DYNASAT

Dynamic spectrum sharing and bandwidth-efficient techniques for high-throughput MIMO Satellite systems

DYNAMIC SPECTRUM SHARING AND BANDWIDTH-EFFICIENT TECHNIQUES IN NON-TERRESTRIAL NETWORKS

Alessandro Vanelli-Coralli and Alessandro Guidotti (Univ. of Bologna)
Alessandro Ugolini, Amina Piemontese and Giulio Colavolpe (Univ. of Parma)
Heikki Kokkinen (Fair Spectrum)
Nadia Arago Higueras and Laurent Combelles (Thales Alenia Space)

EuCNC, June 8, 2021

dynasat.eu

TUTORIAL OBJECTIVES

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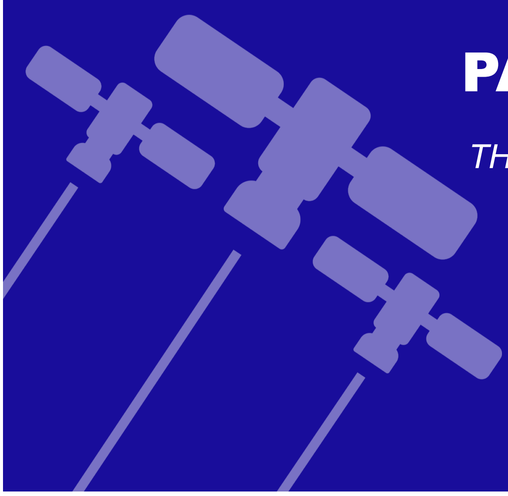
Dynamic spectrum sharing and bandwidth efficient techniques for integrated terrestrial and non-terrestrial B5G architecture

Emphasis on an NTN component consisting in a mega-constellation of Low Earth Orbit (LEO) satellites.

TUTORIAL OVERVIEW

DYNASAT

- Part 0 – Who we are
- Part I – Non-Terrestrial Networks at a glance
  - Introduction to Non-Terrestrial Networks (orbits, constellations, link budgets,
  - propagation aspects, system elements)
  - The NTN component in the 3GPP context (architectures and integration with the terrestrial component)
  - Scenarios, Services and use cases
- Part II – Bandwidth efficient techniques
  - Introduction to interference management and exploitation transmission techniques
  - Multi-user MIMO cooperation techniques
  - The advanced mega-constellation case
- Part III - Dynamic spectrum sharing and coexistence techniques
  - Introduction to Dynamic spectrum sharing and coexistence techniques
  - Satellite communications network characteristics affecting Dynamic spectrum sharing
  - Dynamic spectrum sharing solutions for NGSO satellite communications
- Conclusions



PART 0 - WHO WE ARE

THE DYNASAT PROJECT

FACTS & FIGURES

DYNASAT

Project acronym: DYNASAT
Project name: Dynamic Spectrum Sharing and Bandwidth-Efficient Techniques for High-Throughput MIMO Satellite Systems

Funded by: Horizon2020 programme
Call for proposal: H2020-SPACE-2018-2020
Topic: SPACE-29-TEC-2020: Satellite communication technologies; subtopic b) Bandwidth-efficient transmission techniques

Starting date: 01.12.2020
Duration: 28 months
N° of partners: 6

Project coordinator: Alessandro Vanelli Coralli (UNIBO)

Innovation and risk manager: Nicolas Chuberre (Thales Alenia Space)

CONSORTIUM

DYNASAT

ALMA MATER STUDIORUM UNIVERSITÀ DI BOLOGNA A.D. 1088

MARTEL innovate

ThalesAlenia Space a Thales / Leonardo company

MAGISTER SOLUTIONS

Fairspectrum

UNIVERSITÀ DI PARMA

VISION & MISSION

DYNASAT researches, develops, and demonstrates **the use of innovative techniques for bandwidth-efficient transmission and efficient spectrum usage**, and demonstrates how such techniques can be designed for satellite architecture, so that they can significantly improve the performance of network infrastructure, which is crucial to **serve the mass-market and professional 5G user equipment**, especially in **unserved or underserved areas**.

Focusing on satellite network infrastructure based on a mega-constellation of NGSO, DYNASAT aims to significantly **increase the TRL** for bandwidth-efficient transmission techniques.

In pursuing its objectives, DYNASAT will provide a substantial contribution to the European **SatCom industry competitiveness**.

OBJECTIVES

DYNASAT

- Evaluate the performance gain of using bandwidth-efficient transmission techniques in an NGSO-based 5G satellite access system providing eMBB services to mass-market 5G devices.
- Evaluate the performance gain of using the cellular/satellite spectrum sharing techniques enabling the operation of an NGSO-based 5G satellite access system concurrently with a cellular system in the same frequency band.
- Assess the implementation feasibility of bandwidth-efficient transmission techniques and spectrum sharing techniques for efficient spectrum usage in a practical system.
- Demonstrate the isolated operation of spectrum sharing techniques on DSA software system and bandwidth-efficient transmission techniques on portable RAN lab software demonstration platform at the MWC 2022.
- Define and plan an in-orbit demonstration of the developed bandwidth-efficient and spectrum sharing techniques.
- Demonstrate the integrated operation of bandwidth-efficient transmission techniques and spectrum sharing techniques for efficient spectrum usage with a portable RAN lab software demonstration platform at the MWC 2023.
- Promote future work on multi-satellite cooperative multi-user MIMO and spectrum sharing techniques within the 3GPP community and get the 3GPP non-terrestrial networks Release 18 work item approved at the TSG-RAN plenary.
- Execute the 3GPP NTN Release 18 standardisation of multi-satellite cooperative multi-user MIMO and spectrum sharing techniques in the 3GPP TSG-RAN working groups supported by simulation results.
- Contribute to the preparation of the WRC 2023 to promote the evolution of the regulatory framework needed to support efficient spectrum sharing between satellite and mobile services in the targeted bands allocated to satellite and/or mobile services.

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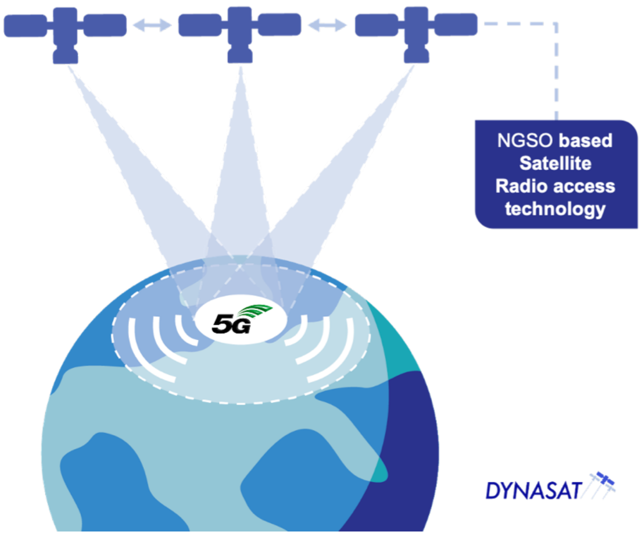

KEY DESIGN PRINCIPLES

- **Minimising the impact on the bill of material of mass market user equipment**, as demonstrated in the 3GPP feasibility study of non-terrestrial network supporting New Radio, which led to the conclusion that the adaptations needed to mitigate the propagation channel, Doppler, Latency and beam pattern will not impact the 5G chipset design.
- **Minimising the impact on 5G network infrastructure** (especially the core network), as demonstrated in the 3GPP feasibility study on architectural aspects for using satellite access in 5G, which concluded that main impacts on core network are QoS management to mitigate the latency.
- **Being able to scale the capacity with the traffic demand,** as lower altitude of the satellite, larger on-board antenna, and higher number of satellites deployed will allow to increase the data rate that can be offered per user equipment as well as the density of users that can be served in the given area.

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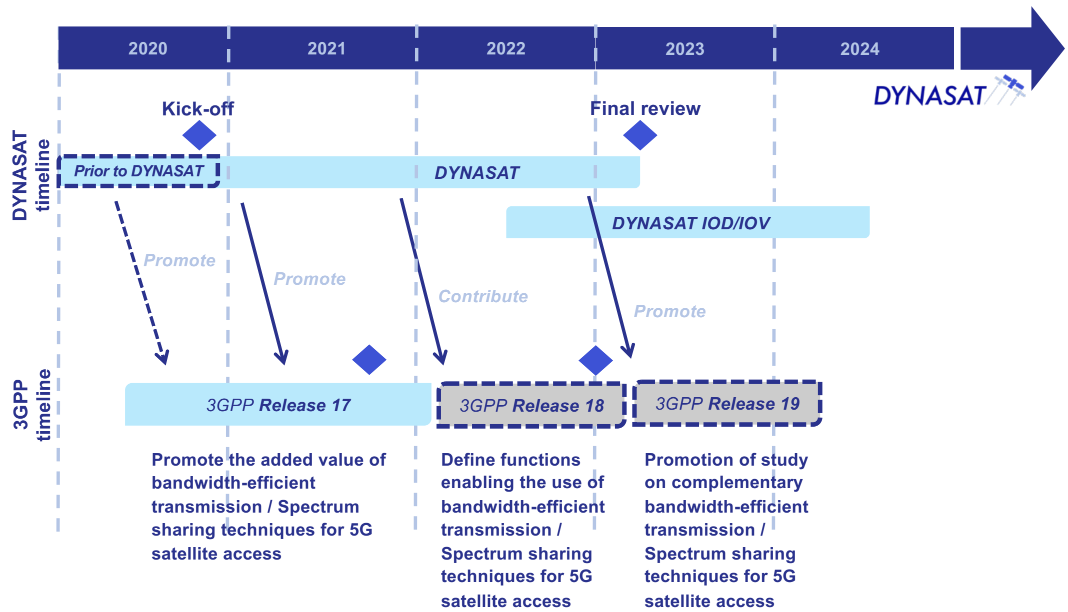


THE DYNASAT PROJECT

DYNASAT

- For more information follow us on
  - web: www.dyansat.eu
  - twitter: @dynasat_project
  - linkedin: Dynasat project

PART I – INTRODUCTION

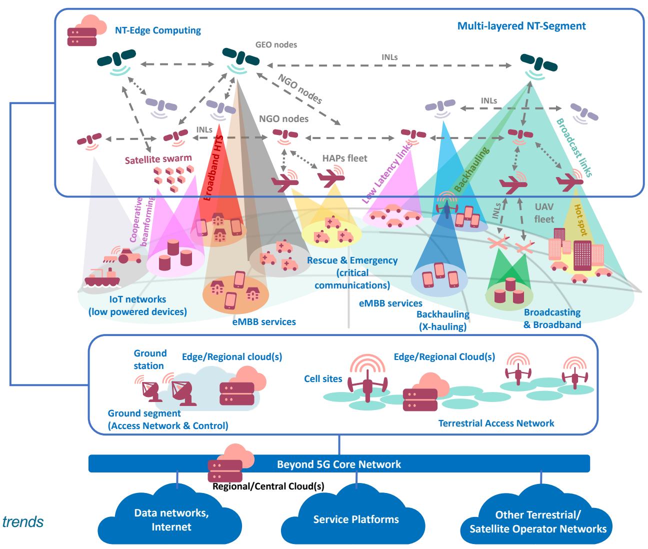
NON-TERRESTRIAL NETWORKS AT A GLANCE

PART I CONTENT

- NTN architecture
- Communication Satellites
  - Orbits
  - Payload (transparent vs. regenerative)
  - Coverage
  - Constellations
- Satellite systems
  - Intra-system interference
  - Inter-system interference
- NTN and 3GPP

NON-TERRESTRIAL NETWORK ARCHITECTURE

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



In this tutorial we focus on space-borne platform: Communication satellites

A. Vanelli-Coralli, A. Guidotti, T. Foggi, G. Colavolpe, G. Montorsi, "5G and Beyond 5G Non-Terrestrial Networks: trends and research challenges," IEEE 5G World Forum, 2020

SATELLITE COMMUNICATIONS SYSTEM

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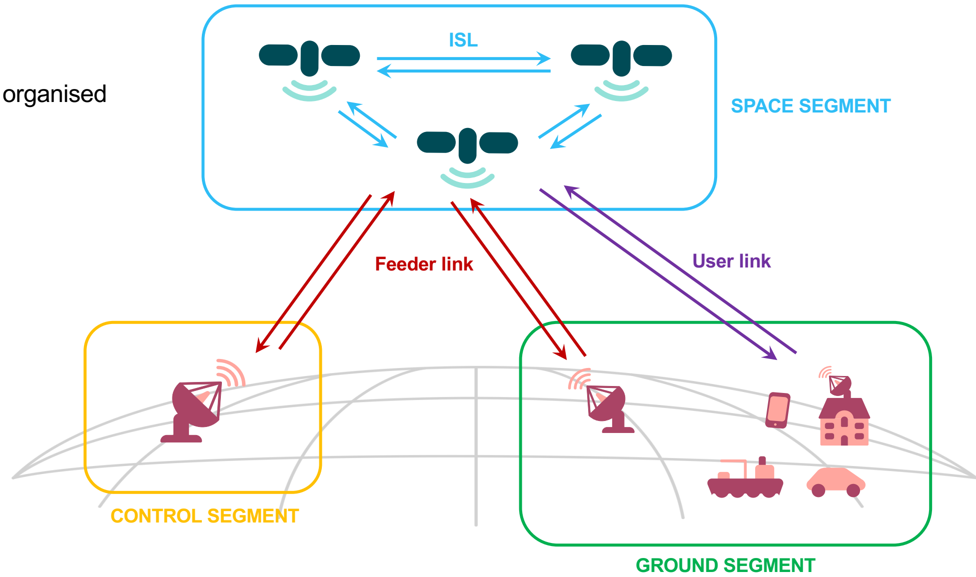
- Space segment
  - 1+ communication satellites organised in a constellation
- Control segment
  - Network Control Center
  - Satellite Control Center
- Ground segment
  - Gateways
  - User Terminals



COMMUNICATION SATELLITES

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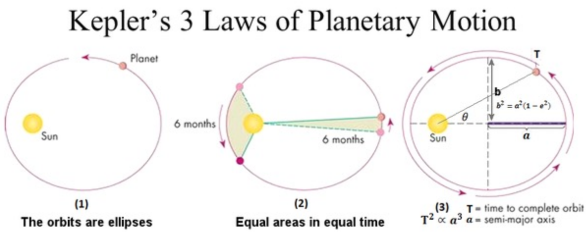
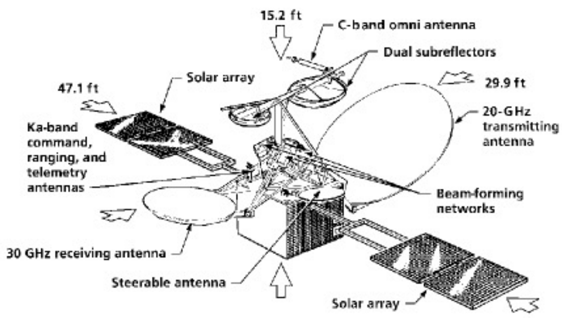
- Satellite
  - A flying object orbiting the Earth according to the Keplerian Laws.
- Communication satellite:
  - A satellite carrying telecommunications elements.



