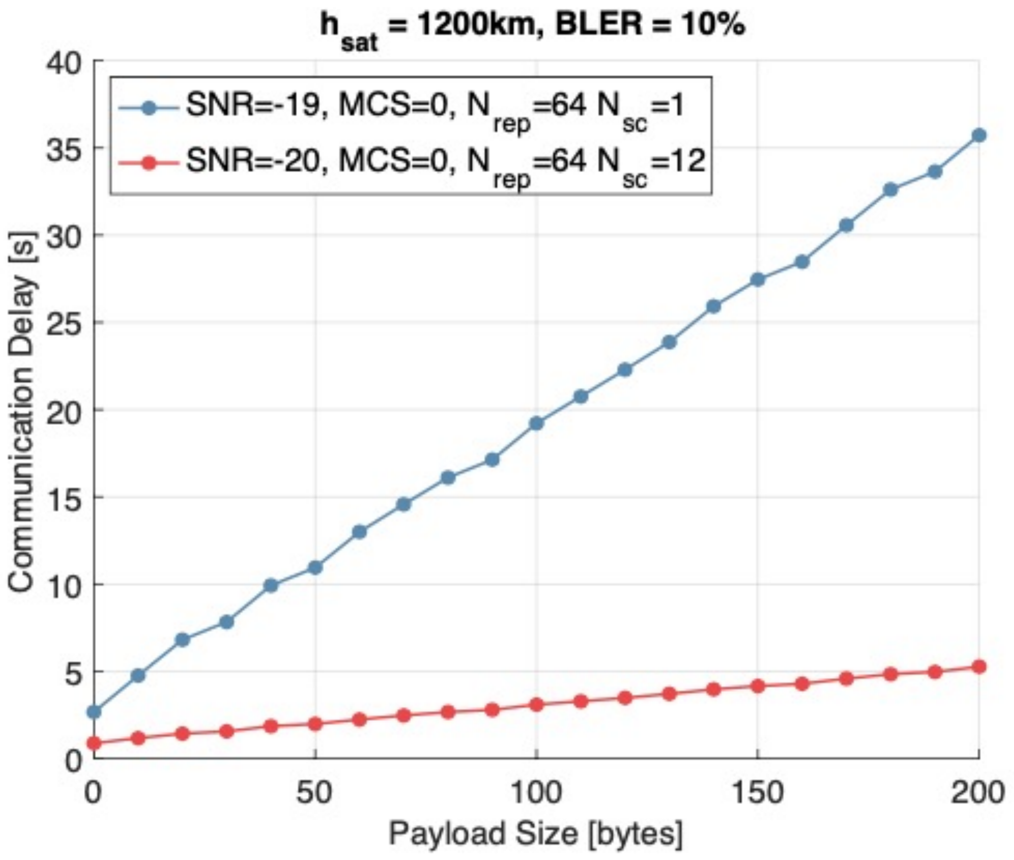
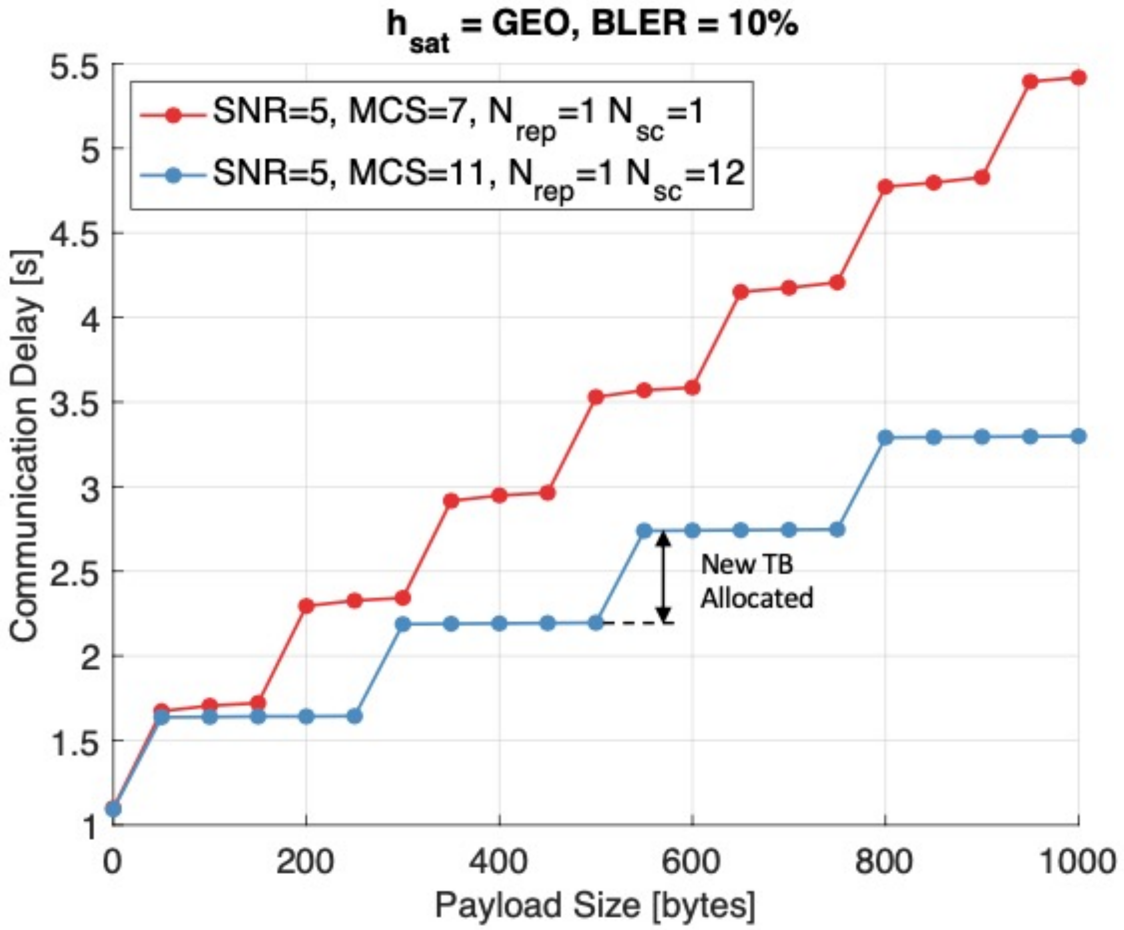
NPUSCH transmission – round trip delay





NPUSCH transmission – round trip delay



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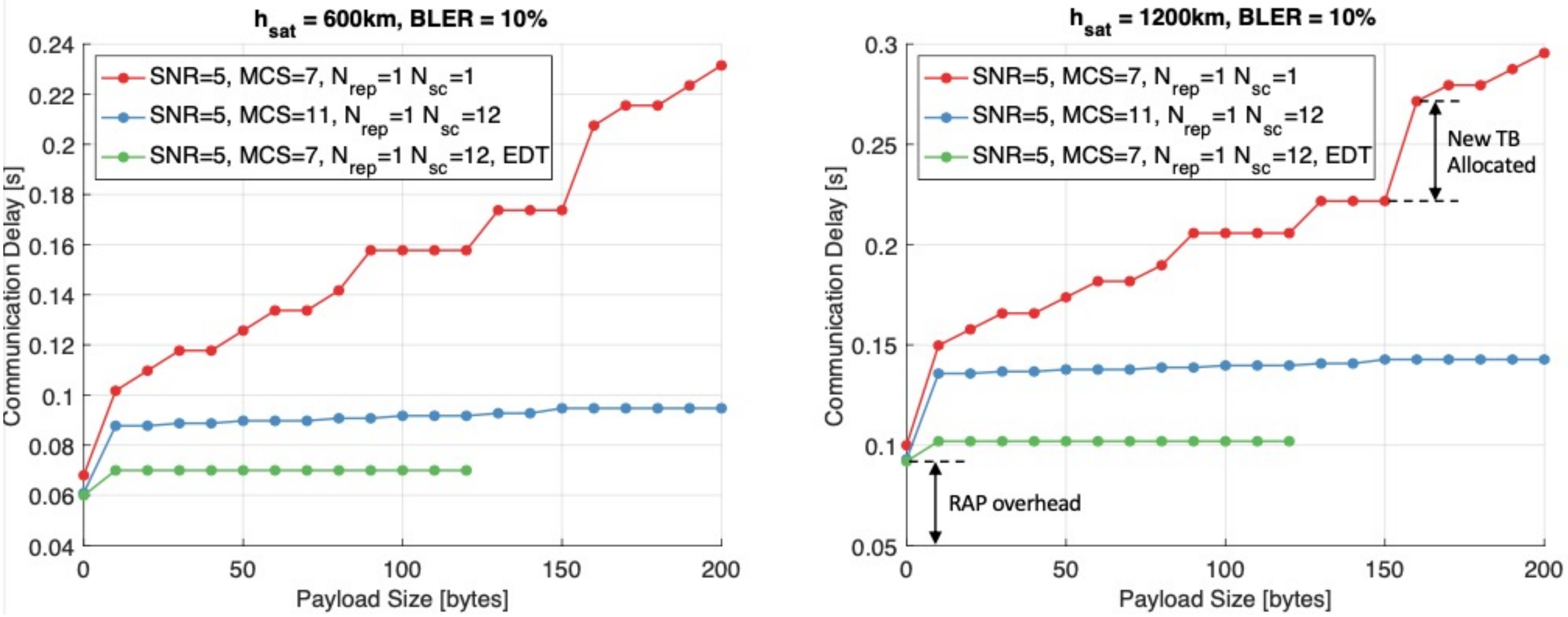
NPUSCH transmission – round trip delay



Impact of the collisions on the RA: System model

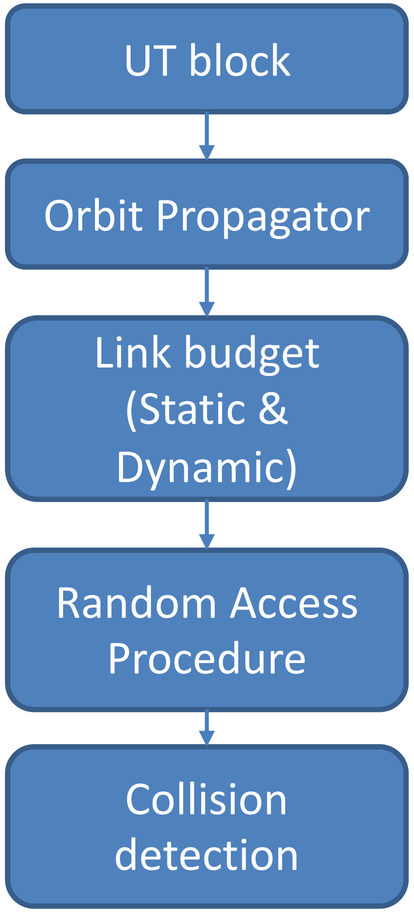
- UT block: a plethora of NB-IoT devices equipped with omnidirectional antenna, directly connected to the satellite, and equipped with GNSS receiver.

- Orbit Propagation: a LEO satellite with **moving beam** operating in **S** band.

- Link budget analysis according to 3GPP NTN documentation and UE characteristics for NB-IoT terminal for NTN.

- Random Access Procedure: definition of the configurable access parameters, i.e., Random Access Periodicity (T_{RAO}), Number of repetitions (N_{rep}), Number of preambles (S)

- Collision detection: $SINR_u \geq \gamma$, $\gamma = SNR_{msg3}\,(BLER = 10^{-1})$



Access parameters: Random Access Periodicity

- In the terrestrial network the Periodicity should be larger than:

$$T_{RAO} \geq T_{msg1} + RAR_W + CRT$$

- The main impairments in the NTN are:

  - The large RTD → impact on the RA Periodicity

$$T_{RAO} \geq T_{msg1} + RAR_W + 41 + CRT + RTD_{max}$$

  - Where 41 ms is the second starting time (T_{start2}) of the RAR_W ($T_{start1} = 4 < RTD_{max}$)
  - The reduced satellite visibility window (T_{sv}) → impact on the Number of Random Access Opportunity (N_{RAO}).

$$N_{RAO} = \left\lfloor \frac{T_{sv}}{T_{RAO}} \right\rfloor$$

Access parameters: number of preamble repetitions

$$T_{msg1} = 6.4 \cdot N_{rep}$$

- where 6.4 [ms] is the duration of one symbol group
- The Number of repetitions (N_{rep}) needs to guarantee a preamble detection probability at least of 99% ($Pd_{99\%}$) at the BS.
- If $N_{rep} < N_{rep}(Pd_{99\%})$ → the miss detection probability increases, worsening the overall performance of the system in terms of number of re-transmissions.
- If $N_{rep} \geq N_{rep}(Pd_{99\%})$ a better performance in terms of detection rate is not guaranteed and the access time increases due to an increased value of length of the preamble (T_{msg1}) .

Access parameters: number of preambles

- Defined S as the total available preambles and N as the users attempting the access in the same RAO, the probability that each device randomly selects one of the available preamble is $P_s = {}^{1}/_{S}$.
- The probability that n users select the same preamble is given by:

$$P_{n,s} = \binom{N}{n} \left(\frac{1}{S}\right)^{n} \left(\frac{S-1}{S}\right)^{(N-n)}$$

Access parameters: Back-Off 1/2

- The back-off mechanism represents a strategy to reduce the congestion in the RAO, by distributing the number of contending devices over the time.

- The BO value has a great influence on the performance of the RA:
  - a small BO allows devices to re-transmit the preamble after a short period of time, increasing the collision probability during burst arrivals;
  - a huge BO value may increase the access success probability causing high access time.

Access parameters: Back-Off 2/2

- The collided UTs in an RAO will randomly choose a back-off value in the interval [0, BO].
- The probability that a collided NB-IoT terminal in the n−th RAO will transmit in the k−th one is computed as follow:

$$P_{BO} = \begin{cases} \frac{T_{RAO}}{BO} \text{ if } n + \lfloor \frac{BO}{T_{RAO}} \rfloor \leq k \\ 0 \text{ if } n + \lfloor \frac{BO}{T_{RAO}} \rfloor > k \end{cases}$$

Collision probability: number of sub-carriers & BO

- Each of the N_{coll} devices randomly selects one of the available sub-carriers in the $k-th$ BO interval with probability $(P_s \cdot P_{BO})$
- The probability mass function (pmf)obtained by distributing the N_{coll} UTs over the $(S \cdot \frac{BO}{T_{RAO}})$ sub-channels in the $k-th$ BO interval is:

$$P_{n,s,k} = \binom{N_{coll}}{n} (P_s \cdot P_{BO})^n \, (1 - P_s \cdot P_{BO})^{(N_{coll}-n)}$$

Simulation parameters

- Type of traffic: pick/bursty, daily uplink report
- User density: [0.1, 1] [users/km^2]
- One coverage enhancement zone
- 48 available preambles