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



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

SATELLITE ORBITS

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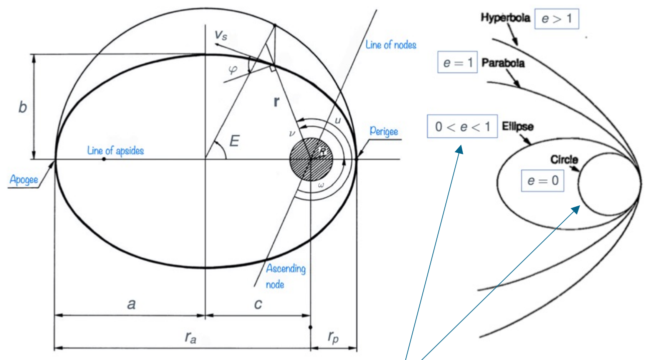
Satellite motion around the Earth

- According to the Keplerian laws and the Universal Law of Gravitation, the magnitude of the position vector of a satellite w.r.t. to the Earth's center is:

$$r = \frac{a(1-e^2)}{1+e\cos v} = a(1-e\cos E)$$

  - where
    - E: eccentric anomaly
    - a: semi-major axis
    - e: eccentricity
    - v: true anomaly



Only those orbits with e<1 are of interest for commercial communication systems

Source: W. J. Larson, J. R. Wertz, "Space Mission Analysis and Design," 3rd ed., Wiley, 1999

SATELLITE ORBITS

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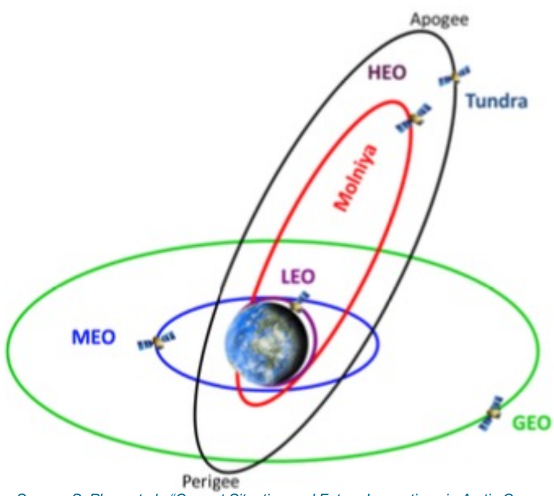
According to altitude and position w.r.t. the Earth (e<1)

- 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
- Polar and Sun-Synchronous, transfer orbits and GTO, L-points

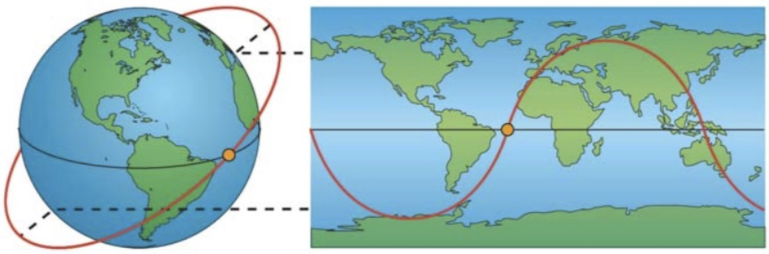


Source: S. Plass et al., "Current Situation and Future Innovations in Arctic Communications," IEEE VTC Fall 2015, Sep. 2015

Ground Tracks: looking at the orbit from the ground

- Trace of the points formed by the intersection of the satellite's position vector with the Earth's surface
  - or the trace of points formed by the Sub Satellite Point locations

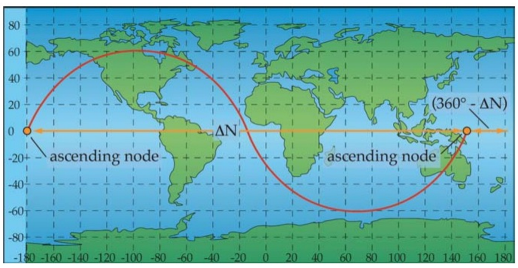
- For a non-rotating Earth, it is a great circle

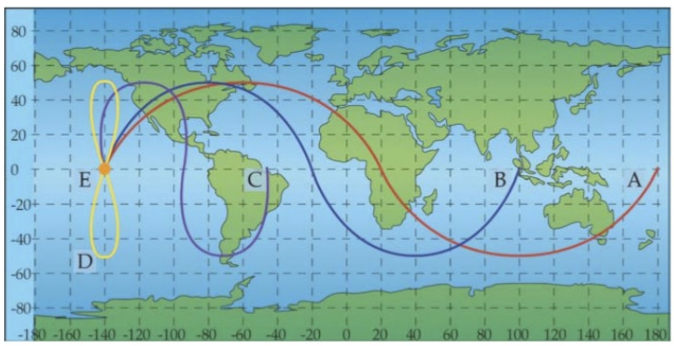


https://www.faa.gov/about/office_org/headquarters_offices/avs/offices/aam/cami/library/online_libraries/aerospace_medicine/tutorial/media/III.4.1.4_Describing_Orbits.pdf

Ground Tracks: looking at the orbit from the ground

- Node displacement ΔN
  - distance between two consecutive ascending nodes, positive in the direction of motion
  - $360 - \Delta N$: Earth's rotation during one orbit
  - the faster the orbit, the smaller $360 - \Delta N$



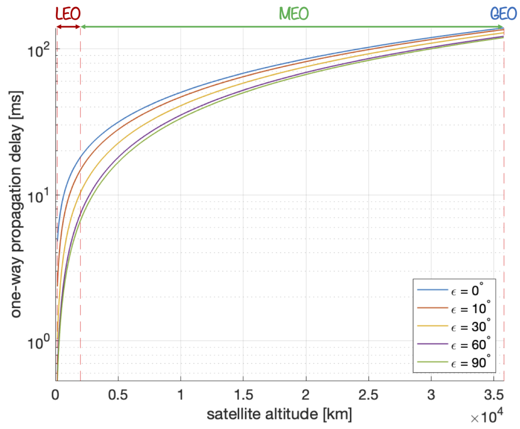


A: NGSO 2.67 hours period
B: NGSO 8 hours period
C: NGSO 18 hours period
D: GSO
E: GEO

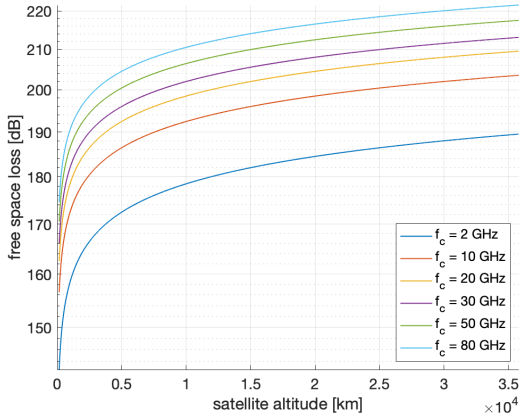
https://www.faa.gov/about/office_org/headquarters_offices/avs/offices/aam/cami/library/online_libraries/aerospace_medicine/tutorial/media/III.4.1.4_Describing_Orbits.pdf

SATELLITE ORBITS

GSO vs. NGSO: latency and free space loss



Latency

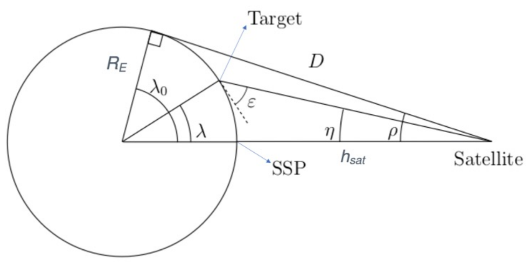


Free space loss

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



$$\rho = \sin^{-1}\left(\frac{R_E}{R_E + h_{sat}}\right)$$

min. elevation angle requirement

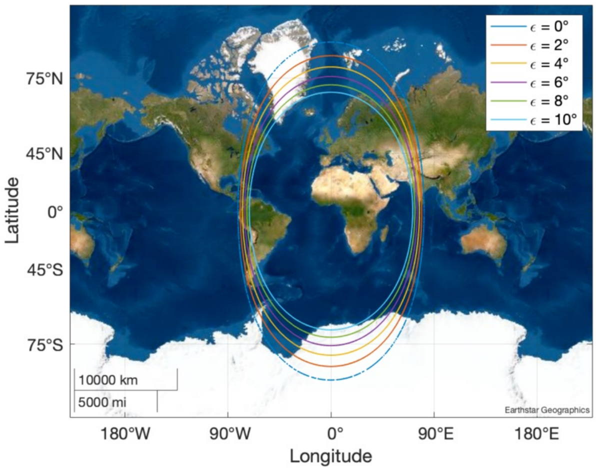
$$\rho = \sin^{-1}\left(\frac{R_E}{R_E + h_{sat}}\cos\varepsilon_{min}\right)$$

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

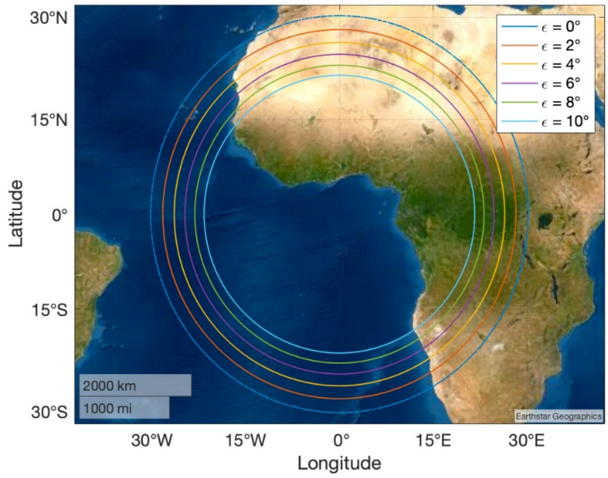
SATELLITE ORBITS

Field of view

GEO

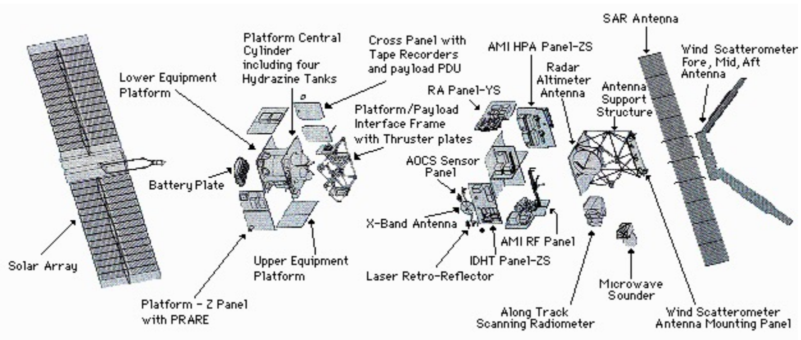


LEO (1000 km)



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

COMMUNICATION SATELLITE PAYLOAD

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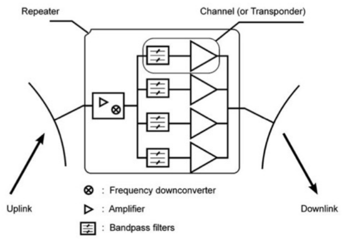
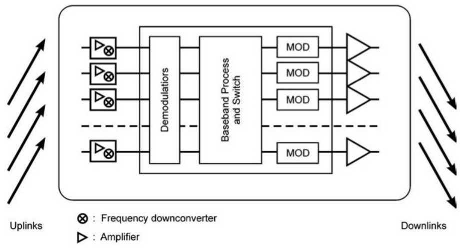
Transparent vs. Regenerative

- Transparent Tx/Rx
  - frequency conversion and amplification
- Regenerative Tx/Rx
  - demodulation and modulation
  - protocol termination



Transparent



Regenerative

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

COMMUNICATION SATELLITE PAYLOAD

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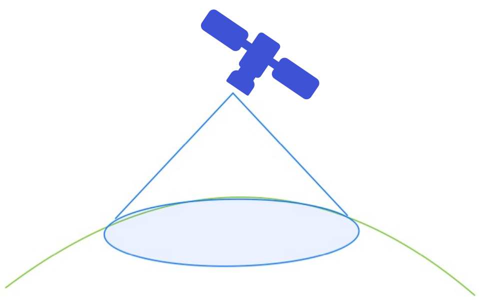
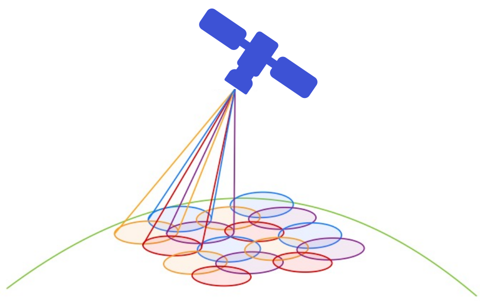
Antenna

- 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

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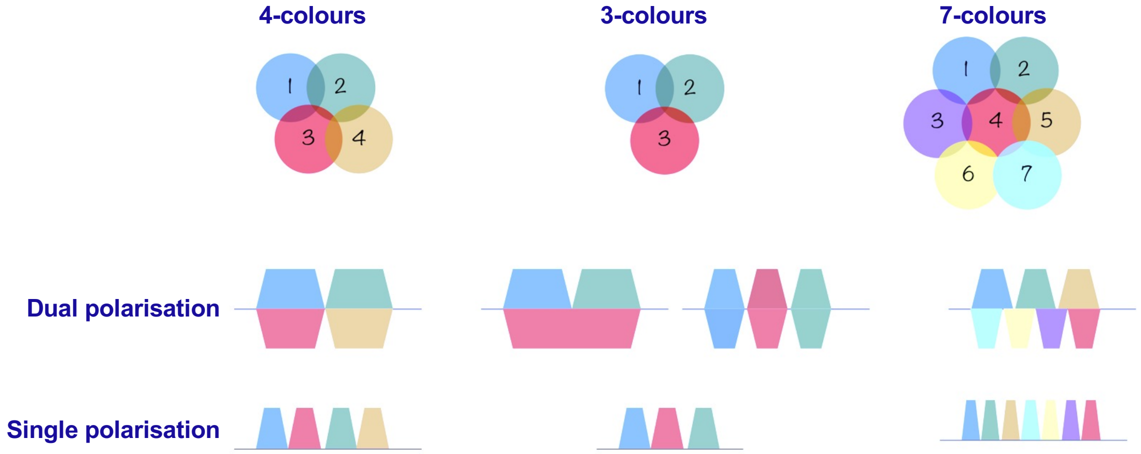
- Frequency reuse scheme: combination of polarisation and frequency band
- Each beam is associated to a “colour”



COVERAGE

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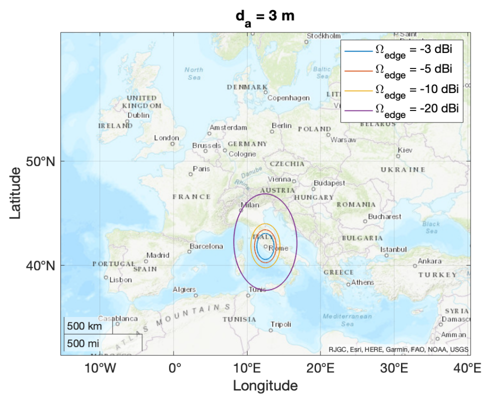
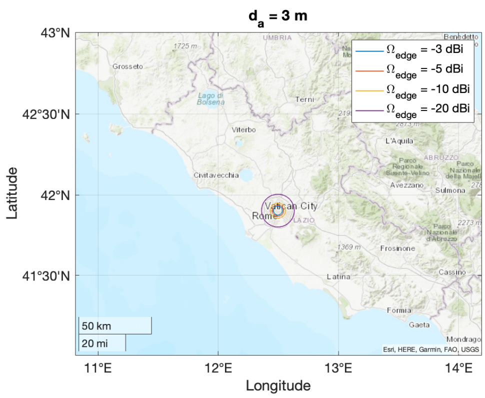
GSO vs NGSO



GEO



LEO

COVERAGE

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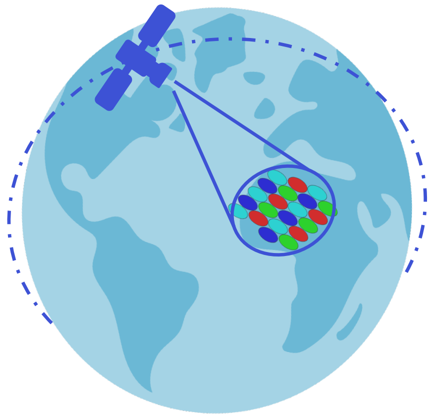
- A single satellite covers a (small) portion of the Earth for a (short) period of time
- To ensure global coverage, or connectivity with a sufficient periodicity, constellations are typically needed



CONSTELLATIONS

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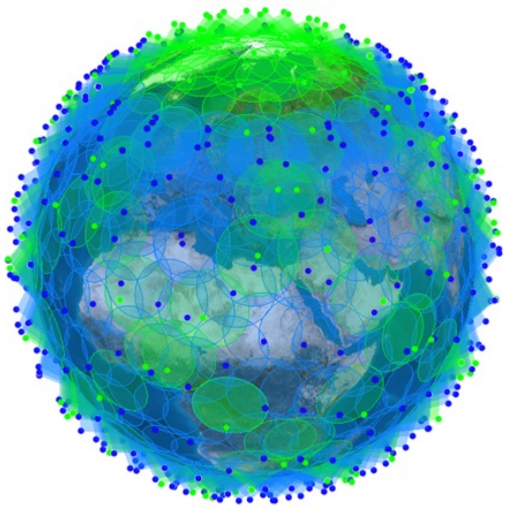
- A number of satellites, of a similar type and function, designed to be in complementary orbits for a shared purpose, and under a shared control.