TABLE I
SATELLITE PARAMETERS

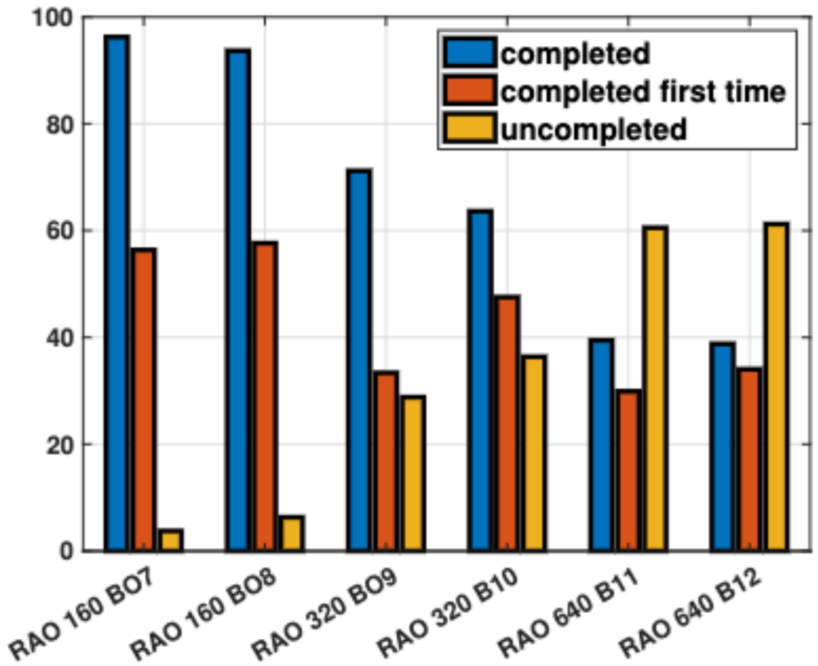
Satellite orbit	Set 2 LEO 600 km	Set 3 LEO 600 km	Set 4 LEO 600 km
Equivalent satellite antenna aperture	1 m	0.4 m	0.097 m
Sat EIRP density	28 dBW/MHz	28.3 dBW/MHz	21.45 dBW/MHz
Sat Tx max Gain	24 dBi	16.2 dBi	11 dBi
3dB beamwidth	8.8320 degrees	22.1 degree	104.7 degree
Sat beam diameter	90 km	234 km	1700 km
Equivalent satellite antenna aperture	1m	0.4 m	0.097 m
G/T	-4.9 dB K^{-1}	-12.8 dB K^{-1}	-18.6 dB K^{-1}
Sat Rx max Gain	24 dBi	16.2 dBi	11 dBi
Sat Visibility window (10° min el)	8.49 min	8.49 min	8.49 min
Beam visibility window = T_{max}	13.4 s	33.86 s	246.9 s

TABLE II
ACCESS CONFIGURATION PARAMETERS

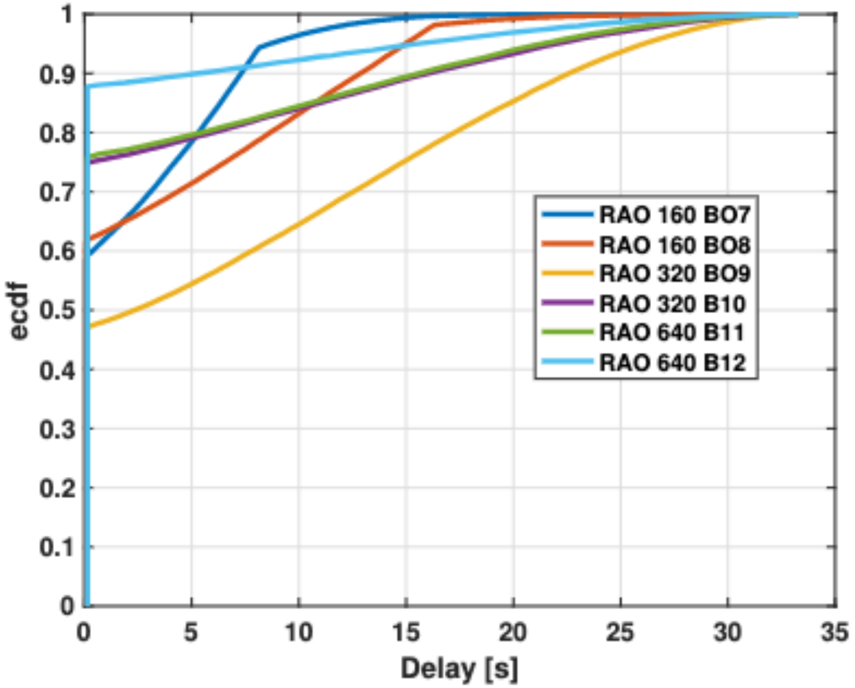
Parameters	Value
N° repetitions	[1,2,4,8,16,32,64,128]
RA periodicity	[40,80,160,240,320,640,1280,2560]ms
Back-off	$[0, 256 \cdot 2^j]$ms, $j \in [0, 11]$

Numerical results 1/2

- Set 3: $\alpha = 0.1\ [users/km^2]$



Access rate



Access delay

Numerical results 2/2

TABLE III

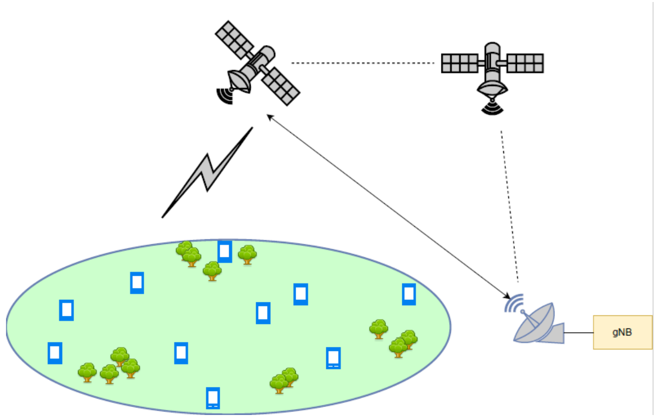
ACCESS PARAMETERS FOR SATELLITE CONFIGURATIONS. *s = success, f = failure, W = remaining time of beam visibility window*

Set	Density	Access parameters	Mean access delay	% of completed users	Mean N° of transmissions	Mean W
Set2	$0.1[users/km^2]$	$RAO = 160ms,\ BO_i = 4,\ N_{rep} = 2$	0.15 [s]	99.56 %, 85.85% (first attempt)	2 (s) - 3 (f)	1.67[s]
		$RAO = 320ms,\ BO_i = 5,\ N_{rep} = 8$	0.45 [s]	99.01 %, 71.91% (first attempt)	2(s) - 3 (f)	0.67[s]
		$RAO = 640ms,\ BO_i = 6,\ N_{rep} = 16$	1.95 [s]	92.44 %, 34.77% (first attempt)	3(s) - 3(f)	0.4[s]
	$1\ [users/km^2]$	$RAO = 320ms,\ BO_i = 10,\ N_{rep} = 16$	2.12 [s]	22.44 %, 14.7% (first attempt)	2(s) - 1(f)	1.18[s]
		$RAO = 640ms,\ BO_i = 11,\ N_{rep} = 32$	2.1 [s]	11.25 %, 7.71% (first attempt)	2(s) - 1(f)	1.29[s]
Set3	$0.1[users/km^2]$	$RAO = 1280ms,\ BO_i = 12,\ N_{rep} = 64$	3.86 [s]	21.38 %, 16.53% (first attempt)	2(s) - 1(f)	2.5[s]
	$1\ [users/km^2]$	$RAO = 320ms,\ BO_i = 11,\ N_{rep} = 16$	11.49 [s]	8.57%, 2.08% (first attempt)	2(s) - 2 (f)	6.67[s]
		$RAO = 640ms,\ BO_i = 12,\ N_{rep} = 32$	10.55 [s]	4.29%, 1.30% (first attempt)	2(s) - 1(f)	6.38[s]
Set4	$0.1[users/km^2]$	$RAO = 320ms,\ BO_i = 12,\ N_{rep} = 16$	103.38 [s]	9.01%, 0.07% (first attempt)	2(s) - 2 (f)	83.21[s]
		$RAO = 640ms,\ BO_i = 13,\ N_{rep} = 32$	100.66 [s]	4.55%, 0.09% (first attempt)	2(s) - 2(f)	80[s]