THE RACE TO MEGA-CONSTELLATIONS

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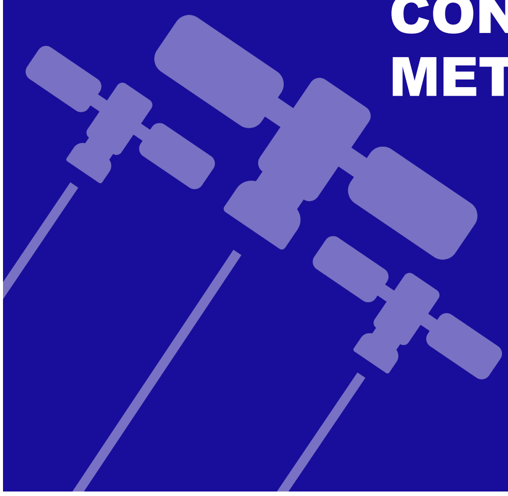
- **OneWeb**: 648 (with spares) LEO satellites in Ku-band
  - June 2014: licensees bought by SkyBridge for Ku-band
  - Satellite manufacturing: Airbus
- **Starlink**: imagined as 4000 satellites in Ku-band
  - Authorised for 12000 satellites, filed a request for 42000
- **Kuiper**: 3236 satellites between 590 and 530 km
  - 10 billion dollars of initial investment
- **Telesat**: 298 satellites with a 700-750 kg mass (Thales Alenia Space)
  - 4 optical ISL per satellite
  - Commercialization by the second half of 2023
- **LeoSat**: 78 (max 108) satellites (780 kg) in Ka-band (Thales Alenia Space)
  - Full mesh inter-satellite network
  - Global coverage by 2022



CONSTELLATION SIZING METHODOLOGY

CONSTELLATION SIZING METHODOLOGY (I)

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Define your need

- Area of coverage
  - Expressed as a latitude band or set of latitude bands
  - Number of satellites in view for each band
- Define target altitude
  - Depends on link budgets
  - Impacts on number of satellites
- Define minimum user elevation
  - Impacts on board antenna performance
  - Impacts maximum user-satelite distance
  - Impacts the number of satellites
  - Covers the region with higher population density

CONSTELLATION SIZING METHODOLOGY (II)

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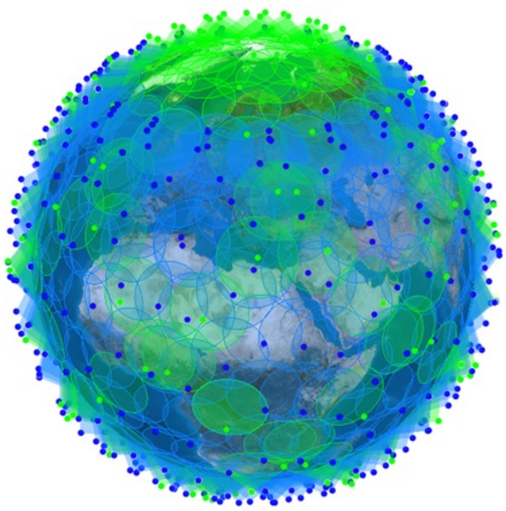
Find the best solution

- All the magic is here !
- Need is fulfilled
- Launch is convenient
  - Take launcher performances into account
  - Take satellite target mass/size into account
  - Minimize number and time of launch
- Number of satellites is close to minimum
- May use hybrid constellation



MULTI-BEAM SATELLITE SYSTEMS: INTERFERENCE SCENARIOS

INTERFERENCE SCENARIOS

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- Intra-system interference
  - same satellite, multi beam
  - different satellites pertaining to the same constellations
- Inter-system interference
  - satellites managed by different organization
  - satellites in different constellations
  - terrestrial to satellite
  - satellite to terrestrial

INTERFERENCE SCENARIOS

INTRA-SYSTEM INTERFERENCE

INTRA SYSTEM INTERFERENCE

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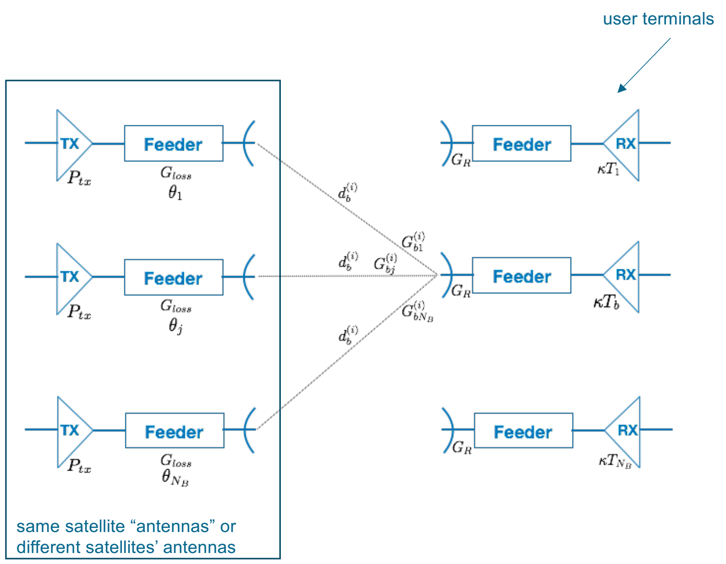

Channel coefficient matrix

$$\mathbf{H} = \begin{bmatrix} h_{1,1} & \cdots & h_{1,N_B} \\ \vdots & h_{b,j} & \vdots \\ h_{N_B,1} & \cdots & h_{N_B,N_B} \end{bmatrix}$$

$$h_{b,j} = \sqrt{\frac{G_R G_{b,j}^{(i)}}{A_{loss}} \frac{1}{\sqrt{\kappa B T_b}} \frac{\lambda}{4\pi d_b^{(i)}}} e^{j\frac{2\pi}{\lambda} d_b^{(i)}} e^{j\theta_b}$$

INTERFERENCE SCENARIOS

INTER-SYSTEM INTERFERENCE

SPECTRUM SHARING

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Why sharing cellular spectrum ?

- Mobile Satellite Systems usually operate in dedicated spectrum bands
  - Low noise spectrum, (quasi) worldwide identification
  - Used with success by existing satellite systems
- Using cellular spectrum allows
  - More bands accessible: increased capacity and services
  - Tighter integration with cellular deployments for seamless operations
- Compatibility must be ensured:
  - Interference towards cellular networks must be kept below acceptable limits
  - The satellite system must be designed to mitigate cellular interference - now and in the future

SPECTRUM SHARING

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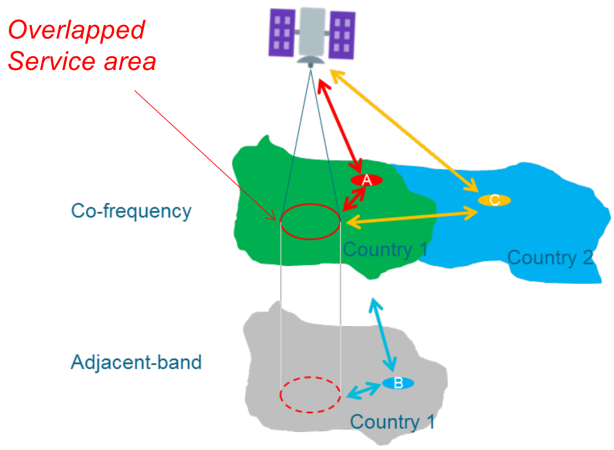
Cooperation and non-cooperation

- Cellular operators are licensed in « blocks » of spectrum by national regulators
    - Different MNOs in neighbouring countries reuse same frequencies
    - Different MNOs in a given country use adjacent blocks
    - Satellite overlays all blocks and countries
- Satellite and Terrestrial networks will coordinate spectrum access in overlapped service area

  → **Active cooperation:** DSA or other techniques
- In non-overlapped areas and adjacent bands, satellite system will mitigate interference without presuming interactions with cellular networks

  → **Non-cooperation:** satellite system flexibility and RF performance



SPECTRUM SHARING

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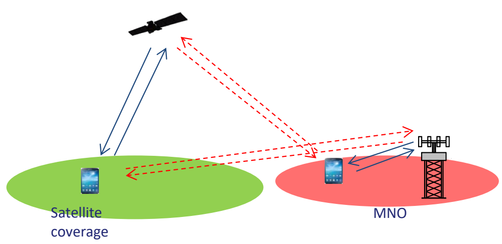
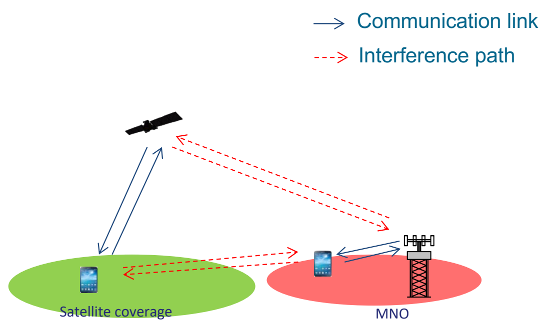
Interference scenario



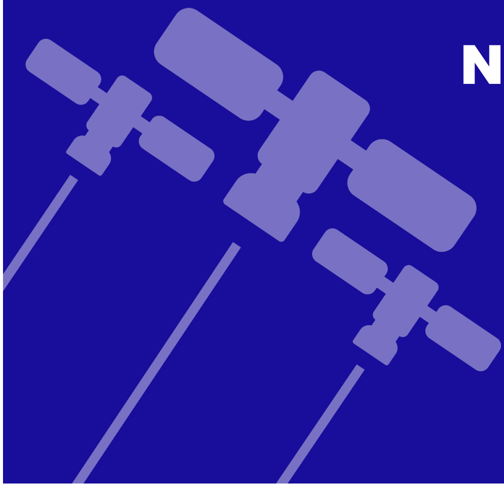
Cellular and satellite with aligned UL/DL duplex directions



Cellular and satellite UL/DL with opposite UL/DL duplex directions

8 interference paths – cofrequency and adjacent band

Cellular interference to satellite expected to be a dimensionning case



NTN IN 3GPP

3GPP NTN SCENARIOS

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- 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

Source: 3GPP TR 38.821, "Solutions for NR to support non-terrestrial networks (NTN) (Release 16)," Dec. 2012

w/o ISL

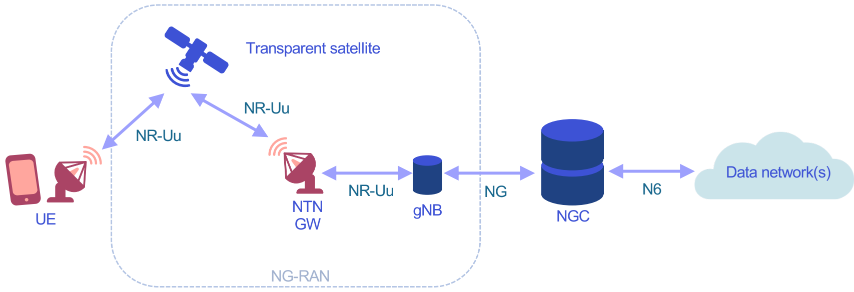
w/ ISL

- In the proposal for the new SI, scenario B is not considered
- The macro-scenarios to be targeted are thus
  - 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

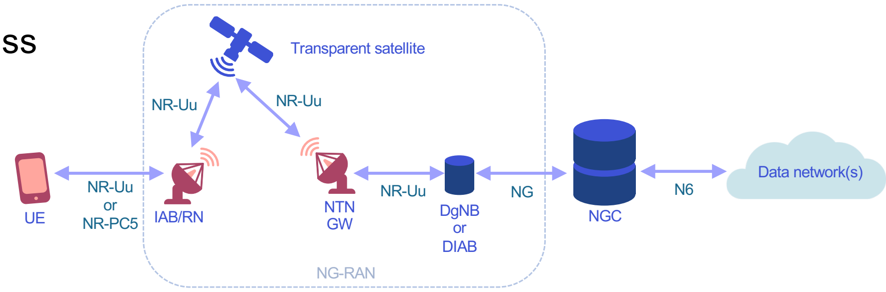
TRANSPARENT PAYLOAD (A, C1, C2): REFERENCE ARCHITECTURE

DYNASAT

- Direct access



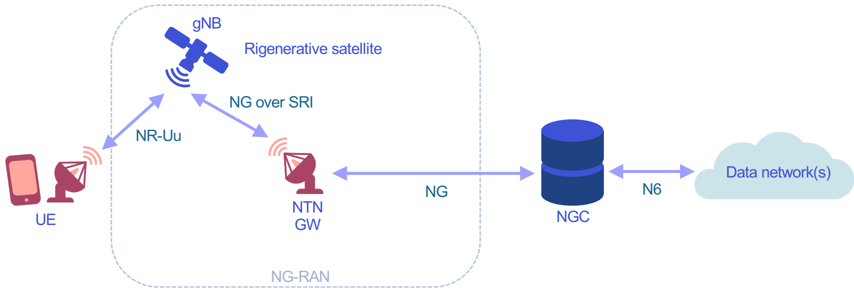
- RN/IAB access



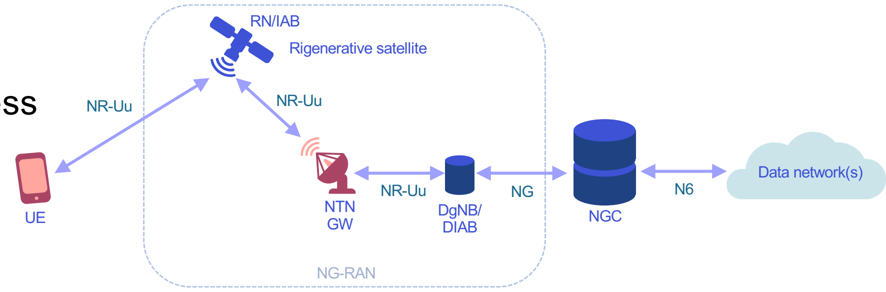
REGENERATIVE PAYLOAD (D1, D2): REFERENCE ARCHITECTURE W/O FUNCTIONAL SPLIT

DYNASAT

- Direct access



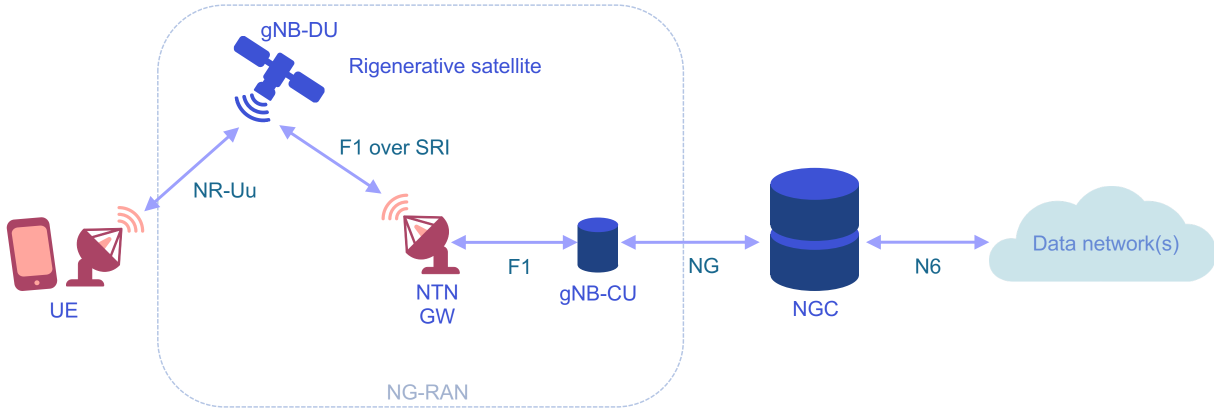
- RN/IAB access



REGENERATIVE PAYLOAD (D1, D2): REFERENCE ARCHITECTURE W/ FUNCTIONAL SPLIT

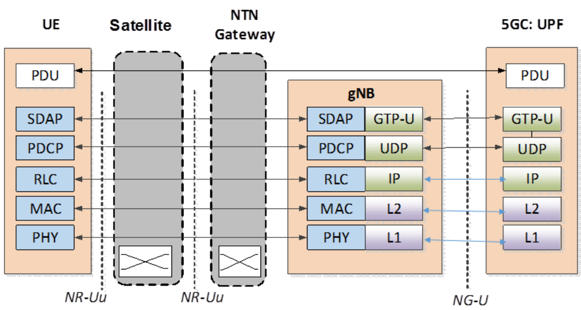
DYNASAT

- Direct access

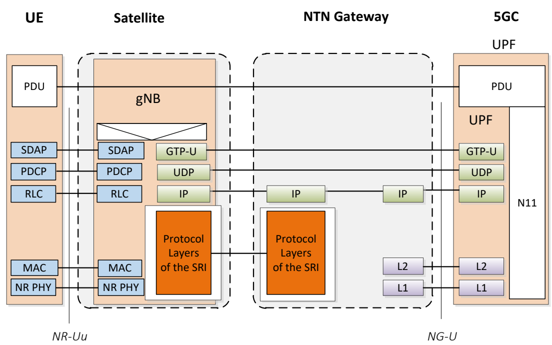


PROTOCOL STACK: USER PLANE

DYNASAT



Transparent



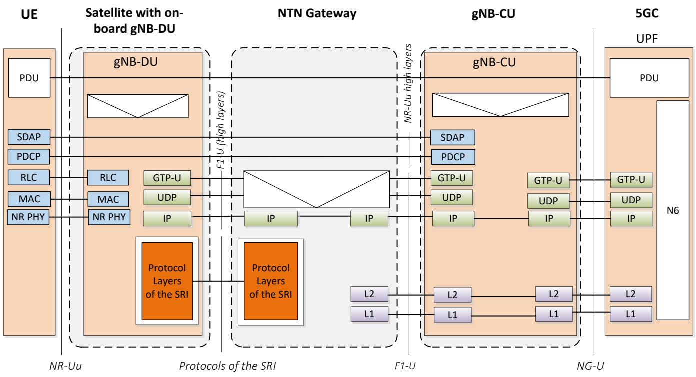
Regenerative

Source: 3GPP TR 38.821, "Solutions for NR to support non-terrestrial networks (NTN) (Release 16)," Dec. 2012

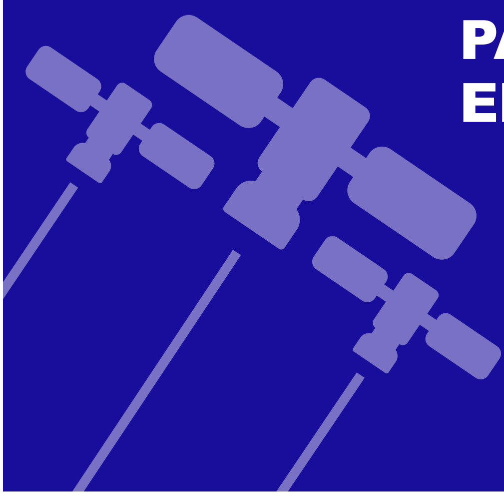
PROTOCOL STACK: USER PLANE

DYNASAT

- Functional split



Source: 3GPP TR 38.821, "Solutions for NR to support non-terrestrial networks (NTN) (Release 16)," Dec. 2012



PART II - BANDWIDTH EFFICIENT TECHNIQUES

PART II CONTENT

- Introduction
    - Capacity of multibeam satellite systems exploiting interference
- MIMO in satellite systems
    - Precoding and beamforming in satellite systems
- Mega-constellations
    - Beamforming in NGSO constellations

CONSIDERED TECHNIQUES

- Advanced strategies in the forward link of a multibeam satellite system with aggressive frequency reuse
    - uniform coverage
    - hotspot scenario
- Beamforming in LEO mega-constellations for NB-IoT services

- In the context of satellite communications, the leading design paradigm has historically been based on interference avoidance
- To meet the increasing requirements, the attention of the research community has recently shifted toward the interference management and exploitation paradigm:

interference is not avoided by design anymore, but a certain amount of controlled interference is intentionally introduced and mitigated or exploited, both at the transmitter and at the receiver sides

- This change of paradigm can allow to reach extremely high gains with respect to the interference avoidance approach of traditional systems

Several bandwidth efficient techniques to be applied at the transmitter and/or at the receiver can be adopted, some of them borrowed from the literature on terrestrial networks:

- **multi-user MIMO** cooperation techniques, i.e., Coordinated Multi-Point (CoMP)
- non-orthogonal multiple Access (**NOMA**) for 5G systems
- **time-frequency packing** for satellite systems
- multi-user detection (**MUD**) at the receiver
- etc..

In the following, we will consider the forward link of a multibeam satellite system adopting an aggressive frequency reuse to improve the throughput

INTERFERENCE EXPLOITATION SCHEMES IN MULTIBEAM SATELLITE SYSTEMS

DYNASAT

- The increase of the use of satellite links for unicast applications leads to higher capacity requirements for satellite links
- In a multibeam satellite scenario, the interference exploitation paradigm is applied by means of resource sharing
- In this scenario, interference arises from beams sharing the same bandwidth
- Several strategies have been proposed to move towards the improve the system throughput in this high interference situation

SYSTEM MODEL

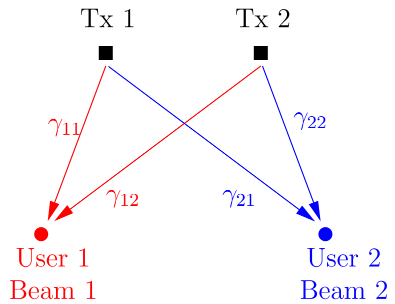
DYNASAT

Tx 1

- Serving User 1 with channel γ_{11}
- Interfering User 2 with channel γ_{21}

Tx 2

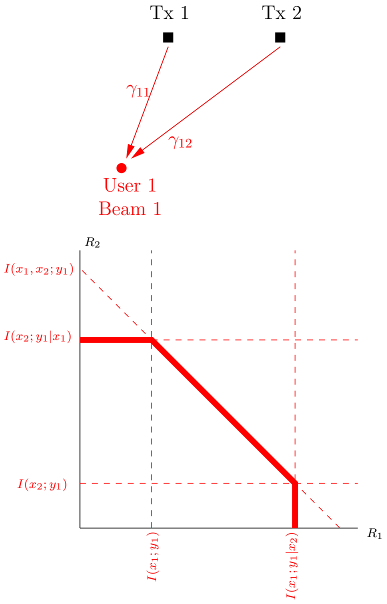
- Serving User 2 with channel γ_{22}
- Interfering User 1 with channel γ_{12}



$y_1 = \gamma_{11} x_1 + \gamma_{12} x_2 + w_1$ $y_2 = \gamma_{21} x_1 + \gamma_{22} x_2 + w_2$

MULTIPLE ACCESS CHANNEL REGIONS

DYNASAT



- For User 1 the rates of the received signals define an achievable rate region as

$$\begin{cases} R_1 < I(x_1; y_1|x_2) \\ R_2 < I(x_2; y_1|x_1) \\ R_1 + R_2 < I(x_1, x_2; y_1) \end{cases}$$

- The maximum sum-rate $R_1 + R_2$ is equal to $I(x_1, x_2; y_1)$ and is achievable with a multiuser detector

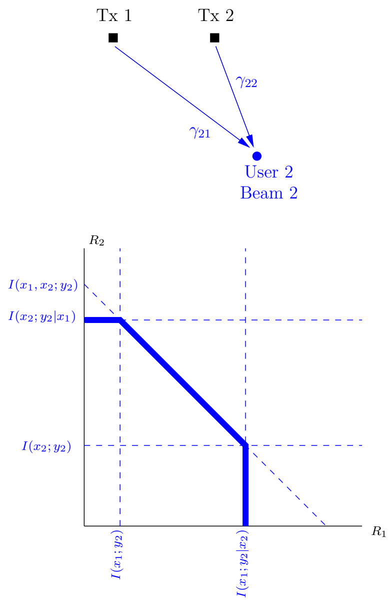
MULTIPLE ACCESS CHANNEL REGIONS

DYNASAT

- For User 2 the rates of the received signals define an achievable rate region as

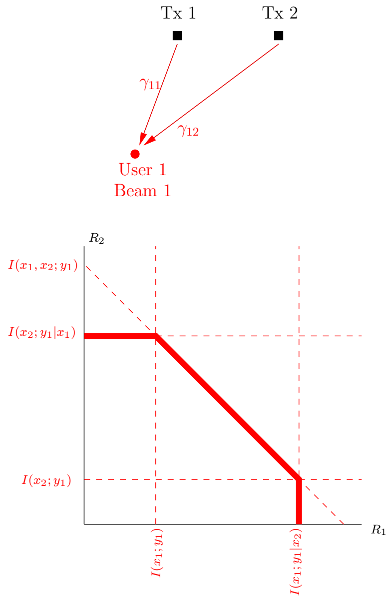
$$\begin{cases} R_1 < I(x_1; y_2|x_2) \\ R_2 < I(x_2; y_2|x_1) \\ R_1 + R_2 < I(x_1, x_2; y_2) \end{cases}$$

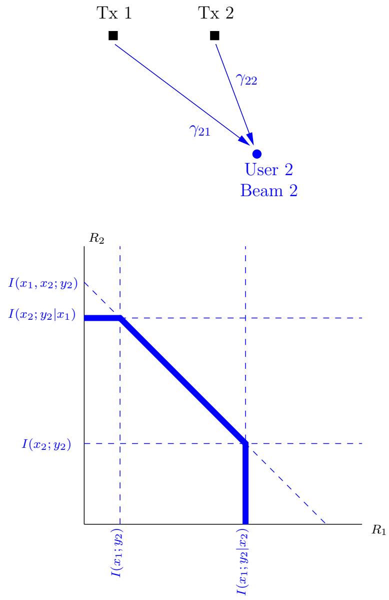
- The maximum sum-rate $R_1 + R_2$ is equal to $I(x_1, x_2; y_2)$ and is achievable with a multiuser detector



MULTIPLE ACCESS CHANNEL REGIONS

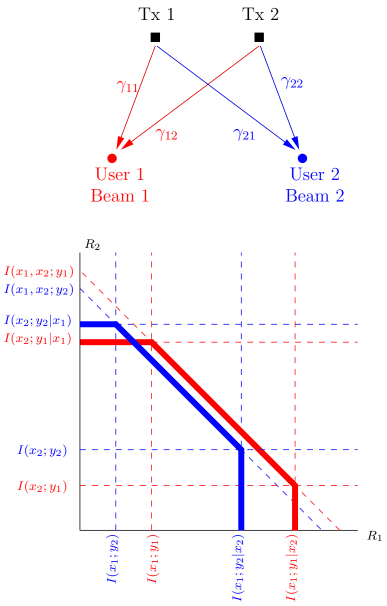
DYNASAT





MULTIPLE ACCESS CHANNEL REGIONS

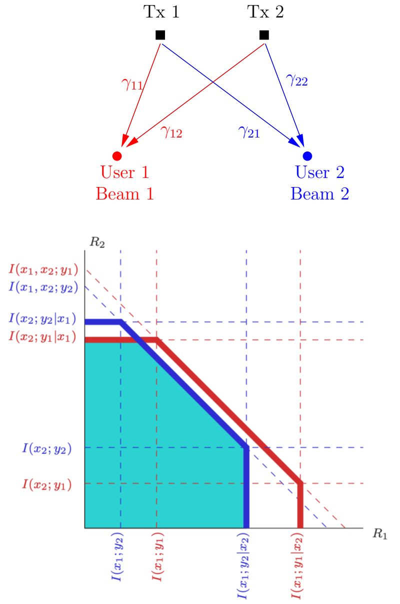
DYNASAT



- R_1 and R_2 are the same, so it is convenient to jointly consider the two achievable rate regions

MULTIPLE ACCESS CHANNEL REGIONS

DYNASAT



- R_1 and R_2 are the same, so it is convenient to jointly consider the two achievable rate regions
- The points in the intersection of the two regions represent the pairs of rates that allow both signals to be detected by both users