Lesson learnt

- Due to the long slant range typical of the NTN, it is **not possible** to use short periodicity of **40 ms and 80 ms**.
- With longer periodicity, such as 1280ms, the number of RA occasion is drastically reduced:
  - increased the number of collisions
  - longer time to gain random access → lower beam visibility window for data
- The utilization of medium-length periodicities, i.e., **160ms and 320ms** implies
  - a good balance between the resources dedicated to the preambles and the data
  - high number of correctly detected signals.
  - low number of preamble repetitions.
- The number of users is considered as a driving factor for choosing the RA parameters and implies the design of a satellite constellation able to serve all the terminals.

An enhanced BO algorithm

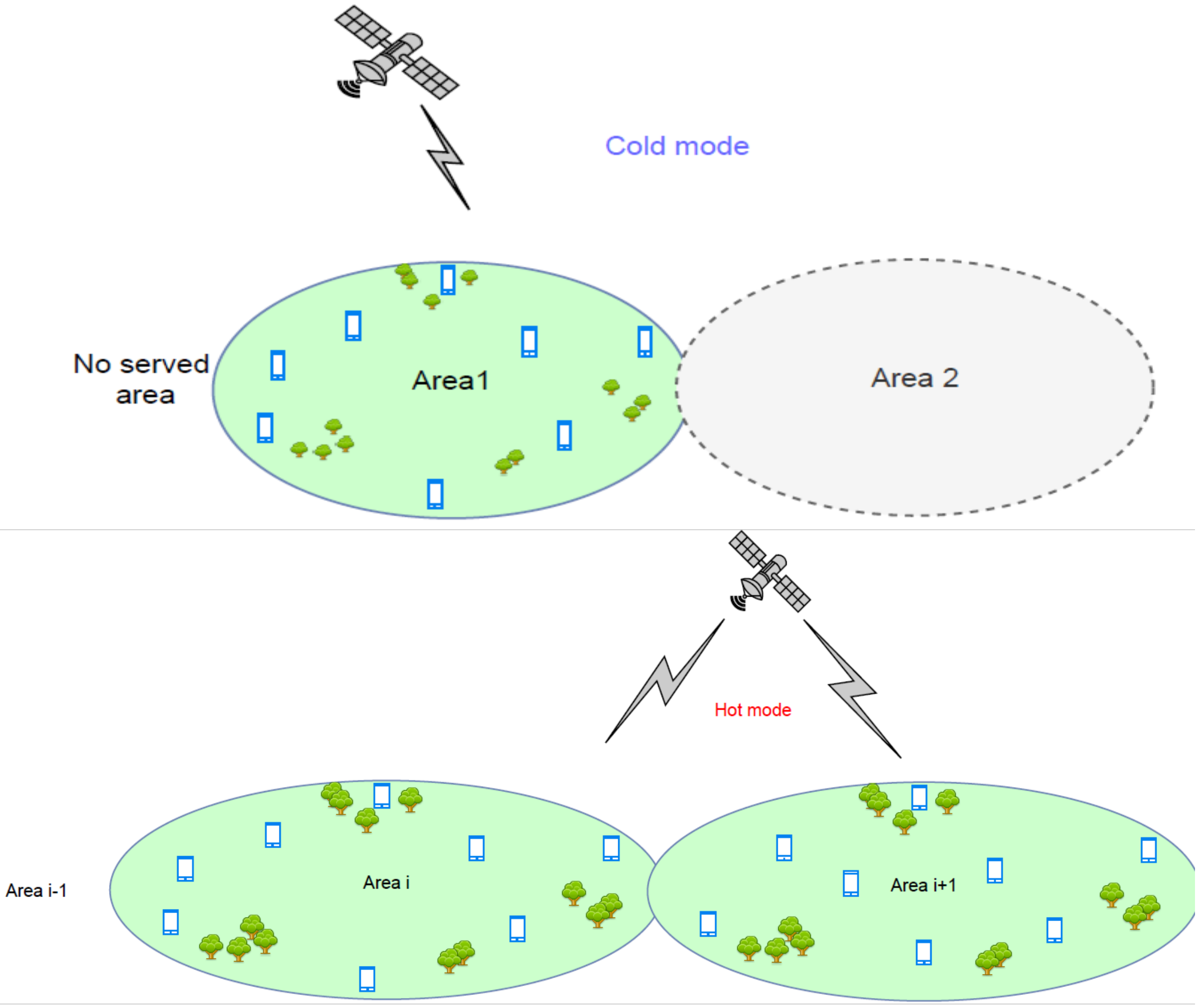


- *IoT (NB-IoT) traffic is sporadic*
  - It does not require 24h/24h channel access
- *Non-continuous satellite coverage* is the baseline scenario
- **Very large number of IoT devices within the LEO coverage**
  - High competition to access the service (channel)
  - Devices should be served within a relatively short time (2 - 4 min)
- **High probability of congestion generated during the signalling phase of the NB-IoT message flows**
  - Risk of deterioration of the protocol/system performance
  - Risk of no service availability
  - High UE power consumption

Proposed approach

- UTs as smart IoT devices
  - Sending RACH preamble depending on the network load and scenario
  - Priority to UTs with high elevation angles

- Two possible scenarios
  - "Cold mode": The satellite is switched-on due to the presence of a new serving areas (i.e., no serving area before) / it serves areas with few UTs
  - "Hot mode": The satellite is already serving an area but becomes available for new area(s) or serving an area with large number of UTs



Optimization 1/2

- *Standard NB-IoT Coverage Enhancement levels (CE)*, defined based on *power* thresholds.
- <u>New concept</u>: Coverage Enhancement Levels (CL) Space Dimension
  - Based on UE location within the satellite beam, and UE visibility period
- Each CL receives a different number of RACH resources.
  - The UTs in CL2 do not perform the RACH
  - UTs in CL1 get most of the RACH resources
  - UTs in CL0 gets less RACH resources

- An *example* of sub-carriers distribution for CLs is displayed in the figure.