ACHIEVABLE RATES ON A MAC

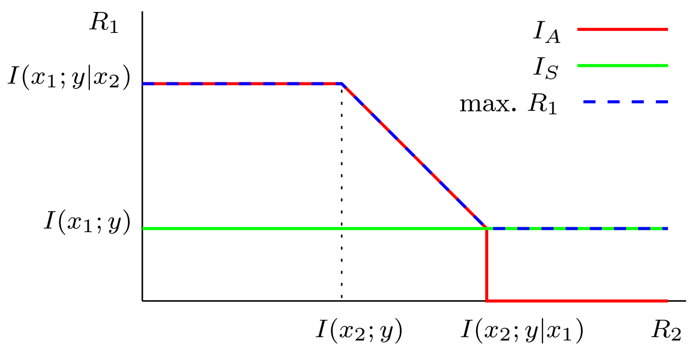
DYNASAT

We can prove that the achievable rate for a single user on a MAC is given by

$$R \leq \max\{I_S, I_A\}$$

where

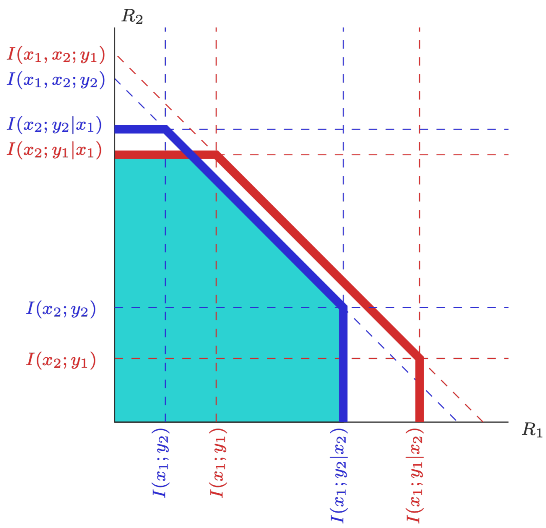
$$I_A = \begin{cases} I(x_1; y\,|x_2) & \text{if } R_2 < I(x_2; y) \\ I(x_1, x_2; y) - R_2 & \text{if } I(x_2; y\,|x_1) \leq R_2 < I(x_2; y|x_1) \\ 0 & \text{if } R_2 \geq I(x_2; y|x_1) \end{cases}$$



$$I_S = I(x_1; y)$$

NEW ACHIEVABLE RATE REGION: "MUD/SUD"

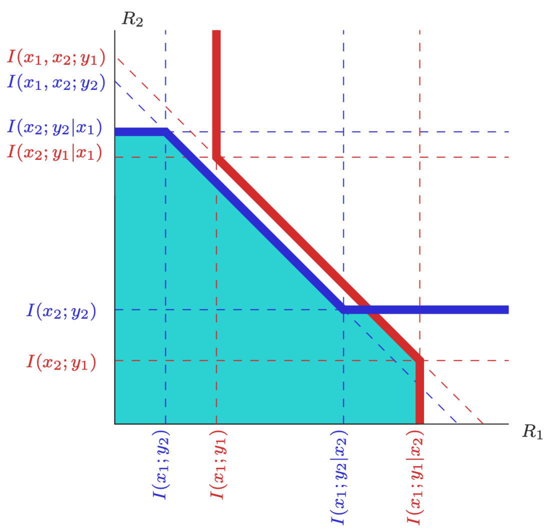
DYNASAT



- Signal x_1 carries information for User 1, signal x_2 carries information for User 2
- User 1 is not interested in x_2, User 2 is not interested in x_1

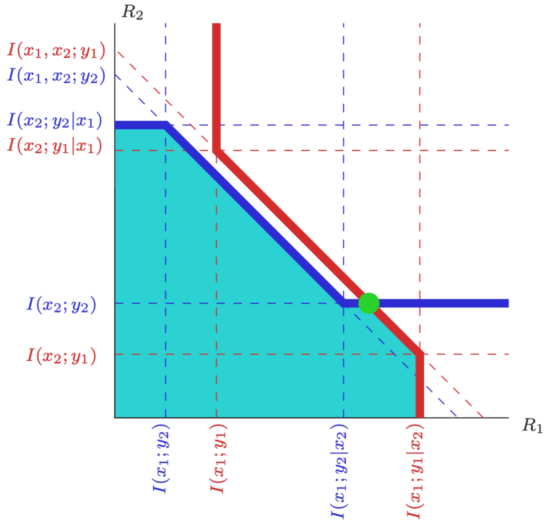
NEW ACHIEVABLE RATE REGION: "MUD/SUD"

DYNASAT



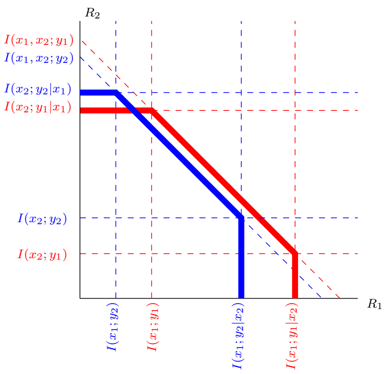
- Signal x_1 carries information for User 1, signal x_2 carries information for User 2
- User 1 is not interested in x_2, User 2 is not interested in x_1
- We can define a new achievable rate region by including points that are achievable only by the interested user
- Each user considers the signals it cannot detect as additional noise

NEW ACHIEVABLE RATE REGION: "MUD/SUD"



- Multiuser detection is exploited if it helps the detection of the useful signal
- Information carried by the other signal is discarded after detection
- We define the working point as the point of the region which maximizes the sum-rate $R_1 + R_2$ and minimizes the rate imbalance

A SIMPLE SOLUTION: "TIME-SHARING MAC"



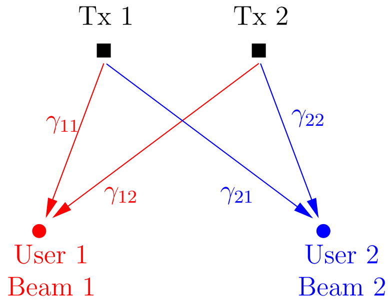
- Both signals serve User 1 for a fraction α of the time
- Both signals serve User 2 for a fraction $1-\alpha$ of the time

- The channel is a classical MAC for both users
- The value of α can be selected to maximize the throughput

However

- We can prove that under reasonable channel conditions the "MUD/SUD" strategy achieves a throughput that is always higher than the "time-sharing MAC" strategy

A SIMPLE SOLUTION: "TIME-SHARING MAC"

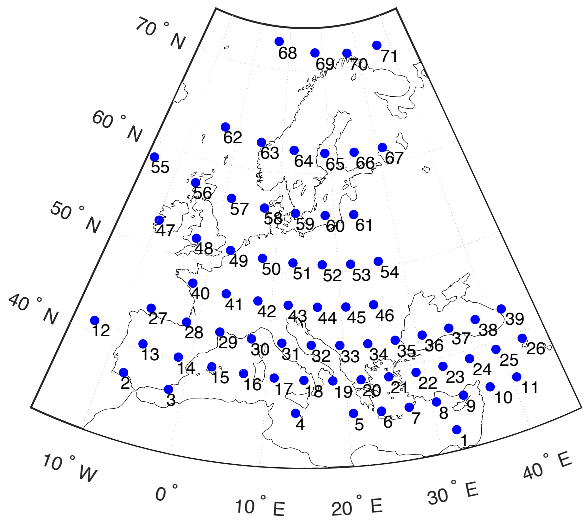


Reasonable channel conditions

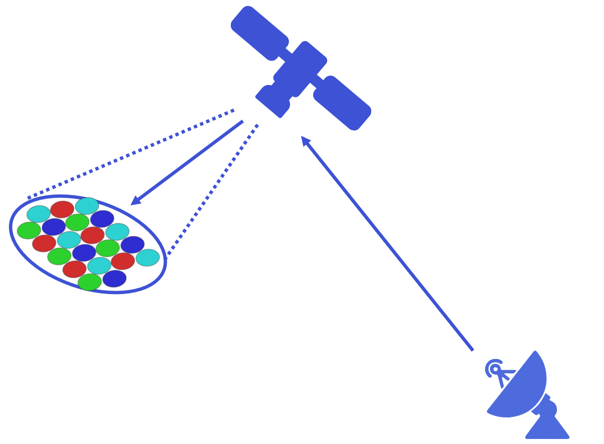
- The SUD rate from Tx i to User i is better than the SUD rate from Tx $j \neq i$ to User i
- The channel from Tx i to User i is better than the channel from Tx $j \neq i$ to User i

This is the situation in current multibeam satellite systems

MULTIBEAM SATELLITE SYSTEM



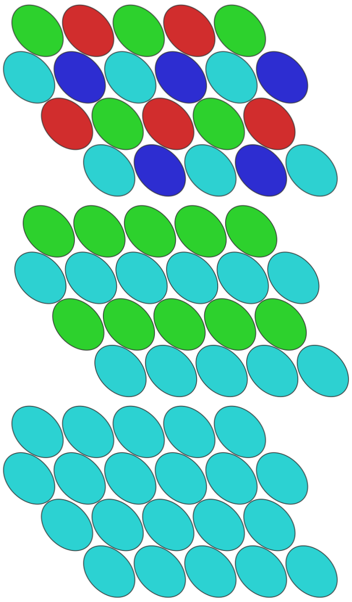
Typical 71-beam coverage of Europe



How to "color" the beams?

FREQUENCY REUSE SCHEMES

DYNASAT



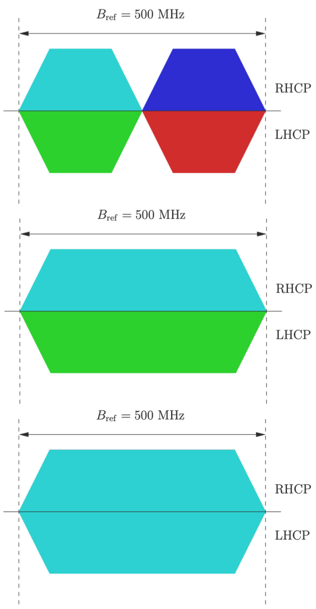
- 4 colors scheme (FR4)
- Used in current systems
- Low inter-cell interference
  SUD is sufficient

- 2 colors scheme (FR2)
- Higher inter-cell interference
  MUD and SUD are used

- 1 colors scheme (FR1)
- Highest inter-cell interference
  MUD and SUD are used

FREQUENCY REUSE SCHEMES

DYNASAT



- $B_{\mathrm{ref}} = 500$ MHz is the reference bandwidth of the beam

- We can define

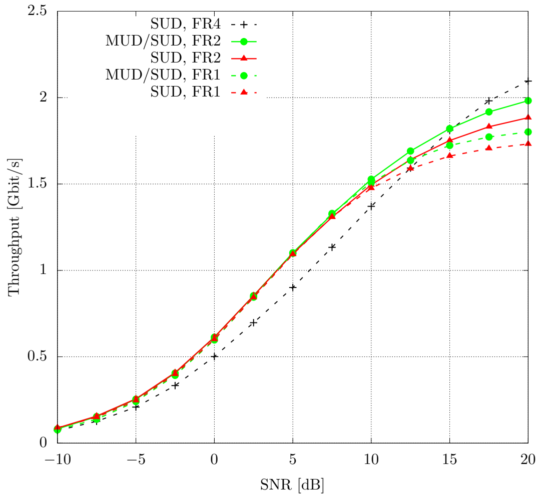
$$\mathrm{Throughput}^{(n)} = \frac{2I_R^{(n)}}{2T_s^{(n)}}$$

$$\mathrm{SNR}^{(n)} = \frac{nP_{\mathrm{b}}}{2N}$$

n: number of colors
I_R: achievable information rate
P_{b}: power per beam
N: noise power
T_{s}: symbol time

NUMERICAL RESULTS

DYNASAT

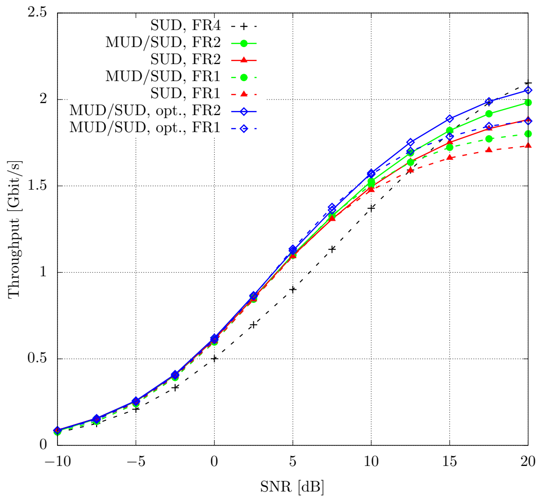


Average throughput per user over the whole 71-beam coverage

- Realistic DVB-S2X system and channel model
- Realistic interference pattern
- Comparison of the three frequency reuse schemes
- Significant advantages (2 dB) over the FR4 reference
- MUD gains 0.6 dB for FR1 and 0.4 dB for FR2 over SUD, at 1.5 Gbit/s

NUMERICAL RESULTS

DYNASAT

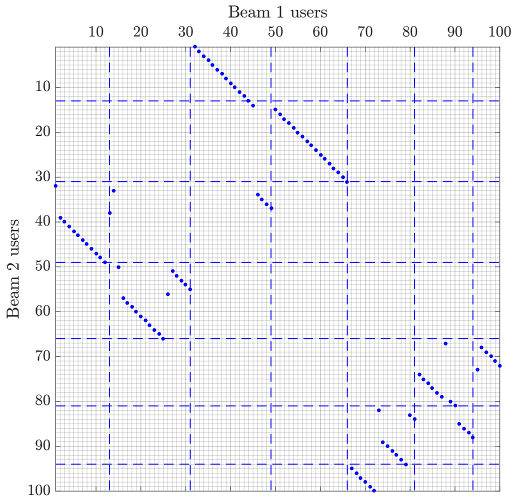


Average throughput per user over the whole 71-beam coverage

- Realistic DVB-S2X system and channel model
- Realistic interference pattern
- Comparison of the three frequency reuse schemes
- Significant advantages (2 dB) over the FR4 reference
- MUD gains 0.6 dB for FR1 and 0.4 dB for FR2 over SUD, at 1.5 Gbit/s
- The optimized assignment gains further 0.8 dB for FR1 and 0.6 dB for FR2, at 1.5 Gbit/s

OPTIMIZED ASSIGNMENT

DYNASAT

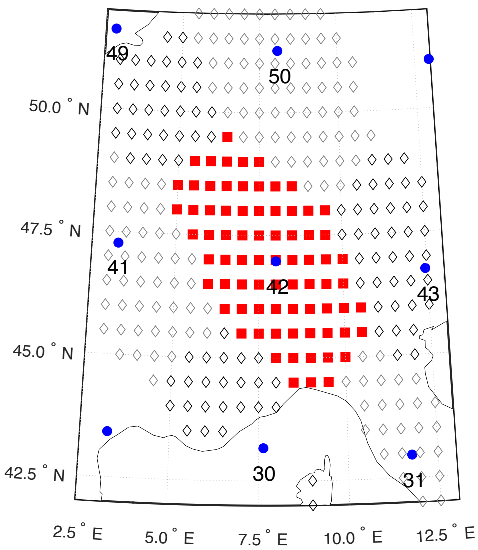


Optimized assignment of the pairs of users, FR2, SNR=10 dB

- 100 users distributed according to the interference pattern
- The Hungarian algorithm optimally solves the assignment problem
- We select pairs of users that should transmit together to maximize the throughput

HOTSPOT

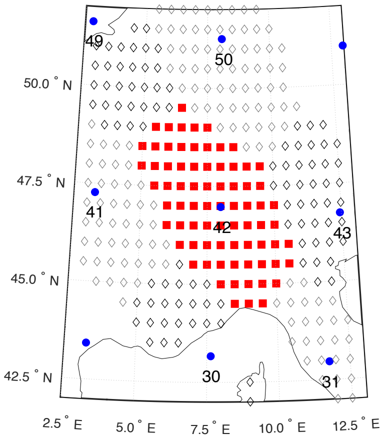
DYNASAT



- A cluster of 7 beams of the European coverage
- The central beam is "hot", while the 6 surrounding beams are "cold"
- We want to draw resources (bandwidth and power) from the 6 cold beams to serve users in the central beam
- The aim is to increase the system flexibility

SYSTEM ASSUMPTIONS

DYNASAT

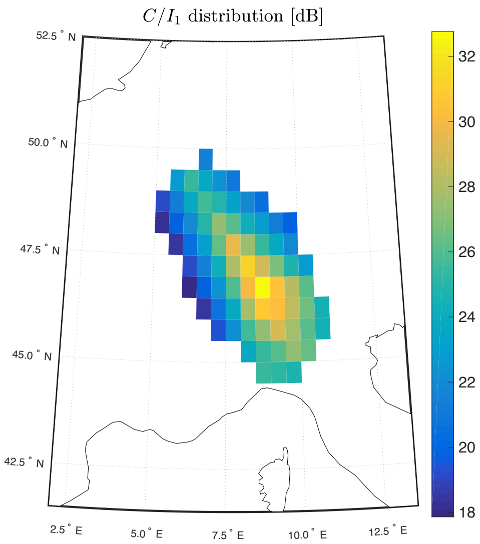


- Linear AWGN channel
- Gaussian symbols and interference
- Outside the hotspot: 4-color scheme
- Available power per beam: 90 W
- Available bandwidth: $B = 500$ MHz
- Beam 42 taken as a reference
- $N_\mathrm{u} = 76$ users in the beam
- N_int interfering signals from other beams

- For each user $i = 1, \dots, N_\mathrm{u}$ in the central beam, we have
  - $C^{(i)}$: power of the signal coming from the central beam
  - $N^{(i)}$: observed noise power
  - $I_j^{(i)}, j = 1, \dots, N_\mathrm{int}$: power of each of the interfering signals, $I_j^{(i)} \geq I_{j+1}^{(i)}$

REFERENCE SCENARIO

DYNASAT



- Uniform 4-color distribution (no hotspot)
- Very low interference
- Only single-user detection is adopted

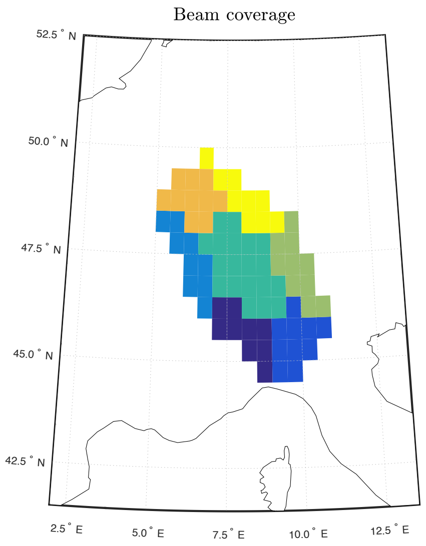
$$I_R^{(i)} = \log_2\left(1 + \frac{C^{(i)}}{N^{(i)} + \sum_{j=1}^{N_\mathrm{int}} I_j^{(i)}}\right)$$

$$\mathrm{Throughput}^{(i)} = \frac{I_R^{(i)} 2B}{4}$$

Average throughput per user: 1.32 Gbps

BEAM DIVISION

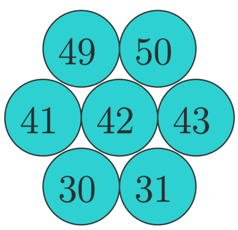
DYNASAT

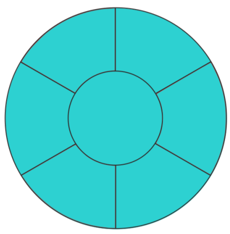


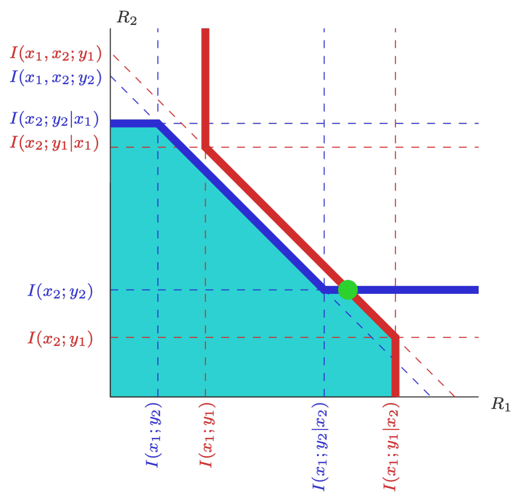
- The beam is divided in 7 sections
- The users in the inner section are served by the central signal
- The users in the outer sections are served by the adjacent signals
- The size of the section is determined by the value of C/I_1
- Different FR/receiver strategies can be designed

MUD/SUD WITH 7 USERS

DYNASAT





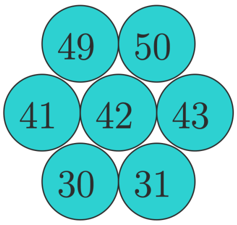


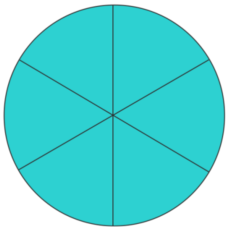
- 1-color scheme
- High interference
- The MUD/SUD strategy is adopted for the central and the most powerful adjacent signals
- The other 5 signals adopt a rate that maximizes the throughput with the rate of the central signal fixed

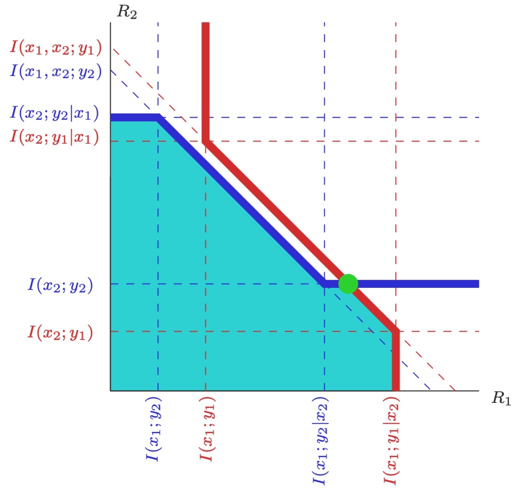
By maximizing over the size of the central section, the maximum throughput of the beam is 5.95 Gbps

MUD/SUD WITH 6 USERS

DYNASAT





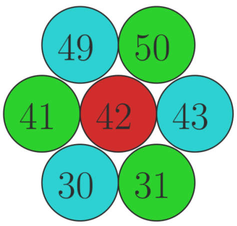


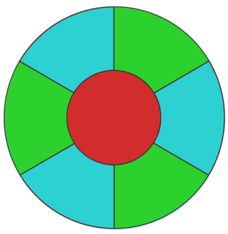
- One user sees the channel as a classical MAC where two signals are intended for the same user and their rates are jointly selected
- The other 5 rates are selected with a constraint on the rate of the central signal
- The other 5 users adopt the MUD/SUD strategy

By maximizing over the size of the central section, the maximum throughput of the beam is 6.88 Gbps

THREE-COLOR SUD

DYNASAT





- 3-color scheme
- Low interference
- Single-user detection is adopted

The rate of the central signal is

$$R_c = \log_2\left(1 + \frac{C^{(c)}}{N^{(c)} + I_{\text{res}}^{(c)}}\right)$$

The rates of the adjacent signals are

$$R_k = \log_2\left(1 + \frac{I^{(k)}}{N^{(k)} + I_{\text{coch}}^{(k)} + I_{\text{res}}^{(k)}}\right)$$

I_{res}: interference from outside the hotspot

I_{coch}: interference from the inside the hotspot

By maximizing over the size of the central section, the maximum throughput of the beam is 9.67 Gbps

DISCUSSION

DYNASAT

Uniform coverage multibeam scenario

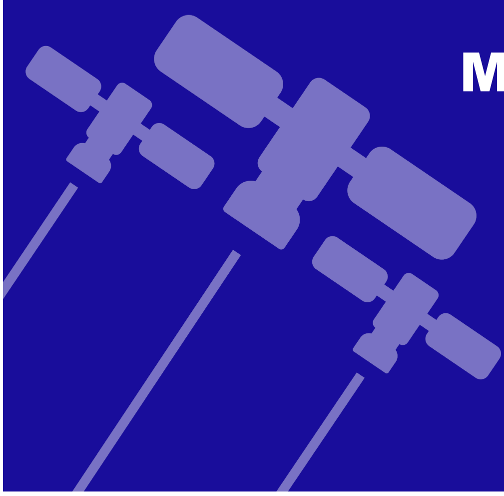
- The presented framework allows to jointly evaluate the achievable rates of two co-frequency beams (or cells)
- The presented technique is based on multiuser detection
- In contrast to usual mud approaches, the MUD is exploited to improve the detection of one user
- In the considered multibeam satellite scenario, interesting performance gains are possible with respect to current architectures, based on single-user detection

Hotspot scenario

- All strategies show large gains w.r.t. the reference
- The three-color SUD gains 40% over the closest alternative
- The MUD/SUD with 6 users gains 15% w.r.t. that with 7 users

References

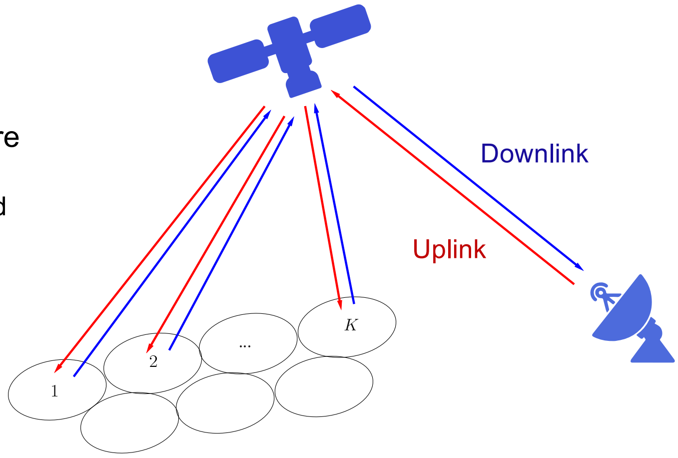
1. A. Ugolini, G. Colavolpe, M. Angelone, A. Vanelli-Coralli, A. Ginesi, "Capacity of interference exploitation schemes in multibeam satellite systems," *IEEE Trans. Aerosp. Electron. Syst.*, Dec. 2019
2. G. Colavolpe, A. Modenini, A. Piemontese, A. Ugolini, "Multiuser detection in multibeam satellite systems: theoretical analysis and practical schemes," *IEEE Trans. Commun.*, Feb. 2017



MIMO IN SATELLITE SYSTEMS

DYNASAT

- The adoption of MIMO technology to satellite systems has been **much slower** than in terrestrial communications
- The application of SU-MIMO to **fixed** satellite systems has several shortcomings, the most important the **LOS channel**
- Broadband fixed interactive multibeam satellite system can benefit from the MU multiplexing gain when **MU-MIMO precoding** techniques are applied
  - less sensitive to LOS or antenna correlation and allow for spatial multiplexing gain without necessitating terminals with multiple antennas
- **This comes at the cost of the necessity of CSI at the transmitter**



DYNASAT

Recently, increased interest in **MIMO transmissions for NGSO** satellite communications is emerging

- **LEO** satellite communications are expected to be incorporated in future wireless terrestrial networks
- LEO satellite communication systems impose less stringent requirements on power consumption and transmission signal delays

Also in this scenario, most of the existing works rely on precise **instantaneous CSI**

But obtaining instantaneous CSI is usually difficult. Main factors:

- long propagation **delay** between a satellite and user terminals (UTs)
- **mobility** of user terminals and satellites
- for **TDD** systems, the coherence time of the channel is shorter than the transmission delay
- in **FDD** systems we need a great amount of training and feedback overhead due to mobility of UTs and more importantly could become outdated as a result of the long propagation delay

MASSIVE MIMO

DYNASAT

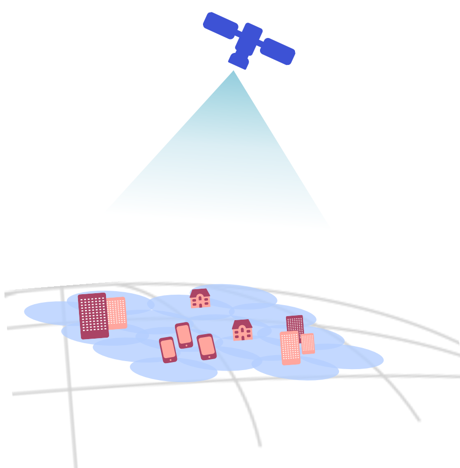
- Scenario: a single satellite equipped with a massive MIMO (M-MIMO) array
- **Key challenges**: implementation aspects
  - Wide adoption of transparent payloads with distributed gateways and four colors frequency reuse schemes not compatible with M-MIMO
  - Very limited adoption of active array antennas with a large number of radiating elements
  - **Impossibility to use Time Division Duplexing schemes** to ease channel estimation because of satellite frequency regulation restrictions in millimeter wave bands (particularly critical)
  - Cumbersome implementation of pre-coding schemes requiring user feedback in satellite Frequency Division Duplexing scheme
  - Limitations in the amount **digital processing implementable on-board**

P. Angeletti, R. De Gaudenzi, “A Pragmatic Approach to Massive MIMO for Broadband Communication Satellites,” IEEE Access, vol. 8, 2020.