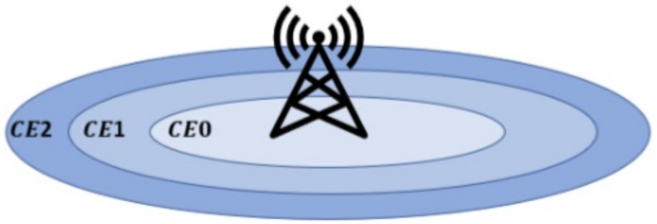
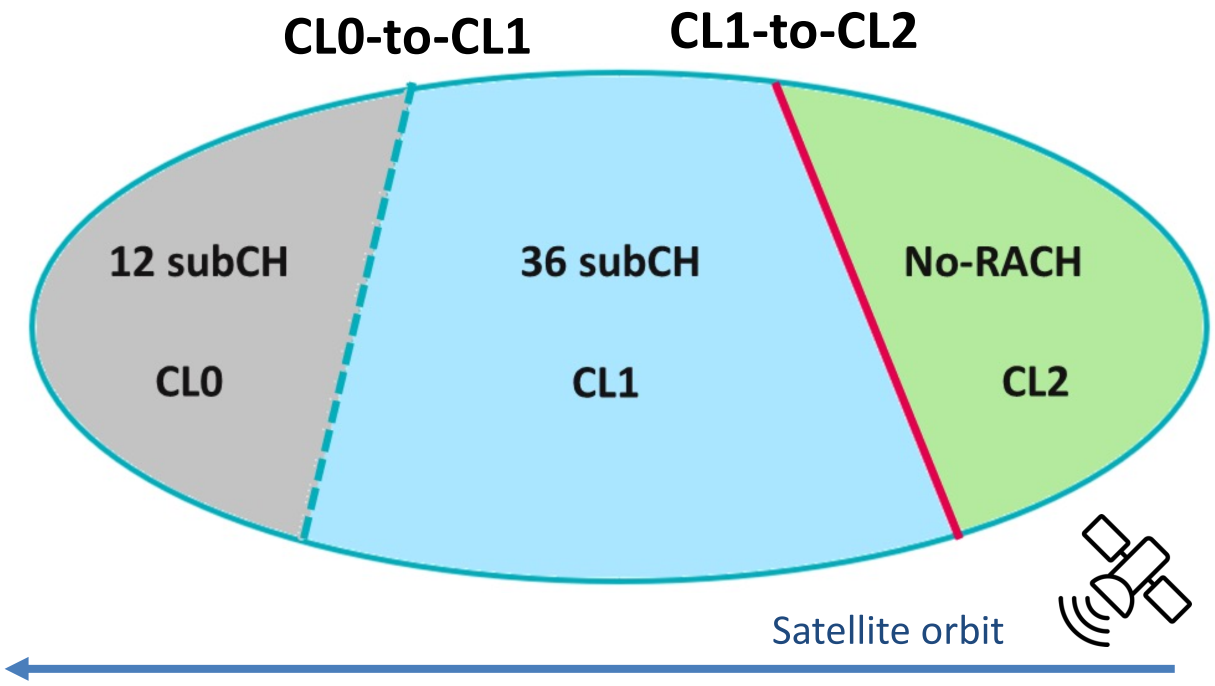


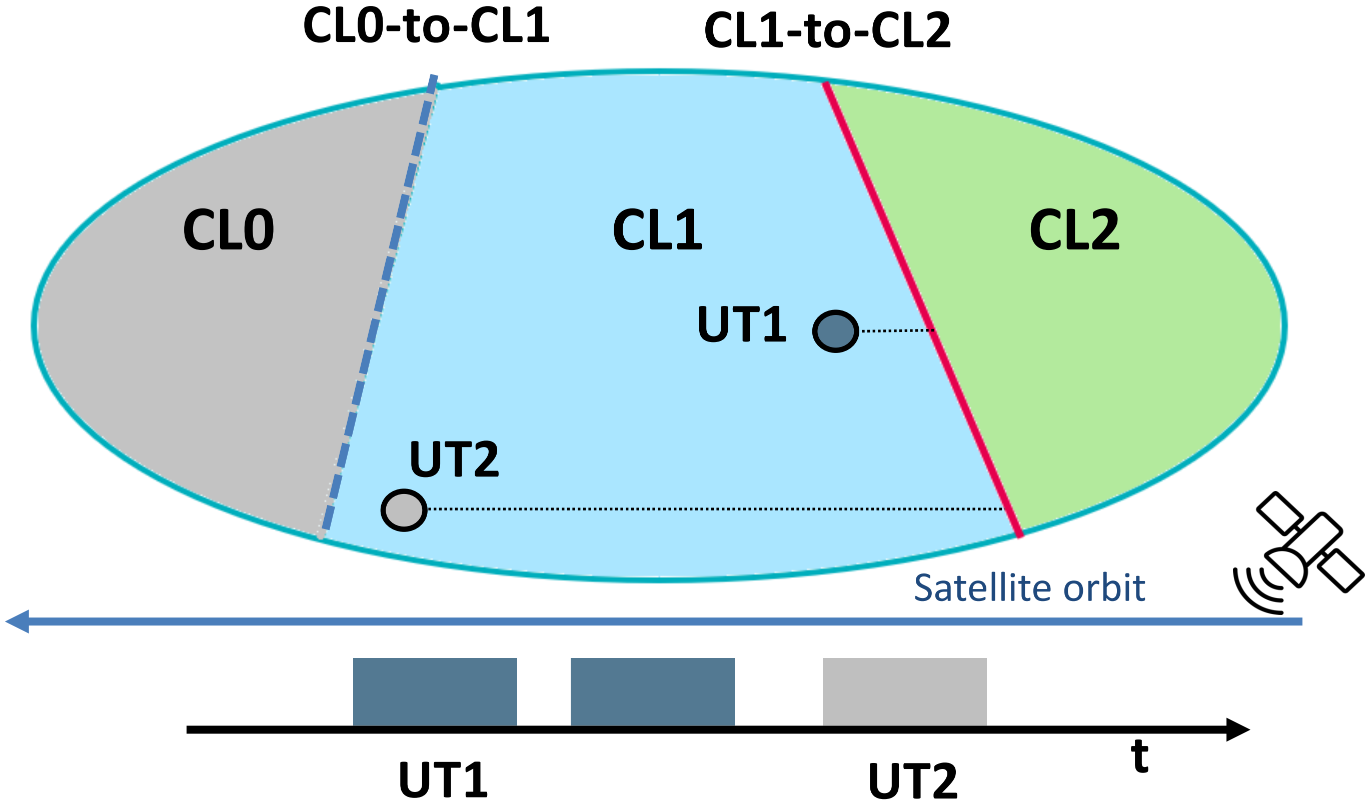
Figure 6: Coverage Enhancement Levels



Note: With RACH resources we mean number of sub-carriers.

Optimization 2/2

- There is still a probability that UTs within the same CL (for instance in CL1), attempt the RACH at the same time, and their preambles collide.
- If they simply use the standard Backoff mechanism, there is still a risk that the collision persists
- Thus, it follows the need of a smart controlled backoff
- As illustrated in the example
  - UT1 should select a smaller BO (since it will be soon in CL2)
  - UT2 should select a higher BO value since it will stay within the CL1 area still for some time.

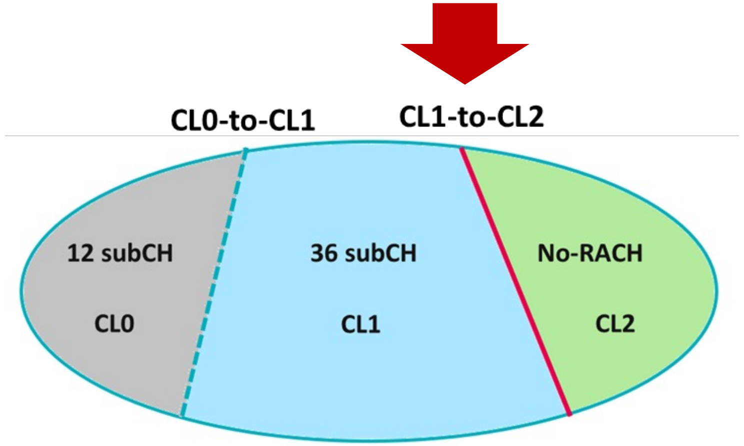


Threshold computation

- Time needed to complete NB-IoT data transmissions
- Time depends on std coverage level (CL) – 144 dB, 154 dB and 164 dB
  - Higher SNRs means lower time for each NB-IoT step (e.g. DL synchronization)
- Satellite-to-NB-IoT UTs links can be classified as belonging to CL 164 dB

- Ericsson estimate ~8 seconds @ CL164 dB[1]
- Nokia estimate ~11 seconds @ CL164 dB [2]

- CL1-to-CL2 threshold should be 8 -11 seconds



[1] Ericsson, ZTE, Alcatel-Lucent, Alcatel-Lucent Shanghai Bell, Nokia, Intel, Samsung, LGE "NB-IoT – Exception report latency evaluation" in R1-156027, 3GPP TSG RAN1 Meeting #82bis
[2] Nokia networks " Latency Evaluation for Guard-band Operation" in R1-157250, 3GPP TSG-RAN WG1 Meeting #83

Smart BO: upper bound

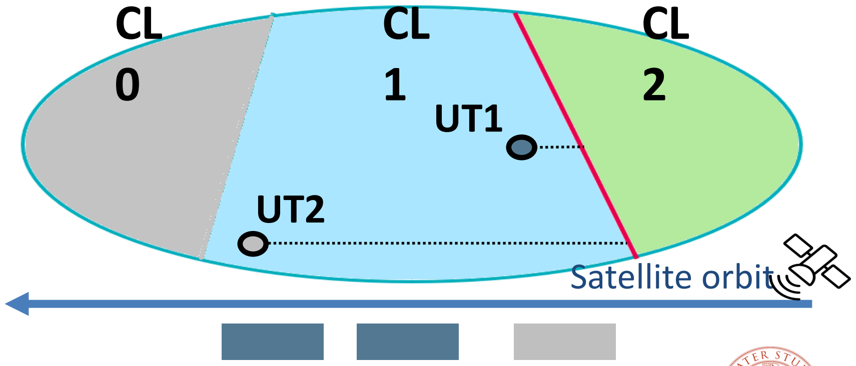
- Solution: **smart back-off mechanism** that allows UTs to adjust their back-off interval to ensure that each UT can retransmit its data within the time-limited coverage visibility.
- UTs may get different random back-off intervals, which reduces the collision rate and ensures that each user can send its data within the coverage time limit.
- **Upper Back-off Bound:**
  - The smart back-off algorithm adjusts the upper limit of the back-off interval considering the UE visibility time, and transmission time (RACH + data).

$$\underbrace{\beta^{n}_{\max}}_{\text{Upper limit of user n}} = \min\left\{\underbrace{\hat{\beta}_{\max}}_{\substack{\text{Fixed upper limit sent}\\ \text{by the BS}}}, \underbrace{T_{v,n}}_{\text{Visibility time}} - \overbrace{T_{tr,n}}^{\text{Transmission time}}\right\}, \forall n \in \mathcal{N},$$

Smart BO: lower bound

- Optimizing the lower bound interval of the random back-off algorithm can also improve the network performance.
  - If the lower bound interval is too low, multiple UTs may try to transmit their data simultaneously, resulting in collisions and data loss.
  - The lower limit should be set to a value that can prevent excessive collisions while still allowing sufficient channel access opportunities.

$$\underbrace{\beta^{n}_{min}}_{\text{Lower limit of user n}} = \max\{0, \underbrace{\beta_{max}}_{\text{Selected upper limit}} - \underbrace{\gamma}_{\text{Parameter to control the number of transmission opportunities within the selected back-off interval}} \overbrace{N_{period}}^{\text{Periodicity time of RA opportunities}}\}, \forall n \in \mathcal{N},$$



Smart BO in a nutshell

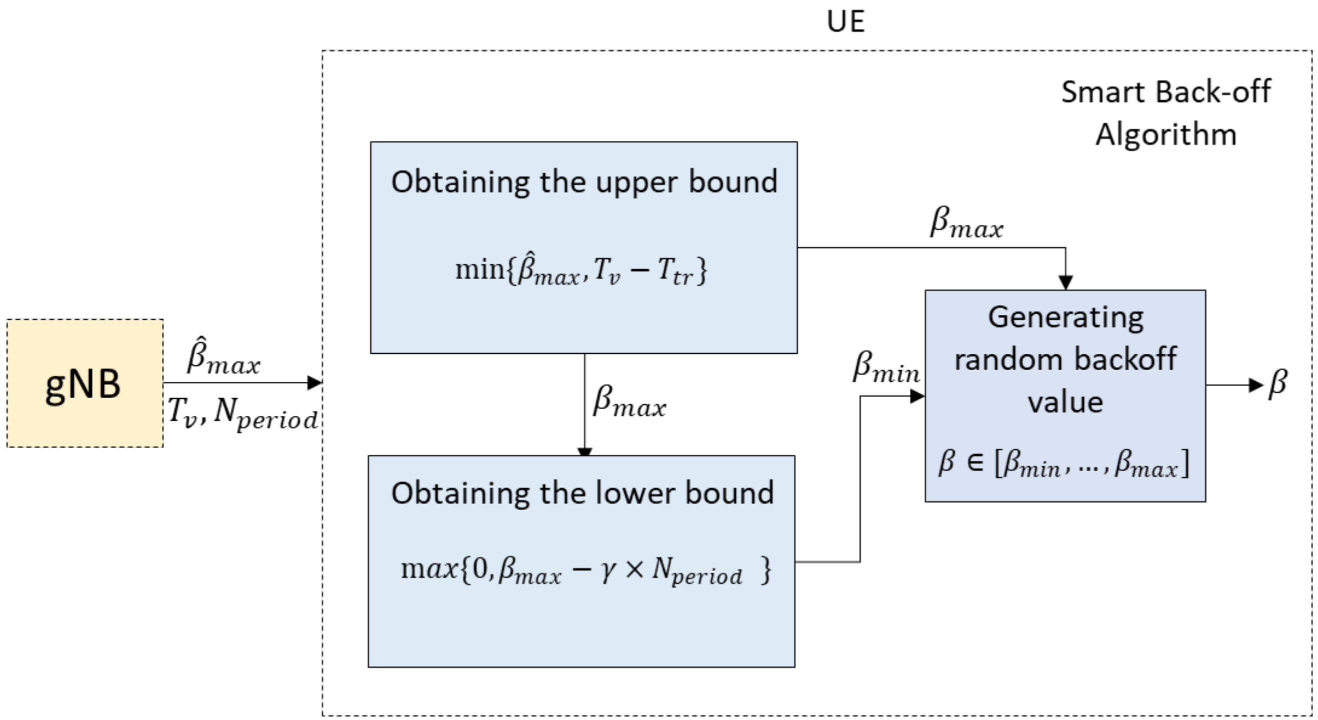
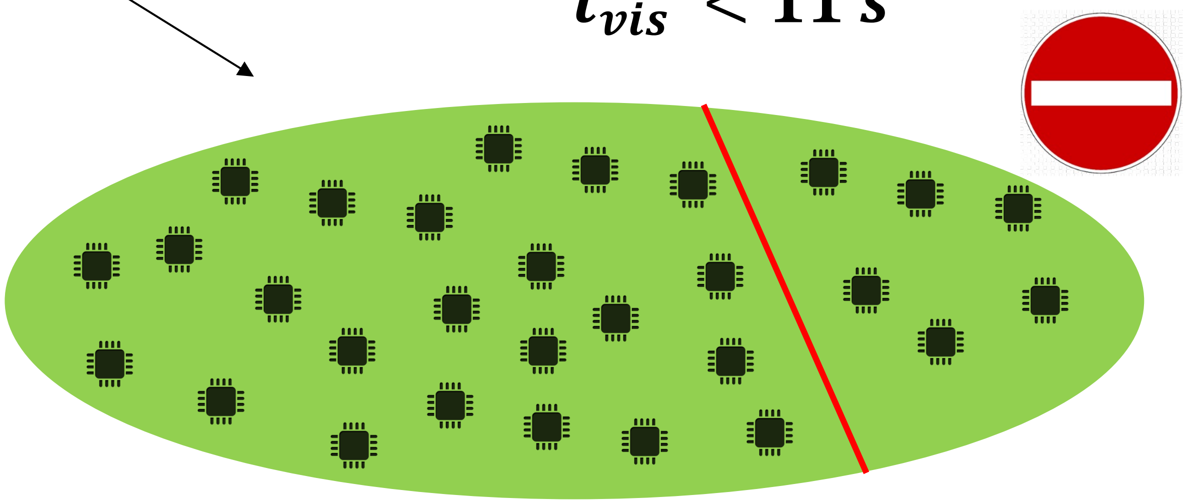