PRECODING IN SATCOMM

DYNASAT

- MIMO techniques rely on **precoding** and **beamforming** at the transmitter
- In general, beamforming can be broadly classified as
  - On-Board or On-Ground BeamForming (OBBF/OGBF)
    - depending on where the beamforming matrix is applied
  - feed space or beam space
    - depending on the signal space in which is it computed



ASSUMPTIONS

DYNASAT

- Let us focus on a simplified scenario
  - single satellite equipped with N_F feeds that generate K on-ground beams
  - single GW managing the users' Channel State Information (CSI)
  - the technical challenges for NGSO with multiple satellites and GWs will be discussed later
- $h_{k,n}$: channel between the n-th antenna feed and the generic k-th user
  - $\mathbf{H} \in \mathbb{C}^{N_F \times K}$: complex channel matrix between the on-board feeds and the on-ground users
  - K: number of users scheduled in the current time slot
    - in general, we have N_U users that shall be served within N_{slot} time slots
    - for each time slot, depending on the scheduled users, we obtain a certain beamforming matrix, i.e., SINR per user
    - optimisation problem, which should also take into account the traffic requests

BEAMFORMING SPACE

DYNASAT

- **Beam space**: two distinct matrices for precoding and beamforming
  - they can still be jointly optimised
  - the $K \times K$ precoding matrix projects the transmit symbols onto the beam space

$$\mathbf{x}^{(beam)} = \mathbf{Ws}, \quad x_k^{(beam)} = \mathbf{w}_{k,:}\mathbf{s} = \sum_{i=1}^{K} w_{k,i} s_i$$

  - the $N_F \times K$ beamforming matrix projects the signals from the beam space onto the feed space

$$\mathbf{x}^{(feed)} = \mathbf{Bx}^{(beam)} = \mathbf{BWs}, \quad x_n^{(feed)} = \mathbf{b}_{n,:}\mathbf{x}^{(beam)} = \sum_{k=1}^{K} b_{n,k}\ x_k^{(beam)}$$

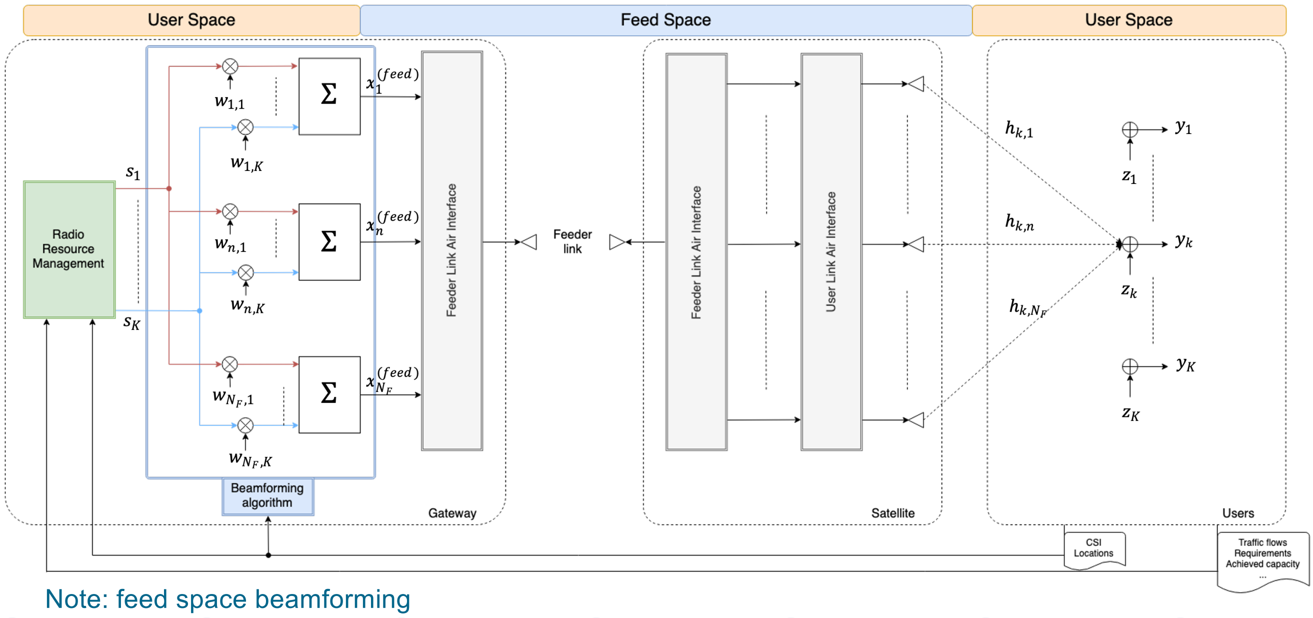
- **Feed space**: precoding and beamforming are joint
  - the $N_F \times K$ beamforming matrix directly projects the transmit symbols onto the feed space

$$\mathbf{x}^{(feed)} = \mathbf{Ws}, \quad x_n^{(feed)} = \mathbf{w}_{n,:}\mathbf{s} = \sum_{k=1}^{K} w_{n,k} s_k$$

  - In general, operating in the feed space provides a better performance since we are operating with more degrees of freedom

ON-GROUND BEAMFORMING: DETAILED

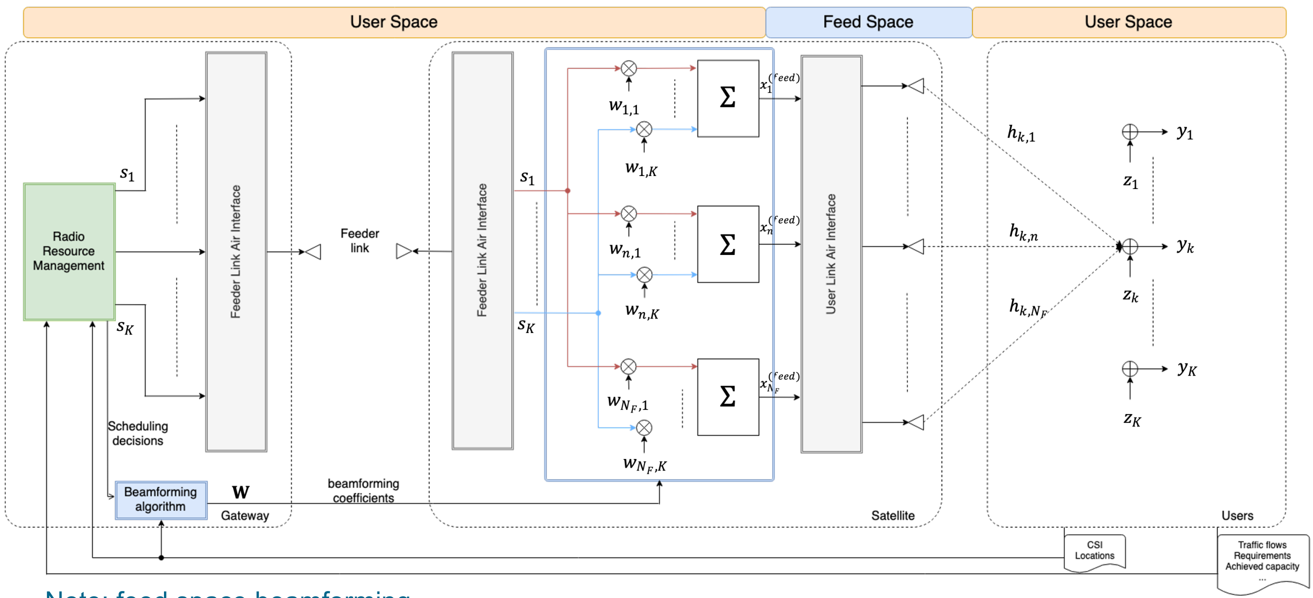
DYNASAT



Note: feed space beamforming

ON-BOARD BEAMFORMING: DETAILED

DYNASAT



Note: feed space beamforming

OBSERVATIONS: FEEDER LINK BANDWIDTH

DYNASAT

- **Single GW**
  - OGBF: $B_{tot,pol}^{(OGBF)} = B_{tot,pol}^{(GW,OGBF)} = N_F B_{beam}$
    - the projection on the feed space is performed on-ground → N_F signals
  - OBBF: $B_{tot,pol}^{(OBBF)} = B_{tot,pol}^{(GW,OBBF)} = K B_{beam}$
    - the projection on the feed space is performed on-board → $K < N_F$ signals
    - the GW should also send the beamforming coefficients
- **Multiple GWs**
  - OGBF: $B_{tot,pol}^{(OGBF)} = B_{tot,pol}^{(GW,OGBF)} = \frac{N_F}{N_{GW}} B_{beam}$
    - each GW should have the signals to be sent to each beam to implement beamforming on its corresponding beams
  - OBBF: $B_{tot,pol}^{(OBBF)} = B_{tot,pol}^{(GW,OBBF)} = \frac{K}{N_{GW}} B_{beam}$
    - the illumination plan and coefficients can be sent by a single GW or central network entity

RECEIVED SIGNAL

DYNASAT

- The received signal can be written as

$$\mathbf{y} = \sqrt{P_T}\mathbf{H}\widetilde{\mathbf{W}}\mathbf{s} + \mathbf{z}$$

  - feed space beamforming: $\widetilde{\mathbf{W}}$ is the normalised $N_F \times K$ complex matrix and $\mathbf{H}$ the $K \times N_F$ channel matrix at feed level
  - beam space beamforming: $\widetilde{\mathbf{W}}$ is the normalised $K \times K$ complex matrix and $\mathbf{H}$ the $K \times K$ channel matrix at beam level (obtained as $\mathbf{HB}$)
  - at the generic k-th user we thus have:

$$y_k = \underbrace{\sqrt{P_T}\mathbf{h}_{k,:}\widetilde{\mathbf{w}}_{:,k} s_k}_{\text{intended signal}} + \overbrace{\sqrt{P_T}\sum_{\substack{j=1 \\ j \neq k}}^{K} \mathbf{h}_{k,:}\widetilde{\mathbf{w}}_{:,j} s_j}^{\text{interfering signal}} + z_k$$

$$\gamma_k = \frac{P_T \left|\mathbf{h}_{k,:}\widetilde{\mathbf{w}}_{:,k}\right|^2}{N + P_T \sum_{\substack{j=1 \\ j \neq k}}^{K} \left|\mathbf{h}_{k,:}\widetilde{\mathbf{w}}_{:,j}\right|^2}$$

ALGORITHMS

DYNASAT

- **Matched Filter (MF)**

$$\mathbf{W} = \mathbf{H}^H$$

- **Zero-Forcing (ZF)**

$$\mathbf{W} = \left(\tilde{\mathbf{H}}^H \tilde{\mathbf{H}}\right)^{\dagger} \tilde{\mathbf{H}}^H$$

  - often, $\tilde{\mathbf{H}}^H \tilde{\mathbf{H}}$ appears to be ill-conditioned and, thus, a regularised version has been introduced

- **Minimum Mean Square Error (MMSE)**, or Regularised ZF (RFZ)

$$\mathbf{W} = \left(\tilde{\mathbf{H}}^H \tilde{\mathbf{H}} + \mathrm{diag}(\boldsymbol{\alpha})\mathbf{I}_N\right)^{-1} \tilde{\mathbf{H}}^H$$

  - $\boldsymbol{\alpha}$ is a vector of regularisation factors (N/P_T is the optimal value)

- **Multi-Beam (MB)**[1]

$$\mathbf{w}_{:,k} = \mathbf{b}_{:,j}, \text{ with } j = \arg \min_{i=1,\dots,K} \|\mathbf{c}_i - \mathbf{u}_k\|^2$$

  - the user is precoded based on the beamforming coefficients of the closest beam center (thus, it can be implemented only in the beam space)

[1] P. Angeletti, R. De Gaudenzi, "A Pragmatic Approach to Massive MIMO for Broadband Communication Satellites," IEEE Access, July 2020

POWER NORMALISATION

DYNASAT

- **Sum Power Constraint (SPC)**

$$\tilde{\mathbf{W}} = \frac{\mathbf{W}}{\|\mathbf{W}\|_F} = \frac{\mathbf{W}}{\sqrt{\mathrm{tr}(\mathbf{W}\mathbf{W}^H)}}$$

  - max. tx power **ensured**
  - orthogonality is **preserved**
  - **no limits** to power per antenna

- **Per Antenna Constraint (PAC)**

$$\tilde{\mathbf{W}} = \frac{1}{\sqrt{N_F}} \mathrm{diag}\left(\frac{1}{\|\mathbf{w}_{1,:}\|}, \dots, \frac{1}{\|\mathbf{w}_{N_F,:}\|}\right) \mathbf{W}$$

  - max. tx power **ensured**
  - orthogonality is **lost**
  - **limits** to power per antenna

- **Maximum Power Constraint (MPC)**

$$\tilde{\mathbf{W}} = \frac{1}{\sqrt{N_F \max_j \|\mathbf{w}_{j,:}\|}}$$

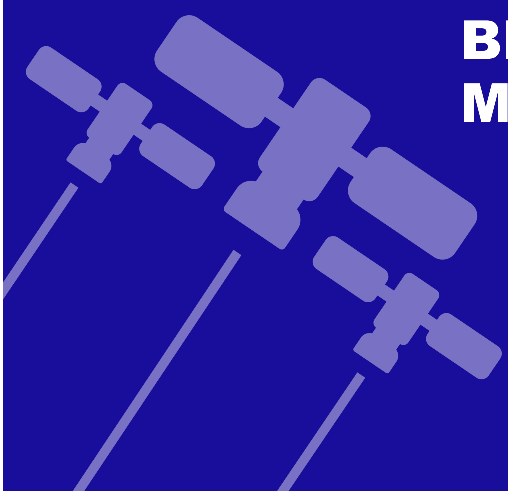
  - max. tx power **not ensured**
  - orthogonality is **preserved**
  - **limits** to power per antenna

Note: feed space beamforming

TECHNICAL CHALLENGES

DYNASAT

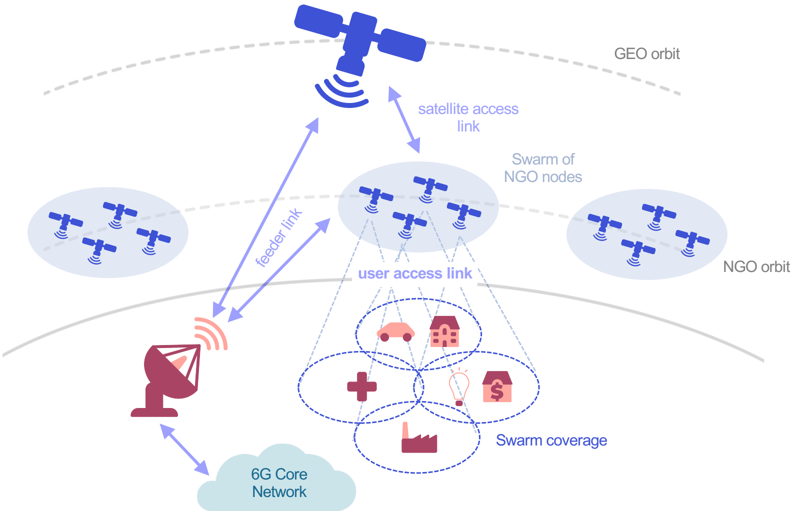
- Multiple GWs are needed to manage the large feeder link bandwidth
  - each GW manages a subset of beams
    - constraints in terms of
      - maximum feeder link bandwidth
      - channelisation
      - bandwidth per beam
    - cooperation among the GWs is required to manage signals and CSI
  - in general, a star topology can be considered so as to manage fading events
- Scheduling: non-trivial, since the beamformed SINR is known *a posteriori*
  - single/multiple time-slot based
  - iterative and integer programming solutions have been recently proposed
  - ML/NN might be considered FFS



BEAMFORNING IN MEGA-CONSTELLATIONS

DISTRIBUTED BEAMFORMING IN MEGA-CONSTELLATIONS

DYNASAT

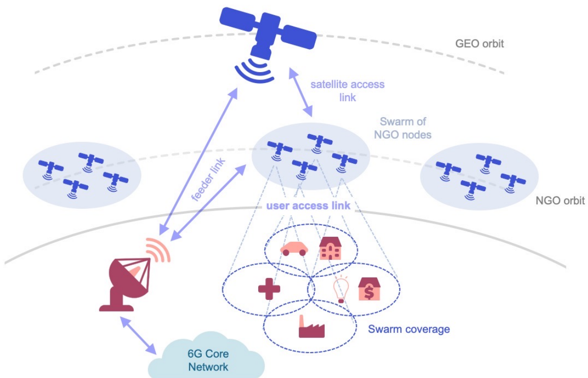


Source: A. Guidotti, M. Conti, A. Vanelli-Coralli, "Distributed Beamforming in LEO Constellations for NB-IoT Services in 6G Communications," submitted to Globecom 2021

BEAMFORMING IN NGSO CONSTELLATIONS

DYNASAT

- A swarm of NGSO nodes can act as a distributed antenna system implementing beamforming
  - at least one connection between a GW and a GEO shall be guaranteed
  - when both are available, cooperation can be considered
  - at least one node in the swarm shall be connected to at least a GEO/GW
    - then ISLs can be used in the swarm
- Users shall have visibility of all the nodes in a swarm
  - if this is not the case, adjustments to the beamforming algorithms might be needed (FFS)
- MMSE beamforming with full frequency reuse