Figure: Proposed Smart Back-off Algorithm.

System model

All the resources for the RA: 48 sub-carriers

$$t_{vis} < 11\ s$$



Random Access

Parameters

Access configuration parameters with BO

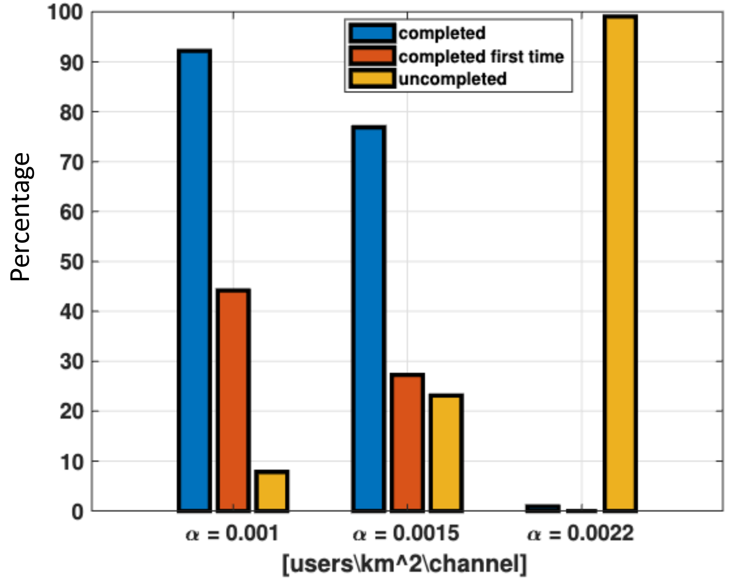
Parameters	Value
N_{rep}	16
N_{period}^{NPRACH}	640ms
Preamble format	1
T_{RAR}, T_{CRT}	4 ms, $N_{rep} * 1ms$
Number of available preambles	48
Back-off	$[0, 256 \cdot 2^j]$ms, $j \in [0, 11]$
Back-off index	$ID \in [1, 13]$

Satellite parameters

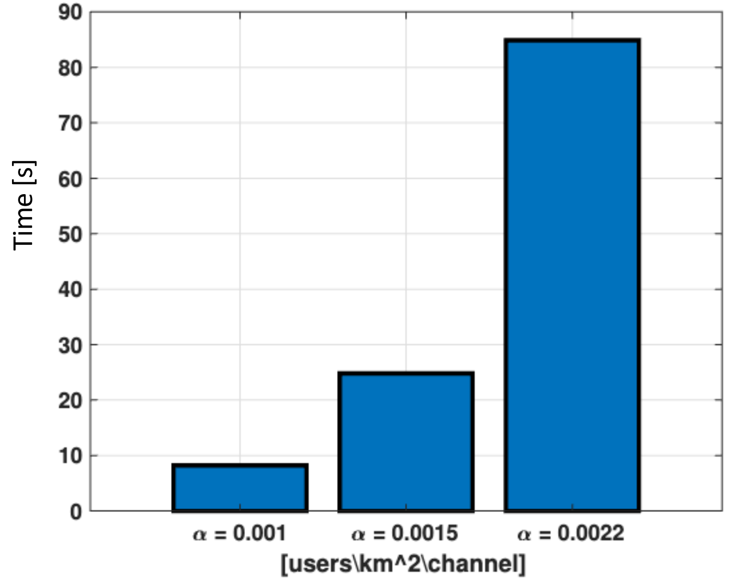
Satellite orbit	Set 4 LEO 600 km
Equivalent satellite antenna aperture	0.097 m
Sat EIRP density	21.45 dBW/MHz
Sat Tx max Gain	11 dBi
3dB beamwidth	104.7 degree
Sat beam diameter	1700 km
G/T	-18.6 dBK^{-1}
Sat Rx max Gain	11 dBi
Sat Visibility window (10° min el)	8.49 min
Beam visibility window = T_{beam}	246.9 s

Numerical results: NO BO and NO threshold

- The aim of this analysis is to find the value of density for which the system is saturated



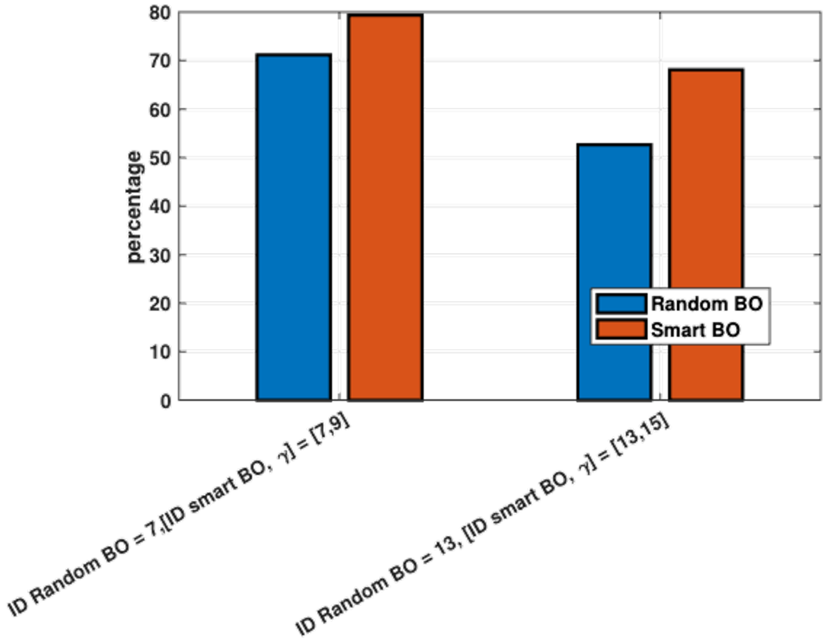
(a) RA Success rate analysis

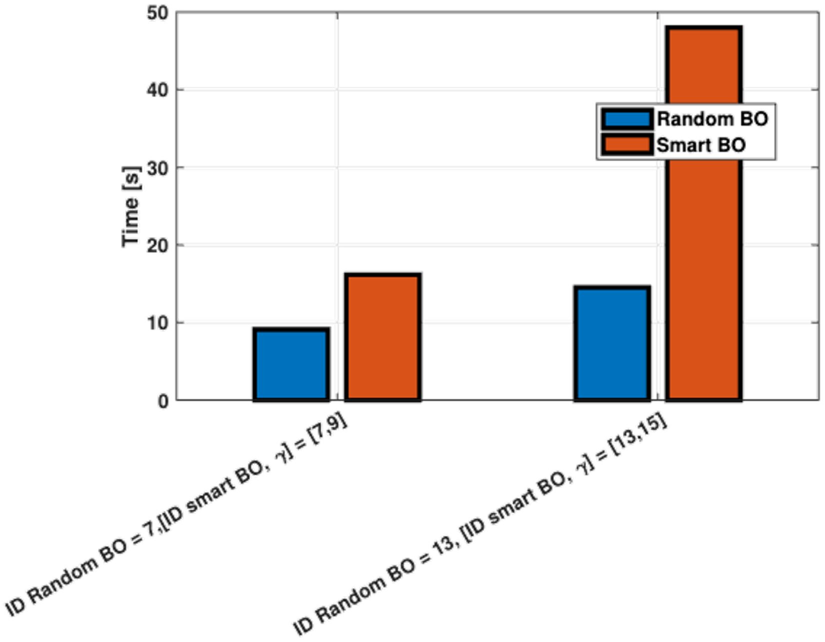


(b) Time necessary to conclude the RA in s

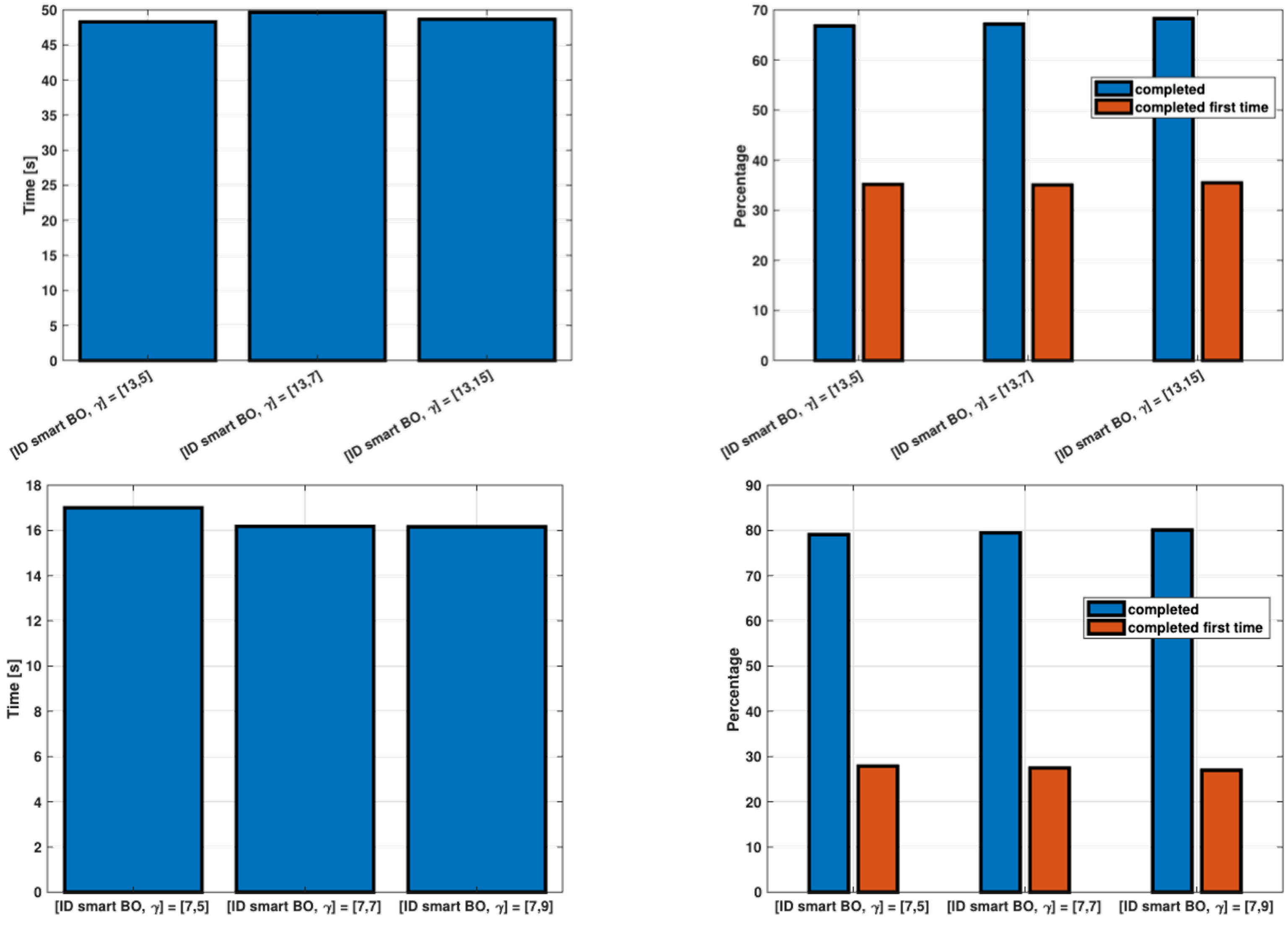
Numerical results: Random BO vs Smart BO

- **With the smart BO: controlled** number of opportunities and consideration **time of visibility**
  - This allows the users to transmit within their visibility period (success probability)
  - The colliding users are normally distributed in fewer opportunities (time to conclude the RA)
  - The access rate increases of 10 % with BO index 7 and 16% with BO index 13
- Trade-off between RA success rate and the time to conclude the RA.





Smart BO: impacact of γ



(a) (b)

- γ is a parameter that can be optimized to find the good compromise between the RA success rate and the time to conclude the procedure.

Lesson learnt

- The smart BO:
  - Pros:
    - The visibility time of each user is considered
    - A degree of freedom is provided by deciding the value of β
    - It is backward compatible with the standard BO algorithm
  - Cons:
    - Knowledge of user position

- The smart BO algorithm has been derived in the framework of **ONION** (Optimization of NB-IoT MAC procedures for NTN) project funded by ESA through the SatNEx program.

Future trends

- We have highlighted the main challenges that needs to be addressed to complete the inclusion of the NTN component into the overall Terrestrial architecture.
- IoT and NTN can contribute to the realization of Ubiquitous networks to create a seamless and always-on network.

IoT NTN Rel.18 main features

- Enhancements to the NB-IoT/eMTC radio protocols to
  - optimise mobility procedures
  - improve the support of small constellations providing discontinuous service over a given area

IoT NTN Rel.19 proposed topics for IoT NTN

Improve service experiences	New capabilities
NTN/TN mobility enhancement (signalling overhead optimization)	Regenerative payload = Store and Forward (i.e., eNB+ ePCnetwork elements)
Enhanced HARQ disablement (e.g. adaptative repetition scheme)	Support of GNSS independent operation for uplink time and frequency synchronization in NTN based access

Current funded projects on NTN

6GNTN

https://www.6g-ntn.eu/
https://www.linkedin.com/company/6g-ntn/
https://twitter.com/6Gntn

EAGER

https://www.eagerproject.eu
https://www.linkedin.com/company/eager-project/
https://twitter.com/eagersatcom

5GSTARDUST

https://www.5g-stardust.eu
https://www.linkedin.com/company/5g-stardust/

THANKS FOR THE ATTENTION