Source: A. Guidotti, M. Conti, A. Vanelli-Coralli, "Distributed Beamforming in LEO Constellations for NB-IoT Services in 6G Communications," submitted to Globecom 2021

PERFORMANCE ASSESSMENT

DYNASAT

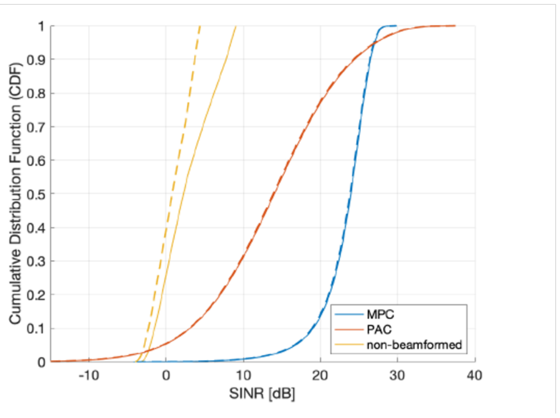
NB-IoT device

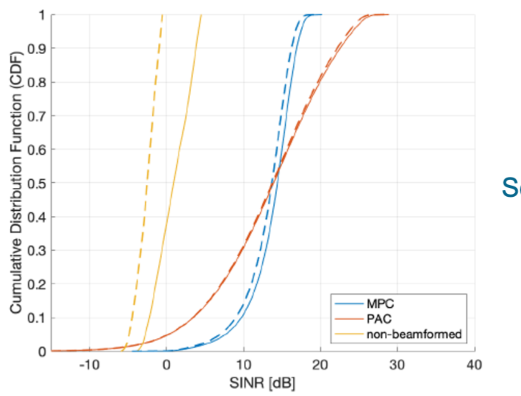
Parameter	Value	Units
antenna model	NTN, [14]	-
G_R	0	dBi
antenna temperature	290	K
noise figure	7	dB

LEO nodes

Parameter	600 km		1200 km		Units
	Set a	Set b	Set a	Set b	
antenna diameter	2	1	2	1	m
$G_{T,max}$	30	24.1	30	24.1	dBi
EIRP density	34	30.3	40	35.7	dBW/MHz
N_s	7				-

Set a





Set b

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PERFORMANCE ASSESSMENT

DYNASAT

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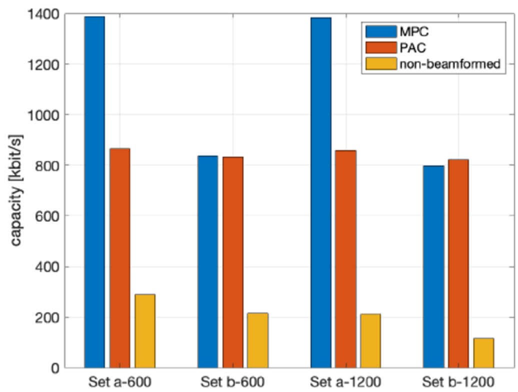
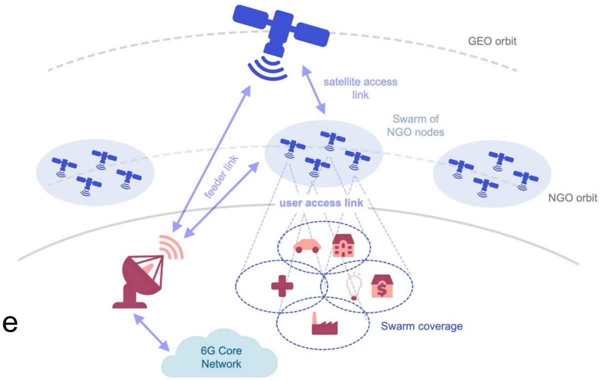


Source: A. Guidotti, M. Conti, A. Vanelli-Coralli, "Distributed Beamforming in LEO Constellations for NB-IoT Services in 6G Communications," submitted to Globecom 2021

- **Challenges**
  - CSI are non-ideal and exhibit a great variability
  - multiple beams per node shall be managed
  - multiple swarms can interfere with each other, thus requiring coordination at swarm level
  - depending on the latitude, an increased or reduced overlap at beam edge will appear
  - scheduling is significantly more complex due to the swarm mobility, swarm combined FoV, ...
  - the actual user density and traffic requests shall be taken into account



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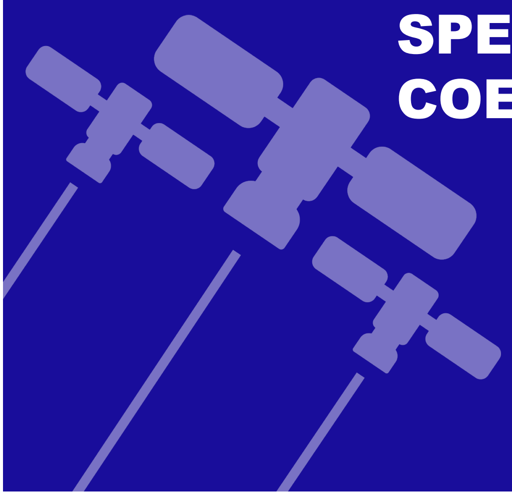


PART III - - DYNAMIC SPECTRUM SHARING AND COEXISTENCE TECHNIQUES

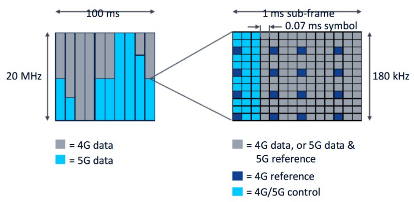
OUTLINE

- Introduction
  - Scope of DSA
  - Frame coordinated vs non-coordinated spectrum sharing
- Scenarios and DSA problem statements
  - Scenarios and problem statements
  - NGSO-specific DSA challenges
- State of the art DSA systems
  - Non-coordinated DSA
  - Frame coordinated DSA
- DSA for NGSO satellites
  - Non-coordinated DSA
  - Frame coordinated DSA
- Summary

FRAME-LEVEL COORDINATED VS NON-COORDINATED SPECTRUM SHARING

Frame-level coordinated

- TDD frame synchronization
- Coordinated MultiPoint
- RAN coordination in heterogenous networks
- 3GPP DSS



Source: Nokia DSS white paper

Non-coordinated

- CBRS
- LSA
- TVWS
- 6GHz AFC

Interference from other networks is white noise

SCENARIOS AND DSA PROBLEM STATEMENTS

SCENARIOS

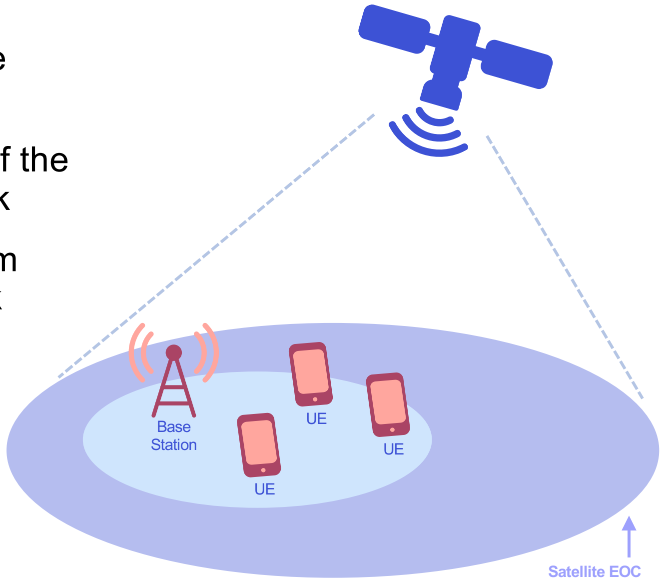
DYNASAT

Scenarios	A	B	C	D
SAT and MNO countries	Same country	Same country	Neighbouring countries	Same country
Co-channel vs adjacent channel	Co-channel	Adjacent channel	Co-channel	Co-channel
Cooperative vs non-cooperative	Cooperative and coordinated	Non-cooperative	Non-cooperative	Cooperative and non-coordinated
Dynamic vs static	Dynamic	Static	Static	Dynamic
Domain of separation	Time, frequency and geography	Frequency	Geography	Geography
Managed by	RAN coordination	NRA	NRA	Non-coordinated DSA

SCENARIO A. SAT AND MNO NETWORKS ARE CONTROLLED BY THE SAME RRM

DYNASAT

- SAT and MNO share Radio Resource Management (RRM)
- Objective is to extend the coverage of the terrestrial network by satellite network
- Capacity is dynamically allocated from terrestrial network to satellite network



SCENARIO D. SAT NETWORK IS CONTROLLED BY DSA

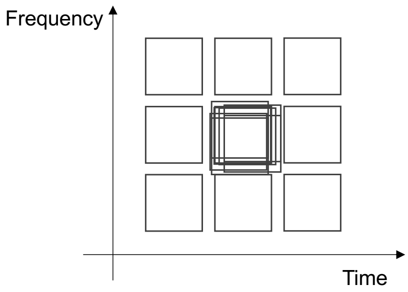
DYNASAT

- MNO reports its network deployment to DSA
- Objective is to allow satellite network use in the areas where it does not cause harmful interference to mobile network
- Satellite coverage is dynamically controlled by DSA
- Satellite coverage area decreases over time

NGSO SPECIFIC CHALLENGES

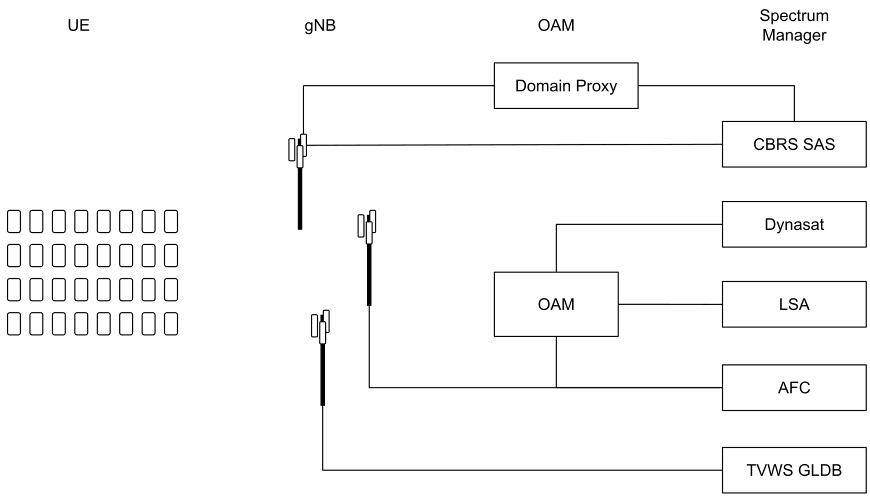
DYNASAT

- Doppler shift
- Variation of Doppler shift
- Propagation delay
- Variation of propagation delay
- Large beam size
- Variation of beam size
- High attenuation due to long distance
- Overlapping of several beams and satellites



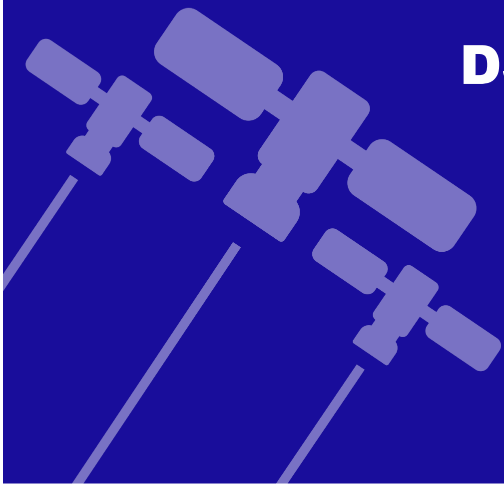
STATE OF THE ART DSA SYSTEMS

NON-COORDINATED DSA



FRAME COORDINATION TECHNIQUES IN 3GPP

- 3GPP Dynamic Spectrum Sharing (DSS)
- 3GPP RAN coordination in heterogenous networks
- 3GPP Coordinated MultiPoint



DSA FOR NGSO SATELLITES

NON-COORDINATED DSA

DYNASAT

	LSA	eLSA	CBRS PAL	CBRS GAA	TVWS	AFC	Dynasat with local	Dynasat national
Licensed and protected	Yes	Yes	Yes	No	No	No	Yes	Yes
Number of spectrum users	Few	Many	Many	More than PAL users	Many	Very many	Many	Few
Number of communicating entities	Few	Many	Many	More than PAL users	Many	Very many	Many	Few
Communication topology	VPN or server	Server	Server	Server	Server	Server	Server	VPN or server
Operating params or restrictions	Both	Both	Oper params	Oper params	Oper params	Oper params	TBD	TBD
Frequency of changes	N.N.	N.N.	1 min	1 min	10 min - 1 h	24 h	TBD	TBD
Aggregate or per device interference	Aggregate	Aggregate	Aggregate	Aggregate	Per device	Per device	Aggregate	Aggregate
SOON and Co-existence	SOON	FCFS	CX CBRS Alliance	CX CBRS Alliance	CX IEEE 802.19.1	CX IEEE 802.19.1	FCFS	SOON
Sensing	No	No	ESC	ESC	US on paper	No	No	No
Propagation model	ITU	ITU	FCC	FCC	ITU or FCC	FCC	ITU	ITU
Device standard	3GPP	3GPP	3GPP	3GPP	Proprietary	IEEE 802.11	3GPP	3GPP
Automatic and manual entry	N.N.	N.N.	Automatic	Automatic	Automatic and manual	Automatic	TBD	TBD
Need for DSA	PMSE, PPDR, Mil	PMSE, PPDR, Mil	Military	Military	PMSE	Consumers	TBD	TBD
Centralized or distributed	Central or distributed	Central	Central	Central	Central	Central	Central	Central or destributed

STARTING POINTS FOR FRAME COORDINATED DSA

DYNASAT

- Physical Resource Block (PRB)
- Bandwidth Parts (BWP)
- Component Carriers (CC)
- 3GPP Dynamic Spectrum Sharing (DSS)
- 3GPP RAN coordination in heterogenous networks
- 3GPP Coordinated MultiPoint

CONCLUSIONS

CONCLUSIONS

DYNASAT

- Non-Terrestrial Networks are gaining importance in 5G, B5G and 6G systems
- Efficient use of the allocated bandwidth and of the available spectrum is to be sought at all system levels
- Integration with Terrestrial networks calls for a smart and efficient dynamic spectrum management to deal with inter-system interference
- Mega-constellations are being designed and deployed
- In such dense mega-constellation deployments, e.g., several nodes in visibility, intra-system interference can be exploited to improve the efficiency of the bandwidth use
- Techniques addressing the exploitation of inter and intra system interference have been presented
- Dynasat is addressing evolutionary and revolutionary techniques in both scenarios

DISCOVER THE CONSORTIUM

DYNASAT

ALMA MATER STUDIORUM UNIVERSITÀ DI BOLOGNA A.D. 1088

MARTEL innovate

ThalesAlenia Space a Thales / Leonardo company

MAGISTER SOLUTIONS

Fairspectrum

UNIVERSITÀ DI PARMA

DYNASAT

THANK YOU FOR YOUR ATTENTION

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